PART III—CONSTRUCTION
CHAPTER XII. Construction—CONTRACT ADMINISTRATION

131. SUMMARY. (a) Dam, Powerplant, and Town.—Owing to the critical need for access to the site of the future dam in Glen Canyon, the first major construction contract was awarded to the Strong Company of Springville, Utah, for work under specifications No. DC-4730 for earthwork and culvert construction for a portion of the Bitter Springs Highway. The work involved construction of subgrade and base course for about 4.6 miles of highway north from an intersection on U.S. Highway No. 89 near Bitter Springs, Ariz., and included deep cuts in rock through the Echo Cliffs monocline. Notice to proceed was received by the contractor on September 24, 1956, and the work was completed on October 1, 1957.

The contract for excavation of the right diversion tunnel was awarded early under specifications No. DC-4747 to provide for river diversion when needed for excavation of the foundation of Glen Canyon Dam and Powerplant. Awarded to Mountain States Construction Co. of Denver, Colo., the contract provided for excavation of a 2,749-foot-long circular diversion tunnel, 43.5 feet in diameter at the “A” line in the upstream portion. The diameter was increased by 3 feet for the downstream portion, which also served as the downstream portion of the spillway tunnel, and concrete lining was not required under these specifications. The contractor received the notice to proceed on October 2, 1956, and the work was completed on March 13, 1958.

Minor construction contracts awarded during this period included; work for exploratory drilling under specifications No. 400C-63; invitation No. GC-420-57-1 providing equipment for more detailed investigations of the Wahweap aggregate deposit with a rotary drill rig; invitations No. 400-424 and 400-428 for operated equipment; and specifications No. 400C-68, which provided for temporary access roads to the west side of the canyon.

W. W. Clyde and Co. of Springville, Utah, was awarded the contract under specifications No. DC-4756 for construction of earthwork and structures for another portion of the Bitter Springs Highway. This work included subgrade and base course construction for about 20.8 miles of highway from a point 4.6 miles north of Bitter Springs, Ariz., to near the east abutment of the Glen Canyon Bridge. Construction of a reinforced concrete bridge at Waterholes Canyon was included in this contract work. The contractor received the notice to proceed on November 5, 1956, and the work was accepted as substantially complete on July 12, 1957.

Surfacing and guardrail construction for the Glen Canyon Dam and access highway and construction of Manson Mesa airstrip was done under specifications No. DC-4887 by Alexander Construction Co., Inc. Notice to proceed was received by the contractor May 31, 1957, and all work was completed and accepted March 3, 1958. Major items included placement of crushed-rock base, plant mix bituminous surfacing and seal coat and constructing guardrail for approximately 25 miles of access road, as well as furnishing and stockpiling additional surfacing aggregate and construction and surfacing of the airport.

The Glen Canyon Bridge was constructed under specifications No. DC-4800 by Keiwit-Judson Pacific Murphy, a joint venture, to provide the connecting link across the canyon between the two sections of the highways leading to the site of the dam and powerplant. The work involved construction of a steel-arch-type bridge with a single span 1,028 feet in length. The overall length of 1,271 feet included abutments, and the concrete roadway was 30 feet wide with a sidewalk 4 feet in width on each side. Notice to proceed with the work was received by the contractor on January 28, 1957, and the last part of the work was completed on January 18, 1959. The bridge was dedicated and opened to the public on February 20, 1959. See appendix E for additional cost and engineering data.

The main contract for construction of Glen Canyon Dam, Powerplant, and appurtenant works was accomplished under specifications No. DC-4825 by Merritt-Chapmen and Scott Corp. of New York, N.Y., and is referred to as the prime contract in this publication. The notice to proceed with the first part of the work was received by the contractor on May 2, 1957, and the last part of the work was completed on October 2, 1964. Part A of the contract schedule called for construction of the dam, powerplant, and related works, including the spillways and diversion tunnels (except certain work under specifications No. DC-4747). This work included rock and common excavation for these features, line drilling, rock bolting, backfilling, drilling and grouting, diversion and care of the river; mass, first-stage, and structural concrete; reinforcing bars, concrete tunnel lining, outlet penstock pipe installation, structural steel, concrete cooling systems, embedded metalwork, piping, gates and related equipment. Part B of the schedule included the excavation and surfacing of a section of highway from Bitter Springs to the left abutment of the bridge. Part C of the schedule included construction of the right and left abutment service roads to the dam and
spillways, the powerplant service tunnel and roadway, and the switchyard service road.

On September 6, 1957, W. W. Clyde and Co. of Springville, Utah, received notice to proceed with construction of access roads, streets, and utilities for Page, Ariz., under specifications No. DC-4896. The contract provided for construction of a 1.7-mile-long connecting road from Page to the service road to the dam; a 0.5-mile-long access road from the Bitter Springs road to the connecting road; a 1.1-mile-long connecting road from the south edge of Page to the Bitter Springs; and 8.44 miles of streets and 13.66 miles of curbs, gutters, and sidewalks in the town of Page. Grading of the townsite and construction of the storm sewer system, the sanitary sewer collection system, and the water distribution system for Page was also included in these specifications. All work was completed and accepted on December 19, 1958.

Minor construction contracts under specifications No. 400C-83 and 400C-98 were awarded during this period for earthwork, structures and roadway surfacing for temporary public use shelters and parking areas on each side of the canyon, just downstream from the construction site. Contracts were also awarded for construction of the foundations for 50 demountable houses under specifications No. DC-4886, and for the 150,000-gallon elevated storage tank and the 3,000,000-gallon storage reservoir under specifications No. DC-4865.

The sewage treatment facilities for the town of Page were constructed by W. W. Clyde and Co. of Springville, Utah, under specifications No. DC-4912. Notice to proceed was received September 6, 1957, and all work was completed and accepted May 2, 1958. Under this contract, an access road was constructed from the powerplant access road to the sewage treatment plant and an outfall sewer pipeline and a water service line, both about 7,000 feet long, were constructed from the town of Page to the treatment plant. Work on the treatment plant proper consisted of construction of concrete structures to house sewage treatment equipment, installing equipment, and building a compartmented stabilization pond.

Specifications No. DC-4924 provided for the construction of a laboratory building, a Government warehouse and a municipal building. Notice to proceed was received by Security Construction Co. of Salt Lake City, Utah, on September 13, 1957, and all work was completed and accepted on July 2, 1958. The laboratory was a wood frame building 39 by 64 feet to provide office space and house normal field concrete control equipment. The warehouse for housing Government material and equipment was a rigid steel frame building 320 by 100 feet with insulated metal wall and roof panels. The municipal building was a wood frame building with a main wing 40 feet 6 inches wide by 114 feet long with a wing measuring 24 by 75 feet. Initially providing general Government office space at Page, this building was later utilized as offices for a number of municipal services.

Southern Engineering Co., Inc., of Long Beach, Calif., constructed the water treatment plant for Page under specifications No. DC-4933. Notice to proceed was received on September 13, 1957, and all work was completed on November 8, 1958. The specifications called for water to be pumped from the Colorado River at a point about a mile downstream from the dam to a pretreatment plant, where initial flocculation and primary removal of sediments were performed. Water was pumped from there through a 12,000-foot-long pipeline to the treatment and storage area, where filtering, final treatment, and storage were carried out.

Permanent residences for Government employees were constructed by The Mobilehome Corp. of Bakersfield, Calif., and others in a joint venture, under specifications No. DC-4989. Notice to proceed was received January 9, 1958, and all work was completed and accepted March 20, 1959. The specifications provided for all on-lot work necessary to construct 200 concrete masonry block residences with concrete slab floors and wood-truss roofs.

Sierra Construction Corp. of Las Vegas, Nev., constructed the administration building and the garage, fire station, and police building under specifications No. DC-5115. The administration building was a one-story steel frame building 256 by 48 feet with concrete masonry and metal window exterior wall construction and a sloping built-up asphalt roof with white stone surfacing. The garage, fire station, and police building was divided into two adjoining parts. The garage and fire station portion had a steel frame, steel roof decking, and sheet metal siding; and the police station portion was of concrete block masonry with a built-up asphalt roof. Notice to proceed was received by the contractor December 10, 1958, and all work was completed and accepted August 20, 1959.

Minor construction contracts awarded during this period included the lighting installations for the airstrip under specifications No. DC-5066, a control cable installation for the municipal water supply system under specifications No. DC-5090, a 50-ton motor truck scale and scale house under specifications No. DC-5123, a seismograph vault and access road under specifications No. DC-5163, soil stabilization and
landscaping for Government facilities at Page under specifications No. 400C-140, parking area and utilities for block 17 at Page under specifications No. DC-5206, temporary tourist center under specifications No. 400C-161, erection of column struts for Glen Canyon Bridge under specifications No. DC-5607, and certain modifications to the Page water supply system under specifications No. 400C-189.

The second main contract for construction of the dam and powerplant proper was the completion contract under specifications No. DC-5750 by the Ets-Hokin Corp. of San Francisco, Calif. Completion work included second-stage blockout and surfacing concrete; partition walls; architectural finishes (except terrazzo floors); installation of turbines, governors, and accessory equipment; piping systems; heating, ventilating and air-conditioning systems; installing power transformers, bus structures, and accessory electrical equipment; electrical control, lighting and distribution systems; switchyard earthwork and surfacing completion, steel structures, and bus and electrical equipment installations in the switchyard; completion of the control cable tunnel and the powerplant transformer-to-switchyard circuits. The notice to proceed was received by the contractor on July 19, 1962, and the last part of the work was completed on October 25, 1966.

The eight generators were furnished and installed by separate contract under invitation No. DS-5522 by General Electric Co., and the turbines were furnished by Baldwin-Lima-Hamilton Corp. under invitation No. DS-5234.

The permanent visitor center at Glen Canyon Dam was constructed by Allen M. Campbell Co., Inc., of Tyler, Tex., under specifications No. DC-6274. The contractor received the notice to proceed on July 12, 1962, and the work was completed on August 17, 1965. The building consists of a steel-framed one-story wing with basement, a steel-framed rotunda, and a concrete-lined elevator shaft. The center will be operated by the National Park Service, who will also furnish the exhibits for the rotunda display.

Completion of the left diversion tunnel plug and spillway elbow was performed under specifications No. DC-6317 by S. S. Mullen Co., Inc., of Seattle, Wash. The work includes final excavation of the lower end of the spillway shaft, placing backfill and lining concrete, drilling and grouting, and epoxy repairs for the existing tunnel lining. Notice to proceed with the work was received by the contractor on August 23, 1965, and the work was accepted as substantially complete on March 7, 1967.

A list of all construction contracts, as well as all significant supply contracts, in the order of issue of specifications is included as appendix A. Some of the above contracts are discussed in detail in the following sections.

In the subsequent sections direct and indirect reference is often made to extra work orders, orders for changes, and purchase orders, which are not presented complete in this publication; therefore, it is suggested that if more detailed information on each type of order is desired, the final construction report should be consulted (see bibliography).

(b) Transmission Lines and Substations.—The Glen Canyon-Shiprock 230-kilovolt transmission line was constructed by Electrical Constructors of Columbus, Ohio, under specifications No. DC-5610. The transmission line is a 3-phase, 60-cycle, single-circuit line approximately 175 miles long. The main features of the work were right-of-way clearing, construction of footings, erection of steel towers, and stringing two 1/2-inch steel overhead ground wires and three 1,272,000-circular-mil ACSR (aluminum conductor, steel reinforced) conductors. Notice to proceed was received by the contractor on October 5, 1961, and work was completed on January 28, 1964. A 7-mile section of the Glen Canyon-Shiprock Line, near Kayenta, Ariz., utilizing experimental towers was constructed under another contract.

A contract was awarded to Irby Construction Co. under specifications No. DC-5710, for the construction of 42 miles of 230-kilovolt 3-phase, 60-cycle single-circuit transmission line from the Shiprock Substation to a point east of Cortez, Colo. The work performed included right-of-way clearing, furnishing and installing gates in right-of-way fences, furnishing tower leg grounds, constructing tower footings, furnishing and erecting steel towers, and furnishing and attaching tower signs. Notice to proceed was received by the contractor on May 14, 1962, and work was initiated at the site on July 5, 1962. All work under the contract was accepted as complete on September 5, 1963.

The construction of the Cortez-Curecanti 230-kilovolt transmission line and stringing conductors and overhead ground wires for the Shiprock-Cortez 230-kilovolt transmission line under specifications No. DC-5753, was awarded in two schedules.

Schedule 1 was awarded to Electrical Constructors of Columbus, Ohio, on April 23, 1962, on their bid of $4,224,514.00. The work consisted of constructing reinforced concrete footings with
embedded stub angles, furnishing and erecting steel towers, and stringing conductors and overhead ground wires for approximately 101 miles of 230-kilovolt transmission line. This schedule was completed on February 28, 1964.

Schedule 2 consisted primarily of furnishing and stringing conductors and overhead ground wires for approximately 42 miles of 230-kilovolt transmission line for which towers had been previously erected under another contract. Malcolm W. Larson Contracting Co. of Denver, Colo., was awarded the contract for this schedule on April 23, 1962. Work was completed on September 5, 1963.

The Glen Canyon-Flagstaff-Pinnacle Peak 345-kilovolt transmission line is a 3-phase, 60-cycle single-circuit line approximately 240 miles in length and consists of two sections. The Glen Canyon-Flagstaff section, approximately 123 miles in length, extends from Glen Canyon Switchyard to the Flagstaff Substation. The Flagstaff-Pinnacle Peak section extends from the Flagstaff Substation to the Pinnacle Peak Substation, a distance of approximately 117 miles. Ets-Hokin and Galvan Corp. of San Francisco, Calif., was awarded the contract for construction of the entire line on June 22, 1962. This firm later changed their name to Ets-Hokin Corp. Construction of the line was divided into four schedules. Schedules 1 and 2, from Glen Canyon to Flagstaff, were under the administration of the Project Construction Engineer at Page, Ariz. Administration of schedules 3 and 4, the section from Flagstaff to Pinnacle Peak, was the responsibility of the Project Manager at Phoenix, Ariz. The work for the Glen Canyon-Flagstaff section consisted of right-of-way clearing, footing construction, steel tower erection, stringing three double-bundle conductors, three single-bundle conductors at river crossings, and two overhead ground wires. All work under schedules 1 and 2 was accepted as substantially complete on November 12, 1964.

The transmission lines in the vicinity of Shiprock Substation were constructed by Reynolds Electrical and Engineering Co., Inc., of Santa Fe, N. Mex., under specifications No. DC-5860. These transmission lines were extensions of the Glen Canyon-Shiprock line, the Shiprock-Cortez line, and the Shiprock-Arizona Public Service Plant line. Land clearing, footing construction, furnishing and erecting steel towers, and furnishing and stringing conductor and overhead ground wires were the primary items of work under the specifications. Notice to proceed was received by the contractor on March 1, 1963. First work was initiated at the site on April 8, 1963, and all work was completed by June 13, 1964.

An experimental section of the Glen Canyon-Shiprock 230-kilovolt transmission line approximately 8.2 miles long near Kayenta, Ariz., was constructed by Construction Helicopters, Inc. of Grand Junction, Colo., under specifications No. DC-5953. The work mainly involved constructing structure footings and guy anchors; erecting 28 special structures and 4 standard-type SM towers; and stringing conductors and overhead ground wires. The specifications required that four of the special structures and two of the standard-type SM towers be erected by helicopter and the remainder by conventional erection methods. All structures and stringing materials were furnished by the Government. The contractor received notice to proceed on July 22, 1963, and all the work was completed by March 25, 1964.

The contract for construction of the Shiprock Substation, stage 01, was awarded to Reynolds Electrical and Engineering Co., Inc., of Santa Fe, N. Mex., under specifications No. DC-5907 on April 17, 1963. Construction of the substation consisted of six principal features of work. These features were earthwork, culverts, drains, parking area surfacing and access roads; transporting the Government-furnished autotransformer; constructing a masonry garage and a masonry service building; constructing reinforced concrete foundations for steel structures and equipment and erecting steel structures; electrical installations; and installing three 230-kilovolt approach spans. The contractor received notice to proceed on June 21, 1963, and all work was completed and accepted by June 5, 1964.

Construction Helicopters, Inc., of Grand Junction, Colo., constructed the Glen Canyon-Page 138-kilovolt transmission line under specifications No. DC-6030. The work involved construction of 138-kilovolt, 3-phase, H-frame wood-pole and steel tower, single-circuit transmission line, approximately 2 miles in length, extending from the Glen Canyon Switchyard to the city of Page, Ariz. Notice to proceed was received by the contractor on January 3, 1964, and work at the site started on January 23. All work had been completed by August 7, 1964. This line was initially energized on February 4, 1966, at 69 kilovolts.

Ets-Hokin Corp. of San Francisco, Calif., was awarded the contract for construction of the Glen Canyon-Flagstaff 345-kilovolt transmission line No. 2 under specifications No. DC-6100. This line is approximately 124 miles long and extends from the Glen Canyon Switchyard to the Flagstaff Substation. The work mainly consisted of furnishing and installing gates, cattle guards, and culverts; right-of-way clearing;
constructing tower footings; testing, furnishing and erecting steel towers; furnishing and performing RIV and corona tests on insulator assemblies and hardware; and furnishing and stringing conductor and overhead ground wires complete with all accessories. Notice to proceed was received by Ets-Hokin Corp. on July 14, 1964, and all work had been completed by April 24, 1966.

The Flagstaff Substation, located near Winona, Ariz., was constructed under specifications No. DC-6220 by The Howard P. Foley Co. of Tucson, Ariz. The principal features of the work performed under these specifications were earthwork for the substation site and access road; constructing a service building, constructing concrete foundations for structures and equipment; furnishing and erecting steel structures; electrical installation work; and installing Government-furnished materials and furnishing and installing contractor-furnished materials for the approach spans for the Glen Canyon-Flagstaff Transmission Lines No. 1 and 2 and the Flagstaff-Pinnacle Peak Transmission lines No. 1 and 2. Work at the substation site began on April 4, 1965. The overhead conductors were first energized through the substation on June 29, prior to the completion of all work on December 9, 1966.

The actual construction of the features contained in the contracts briefly outlined in this subparagraph (b) are not discussed in this publication.

A. MAJOR CONTRACTS

132. SPECIFICATIONS NO. DC-4825 (PRIME CONTRACT)—CONSTRUCTION OF GLEN CANYON DAM AND POWERPLANT. The contract awarded for work under specifications No. DC-4825 was the largest of all contracts dealing with the construction of the Glen Canyon Dam and Powerplant. It was also and still is (June 1969) the largest single contract ever awarded by the Bureau of Reclamation.

In general, the contract required construction of an arch-type concrete dam, construction of a powerhouse structure, construction of two tunnel-type spillways, earthwork for the switchyard and control cable tunnel, and construction of service roads and parking areas. In addition, the contract included care and diversion of the river during construction.

The contract required all excavation work for the dam, drilling and grouting of the foundation, and drilling of drainage holes; placement of concrete, including the construction of galleries and shafts; installation of all embedded materials in the dam; and the installation of gates and other major equipment and metalwork, including penstocks and outlet works.

For the two spillways, the contractor was to perform all excavation, except the downstream portion of the right spillway, perform the required drilling and grouting, place reinforced concrete lining, and install the radial gates and hoists at the intake structure. The left diversion tunnel, the downstream portion of which became part of the completed spillway, was also constructed under this contract.

The contract included excavation for the construction of the entire powerplant structure, but, it did not include the placement of second-stage concrete, installation of turbines, generators, and electrical and hydraulic apparatus, installation of floor finishes and other finish items or the installation of piping and other metalwork that was to be performed later under the completion contract. The installation of powerplant cranes and the draft tube bulkhead gates was included.

Other general items included the construction of foundation piers for the penstocks, installation of penstocks between the dam and powerplant, installation of outlet pipes downstream of the dam and the mass concrete for these, installation of hollow-jet valves, excavation of the 10,056-foot access roadway tunnel, erection of service bridges at the top of the dam, and construction of the approaches to the Glen Canyon Bridge.

Prior to opening of bids, 13 supplemental notices were issued to clarify and supplement the original specifications.

(a) Summary of Bids, Award of Contract, and Execution of the Work.—Bids were opened at Kanab, Utah, on April 11, 1957, for Glen Canyon Dam and Powerplant, under specifications No. DC-4825. Four bids were received. Merritt-Chapman and Scott Corp. was the low bidder. The three lowest bids received and the engineer’s estimate are listed below:

(1) Merritt-Chapman
   and Scott Corp.
   260 Madison Ave.
   New York 16, N.Y. $107,955,522.00

(2) Glen Canyon Contractors
   10 West Orange Ave.
   South San Francisco, Calif. $118,336,476.00
(3) Morrison-Knudsen Co., Inc., et al  
Boise, Idaho  $120,178,853.00  
Engineer’s estimate  $135,608,170.00  

The contract, No. 14-06-D-2403, was awarded to Merritt-Chapman and Scott Corp. on April 29, 1957. The time for completion allowed in the specifications was as follows:

Part (1) All work to complete the powerplant structure, including required equipment installations; all work to complete the powerplant access road and to complete the parking area between the powerplant structure and the river-outlets valve structure; all work to complete switchyard grading, switchyard access road and cable tunnel excavation—1,760 days.

Part (2) All work to complete the access highway within 60 days after receipt of written notice from the contracting officer that work on the Glen Canyon Bridge, under specifications No. DC-4800, has been completed to the extent necessary to allow work under these specifications to proceed.

Part (3) The remainder of the work—2,500 days.

Notice to proceed was received by the contractor May 2, 1957, thereby establishing the completion dates as follows:

Part (1) February 25, 1962  
Part (2) Determined by specifications No. DC-4800  
Part (3) March 6, 1964  

Construction started June 12, 1957, with the delivering of construction equipment to the jobsite.

(b) Orders for Changes.—There were 25 orders for changes under this contract totaling approximately 8 million dollars. For a brief description of the extra work performed and the resulting cost adjustments, see appendix B. A full description of this work may be found in the final construction report (see bibliography).

(c) Special Agreements.—There were four special agreements under this contract pertaining to construction power requirements and expediting certain work to avoid delaying turbine installations. A full discussion of this work is contained in the final construction report (see bibliography).

(d) Findings of Fact on Requests for Extension of Contract Time.—Findings of fact by the contracting officer, dated May 22, 1959, extended part 2 a total of 38 days. This delay was due to the Government’s directive that the contractor postpone work on the surface treatment of the highway approaches to the Glen Canyon Bridge, due to low ground temperatures.

(e) Claims Against the Government.—A major claim developed early in the contract in connection with a contract provision for adjustment for increases in labor costs in which the Government was to pay 86 percent of the cost of wage rate increases. The controversy arose in late 1959, when a new labor agreement was negotiated with the five basic crafts (carpenters, cement masons, laborers, teamsters, and operating engineers). The new agreement provided for wage increases which were 50 cents an hour higher than wage increases for these crafts in the Arizona Master Labor Agreement. The Government refused to allow adjustment on this portion of the wage increases on the basis that this amount represented a subsistence payment which was specifically exempted by the specifications from the adjustment.

After considerable controversy involving the contractor, the Bureau, and the Board of Contract Appeals, the Government paid a portion of the contractor’s claim, or $289,567.67, in full settlement of the claim. Further discussion of this matter is given in section 141 and in the final construction report (see bibliography).

133. SPECIFICATIONS NO. DC-5750—COMPLETION OF GLEN CANYON POWERPLANT, SWITCHYARD, DAM, AND APPURTENANT WORKS. Completion of the Glen Canyon Dam and appurtenant works consisted of completing architectural finishes, furnishing and installing plumbing fixtures, doors, partitions, handrails, heating and ventilating systems, and electrical installations. Completion of Glen Canyon Switchyard included earthwork, grading and surfacing, concrete foundations, furnishing and erecting steel structures, fence, and electrical installations. The work also included four transmission circuits from the powerplant transformer deck to the switchyard.

The completion of the Glen Canyon Powerplant consisted of placing second-stage concrete for embedding turbines and support for generators; placing blockout concrete and miscellaneous concrete at various locations throughout the plant; constructing partition walls and completing architectural finishes; installing penstock makeup pieces, hydraulic turbines
CONTRACT ADMINISTRATION

governors for hydraulic turbines, accessory hydraulic equipment and machine tools; installing or furnishing and installing fire protection equipment, piping systems, air-conditioning, heating and ventilating systems, sewage treating equipment, plumbing fixtures, metalwork, electrical conduit, wires, cables, lighting fixtures, and other electrical equipment and accessories except the generators which were installed under a separate contract.

Four supplemental notices were issued prior to the opening of bids. These notices made changes and additions in the specifications in order to correct, supplement, and clarify the specification provisions and to include revised drawings.

(a) Summary of Bids, Award of Contract, and Execution of the Work.—Bids were opened at Page, Ariz. on June 5, 1962, for completion of Glen Canyon Powerplant, Switchyard, Dam, and appurtenant works, under specifications No. DC-5750. Seven bids were received; Ets-Hokin and Galvan, Inc., was the low bidder. The three lowest bids received and the engineer’s estimate are listed below:

(1) Ets-Hokin and Galvan, Inc.
551 Mission Street
San Francisco 5, Calif. $7,891,271.70

(2) Morrison-Knudsen Co., Inc.
319 Broadway
Boise, Idaho $7,985,494.00

(3) Gunther-Shirley-Lane
4560 Sherman Oaks Ave.
Sherman Oaks, Calif. $8,248,980.00

Engineer’s estimate $7,736,602.00

Contract No. 14-06-D-4429 was awarded to Ets-Hokin and Galvan, Inc., on June 25, 1962. A period of 1,350 days was allowed by supplemental notice to the specifications for completion of all work under the contract. The work was divided into nine parts and, where applicable, each unit had a completion time within that part. Notice to proceed was received by the contractor July 19, 1962, thereby establishing March 30, 1966, as the date for completion. Work at the site was started on July 30, 1962. A strike, delays in delivery of Government-furnished turbine parts, and drawing approval were causes of delays subsequently approved by findings of fact and by contracting officer’s letter. An amendatory agreement to expedite the work (subsection (d)) revised the completion dates for some parts. The work was accepted as substantially complete on October 25, 1966, within the adjusted time allowed.

(b) Orders for Changes.—There were 13 orders for changes under this contract totaling about $320,000.00. For a brief description of the extra work performed and the resulting cost adjustments see appendix C. A full description of this work may be found in the final construction report (see bibliography).

(c) Findings of Fact.—Findings of fact dated January 15, 1964, considered a delay in completion of the contract due to a strike by the Operating Engineers Local 428. As a result of the findings, the completion of all parts of the contract was extended 22 calendar days.

Findings of fact dated September 9, 1964, considered delays due to late delivery of Government-furnished turbine parts for units 1, 2, and 3 installed under part (1) of paragraph 16a of the specifications. As a result of the findings, the completion of part (1) of the contract was extended 224 calendar days for unit 1, 157 calendar days for unit 2, and 73 calendar days for unit 3.

By letter of February 28, 1964, the contracting officer allowed extensions of time for the various parts of the contract for delays in approval of drawings by his office.

(d) Amendatory Agreement.—An amendatory agreement dated January 6, 1964, established earlier completion dates from those in the specifications so that power production could begin sooner and allowed additional compensation to the contractor for the expenses incurred in speeding up his operation to meet the new dates. The net increase in the amount due under the contract for this work was $575,000.00.

B. MINOR CONTRACTS

134. SPECIFICATIONS NO. DC-4747—RIGHT DIVERSION TUNNEL. The diversion tunnel consists of 1,818 linear feet of unlined tunnel 43 feet 6 inches inside diameter, and 950 linear feet of unlined tunnel 46 feet 6 inches inside diameter. The principal features of the work for construction of the diversion tunnel were excavation, in open cut, at the upstream and downstream portals, and excavation for the diversion tunnel including furnishing and installing permanent tunnel supports.

(a) Summary of Bids, Award of Contract, and Execution of the Work.—Seven bids were received at Kanab, Utah, and were opened on September 11,
1956. The three lowest bids and the engineer’s estimate are listed below:

(1) Mountain States Construction Co.
Denver, Colo. $2,452,340.00

(2) Morrison-Knudsen Co., Inc., and Henry J. Kaiser Co., a joint venture
Los Angeles, Calif. $2,961,800.00

(3) Coker Construction Co., Peter Kiewit Sons’ Co., and Condon-Cunningham Co., a joint venture
Omaha, Nebr. $3,334,100.00

Engineer’s estimate $3,845,100.00

The contract, No. 14-06-D-2045, was awarded to Mountain States Construction Co. of Denver, Colo., on October 1, 1956. A period of 450 days was allowed in the specifications for the completion of the contract. Notice to proceed was received October 2, 1956, thereby establishing the completion date as December 26, 1957. The contractor began moving in equipment to the jobsite on October 8, 1956.

All work was completed and accepted March 13, 1958. The net contract amounted to $2,278,575.62.

(b) Orders for Changes.—There were three orders for changes under this contract totaling approximately $186,000.00.

135. SPECIFICATIONS NO. DC-4800—GLEN CANYON BRIDGE. Glen Canyon Bridge consists of a steel arch with a single span of 1,028 feet and a total overall length of 1,271 feet including abutments. The bridge has a 30-foot-wide concrete road with sidewalk 4 feet wide on each side.

(a) Summary of Bids, Award of Contract, and Execution of the Work.—Two bids were received and opened in Kanab, Utah, on December 18, 1956. Kiewit-Judson Pacific Murphy of Emeryville, Calif., was the low bidder on the bid of $4,139,277.00. The second bidder was Bethlehem Pacific Coast Steel Corp. of San Francisco, Calif. Their bid was $4,408,944.00. The engineer’s estimate was $2,944,750.00.

Contract No. 14-06-D-2240 was awarded to Kiewit-Judson Pacific Murphy on January 21, 1957, and notice to proceed was received on January 28, 1957. Completion of the work was divided into four parts. Part (1) provided for completion of the entire bridge, exclusive of painting below the concrete bridge deck, within 750 days. Painting below the concrete deck, under part (2), was to be completed within 870 days. Removal of equipment and facilities between lines 80 feet each side of the centerline of the east approach and 40 feet each side of the centerline of the west roadway approach within 720 days was required under part (3). Part (4) provided for the installation of metal railings for the abutments within 720 days. The established dates for completion of the four parts are as follows: Part (1), February 17, 1959; part (2), June 17, 1959; part (3), January 18, 1959; and part (4), January 18, 1959. All work under the contract was accepted as substantially complete on March 25, 1959. The contract amounted to a total of $4,658,497.57.

(b) Orders for Changes.—There were four orders for changes under this contract totaling approximately $186,000.00.

(c) Reference.—See appendix E for a brief discussion of the Glen Canyon Bridge as well as a presentation of cost data. More detailed information is given in the technical record of design and construction on the feature.

136. SPECIFICATIONS NO. DC-6274—VISITOR CENTER COMPLEX AT GLEN CANYON DAM. The main features of the building are a steel-framed, one-story wing with basement, a steel-framed rotunda and concrete-lined elevator shaft. Precast panels with facings of exposed aggregate were used for the walls of the building wing and rotunda. A concrete-lined tunnel was constructed to connect the elevator shaft to the top of the dam. Other work included the construction of parking areas, roadways, water supply systems, and miscellaneous switchyard work in connection with the center electrical control and power systems.

(a) Summary of Bids, Award of Contract, and Execution of the Work.—The bid opening was held in Page, Ariz., on June 8, 1965, with six bids being received. The three lowest bids and the engineer’s estimate are listed below:

(1) Allen M. Campbell Co.
General Contractors, Inc.
Tyler, Tex. $1,123,000.00

CONTRACT ADMINISTRATION

(2) Lembke Construction Co., Inc.
Albuquerque, N. Mex. $1,187,341.00

(3) The Brezina Construction Co., Inc.
Rapid City, S. Dak. $1,224,440.00

Engineer’s estimate $ 900,330.00

Award of contract No. 14-06-D-5634 was made to Allen M. Campbell Co. on June 30, 1965. The specifications provided for the completion of the work in two parts. Part (1) was for all work to complete the elevator lobby and shaft to permit installation of the elevator by the elevator contractor within 800 days. Part (2) was for the remainder of the work and was to be completed within 480 days. Notice to proceed was received by the contractor on July 12, 1965, and completion dates for parts (1) and (2) were established as April 26 and October 23, 1966, respectively. At the time notice to proceed was received, a statewide construction strike was in progress. This strike was not settled until about August 15 when a 5-year agreement was signed by the operating engineers. Construction began on August 16, 1965, with the erection of the contractor’s field office.

The time allowed for completion of the contract was extended 41 days under part (1) and 53 days under part (2) due to delays in returning approval drawings. A findings of fact dated April 22, 1966, extended the time allowed for completion of parts (1) and (2) by 45 days. The time for completion of part (2) was also extended 56 days by a findings of fact dated April 27, 1967. All work was accepted as substantially complete on August 17, 1967.

(b) Orders for Changes.—There were four orders for changes under this contract totaling about $75,000. A full description of this work may be found in the final construction report (see bibliography).

137. SPECIFICATIONS NO. DC-6317—COMPLETION OF LEFT DIVERSION TUNNEL PLUG AND SPILLWAY ELBOW. The principal features of the work under these specifications included final excavation of the lower end of the spillway shaft, placing backfill concrete in adits, conduit, gate chamber and tunnel plug sections; placing spillway lining; drilling and grouting; and epoxy repairs to the existing lining.

(a) Summary of Bids, Award of Contract, and Execution of the Work.—Five bids were received. The bids were opened at Page, Ariz., on July 29, 1965. The three lowest bids and the engineer’s estimate are listed below:

(1) S. S. Mullen, Inc.
Seattle, Wash. $1,535,333.13

(2) Martin K. Eby Construction Co., Inc.
Phoenix, Ariz. $1,985,016.52

(3) The Eagle Construction Corp.
Loveland, Colo. $2,066,298.13

Engineer’s estimate $1,638,423.13

Contract No. 14-06-D-5670 was awarded to S. S. Mullen, Inc., on August 6, 1965. The specifications allowed 300 days for completion of the work. Notice to proceed was received by the contractor on August 23, 1965, thereby establishing June 19, 1966, as the completion date. Order for changes No. 2 extended the contract completion time 95 days. A findings of fact, considering several miscellaneous delays, extended the time 76 additional days. The net earnings under the contract were $1,741,098.03.

(b) Orders for Changes.—There were two orders for changes under this contract. A brief description of this work may be found in the final construction report (see bibliography).

C. GOVERNMENT AND CONTRACTOR’S ORGANIZATION

138. CONTRACTOR’S ORGANIZATION. Major construction on Glen Canyon Dam, Powerplant, and Switchyard was completed by two main contractors, which have been designated as the prime contractor and the completion contractor. The prime contract was awarded to the Merritt-Chapman and Scott Corp. of New York City for work under specifications No. DC-4825 and the completion contract to Ets-Hokin and Galvan, Inc., of San Francisco under specifications No. DC-5750. The name of Ets-Hokin and Galvan, Inc., was later changed to the Ets-Hokin Corp.

(a) Prime Contractor (Specifications No. DC-4825).—The prime contractor’s principal staff included a project manager, a project engineer, an office manager, a general superintendent, and an administrative assistant.

With the office manager were the chief timekeeper, the job accountant, and the chief
warehouseman. Reporting to the general superintendent were his assistant, the shift superintendents, the rigging, carpenter, aggregate plant, concrete, batching plant, pipe, excavation and electrical superintendents, a master mechanic and an electrical engineer. A chief field engineer and an office engineer reported to the project engineer. The chief field engineer supervised a computer, a subcontract inspector, three survey parties, and an excavation man. The office engineer was in charge of a quantity engineer, materials engineer, an estimates man, two laboratory technicians, a mechanical and hydraulic engineer, a chief structural engineer, four assistant engineers, and a files and reproduction man.

Under the administrative assistant were a safety engineer, a cost engineer, a cost coder, a personnel and labor relations man, and the security guards which organization was under subcontract.

The maximum and average employment by the prime contractor for each year of construction follows:

<table>
<thead>
<tr>
<th>Year</th>
<th>Maximum</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>1962</td>
<td>88</td>
<td>49</td>
</tr>
<tr>
<td>1963</td>
<td>350</td>
<td>170</td>
</tr>
<tr>
<td>1964</td>
<td>276</td>
<td>175</td>
</tr>
<tr>
<td>1965</td>
<td>82</td>
<td>45</td>
</tr>
<tr>
<td>1966</td>
<td>40</td>
<td>26</td>
</tr>
</tbody>
</table>

A partial list of Ets-Hokin Corp. subcontractors and the work they performed is presented in the final construction report (see bibliography).

139. GOVERNMENT ORGANIZATION. On July 1, 1956, a project construction engineer and one engineer were assigned to the Glen Canyon unit. Headquarters were established in the old high school building in Kanab, Utah, about 71 miles west of the damsite. The number of Government employees assigned to the project work totaled 144 by December 31, 1956. A geologist was initially detailed from the Bureau's Region 3 office at Boulder City, and he was later assigned to the project.

In the fall of 1958, after the municipal building and an adequate number of residences were completed to house employees, the project headquarters were moved to Page. Temporarily occupying the municipal building and two employee residences across the street from it, project headquarters were moved to the administration building a few months later in August 1959, when that building was completed. Procurement, property management, and materials control personnel moved into the warehouse offices at the time the headquarters moved to Page and remained there throughout construction.

During the succeeding years, a full scale construction organization was established as the expanding program demanded. This organization ultimately consisted of seven divisions, which were subdivided into branches and sections assigned to specific phases of the work. The seven divisions were: field engineering division, office engineering division, administrative division, city management division, special services division, safety management division, and on February 8, 1961, the transmission line division.

On March 25, 1964, the Glen Canyon unit construction office was consolidated with the Glen Canyon field division of the CRSP power operations office. As construction continued to be a dominant activity for the next 2 years, a project construction engineer remained at the head of the division, under
the administrative direction of the Regional Director. He was the authorized representative of the Chief Engineer on construction matters, was responsible to the Project Power Manager at Montrose, Colo., on power operations and maintenance matters, and was responsible to the Regional Director concerning Page city management matters.

Construction functions and personnel were incorporated in a new construction branch which included a field engineering section, office engineering section, and transmission line section. The divisional structure of the former unit office was changed to branch designations composed of the following: construction, plant maintenance, plant operations, city management, and administrative services branches.

In early February 1967, all office personnel except those in city management, property management, and procurement moved to the permanent offices on the ninth floor of the powerplant.

On February 27, 1967, the Glen Canyon field division was reorganized for operations and maintenance status under the immediate direction of a division chief who was under the general direction of the Project Power Manager at Montrose, Colo. The chief of the construction branch, served under the general administrative direction of the chief of the Glen Canyon field division, and was responsible for the remaining construction of Glen Canyon Dam, Powerplant, and appurtenant facilities. He also served as authorized representative of the contracting officer on contracts for construction and for repair, installation, and modification of facilities in construction status.

During the peak of construction in 1962, the construction organization had as major components: field engineering, office engineering, administrative services and city management divisions. A maximum of 359 Government employees was reported at the year's end in 1962.

(a) Field Engineering Division.—The field engineering division, with the field engineer at the head, consisted of a dam inspection branch, a powerplant inspection branch, an electrical engineering branch, a concrete control branch, a mechanical engineering branch, and a surveys branch.

(1) The dam inspection branch consisted of a general inspection section, a grouting inspection section, and a cooling section. The general inspection section, consisting of 9 engineers and 21 inspectors, was responsible for inspection of all concrete placing in the dam and for inspection of related work under any other contracts on the project. The grouting inspection section, which consisted of two engineers and five inspectors, was responsible for inspection of all grouting in the dam foundation, the dam, and the diversion tunnels and spillways. The cooling section, consisting of two engineers and one technician, was responsible for inspection of the proper installation of the cooling system and for maintaining a check to insure that proper temperatures were maintained in the mass concrete that required cooling.

(2) The electrical engineering branch consisted of an engineer, a technician, two inspectors and one engineering aid, as well as the technical instruments section. The technical instruments section, consisting of seven technicians and four engineering aids, was responsible for the placement and reading all technical instruments in the dam. These instruments consisted of deformation meters, joint meters, stress meters, strain meters, no-stress strain meters, and resistance thermometers.

(3) The powerplant inspection branch, consisting of two engineers and nine inspectors, was responsible for inspection of all concrete placements and related work by the prime contractor on the powerplant.

(4) The concrete control branch, headed by an engineer and an assistant, consisted of 40 engineers, technicians, and inspectors of various grades and experience during the peak of construction. The branch chief and assistant were assisted by an office and laboratory chief technician and one supervisory engineer on each shift who coordinated and directed inspection and testing procedures. The branch was responsible for the investigation and selection of suitable concrete aggregate and soil materials; the design and inspection control of all aggregate and concrete production; sampling and testing for acceptance, all pozzolan and cement as delivered to the project; sampling and testing of other construction materials, including soils, used during construction of the dam and appurtenant structures; and preparation of all progress reports for the concrete control branch and preparation of data necessary for progress payment estimates with respect to concrete, soils, cement, and pozzolan.

(5) The mechanical engineering branch consisted of three engineers and one inspector reporting to an engineer who was chief of the branch. The branch was responsible for the installation of all mechanical equipment such as
penstocks, outlet gates, ring-follower gates, hollow-jet valves, radial gates in the spillway, spiral and inclined stairs, etc. One engineer in the branch was stationed at the Vinnell Steel fabrication plant at Flagstaff, Ariz., from August 10, 1959, to December 1, 1960, to supervise the fabrications and welding of the penstocks. The work consisted of inspection of stress relieving of the penstock sections, X-ray inspection of the welds, hydrostatic pressure tests, and expansion joint jacking tests.

(6) The surveys branch consisted of an engineer as chief of branch, six technicians, four survey aids, and one highscaler. A survey party of four began locating the west side access road from the Arizona-Utah State line to the damsite on May 29, 1956. The branch was responsible for the triangulation, precise level net at the damsite, making cross sections of canyon walls for dam and appurtenant works, setting lines and grades for forms, lot layout in commercial and residential areas of the townsit, and structural behavior measurements.

(b) Office Engineering Division.—The office engineering division consisted of an office engineer, a contract administration branch, a design and cost estimates branch, and a materials control branch.

(1) The contract administration branch, at the head of which was one engineer (with one clerk-typist), included a contract adjustment section and a cost summaries section. The contract adjustment section consisted, during the peak of construction, of two engineers, one engineering technician, and one general clerk and was responsible for negotiation with all contractors on all claims for extra compensation and delays and for the drafting of all orders for changes and findings of fact. The section was also responsible for bid openings and bid reports, for transmittal of all construction drawings and instructions to the contractor, and for furnishing drawings to the Government field forces. The contractors’ and subcontractors’ payrolls were checked for conformance to labor standards provisions. The Contractors’ compliance with nondiscrimination requirements was also the responsibility of the contract adjustment section. A check on labor escalation payments claimed by the contractor was made after May 31, 1959.

The contract summaries section consisted of two engineers and two engineering technicians, with additional temporarily assigned personnel to meet peak workload demands, and was responsible for the preparation of all contract summaries and vouchers for monthly partial payments and final payments to construction contractors. The contract summaries section also checked the contractors’ shop drawings, concrete placement drawings and reinforcement drawings, and reviewed the contractors’ construction schedules for proper coordination of the work.

(2) The design and cost estimates branch, with an engineer in charge, included a computation and estimates section, a design section, and a drafting section. The computation and estimates section, consisting of five engineers and two engineering technicians, was responsible for computation of quantities for monthly and final pay estimates for all items of work concerning earthwork and concrete. The section was also responsible for all other computations relating to the project, reduction of all field survey data, and marking of prints relating to work in the section. The design section, consisting of two or three engineers, was responsible for all project layout work, preparation of grout pipe and drainhole drawings, and cooling pipe drawings, town lots, street grades, sewer and waterline alignment and profile, and the storm sewer alignment and profile. A number of drawings were revised after the Denver office had prepared the design in a general way or if a need for revision was critical, such as for excavation of the keyways. The right and left abutment duct bank design and the uplift pressure pipes layouts were also made in the design section. Preliminary design drawings were also made in the section and transmitted to the office of the contracting officer. The drafting section consisted of one drafting supervisor, one to three draftsmen, one clerk-typist, and was responsible for all project drafting, filing of all drawings, and furnishing of prints as needed on the project.

(3) The materials control branch, at the head of which was an engineer, consisted of one engineer, two engineering technicians, one laborer, and one clerk-typist. The branch was responsible for inspection and checking of all Government and contractor-furnished equipment received for all construction contracts. Where inspection of equipment was waived at the shipping point, inspection was made by the branch at the railhead or at Page if shipped by truck. This required the presence of one or more employees at the unloading point to check for damages, shortage, reloading if necessary, and for proper storage. A record was kept of all materials received, installed, and returned to the Government. In case of a shortage after the contractor had signed for equipment received, a charge would be made against the contractor.
Material was checked for conformance to Federal specifications or to manufacturers' catalogs when required. Checking of equipment, including all parts, against the drawing was especially important so that a construction contractor would not be delayed due to shortage of parts.

(c) Administrative Services Division.—The staff of the administrative services division, under the direction of an administrative officer, was responsible for all clerical and administrative functions in connection with project activities. The work included the procurement of a variety of Government-furnished supplies and equipment, and management, storing and accounting for both expendable and nonexpendable property; the final coordination of the project's function for budget, costs, time, leave and payroll, travel, collections for construction activities, and other fiscal functions; managing special tours, accommodations and local itineraries of foreign officials and dignitaries and special scientific groups; office services functions such as mail, files, stenographic services, telephone and teletype facilities, office building maintenance, records management and disposal, the personnel management program with delegated appointing authority and position classification through GS-11 and all wageboard positions; the preparation of budget documents for the various project features; the preparation of program schedules to reflect work accomplished and work contemplated; and the preparation of various technical and descriptive reports of the entire construction activity.

(d) City Management Division.—This division headed by a city administrator and assistant, consisted of a city engineering branch, under which was a city engineering and inspection section and an operation and maintenance section; a ranger branch; a fire control branch; and a city services branch, Page, Ariz., was established in connection with the construction of Glen Canyon Dam and Powerplant to provide necessary housing and community facilities and services for Government and contractors' employees engaged in the construction and operation of the dam, reservoir, and powerplant. Under the supervision of the city administrator, the division was responsible for representing the Government in the management affairs of the Federal Municipality of Page; the conduct of municipal affairs under applicable county and state laws and Federal regulations and statutes; development of specific programs for each phase of local affairs, including the encouragement of private business enterprises and residential development by facilitating the sale of commercial and residential building sites; devising and administering procedures for accomplishing eventual self-government under Arizona laws, such as zoning and disposal of lands and real property, tax structure and source of revenue for municipal financing under laws of incorporation, transfer of utilities, shops, and other public properties from Federal to municipal ownership, and articles of incorporation and charters and correlating economic and social interests of various citizen groups.

(e) Organization.—An organization chart as of December 31, 1961, is presented in figure 244. The maximum number of Government employees during the principal years of construction were as follows:

<table>
<thead>
<tr>
<th>Year</th>
<th>Employees</th>
</tr>
</thead>
<tbody>
<tr>
<td>1956</td>
<td>150</td>
</tr>
<tr>
<td>1957</td>
<td>211</td>
</tr>
<tr>
<td>1958</td>
<td>219</td>
</tr>
<tr>
<td>1959</td>
<td>229</td>
</tr>
<tr>
<td>1960</td>
<td>279</td>
</tr>
<tr>
<td>1961</td>
<td>324</td>
</tr>
<tr>
<td>1962</td>
<td>359</td>
</tr>
<tr>
<td>1963</td>
<td>355</td>
</tr>
<tr>
<td>1964</td>
<td>293</td>
</tr>
</tbody>
</table>

140. SAFETY. The accident prevention program was included as a specific part of the contractual obligation under specifications No. DC-4825. By reference, the Bureau of Reclamation manual, “Safety Requirements for Construction by Contract, Second Edition” was included in the specifications. During the tenure of the contract, a third edition of the manual was issued, which was readily accepted by the contractor. The “Manual of Accident Prevention in Construction,” published by the Associated General Contractors of America, was also used by the contractor as a guide to establish safe practices in the work.

The project safety program was initiated in November of 1956, prior to initiation of work under the prime contract, continued throughout the life of the prime contract in late 1964, and then until completion of project work. Prior to construction, a conference was held with key representatives of the prime contractor and the Bureau to insure a clear understanding of the safety standards required and to eliminate any areas of procedural misunderstandings and probable conflict. In particular, the need for constant emphasis on accident prevention by the superintendents and foremen was stressed, responsibility for each area of work was established, and the necessity of a constant program of workman education was emphasized.
Figure 244.—Organization chart for Glen Canyon Unit as of December 31, 1961.

CONSTRUCTION
Details of the contractor's safety program were formulated by the full-time safety engineer employed by the contractor. Basically, the safety program recognized that most accidents were caused by human failure rather than mechanical failure, which was reflected in a continuing education and information program for the workmen. In addition, mandatory requirements were established to insure safe working environment, including the use of protective equipment furnished by the contractor for use by the individual employees.

Another basic part of the accident prevention, with respect to the individual employees, was an initial medical screening program arranged by the contractor. Performed prior to employment, the screening included a physical examination when appropriate depending upon the position or past history of the individual. There was a wide-spread acceptance of wearing the customary hardhats, hard-soled shoes, and safety goggles or glasses. This attitude was reflected in the general acceptance of the safety program by the employees as well as the individual good records. Use of measures to protect the skin from cement dust and other irritants was only gradually accepted, as a matter of routine course, but persistence by the foreman in briefing of new employees proved effective. There were very few cases in which employees had to be reminded that failure to follow standard safety procedures could result in termination of employment.

A joint safety policy committee was established to discuss problems of mutual interest involved in accident prevention. Meeting monthly, the committee was composed of key supervisory personnel from each of the active contractors at the site and Government representatives. Representing the largest employer with over 2,000 employees at peak construction, the prime contractor's safety engineer was a leader in the effectiveness of this committee. Policies or procedures established, as well as changes in past regulations, were also disseminated in this manner. At the workmen's level, the crew foreman, the key link in safety indoctrination, would inform the individual workmen of these new regulations and describe the implementation required. In turn, the workmen were encouraged to bring any potentially unsafe practices to the attention of the foreman, and the matter was forwarded for presentation to the safety committee when a general change in procedures or policy might be required. Review of subsequent accident reports also provided a source of information needed to avoid duplication of the same accident environment or condition. Visual aids were also used, including posters, signs, pamphlets, and films.

First aid kits were installed in close proximity to each area of work. All vehicles and pieces of major equipment were equipped with the first aid kits. Training and certification of foreman in the American Red Cross or Bureau of Mines first aid courses produced a capable group of workmen who assisted in immediate job evacuation of injured employees and in assuring early medical attention of injuries. Two fully equipped mobile trailers, along with two ambulances, were located immediately on either side of the job and were staffed by registered nurses on a 24-hour basis under the general supervision of a physician. A first aid kit was also provided for the cableways to evacuate severely injured employees from inaccessible areas on the damsite. Prompt and efficient treatment of minor wounds and injuries prevented development of more serious problems and also reduced the number of lost time injuries.

The specifications also provided that the contractor construct and staff a small hospital near the town of Page, as soon as possible after the award of the contract. This permanent-type hospital was to have a minimum capacity of 25 beds. Medical personnel, including doctors, nurses and technicians, were recruited and retained for operation of the hospital. Early opening of the hospital eliminated the occurrence of complications from delays in reaching distant medical facilities. The hospital was also open to the general public on a space available basis, who would pay for the services they received. Airport facilities were also utilized in a plan for rapid evacuation by air, when more complicated problems required the attention of the medical centers in the larger cities.

It is interesting to note that the contractor's accident program included orientation on offsite accidents. Recognizing that two offsite accidents happen for every onsite accident, the contractor also stressed home and highway safety in his basic program of accident prevention.

The greatest hazards in the work were related to the height differentials involved in construction. As a result, great emphasis was placed upon protection from falling rock and other objects, and upon precautions to prevent falls by the employees themselves. Although the accident prevention program was highly successful in this regard, as compared with other projects of this nature, injuries from these two causes accounted for over one-half of the lost-time accidents. Safety precautions for electrical powerlines and equipment were exceptionally vigorous, and injuries and accidents from this source were relatively small in number and minor in severity. Adequate ventilation was provided during tunnel excavation and tests for toxic gases were conducted at frequent intervals. Extensive onsite equipment and machinery repair facilities, coupled with the regular program of inspection and
CONSTRUCTION

maintenance, considerably reduced accidents and injuries due to equipment failure. Adequate facilities for storage and handling of explosives were provided and maintained properly. Good housekeeping, the indicator of efficient working conditions and good safety habits, was continually stressed by the contractor with generally successful results. The aggregate haul road from the Wahweap screening plant to the stockpiles adjacent to the damsite was well designed and maintained by the prime contractor. As the haul road was 6 miles in length and along the canyon rim, only two well-regulated crossroads were necessary for cross traffic, one near each end of the road.

The safety programs of other contractors generally paralleled the program described for the prime contractor. The contracts were usually smaller and for more specialized work and the personnel responded readily to the weekly toolbox safety discussions. Little difficulty was experienced in maintaining adequate safety programs for these contracts, except for the inconvenience of the long travel distances involved in the transmission line contracts.

As a result of this program of accident prevention, contractors' employees experienced an overall average accident-frequency rate of 17.3 disabling injuries per million man-hours of exposure during the project construction period. A total of 14 fatalities occurred on the prime contract during the 7 years of tenure, nearly all of which resulted from errors in human judgment or freak accidents. There was one fatal accident among contractor employees during construction of the right diversion tunnel and two fatal accidents during construction of transmission lines under other separate contracts. In addition, there were two Bureau fatalities; however, one of these was caused by an act of God and was not chargeable against the project safety record. There was a total of 18 fatal accidents during construction of the entire project. During the construction of the bridge, there were no fatalities even though the bridge is the highest steel arch bridge of known record. In summary, there were 343 lost-time on-the-job injuries to all contractors' employees while performing 19,789,000 man-hours of hazardous construction.

In addition to the contractors' safety efforts, a program of accident prevention was pursued by the Government employees. Although particular emphasis was placed on vehicular safety and first aid training, all contractors' safety programs were observed and encouraged by engineering and inspection personnel as a matter of good practice, as well as setting an example. Maintenance employees followed a program of accident prevention similar to those of the contractor, including weekly toolbox safety meetings. There was a total of 22 lost-time injuries to Government employees during the 5,105,000 man-hours worked, or an accident frequency rate of 4.3 disabling injuries per million working hours.

The contractor's and the Government employees lost-time accident summaries are shown in tables 1 and 2, respectively.

<table>
<thead>
<tr>
<th>Year</th>
<th>Man-hour exposure</th>
<th>Number of injuries</th>
<th>Days lost</th>
<th>Frequency rate</th>
<th>Severity rate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Disabling Fatal</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1957</td>
<td>1,044,753</td>
<td>18 3</td>
<td>18,403</td>
<td>20.1</td>
<td>17,614</td>
</tr>
<tr>
<td>1958</td>
<td>2,805,346</td>
<td>43 2</td>
<td>16,970</td>
<td>16.0</td>
<td>6,049</td>
</tr>
<tr>
<td>1959</td>
<td>1,113,625</td>
<td>13 1</td>
<td>6,315</td>
<td>12.6</td>
<td>5,670</td>
</tr>
<tr>
<td>1960</td>
<td>2,422,089</td>
<td>39 4</td>
<td>25,493</td>
<td>17.7</td>
<td>10,112</td>
</tr>
<tr>
<td>1961</td>
<td>3,771,901</td>
<td>63 3</td>
<td>21,105</td>
<td>17.5</td>
<td>5,595</td>
</tr>
<tr>
<td>1962</td>
<td>3,366,333</td>
<td>68 1</td>
<td>8,911</td>
<td>20.3</td>
<td>2,655</td>
</tr>
<tr>
<td>1963</td>
<td>3,259,369</td>
<td>50 2</td>
<td>13,653</td>
<td>15.3</td>
<td>4,189</td>
</tr>
<tr>
<td>1964</td>
<td>1,222,832</td>
<td>24 0</td>
<td>1,386</td>
<td>19.6</td>
<td>1,133</td>
</tr>
<tr>
<td>1965</td>
<td>387,548</td>
<td>4 1</td>
<td>6,059</td>
<td>12.9</td>
<td>15,634</td>
</tr>
<tr>
<td>1966</td>
<td>405,681</td>
<td>4 0</td>
<td>188</td>
<td>9.9</td>
<td>463</td>
</tr>
<tr>
<td>Totals</td>
<td>19,789,247</td>
<td>326 17</td>
<td>118,483</td>
<td>17.3</td>
<td>5,987</td>
</tr>
</tbody>
</table>
141. LABOR RELATIONS AND CONTRACTOR'S WAGE RATES. (a) Labor.—Although the Glen Canyon unit is in an isolated and remote location, approximately 135 miles from the nearest Arizona town of any size, an adequate supply of labor was generally available for the construction work. Recruitment of construction labor by the contractors was, in general, through the union halls of the various crafts, either in Flagstaff or Phoenix. The heavy demand for construction labor at Glen Canyon had a significant effect on the labor situation in Arizona and undoubtedly contributed to the acceleration of wage rate increases and fringe benefits which occurred in Arizona during the period of construction at Glen Canyon.

Wage rates more than doubled during this period as can be seen by table 3 which shows the rates paid each craft in 1956 and in 1964. Approximately 80 million dollars in gross wages were paid by contractors working at the site during the construction period. Of this total, Merritt-Chapman and Scott Corp., the prime contractor on the dam and powerplant, and its subcontractors paid a total of 68.3 million dollars in gross wages, or approximately one-half of the final contract value. Total employment under this contract by year is shown in section 138.

At the time work began on the Glen Canyon unit, most of the construction crafts received subsistence payments when working at distant locations from the union halls. Typical of the working agreements in effect at the time work started was the statewide Master Labor Agreement between the Associated General Contractors and the unions representing the five basic crafts (carpenters, teamsters, operating engineers, cement masons, and laborers). This agreement contained a "Remote Projects" provision which required that when a project was declared remote, as determined by a special Remote Projects Committee made up of members of both parties, the contractor would have the option of providing a camp at the jobsite or of providing free transportation from the nearest town where suitable living accommodations were available. If a camp was provided, no charge was to be made to employees for the board and room facilities provided. If free transportation was provided, travel time was to be paid at the regular straight time rate. The Remote Projects Committee established under this provision designated the Glen Canyon project as remote on December 12, 1956, and advised that the project would remain remote until 30 days after the committee found that residential housing facilities were available for those employees who wished to avail themselves of these facilities.

Early contractors at Glen Canyon operated under the Master Labor Agreement and complied with the requirement of the Remote Projects provision. Free board and room was provided, usually through a concessioner.

The prime contractor for the dam and powerplant, Merritt-Chapman and Scott Corp., arrived in late spring of 1957, and established temporary headquarters at Kanab, Utah, some 75 miles west of the site of the work. Merritt-Chapman and Scott expected to operate under the terms of its national agreement with the various crafts and did not anticipate becoming a signatory party to the existing statewide Master Labor Agreements. But when Merritt-Chapman and Scott contacted the local unions

### Table 2.—Lost-time accident summary for Government employees.

<table>
<thead>
<tr>
<th>Year</th>
<th>Man-hour exposure</th>
<th>Number of injuries</th>
<th>Days lost</th>
<th>Frequency rate</th>
<th>Severity rate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Disabling</td>
<td>Fatal</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1957</td>
<td>354,585</td>
<td>2</td>
<td>0</td>
<td>98</td>
<td>5.6</td>
</tr>
<tr>
<td>1958</td>
<td>426,978</td>
<td>4</td>
<td>0</td>
<td>78</td>
<td>9.4</td>
</tr>
<tr>
<td>1959</td>
<td>433,072</td>
<td>2</td>
<td>0</td>
<td>44</td>
<td>4.6</td>
</tr>
<tr>
<td>1960</td>
<td>514,320</td>
<td>2</td>
<td>1</td>
<td>6,014</td>
<td>5.8</td>
</tr>
<tr>
<td>1961</td>
<td>650,600</td>
<td>5</td>
<td>0</td>
<td>57</td>
<td>7.7</td>
</tr>
<tr>
<td>1962</td>
<td>705,966</td>
<td>4</td>
<td>0</td>
<td>794</td>
<td>5.7</td>
</tr>
<tr>
<td>1963</td>
<td>706,022</td>
<td>1</td>
<td>0</td>
<td>230</td>
<td>1.4</td>
</tr>
<tr>
<td>1964</td>
<td>527,012</td>
<td>2</td>
<td>0</td>
<td>39</td>
<td>3.8</td>
</tr>
<tr>
<td>1965</td>
<td>447,989</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1966</td>
<td>338,020</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Totals</td>
<td>5,104,564</td>
<td>22</td>
<td>1</td>
<td>7,354</td>
<td>4.5</td>
</tr>
</tbody>
</table>
to make arrangements for a supply of labor for the job, the contractor was required to sign the Master Labor Agreements as a condition to the union's furnishing labor. In order to comply with the Remote Projects provision, the contractor immediately began construction of barracks building, a messhall and a trailer court, and multiple-unit type dwellings. Construction was also started on the hospital that was required by the construction contract with the Government. Hoping to be relieved of the requirement for furnishing free board and room, the contractor requested the Remote Projects Committee, late in 1957, to declare the project no longer remote. Because of a tie vote on the question in the committee the matter was submitted to arbitration. The arbitrator's decision was that the contractor had not made adequate residential facilities available. After the contractor had taken steps to correct the deficiencies found by the arbitrator, and had completed the hospital, he again sought to have the project removed from the remote classification. After the arbitrator ruled, on January 15, 1959, that adequate residential facilities were available the contractor advised his employees that free room and board would cease on January 25, 1959. Members of the five basic crafts walked off the job immediately, shutting down the work for several days. The workers voluntarily returned to work, a few at a time, until full operations were resumed, even though free board and room were no longer furnished.

The Master Labor Agreement, in effect at the time, expired on May 31, 1959. The new statewide agreement, in addition to providing wage increases of about 20 cents per hour for each of the next 3 years, discontinued the Remote Projects provision and required payment of expense allowances for work performed at locations a certain distance from several established basing points. The expense allowance varied by zones, Glen Canyon being in a zone requiring payment of $6.00 per day. The contractor agreed to pay the new basic wage rates established in the agreement, but rejected the requirement for payment of the expense allowance, and attempted to negotiate a separate agreement for Glen Canyon. Members of the crafts involved continued to work without payment of any subsistence or expense allowance until July 6, 1959, when union pickets were established and the workers did not report for work. Except for work that was necessary for maintenance, work under the contract was at a standstill the remainder of the year. The contractor's principal objection to the new statewide agreement was the requirement for payment of a subsistence allowance. The escalation clause in its contract with the Government provided for reimbursement to the contractor of 85 percent of the cost of wage increases above the basic rates established in the Davis-Bacon decision applicable to the work, but specifically excluded reimbursement of costs for subsistence paid to employees. Eventually a separate job agreement for Glen Canyon was accepted by the union and the contractor, and work under the contract was resumed on January 4, 1960. In the new agreement, wages of the five basic crafts were established as 50 cents an hour higher than required under the statewide agreement and no expense or subsistence was required. Higher rates at Glen Canyon thus became established and continued throughout most of the remaining construction period at Glen Canyon. The electricians agreement, which prior to June 1958 had required payment of $7.00 per day subsistence in areas away from town, had already dropped the requirement for subsistence but at the same time called for substantial increases in wages. Other crafts, after a separate agreement was made for Glen Canyon for the five basic crafts, soon followed the pattern of converting the subsistence payments to wages.

The Government refused to pay the increases in labor costs which were attributed to the wage increases paid in lieu of subsistence. The contractor submitted a claim for these amounts on which reimbursement was not allowed. By date of April 20, 1960, the contracting officer issued a findings of fact and a decision which denied the contractor's claim for additional labor costs in connection with the five basic crafts and electricians.

A similar findings and decision was issued by the contracting officer, under date of January 9, 1963, to cover wage increases on painters, plumbers, pipefitters, sheetmetal workers and ironworkers. The contractor appealed both of these decisions to the Board of Contract Appeals who eventually, after lengthy hearings and considerations, reversed the contracting officer's decisions and granted the contractor's claim on the wages paid to the five basic crafts in its entirety, and allowed a portion of that claimed on other crafts.

The total of all escalation paid to the contractor for increased wages paid by him and his subcontractors, including the amounts allowed under the claims, was $11,553,565.53 (see appendix B).

There are a number of features in the labor agreement between the prime contractor, Merritt-Chapman and Scott Corp., and the unions of the five basic crafts which are noteworthy:

(1) All workmen would be requisitioned through the local union halls, in Phoenix, Ariz., for most crafts, but if the union was unable to furnish workmen within 48 hours the contractor could obtain them from other sources, provided
arrangements were made promptly for proper referral of workmen after they are hired. However, the agreement did permit the hiring of key or specialized personnel without regard to the above requirements where such hiring was agreed to in a conference between the contractor and union.

(2) When a workman was dispatched from the union hall the contractor was required to pay travel expenses from the union hall, or the employee's home if closer, to the jobsite and back to the beginning point after his termination. This amounted to 5 cents per mile plus wages depending on the distance traveled. Payment of these travel expenses was also required when the workman was rejected when arriving at the worksite. However, if an employee quit before working 5 days, no travel time pay was required to be paid.

(3) All work performed in excess of 8 hours per day or 40 hours per week was to be paid at one and one-half times the straight time rate. Time and one-half was also to be paid for Saturday work and for time worked before and after the established starting and ending times for the shift. Work on Sundays or holidays was to be paid for at twice the straight time rate.

(4) When two shifts were employed the second shift received 8 hours pay for 7-1/2 hours worked. On three-shift operations the third shift received 8 hours pay for 7 hours of work. Otherwise, no pay differential was to be made on shift work. Tunnel workers on any shift, however, were required to work only 7 hours for 8 hours of pay.

(5) The agreement specified the rates to be charged for food and living quarters as follows:

Cafeteria—$21.50—minimum of 5 days per week at $4.30 per day
Lodging in dormitory—$7 per week
Apartment units—$75 per month for one-bedroom units, $80 per month for two-bedroom units, $100 per month for three-bedroom units
Company trailers (rental or rental purchase) $60 per month by payroll deduction (a $25 deposit required)
Trailer space—$40 per month

The rates for trailer space were to be paid in advance and included electricity, water, sewage, and garbage disposal.

(6) A workman who reported for work when job conditions prevented working received 2 hours show-up pay unless notified not to report before the end of his last shift worked. If work was provided the reporting employee was to receive at least 4 hours pay, and if more than 4 hours were worked he was to receive at least 8 hours pay unless prevented from working by reasons beyond the control of the contractor, such as inclement weather, completion of the job, or breakdown of operations.

The agreement was to remain in effect for 5 years, but provided that if either party desired to change that party should give written notice to such effect 60 days prior to June 15, 1962. However, since the agreement established rates for only 3 years, a new agreement was made on June 16, 1962, which established new and higher rates for the next 3 years. No other significant changes were made.

By the time the agreement expired in June 1965, the contractor had completed his work and no further special job agreements were established for Glen Canyon. For most crafts, work was subsequently performed under the statewide agreements which by this time had nearly all established separate rates for northern Arizona or had zone rates determined by the distance from local union halls.

Other than the 6-month strike in 1959, the only other significant delays due to strikes during the construction at Glen Canyon occurred during 1965 when failure to reach new statewide agreements in Arizona delayed the start of work on the visitor center and the completion of the left spillway for several weeks. The work on the completion contract was nearly completed by this time and was not affected. Work on the Flagstaff Substation was also delayed by the strike, and the start of footing construction for the second Glen Canyon-Flagstaff 345-kilovolt transmission line was also delayed. Although jurisdictional disputes were fairly common, they actually stopped the work on only a few occasions and then for only 1 or 2 days at a time.

There were no significant problems in enforcement of labor standards provisions of the contracts, particularly with the large contractors who had prior experience on Government contracts. Minor difficulties with misclassification, unauthorized deductions, failure to pay overtime, and failure to include labor standards provisions in subcontracts, were encountered with some of the
smaller contractors who had little previous experience on Government work. On all contracts, labor standards provisions compliance was emphasized during preconstruction conferences, labor classification checks were made weekly in the field, and all payrolls were checked for compliance and accuracy. In addition, each contractor was urged by letter to hire the local Navajo Indian people as much as possible, and substantial numbers of them were employed in the work on the dam and powerplant and the transmission line work. Most of them worked in the various laborer classifications, but some were employed as teamsters, cement finishers, and ironworkers.

(b) Contractor’s Wage Rates—The contractor’s wage rates for 1956 and 1964 are presented in table 3.

<table>
<thead>
<tr>
<th>Classification</th>
<th>Rate 1956</th>
<th>Rate 1964</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carpenter</td>
<td>3.03</td>
<td>5.05</td>
</tr>
<tr>
<td>Carpenter-welder</td>
<td>3.155</td>
<td>5.175</td>
</tr>
<tr>
<td>Saw filer</td>
<td>3.03</td>
<td>5.05</td>
</tr>
<tr>
<td>Saw operator</td>
<td>3.28</td>
<td>5.30</td>
</tr>
<tr>
<td>Millwright</td>
<td>3.28</td>
<td>5.10 (1963)</td>
</tr>
<tr>
<td>Carpenter helper</td>
<td>2.18</td>
<td>2.36 (1958)</td>
</tr>
<tr>
<td>Ironworker, structural</td>
<td>3.25</td>
<td>5.80</td>
</tr>
<tr>
<td>Ironworker, splicer</td>
<td>3.50</td>
<td>6.05</td>
</tr>
<tr>
<td>Batch plant operator</td>
<td>2.995</td>
<td>5.07</td>
</tr>
<tr>
<td>Field equipment service-man</td>
<td>2.675</td>
<td>4.64</td>
</tr>
<tr>
<td>Equipment serviceman helper</td>
<td>2.415</td>
<td>3.495 (1960)</td>
</tr>
<tr>
<td>Heavy duty repairman</td>
<td>2.995</td>
<td>5.07</td>
</tr>
<tr>
<td>Heavy duty repairman helper</td>
<td>2.415</td>
<td>4.30</td>
</tr>
<tr>
<td>Heavy duty mechanic</td>
<td>2.995</td>
<td>5.07</td>
</tr>
<tr>
<td>Heavy duty mechanic helper</td>
<td>2.415</td>
<td>3.525 (1960)</td>
</tr>
<tr>
<td>Air tool mechanic</td>
<td>2.995</td>
<td>5.07</td>
</tr>
<tr>
<td>Heavy duty welder</td>
<td>2.995</td>
<td>5.07</td>
</tr>
<tr>
<td>Heavy duty welder helper</td>
<td>2.415</td>
<td>3.495 (1960)</td>
</tr>
<tr>
<td>Heavy duty lathe operator</td>
<td>2.995</td>
<td>5.07</td>
</tr>
<tr>
<td>Shovel operator</td>
<td>3.17</td>
<td>5.32</td>
</tr>
<tr>
<td>Crane operator</td>
<td>3.17</td>
<td>5.32</td>
</tr>
<tr>
<td>Motor crane operator</td>
<td>3.17</td>
<td>5.57</td>
</tr>
<tr>
<td>Whirley crane operator</td>
<td>3.17</td>
<td>5.57</td>
</tr>
<tr>
<td>Whirley crane oiler</td>
<td>2.415</td>
<td>4.55</td>
</tr>
</tbody>
</table>

1 Where certain classifications were not employed in 1964, their last year on the job has been indicated with their hourly rate at that time.
**CONTRACT ADMINISTRATION**

<table>
<thead>
<tr>
<th>Classification</th>
<th>Rate 1956</th>
<th>Rate 1964</th>
</tr>
</thead>
<tbody>
<tr>
<td>Painter</td>
<td>2.80</td>
<td>5.00</td>
</tr>
<tr>
<td>Pot tender (sandblast)</td>
<td>2.34</td>
<td>4.24</td>
</tr>
<tr>
<td>Warehouseman</td>
<td>2.265</td>
<td>4.075</td>
</tr>
<tr>
<td>Conveyor operator</td>
<td>2.525</td>
<td>4.25</td>
</tr>
<tr>
<td>Dinkey operator</td>
<td>2.675</td>
<td>4.44</td>
</tr>
<tr>
<td>Tireman</td>
<td>2.34</td>
<td>4.16</td>
</tr>
<tr>
<td>Pipefitter</td>
<td>3.35</td>
<td>5.70</td>
</tr>
<tr>
<td>Plumber</td>
<td>3.35</td>
<td>5.70</td>
</tr>
<tr>
<td>Motor crane driver</td>
<td>2.675</td>
<td>4.89</td>
</tr>
<tr>
<td>Winch truck driver, less than 10 tons</td>
<td>2.29</td>
<td>3.86 (1962)</td>
</tr>
<tr>
<td>Roofer</td>
<td>2.76</td>
<td>3.80 (1962)</td>
</tr>
<tr>
<td>Electrician and lineman</td>
<td>3.325</td>
<td>6.20</td>
</tr>
<tr>
<td>Groundman</td>
<td>2.725</td>
<td>5.08</td>
</tr>
</tbody>
</table>

Apprentices were used throughout most of the job and they were paid in accordance with the apprentice program at rates required by the specifications or the State of Arizona, union rates or percentages of the mechanic's pay.

**D. LAND AND LAND RIGHTS**

142. **LAND ACQUISITION.** Land and land rights have all been acquired for Glen Canyon Dam and Reservoir at the time of this writing except four parcels for which condemnation proceedings have been initiated. Included in the properties acquired and reported herein are mining interests, withdrawn public land, state land privately owned land, and termination of grazing permits on public land.

The total acreage acquired from private interests is 763.54 acres representing a payment of $107,905. The area for which condemnation was initiated is 176.39 acres at an estimated combined value of $13,315. Land acquired from the State of Utah, by court action, comprised 10,039 acres at a cost of $125,000. There were 1,177,610 acres withdrawn from public lands which include property acquired under Public Law 85-868 (72 Stat. 1686) (51,606.78 acres) from the Navajo Indians as shown below.

The Bureau of Land Management (BLM), through agreement with the Bureau of Reclamation on a reimbursable basis, investigated a total of 7,531 mining claims in the Glen Canyon withdrawal area. Of that number, 9 claims were patented and 4 others determined to be valid; these 13 claims were purchased by the Bureau. Four hundred ninety-three of the claims investigated were not taken to final validity determinations (although several of these were considered valid or ostensibly valid) since they were considerably above the reservoir basin and outside the area considered essential to the project from a Reclamation standpoint. A total of 7,025 of the claims were invalid either by acquisience on the part of the owners or through contest hearing procedures. Total cost to the Bureau for the BLM investigation work in the Glen Canyon withdrawal area was $384,207.00.

Under Public Law 85-868 (72 Stat. 1686), an Act “to provide for the exchange of lands between the United States and Navajo Tribe,” 51,606.78 acres were acquired from the Navajo Indians in exchange for which the Navajos received virtually the same acreage on McCracken Mesa in Utah. As provided by said Act, these exchanged lands have the status of ordinary Reclamation-withdrawn public lands. In connection with the exchange, the grazing permittees and owners of range improvements on the McCracken Mesa public lands were compensated by the Bureau for their permits which were canceled to accommodate the exchange at a total cost of $144,000.00. In addition, the BLM, through agreement with the Bureau of Reclamation and on a reimbursable basis, investigated the mining claims on the Mesa; a considerable number of claims were involved but all were finally determined to be invalid. The BLM was reimbursed $29,678.58 by the Bureau of Reclamation for this work.

Approximately 30 individual Indian owners of improvements on the 51,606.78 acres of Tribal lands acquired under P. L. 85-868 were compensated for their improvements at a total cost to the Bureau of $11,840.00.

Altogether the acreages amount to 1,188,588.93 at a total acquisition cost of $1,252,721. The final total cost will change consonant with the outcome of the ensuing litigation.

143. **LAND FOR ESTABLISHMENT OF THE CITY OF PAGE.** Public Law 85-868, September 2, 1958, transferred to the United States all the right, title, and interest of the Navajo Tribe in and to certain lands required for the Colorado River Storage project, including the land required for the establishment of a city for construction and operation and maintenance purposes, named Page, Ariz.

Prior to the enactment of P. L. 85-868, land at Page could be made available for private use only on a lease basis under Section 10 of the Reclamation Project Act of 1939. Public Law 85-868 authorized the Secretary to dispose of lots in townsites established on the lands transferred under P. L. 85-868 under such terms and conditions as he determined appropriate, but at not less than the current fair market value, except for dedication of lands for public purposes. Subsequent to the enactment of P. L. 85-868, lots at Page, Ariz., have been sold at appraised values determined by FHA and
Bureau appraisers. Under the same authority, Government-owned houses are sold at FHA appraised values.

144. ARCHAEOLOGICAL INVESTIGATIONS. Archaeological investigation and salvage programs were conducted in the Glen Canyon Reservoir (Lake Powell) area and environs under two arrangements:

(1) The antiquities act of June 8, 1906, (34 Stat. 225) and the accompanying "Uniform Rules and Regulations", prescribed by the Secretaries of the Interior, Agriculture, and War. This Act authorizes the Secretaries to issue archaeological survey and salvage permits to reputable museums, universities, colleges, or other recognized scientific or educational institutions or their duly authorized agents. The Secretary of the Interior has delegated the issuing of these permits to the Chief Clerk of the Department.

(2) The Historic Sites Act of August 21, 1935, (49 Stat. 666). This Act provides that the Secretary of the Interior, through the National Park Service, shall conduct a program for the preservation of historic American sites, buildings, objects and antiquities of national significance.

In 1955, the Chief Clerk of the Department of Interior issued a permit to the Museum of Northern Arizona for archaeological investigations of the San Juan River arm of Glen Canyon Reservoir. In 1956, a permit was issued to the University of Utah for archaeological surveys along the Colorado River and the tributary stream basins that would be affected by future storage in Glen Canyon Reservoir.

During 1956 the National Park Service entered into memoranda of agreement with the Museum of Northern Arizona and the University of Utah for continuing archaeological surveys and salvage operations throughout the Glen Canyon Reservoir area and environs. One of the memoranda of agreement provided for the Museum to carry on an emergency salvage operation at station 371 of the Bitter Springs Glen Canyon access road.

Staff members of the Museum of Northern Arizona and the Department of Anthropology of the University of Utah have prepared numerous articles and publications presenting the results of their studies in the Glen Canyon area. A partial listing of this material is presented in appendix H.

E. CONSTRUCTION SUPPORT FACILITIES

145. REFERENCE. The construction support facilities for construction of the Glen Canyon complex were many and varied. Certain of these facilities, such as service, municipal, housing, and public use, will not be discussed in this publication. Information on the above listed facilities is included in the final construction report, an unpublished internal document (see appendix H).

146. CONSTRUCTION PLANT—GENERAL. The prime contractor, Merritt-Chapman and Scott Corp., obtained a large amount of equipment for a plant to construct Glen Canyon Dam and Powerplant. The largest portion of this plant was for concrete production facilities, which included an aggregate processing plant, a concrete mixing plant, a cooling plant, and cement and pozzolan storage. Some of the major items of other construction support facilities were traveling cableways, a temporary powerplant, monkey slides and footbridges, and carpentry, reinforcing steel, and office and equipment repair shop areas. In addition, the contractor provided housing facilities for employees, such as trailer courts, barracks, apartments and houses, as well as concessions and messhalls.

Some of the points of special interest in the contractor's construction plant were 12-cubic-yard concrete placing buckets transported by high-speed, 50-ton traveling cableways, a vertically arranged batching plant 217 feet high, a large refrigeration plant for concrete and aggregate cooling, and an aggregate processing plant which incorporated heavy media separation. Operations and further details of the major plant items are included in the description of the construction of the appropriate project features in this publication.

In accordance with contract provisions, payment in the amount of $4,500,000 for preparatory work was advanced to the contractor for the special plant and equipment necessary for processing, conveying and storing of aggregates; storing cement and pozzolan; batching, mixing, and transporting concrete; concrete and aggregate cooling plants; cableway structures and cableways for river crossings, or other equipment employed to place concrete. Subsequent repayment of the above amount to the Government was made by deducting $1.25 per cubic yard from payments made to the contractor for mass concrete in the dam.
### 147. AGGREGATE PROCESSING PLANT AND AGGREGATE STORAGE

The aggregate processing plant (fig. 245) was located on a ledge above Wahweap Creek about 6 miles from the damsite on the lower end of a natural deposit some 7 miles long and averaging about one-fourth of a mile in width. The basic components of the plant consisted of the following items:

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Item</th>
<th>Size or capacity</th>
<th>Item</th>
<th>Size or capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Truck unloading hopper</td>
<td>100 cu. yd.</td>
<td>Hydraulic sand sizers</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Scalping grizzly</td>
<td>Plus 6-inch</td>
<td>Vibrating screen</td>
<td>Triple deck, 7/8-inch, No. 4, and 1/8-inch mesh</td>
</tr>
<tr>
<td>1</td>
<td>Vibrating screen</td>
<td>Double deck, consisting of 3-1/2- and 1-3/4-inch mesh</td>
<td>Vibrating screen</td>
<td>No. 8 mesh</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Dewatering screw</td>
<td>Twin-spiral</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Heavy media separation unit</td>
<td>No. 4 to No. 8 sand</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Vibration screen</td>
<td>Twin deck, 3/4-inch to No. 4 mesh</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Conveyors</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Truck loading tunnel</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Water supply and distribution</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>system</td>
<td></td>
</tr>
</tbody>
</table>

Figure 245.—Aerial view of aggregate processing plant on ledge above Wahweap Creek. P557-420-5568, December 14, 1960.
Finished stockpiles at the aggregate plant consisted of eight stockpiles of the following maximum sizes: 6-inch, 3-inch, 1-1/2-inch, 3/4-inch, 3/4-inch heavy-media-treated, 1-1/2-inch heavy-media-treated, graded natural sand, and graded heavy-media-treated sand. Larger stockpiles in three finished sizes were also provided at the construction site, and the material was delivered to the batching plant by way of conveyor belts in a reclaiming tunnel underneath the piles.

148. CONCRETE BATCHING AND MIXING PLANT. The main concrete batching and mixing plant (fig. 246) for construction of Glen Canyon Dam and Powerplant was designed by the Noble Co. of Oakland, Calif. This plant was designed to produce concrete at an average rate of 420 cubic yards per hour, or a maximum rate of 480 yards per hour for short periods of time, using automation as far as possible. The octagon-shaped mixing plant had six main floors, served by an exterior man-lift, and was 217 feet high. Large 3,000-ton-capacity aggregate storage bins, containing eight bin compartments for two types of sand and the six sizes of coarse aggregate, were located in the middle of the plant. The screening tower and chutes were located in the portion of the plant above the storage bin, and the batching and concrete mixing floors were located below the storage bin. On the mixer floors, six tilting mixers were installed in a circular pattern, each having a capacity of 4 cubic yards. The mixers were discharged into three separate holding hoppers, which in turn were loaded into 12-cubic yard ladle buckets on electric-driven transfer trains on a trestle below the plant. The primary economic reason for locating the mixing plant on the bench at elevation 3540 was that over 80 percent of all concrete would be placed by cableways to areas below this elevation.

149. OTHER CONCRETE PRODUCTION COMPONENTS. On a ledge above and just downstream of the batching plant, a refrigeration plant was constructed to provide cold air, cold water, and crushed ice for use in lowering the temperature of the plastic concrete. This plant also served in cooling the placed concrete during hydration and post-cooling of the main concrete for contraction joint grouting. More than 4,000 tons of refrigeration with a power installation of 6,275 horsepower was required. The plant included a battery of 18 ammonia compressors, eight 48-inch condensers, and a cooling tower, which were supplemented by 10 shell and tube chillers. Fourteen of the 18 compressors were arranged for multipurpose use as follows: eight 600-horsepower, one 450-horsepower, two 150-horsepower, two 100-horsepower, and a 25-horsepower compressor.

The other four 125-horsepower compressors were used for the 22 "shaved" ice-making machines. Two of the shell and tube chillers were 32 inches in diameter and were used to chill the mixing water, three 52-inch units chilled water for cooling the coarse aggregate on the conveyor belt, and the other five cooled circulating water for the cooling pipes and the dam and were 38 inches in diameter.

Seven silos were provided to store bulk cement and pozzolan and were located on the canyon rim, above the batching plant. Each of the four cement silos had a capacity of 10,000 barrels of cement and each of three pozzolan silos held 1,000 tons, a capacity of 40,000 cubic feet. Both cement and pozzolan were delivered to the site in special trailers, which were bottom dumped into a screw conveyor which lifted the materials to air slides and transported it to the silos. The mixing plant received both cement and pozzolan...
by screw conveyors from the bottom of the silos, and the cementing materials were transported by air slides to balancing storage at the batching plant. Bulk storage tanks for calcium chloride solution, air entraining agent, and liquid water reducing agent were located on the canyon rim adjacent to the plant, and were piped for gravity flow to the batching floor.

150. CABLEWAYS. Two 50-ton-capacity cableways were used for placing concrete in the dam. The cableways were equipped with moving head and tail towers set on two sets of parallel tracks. One of the cableways had higher towers to enable it to cross over the other cableway so that each could be operated independently and simultaneously. This cableway system was designed for the contractor by Lidgerwood Industries and was the largest of this type ever used in dam construction. A used, low 25-ton cableway was erected and placed in operation later, primarily for powerplant use in concrete placement, and subsequently for use as a general service crane.

The higher of the two 50-ton cableways had a cable span of 2,050 feet between the head tower and the tail tower. The lower 50-ton cableway had a span of 1,800 feet between towers, both load-carrying cables being 4-inch lock coils. These two cableways were designed for a normal capacity of 31 tons at a normal operating speed and condition, and up to 50 tons each at a reduced speed and greater main cable sag. The vertical velocity of the fall block with a hook load of 31 tons was 600 feet per minute, and about half this velocity at full load. Further details of the cableways, as well as operations, are included in section 174.

151. TEMPORARY POWERPLANT. Under a supplemental agreement, the prime contractor furnished electrical energy for construction and for the townsite. A temporary powerplant was built on the right abutment which initially housed four 1,360-kilowatt electric generators. Ten diesel powered generators of 1,100-kilowatt capacity each were added later, for a total rated plant capacity of 16,440 kilowatts.

Under the specifications, the Government was to furnish electric power for construction purposes to the contractor at the rate of 15 mills per kilowatt-hour. Under the supplemental agreement, the contractor provided power for his own construction purposes and would also furnish up to 3,000 kilowatts to the Government at the rate of 13.5 mills per kilowatt-hour, subject to adjustment, and the Government advanced $2,100,000 to the contractor which was to be repaid by deduction of 50 cents per cubic yard for mass concrete placed until the full amount of the advancement had been returned. By an amendatory agreement to the supplemental agreement, the power was delivered in the service area of Page, Ariz., rather than at the contractor's generator-plant switchyard adjacent to the temporary generator plant. The Government paid $33,125.46 or 51.546 percent of the cost of the transmission line and other facilities.

Under invitation No. 400S-97, Arizona Public Service Co. constructed, owned, and maintained all of the distribution facilities, including a street lighting system, required for the purpose of furnishing electric service in the Government areas of Page, Ariz. Power and energy required for such electric service was furnished by the Government through purchase from the prime contractor. Arizona Public Service Co. constructed a 69-kilovolt transmission line from Cameron, Ariz., to Page and the line was energized on the weekend of April 22, 1961. Electric energy for both the townsite and the construction work was thereafter supplied through this line. At the end of construction of the Glen Canyon unit the contractor dismantled the temporary powerplant.

152. OTHER CONSTRUCTION SUPPORT FACILITIES. The contractor also constructed a number of other buildings for use as office, shop, and storage facilities for the various construction needs. These buildings were generally made of the "Butler-type" construction with steel panels on structural steel bents and concrete floors. These buildings were used for the office space, equipment repair shops, and service shops, which were located on the west side of the river; and for the warehousing, electrical, plumbing, carpentry, and reinforcing steel bending shops on the east side of the river. Many miles of access roadways and large areas were graded and gravel surfaced for transporting, handling, and storage of equipment and materials on both sides of the canyon. In addition, the contractor constructed a large number of small buildings, usually corrugated metal on wood frames, for use as small field offices and tool rooms. These buildings were usually constructed so that they could be moved by cableway or mobile crane to various locations about the work. Small powder shelters were also provided a safe distance from the construction site on the west side of the canyon. First aid facilities were provided at appropriate locations, including fully equipped trailers on each side of the worksite, as discussed further under the section of this report on safety matters.

A steel-cable suspension-type footbridge (fig. 247) was constructed in October 1957, which spanned the canyon from the top of the canyon walls upstream
from the damsite. Two temporary wood catwalks on cables were also built across the canyon, about 30 feet above the river, one near the downstream portals of the diversion tunnels and the other near the upstream portals. These lower catwalks were in use until the time of the diversion of the river, after which they were removed.

Two electric-powered monkey slides were erected on the east side of the canyon. One was located upstream of the left abutment of the highway bridge and the other just downstream of the upstream portal of the left diversion tunnel. The location of the monkey slides was later changed; one pair was placed in the left keyway to provide access to the dam and another pair was located over the machine shop bay to provide access to the powerplant. As the top of the dam narrowed and the downstream face moved further upstream, one of the monkey slides was removed and access to the dam was provided by catwalks at different levels from the downstream slide.

A stiff-legged derrick of 50-ton capacity was erected on the canyon rim above the upstream cofferdam. A 25-ton highline cableway was also erected just upstream of the upstream portal of the left diversion tunnel. The stiff-legged derrick was later moved to the rim above the intake structure of the left spillway tunnel and was also used on the lining of the left spillway tunnel. Still later, the stiff-legged derrick was moved back upstream to just above the upstream portal of the left diversion tunnel. A large revolving (whirley) crane was erected on tracks set just downstream of and parallel to the powerplant, primarily for yarding.

Six water wells were drilled 6 miles north of the site to provide a water supply for the aggregate screening and washing plant. These wells were drilled from 625 to 800 feet in depth and had a total rated capacity of 7,750 gallons per minute. In addition, four other wells were drilled to serve the contractor's needs on the west side of the construction site.
A compressor station, containing two large compressors each having a capacity of 3,350 cubic feet per minute, was constructed on the east side of the canyon in March 1959. Permanent-type air piping was erected from the compressor station to the bottom of the canyon to supply job air requirements. Four compressors, also for job air, were set in the refrigeration plant building, each with a capacity of 1,860 cubic feet per minute.

The contractor also provided housing facilities for employees which included trailer courts, concessions, barracks, and messhalls which were discussed previously in section 146.

153. CONTRACTOR’S CONSTRUCTION EQUIPMENT. The following is a list of the major construction equipment used by the prime contractor and the subcontractors under specifications No. DC-4825:

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Item</th>
<th>Size or capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Truck-mounted</td>
<td>6 drill</td>
</tr>
<tr>
<td></td>
<td>jumbo</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Wheel loaders</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Crawler tractors</td>
<td>175 drawbar hp.</td>
</tr>
<tr>
<td>3</td>
<td>Power graders</td>
<td>125 flywheel hp.</td>
</tr>
<tr>
<td>1</td>
<td>Crawler tractor</td>
<td>95 drawbar hp.</td>
</tr>
<tr>
<td>1</td>
<td>Crawler tractor</td>
<td>200 drawbar hp.</td>
</tr>
<tr>
<td>1</td>
<td>Crawler shovel</td>
<td>115 flywheel hp.</td>
</tr>
<tr>
<td>3</td>
<td>Semitrailers—low</td>
<td>2 cu. yd.</td>
</tr>
<tr>
<td></td>
<td>slug</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Truck tractors</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Semitrailers</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Buses</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>Rear-dump trucks</td>
<td>20 ton</td>
</tr>
<tr>
<td>2</td>
<td>Bottom-dump haulers</td>
<td>27 cu. yd.</td>
</tr>
<tr>
<td>14</td>
<td>Truck tractors</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Water wagons</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Aggregate trailers</td>
<td>50 ton</td>
</tr>
<tr>
<td>3</td>
<td>Special dump trucks</td>
<td>5 cu. yd.</td>
</tr>
<tr>
<td>2</td>
<td>Motorized scrapers</td>
<td>25 cu. yd.</td>
</tr>
<tr>
<td>2</td>
<td>Ambulances</td>
<td>300 hp.</td>
</tr>
<tr>
<td>4</td>
<td>Trucks, pickup and flatbed</td>
<td>Assorted sizes</td>
</tr>
<tr>
<td>10</td>
<td>Automobiles</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Stationary air compressors</td>
<td>1,700 c.f.m.</td>
</tr>
<tr>
<td>2</td>
<td>Stationary air compressors</td>
<td>3,350 c.f.m.</td>
</tr>
<tr>
<td>3</td>
<td>Rear-dump trucks</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Grease trucks</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Mechanic’s trucks</td>
<td>2-1/2 ton</td>
</tr>
<tr>
<td>8</td>
<td>Hoists, pneumatic</td>
<td>2,000 pound</td>
</tr>
<tr>
<td>2</td>
<td>Hoists, 2 drum</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Hoists, 3 drum</td>
<td>40 ton</td>
</tr>
<tr>
<td>1</td>
<td>Hoist, 2 drum</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Hoist</td>
<td>15 ton</td>
</tr>
<tr>
<td>2</td>
<td>Hoist, 1 drum</td>
<td>5 ton</td>
</tr>
<tr>
<td>2</td>
<td>Hoists, 2 drum</td>
<td>31 ton</td>
</tr>
<tr>
<td>3</td>
<td>Hoists</td>
<td>Assorted</td>
</tr>
<tr>
<td>1</td>
<td>Winch, air</td>
<td>1 ton</td>
</tr>
<tr>
<td>1</td>
<td>Hoist, mina electric</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Deepwell pumps</td>
<td>5,000 g.p.m.</td>
</tr>
<tr>
<td>1</td>
<td>Deepwell pump</td>
<td>1,500 g.p.m.</td>
</tr>
<tr>
<td>1</td>
<td>Deepwell pump</td>
<td>500 g.p.m.</td>
</tr>
<tr>
<td>5</td>
<td>Suction pump</td>
<td>8,700 g.p.m., 1,000 hp.</td>
</tr>
<tr>
<td>1</td>
<td>Centrifugal pumps</td>
<td>4,000 g.p.m., 4 inch</td>
</tr>
<tr>
<td>2</td>
<td>Pump, water</td>
<td>8,000 g.p.m., 8 inch</td>
</tr>
<tr>
<td>76</td>
<td>Pumps, submersible</td>
<td>Assorted</td>
</tr>
</tbody>
</table>

405
F. CITY ADMINISTRATION FOR PAGE, ARIZ.

154. GENERAL DESCRIPTION AND LOCATION. The proposed site of Glen Canyon Dam was 75 miles from and without direct highway access to the nearest community of Kanab, Utah. The nearest city and railhead was Flagstaff, Ariz., which was about 135 miles south of the site of construction. In general, this arid, high plateau area is very rugged and prior access was available only over the most primitive trails.

To construct a project of this magnitude, a large number of construction employees would be required, as well as those in indirect support of the work. Some facilities for permanent operating and maintenance personnel would also be required, and designed facilities invariably prove the most economical when considering initial costs and operating and maintenance costs. Prior experience had shown that temporary construction support accommodations create severe problems during and after construction, both in respect to morale and economic considerations. In addition, large projects have historically generated small permanent communities with little regard to long-range planning. The demand for additional facilities to support public recreation usually becomes a major factor with the formation of a reservoir of this size.

The actual site of Glen Canyon Dam was established 4 miles south of the Arizona-Utah State line and 12 river miles downstream on the main stem of the Colorado River. Public lands lie on the west side of Glen Canyon and Navajo Tribal lands to the east. Small mesas, surrounded by blowsand areas, are near the construction site on both sides of the canyon. The mild, arid climate is typical to the high desert country.

After full consideration of the various possible locations, Manson Mesa on the east side of the river was chosen as the most advantageous for a potential townsit. Conveniently located about 2 miles from the
site of the dam, this mesa is about 4,300 feet above mean sea level and offered optimum conditions for housing, businesses, and municipal facilities. Being on Navajo Tribal lands, an area of 24.3 square miles was exchanged for other lands adjacent to the Reservation in the Navajo Exchange Act of September 2, 1958, Public Law 85-868. A townsite plat was laid out for a portion of this area and the city was named after Mr. John C. Page, a former Commissioner of Reclamation (fig. 248.).

Basically, Page was designed to provide a permanent townsite to serve those residents engaged in the operation and maintenance of the dam and power facilities, recreation and tourist services, personal services and general business enterprises, and the Federal, State and municipal activities and services. Municipal facilities and services were designed primarily to serve the permanent segment of this population and, secondly, to support the peaking population during construction. That portion of the permanent system which was necessary to build for the temporary population was designed to provide a margin for reserve and for future expansion. Fully temporary facilities were located adjacent to the initial permanent development on Manson Mesa, and the contractor was required to remove them on completion of his construction work. A congressional appropriations limitation of $11,800,000 was placed upon the various items of municipal and construction support facilities at the city of Page, and this limitation was not exceeded.

The Government constructed 200 permanent houses for employees, which was the original estimate of employee family units required for operation and maintenance of the project. Additional temporary housing for construction employees was composed of 50 demountable “transa-house” housing units, and a small trailer court with about 40 Government-owned

Figure 248.—Aerial view of the town of Page, Ariz., looking north. Glen Canyon Dam is in background. P557-420-8316, May 15, 1963.
trailers and several spaces for employee-owned trailers. Five permanent houses were also constructed by the National Park Service for their personnel. There were also 225 lots left for private homesites in a developed area adjacent to the houses constructed by the Government.

The prime contractor constructed nine permanent-type houses in the residential area and 24 quadriplex and triplex apartment houses with 93 units for key employees. A large temporary trailer court was designed with 700 spaces for the construction employees. It was expanded more than once during construction, and there were eventually more than 1,000 house trailers in this one court managed by a concessioner. The prime contractor also allowed businessmen and other project-connected personnel to occupy trailer spaces when available. Upon completion of the work, the temporary court facilities were leveled and the site was restored to as near original condition as practical.

Temporary housing for teachers consisted of six apartment houses containing 40 units. The Department of Health, Education and Welfare provided funds to aid in their construction.

The contract for construction of the 200 Bureau houses also provided for optional construction of an additional 150 houses for sale to the general public. The contractor did not exercise this option. Subsequently, individual financing was obtained for construction of housing and, at the end of construction, 44 single-family dwelling units, three duplexes, and one two-story quadriplex had been completed. A permanent commercial trailer park, consisting of 174 rental spaces, was also constructed and mobile home subdivision was under development at the end of construction.

155. MUNICIPAL SERVICES AND UTILITIES. Streets constructed in Page, included 4-1/2 miles of 42-foot-wide streets and almost 4 miles of 70-foot-wide streets. Four inches of crushed rock base was surfaced with 1-1/2 inches of asphalt concrete sealed with a stone chip wearing coat, except for Seventh Avenue which had a 6-inch rock base. Concrete sidewalks with sloped curbs and gutters were also constructed on most of these streets. As a result of this high-quality, permanent-type construction, maintenance costs have been relatively small and no major repairs have been necessary. The only significant maintenance problem encountered involved cleaning blowsand from the streets, which was significantly reduced by installation of lath drift fences, covered with burlap, at strategic locations. Conversely, the north and south community access roads had minimal curb or shoulder treatment and have required constant routine maintenance to retain shoulder shaping in the blowsand areas.

By designing the sewage treatment system for the peak construction population, no unusual difficulties were experienced due to treatment capacity. Early difficulties with blowing sand were reduced as the general area became more stabilized, and the area immediately adjacent to the plant was protected with landscaping and tree windbreaks. Flooding from a thunderstorm on August 30, 1963, caused considerable work to repair damage to the outfall sewerline and access roads. As was the case with the city streets, quality construction of the sewage system has contributed significantly to the reduction of maintenance costs.

The water treatment plant, storage facilities, and distribution systems were also constructed to meet the peak population demands during the construction period. However, some expansion of the plant was necessary to meet a higher demand than originally anticipated. Early difficulties and high operational costs experienced with pretreatment of the muddy river water was eliminated when a permanent connection was made. The raw intake is now located on the upstream face of the dam in the outlet works trashracks and receives clear water from Lake Powell. A small, but separate, service charge is made to the consumers for operational costs of the waterplant.

A regular program of refuse collection and disposal is performed for the city under contract. This contract provides for the collection of garbage, both private and commercial, and the charge is billed directly to the individuals under a rate schedule established by the competitive bidding. This contract includes the collection of normal refuse and trash, grass, tree and shrub cuttings. Trimmings from the grass and tree cuttings are handled separately and the contractor is paid on the basis of an hourly rate under the supervision of city employees. Disposal of the garbage, refuse, trash, and other debris is made at a cut-and-fill type sanitary disposal pit at a site furnished by the Bureau well outside of the townsite limits.

Electrical service for Page is provided under contract by the Arizona Public Service Co. This service includes the operation and maintenance of the distribution system and the street lighting systems in the
community. Billing is made directly to the consumers by the Arizona Public Service Co. on a rate schedule subject to the Arizona State Corporation Commission.

Gas for domestic use is furnished by the Petrolane Gas Service in the form of liquified petroleum gas. Large tanks are located strategically, each with a small distribution system which serves a group of houses or businesses. Initially, the rate schedule was established under contract with the Government. Subsequent to the expiration of the original contract, the rate schedule was no longer controlled for private consumers; however, the gas service company unilaterally continued to furnish gas service to private consumers at the same rate set in the contract for furnishing gas to the Government facilities.

Telephone service is provided by the Mountain States Telephone and Telegraph Co. A telephone exchange and office building, a maintenance yard, and a microwave terminal facility were established in the town of Page. Normal private and commercial service is available subject to the standard rate schedule. Installation of the service was started in October 1957 and was completed in early 1958.

A microwave television service with a cable distribution system is available. Four Phoenix network channels are available at a monthly service rate of $6.50 after an initial connection charge of $90.00. For short-time subscribers, an alternate rate of $10.00 per month is available without the payment of the $90.00 connection charge.

In addition to constructing the water treatment plant, the sewage disposal system, and the streets and surface drains, it was necessary to construct other municipal facilities to serve the city of Page; these included a municipal building, a police and fire station, an operation and maintenance shop, an airstrip, and a hospital.

With the peak of construction, the police and fire station operated from this facility for police services. For instance, round-the-clock police protection was furnished by the Bureau Rangers but enforcement of the laws of Arizona began with the Justice of the Peace, an elective office in Coconino County. The assessment of property taxes and license fees was established by the Deputy County Assessor, the evaluation also being the basis of the municipal service charge. Similar interrelation of functions were also present in regard to public health conditions, civil defense activities, elections, and similar community affairs. County and State representatives were cooperative, despite the many inconveniences of distance, and much of the successful operation of the city was due to their efforts.

The fire station is a partitioned-off section of the garage building and houses two 750-g.p.m. pumpers which were obtained through Government surplus. A 1,000-pound direct-chemical unit was mounted on a pickup and a 500-gallon water tank on a trailer is held in reserve at another location. Communication facilities are coordinated with the ranger communication system and alarm equipment is activated in the ranger office. The fire detachment consists of a full-time chief and 15 volunteers, all of whom are employed and trained by the Bureau. The majority of the volunteers are employed in buildings and shops immediately adjacent to the fire station.

Maintenance shops for city operations are located in a Butler-type metal building adjacent to the Bureau's warehousing facilities, primarily to utilize an adjacent, improved storage area. The shops also serve for maintenance of the other Bureau project supporting facilities in the city of Page, including offices and housing. These shops include areas for carpentry, plumbing, electrical work, painting, offices, and storage.
of spare parts. Major equipment repairs are performed in the garage facilities. Adequate staffing by members of the various crafts was maintained to support the municipal and construction facilities during the construction period. Operational equipment serviced included the street sweeper, grader, dozer, lawn maintenance equipment, and pest and weed control equipment.

A blanket service charge was made for municipal services furnished to private individuals and businesses. These services included police and fire protection and the operation and maintenance of streets, parks, street lighting, and water and sewer utilities. Charges for these services were based on a mill levy rate, established by the Bureau of Reclamation, applied to the assessed value of the land and building, plus assessable property, established by the Coconino County Assessor. Land use and zoning regulations provided that the levy rate could be adjusted by the Bureau, but that it would not exceed the tax rate in Flagstaff, Ariz. Except those exempt by State law, every property owner was required to pay for the municipal services furnished by the Bureau. The whole amount of the charge could be paid in November of each year or, at the option of the property owner, could be made in semiannual payments in November and May. A City Services Section in the City Management Division prepared bills and received payment for utility services and deposits, leases, land sale, building and peddler permits, and municipal service charges.

Under the provisions of the prime contract for construction of Glen Canyon Dam, contractor Merritt-Chapman and Scott Corp. constructed and operated a 25-bed hospital during the term of their contract. When the hospital was turned over to the U.S. Government on January 1, 1965, a contract was made with the Hospital Sisters of the Third Order of St. Francis to continue operation of the hospital facilities. The prime contractor was able to attract competent staffing for the hospital and these arrangements have proved highly satisfactory for a community hospital facility.

In addition to these municipal service facilities, some construction and operational support facilities were also constructed in the city of Page for convenience. These facilities included an administration building, a large warehouse with fenced storage yard, a concrete testing laboratory, and a garage with fenced parking area. A post office building was also constructed by the Postal Department in the shopping center.

Owing to the general remoteness of the damsite, it was necessary to construct an airstrip in order to provide air service for the community. The main runway is paved with asphaltic concrete and is 150 feet wide by 4,500 feet in length. A lesser, graveled runway is also available for light planes. The airport facilities furnished by the Government include navigational beacons, guidance and runway lights, and fencing around the airport. Regular passenger service was inaugurated on April 26, 1959, by Bonanza Airlines with flights to and from Phoenix, Ariz., and Salt Lake City, Utah. Airport management is provided under a contract between the Government and Page Aviation. Other services available are a private charter plane service, mechanical repair, flight instructions, and automobile rentals, all of which are furnished by the commercial flight service operation. All terminal and repair facilities have been constructed by the airport operator. Space has also been provided for future expansion on the main runway and additional parking areas. Another transportation means, bus service, was established by Continental Trailways on May 15, 1959, placing Page on a route between Kanab, Utah, and Flagstaff, Ariz.
CHAPTER XIII. Construction—DAM, POWERPLANT, AND APPURtenant STRUCTURES

A. DIVERSION AND CARE OF RIVER

156. GENERAL. Diversion of the Colorado River during construction of Glen Canyon Dam and Powerplant was accomplished through two concrete-lined tunnels, one located in each abutment. The inside tunnel diameter of 41 feet was determined from routing studies made of the 25-year frequency flood. The length and location of the tunnels were laid out to allow ample space for disposal of all foundation excavation material between the upstream face of the dam and the upstream cofferdam. Space for the downstream cofferdam was also considered in the location of the tunnel outlets.

The diversion tunnel in the right abutment (fig. 28) was 2,749 feet long with an invert elevation of 3137.37 feet at its entrance, which was essentially river level. The left abutment tunnel was 3,011 feet long, but the entrance invert elevation was at 3170.67 feet, or 33.30 feet higher than the right tunnel. The difference in entrance elevations was made to allow for installation of outlet gates in the left tunnel during a low-flow season without benefit of an entrance closure structure. The upstream cofferdam, designed by the contractor, had a top elevation of 3300 and the downstream cofferdam had a top elevation of 3165.

The downstream portions of the diversion tunnels also served as the lower, horizontal section of the spillway tunnels. Final closure of the right diversion tunnel was made by installing a 150-foot-long plug in three sections. A closure structure was provided at the entrance of this tunnel to facilitate construction of the plug section. The closure structure consisted of three structural steel slide gates, designed for 90 feet of head, and a temporary concrete plug immediately downstream from the gates, designed to withstand 200 feet of head.

Features of the left abutment tunnel were similar to those of the right, except that high-pressure outlet gates were installed in the plug section and a concrete trashrack structure was installed at the tunnel entrance. Installed in the two upstream sections of the tunnel plug, the outlet works consisted of three steel-lined conduits through the plug section, two 7- by 10.5-foot high-pressure gates in tandem in each conduit, and an operating chamber (fig. 31). The outlet works was necessary to meet downstream water requirements during the period between closure of the right tunnel and availability of the permanent waterways in the dam and powerplant.

The right diversion tunnel was excavated by an early separate contract under specifications No. DC-4747 to provide lead time for establishment of the major construction facilities by the prime contractor for the dam and powerplant. Except for final closure on the left diversion tunnel, the remainder of work related to care and diversion of the river was performed under the prime contract, specifications No. DC-4825. Closure of the left tunnel and completion of the spillway elbow was made by separate contract after the downstream water requirements were being met through the power facilities.

157. EXCAVATION OF RIGHT DIVERSION TUNNEL. Mountain States Construction Co., of Denver, Colo., started construction operations on October 8, 1956, for excavation of the right diversion tunnel under specifications No. DC-4747, by moving equipment to the jobsite and setting up a temporary camp. On October 15, 1956, construction formally began by setting off the initial blast at the downstream portal of the tunnel at a signal transmitted by President Eisenhower in connection with the formal Glen Canyon ground breaking ceremonies. A large slab of rock directly over the lower portal was blasted from the canyon wall.

Initial work consisted of blasting and scaling overhanging rock from the canyon wall over the downstream portal. Construction of a warehouse, mess hall, bunkhouses, and other necessary camp buildings was completed in December.

A barge was constructed in November 1956, to ferry equipment from the mouth of Wahweap Creek to the upstream tunnel portal. A crawler tractor, hoist, and miscellaneous tools were lost in the river when the barge sank and this scheme was abandoned. All equipment was recovered except some miscellaneous tools. A highline cableway was under construction, but because of many delays in its completion, an access road was pioneered from the mouth of Wahweap Creek to the upstream tunnel portal.

A drill and associated equipment were lowered over the canyon wall with a temporary hoist early in December, and drilling in opencut was started upstream of the upstream portal. On December 21, 1956, the highline was completed and put in operation and a crawler tractor equipped with bulldozer was lowered down the canyon wall and set on the talus near the downstream portal. The bulldozer began construction of an access road along the talus between the two portals.
Excavation in opencut progressed at both portals, and on February 13, drilling of the tunnel began at the upstream portal at station 7+80. The drilling was subcontracted to Northwood, Inc., of Seattle, Wash. Moving the muck from the tunnel to the disposal area was subcontracted to Theo Wood Construction Co., of Salt Lake City, Utah.

Drilling was done from a jumbo designed and built by Mountain States Construction Co. The jumbo was not too efficient, as it had to be moved to and from the heading of the tunnel by a crawler tractor and numerous breakdowns occurred due to inadequate bracing. The jumbo was 31.5 feet high and 40 feet wide and had four platforms from which drilling was accomplished. The lower two of the four platforms were split in the middle and were raised by two air tuggers and held vertical by cables during mucking operations to permit equipment to pass through the 16-foot square opening. Mucking equipment consisted of end-dump trucks and a crawler-mounted tractor-shovel loader. Trucks were equipped with exhaust scrubbing equipment. The tunnel was lighted by 75-watt bulbs spaced 35 feet apart and also with floodlights on the jumbo. Ventilating air was provided at 70,000 cubic feet per minute from a 48-inch fan with 42-inch vent lines into the tunnel.

An average of 14 feet of drilling per day was accomplished and approximately 750 cubic yards of rock was removed per round. About 1,140 pounds of 35 percent No. 3 powder with 9 delays was used for each round. An average of 144 holes, 1-1/2-inch-diameter starters, were drilled on approximately 3-foot 4-inch centers. Twelve main V-cuts and 32 lifters were drilled 18 feet in depth. The remainder were 16 feet deep except for the set of 8-foot center pilot, or baby cut, holes.

Some difficulties were experienced because of the roof of the tunnel slabbing off along the left side of the drift. This was probably caused by the fact that the tunnel was apparently being driven along, or close to, a strike of extremely steep dipping crossbeds, complicated by a localized tendency towards exfoliation. The dip of the crossbedding along the left side of the tunnel roughly parallels the tunnel wall, whereas the dip intersects the right wall of the tunnel at a steep angle. The slabbing off, or caving, along the left side of the tunnel roof required the use of many additional roof support bolts. Mine roof ties of steel-ribbed 2- by 6-inch by 13-foot channels, fastened by 6- to 8-foot bolts, were used in lieu of chain link fabric for tunnel roof support.

During April, May, and June 1957, the water rose in the river and considerable trouble was caused by water seeping through the canyon wall into the tunnel. This problem was resolved by trenching to sumps and dewatering with 4-inch pumps. The peak flow of the Colorado River during the drilling period was 124,000 cubic feet per second on June 12, 1957.

Opencut excavation in the downstream outlet channel area continued until September 1957 when this work was discontinued. The remaining opencut excavation was deleted from the contract and was later completed by the prime contractor on the dam. The common excavation deleted from the contract amounted to 47,431 cubic yards and the rock excavation amounted to 46,846 cubic yards.

Drilling of the tunnel continued at the rate of about 340 feet per month until October 30, 1957, when the tunnel was holed out at station 35+20. A portable jumbo was constructed by Northwood and used behind the drilling jumbo for barring loose rock and for placing roof bolts. The invert of the tunnel was left about 6 feet above grade and the removal of this invert section, as well as removal of radial tights and installation of roof bolts, was completed on March 13, 1958, which was also the date all work under the contract was completed and accepted.

The excavated diameter of the tunnel to the A-line was 43.5 feet from the upstream portal to station 25+70. From station 26+11.72 to the downstream portal, the diameter was 46.5 feet with a tapered transition section between these stations. The difference in diameter was due to the difference in thickness of concrete lining of the two sections. The downstream, or spillway section of the tunnel, was lined with 2 feet 9 inches of concrete and the upstream or diversion tunnel section was lined with 1 foot 3 inches.

Overbreak amounted to 3,096.58 cubic yards for which payment to the Government was made at the rate of $15.00 per cubic yard for a total of $46,448.70. The total contract less liquidated damages and payment for overbreak amounted to about $2,280,000.00.

158. COMPLETION OF RIGHT DIVERSION TUNNEL AND CONSTRUCTION OF LEFT DIVERSION TUNNEL. The right diversion tunnel was being excavated under specifications No. DC-4747 by Mountain States Construction Co. at the time the prime contract was awarded. The tunnel under this previous contract was completed March 13, 1958, and
was not lined. Excavation of the keyways in the plug section and lining of the tunnel were parts of the prime contract under specifications No. DC-4825. Excavation for the keys in the plug section was started in May and completed in August of 1958.

Under order for changes No. 1, the contractor was directed to perform all opencut excavation for the outlet channel of the right diversion tunnel above the grade line. This work was deleted from the contract of Mountain States Construction Co., for the driving of the tunnel. Excavation at the downstream portal of the tunnel started in April 1958. Numerous rock bolts were placed on the canyon wall. Excavation at the downstream portal was completed early in February 1959, just before the diversion of the river and after the lining of the tunnel had been completed.

Opencut excavation at the upstream portal of the left diversion tunnel was completed in November 1957, and driving of the tunnel started. All tunnel excavation work was subcontracted to Frazier-Davis Construction Co. of St. Louis, Mo. Drilling of the tunnel was carried out on a three-shift, 6-day-week basis and progressed at a rate of from 22 to 30 feet per day. A round was shot and mucked on each shift. The drilling scheme and blasting procedures were essentially the same as on the right tunnel. The invert of the tunnel was also left about 6 feet high to provide a roadway for trucks and the truck-mounted jumbo. Drilling of the tunnel plug section was completed in April 1958. On June 10, 1958, a 12- by 15-foot pilot hole was completed a distance of 100 feet to daylight the tunnel in the opencut section. The invert of the tunnel was drilled, shot and mucked out, tights were removed, and additional roof bolts placed where needed.

Because of rock conditions at and downstream from theoretical portal station 36+52, it was decided to extend the left tunnel. The tunnel was extended 42 feet, and the downstream portal was located at station 36+94 with the concrete face later extending to station 36+96. A slide occurred above the downstream portal of the left tunnel in the opencut section between tunnel stations 36+60 and 39+20 on August 5, 1958. The fallen material was removed and the wall scaled.

Excavation of the invert was completed the week of October 19, 1958. Excavation of the gate chamber was started in June 1958 and completed, except for removal of tights, in the latter part of July. An 8- by 10-foot pilot hole was driven from the tunnel for the left spillway raise for a distance of 550 feet and was then completed from the top.

Lining of the right tunnel (fig. 249) was started in May 1958 with the placing of concrete curbs, and lining of a 70' invert arc began in June. The remaining 290' of arch concrete was made in a second placement series. Concrete was furnished from the temporary mixing plant on the right abutment, located about one-fourth of a mile from the highline cableway. A water-reducing, set-retarding agent, with a calcium salt of lignosulfonic acid as the active ingredient, was used in the concrete at the rate of 0.25 pound per sack of cement. Concrete was trucked from the batching plant to the highline in 4-cubic-yard buckets and lowered to the canyon bottom. It was then discharged into a specially constructed concrete hopper mounted on a truck chassis and delivered to the tunnel. After loading into a 1/2-cubic-yard bottom-dump concrete bucket, which was lifted by crane, the concrete was discharged into the forms and was consolidated with electric, immersion-type vibrators. After the initial placement in the invert, a pumpcrete machine was used and concrete was delivered to it in the same manner as noted above. Concrete was pumped a distance as great as 900 feet. The placing schedule called for three 60-foot-arch placements per week and the schedule was generally met.

![Figure 249](image-url)

Figure 249.—View of north portal of the right diversion tunnel showing concrete lining in place. P557-420-2818, September 17, 1958.

The lining of the plug section of the right tunnel was placed in a different sequence. The invert, an arc slightly over 11 feet in length, was placed last to allow for additional clearance. The arch was lined in six placement of 6 feet of arc each to a point just over 3 feet above the springline. These placements were formed with wooden-truss, rib-type forms. The
remaining arch section was lined in one placement. On this placement above the springline, Blaw-Knox steel forms were used, upon which a wooden form was superimposed to develop the wedge shape of the keyway. Lining of the right tunnel was completed early in January 1959, as was the concrete for the intake closure structure at the upstream portal.

Lining of the left diversion tunnel was started the last week of August 1958 with the placing of rail concrete from station 17+00 to station 20+82. Lining of the invert and arch sections followed in the same manner as in the right tunnel, except for the plug section where the invert was placed first. Two more lifts brought the lining to a level just above the springline. The remaining arch was placed in one single placement as in the right diversion tunnel. Lining of the left diversion tunnel was completed in March 1959.

Rail concrete consisted of a curb or rail on each side of the tunnel to provide a base for carrying the lining forms. The curbs were formed with wood forms and the concrete was placed by a conveyor or bucket from a specially equipped dump truck. The usual dump body was replaced by a 4-cubic-yard hopper fitted with a bottom-discharge chute and clam gates. The concrete was discharged into a short inclined conveyor and was carried up to the curb forms. In some cases, the concrete was discharged from the hopper into a bottom-discharge chute and clam gates. The concrete was placed by a conveyor or bucket from a specially equipped dump truck. The usual dump body was replaced by a 4-cubic-yard hopper fitted with a bottom-discharge chute and clam gates. The concrete was discharged into a short inclined conveyor and was carried up to the curb forms. In some cases, the concrete was discharged from the hopper into a laydown bucket hoisted to the forms by a tractor with a swing boom.

The invert placement was made by use of an invert screed car riding on rails bolted to the top of the curbs. The car was propelled by a cable anchored into the curb ahead and attached to a 15-ton winch. An air wrench actuated the winch. As the screed car moved ahead, it shaped the invert and struck off the concrete to a smooth surface.

Closure of the right diversion tunnel was started January 21, 1963, and completed January 23, and the river was diverted through the left diversion tunnel with the outlet gates fully open. The lower sections of the right diversion tunnel plug were placed early in February 1963, to elevation 3142.25. The contractor's 21-foot plug, adjacent to the intake closure gates was placed February 11. This 21-foot plug was part of the design of the contractor-furnished intake closure gates. The plug sections were completed about the middle of March, and the contraction joint, periphery, and cooling pipe grouting were completed after the concrete had cooled sufficiently. The 18-inch bypass pipe in the plug section was plugged in June. The backfill section of the right diversion tunnel was placed during June and July 1963, and the contraction joints and periphery grouted.

Placements 1 through 6 of the left diversion tunnel were made in September 1962 to elevation 3147.75 and the upstream sections of conduits and outlet gates were set in place in October. Plug section sequence placements were made to embed these sections. Installation of the outlet gates was completed and the six gates were operative early in January 1963. Placement of the two upstream sections of the left diversion tunnel plug was completed in December 1962.

The six outlet gates were supplied by Yuba Consolidated Industries, Inc., of Benicia, Calif., under invitation No. DS-5216. The 7- by 10.5-foot bulkhead gate is of welded and cast steel construction, and consists of a body, a leaf, and a hydraulic hoist which is an integral part of the gate. The main portions of the gates were received in Flagstaff, Ariz., starting on October 5, 1960, and deliveries were substantially complete on March 1, 1961. It was noted that the supplier had experienced difficulties in application of the CA-50 paint and field repair was required after materials were at the jobsite. The control cabinet was supplied by Kendo Equipment Co., of Denver, Colo., under invitation No. DS-5364.

The 7- by 10.5-foot bulkhead gates were installed by the prime contractor under specifications No. DC-4825. Owing to the location of the bulkhead gates, the contractor's concrete placement schedule in the left diversion tunnel, the embedded structural steel supports, and leveling jacks provided by the Bureau installation plan were not used. The contractor placed the concrete in the tunnel plug invert to about elevation 3147. Rows of 150-pound railroad rails were embedded in a vertical position with the top of the exposed rails higher than the elevation required to support the gates. When the gates were to be placed in position, the rails were cut to exact elevations and capped with a steel plate. The gate bodies were moved into position on cribbing, and final alinement and level were obtained with embedded turnbuckles and metal wedges on the rail supports. The procedure produced good results, and the allowable tolerance between the gate leaves and their body seats was obtained without reworking the seats. The remaining parts of the gates were assembled, the controls installed, and the system was filled with oil without unusual difficulties. Servicing and testing were completed and closure was made in March of 1963.
DAM, POWERPLANT, AND APPURTENANT STRUCTURES

Installation of the left plug and completion of the spillway elbow were originally required under the prime contract. Because of downstream water requirements, however, this work was deleted from the contract and temporarily deferred. Following the desired service during reservoir filling, the high-pressure gate conduits and gate chamber were later plugged with concrete during completion of the left plug and spillway elbow (figs. 250 and 251) under specifications No. DC-6317.

159. COFFERDAMS AND CARE OF RIVER. Construction of the upstream and downstream cofferdams under the prime contract, specifications No. DC-4825, began in October 1958, with the dumping of materials excavated from the right keyway. Both cofferdams were extended from the west side. The material was wetted and compacted with tamping rollers as it was placed. Placing of earth and rockfill continued until February 8, 1959, when closure of the upstream cofferdam was started. The dike in front of the right diversion tunnel was removed. Steel tunnel liner forms, structural steel ramps, and boulders were used to complete the closure, and the river was first diverted through the right diversion tunnel, at 7:30 a.m., February 11, 1959.

Fine material was placed at the upstream face of the cofferdam and the dam was widened. The dam was then at approximate elevation 3183 and was widened to 50 feet. A cutoff trench was constructed just downstream of the 50-foot section, and sheet steel piling 60 feet in length was driven into the trench. Sand and bentonite were mixed and placed around the piling. The downstream cofferdam was closed during the week of February 22, 1959, but was reopened to permit seepage water to flow through. The average elevation of the top of the sheet piling at the upstream cofferdam was 3158. The mixture of the sand and bentonite was placed throughout the cutoff trench as the dam rose. Three electric-driven pumping units with a total capacity of 8,000 gallons per minute were installed on rafts and placed on the pond between the two cofferdams.

River diversion was through the river level reached about elevation 3171, at which time the left diversion tunnel began to accept a portion of the 20,000 c.f.s. river discharge.

Free-draining material from the river bottom was stockpiled on the downstream cofferdam for later use between the dam and powerplant and in the tailrace. In February of 1960, a buttress-type concrete cutoff or retaining wall was erected at the upstream toe of the downstream cofferdam to prevent the free-draining material from sliding into the downstream sump. A concrete sump was constructed in the river bottom on the upstream side of the retaining wall for controlling the seepage water by pumping. During the first 2 weeks of June, some undercutting occurred at the downstream edge of the cofferdam at a riverflow of...
about 40,000 cubic feet per second. When the haul road through the dam and powerplant areas was removed, part of the excavated material was hauled to the downstream cofferdam and dumped on the right side.

During 1960, a concrete cutoff wall was placed at the downstream edge of the upstream cofferdam and just upstream of the upstream sump. Two 10-foot lifts were placed to complete this wall. Water which formed behind the wall from seepage through the cofferdam was pumped from a sump behind the wall. Maximum flow of the Colorado River recorded at Lee Ferry during 1960, was 46,300 cubic feet per second on June 9.

During 1961, a considerable amount of free-draining material was removed from the upstream side of the downstream cofferdam for use as backfill between the dam and powerplant. Other material from the cofferdam was used as backfill over the outlet works mass concrete and over the machine shop and service bays. The upstream side of the downstream cofferdam was changed considerably while excavating and grading for the tailrace slab. Later some of this material was used as backfill on the tailrace slab from the crest of the slab to its downstream edge. Maximum flow of the Colorado River in 1961 was 39,200 cubic feet per second and occurred on June 4 and 5; maximum flow in 1962 occurred on May 16 with a flow of 84,450 cubic feet per second.

The high flow of the river during the runoff season deposited a large amount of driftwood and trash around the upstream portals of both diversion tunnels. A bulldozer was transported to the upstream cofferdam by an LCM (landing craft, medium) boat. Both were lowered to the pool just above the dam. Driftwood was removed from the left diversion tunnel trashrack structure by the bulldozer. The driftwood around the upstream portal of the right diversion tunnel was burned.

The lower center beam of the left diversion tunnel trashrack structure was installed in August. This beam had been left out to permit the passage of trucks into the tunnel during installation of the outlet gates, but it was decided to haul in the gates and concrete from the outlet end of the tunnel. The metal trashrack, except for four sections, was installed on the concrete trashrack structure and gravel placed on top of the structure.

A wood and canvas bulkhead was placed around the trashrack structure to about elevation 3210, or 40 feet above the base of the trashrack, to protect the tunnel plug concrete and conduit in case of a sudden rise in the river. During the rise of the river on October 21 and 22, the pool upstream of the upstream cofferdam rose to approximate elevation 3175, which is slightly higher than the base of the structure. The bulkhead leaked, but by using additional pumps, the water was prevented from rising to the level of the river outlet conduits.

Closure of the intake gates in the right diversion tunnel began January 21, 1963, and was completed on January 23. The river was diverted through the left diversion tunnel, which had an entrance invert elevation 39.30 feet higher than the right tunnel. The outlet gates in the left diversion tunnel were kept fully open until March 13, 1963, when the initial storage began in Lake Powell. The reservoir was at elevation 3203.3 at this time.

At 2:00 p.m., March 13, outlet gates No. 1 and 3 in the left diversion tunnel were fully closed and gate No. 2 was lowered to within 4 feet, 2-5/8 inches of closing. The discharge was kept at 1,000 cubic feet per second or slightly above until June 3. Numerous adjustments to outlet gate No. 2 were necessary to maintain this discharge as the lake rose; and at 8 a.m., on June 3, 1963, the gate was set at a 1-foot 10-inch opening with 1,000 cubic feet per second being discharged. At 9:13 a.m., on June 3, outlet gate No. 2 was set at 4 feet 4-1/2 inches to discharge 2,500 cubic feet per second. With 1,000 cubic feet per second discharging for 9 months of the year and 2,500 cubic feet per second discharging the remaining 3 months, 1,000,000 acre-feet would be passed downstream as required by the filling criteria. At 8:21 a.m., on July 10, 1963, outlet gate No. 2 was set at 1 foot 8 inches to discharge 1,000 cubic feet per second.

The spring runoff in 1963 was the lowest recorded for a number of years and, therefore, the lake did not rise as rapidly as expected. On June 15, 1963, the reservoir was at elevation 3360.9 and was rising at the rate of about 0.5 foot a day. During the week of July 6-12, 1963, the lake elevation remained at 3371.0, and after the outlet gate was closed on July 10 to discharge only 1,000 cubic feet per second the rise amounted to only about 0.1 foot a day.

It was thought that Lake Powell would reach elevation 3390, on or before November 1, 1963, to permit discharge of 1,000 cubic feet per second through the four 96-inch-diameter outlet pipes and permit closing of the left diversion tunnel. The reservoir did reach elevation 3390 on September 16,
1963. However, the filling criteria stated that “until elevation 3490 is first reached, any water stored in Lake Powell shall be available to maintain rated head on Hoover Powerplant.” The risk of failing to maintain an elevation of 1123 in Lake Mead appeared to be too great to justify plugging the left diversion tunnel until turbine capacity was available and with discharge available through Glen Canyon Dam only by the four river outlet pipes. Therefore, the prime contractor was relieved of the work of plugging the left diversion tunnel and completing the excavation and lining of the lower elbow section of the left spillway tunnel.

Discharge from Lake Powell was kept at or near 1,000 cubic feet per second until January 29, 1964, when outlet gate No. 2 was set to discharge 2,500 cubic feet per second. On January 30, 1964, all three gates in the left diversion tunnel were opened to 2 feet to discharge 4,000 cubic feet per second. A release of near that amount was held until March 26, when instructions were received from the office of the Secretary of the Interior to increase the release as it was necessary to maintain generator operating head at Lake Mead of elevation 1123. Releases from March 26 through March 30 increased from 10,000 to 18,000 cubic feet per second and on March 31, the release was cut to 16,000 cubic feet per second. On April 3, the release was lowered to 12,500 cubic feet per second and on April 17 it was cut to 11,000. From April 27 through May 10, releases were held to near 12,500 cubic feet per second. On May 11, because of a more favorable estimate of the April–July runoff, the gates were again set to release 1,000 cubic feet per second with the object of filling Lake Powell to elevation 3490 in order to start generating in September 1964.

From the period March 26 through May 11, the level of Lake Powell dropped from elevation 3414.9 to elevation 3394.5, or a distance of 20.4 feet. The downstream cofferdam was removed in May 1964. The reservoir at elevation 3394.5 on May 11, 1964, contained 2,560,000 acre-feet. Elevation 3490 was attained in the reservoir on August 17, 1964, and it contained 6,124,000 acre-feet at that height. On this date, the release was increased to 6,000 cubic feet per second as Lake Mead had dropped to elevation 1100.96.

Scheduled generation of power from unit 1 started at 11:30 p.m. on September 4, 1964, and at 6:55 p.m. on that date the outlet gates were fully closed and discharge was through the generating units until December 28. Discharge varied between 2,700 and 4,000 cubic feet per second from September 10 through November 5, 1964, was at about 6,000 cubic feet per second until December 28, 1964, and was 13,150, 12,410, and 8,890 cubic feet per second on December 29, 30, and 31, respectively.

160. LEFT DIVERSION TUNNEL PLUG AND SPILLWAY ELBOW LINING SECTION. (a) Preparatory Work.—As indicated previously, construction of the left plug and spillway elbow, originally provided under the prime contract, was deferred. Following the desired service of the high-pressure gates during reservoir filling, specifications were issued for completion of this work.

Preparation work to provide access to the left diversion tunnel for prospective bidders under specifications No. DC-6317 consisted of installation of a hoist and a mancar at the upper end of the spillway and a pump to dewater the downstream part of the diversion tunnel.

A single-drum 440-volt electric hoist was leased from the Sunfeldt Equipment Co., of Long Beach, Calif. The hoist had a capacity of 17,000 pounds direct line pull at 40 feet per minute with a reversible worm gear drive. Three-quarter-inch wire rope was installed on the drum and connected to the mancar previously used in the spillway by Merritt-Chapman and Scott Corp.

Access to the waterway from the spillway bridge was by means of a mancage on a truck crane situated on the bridge. This truck crane was also used to lower the hoist down to the waterway ground level. This truck crane was the property of the Bureau of Reclamation and was operated by a Government employee. The electric power source was the spillway gate panelboard.

Access to the downstream end of the diversion tunnel was by boat until such time as a trail and walkway from the powerplant parking lot was constructed by operation and maintenance laborers and carpenters. The pump used to unwater the diversion tunnel was a 12-inch vertical propeller type, 2,400-g.p.m. pump, with a 25-horsepower, 3-phase, 220/440 volt, electric motor. The power source for this pump was the power panel at the hollow-jet valves.

The installation of this pump was accomplished by lowering it and the required discharge pipe down the wall of the canyon from the east rim, a vertical distance of approximately 700 feet. This was done by use of an air-operated hoist mounted on the back of a hydraulic truck crane. A two-part 3/8-inch wire rope line was used which fed through a pulley on the boom
hook and dead ended at the end of the boom. A second air hoist was set up beside the truck crane with an A-frame on the canyon rim to lower and raise the high scalers. Air to operate these hoists was furnished by a 600-c.f.m. diesel-powered air compressor.

During the lowering of the pump, a high scaler was needed to keep the pump from being snagged by rock bolts or projecting rock. This same procedure also had to be followed for each section of the discharge pipe and hose. The pump was suspended vertically on chain hoists which were hung on anchors above the tunnel portal headwall. A flexible rubber hose was connected between the discharge pipe and the pump so the pump could be lowered with the water level. Continuous pumping for approximately 57 hours was required to pump out the diversion tunnel. To keep the water level down required pumping approximately 50 percent of the time.

Prospective bidders were taken into the tunnel from the powerhouse parking area by a walkway along the left canyon wall to the flip bucket, down a ladder into the diversion tunnel, and along the invert of the tunnel on foot to the plug section. A small boat was used to cross the plug section to a ladder up to the 7-by 10.5-foot gates. Access to the gate chamber was through the gate chamber adit in the dam at elevation 3157.5. Access to the spillway was by cage and crane from the spillway bridge down to the waterway level, then by ladder and walkway, and by hoist and mancar down to the elbow form in the spillway. From where the jumbo form was suspended, access to the bottom of the spillway excavation was by way of ladders. Prospective bidders were also shown available work areas and were taken to the aggregate storage area.

(b) Award of Contract.—The contract was awarded to the low bidder, S. S. Mullen, Inc., of Seattle, Wash., and the notice to proceed was issued on August 23, 1965. The contractor rented a vacant store building in Page and on September 13, 1965, started building partitions for offices in the building. On the same date a truck arrived with a 600-c.f.m. diesel-powered portable air compressor, an air receiver tank, an air-track drill, and an arc welder.

(c) Diversion Tunnel Plug.—Preparatory work started on the following day consisting of pumping the water out of the tunnel, building an approach road to the access adit along the left wall of the canyon downstream from the powerhouse parking area, building a stairway with metal commercial scaffolding from the spillway bridge to the ogee section, and drilling and blasting out the concrete plug in the adit tunnel for access to the diversion tunnel at the lower end. The contractor assumed the lease on the hoist at the upstream end of the spillway and rented the pump in the deflection bucket from the Bureau.

From September 13 to October 13, the work performed by the contractor consisted of blasting the plug out of the access adit, installing a 12-inch drainline in the diversion tunnel, running air and powerlines into the work area from both the top and bottom of the tunnel, cleaning out the debris and waste concrete in the bottom of the spillway shaft, providing man access to the spillway and through the form jumbo to the bottom of the shaft, and moving in construction equipment. A two-shift work schedule was initiated on October 4, and the first pay item work started with the installation of rock bolts and wire mesh in the raise and mucking out loose material that had been left in the spillway. Mucking was done with a crawler-type tractor equipped with a front-end loader. This tractor was lowered down the spillway from the top and through the form jumbo on a timber ramp. It was diesel powered and equipped with an exhaust scrubber.

All material excavated in the spillway shaftway was dumped through the pilot shaft into the diversion tunnel below, loaded in dump trucks, and hauled outside and dumped downstream of the access adit along the left wall of the canyon.

Three 3-inch holes were drilled with an air track drill on the right side of the invert at the downstream end of the existing spillway lining. These holes were drilled vertically down through the lining of the diversion tunnel. Pipes were calked into the lower end of these holes and connected to the 12-inch drainpipe leading out of the tunnel. The water from the drain holes in the existing lining was then diverted into these holes. Later three more holes were drilled approximately 30 feet downstream and used to collect water seeping out of the rock. Some 3-inch drain holes were drilled 25 feet into the rock to relieve water pressure, but this was discontinued as it was observed that the rock bolt holes were acting as drain holes.

The excavation was shot out in 5-foot lifts with the contractor's engineers and the Bureau survey crew setting control for alternate lifts.

During the time excavation was underway, preparations were being made to place concrete in the access adit from the dam to the spillway. This work consisted of placing metal panning in the adit for water control, with grout systems installed on each side.
behind the panning and a vent system in the arch to facilitate void grouting after concrete placement. Also during this time the batching plant was being erected near the upper portal of the powerplant access tunnel. This was a mobile plant with a 3-1/2-cubic-yard turbine-type mixer. On November 19, 1965, the first concrete was placed in the diversion tunnel plug section to elevation 3140.25. This was followed by a 5-foot lift on November 24, 1965.

Prior to placing concrete in the plug section of the diversion tunnel, it was necessary to control the water leaking around the upstream 7- by 10.5-foot high-pressure gates. This was done by cutting 8- by 8-inch timbers to fit the bottom of the downstream gate seats. These were wedged in watertight, with 1-1/2-inch pipes through holes in the timbers. The water was carried through these pipes to a point downstream of the backfill concrete. The downstream gates were then lowered and closed tight on the timbers. After the second lift of concrete in the plug section was placed, a 7-foot lift was placed in each of the diversion conduits downstream of the high-pressure gates.

Concrete was pumped from the pumpcrete machine, located at approximately station 26+20 in the diversion tunnel, up to and through the 7- by 5-foot adit, to the gate chamber and then through the dam gate chamber adit to the downstream end of the 90-foot plug section. Placing of concrete was started on December 3, 1965. With approximately 50 percent of the concrete in place, pumping was delayed while the contractor pulled the slickline back; and the pipe was plugged when this operation was completed. As it was impossible to start the flow of concrete again, the pumpcrete pipe was broken down and cleaned out except for a 240-foot section that had set up too hard to clean out. This section was discarded. New pipe was installed and the placement of concrete in the adit plug was resumed and completed on December 8, 1965, with no further trouble.

On succeeding days the placement of concrete was completed in the three diversion conduits. The metal seals in the top downstream end of the conduits was in good condition and required only bending out and welding. The grout supply and vent systems were also found to be clear and required only the installation of grout box covers.

Concrete placing in the diversion tunnel plug section continued while waiting for time lapse before grouting the plug in the dam-to-gate-chamber adit. Also, grout holes were drilled out of the gate chamber upstream of the dam-to-gate-chamber adit and out of the 7- by 5-foot adit downstream of the gate chamber to the joint between the plug and the tunnel lining.

On December 27, 1965, the holes out of the 7- by 5-foot adit were pressured with thin grout, but there was no take on any of the eight holes. On December 29, 1965, the void grouting in the plug section in the dam to gate chamber adit was completed. Because of the seepage of water out of the rock, it was not possible to get a return of thick grout from the arch vent system. Final filling was accomplished by hooking the vent system and forcing the water back into the rock until there was no further take of grout. This required 440 sacks of cement. Grout was pumped with a grout pump rented from the Bureau.

On December 14, 1965, the contractor suspended excavation in the spillway raise due to conflict with concrete operations in the diversion tunnel below the pilot shaft which was being used as a muck chute. The invert of the tunnel was mucked out and backfill concrete was placed up to elevation 3145 to eliminate water problems in the working area. This concrete was placed using a 16-inch concrete conveyor suspended from a hydraulic crane.

Concrete was transported from the batching plant to the tunnel in five 7-1/2-cubic-yard transit mixers mounted on diesel trucks equipped with exhaust scrubbers. The trucks dumped onto a conveyor belt which in turn dumped into the pumpcrete hopper.

The existing grout system in the gate chamber was found to be usable except for the vents to the top. Grout covers were installed and new vent lines were
run into the dome. The access doors to both adits were bolted in place with a manhole in the downstream door. A length of 36-inch corrugated split pipe was installed on the end against the downstream wall of the gate chamber for access during placing of concrete. The plastic drainpiping, a 6-inch drain from the dam-to-gate-chamber adit doorway and five 1-1/2-inch pipes from the grout holes drilled out of the gate chamber were extended through the downstream door. The pumpcrete pipe was installed through a hole in the door and extended to the dome of the chamber. A swiveled deflector was installed on top of the pipe which dumped into chutes that distributed the concrete fairly uniformly over the area of the chamber. Steel scaffolds were built on the gate hoist cylinders for vibrator crews to work on. A thermocouple was installed near the center of the gate chamber and 12 feet above the bottom, and the wires were brought out through the downstream bulkhead.

Pumping of concrete in the gate chamber was started on January 4, 1966, and was completed on the following day. Vibrator crews worked in the chamber until the concrete reached the top of the corrugated pipe manway. Men and tools were brought out and pumping continued to refusal. Electric switches installed in each end of the chamber dome closed and turned on indicator lights outside just before the pump stalled.

All grout, vent, and drainpiping, and thermocouple wires were extended to the downstream end of the 7- by 5-foot adit. Grout covers were installed on the existing grout and vent systems and the adit was pumped full of concrete. Steel baffles were installed across the adit to help hold the concrete in place and prevent excessive voids in the top due to sliding.

Placing of concrete was resumed in the plug and backfill sections of the diversion tunnel. This was done in 5-foot lifts with cooling pipe installed between lifts. Seep water from the rock was used for cooling until such time as the water in the tailrace reached a temperature below 52° F. which was the temperature of the seep water. This occurred on January 5, 1966.

The concrete was placed with a conveyor system consisting of an inclined conveyor discharging onto a horizontal conveyor. The horizontal conveyor was of the side-delivery type and was mounted on rails. The upstream rail was supported on brackets bolted to the existing concrete, and the downstream rail was bolted on top of the form the top of which was 2-1/2 feet above concrete grade. The horizontal conveyor was hydraulically self-propelled laterally and the side-delivery chute moved longitudinally on a hydraulically operated chain. This system gave good coverage over the placement area.

On January 12, 1966, the 6 inch drain from the dam-to-gate-chamber adit and the five grout holes drilled out of the gate chamber were grouted.

The grout systems for the diversion conduits and the drains for the gate chamber were piped above elevation 3175 and backfill concrete was placed as shown in the following tabulation:

<table>
<thead>
<tr>
<th>Station</th>
<th>To</th>
<th>To elevation</th>
</tr>
</thead>
<tbody>
<tr>
<td>23+28.2</td>
<td>23+78.2</td>
<td>3175.00</td>
</tr>
<tr>
<td>23+78.2</td>
<td>24+35.2</td>
<td>3170.50</td>
</tr>
<tr>
<td>24+35.2</td>
<td>24+92.2</td>
<td>3160.50</td>
</tr>
<tr>
<td>24+92.2</td>
<td>25+46.8</td>
<td>3155.00</td>
</tr>
</tbody>
</table>

Several places in the existing metal seal at station 23+77 were badly damaged and broken by the flow of water during diversion and required extensive repairs.

On February 2, 1966, concrete work was suspended and excavation was resumed in the spillway shaft and existing diversion tunnel lining.

On February 7, 1966, the arch voids in the three diversion conduits were grouted using a total of 101 sacks of cement. The following day the voids in the gate chamber and the 7- by 5-foot adit and the plastic drainage system in the gate chamber were grouted using a total of 255 sacks of cement. The concrete temperatures at the time of grouting were as follows:

- Conduit No. 1—-58° F.
- Conduit No. 2—-60° F.
- Conduit No. 3—-59° F.
- Gate chamber—-80° F.

By March 10, 1966, excavation of rock and concrete lining was substantially completed and the placing of backfill concrete was resumed. Pumpcrete was used to fill under the arch of the existing lining and conveyors on the remainder. The concrete was placed on the downstream slopes without the use of forms. Placing of backfill concrete was completed March 26, 1966. While the backfill concrete was being cooled the contractor worked at removing tight rock from the ribs and arch of the tunnel. During the cooling process the water in the tailrace ranged in temperature from 44° to 48° F. depending on the amount of discharge through the powerplant.
All backfill concrete was down to the required maximum temperature of 60° F. and joint and void grouting was started on April 20, 1966. On this date the joints at stations 23+28.2 and 23+78.2 and the arch voids from station 23+28.2 to 24+14 were grouted. The following day the station 24+35.2 joint, the station 24+92.2 joint, the cooling coils, and the drainpipes between the high-pressure gates were grouted.

After grouting was completed the contractor finished the excavation which consisted of removal of the invert of the old concrete lining between the backfill concrete and station 26+11.72.

(d) Spillway Elbow Lining Section.—It was decided to place the entire length of the invert of the spillway elbow lining by the slipform screed method. Placing of invert concrete was started on May 12, 1966, using a sliding screed pulled with two air-operated winches. The concrete was trowel finished by hand behind the screed. Water was kept off the fresh concrete by a roof suspended over the area on cables; the roof was made of fiberglas-reinforced sheet plastic. Seepage water was controlled by a gravel blanket and perforated pipes draining under the concrete to the downstream end and into a sump. The concrete was delivered from the trucks to the screed by belt conveyors. Placing of invert concrete was completed on May 28, 1966. The form jumbo which had been suspended in the existing portion of the spillway was rigged with eight-part lines each on two 50-ton air-operated winches. Wheels were mounted under the shortened needle beams and the form was lowered into the downstream end of the elbow. This had to be done in two steps as the winch drums did not have enough line to lower the form all the way to station 26+11.72. An extra set of anchors was set at approximately station 24+40 when invert concrete was placed. The form was tied off to these and the pulling lines were brought down to the anchors to lower the form to final position. The form required a complete new plywood skirt, and part of the sheathing under the skin had to be replaced. The bottom wood buildup was removed from the form, leaving a lapover onto each edge of the invert concrete.

Preparations for lining the elbow are shown in figure 252. The first concrete placement in the arch of the elbow lining was made on July 11, 1966, using two lines off the pumpcrete machine with one going to either side of the form. After a number of delays the placements were completed and closure was made at station 23+82 on October 7, 1966. The major problem encountered during arch placements was excess water at invert construction joints. Approximately 75 percent of the entire surface was covered with metal sheets or polyethylene shield to divert the water into a drainage system provided through the invert concrete which drained into a sump at the lower end.

A subcontractor, Lynch Brothers Drilling Co., started grouting the drainage system from the invert sump at about station 26+00 on October 28, 1966, working 21-hour shifts. Grouting of the drainage system and arch voids was completed on November 7, 1966. The total amount of cement used was 2,713 sacks; 125 sacks were pumped into the 12-inch dewatering drainpipe.

On November 12, 1966, the subcontractor started drilling and grouting the radial grout holes from the first ring at station 25+89 and continued upstream to station 23+85. Drilling and grouting radial holes was completed on December 30, 1966, with a total of 106 holes 40 feet deep.

Drilling for the 3-inch drain holes, which were 25 feet into rock, started on December 19, 1966. Between stations 26+95 and 23+08, a total of 22 rings with 4 holes each were drilled, as well as 4 diagonal holes on the centerline invert. The drilling for drain holes was completed on January 19, 1967. All drain holes and 2-1/2-inch connecting pipe headers were then flushed open and clear. The lower drains were capped and the surface recess was dry-packed or filled with epoxy mortar.
Boyles Brothers subcontracted the work for placing epoxy mortar and bonded concrete invert repairs. The contract required repairs to existing invert concrete downstream from station 26+11, because of heavy erosion that had occurred during the diversion period. Technical assistance with the repairs and help in organizing crews for epoxy work were obtained from the Denver office. Water control was a significant problem. Construction joints and cracks in the lining had to be caulked with lead throughout the repair area. Temporary hot patch dikes and tapped drain holes above the springline were necessary to divert water outside the repair area. Temperature control was provided by two air-jet heaters.

During cleanup preparations for epoxy-bonded concrete, a rock pocket extending from the surface to foundation rock, was discovered. The unsound concrete lining was repaired by the contractor with payment made as extra work. Epoxy-bonded concrete was placed from February 2, 1967, to February 9, 1967, on the invert to 11.75 feet each side of centerline. Epoxy-bonded concrete was placed on the left side in the rough, eroded surface to the proposed limits between stations 26+11 and 27+20 and was also the most practical solution for repairing another area between stations 26+32 and 26+98.

Epoxy mortar repairs started on February 16, 1967, and were completed on March 7, 1967. After completion, the surface was found to have several irregularities which required grinding to allowable tolerances. This work required two finishers to grind out surface irregularities from March 16, 1967, to April 7, 1967, between stations 26+11.72 and 27+84.

The finishing crew completed the work on repairs, grinding, and epoxy patching of the spillway raise invert and sidewalls to centerline between March 2 and 20, 1967. Using the drilling and grouting jumbo the crew consisted of a finisher foreman, three finishers, two laborers finisher helpers, two hoist operators and two ironworkers. Part of the repair work involved repairs to lining constructed by others for which payment was made as extra work. Finishers with the same crew continued on down through the elbow section, epoxy patching, and grinding abrupt and gradual irregularities to required tolerances. After this work was completed on April 20, 1967, the jumbo was dismantled and removed from the tunnel.

The construction access adit to tunnel station 36+02 was prepared for the concrete plug. The periphery grouting system and metal seals were installed, as well as two coils of 1-inch aluminum cooling pipe and one thermocouple.

Concrete was placed by pumping methods on May 8, 1967, and tailrace water at 48°F was circulated for cooling concrete. The maximum temperature reached 140.6°F and cooling was necessary for 15 days to bring the concrete to 69°F. On May 24, 1967, the plug arch, periphery, and cooling coils were grouted using 5 sacks of cement at 1:1 water-cement ratio. Final cleanup of the immediate worksite and other working and storage sites required about 2 weeks to complete.

B. CONSTRUCTION OF DAM

161. KEYWAY EXCAVATION. Excavation of the right keyway began in October 1957 and was started in the left keyway in December 1957. Work continued in the keyways until July 6, 1959, when a strike against the contractor started. At that time the left keyway had been excavated to elevation 3100 and the right keyway to elevation 3080. Figure 253 is a general view of the dam construction area on May 20, 1959.

Excavation material in the keyways was at first pushed over the side by bulldozers and removed from below by shovels and hauling equipment. A 3-1/2-cubic-yard shovel assisted in moving the excavated material toward the edge of the canyon. Most of this material was used in the cofferdams. Some of the material fell in the river and had to be removed by draglines. Keyways were excavated in 10- to 12-foot lifts, generally using several rounds to remove the entire level so that while a blasted area was being mucked out another round of blast holes were being drilled in another section of the level. The drill pattern and amount of charge varied considerably according to conditions, but usually from 3,000 to 5,000 pounds of 40 percent powder was loaded in from 200 to 400 vertically drilled holes and 3 to 5 delays were used. Drilling was accomplished with up to six wagon drills.

In November 1958, when the right keyway had been lowered to approximate elevation 3265, a haul road was constructed from the keyway to the canyon.
bottom and the excavated material was then moved over this road. In December 1958 a haul road for excavated material was built from the canyon bottom into the left keyway. The keyway had been lowered to approximate elevation 3280 at this time.

Three foundation tunnels were driven in each keyway. The foundation tunnels were designed with dimensions of 5 by 7 feet, but the contractor was permitted to excavate a 1-foot arch in the roofs in order to use a crawler-mounted overshot loader. This extra excavation was at his request and at his expense. In the right keyway the tunnels were at elevations 3630, 3480, and 3247.5 and for lengths of 254, 317 and 565 feet, respectively. In the left keyway, the elevations were the same and the lengths were 250, 350 and 451 feet, respectively.

Because of poor rock conditions it became necessary to retrim the downstream toes of both keyways. This work began the week of April 19, 1959, and at that time the right keyway had been excavated to approximate elevation 3123 and the left to elevation 3131. The right keyway was retrimmed or deepened at the downstream toe from elevation 3465 to elevation 3280 and the left keyway from elevation 3300 to elevation 3175, when during the week of June 14, 1959, the work was suspended and excavation plans...
revised. On June 30, 1959, retrimming of the right keyway was resumed between elevations 3390 and 3200 to revised excavation lines.

On July 25, 1959, a fallout occurred at the upstream edge of the excavation for the left keyway between approximate elevations 3350 and 3510. During September 1959 an additional section of this rock fell out. The dangerous overhang above the fallout was removed in February 1960 and retrimming operations in the downstream section started from elevation 3300 down. The keyway was completed to elevation 3080 in April 1960 and the foundation was then sloped from elevation 3080 to elevation 3030 in the river bottom. Chain link mesh was anchored across a joint at the upstream edge of the left keyway excavation between approximate elevations 3250 and 3150.

From field studies early in August 1960, it was apparent that a rock slab on the left canyon wall, immediately downstream from the toe of the dam, needed anchoring. The area investigated was between stations 4+10 and 5+14 at about elevation 3170 and between stations 4+10 and 5+37 at about elevation 3100.

Six test holes drilled at approximate elevation 3150 indicated that the slab at that location was 8 to 9 feet thick with a 3/4- to 1-inch opening behind it. Seven test holes at about elevation 3115 indicated that at that level the slab was 6 to 6-1/2 feet thick with a 1/2- to 3/4-inch opening. Four other test holes, drilled at random locations between stations 4+10 and 4+45, indicated that between these stations the slab was 4 to 5 feet thick with a 1/2- to 3/4-inch opening between it and the solid rock of the canyon wall.

A price was negotiated with the contractor for extra work and seventy 20-foot anchor bars were placed to anchor the slab to the canyon wall. After the mass concrete was placed in this area, the opening between the slab and the solid rock was grouted by very low pressure grouting.

Two 5- by 7-foot drifts were driven into the right keyway in April and May 1960, both near the hill of the dam and at invert elevations 3112 and 3065, respectively. The purpose of the drifts was to observe seepage and to provide a seepage cutoff. The drift at elevation 3112 was stopped at 73 feet as very little seepage water was encountered. The lower drift was driven 173.7 feet. Considerable seepage occurred in this drift as it was driven along the weeping seam which extended into the abutment at elevation 3070. A total flow of approximately 50 gallons per minute seeped throughout most of the length of the drift, but for the last 25 to 50 feet only very light weeping occurred. Both drifts were backfilled with concrete and grouted. A french drain was installed in the lower drift, and after the arch void grouting was completed the drain was also grouted.

Work in the dam foundation area was started about April 1, 1959, and at the time of the strike had reached elevation 3078 in the upstream section. With the resumption of work in January 1960, mucking was started with draglines in the upstream and downstream sumps, and excavation followed in the area to the left of the plane of centers in the upstream section.

This area was gradually extended downstream to include the area between the dam and powerplant and into the powerplant area. The left side of the dam foundation was sloped from elevation 3080 at the base of the keyway to elevation 3030 in the upstream of "A" section of the blocks. The downstream or "B" sections were lower with the elevation on the left of block 10-B at elevation 3020 and sloping down to elevation 3004.7 at the left of block 11-B, lowest point of the dam foundation, and back to elevation 3020 in block 13-B. From this point the slope was relatively uniform to elevation 3110 at the base of the right keyway.

Figure 254 shows early concrete placement in the dam and powerplant.

1. Concrete Production and Placement

162. GENERAL DESCRIPTION. The bulk of the prime contractor's plant and equipment required for the work was directly related to the production and placement of concrete. The major components were the aggregate processing plant and the concrete mixing plant. Screening and washing of aggregate was performed at a plant located on a natural bench over Wahweap Creek some 6 miles from the worksite. The concrete batching and mixing plant was located on a bench excavated into the right canyon wall adjacent to the dam. In addition, a large refrigeration plant was erected near the concrete mixing plant, primarily to
cool the concrete, and two 50-ton and one 25-ton cableways were constructed to transport the concrete and other materials. A flow chart for the aggregate processing plant is presented in figure 255.

163. AGGREGATE PIT OPERATION. Before pit excavation operations were started, the Wahweap Creek channel was diverted and confined to protect excavation operations from the intermittent and silt-laden flows of Wahweap Creek. The contractor constructed this channel adjacent to the left bank of the deposit, by utilizing waste overburden. An embankment was constructed 10 to 15 feet in height with a berm width of about 12 feet, which maintained the creek width of about 20 feet at the same grade and elevation as the surface of the original channel. The Wahweap Creek was diverted at the upstream end of the operations, station 170+00, by an earth embankment constructed across the channel from bank to bank, approximately 20 feet in height and 2,000 feet in length. Self-loading scrapers and bulldozers were used for removing the overburden and depositing on the dike embankments. No special compaction was used for constructing these embankments, except that obtained by the earth-moving equipment.

At the beginning of excavation operations in the borrow area, no attempt was made to dewater the pit. However, it was found that the saturated pit-run material could not be elevated on the 18° slope conveyor belts delivering material to the aggregate plant. The borrow areas were therefore dewatered by pumping and excavation proceeded to bedrock. The face of the pit was developed from the lower end of the deposit to take advantage of the natural drainage slope. Excavation in the pit was performed by the use
of two draglines with 6-1/2- and 7-cubic-yard capacities, usually loading into a 50-cubic-yard hopper. The contractor initially used twelve 35-cubic-yard-capacity bottom-dump trucks in the pit excavation. Under full production, six of these trucks were replaced with four 45-cubic-yard bottom-dump trailers, drawn in tandem, for use on the longer hauls.

Raw material delivered from the borrow areas was discharged into a 100-cubic-yard unloading hopper at the base of the canyon cut by Wahweap Creek. The pit-run material discharged from the hopper onto a vibrating scalping screen equipped with parallel bars with openings between the bars of 6 to 6-1/2 inches. Rock larger than 6-inch size, often chunks of clay or tabular sandstone, were wasted at this point. Material passing through the vibrating grizzly was fed through a belt feeder onto a 36-inch conveyor belt traveling 640 feet per minute on an 18° slope. The material was conveyed to a balancing raw storage stockpile having a live storage capacity of approximately 5,000 tons, which provided uniform feed to the plant and at least 3 hours of storage margin. The material passed through a metal-lined cone or hopper at the base of the stockpile, where the amount of feed required was controlled by a manually operated gate above a belt feeder. The feed fell directly onto a 36-inch endless conveyor, 1,800 feet in length, also on an 18° slope, which delivered the material to the top of the aggregate screening and washing plant. This conveyor was equipped with a recording-type weighing scale which recorded the instantaneous load and the total daily tonnage.

164. AGGREGATE SCREENING AND WASHING PLANT. The prime contractor, Merritt, Chapman and Scott Corp., designed and erected a screening and washing plant to supply the coarse and fine aggregate required for producing concrete at a sustained rate of 420 cubic yards per hour at the concrete batching and mixing plant. The plant was located on the right bank of the Wahweap Creek channel at elevation 3715,
opposite area B, and approximately 225 feet above the channel floor.

To obtain the required aggregate size gradation, the minus 6-inch raw material passed through a complex flow pattern. Water was introduced as the material was fed to the plant and was further washed with spray bars over all of the vibrating screens. Approximately 8,000 gallons per minute of water at a pressure of about 80 pounds per square inch was used while washing and screening. The first set of two sloping, vibrating screens, each having a double deck with screen meshes of 3-1/2 and 1-3/4 inches, removed the 3- to 6-inch and 1-1/2- to 3-inch coarse aggregate. Both of these size fractions were conveyed directly to the finished stockpiles located at the aggregate plant, without further processing.

Aggregate which passed through the 1-3/4-inch mesh screen was routed by gravity to two sloping vibrating screens, each having a triple deck with screen meshes of 7/8 inch, No. 4 size, and 1/8 inch. Aggregate retained on the 7/8-inch mesh screen was conveyed to the 3/4- to 1-1/2-inch finished stockpile, or a portion could be diverted for heavy-media processing to remove lightweight rock. Aggregate which was retained on the No. 4 and 1/8-inch screens was similarly handled going to the No. 4 to 3/4-inch and the No. 4 to No. 8 stockpiles or a portion of these could also be diverted for the heavy-media process.

The minus 1/8-inch sand was routed to three hydraulic sizers where the sand was separated into fractions. The excess fines, consisting of the No. 8, No. 100, and minus No. 100 were wasted and the remaining portion was diverted by gravity to two 30-inch spiral screw classifiers where it was further blended and dewatered before it was conveyed to the minus No. 8 finished stockpile. Initial sand production results in three initial stockpiles, one containing the No. 4 to No. 8 sand fraction, not heavy-media treated. One stockpile contains minus No. 8 sand and the third stockpile contains the No. 4 to No. 8 heavy-media treated fraction. Final sand production required blending approximately 20 percent of No. 4 to No. 8 untreated sand with 80 percent of the minus No. 8 sand to produce untreated natural sand, or 20 percent treated No. 4 to No. 8 fraction with 80 percent of the minus No. 8 fraction to produce heavy-media treated sand.

This completed the screening cycle of raw material from the borrow areas. It should be noted that an excess of any aggregate or sand fraction could be diverted to the waste pile on a separate conveyor without affecting the rest of the plant operation. During processing of coarse aggregate, only the No. 4 to 3/4 inch and the 3/4- to 1-1/2-inch material was in excess. Most of the excess No. 8 to No. 4 fraction of the fine aggregate was wasted in the hydraulic separators and diverted to the coarse aggregate waste pile, but a portion of this waste was used for the production of sandblast sand. The remaining waste fine aggregate was diverted with the plant wash water by gravity to the excavated area at the downstream end of area B where settling area B where settling basins were constructed for separating the waste sand from water. A portion of this water was reused again, as discussed in section 166.

No serious problems during production of aggregate were encountered, although various minor difficulties were experienced. One problem involved the recovery of critical size fractions in sand, especially the No. 30 sand. The actual cause of this difficulty originated in the overloading of the lower deck of the triple-deck shakers containing the No. 8 screen. Consequently, some of the No. 16 and No. 30 sizes passed over and were not saved. Some relief of this condition was gained by replacing the No. 8 screen with a 1/8-inch screen, allowing the coarser material to pass on into the hydraulic sand separators. When leaving the hydraulic separators, it was removed by passing over a No. 10 screen, provided with water sprays. This further removed the smaller sizes of sand which fell directly in the sand dewatering screws. This operation allowed the contractor to salvage the No. 8 size fraction at a convenient location and divert some of the excess material to a rotary dryer for the production of sand blast sand for use in concrete construction joint cleanup. Approximately 100 tons of this sandblast sand was produced per day.

165. HEAVY-MEDIA SEPARATION. The raw material from all borrow areas contained variable amounts of lightweight, unsound, and deleterious rock. Preconstruction investigations determined that most of these deleterious materials were contained in the minus 1-1/2-inch aggregate, with most of the lightweight and undesirable material present in the No. 8 to No. 4 fraction. Tests also indicated that concrete of good quality could be produced when lightweight material below 2.50 specific gravity was removed. As a result, the specifications for Glen Canyon Dam and Powerplant required that all fine aggregate between the No. 8 and No. 4 sand size and all coarse aggregate between the No. 4 and 1-1/2-inch size would be subject
to heavy-media treatment when used for production of exposure, or exterior, concrete. This concrete included a minimum thickness of 5 feet on both faces and the top of the dam, the lining of the diversion and spillway tunnels, and all powerplant concrete, except the initial mass concrete, amounting to about 10 percent of all concrete. The specifications also provided that lightweight material having a specific gravity of 2.50 or less would not exceed 2.0 percent by weight of the sink in the above two fractions. As this process is somewhat unusual, considerable details follow in this publication.

For production of this aggregate, the contractor incorporated two heavy-media separation units (fig. 256) in conjunction with operation of the screening and washing plant to meet the requirements of the specifications. An early attempt was made to process a composite feed of No. 8 to 1-1/2-inch size range, which proved unsuccessful when using the spiral screw in an inclined tank type of classifier. The main difficulty appeared to be with weir openings. Being set for enough flow to permit passage of the larger size lightweight particles, many fine heavy particles were swept by the medium current over the weirs, and many were carried on top of larger lightweight particles. As much as 90 percent of No. 8 sand was lost with the float product in field trials. As a result, a separate heavy-media unit was installed consisting of a cone-type separator for treating the No. 8 to No. 4 sand fraction. The key elements of both types of separators are the separating vessel and the circulating medium. The medium contains 30 to 40 percent magnetite having a specific gravity of 4.7 and ground to 100 mesh, and 60 to 70 percent ferrosilicon having a specific gravity of 6.9 and ground to 65 mesh. These finely ground materials are proportioned and mixed with water to make a suspension having a specific gravity in the separating vessel which would be sufficient to separate the lighter particles from the heavy particles at a division point of 2.50 specific gravity. The medium in suspension in the cone separator ranges from 2.35 specific gravity at the surface to 3.05 at the bottom. In the inclined-screw type classifier, the specific gravity of the media as it enters the system ranges between 2.47 and 2.50.

Aggregate to be heavy-media processed was diverted from the regular aggregate plant and conveyed to three 200-ton storage bins. Untreated aggregate was drawn from these bins and passed over dewatering screens before entering the heavy-media plant. These dewatering screens provided a more uniform moisture content and better control of the heavy-media specific gravity. Due care was taken to
thoroughly wash the material, as dirty material affected the specific gravity of the medium, causing more frequent cleanup and recharging costs.

Aggregates were fed into the separation pool at the lower end of the tank. The coarser fraction, 3/4 to 1-1/2 inch, entered at the side of the separation pool while the finer fraction, 3/16 to 3/4 inch, was fed into the end of the pool where the depth was greatest and the material had a longer retention time. The heavy aggregate particles sank through the medium and were carried up the inclined tank by the rotating spiral. They were discharged from the upper end onto one side of a compartmented vibrating drainage screen. The light particles floated on or near the surface of the separation pool and were carried with the medium overflow through weirs located on the side of the tank opposite that of the aggregate feed. The medium, transporting the float particles, passed through a channel to the float side of the compartmented screen.

The first few feet of the compartmented vibrating screen were located directly over a medium drainage sump. The medium draining from the aggregate was collected in this sump and continuously pumped back to the separating vessel. Most of the medium leaving the separatory vessel was returned in this manner. As the aggregate products continued along the vibrating screen, they passed under washing sprays where the remaining medium clinging to the particles was removed. The products were then discharged separately at the end of the screen in a dewatered condition. The finished product was then conveyed to a rescreen plant where the two coarse fractions were separated and conveyed to the aggregate plant stockpiles.

The water and medium which were washed from the aggregate were collected in a wash sump. This diluted medium was pumped to a magnetic separator where the magnetite and ferrosilicon were concentrated into a semidewatered condition. Nonmagnetic solids and excess water were wasted. The magnetic concentrate recovered from the magnetic separator flowed into a spiral densifier. Here the reclaimed medium was dewatered and continuously fed back into the spiral separator. The rate of return of the medium was controlled by raising or lowering the densifier spiral. An electric coil was placed in the circuit between the densifier and the separator for the purpose of demagnetizing the solids as they were discharged, thus preventing flocculation of the medium within the separatory vessel.

A cone-type separatory vessel was used for processing No. 8 sand. The cone had a greater depth and volume than the spiral separator and was capable of retaining a given rate of feed for a longer period in the separation pool. It consisted of an inverted 7-foot-diameter cone equipped with paddles to agitate the heavy medium, and appurtenances similar to those used with the spiral separator for product drainage, medium reclamation, storage, etc. The heavy particles sank to the bottom of the cone where they were removed through a vertical pipe. The sink was carried upwards in this pipe by the circulation of the medium and the action of an air jet; it was then deposited at the upper end onto a drainage screen. The float material flowed over a weir at the top of the cone and was deposited on the draining and washing screen for medium removal. Treatment beyond this point was similar to that described for the spiral-type plant.

The cone separator was operated to obtain a large differential between specific gravities of the medium at the top and bottom of the separating pool. This was helpful in producing efficient separation, particularly when there was little difference between specific gravities of many sound and unsound aggregate particles in the feed. Tests showed that the larger the differential, the better the product obtained. The differential in medium specific gravity increased with increasing depth of pool, with increasing ratios of ferrosilicon to magnetite, and with reduced agitation and circulation. These factors also increased the possibility of plugging, in the circulatory system, with resultant delays and costly cleanout and restarting expenses. Therefore, it was important to frequently sample the medium near the top and bottom of the pool and maintain a differential that would provide efficient separation and smooth operation. Although the specific gravity of separation was 2.50 for the aggregate used in the dam, separation can be accomplished at any required specific gravity up to about 3.0. When it is desired to separate below a specific gravity of about 2.40, a slurry with magnetite alone may be used; for separation at a specific gravity of 2.80 or above, a slurry of ferrosilicon alone can be used.

The specific gravity differential diminished when the medium became contaminated with silt and clays appearing on the surface of the aggregates. These slimes also increased the viscosity of the medium and lowered the average specific gravity. It was important, therefore, to continually remove slimes even at the expense of losing a small amount of ferrosilicon and magnetite. This was done by regulating overflow weirs in the tank containing the magnetic separator as well as regulating the rotational speed of the magnet. Proper weir setting would assist in washing most of the slimes out of the system without excessive waste of magnetite and ferrosilicon. Average loss of the latter materials at
the dam was estimated at about 1 pound per ton of sink product.

166. WATER SUPPLY. A substantial amount of water was required to thoroughly wash aggregates, manufacture sand by the wet process, remove water soluble sulfate and chloride salts, plus supply normal plant cleanup needs. The flow from Wahweap Creek was small, erratic, and the water was high in sulfate content. The silt content in the Colorado River, some 5 miles distant, was high even during normal flow, and the cost of desedimentation and pumping would be high. The contractor elected to drill six wells near the aggregate processing plant in order to provide nearly 8,000 gallons per minute needed for full operation. The six plant wells were drilled to depths ranging from 625 to almost 800 feet and had a combined rating capacity of 7,750 gallons per minute. Four other wells were drilled to provide domestic water for construction purposes, the contractor's camp, and shop areas on the west side of the Colorado River near the damsite.

Four earth reservoirs were provided: two for storage and holding 26,000,000 and 5,000,000 gallons; one for sediment settling, and one surge and blending reservoir for holding 500,000 gallons. The system was designed so that water could be pumped to the storage reservoirs, the screening plant, or damsite, or pumped from the reservoirs to the other features. Water used in the screening plant returned to the sediment reservoir. About 20 to 30 percent of the used water was mixed with 70 to 80 percent of fresh water in the surge and blending reservoir for reuse in the screening plant. Extent of water reuse was governed by the soluble sulfate in the finished sands; and the sediment reservoir was usually drained, cleaned and refilled with fresh water about once a week. Replacement of pump bowls was necessary about every 4 months, and occasional periods of short supply did occur when more than one pump was out of service for repairs. However, the water system proved adequate for job requirements and produced well-screened and clean aggregate. Settling basins in the Wahweap Creek were developed later and use of the basin at the aggregate plant was discontinued.

167. STOCKPILES OF AGGREGATE. Processed aggregate was stored in large stockpiles adjacent to the screening plant. The stockpiles were arranged in a single row (fig. 257) with one stockpile each for natural (or untreated) material of 6- to 3-inch, 3- to 1-1/2-inch, 1-1/2- to 3/4-inch, and 3/4-inch to No. 4 sizes; graded sand; heavy-media treated sand; heavy-media treated 3/4-inch to No. 4 aggregate; and heavy-media treated 1-1/2- to 3/4-inch aggregate (fig. 255). The heavy-media treated sand stockpile contained the No. 4 to No. 8 size fraction which was beneficiated and then recombined with the minus No. 8 natural sand (see sec. 164).

A large tunnel extended under the line of stockpiles where 30-ton bottom-dump trucks were loaded for the 6-mile haul to the concrete batching and mixing plant storage stockpiles. There were no steep grades on the gravel-surfaced haul road, and the only maintenance normally required was use of a water truck to keep down dust and a grader to maintain the roadbed.

As the six separated sizes of coarse aggregate were delivered to the damsite, they were stockpiled according to size. The bottom-dump trucks arriving from the aggregate plant discharged into an unloading hopper of sufficient capacity to hold two truckloads. The material was conveyed from the hopper to an overhead, shuttle conveyor which extended above the stockpiles. The elevated tracks on which the reversible shuttle was mounted ran the full length of the stockpiles; the shuttle conveyor was one-half the length of the tracks. When concrete operations got under full production, it was found that too much time was consumed moving the conveyor to the various stockpiles. A separate conveyor was therefore installed for stockpiling the 3- and 6-inch aggregate. Rock ladders were constructed for each coarse aggregate stockpile greater than the 3/4-inch size. Material was drawn from the bottom of the stockpiles from two different gates for each aggregate for delivery to the batching plant.

The two types of graded sand were stockpiled by the use of a radial stacker, drawing material from a common unloading hopper. The radial stacker traveled on tracks through an arc of 135°, delivering the heavy-media-treated sand at one end of the arc and the natural sand at the other. Heavy-media-treated sand was drawn from the bottom of the stockpile through one of three different gates for delivery to the concrete batching plant, while the natural sand was drawn from one of seven different gates. Multiple gates were provided to assist in obtaining greater consistency in moisture content for production control purposes.

The contractor operated the stockpile area with five men on each shift; one operator for the coarse aggregates and two for the sands, one laborer in the reclaim tunnel, and one laborer for general work.

168. CONCRETE SPECIFICATIONS DATA SUMMARY. Specifications for the Glen Canyon Dam and Powerplant provided for the use of pozzolan for
30 percent of the cementing material of concrete placed in the dam, mass concrete for powerplant and other massive concrete, as well as some interior or unexposed concrete.

The temperature of concrete placed in the right and left diversion tunnels and spillway tunnels was not to exceed 80°F. or be less than 40°F. The temperature of all other concrete, including concrete in the dam, was not to exceed 50°F. or be less than 40°F. Initial temperature restrictions aided in controlling the heat of hydration when the concrete was setting, which was supplemented by circulation of cold water through tubing embedded in the concrete. A water-reducing set-retarding agent, was used after concrete operations got underway, which was covered in orders for changes No. 2 and 12. The use of this agent also aided in holding heat of hydration temperatures down by further reducing the cement content.

The percent of air entrained in concrete varied according to the maximum size of coarse aggregate in the concrete in the following designed amounts:

<table>
<thead>
<tr>
<th>Coarse aggregate maximum size, inches</th>
<th>Total air percent by volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>3/4</td>
<td>6 ± 1</td>
</tr>
<tr>
<td>1-1/2</td>
<td>5 ± 1</td>
</tr>
<tr>
<td>3</td>
<td>4 ± 1</td>
</tr>
<tr>
<td>6</td>
<td>3-1/2 ± 1</td>
</tr>
</tbody>
</table>

The slump of deposited concrete varied with the location and use, and these limits were followed:

(1) Two inches maximum slump: mass concrete containing 6-inch maximum coarse
aggregate; concrete placed in the tops of walls, piers, parapets and curbs; and concrete placed in tunnel inverts and horizontal, or nearly horizontal, slabs.

(2) Four inches maximum slump: concrete pumped or placed in side walls and arch of tunnel linings.

(3) Three inches maximum slump: all other concrete.

169. CONCRETE BATCHING AND MIXING PLANT. Before the large batching and mixing plant for full concrete production was available, the contractor erected a temporary plant to supply his plant construction needs and for supplying concrete for lining the diversion tunnels. This temporary plant was erected on the right side of the damsite and adjacent to the aggregate stockpiles. This plant was equipped with two 4-cubic-yard mixers, automatic weigh batchers, and automatic recording devices for batch weights and consistency. Final screening of aggregate was performed adjacent to the plant and cement was stored in three 2,000-barrel-capacity silos. Bulk cement from the Permanente Cement Co., Lucerne, Calif., was transported by truck and furnished by the contractor. Discharged into 4-cubic-yard cableway buckets, concrete was transported on flat-bed semitrailers to a cableway erected for the diversion tunnel construction. The plant was capable of producing about 80 cubic yards of concrete per hour. No significant difficulties were experienced with the operation of this plant.

Late in 1957, the Noble Co., Oakland, Calif., was given the task of designing a plant which could produce concrete on an average hourly rate of 420 cubic yards, and a maximum rate of 480 yards for short periods of time. The plant was to be as automated as possible and still maintain quality control to produce concrete in compliance with the specifications.

Usually called the mixing plant, the concrete batching and mixing plant was located on a bench excavated from the west canyon wall at elevation 3540 just upstream from the right abutment of the dam. The bench also served as a roadbed for the tracks of the electric-powered transfer trains which moved the concrete-loaded ladle buckets from the mixing plant and across a structural steel trestle for transfer to the cableway buckets.

Concrete footings for the plant were placed during March 1959, and erection of the supporting steel frame began in April. Steady progress was made erecting steel until July when labor difficulties stopped all work on the project until January 1960. Erection of the plant was then resumed and was essentially completed in April 1960. Tests and checking out of all electrical and mechanical components were made during May and the mixing plant began operation in June 1960.

The octagon-shaped mixing plant (fig. 258) was 217 feet in height and contained six main floors. A large 3,000-ton-capacity aggregate storage bin was located near the middle of the plant. This bin contained eight compartments for the two types of sand and the six different sizes of coarse aggregates required for concrete production. The portion of the plant above the storage bin was called the screening tower; the batching and concrete mixing floors were beneath the storage bin.

Sand and coarse aggregates were transported to and entered the plant by belt conveyors. At the top of the plant, coarse aggregates passed over sloping, vibrating screens (final screening) and dropped into proper bin compartments. Sand was delivered directly from the sand stockpiles by a separate conveyor system to the mixing plant storage bins. Sand and aggregates were weighed through batching scales, discharged into one of six 4-cubic-yard mixers, and combined with cement, water, and required admixtures into a batch of concrete. The concrete was discharged from the mixers into one of three holding hoppers for loading into the 12-cubic-yard ladle buckets on the transfer trains. Two of the holding hoppers had a capacity of 26 cubic yards and the other 12 cubic yards.

Location of the plant on the rock bench below the canyon rim allowed almost horizontal delivery of materials to the plant and retained the advantage of gravity flow during production. Another prime factor in this location of the plant was that about five-sixths of the almost 5 million yards of concrete required would be located below the bench at elevation 3540, resulting in a substantial savings in the cost of operating the cableways.

(a) Arrangement.—At the top of the mixing plant, on floor 6, sand and coarse aggregates entered by conveyor from the cooling chamber and dewatering screens. A 42-inch reversible transfer conveyor, 10 feet in length, transferred sand to the proper storage bin compartment for "natural" sand or for heavy-media treated sand. Coarse aggregates passed through a transfer chute with the flow divided between two 6- by 14-foot sloping vibrating screens, located below on floor 5, where the aggregate received the first step in final screening.
Figure 258.—Elevation of mixing plant.
Both of the two sloping vibrating screens on floor 5 were double decked. The top deck on each screen had a 3-1/2-inch mesh for final screening for the 3- to 6-inch coarse aggregate, which passed directly down a rock ladder to a bin compartment. The two lower decks had 1-3/4-inch mesh screens and gave final screening to the 1-1/2- to 3-inch coarse aggregate, which also passed by rock ladder to a bin compartment. Aggregate passing the 1-3/4-inch deck screens dropped below to sloping vibrating screens on floor 4.

There were two double-deck, 6- by 14-foot vibrating screens on floor 4, each with 7/8- and 3/16-inch mesh screens. The top deck on each screen removed the 3/4- to 1-1/2-inch coarse aggregate which passed by chute to a storage compartment. The lower screen decks gave final screening to the 3/16- to 3/4-inch coarse aggregate which also passed by chute to a storage compartment. Material passing each of the 3/16-inch mesh screens was wasted. When screening the 3/4- or 1-1/2-inch maximum size aggregates, there were flow arrangements available to divert either size of aggregate to one of two storage compartments depending on whether the material had received heavy-media treatment.

Floor 3 consisted of decking over the main storage bins and provided access to inspect the various bin compartments and repair worn chutes and rock ladders. Floor 2 was located below the 3,000-ton storage bin and was known as the batcher floor. Here the individual weigh hoppers were suspended below the storage bin compartments, along with others to weigh cement, pozzolan, water, ice, air-entraining agent, water-reducing agent, and calcium chloride solution. Gates to fill and empty each weigh hopper were operated electronically through an automatic sequence, or individually by manual control. The contractor's plant office, a tool and workshop room, and a materials laboratory were also located on this floor. The laboratory was maintained by the Bureau in order to check coarse aggregate and sand samples for grading and moisture content, and for control of liquid admixtures by specific gravity tests.

Adjacent to floor 2 and between the plant and right abutment wall two surge silos were located, one 750-barrel silo for bulk cement and one for 75 tons of pozzolan, and a 5-ton storage bin for crushed ice. Cement, pozzolan, and ice were delivered to their weigh hoppers, located inside the plant on floor 2, by remote-controlled screw conveyors. All weigh hoppers loaded to the predetermined amounts required for the mix of concrete being produced.

The six tilting mixers were installed on floor 1 in a circular pattern, being supported by a separate concrete foundation and structural members to reduce vibration in the rest of the plant. Each mixer had a capacity of 4 cubic yards and was charged from the front. The mixers were charged by a collecting hopper and a swivel chute, which is tapered to an offset angle with an opening of about 32 inches at the lower end. When the swivel chute was centered in front of a mixer, the lower end contacted a shorter length of chute, called the retractable chute, and the two sections provided a clear passage for charging that mixer with materials from the weigh hoppers on floor 2.

The control room at the top of the screening tower located above the 3,000-ton storage bin was equipped with pushbutton controls to enable the tower operator to draw sand and coarse aggregate from the storage stockpiles for delivery to the mixing plant on belt conveyors. A 36-inch-wide conveyor was used from the reclaim tunnel to the chilling chamber, a distance of 2,000 feet, having two shuffle points. A belt conveyor 42 inches in width and 250 feet in length was used through the chilling chamber. After the coarse aggregates passed through the chilling chamber, they passed through a vibrating double-deck dewatering screen by gravity, and then were conveyed to the top of the mixing plant, a distance of 150 feet. The plant storage bins were originally equipped with high and low bin indicators to show when the bins were nearly empty and when filled. This system was replaced with a closed-circuit television system which enabled the operator to see the actual bin level and to maintain better control on filling the compartments.

Coarse aggregates drawn from the storage stockpiles traveled through a covered section enclosing the conveyor called the chilling chamber. During hot weather, the aggregates were sprayed here with water chilled to 34° to 40° F. to lower their temperatures. Sand was delivered to the mixing plant on a separate conveyor system, but did not pass through the chilling chamber. The storage compartments for natural 1-1/2-, 3-, and 6-inch maximum aggregates and the 1-1/2-inch maximum size heavy-media treated aggregate were insulated with exterior fiberglas blankets. Further chilling of these aggregates was provided by means of cold, refrigerated air, injected and circulated through the compartments.

The main plant control room was located above the mixers on a small mezzanine floor, adjacent to the downstream side of the plant. The control room was glass enclosed, giving a clear view of the mixers and
swivel chute action, and was maintained under slight air pressure to reduce maintenance on electronic devices and meters due to dust. An open-mesh catwalk circled in front of and above the six mixers, enabling the operator and technicians to visually spot check the actual concrete mixing action in any one or all of the six mixers.

(b) Operation.—The control room operator could operate the mixing plant, either automatically or manually, by switches and pushbuttons conveniently arranged on a single console board. The operator had a choice of 12 different concrete mixes, which had been previously computed by a Bureau representative. A large panel of monitoring dial instruments were electrically connected to each of the weigh hoppers on floor 2 to show the progress of weighing materials used in a batch of concrete. The operator could readily see if the weigh hoppers were filled correctly or if any material batches were under or over the required weight desired. Underloads which if not immediately corrected disrupted the mixing cycle, and overloads greater than permissible specification limits would be corrected by addition or deletion of materials in proper amounts.

When the plant was set to operate on automatic production, a complete mixing cycle for each mixer took 3 minutes; one-half minute was allowed for filling and emptying the weigh hoppers and 2-1/2 minutes were used for the mixing time for each mixer. After any mixer was charged with the batch ingredients, the swivel chute automatically rotated clockwise to the next mixer. With the completion of the first charging cycle to all mixers, the plant continued to produce 24 cubic yards of concrete each 3 minutes until the charging and mixing cycle was stopped or the operator placed the plant on manual control.

During 2 years of maximum concrete production, an average of 335 cubic yards per hour on a 24-hour day, 5 or 6 days a week, was produced. During one 8-hour shift the plant produced the maximum plant capacity of 3,840 cubic yards, and the maximum production for a single 24-hour period was 10,127 cubic yards.

An automatic recording machine printed a graphic record of the weight of each material used in a batch of concrete. This record, or roll, was used to check the number of batches of each kind of concrete produced by shift, and to check on the amounts of materials weighed. Another recording machine, called a consistency meter, recorded the electrical current required to turn any mixer. Concrete having a “dry” consistency or low slump took more current to turn the mixer than a mix of a “wet” consistency or higher slump concrete. Both of these records became part of the permanent Government data and were retained for a period of time after completion of the work.

Communications throughout the various floors of the mixing plant and to other features of the jobsite, were facilitated by an elaborate system of telephones, intercoms, and two-way radios. Access throughout the plant was by stairways, ladders, and an outside elevator to all main floors.

(c) Cement.—Four silos were provided to store bulk cement, each having a capacity of 10,000 barrels. Three silos, each holding 1,000 tons, were provided to store pozzolan. Cement was delivered by truck from the Phoenix Portland Cement Co., Clarkdale, Ariz., a distance of 188 miles, under invitation No. DS-5023. Pozzolan was supplied under invitation No. DS-5053 by J. G. Shotwell from a plant located on pumice deposits about 25 miles north of Flagstaff, Ariz., and trucked 110 miles to the damsite.

Trucks containing cement or pozzolan were received at the Government scale house for weighing and then proceeded to the storage silos for unloading. The trucks bottom-dumped into a 14-inch screw conveyor which passed the cement or pozzolan to a bucket elevator where the material was lifted to air slides at the top of the silos and transported to the respective silos. Cement was transported to the mixing plant by screw conveyors from the bottom of the silos, then transported by air slides and gravity to the balancing storage silos, located adjacent to the plant at the batching floor elevation.

On the canyon rim adjacent to the plant, bulk storage tanks contained calcium chloride solution, air-entraining agent, and liquid water-reducing set-retarding agent, which were piped for gravity flow to the batching floor for dispensing.

(d) Crew.—The contractor operated the mixing plant with a crew of 12 men on each shift, with a general superintendent in charge of all work except the refrigeration plant. Each shift consisted of one foreman, one operator at the cement and pozzolan silos, one operator at the dewatering tower, one operator for rescreening operations at the top of the plant, one operator for batching and mixing, one dispatcher at the bottom of the plant for dispatching concrete, one signalman for routing trains, one electrician and one mechanic for maintenance and general repair, three or four general laborers for cleanup and general help.
(e) Delays.—During operation of the plant, three difficulties were encountered which slowed down concrete production at times. As previously mentioned, the final rescreening of coarse aggregate was performed at the top elevations of the plant, and plant storage was about 3,000 tons, or each aggregate bin had a capacity of 275 tons when full. However, it was not possible to maintain all the bins full all of the time and the operational level for each coarse aggregate was closer to 200 tons. In addition, the 36-inch conveyor delivering material from the stockpiles could not deliver more than three materials at one time. It was not possible to load 3- and 6-inch rock on the 36-inch conveyor belt at one time because all feeder gates were manually operated and required different settings for these fractions. Consequently, as these materials were alternated from one gate to the other, the storage bins had a tendency to become layered with the results that the aggregate grading in each bin was not uniform.

The rescreening plant had sufficient capacity if it had been possible to feed all the different materials uniformly at one time. This condition would have been improved by utilizing a wider conveyor belt between the reclaim tunnel and the chilling chamber and installing a belt feed in the reclaim tunnel for the 3- and 6-inch aggregate. When rescreening the two sizes of heavy-media-processed aggregate, only these two sizes of aggregate could be screened. Consequently, with sustained operation above 400 cubic yards of concrete per hour, the storage of aggregate was gradually depleted and separation increased within the bins. If a repair delay of more than 1 hour occurred, the supply of some size of aggregate was exhausted, usually the 3-inch size.

Another difficulty in the plant involved obtaining a suitable timing sequence for charging the various materials to each of the six mixers. A timing sequence that would be good for one or two mixers would not be satisfactory for the other mixers. This difficulty was related to the 35-foot distance of travel of materials between the weighing hoppers and the mixers, and the different angles of approach the swivel chute would have in relation to each weighing hopper and each mixer. This difference in travel time of materials for charging the mixer was improved by installation of two more timing devices. Best results were obtained, after considerable experimentation, by having three mixers on one sequence, two mixers on another, and one mixer on separate sequence.

An unusual problem was presented as the result of the lead time needed to allow a pause in production because of delays at the placing site. These delays frequently resulted when the cableway was used for yarding, leaving up to 136 cubic yards of concrete in storage between the placement and the mixers. This yardage was distributed as follows: 24 cubic yards in the mixers, 64 cubic yards in the three “gob” hoppers, and 48 cubic yards in the transfer cars. This naturally created a tendency for slump loss, especially during warmer weather, which further slowed down placing operations. This situation would have been somewhat improved by closer coordination of the placing and batching operations in providing lead times and deceleration of placements.

170. REFRIGERATION PLANT. A refrigeration plant was erected on the west side of the canyon on a bench above the mixing plant. The plant was assembled by the Lewis Refrigeration Co. of Seattle, Wash., and was nearly complete at the time of the strike, July 6, 1959. A cooling tower was erected on a bench above and just upstream from the refrigeration plant.

The primary purpose of the plant was to control concrete temperatures in three phases: precooling of components and mix, cooling during hydration, and postcooling the mass for contraction joint grouting. The refrigeration required totaled more than 4,000 tons with a power installation of 6,275 horsepower. Cost of the plant was approximately $2 million, with equipment alone valued at $1.25 million.

Construction specifications required that mass concrete be placed at a temperature between 40° F. and 50° F. Further cooling was accomplished through pipe coils embedded at the base of each 7.5-foot lift. A total of 4,873,408 cubic yards of concrete required cooling.

The contractor’s system incorporated the following process stages:

(1) Cooling of coarse aggregate by chilled water.

(2) Air cooling of coarse aggregate in mixing plant bins.

(3) Chilling mixing water.

(4) Direct addition of ice to mix.
(5) Cooling placed concrete with water or brine through embedded pipes.

As used in sustained production, the first four items, involving reduction of the mix to below 50° F., required about 40 percent of the plant output. Twenty percent was used in initial cooling of the coarse aggregate prior to delivery to the batching plant.

Several features in the installation were of special interest. For example, refrigeration coils were installed beside each aggregate bin at the batching plant to chill the air that cooled the rock. At another location, one central bank of coils was installed with air ducts to the different bins. Temperature of the aggregates in the bins was controlled by thermostats to prevent freezing.

In addition, the refrigeration coils were cleaned of frost and dirt accumulations by automatic water flushing systems operating on a timeclock.

Another interesting feature was the automatic operation of the ice batching system. Most ice systems have been semiautomatic, requiring a man in the ice storage bin to keep the ice friable and moving into screw conveyors. In this plant, however, the flake ice fell from the ice-making machine onto a fast-moving rubber belt which carried it some 50 feet to an 8-inch-diameter chute where it dropped 125 feet. It fell into a small storage bin immediately adjacent to the batching plant weigh hopper floor. This bin contained about a 30-minute supply of ice. To insure an adequate supply of ice at all times, 22 ice-making machines were installed. An automatic signal from the batching plant ice bin activated more or fewer of these ice-making machines as necessary to keep up with mixing operations.

The plant included a battery of 18 ammonia compressors most of which were arranged for multiple-purpose use. Four 125-horsepower compressors were used solely to provide refrigeration for the 22 ice-making machines which produced 20 tons of flake ice per hour. The other units were connected with appropriate controls so that they could be used effectively for varied load demands. These other units consisted of eight 600-, two 100-, one 450-, two 150- and one 25-horsepower compressors. The compressors were serviced by eight 48-inch condensers. Excess heat, peaking at more than 1,000,000 British thermal units per minute, was wasted to the air by a cooling tower installation. The tower recirculated water at 15,000 gallons per minute to the condensers.

There were 10 shell and tube chillers. Two of these, 32 inches in diameter, were used to chill the mixing water. Three, 52 inches in diameter, chilled water for cooling the coarse aggregate on the conveyor belts. The other five, 38 inches in diameter, cooled water for circulating through the cooling pipes embedded in the dam. These units were initially located at the base of the dam for cooling of the first 2 million cubic yards of concrete, but were moved to the right canyon rim for cooling of the remaining 2.9 million cubic yards.

The refrigeration plant was designed to meet a concrete placing rate of 480 cubic yards per hour. With a normal temperature of aggregates at 87.5° F., cement at 150° F., pozzolan at 120° F., and water at 80° F., the temperature of the resulting mix would be about 95° F. This is 45° F. higher for placing than the allowable 50° F.

To bring the concrete mix temperature to 50° F., the following four steps were used:

(1) Spray the aggregates. This step involved spraying the coarse aggregate (3/16 to 6 inches) on the conveyor belt as it moved from the stockpile area to the batching plant. This required 830 tons of refrigeration and involved the use of 2,200 gallons of water per minute at 35° F. The water was recovered for recirculation. Accumulated particles were settled out of the water before recirculation. The aggregate was passed over dewatering screens before proceeding to the batching plant. This process cooled the rock to 50° F. and would reduce the mix temperature to 72° F.

(2) Air cool the aggregate. The aggregate was stored at the batching plant in eight bins with a total capacity of 3,000 tons. Four of these bins were equipped for air cooling. These were the 3- to 6-inch, the 1-1/2- to 3-inch, and the two bins holding 3/4- to 1-1/2-inch aggregates. One of these latter bins held aggregate from which lightweight rock had been removed by the heavy-media process. No attempt was made to air cool aggregates smaller than the three-fourths inch.

Air cooling of the larger aggregates required 270 tons of refrigeration and reduced the rock temperature to 30° F. This action would further reduce the mix temperature to 64° F. As mentioned, each of the bins had its own individual air-cooling coils which were automatically defrosted and cleaned. Air circulation was on a closed circuit basis with air moved by blowers.

(3) Chill the mix water. In this step, the mix water was chilled from 80° to 35° F. This required
180 tons of refrigeration; the chilled water, together with the aggregate cooling, would reduce the temperature of the resulting mix to 59°F.

The chilled water, including the water in the surge tank at the batching plant, was continuously circulated. The chilled water was also used by the ice plant.

(4) Add flake ice to the mix. Flaked ice was fed direct to the surge tank at the batching plant without intermediate storage. This tank had capacity for 30 batches. Automatic operation started and stopped ice machines as necessary to keep the surge tank filled. The ice was constantly agitated in the tank to provide ready delivery to the weigh hopper. The 22 ice machines could provide about 20 tons of ice per hour which required 400 tons of refrigeration effort. By adding 300 pounds of ice per 4-cubic-yard batch, the mix was finally cooled to about 47°F. This is about 3°F below the specifications requirement, but this margin was needed to insure that the final placing temperature at the forms was 50°F. or less.

Cooling of placed concrete was accomplished in two stages and required 1,600 tons of refrigeration effort. The first phase was for removing the heat of hydration and used water at 38°F to 47°F circulating through 1-inch aluminum tubing embedded at the base of each 7.5-foot lift. Specifications required that water be cooler than the concrete being placed. Circulation of this water was required for 12 days. The purpose of the first phase of the cooling was primarily to control potential cracking in the concrete. Secondary cooling was used to reduce the temperature of all concrete in the dam below elevation 3450 to 40°F. The required temperatures from 3450 to the crest elevation of 3715 varied from 40°F to 50°F. Time for secondary cooling was about 52 days for the 7.5-foot lifts used. To get the dam concrete to 40°F, chilled water at 38°F was used initially and was switched to brine at 35°F to 28°F in the final stages. Secondary cooling was used to open up the contraction joints which permitted effective grouting to make a monolithic structure of the dam. Instruments embedded in the dam provided temperature controls during construction and will provide structural behavior data under reservoir loading conditions.

171. CONCRETE CONTROL OPERATIONS. To perform the assigned duties of the branch, a complement of 40 engineers, technicians, and inspectors of various grades and experience were employed under the direction of the branch chief. A supervisory engineer was assigned to correlate and direct inspection and testing on the site for the three shifts of concrete production.

The contractor's operations at the Wahweap aggregate washing and screening plant were inspected on all shifts of operation. On day shift, two inspectors were scheduled and one each on the other shifts. Special tests, as well as routine tests were performed on the day shift, such as aggregate production tests. Although the specification requirements limited the acceptance of materials at the batching plant as batched, it was found more practical to perform routine tests, such as sand gradation, quantity of light-weight materials in heavy-media processed aggregate, and soluble sulphate content in the fine aggregate as produced at the production site. These same tests were performed, but not as frequently, on all the material as it was batched to assure that these materials had not been contaminated or mishandled during transit to the batching bins. This procedure proved satisfactory, and when materials did not meet specifications during production, it was more practical and economical to reject material at the source of production rather than waste large quantities in the various stockpiles. Gradation tests on coarse aggregate were not performed at the aggregate screening and washing plant because coarse aggregate was later screened at the concrete batching plant.

Owing to the nature of the concrete production facilities and the intended use, adequate quality control was necessary for each step in the manufacture of the component materials, the production of the concrete mixture, and the placement. Adequate inspection and production testing were therefore provided to insure acceptable concrete in accordance with the specifications. Being a key feature in the whole operation, a substantial part of the concrete control effort was expended at the batching and mixing plant.

The inspection force for each shift of operation consisted of an engineer and shift chief, who was assisted by four inspectors. On the day shift tour of duty, a supervisory engineer was assigned to the plant to coordinate the work and test procedures on all shifts, calibrate and maintain all testing equipment used at the plant, make mix adjustments for gradation, supervise the adjustments necessary for mixer charging sequences to obtain mixing efficiency, and supervise the checking of all batch weighing scales.

Duties of the plant inspectors for an average shift consisted of selecting and setting up the proper
concrete mixes for all authorized concrete placements, performing tests and insuring conformance with the specifications. This involved observing and recording the scale weighing cycle for accuracy; observing the mixing action of each mixer visually and also checking the recorded record of concrete consistency for each batch; obtaining test batches of concrete on each major mix used on the shift; obtaining a breakdown from the test batches to show aggregate moisture and gradation of aggregate, slump, temperatures, entrained air content, unit weight; and casting at least four 6- by 12-inch test cylinders for later testing of compressive strength. During the shift, other routine tests were made to verify slump, temperatures, entrained air content, and unit weight. Two mixer efficiency tests were made on each shift per week, which constituted an efficiency test on each mixer for approximately every 6,500 cubic yards of concrete mixed.

The tests performed at the central laboratory required the use of more precise equipment and temperature and humidity controls. Among these tests were the physical properties, acceptance tests on pozzolan, the storage and testing of all test cylinders for compressive strengths (see fig. 259 for typical test results), the soluble sulphate tests on sands, and all other special tests.

The government furnished all cement and pozzolan to the contractor at his unloading facilities. This required that all cement and pozzolan be acceptance tested and weighed before delivery to the contractor. No unusual difficulties were experienced with the delivery of cement. During the winter months, heavy snowfalls near Flagstaff, Ariz., caused hazardous road conditions and shipments were delayed on several occasions, but the project supply was never depleted.

Although even greater problems in supply were experienced with pozzolan, the project supply of this material was also never completely depleted.

The Government scale house was located on the west side of the canyon between the highway and the storage silos and operated with one technician on each shift. Aside from weighing cement and pozzolan, the technician obtained samples and performed site acceptance tests on both products. Acceptance tests on cement included one for temperature, which was not to be above 180°F in the cement as delivered; and a false set test, which was not to exceed 17 millimeters between the initial and final readings. All other acceptance tests on cement were performed by the National Bureau of Standards at the cement plant. The project tests were performed on about every tenth truckload of cement (or 1,400 barrels) delivered under normal conditions. No difficulty was experienced with
temperature. During the summer of 1962, some difficulty was experienced with false set in cement. For a short time thereafter, all truckloads of cement were tested before unloading and several truckloads were rejected. The cause of the condition was apparently corrected promptly, as no further difficulties were experienced with false set.

A temperature acceptance test on pozzolan was performed at the scale house. The upper allowable temperature limit for pozzolan was 170°F and a 15-pound sample of pozzolan was obtained from each 150 tons, or every sixth truckload delivered. At least two truckloads were sampled each day for determining the moisture content of pozzolan. Truckloads were not accepted before the Blaine test had been completed, which generally consumed approximately 45 minutes of time. When the test failed on a truckload, tests were taken on each subsequent truckload until 10 consecutive truckloads met the specifications. On different occasions, several consecutive truckloads of pozzolan were rejected.

The delivery of pozzolan of acceptable quality and in sufficient quantities at the peak of construction caused some concern. At one time it was necessary to ship in several carloads of fly ash from the Chicago area, and on two other occasions pozzolan was trucked 250 miles from Panaca, Nev., in order to keep the prime contractor in supply. Although the project supply was never depleted, it was down to less than a 1-day supply on several occasions, and part of the pozzolan in the concrete was replaced by cement.

The concrete control office compiled all concrete data from the field and prepared its part of the daily and weekly progress reports and the monthly L-29 report. The daily, weekly, and monthly compilations of these data were valuable in analyzing the progress of the work, and aided the branch chief in making any necessary changes in mix design, test procedures, or the requirement for additional tests. Data were also used for the purpose of ordering cement and pozzolan for project needs in a regular and orderly manner on a weekly and monthly basis.

172. CEMENTING MATERIALS. The Government-furnished type II, low-alkali cement for the construction of Glen Canyon Dam and Powerplant was supplied under invitation No. DS-5023. This contract was awarded to the American Cement Corp. of Los Angeles, Calif., on April 3, 1958, on their low bid of $9,741,900 for the estimated quantity of 3 million barrels of cement. The Phoenix Cement Co., a subsidiary of the American Cement Corp., proceeded to construct a mill at Clarkdale, Ariz., which was completed and in operation late in 1959. The Clarkdale area was chosen because there were large limestone deposits in the immediate area, other necessary materials for making cement were readily available, and there were no other mills in northern Arizona.

Two types of limestone, Redwall limestone and Lakebed limestone, are found near Clarkdale, each being created in a different geologic age. The Redwall limestone is a high-quality white limestone laid down in Pennsylvania times about 100 million years ago. This limestone is found in a fractured state due to the movement of the earth since it was deposited and the pieces are coated with Supai sandstone, making them red in color, which was also deposited in the same era. The Lakebed limestone, also a high-quality white limestone, was laid down by a fresh water lake 750,000 years ago or in the Pleistocene age. The argillaceous materials needed for cement came from slag from the old Clemenceau smelters, located only 4 miles away from the mill, and from other nearby quarries. Gypsum was obtained from the Verde Gypsum Co., mined near Camp Verde about 20 miles from the Clarkdale mill.

Utilizing the dry-process manufacturing method, the Clarkdale plant was reportedly capable of producing 5,500 barrels of cement daily. It was estimated that the maximum monthly quantity of cement required at Glen Canyon would not exceed 120,000 barrels. The contractor was able to meet all cement requirements during the life of the contract. Inspection of the manufacturing process and plant testing of the cement was made at the plant by a resident inspector from the National Bureau of Standards. Maximum temperature and false set tests were performed by the Bureau's concrete control section at the construction site.

Phoenix Cement Co. issued a subcontract to Belyea Trucking Co. of Los Angeles for transporting the cement from the mill to Glen Canyon, a one-way distance of 188 miles. Twenty truck-tractors pulling two hopper-type trailers, specially designed to haul the maximum load allowed under Arizona State laws, were used to make the haul. Each tractor-trailer combination had an overall length of 59 feet and 11-1/2 inches and was capable of hauling 142 barrels or 27-3/4 tons of bulk cement.

Had the Clarkdale mill not been constructed, all of the cement, would have had to have been hauled from southern Arizona or southern California which would have substantially increased the cost of the cement to the Government. A total of 3,046,441 barrels of cement were purchased for use by the prime contractor.
and 40,043 barrels for use by the completion contractor at a net cost to the Government of $10,649,706.

173. POZZOLAN. J. G. Shotwell of Mercer Island, Wash., was awarded the contract under invitation No. DS-5023 to supply pozzolan for use in the construction of Glen Canyon Dam and Powerplant.

The pozzolan plant is located about 30 miles north of Flagstaff, Ariz., and was constructed in 1959. Raw material was taken from an area known as the Bonner deposit which was located on both sides of U.S. Highway No. 89 and became the plant site. This natural ash deposit is located just north of the San Francisco Peaks in an area of relatively recent volcanic activity. When this deposit became nearly depleted in August 1962, another nearby source, referred to as the Sugar Loaf deposit and located about 12 miles from the plant, was investigated. Test samples from this deposit met the specifications requirements and the first pozzolan delivery was made during September 1962. The Bonner Deposit was finally exhausted in October 1962.

The initial excavation in the pit was done by a scraper which resulted in excessive contamination of the material from the overburden. As this condition caused lower compressive strength in the concrete using the pozzolan, it was necessary for the contractor to modify his stripping operations. This was accomplished by using a dragline for pit excavation, rather than the scraper.

A ring mill and a hammer mill were originally used for crushing the minus 3/8-inch material. This plant was not capable of producing material of sufficient fineness in the necessary quantity to satisfy the requirements of Glen Canyon. Major renovation of the plant took place throughout 1960. Four large ball mills and a hammer mill were erected followed by another large ball mill and hammer mill added in 1961. A 600-ton storage tank was constructed to store the pozzolan at the plant site. This amount of storage proved to be inadequate, and there were times when the temperature of the pozzolan was too high as it was delivered at the construction site.

The first delivery of pozzolan was made to the dam site on April 6, 1961. Deliveries of pozzolan during 1961 and 1962 were generally below the quantity required. Additional pozzolan was shipped to the project from a plant in Panaca, Nev., and approximately 662 tons of fly ash was shipped from Chicago. At times the insufficient rate of delivery reduced the amount of pozzolan in the design mix from 94 pounds per cubic yard of concrete to 80 pounds, and at times as low as 70 to 75 pounds per cubic yard. Although pozzolan production and delivery was low, the concrete placing operations were never suspended due to the lack of pozzolan.

A total of 204,367 tons of pozzolan was used by the prime contractor and completion contractor at a net cost to the Government of $2,510,235.

174. CABLEWAYS. Two 50-ton-capacity mobile cableways (fig. 260) were erected for use in placing concrete in the dam and one of these was in operation early in February 1959. The cableways were equipped with traveling head and tail towers, and the load-carrying cables were 4-inch lock coils, the largest ever spun. The high towers of the higher cableway enable it to cross over the lower cableway so that each cableway can be operated independently of the other. A 35-ton load test was satisfactorily made on the higher cableway on February 11, 1959. The lower No. 2 cableway was placed in operation early in March 1960. The 4-inch cables required replacement every 9 or 10 months; the armor coating on the cable would develop separations in individual strands and ravel to such an extent that replacement was necessary. The 4-inch cable for cableway No. 2 was replaced in March and August of 1961 and May of 1962. The cable on cableway No. 1 was replaced in June 1961, March 1962, and January 1963. A 25-ton-capacity mobile cableway was erected and placed in operation late in 1960.

The cableway system was designed for the contractor by Lidgerwood Industries, and was the largest ever used in dam construction.

Two of the cableways had a rated capacity of 50 tons with a combined capacity of 100 tons when teamed together by means of an equalizer beam. The size and capacity of the 50-ton cableways were determined by the necessity of handling a 12-cubic-yard bottom-dump concrete bucket that weighed approximately 30 tons when filled with concrete. Two cableways, capable of carrying 12-cubic-yard buckets were needed to handle the volume of concrete to be placed in each 24-hour period. This volume was set by the contractor's concrete placement schedule. The 12-cubic-yard bucket was selected over the usual 8-cubic-yard bucket because of the relatively long time required for one cableway to make a complete cycle from the concrete transfer car trestle to the placement area in the dam. At the start of concrete placements in the dam, the
Figure 280. Elevations of cableways.
bucket cycle time was about 4 minutes, but this decreased steadily to under 2 minutes as the dam rose to the elevation of the trestle. These two cableways were designed and constructed with a normal capacity of 31 tons each and up to 50 tons each under reduced speed and greater main cable sag.

The higher of the two 50-ton cableways had a span of 2,050 feet between the head tower and tail tower. The head tower was 180 feet high, the tail tower 130 feet high, with a lateral movement of 910 feet for each tower. The lower 50-ton cableway had a span of 1,800 feet between towers. The head tower was 125 feet high and the tail tower 85 feet high, with a lateral movement of 810 feet for both towers. The difference between head and tail tower heights is due to the difference in elevation of the tower rails, the rails on the west side being higher. The towers traveled on tracks of 175-pound rail.

To place tracks for the tail towers where the cableways would be the most advantageous, the contractor had to excavate a large portion of an existing rock landmark. This rock of solid sandstone, called the Beehive because of its shape, stands approximately 250 feet above the canyon rim on the west side. The excavation from the east face of the Beehive amounted to approximately 135,000 cubic yards.

The third cableway was added to take care of yarding and concrete placement in the powerplant so that the other two could be used for concrete placement in the dam without interruption. The track of the third cableway was later lengthened upstream, and it was also used on the dam. This cableway, with a track cable of 3-inch diameter and a rated capacity of 25 tons, was used primarily for handling materials and for carrying an 8-cubic-yard bottom-dump concrete bucket. This cableway moved on one of the track rails of the lower 50-ton cableway and one other rail. The use of the third cableway was discontinued in February of 1963 when it was disassembled and shipped to another project.

Except for local plate stiffening for concentrated loads, all members of the tower structures were fabricated from wide-flange beams. Plate stiffening was used at the head of each tower to accommodate the pull of the main cable. Welds and rivets were used in the shop for subassemblies, with high-tensile bolts used for field assembly. All structural steel for the towers for the two 50-ton cableways was furnished by Judson Pacific-Murphy Corp., Emeryville, Calif. (fig. 261).

Each tower was mounted on 4 identical 8-wheeled trucks, 1 under each tower leg, or 32 wheels in all. Each of the trucks was electrically driven by a 40-horsepower, alternating-current wound roto-gear motor with direct gearing to the axles. The trucks were furnished by Consolidated Western Steel.

Maximum travel speed of the towers was 120 feet per minute. To equalize the overturning moment of the towers, reinforced concrete counterweights, weighing up to 900 tons for the tail tower of the lower cableway, were placed just above the eight-wheeled trucks across the vertical legs of each tower.

The main cable or track cable for each 50-ton cableway weighed approximately 38 pounds per foot and was manufactured by American Steel and Wire Co., Division of U.S. Steel Corp. The tail towers were equipped with take-up winches for adjusting the sag of the track cable for either a 31-or 50-ton hook load. A 50-ton-capacity carriage assembly, mounted on two 10-wheel units, rode the track cable of each cableway and was pulled by a 1-1/2-inch haul line. The haul hoist consisted of two sheaves in tandem, one an idler. These sheaves handled the 1-1/2-inch wire rope which served as an endless conveyornline. The haul hoist system was driven by a single-horsepower direct-current drive motor. The carriage velocity was 1,200 feet per minute with a 31-ton hook load, and 600 feet per minute with a hook load of 50 tons.

The fallblock had two sheaves with four parts of a 1-1/8-inch hoist line running to an equalizer beam attached to the carriage assembly. This 1-1/8-inch wire rope was dead-ended at the tail tower and reeled on a single drum, grooved for 1-1/8-inch wire rope, in the head tower. The hoist drum was 106 inches in diameter with a face width of 96 inches. It could wind 2,180 feet of 1-1/8 inch wire rope on the first layer. The drum was operated by two 500-horsepower, direct-current drive motors. The vertical velocity of the fallblock with a hook load of 31 tons was 600 feet per minute, and 300 feet per minute with a hook load of 50 tons. Independent motors and gearing allowed combinations of horizontal, vertical, and lateral movements of the fallblock.

The three direct-current drive motors that operated the haul line sheaves and hoist drum of each 50-ton cableway had identical ratings. This made standardization of spare parts possible. The motors were 500-horsepower, 900-r.p.m., 480-volt units. Power for the direct-current drive motors was derived
from three generators mounted on a common motor-generator with a 1,250-horsepower alternating-current drive motor.

Housing for the mechanical and electrical equipment was located on the lower platform of each head tower, directly in front of the counterweight. The electrical equipment was furnished by General Electric Co. and the mechanical equipment by Lidgewood Industries. Figure 262 is an interior view of the hoist room in the head tower of the mobile cableway.

The 1-1/2-inch haul line and the 1-1/8-inch hoist line were suspended from the track cable by six differential carriers. These carriers, three on each side of the carriage assembly, were used as moving hangers to prevent sagging of the lines. Use of the differential carriers limited the maximum unsupported length of the haul and hoist line to about one quarter of the cableway span. A platform on each side of the track cable was cantilevered from each tower to make possible maintenance on the carriage, fallblock, differential carriers, and take-up winches.

A monorail system was used to carry power and control wiring to the equipment in the head towers with a minimum of cable maintenance. Special flexible electrical cables were mounted on steel hangers and were sagged on the monorail parallel to each set of head tower tracks. Electrical power for the main hoist equipment was supplied through this monorail system at 4,160 volts. The power for propulsion motors was reduced to 440 volts.

Undesirable stress was introduced into the main track cable if the cableway towers were not kept
DAM, POWERPLANT, AND APPURTEINANT STRUCTURES

directly opposite each other when in operation. Therefore, a unique application of closed circuit television was devised to keep the towers of the two 50-ton cableways directly opposite each other. In a housing on each tail tower, a television camera was mounted with a 20-inch telephoto lens aimed at a target on the head tower across the canyon. After some experimentation, the best target was found to be a 16-foot-long fluorescent tube which could be seen in any kind of weather. If the towers began to drift out of direct opposition, the divergence showed up on a receiver in the operator’s control booth and could be corrected immediately. This receiver had a vertical reference line on the screen, and the operator had only to keep the image of the fluorescent tube matched to the reference line. The television system was originally installed to supplement a somewhat unreliable automatic electrical system. It worked so well that it was later considered to be a primary control. This closed circuit television system utilized transistorized cameras. The towers were kept directly opposite each other by the operator’s use of a simple sighting device.

Operation of each cableway was handled by one man. The operators for the two 50-ton cableways were located in a double-deck control booth cantilevered from the west canyon wall, level with the concrete transfer trestle tracks and within sight of the landing platform where concrete was transferred to the cableways. This location allowed the operator an unlimited view of the entire work area. On each operator’s control panel were a series of levers, buttons, and switches that permitted handling of materials and the concrete buckets with ease. Since the distance from the operator’s booth to the concrete placement in the forms was so great, a “bellboy” or spotter was used at the point of placement. The operator used a double system of two-way radio to confer with the spotter.

The operator’s booth for the 25-ton cableway was located in the head tower on the east rim of the canyon. When this cableway was used for concrete placing, a spotter was needed on the concrete transfer trestle platform as well as at the point of placement. The spotter at the point of placement kept in touch with the cableway operator by carrying two lightweight radio transmitters and one transistorized receiver on a special belt. Total weight was only 6-1/2 pounds and the use of the radio gave him complete freedom and mobility and eliminated trailing wires.

In one hand, the spotter carried a microphone for talking directly to the cableway operator, and in the other hand he carried a signaling device, job-made from two hacksaw blades, by which he could cause 1,000-cycle “beeps” to sound in the operator’s booth.

When the concrete bucket was near the forms, both communication systems were used at the same time to speed up the exchange of information. The spotter also wore a small earphone through which he not only heard the operator’s voice but his own voice and the beep signals sounding in the operator’s booth. He, therefore, knew at all times whether both of his communication systems were working. Either system alone was sufficient to conduct this operation while the other system was being repaired. A red light would come on in the operator’s room if anything went wrong with the base station transmitter. Difficulties with the system were negligible, due partly to the thorough servicing program carried out. All sets were
taken to the shop for servicing at the end of each shift. This required two complete sets of equipment, but practically eliminated breakdowns. The radio communication system and the closed circuit television were designed and installed by Carl Hutton, owner of Kaibab Radio, Page, Ariz.

Preventive maintenance servicing of the cableways and inspection of the cables were made each week. A second set of controls was located in each head tower to permit routine maintenance operations. Inspection of the cableways was very important, not only from a safety standpoint but also to keep a close check on the condition of the track cable. The total concrete yardage handled by each cableway is the only means of evaluating the life of the track cable. In the first year and a half of placing concrete, the track cable for each of the 50-ton cableways had to be replaced twice. The life of the first track cable was approximately 400,000 cubic yards of concrete but the other 4-inch track cable handled only 300,000 cubic yards. The primary source of trouble was the armor facing of the cable which broke at numerous locations and eventually became entangled with the wheels of the carriage assembly. When this happened, the carriage assembly had to be freed by cutting the armor facing loose with a cutting torch and a new track cable installed.

175. MASS CONCRETE IN THE DAM. The first mass concrete was placed in block 10-B of the dam from elevation 3005 to elevation 3015 on June 17, 1960, when Fred A. Seaton, then Secretary of the Interior, pulled the lanyard to dump the first 12-cubic-yard bucket. The ceremony was attended by the Assistant Commissioner and Chief Engineer of the Bureau of Reclamation and some members of his staff, the Regional Director, Governors of Arizona, Colorado, and Utah and many other dignitaries. Several thousand interested spectators watched the ceremony from the Glen Canyon Bridge and the vista points. Figure 263 shows early dam concrete placement.

Following the ceremony, concrete placing operations continued and block 8-B was placed from rock to elevation 3052.5. The lowest point of the dam was at the downstream left side of block 11-B at elevation 3004.7. Concrete placing was slow for several months while the batching plant was undergoing considerable adjustments and placing crews were being trained for the work. On the weekend of August 20, 1960, the plant was shut down for installation of replacement equipment. Work in the bottom was also slow as the placing crews were new at their jobs and were not too well organized. With continued adjustments, production gradually increased and for the week ending December 23, 1960, total concrete placed amounted to 34,300 cubic yards. The highest weekly production was 49,581 cubic yards for the week ending November 17, 1961. In 1960, a total of 356,588 cubic yards of concrete was placed in the dam. In 1961, 1,800,759 cubic yards were placed; 2,050,658 cubic yards were placed in 1962; and 686,378 cubic yards in 1963. Six-thousand five-hundred and thirty-two cubic yards were placed in 1964 for a total of 4,900,915 cubic yards. Mass concrete alone in the dam amounted to 4,873,700 cubic yards. Figure 264 shows concrete placing operations using ladle cars and 12-cubic-yard bucket in 1960.

The dam was built in blocks formed by a system of transverse and longitudinal joints. The maximum size of a block was approximately 60 feet wide by 210 feet long. Initial placement was made with wood forms; but when the blocks were high enough for a full placement of 7-1/2 feet on each side, and with enough space at the bottom to attach the forms, steel forms were used.

Cleanup of bedrock was by water jets. Debris consisting of mud, small rock, trash, etc., was loaded into skips and removed. Cleanup of the construction joints before placing the next lift in any block was made by water jets and sandblasting. No. 4 to No. 8 beneficiated sand fraction was used for sandblast sand. Grout was placed by the concrete bucket and broomed over the surface before placing the first block on the foundation and on the construction joint before placing the next lift.

In accordance with paragraph 117 of the specifications, the contractor had the option of placing the dam blocks in 5- or 7-1/2-foot lifts and he elected to use 7-1/2-foot lifts. Concrete was placed in layers not to exceed 20 inches and was consolidated by immersion-type pneumatic vibrators. The contractor decided to place the downstream blocks before the upstream blocks. The maximum differential between adjacent blocks was 30 feet and the highest block in the dam could not be more than 52.5 feet above the lowest block. This was later extended at the contractor's request for construction reasons to 37.5 feet and 60 feet, respectively. These differentials were waived and no height differentials existed after odd-numbered low blocks 7 through 17 reached elevation 3375.0 where the first longitudinal joints were terminated. No concrete could be placed directly above the termination of a longitudinal joint until all concrete in the upstream and downstream blocks separated by such longitudinal joint had been cooled to 50°F. Twelve-inch half-round pipe was placed at the
termination of longitudinal joints in all blocks. The rate of placement in any one block was limited to not more than one lift in 72 hours.

At the end of 1960, A and B blocks had been placed from block 6 through block 18 with blocks 5-B, 19-B, and 20-B also placed. Blocks 8-B and 16-B were the highest blocks at elevation 3135, and blocks 9-A, 11-A, and 13-A were lowest at elevation 3090.0. During December 1960, temperatures fell below the freezing point most nights and remained below $40^\circ$ F. on many days but did not hamper concrete placements significantly. Two snowstorms brought enough moisture to make dewatering operations necessary on placements.

After two consecutive days with mean temperatures below $40^\circ$ F., concrete was maintained at a temperature of about $50^\circ$ F. for the required 72 hours by means of fire barrels placed above and around the newly placed concrete. Scrap lumber was generally used as fuel, but at the end of December a few oil burning salamanders were used. Late in December, the contractor inaugurated a program of spraying the steel forms with an asphaltic base material containing a high percentage of ground cork. Total concrete placed in the dam in 1960 amounted to 356,588 cubic yards. Figure 265 shows the downstream face of the dam as of May 19, 1961.

At the end of 1961, A and B blocks had been placed from blocks 3 through 22, with block 23-B also placed. Block 16-B was the highest block at elevation 3352.5 and block 3-A was lowest at elevation 3292.5. A total of 1,800,759 cubic yards of concrete was placed during this year.
Concrete placing was shut down on December 11, 1961, because of subfreezing temperatures and was not resumed until December 18. Minimum temperatures in the canyon bottom on December 12, 13, and 14 were 12°, 11°, and 12°F, respectively. From December 18 through 31, temperatures ranged from 18°F to 28°F F. and protective measures were necessary.

Two 60-horsepower boilers were used at the batching plant and the mixing water was heated to temperatures ranging from 70° to 95° F., depending on the temperature of the aggregate. The blocks were warmed with fire pots and other type heaters to receive the concrete, and each placement was covered with one-half inch mats of closed-cell butyl plastic. The mats maintained the surface temperature of the blocks within the required range. The steel forms were coated with insulating material as was done the previous winter. One percent of calcium chloride, by weight of cement, was used in the concrete mix from December 11, 1961, through February 7, 1962.

Early in June 1961, a change in the top echelon of the contractor's forces was made. The new project manager had off slightly more than 500 employees and scheduled concrete placing for only the swing and graveyard shifts, 5 days per week, except that placements not completed on graveyard shift were completed on the day shift. The main work on the day shift then consisted of freighting reinforcing steel and other materials and equipment with the highlines, for setting and general maintenance. Heretofore, forms had been raised and lowered by jacking, which required quite a number of laborers and was rather slow. Several mobile cranes were acquired for use in raising and placing forms, and after the crews had been trained, some time was saved and the operation was less expensive.

Decreased concrete placing because of the changed schedule was reflected in July 1961, when only 135,800 cubic yards were placed in the dam. However, concrete placing was gradually accelerated, and in October concrete placed in the dam amounted to 177,774 cubic yards. For the first 6 months of that year, concrete placement in the dam amounted to 880,774 cubic yards, and for the last 6 months the total was 919,989 cubic yards. The one-millionth cubic yard of concrete was placed in the dam on May 8, 1961, and the two-millionth cubic yard was placed on November 17 of that year.

At the end of 1962, concrete had been placed in all 26 blocks. Blocks 2 and 4 were the highest at elevation 3622.5 and block 26 was lowest at elevation 3487.5. Only four B blocks remained in blocks 22 through 25, as the other B blocks had been topped out at various elevations beginning with odd blocks 7 through 17 at elevation 3375.0. In December of 1962 removal of the downstream portion of the concrete transfer trestle began so that concrete could be placed in blocks 24, 25, and 26, and in March 1963 the section of the trestle was removed from blocks 22 and 23.

The use of insulating protective mats on the exposed surface of newly placed block lifts was started December 26, 1962, because of the cold weather. These were the same mats used during the 1961-1962 winter concrete placing season and were used through most of February 1963 except for a short period of warm weather. During cold weather concrete placing, 1 percent of calcium chloride by weight of cement was used in the concrete mix.

Concrete placing early in 1963 proceeded at about the same rate, or only slightly less than previously,
Figure 265.—View looking east along downstream face of dam, showing penstock pipes protruding from face of dam. Penstock support is at right foreground. P557-420-6001, May 19, 1961.

until a number of blocks got close to their ultimate height. Block 2 was topped out at elevation 3715.0 on March 30, 1963. Blocks 4 and 6 followed on April 10 and 19, respectively. Beginning with block 20 on May 8, other blocks were topped out at about 7-day intervals. The last two lifts from elevation 3705.0 to elevation 3710.0 and from elevation 3710.0 to elevation 3715.0 were 5-foot lifts. Block 25, the last block to be completed, was topped out at elevation 3715.0 on September 13, 1963. Placement of mass concrete in the dam took slightly more than 3 years, with the first placement being made on June 17, 1960, and the last placement on September 13, 1963.

Figure 266 shows the upstream face of the dam as of July 25, 1963.

2. Structural Behavior Installations

176. REFERENCE. Chapter IV presents a discussion on the structural behavior testing apparatus that is used in the dam. These are briefly described below.

177. EMBEDDED INSTRUMENTS. The embedded instruments include resistance thermometers for measuring the temperature of the concrete in the dam, strain meters for measuring the conditions of strain in the concrete, stress meters for measuring the stress in the concrete, joint meters for measuring the opening of the contraction joints, and deformation meters for measuring the deformation of the foundation and abutment rock. These instruments
were installed in the dam as shown on the drawings. All of the meters were furnished by the Government and installed by the prime contractor. These instruments are of the elastic-wire type with the exception of the resistance-wire type thermometers. Embedded in the mass concrete of the dam, the instruments are connected by electrical cables to terminal boards located in the galleries of the dam where systematic readings are made with portable wheatstone bridges.

The several systems of 1,658 embedded instruments include 1,142 strain meters, 60 stress meters, 74 resistance thermometers, 264 joint meters, and 112 deformation meters.

All instruments are embedded in the mass concrete of the dam and are connected to convenient terminal boards by three or four conductor electrical cables. The cables are rubber jacketed, rubber insulated, No. 16 A.W.G., stranded, and of matched resistance. The terminal boards and outlet boxes are located in the galleries of the dam where readings are made using specially built, portable, wheatstone-bridge test sets. A total of 74 terminal boards were used; eleven 10-terminal boards, four 12-terminal, seventeen 20-terminal, twenty-two 25-terminal, and twenty 30-terminal boards. In addition, 116 outlet boxes were used for terminating meter cables in the dam. Two types of test sets are used, a wheatstone-bridge test set and a strain meter test set, which is a specially built wheatstone bridge. Padded carrying cases are used to protect the test sets.

Strain meters are installed in clusters of 12 instruments each at several points on radial lines that define section of arches and cantilevers in the dam, forming the major system of instruments. The radial lines of strain meter clusters are located near the base
of the maximum dam section and in three arches, uniformly spaced between the base of the dam and about two-thirds of the elevation of the dam. In each arch, the lines of instrument clusters are in the maximum section, near each abutment and at applicable intermediate locations between the abutments and the maximum section. The lowest arch contains three lines of instruments, the second contains five lines of instruments, and the third arch contains seven lines of instruments. Two arches between the two-thirds elevation of the dam and the top of the dam are instrumented using series of stress meters installed on seven radial lines in each arch. These instruments determine stress only in the direction of arch thrust. Pairs of strain meters are installed under free-surface metal canister-like covers, one pair of meters with each elevation of instruments, to detect possible autogenous growth or shrinkage of the mass concrete. At three widely separated locations near the top of the dam, trios of three-dimensionally arranged strain meters are installed near the upstream and downstream faces of the dam to detect surface stress in the structure.

In conjunction with the installation of strain meters and stress meters throughout the dam, joint meters were placed on the radial contraction joints at the same elevations as the meter clusters. Where the dam's longitudinal joint crosses blocks containing strain meters or stress meters, joint meters were installed on the longitudinal joint near its intersection with the radial joints. Additional joint meters were installed on the longitudinal joint at intermediate elevations between arches containing the strain meters and stress meters. Patterns of joint meters were installed on each of the two radial joints nearest each dam abutment and in the upper 200 feet of the dam elevation. The joint meters were embedded so that they were bisected by the transverse or longitudinal contraction joints and were properly anchored.

An installation of three mutually perpendicular meters—two strain meters and one joint meter—is located in the control cable tunnel where a stress relief joint in the abutment rock, termed the A joint, crosses the tunnel to detect movement of the joint. Electrical cables from the meters extend to three outlet boxes located in the powerplant.

Deformation meters were installed to detect initial foundation deformation as the load is applied to the sandstone foundation, and the elastic deformation of the foundation after the initial deformation has stopped. The deformation meters were installed so that they were bisected by the plane of contact between the foundation or abutment rock and the concrete of the dam and were anchored in the rock and the concrete of the dam. These long-range joint meters have anchorages that are made approximately 20 feet beyond the foundation surface, and are installed vertically on several radial lines at the base portion of the dam and in horizontal and sloping patterns at several elevations on each abutment.

Resistance thermometers were installed in the maximum dam section in a vertical grid pattern, having an approximate 40-by-50-foot spacing for determining temperature in the section. The temperature readings from the thermometers were augmented by temperature readings from the strain meters and stress meters in the same section. Special-purpose installations of a series of thermometers were made near one penstock at two elevations, and near the downstream face of the dam at three widely separated locations to determine localized temperatures.

178. INSTALLATION OF EMBEDDED METERS. The meters were furnished and assembled in groups by the Bureau and were installed under the prime contract by an electrical subcontractor. The cables, ground wires, outlet boxes, terminal boards, and covers were also furnished by the Government. Drawings of the meter installation layout and cable routing were furnished to the contractor for each individual block installation.

Initially, the contractor tried a blockout procedure for meter group installation. However, this was rejected early for economic reasons and the meter groups were most efficiently installed in excavations in the fresh concrete. As the clusters were assembled on a metal template, or spider, installation was quickly made by leveling and plumbing a horizontal and vertical meter of the cluster. Cable trenches were excavated in the fresh concrete to provide for a minimum coverage of 6 inches. The cables were laid in the trenches and the trenches backfilled by hand. The locations of the buried cables and meters were marked with an iron oxide dust, which was worked into the concrete surface, to minimize damage to the installation by drilling of holes for form installations and other purposes. Meter outlet boxes were installed at the terminal points directly upon the forms, and the terminal boards and covers were installed later when the terminals were soldered. When terminal boards were below the meter installation, conduit was usually installed for routing the cable from the meters to the boards.
As individual unit pay items were provided for these installations, no unusual difficulties were experienced in minor changes in the quantity of items. Some difficulties occasionally occurred when inexperienced workmen were assigned to the meter installation work. The most efficient and best installations were made when a single experienced crew was responsible for the meter installation.

179. DEFLECTION MEASUREMENTS. In addition to the embedded instrument installations, two systems of measurements employing refined methods of surveying were provided for determining the manner in which the dam deflects during periods of reservoir filling and operation.

One system comprises five plumblines, each in a formed well (fig. 267) extending from the top of the dam to a point near the foundation. The wells are located in the maximum section and at points approximately one-third and two-thirds the distances between the maximum section and the abutments. The plumblines are located in blocks 4, 7, 12, 18 and 21 of the dam, and have a total of 19 reading stations. At each reading station, movement between the dam and plumbline is measured using a micrometer slide and microscope apparatus. The micrometer can be read in ten-thousandths of an inch. The reading stations are oriented in plan so that measurements of deformation are in planes which are radial and tangential to the dam's axis. By this expedient, the measurements require no trigonometric resolution to obtain deformation in the desired directions. Readings are made periodically and are tabulated on forms in a manner that computer card punching can be made directly from the data sheet without further transposition or trigonometric resolution. The second system for determining deflection of the dam consists of a grid system of 68 targets placed on the downstream face of the dam and 17 targets on the foundation along the abutments. Locations of the targets are charted periodically from primary theodolite stations on each abutment downstream of the dam and from secondary stations on the canyon rim, using precise triangulation surveying methods. This system is discussed in further detail under section 186 on surveys.

180. UPLIFT PRESSURE PIPES. Hydrostatic uplift at the base of the dam is measured at 41 locations by pipes connecting to wells at the concrete-rock contact plane and terminating in the dam galleries. Located in blocks 2, 4, 5, 7, 11, 16, 19 and 25, the pipes are arranged in seven lines, each line being made up of from five to seven pipes. Permanent data showing the elevation at which the pipes are installed are recorded on data sheets and readings are made at appropriate intervals. Pressure is measured by means of a Bourdon-type pressure gage calibrated in feet of water, attached through a gage cock to the uplift pipe. When zero pressure is indicated in a pipe, the water level is determined by sounding. Continued zero pressure with water standing at the level of the pipe is investigated further by adding a transparent standpipe section to the pipe to observe the level to which the water rises.

181. DRAINAGE MEASURING DEVICES. Weirs have been installed to elevation 3480 in the gallery gutters to measure total drainage flows from the following areas.

(1) Each foundation tunnel, including the access tunnel to the left diversion tunnel.

(2) Each area between the above tunnels.

(3) Each area in the foundation gallery from the lowest of the above tunnels to the pump sump.

(4) Each area in the drainage gallery from right and left of the transverse adit in block 11 to the top of the drainage curtain.

182. SEISMOGRAPH STATION. A seismograph station, located approximately 11 miles northwest of the damsite, records earthquake shocks. Records from the station show the magnitude of any earthquake.
tremors in the vicinity and also serve to determine any possible change in local seismic activity that may occur in the area due to the increased weight of the reservoir. The equipment from the Bureau's Hungry Horse project was initially installed, but was replaced by new equipment in September 1964 when replacement parts for the obsolete equipment could no longer be obtained. Installation was made by members of the U.S. Coast and Geodetic Survey who also trained Bureau personnel in operation of the station.

The seismograph vault was constructed under specifications No. DC-5163 by W. W. Clyde and Co. of Springville, Utah, in the summer of 1959. The vault is 10 by 22 feet with reinforced concrete floor, walls, roof, retaining walls, and instrument piers. The walls and roof were 9 inches thick, the floor was 4 inches thick and the retaining wing walls ranged from 9 to 6 inches in thickness. The roof sloped 2 feet in 22 feet toward the open end of the vault. Backfill was placed around three sides and over the roof. A complete electrical system was installed by the contractor and electric power was supplied by Arizona Public Service Co. over a line which they constructed.

Approximately 2 miles of 12-foot-wide unsurfaced road was constructed under specifications No. DC-5163 to provide access from U.S. Highway No. 89 to the vault.

3. Concrete Cooling and Grouting

183. CONCRETE COOLING. Initial cooling of the mass concrete in the dam was provided to remove the heat of hydration. This was accomplished by circulating chilled water for a period of 12 days through 1-inch aluminum tubing, placed on top of each 7.5-foot lift (fig. 63). Secondary cooling to shrink the blocks prior to grouting continued for about 40 days or until a temperature of $40^\circ$ F. was reached in concrete below elevation 3450 and $50^\circ$ F. in concrete for elevation 3450 to the top of the dam.

Cooling water first came from a package refrigeration unit located just downstream of block 11, with a similar unit being used to cool the mass concrete in the machine shop and service bays. This package unit was used to cool concrete in the dam until August 3, 1960, and then a chiller, supplied with liquid ammonia from the main refrigeration plant, was used.

Between January and April 1961, six chillers were installed to supply additional cooling water. Three chillers were installed upstream of unit bay 1 of the powerplant and were connected to 8-inch headers installed on brackets above the elevation 3120 catwalk across the downstream face of the dam. The fourth chiller supplied cooling water for concrete in the machine shop, the service bay, and the dam above elevation 3060. Two chillers were placed on the elevation 3180 catwalk for initial cooling above elevation 3180 while the other cooling system was used for secondary cooling of the elevation 3120 grout lift.

In January 1962, three chillers were moved to the downstream end of the refrigeration plant on the elevation 3715 bench. Gravity flow of cooling water through the cooling coils was used for both initial and secondary cooling. Pressure was reduced by valves located on the elevation 3240 catwalk on the downstream face of block 21. Two pumps, rated at 1,800 gallons per minute at 392 feet of head, were installed on the elevation 3240 catwalk to pump the water back to the chillers.

Pressure-reducing valves and return pumps were also installed on the elevation 3300 catwalk on the face of block 22 for initial cooling. These pumping stations were raised to higher stations as necessary. The cooling water was delivered through 8-inch horizontal headers installed across the face of the dam. Vertical 4-inch headers led from the 8-inch header to blocks being cooled, and 1-1/2-inch headers led from there to the 1-inch aluminum cooling pipe. As the blocks became small, near the top of the dam, the flow of cooling water had to be reduced below 4 gallons per minute to keep the lifts from cooling faster than 1-1/2$^\circ$ F. per day. Cooling water normally flowed at the rate of 4 gallons per minute, except during some cold periods when the rate of flow was increased to prevent freezing.

184. UNUSUAL STRESSES DURING CONSTRUCTION. Numerous horizontal and vertical cracks appeared in the dam blocks beginning in 1960. These cracks appeared especially during final cooling and grouting. They were plugged with lead wool before grouting of a grout lift and sealed by the contraction joint grouting. A number of cracks showed up in block 8-B. Two mats of reinforcing steel were placed in the elevation 3112.5 lift to stop a crack which extended from the 8-B–9-B block line at elevation 3067.5 and from the 7-B–8-B block line at elevation 3075 extending to the top and across the surface of the elevation 3097.5 lift and to the top of the elevation 3105 lift. The crack was not noted higher than elevation 3105.

It was thought that changing the intensity or pattern of the temperature stresses within each block by reducing the temperature gradient might be a solution to avoid this cracking. The cooling procedure
was, therefore, changed. After grouting the elevation 3180 lift, the next area cooled was the 3240 to 3300 grout lift instead of the 3180 to 3240 grout lift. Since some of the concrete in the higher lift was relatively new when secondary cooling was started, the cooling was performed in the cooling coils at elevations 3277.5, 3285.0, 3292.5, and 3300.0 only until the temperature at thermocouple elevation 3288.75 was 60°F. At the same time cooling was performed in the cooling coils at elevations 3247.5, 3255.0, 3262.5, and 3270.0 until the temperature at thermocouple elevation 3258.75 was 55°F. Upon completion of the above-described partial secondary cooling for the 3240 to 3300 grout lift, the 3180 to 3240 lift was cooled to 40°F. This procedure took place in succeeding pairs of lifts. The top half of the upper lift was cooled to 60°F, while the lower half of this lift was being cooled to 55°F. The lower lift was then connected for the second time, cooled to 40°F, and grouted. This sequence was followed up to elevation 3420 where practicable. Some modification was necessary due to topping out of the longitudinal joints of the odd-numbered blocks 7 through 17 at elevation 3375. This change permitted the cooling of all concrete below the top of the longitudinal joints to the required 50°F temperature after the 3180 to 3240 grout lift was cooled to its final temperature of 40°F. In a similar manner, the cooling in blocks 5, 6, 19, and 21 deviated from the two-step sequence of cooling operations. The cooling in these blocks at 50°F was accomplished after the 3240 to 3300 grout lift had been cooled to 40°F.

In January 1962, a mat of reinforcing steel was placed in block 21-B in the 3300 to 3307.5 placement lift to prevent further extension of a longitudinal crack.

During 1962, the plan for final cooling in the dam was changed from that given in paragraph 140 of the specifications to the following:

Up to elevation 3300 . . . . . . . . . . . . . . 40°F.
Elevation 3300 to elevation 3360 . . . . 45°F.
Elevation 3360 to elevation 3600 . . . . 50°F.
Elevation 3600 to top of dam . . . . . . . 55°F.

The Board of Consultants\(^1\) in their report of October 12, 1961, stated: "The cracks described which were not available for inspection by the Board, are undesirable but are not believed to endanger the safety of the structure. Their elimination at the expense of appreciably increasing abutment stresses above the present specified limit is not justified."

On August 1, 1962, permission was received from the Denver office to extend the initial cooling periods for those lifts at or below elevation 3420, provided that the drop in temperature did not exceed 10°F per day. Further, the cooling of the upper and lower halves of the 3360 to 3420 grout lift to 60°F and 55°F, respectively, was done simultaneously. Final cooling of the 3360 to 3420 grout lift to 50°F coincided with the cooling of concrete to 50°F in the high blocks having joints which terminated at elevation 3480.

On February 12, 1962, the Denver office requested that a special thermocouple installation be made in block 4-A, at the elevation 3397.5 lift. The thermocouples were located halfway between the elevation 3390 gate chamber gallery and the block 4-A-4-B longitudinal contraction joint, and midway between the transverse joints. The purpose of this installation was to provide additional temperature data on the temperature differentials within a lift in order to correlate temperature stress studies with 7-1/2-foot placement lifts.

The first thermocouple was placed on top of the lift at elevation 3390 and was taped to a cooling pipe. Thermocouple No. 2 was embedded vertically above thermocouple No. 1 at a distance of 6 inches, and the next seven thermocouples were embedded vertically above No. 2 at 1-foot intervals. Thermocouple No. 9 was placed at the top of the lift at elevation 3397.5. Thermocouples No. 10 through 15, inclusive, were placed at elevation 3390, adjacent to thermocouple No. 1. These five thermocouples were placed in a line normal to the cooling pipe at 6-inch intervals. The distance from the last of these, No. 14, to the next cooling pipe was measured and recorded.

Readings on all thermocouples were taken at the time of embedment. For the first 5 days of the initial cooling period, three readings were taken per 24-hour period at about 7- or 8-hour intervals. For the remainder of the initial cooling period, one reading per day was taken. No further readings were taken until final cooling was started in this area. At that time, readings were taken on a twice-a-day schedule for the first 5 days then twice a week until final cooling was completed. No readings were required thereafter.

---

Other thermocouples were installed in the dam at 30-foot vertical intervals. During initial cooling, readings were taken twice daily for the first 5 days and once daily for the next 7 days. During the interval, until secondary cooling began, readings were taken twice a month. When secondary cooling was started in a grout lift, the thermocouple readings were taken once a week for 2 or 3 weeks and when the temperature in the grout lift approached 40°F, they were taken two or three times a week. About 800 thermocouples were installed in the dam during the placing of mass concrete.

Although considerable cracking occurred in the dam blocks throughout 1962, fewer cracks were noted than in previous years. The cracks ranged from 1/16 inch to 1/32 inch in width. Water emitted from most of the cracks, and the lifts were water tested and all cracks which made water were calked with lead wool before grouting.

Almost no cracks were noted during 1963. As the dam rose, the blocks became smaller which no doubt reduced the tendency toward cracking. However, in the fall of 1963, a crack was noted near the contact of the concrete and sandstone at the right abutment. The crack started in the rock upstream of the dam, entered the adit at the end of the utility gallery, came out of the adit and continued across the contact of the dam and the rock and continued down the concrete-rock contact to about elevation 3680.

Twenty-one holes were drilled from the top of the dam and the utility adit and gallery, elevation 3697.5, to intersect this crack above elevation 3680. The four downstream holes at elevation 3680 lost water near the contact. This crack was grouted early in June of 1964.

The grout was injected at a maximum pressure of 20 pounds per square inch, and no sand was used in the mix. Type II cement from paper bags was used with a water-cement ratio of 1:1 by volume. A circulating line from air-driven 6- by 3-1/2- by 6-inch and 7- by 3- by 10-inch duplex piston-type pumps was used to deliver the grout to the manifold at the collar of the hole where the injection pressure was controlled by valves. A maximum of five grout units were in operation at one time with the fifth unit containing a helical screw-type pump. Later, another screw-type pump was used to replace one of the duplex piston pumps.

The mixer was a horizontal cylinder tub with mixer blades rotating around a horizontal axis. The agitator sump was a vertical cylinder tub with baffles; and paddles were attached to a vertical shaft. Both were powered by small air motors. The water meter read to tenths of a cubic foot. Telephone communication was provided between the manifold and pump. Drilling equipment consisted of lightweight air-powered, power-vane diamond drills. Bits were EX size (1-5/16-inch) and both core and plug bits were used. Movable jumbos were used in the 41-foot-diameter tunnels for drilling and grouting operations.

Radial grouting was started in December 1958, and the french drain was grouted at the upstream portal. Arch void and radial grouting and drilling of drainage holes continued in the right diversion and spillway tunnels through January 1959, when work was suspended in anticipation of diversion of the river through the right diversion tunnel. Closure was completed and the river was diverted through the right diversion tunnel at 7:30 a.m. on February 11, 1959.

The following work remained to be done in the right spillway and diversion tunnel at that time:

(1) Drilling of 35 radial grout holes between stations 23+95 and 25+79.

(2) Drilling of 21 radial grout holes between stations 32+39 and 39+99.

(3) Drilling of a few holes to check the adequacy of arch void grouting from station 25+39 to station 24+37 due to omitting radial holes in this area.

(4) Drilling of drainage holes from station 27+11 to station 30+11.
Drilling of radial grout holes was started in the left diversion and spillway tunnel in February 1959. Grouting of arch voids and radial grouting continued in the left tunnel until April 7, 1959, when the work was suspended in anticipation of the left diversion tunnel carrying a part of the spring runoff. Pressure in the radial grouting varied from 10 to 100 pounds per square inch, and the water-cement ratio was 5:1 by volume. Arch void grouting was completed by April 1959, but some radial grouting remained to be done.

Grouting of voids under the liners and outlet gates in the left diversion tunnel was started in December 1962, and completed under the three liners and gates in January 1963. Drilling and grouting of the remaining radial grout holes were started in the left diversion and spillway tunnel on December 21, 1962, and completed on January 15, 1963. Contraction joints, periphery and cooling pipe in the left diversion tunnel plug section were grouted, and also the periphery of the contractor's access adit. Two drainage holes were drilled.

Final closure of the right diversion tunnel was made on January 23, 1963. The contractor's 16-foot plug adjacent to the closure gates was grouted in March. Radial grouting was completed in the backfill section of the right diversion tunnel and contraction joints, and periphery and cooling pipe were grouted in the plug section. The 18-inch bypass pipe through the plug section was plugged with concrete in June. All concrete had been placed in the backfill section of the tunnel by mid-July 1963. Arch void and radial grouting and drilling of 3-inch drainage holes were completed in the right spillway early in June 1964.1

Arch void grouting, radial grouting, and drilling of drain holes were started in August 1963, at the upper end of the left spillway tunnel behind station 21+40. The arch void grouting as completed in September and the radial grouting and drilling of 3-inch drainage holes were completed in October 1963.

(b) Stress Relief Joint.—The report of the Board of Consultants,2 dated May 5, 1960, recommended that suitable instrumentation should be provided for determining possible future movement of a wedge-shaped rock mass at the downstream side of the right abutment keyway below elevation 3370. The mass was separated from the canyon wall by a stress relief joint, and this joint was designated as joint A.

The A-joint was readily accessible for instrumentation in the powerhouse control cable tunnel and along the joint exposure at the surface of the right keyway. Carlson strain meters and a joint meter were installed in the control cable tunnel in February 1961. Small vertical and horizontal movements were recorded but they appeared to be the result of temperature changes. The Consulting Board in its report of October 12, 1961, recommended that the measurements be continued.

Additional vents to the A-joint were drilled downstream of the A-line above elevation 3174 where there is no concrete to support or hold the rock on the right canyon wall. An NX hole (2-3/8-inch drill size) at powerplant station 4+14 at elevation 3172, drilled on the right canyon wall, showed a grout seam at a depth of 32.6 feet, which is the A-joint. Three additional holes at stations 4+62, 4+14, and 3+64 at about elevation 3196 indicated the depth to the A-joint ranges from 38 to 36 feet.

Beginning in February 1961, stress relief joints in the right abutment above elevation 3121.5 were grouted in 7.5-foot lifts as the concrete lifts were placed in the blocks, so as to maintain concrete against the rock being grouted. Grouting was accomplished through 1-inch risers with relief vents just above the top of the next lift to be placed. Vents were washed after being used for grout returns and then utilized as supply holes for ensuing lifts. These grout holes passed through the A-joint in most cases. In November 1961, the surface of the A-joint was exposed in the downstream area above elevation 3260 and, therefore, the stress relief holes no longer intercepted the A-joint with the exception of the vent 10 feet downstream of the dam. As the collars of the stress relief holes were on the surface of the A-joint, there was no grout travel downstream along the joint above elevation 3256. The stress relief joints were grouted to elevation 3496.5 when the final vents at this elevation were grouted in February 1963.

(c) Dam Foundation.—Preparations for drilling and grouting B-holes in the dam foundation began on May 12, 1960, when nipples were set between dam axis

---

DAM, POWERPLANT, AND APPURTENANT STRUCTURES

stations 6+00 and 8+40 in the upstream portion of the dam foundation. Grout take in the area below elevation 3078 was relatively small.

Drilling equipment consisted of lightweight, air-powered, power-vane diamond drills. The drilling speed normally used was 50 revolutions per inch of forward movement. Standard EX size plug bits were used.

The grouting equipment included a helical screw-type pump electrically powered. Mechanical packers were largely used with pneumatic packers available for oversize holes. Cement used was type II in paper bags from the plant in Clarkdale, Ariz. Initial B-hole grouting was confined to blocks 6 and 7. Grouting of these holes, which intersected the bedding plane at elevation 3078, succeeded in confining water leakage to the vicinity of the heel with minor leakage about 200 feet downstream from the heel along the bedding plane.

Five holes on 20-foot centers were drilled and grouted downstream of line 8+93 on dam axis station 11+80 to locate the line of flow of water which was leaking on the elevation 3069 bedding plane joint, about 60 feet downstream of line 8+93. The grout in these holes intersected the water from the bedding plane joint as planned. The concentrated flow was then located on the same joint in block 15 some 200 feet downstream of the dam axis. The flow was piped to the drainage gallery in block 14. Progress in B-hole grouting depended on the rate of placement in adjacent low dam blocks. As the dam rose, B-hole grouting was continued in the right and left abutments. The holes averaged 25 feet in depth, the pressure was about 25 to 45 pounds per square inch, and the water-cement ratio 5:1. Drilling and grouting of B-holes in the left abutment was completed in April 1963 and in the right abutment in July 1963.

A-hole grouting from the foundation gallery was initiated in November 1961, in blocks 10, 12, and 14. Very little grout was taken at first. The A-holes made water which accumulated gradually as the hole was drilled deeper, indicating the permeability of the sandstone. Hole 45, drilled to a depth of 126 feet, made water at the rate of 8 gallons per minute and a maximum water pressure of 38 pounds per square inch. Water flowed from other holes in comparable quantities. Holes were drilled in 40-foot stages because deeper stages frequently caused oversized holes in which packers could not be seated. Grouted stages of incomplete holes were washed from 6 to 8 hours after grouting to prevent the necessity of redrilling. Holes were grouted in 20-foot stages from 0- to 100-foot depths, in 25- or 30-foot stages between 100 and 150 feet, and in 40-foot stages below 150 feet. Maximum pressures of stages were determined from the formula:

\[ \text{Pressure (p.s.i.)} = 250 + 2d \]

where

\[ d = \text{depth of the packer in rock}. \]

A water-cement ratio of 10:1 was used after trying thinner ratios up to 20:1 for deeper stages with no apparent increase in take.

Because of water flowing from drilled A-holes, the area between holes 29 and 45 was made a test area to check the feasibility of decreasing the flow of water in the upper stages of holes prior to drilling the lower stages. All holes were drilled and grouted in 40-foot stages before proceeding deeper in any one hole. The holes were drilled and grouted to the same depth according to the method-of-closure sequence, i.e., on 80-, 40-, 20-, and 10-foot centers, respectively. Flow quantities from each hole were measured after drilling and after washing the stages. It appeared when following out this procedure that none of the water was being sealed off by grouting and that the entire depth of the hole, in rock, was making water.

The grout curtain between holes 29 and 45 was completed in April 1962. Drainage holes near grout hole 30 were drilled in February 1962, and a measuring device installed with which the pressure and flow could be measured. The flow at first measured from 5 to 8 gallons per minute but dropped to 5 gallons or less within a few weeks. The A-hole grouting program was completed in July 1963.

(d) Chemical Grouting Experiment.—At this time the Denver office was formulating a test program of the feasibility and effectiveness of chemical grouting of foundations. Before starting actual insertion of chemical grout, as much information as possible was desired in connection with source of foundation flow, effectiveness of cement grouting, rate of flow, and similar data. Accordingly, the following procedures were suggested and followed:

Step 1. Complete A-hole drilling and grouting of the test area between holes 29 and 45, in the stages reported above.

Step 2. After completion of above, drill the drain holes in both the foundation and the drainage galleries through the embedded pipes closest to the radial lines through...
A-holes 30, 37, and 44, to full depth, i.e., 85 feet plus or minus into rock, and record flows daily.

Step 3. About 2 weeks after completion of step 2, drill the drain holes in both the foundation and the drainage galleries downstream of A-holes 36 and 38 to full depth and record flows daily.

There was also some early concern regarding erosion behavior of the foundation drainage holes. Water flowing from the initially drilled A-holes deposited sand on the gallery floor and gutter when left uncapped for a period of several hours. Therefore, in addition to the water flow data for drainage holes as outlined in steps 2 and 3 above, the volume of sand that was washed or eroded from each of the drainage holes was recorded. All of the above records were reported in the weekly progress report. The sand deposit proved to be negligible. Step 2 was completed in March 1962, and step 3 started immediately.

The advisability of using a chemical grout to seal the Navajo sandstone had been considered previously, but inadequate data were available for proper evaluation. Further testing was therefore necessary to determine if chemical grouting would be effective and which chemicals would give the best results. The Bureau did not have the necessary grout injection equipment nor available personnel to supervise performance of the work. The Navajo sandstone is composed of fine to medium sized quartz grains with minor amounts of feldspar, which are only poorly to moderately well cemented. Much of it is cemented only at the points of contact between the grains, leaving a fairly high percentage of open and connected voids through which water will pass slowly but through which cement grout will not pass.

Contract No. 14-06-D-4470 was negotiated with Halliburton Oil Well Cementing Co. of Duncan, Okla., who was considered the sole source of supply for the work to be performed. Under this contract the contractor furnished one grouting unit and all necessary related equipment, six chemical grouting materials, and the service of two engineers or technicians who were thoroughly familiar with the equipment and materials furnished by the contractor, and who were competent to advise the Bureau as to chemical grouting procedures.

The test site selected was the floor of the left spillway approach channel. Agreements were made with the prime contractor for preparing the site, drilling, furnishing operating personnel, water, electricity and air. Items not payable under specifications No. DC-4825 to Merritt-Chapman and Scott were included under an order for changes.

The test area was divided into five contiguous subareas, each 15 feet in diameter. The central hole in each subarea was preserved for injecting grout after saturating each area with several thousand gallons of water through the six holes spaced around the perimeter of the test area. The holes were 1-1/2 inches in diameter and 30 feet deep.

The tests included use of four chemical grouts, designated for convenience as follows: type A—a resin-type grout with a viscosity of 6 centipoise; type B—a lignin-type grout with a viscosity of 8 centipoise; type C—sodium silicate plus sodium chloride of very low viscosity; and type D—a combination of chemicals that polymerize to produce a stiff gel, viscosity 3 centipoise at 78°F.

Injected quantities of grout were negligible. The sandstone refused to accept the chemical grout in quantity. A new test area was therefore prepared and a different source of water was obtained, as it was felt that dissolved solids in the mixing and saturation water were reacting chemically with grout materials. The new water supply was obtained from Merritt-Chapman and Scott’s domestic water supply which contained 70 to 80 percent less dissolved solids than the water used in the first series of tests. Water used in the first series was from the same source as that used for concrete.

Grouting operations in the new test area were more successful than those in the original area, the penetration into the sandstone of the three chemical grouts, types A, C, and D, being greatly increased. Acceptance by the sandstone of these grouts in decreasing order was type D (5 percent concentration), type A, and type C (10 percent and 11 percent solutions with or without addition of 2 or 2-1/2 percent, respectively, of sodium chloride). Injection of type B grout was not successful due to its immediate reaction with the chemicals of the sandstone which apparently plugged the voids.

As a result of these tests, further consideration of chemical grouting of Navajo sandstone at Glen Canyon was terminated because of the small quantities accepted and short travel of the four chemical grouts tried. The field tests were carried out between October 2 and October 30, 1962.
(e) Rock Bolting.—In its report of October 12, 1961,1 the Board of Consultants, in view of stress relief joints that had developed, or might develop, in the abutment rock downstream of the dam, particularly in the right abutment, and the increase of rock stresses that would result from the arch thrust, recommended that extensive rock anchorage and drainage be provided to insure stability of these arch masses. The most critical areas appeared to be those below elevation 3450 in the right abutment and somewhat below elevation 3350 in the left abutment where the intrados of the arch at the abutment lies close to the surface and where relief jointing is most noticeable. The Board was of the opinion that the anchorage in the right abutment should extend at least 25 feet back of the A-joint.

Holes ranging from 40 to 80 feet in depth were drilled between elevations 3420 and 3150 and from station 5+00 at the A-line of the powerplant, downstream to station 3+00. Most of the holes were from 60 to 70 feet in depth and all extended more than 25 feet back of the A-joint.

The holes were cleaned thoroughly with air and water. The bottom 15 feet of each hole was sandblasted to remove grease, etc., to assure bonding with grout, and the top 5 feet of each bar was wrapped with waterproof building paper to prevent bonding. When a bar was lowered into the hole, 1/2-inch plastic tubing was attached to the bottom of the bar through which a measured quantity of 0.8:1 cement grout with 5 parts of aluminum powder to 100,000 parts of cement was injected into the bottom of the hole to assure that the bottom 12 feet of hole was filled with grout. The grout stop was then set at 5 feet from the top of the hole and the top section of the bar grouted in place.

The surface of the bearing plate was roughed out by bush-hammering, then finished with a grinding wheel with diamond inserts built especially for this operation. Each bar was loaded by a hydraulic ram, having a 40-ton capacity, to a tension of 63,000 pounds, after which the nut was tightened against the bearing plate with a torque of 3,500 inch-pounds. The combination of elongation of the bar and possible compression of the sandstone ranged from 5/16 inch to 9/10 inch.

Three-hundred and twenty-five bolts were installed and loaded on the right canyon wall and 189 bolts were installed and loaded on the left canyon wall. The right canyon wall was completed in July 1963, and the left wall in September of that year. The anchor bars were loaded not less than 28 days after the bars were grouted in place. A total of 134 drain holes was drilled on the canyon walls. After the initial start, a rotary drill was used with lightweight drill rods and tricone roller rock-bits.

Under order for changes No. 24, the contractor furnished and installed regular rock bolts and 1-1/2-inch anchor bars in the west canyon rim in the vicinity of the skewback of the Glen Canyon Bridge. This work was done in September and October 1964, after a fallout occurred under the skewback. Ninety feet of regular rock bolts were installed and 1,225 feet of anchor bars were installed and grouted in place. The anchor bars were approximately 20 feet in length.

(f) Grout Adits.—Drilling and grouting from the right and left abutment grout adits was started in June 1962 in the elevation 3157.5 and elevation 3270 adits. Vent or pressure relief holes were drilled in the right abutment downstream of the dam on the powerplant A-line between elevations 3150 and 3250 to act as vents while grouting from the grout adits. Grouting in the left abutment took place in the grout adits at elevations 3315, 3367.5, 3427.5, 3480, 3547.5 and 3630 and was completed in May 1963. Grouting in the right abutment was performed from the grout adits at elevations 3157.5, 3217.5, 3270, 3322.5, 3367.5, 3427.5, 3480, 3547.5 and 3630 and this work was completed in July 1963. Holes ranged from 40 feet in depth to 100 feet. The pressure ranged from 100 to 125 pounds per square inch, with most of the holes being grouted at 125 pounds per square inch.

During the period from May 1961 through April 1964, eighty-eight 10-inch-diameter concrete cores were drilled in the dam. Ten cores were drilled in B-blocks 7, 8, 11, 14, 15 and 17. Sixty-one cores were drilled in the floor and walls of the galleries and adits of the dam at various elevations, and 17 cores were drilled in the face of the dam at various elevations. These cores were drilled in blocks 5, 6, 8, 11, 12, 14 and 26. Two cores were drilled vertically in the service bay at elevation 3188.

(g) Contraction Joints.—First contraction joint grouting was from bedrock to elevation 3060 and was completed in May 1961. The joints grouted included:

(1) Four transverse joints between blocks 9-10, 10-11, 11-12, and 12-13. Each transverse joint was separated by metal seals into two separate areas. A small area, 4 feet 6 inches wide, was located near the upstream face of the dam.

(2) Five longitudinal joints in blocks 9 through 13.

This was the total of the contraction joints below elevation 3060. Temperatures of the joints were mostly lower than the 40° F. requirement and some reached a minimum of 29° F. in the final stages of secondary cooling. Joint meters indicated joint openings of 0.105 to 0.157 inch at elevation 3037.5; and at elevation 3060 openings ranged from 0.022 to 0.089 inch in the same blocks.

Backfill between the dam and the powerplant was placed to elevation 3060 at the downstream face of the dam at the time of the grouting. This required the contraction joint piping systems extruding from the face of the dam below elevation 3060 to be grouted through 1-1/2-inch risers extending to approximate elevation 3067.

Contraction joints in the elevation 3060 to elevation 3120 lift were grouted in October 1961. Thirteen transverse joints were grouted, extending from joint T6/7 to joint T18/19 and 13 longitudinal joints in blocks 6 through 18 were grouted.

Refrigerated brine was used during the latter part of secondary cooling, and all blocks were lowered to 40° F. except block 11 which was at 50° F. While testing the contraction joints and attempting to fill the transverse joints with water, numerous leaks appeared from cracks in the drainage and foundation galleries. The cracks were calked with lead wool by use of pneumatic chipping hammers and then grouted to seal the leaks.

Contraction joints in the 3120 to 3180 lift were grouted in January 1962 as follows: (1) Seventeen transverse joints extending from joint T4/5 through joint T20/21; (2) 15 longitudinal joints extending from block 5 through block 19; and (3) 13 special transverse joints extending from T6/7 through T18/19. Concrete temperatures were lowered to 40° or 45° F. prior to grouting. Leaks again developed and were calked with lead wool and sealed with grout.

Contraction joints in the 3180 to 3240 lift were grouted in May 1962, as follows: (1) Nineteen transverse joints extending from joint T3/4 through joint T21/22; (2) 18 longitudinal joints extending from block 4 through block 21; and (3) 15 special transverse joints extending from joint T5/6 through joint T18/20. Numerous leaks again appeared in cracks and these were calked and grouted.

The 3240 to 3300 grout lift was grouted in July 1962, and included the following contraction joints: (1) Twenty transverse joints extending from joint T3/4 through joint T22/23; (2) 20 longitudinal joints extending from block 3 through block 22; and (3) 70 transverse joints extending from joint T4/5 through T20/21. Some leaks were found in the galleries, adits and shafts, and these were calked and sealed with grout.

The 3300 to 3360 grout lift was grouted in November 1962 and included the following contraction joints. (1) Twenty-one transverse joints extending from joint T3/4 through joint T23/24; (2) 21 longitudinal joints extending from block 3 through block 23; (3) 19 special transverse joints extending from T3/4 through T21/22; and (4) 1 longitudinal perimeter joint in block 3. Fewer leaks occurred in this grout lift than in previous lifts and these were calked and grouted as before. Figure 65 presents some transverse contraction joint information.

The 3360 to 3420 grout lift was grouted in December 1962 and included the following contraction joints: (1) Twenty-one transverse joints extending from joint T3/4 through joint T23/24; (2) 21 longitudinal joints extending from block 3 through block 24; (3) 20 special transverse joints extending from T3/4 through T23/24 exclusive of T21/22, which was grouted in March 1963; and (4) 2 longitudinal perimeter joints, blocks 3 and 24. Only one leak which required calking was found in this lift.

The 3420 to 3480 grout lift was grouted in March 1963 and included the following contraction joints: (1) Twenty-one transverse joints extending from joint T3/4 through joint T23/24; (2) 22 longitudinal joints extending from block 3 through block 24; (3) 20 special transverse joints extending from T3/4 through T23/24 exclusive of T21/22, which was grouted in March 1963; and (4) 2 longitudinal perimeter joints, blocks 3 and 24. Some leaks were again found and were calked and sealed with grout.

On March 11, 1963 a check was made on transverse contraction joints 1/2 and 2/3 from bedrock to elevation 3480 to determine the extent of interconnections and leaks that could be anticipated while water loading these joints with a pressure of 100
pounds per square inch. On March 12, the same check was made on transverse joints 24/25 and 25/26 from bedrock to elevation 3480.

The procedure consisted of installing a 1-1/2-inch water supply line to each transverse joint. A three-way header was used with valves and a gage to determine the water pressure at the header before and during the injection of water into the joints. Gages were also installed on the vent system of the joint being tested in order to keep the pressure below 25 pounds per square inch, initially. Each transverse contraction joint was tested individually.

All of the four transverse contraction joints below elevation 3480 were found to be connected to their respective transverse perimeter and transverse face perimeter.

On March 28, 1963, the T2/3 and T1/2 joints were water loaded, but it was impossible to obtain a pressure of 100 pounds per square inch due to excessive leaks where the joints crossed galleries or adits. On March 29 the joints were grouted, each grout lift from bedrock to elevation 3480 being grouted individually. All transverse joints were interconnected with their respective perimeters, and in each case the face perimeter was grouted with the perimeter. All joints were sealed off under pressure. Beginning April 15, the same procedure was used on the right end joints, but it was not possible to obtain a pressure of 100 pounds per square inch on the joints.

The 24/25 joint between elevations 3420 and 3480 developed a leak where the joint crossed the grout adit at elevation 3427.5. The joints were grouted on April 16, each joint being grouted individually.

Duplex piston-type pumps, size 10 by 3 by 10 inches, were used at each location for grouting of the contraction joints. A circulating grout supply line, 1-1/2 inches in diameter, was laid on the catwalk most convenient to the lift being grouted. Type II cement in waterproof bags was used and the starting water-cement ratio was 1:1. This was reduced to 0.8:1 when the joints became half full.

The 3480 to 3540 grout lift was grouted in November 1963 after the reservoir had reached elevation 3395. The joints grouted were as follows: (1) Twenty-three transverse joints extending from joint 213 through joint 24/25; (2) 2 longitudinal joints L-2 and L-24; (3) 23 special transverse joints extending from T2/3 through T24/25 and one longitudinal perimeter joint L-2. The joints were tested by filling with water, and those which leaked were calked with lead wool before grouting. All joints were grouted under pressure.

Grouting of the 3600 to 3660 grout lift was completed in December 1963 and included the following contraction joints: (1) Twenty-three transverse joints; and (2) 23 special transverse joints extending from the 2/3 joint through the 24/25 joint. Joint meters and dial indicator gages were read at time intervals during grouting to detect movement of blocks. The joints were filled with water prior to grouting and those which leaked were calked with lead wool. All joints were grouted under pressure.

Grouting of the final grout lift between elevations 3660 and 3715 was completed December 20, 1963. This included 23 transverse joints and 23 special transverse joints from the 2/3 joint through the 24/25 joint. Joint meters and dial indicator gages were read at time intervals during the grouting to detect movement of blocks. Prior to grouting, the joints were filled with water and those which leaked were calked with lead wool. All joints except four T and four TT joints were grouted under pressure and these joints would not hold pressure. Joint meters and dial indicator gages were read at time intervals before and during grouting to detect movement of the dam blocks.

Water loading and grouting of end contraction joints 1/2 and 25/26 from elevation 3480 to elevation 3660 and the top two lines of the reinjectable grout system below elevation 3480 was completed January 21, 1964. The 1/2 transverse joint was water loaded but due to extensive leaks only pressures between 21 and 40 pounds per square inch could be held. In the 25/26 joint, pressures between 40 and 60 pounds per square inch were held for 6 hours but it was impossible to obtain 100 pounds per square inch. An attempt was made to inject grout into the 3420 to 3480 grout lift through the reinjectable grout system but grout was refused.
A crack developed at the concrete-sandstone contact above elevation 3667 at the right abutment and this was grouted in June 1964 to complete the grouting program on the dam.

Figure 66 shows some of the longitudinal contraction joint grouting system.

4. Construction Surveys

186. GENERAL. Surveys for construction of Glen Canyon Dam were conveniently divided into two categories—control and construction. Control surveys refer to those directly related to geodetic principles; construction surveys are those loosely grouped under the localized application of plane surveys. Controls were further divided into the usual horizontal and vertical surveys. Vertical controls and all applications at the dam are those with elevations in feet above the mean sea level datum. The triangulation network possesses the more unique quality of horizontal control due to the local terrain and construction requirements. This network is a chain of quadrilaterals having upper and lower net portions with suitable ties and offsite references. Horizontal distances of the network were adjusted to datum plane elevation 3500 as an average elevation of the construction area.

187. CONTROL SURVEYS. Preliminary studies for feasibility of construction of the high dam at the Glen Canyon site were based on fourth order surveys and the U. S. Geological Survey quadrangle topographic map. More detailed topographic maps and some aerial photographs were made as investigations progressed. These were used to record the geological data obtained from diamond drill holes, exploratory tunnels, and surface examination of the site. When the overall suitability of the site became evident, higher order controls were desired for design studies and for later construction use.

Vertical controls from bench marks set along the Colorado River by the U. S. Coast and Geodetic Survey in 1921 were accepted. Through financial contribution by the Bureau of Reclamation, the Coast and Geodetic Survey brought in a second order triangulation network in 1947. This network consisted of six stations within a mile radius of the site. It included a measured baseline of more than 7,000 feet in length as a check, and provided basic data on a central zone of the Arizona State coordinate system. These stations, supplemented by secondary points at the site, were used to complete investigations and preliminary design work for the principal features of the project.

During 1956, the Bureau of Reclamation survey crews checked out the Coast and Geodetic Survey stations by turning angles with a European-made 1-second theodolite to confirm that the stations to be used had not been disturbed over the preceding 9-year period. The Bureau then laid out the local primary control network with stations along each side of the canyon rim and incorporated one station each on the east and west sides of the river. The coordinates of these stations were adjusted to the mean elevations, and the adjusted distances and bearings between them were computed. This adjusted line was used in further computations for projecting the Bureau local net.

The initial observations were started in November 1956. The primary local network included an upper net along the canyon rim and a lower net along the floor of the canyon. There were 6 stations along each canyon rim on an approximate 1,000-foot grid pattern, 5 stations about 500 feet back from the canyon rim on each side, and 12 stations along each wall near the canyon floor. A 1-second theodolite was used for the observations, utilizing 12 positions of the circle. Many of the observations of angles were made at night. However, when weather and atmospheric conditions were favorable, observations were made during the daylight hours. Some difficulty was experienced in getting triangulation to close to second order accuracy because of the steep vertical angle. Under this condition, when the instrument plate was even minutely out of level, inaccuracies in the horizontal angle were substantially magnified. A striding level was affixed to the theodolite in making these observations, and all triangles were closed within 5 seconds of 180°.

After the positions of the network station had been observed, adjusted, and coordinates computed, an azimuth check was made to the Coast and Geodetic Survey stations. Excellent results were obtained as the average azimuth check from the top to the bottom was within approximately 1.5 seconds of the computed bearings. The completed network consisted of 28 second-order quadrangles, 12 third-order quadrangles and central point figures. A triangulation network was later established on top of Manson Mesa in conjunction with the layout of Page townsite. This consisted of five additional quadrangles and one central point figure. The triangles were closed to third-order accuracy.

The existing vertical control of the damsite is based upon a line of levels run up the Colorado River in 1921 by the U. S. Coast and Geodetic Survey. The local precise net established by the Bureau of Reclamation was begun at one of these bench marks on the canyon floor about 2-1/2 miles upstream from the damsite.
The initial line was run downstream through the canyon to make a tie to the first Coast and Geodetic Survey bench mark below the damsite. Upon tying into this bench mark, a large discrepancy was found due to the bench mark having been disturbed. The levels were then continued downstream another 5 miles to a third bench mark where satisfactory closure was made. The equipment used to run the level net consisted of precise tilting levels, invar rods graduated in yards to the nearest hundredth of a yard, and steel pins 1 inch in diameter by 18 inches long for turning points. The three-wire method was used in reading the rod.

The primary level loop was formed by running levels from an established bench mark on the canyon floor, up the side canyon to the rim, along the canyon rim to the damsite, across the canyon, downstream along the east rim to a joint in the wall, then down the canyon wall to the river, and then back up the river to the point of the beginning. The levels were run to the west canyon rim by a circuitous route utilizing a series of rock shelves and benches in a side canyon. A route was chosen in advance of the level party and the turning points were established with a hand level. Turning points were made from 3/8-inch bolts grouted into the canyon wall with heads protruding about 1 inch. The levels were then run along the top rim to the west abutment of the damsite. The river crossing was made over the 1,200-foot-wide canyons by reciprocal leveling methods developed by the Coast and Geodetic Survey, as described in their special publication No. 239, Manual of Geodetic Leveling. This method employs the use of two tilting levels with graduated micrometer screws on the tilting device.

The total primary loop was 17.4 miles in length and the error of closure to the original bench mark was 0.027 foot, an error of less than 0.002 foot per mile. Nine secondary control loops were also run for a total level loop distance of 36 miles. Standard brass disks were used for bench marks and were conveniently located along the primary loop and at points most useful for construction. A number of these bench marks were also set above the maximum lake elevation and back for some distance from the lake area to preserve the datum and for use in future settlement studies.

188. CONSTRUCTION SURVEYS The primary control network was tailored to the design and construction requirements for the project. Construction layout was based on two principal control features of the dam—the plane of centers and the radius of curvature of the axis of the dam. From these major references, a complex construction layout was achieved for the three-dimensional curves of the arch structure. The plane of centers, a vertical plane down the approximate center of the canyon, provides the directional base of the project. This base line was targeted on the canyon wall both upstream and downstream from the site. A 900-foot radius of curvature of the axis of the dam has its center point on the plane of centers, giving a starting position suitable for use in the basic layout system. The radius point was established by triangulation astride the plane of centers.

Original and final topography of the large keyways posed a problem in surveys due to the 700-foot-high, nearly vertical canyon wall. The original cross sections for the rock excavation were taken about 10 feet apart, both horizontally and vertically. It was necessary to include an area sufficient to cover all excavation for each of the features, a linear distance of about 2,500 feet down the canyon length. Sections in the foundations and keyway excavations of the dam were taken in a more detailed form than in some of the other areas. Using offset base lines parallel to the plane of centers, where practical, a series of normal sections were established on stations 10 feet apart along the very edge of both canyon rims.

The triangulation group was comprised of three teams. The actual transit team was composed of an instrumentman, a recorder, and a high-scaler to serve as rodman. The three transits were placed on the canyon rim opposite the side where the sections were to be taken. The end transits were deployed along the offset baselines at a distance which would give horizontal angles of approximately 45°. The center transit was placed on the offset baseline at the station where section was being taken and used as a constant 90° horizontal angle. The center transit alined the high-scaler on the opposite canyon wall to mark and number vertical stations at intervals of approximately 10 feet, using a small pressurized paint dispenser. The end transitmen read both horizontal and vertical angles at each numbered position as the high-scaler descended the wall. The center transit also read the vertical angle of the numbered position.

---

Approximately 300 of these sections were taken for the original topography of the canyon wall, the majority of these being made down the entire height of the canyon wall. There were approximately 20,000 points surveyed by this method. A total of 32 man-days was required for reduction and listing of the notes of the triangulation of all 20,000 points as compared to an estimated 500 man-days of manual computation. The original notes were punched on electronic computer cards in only 20 man-days, following 2 days of programming in the Denver office. Computer time actually required 6 days and reporting time was 4 days. The original program was maintained on file and was used in the final cross-section tabulation which doubled the benefits of the program.

189. STRUCTURAL BEHAVIOR MEASUREMENTS. Provision was made for obtaining data periodically on the structural behavior of the dam, both during construction and after construction, as the reservoir becomes impounded. Some of these data will be obtained electrically by the use of strain and stress meters embedded at selected locations within the dam, but others on movement or deformation will also be obtained by survey methods.

Five plumpline wells are located along and near the upstream face of the dam, extending from approximately the foundation to the top of the dam. They are provided to detect tilting. An optical plummet was used to project the plumpline from the top to the bottom of these wells. Three foundation deformation wells are located near the toe of the dam. These points are accurately located and coordinated with permanent triangulation points established from the horizontal control net. Differences between initial and successive coordinate position of the points furnish measurements of horizontal movement resulting from foundation deformation.

Another system for determining the dam deformation consists of a grid pattern of 70 targets on the downstream face of the dam and 18 targets on the foundation along the abutments. On the dam, the targets are ranged as five equally spaced elevations between the top and a plane at about one-fourth the elevation of the dam. The targets are aligned in 11 vertical planes. The target locations are charted periodically by observations from a system of eight theodolite piers downstream from the dam and two piers near the base of the dam, using precise triangulation methods. In addition to the exposed targets, three targets in observation wells were installed in the foundation of the dam. These targets are used for determining horizontal foundation deformation.

Selection of the target face patterns suitable for observations at the dam presented a problem due to local conditions. After a number of trial designs and field observations, two types of the acceptable target were used, one having a full rim body for headon observation, and the other having a body with a cutaway rim for offsise observation. The 3-1/4-inch outside-diameter bodies were finished in a baked-on low-gloss black enamel. Two types of sighting points were also chosen. One has a 3/8-inch-diameter cylinder with alternate red and white enamel bands, and the other a 3/8-inch-diameter white ball mounted on the end of a threaded stud. Both sighting points are attached to the target bodies by screw threads. The targets are attached to the dam and foundation rock by the threaded target body that screwed into pipe couplings attached to short lengths of 1-1/2-inch-diameter embedded pipe.

Following accumulation of initial data on the target location, observations made on the targets are anticipated at 50-foot increments of increasing reservoir elevation. After the reservoir elevation reaches about two-thirds the height of the dam, observations are anticipated on a quarterly basis until normal reservoir operations are achieved. After that time, the observations will probably be continued on a quarterly or semiannual basis for at least one or two cycles of reservoir operations. Data will include sets of observations in the summer and winter during periods of maximum and minimum monthly air temperature. The reduction of the observed data will be carried out by automatic data processing methods in the Denver office. Computer programs are available for reducing the target observation data and for adjusting the triangulation data pertaining to the primary and secondary theodolite stations.

In addition, there are invar reading stations in four abutment tunnels for measurement of foundation rock deformation (Subsec. 38(f)). One set is located each in the right and left abutment tunnels of the dam at elevations 3630 and 3480. Each tape set is 225 feet in length, measured from a zero station near the concrete abutment of the dam, with intermediate stations at 100, 75, and 50 feet. Periodic readings are taken, coordinated with water surface elevations, and reported to the Denver office for evaluation.

Further details on surveys at Glen Canyon Dam are included in the reference paper.4

C. OTHER FEATURES IN THE DAM

190. PARAPETS AND TRASHRACKS. Placement of parapets on the dam started shortly after the final placement of mass concrete in each block except for those left out on the upstream side while “monkey slides” were being used for trashrack structure placements. These sections were placed after the trashrack and gate hoist structures were completed. The concrete approach slab, with parapets, was placed on the left abutment adjacent to block 1 in October 1963.

The elevator shafts in blocks 8 and 17 were placed with the dam to elevation 3680.9 and the elevator towers were separate placements from that point to the roofs at elevation 3750.1. Stairs were placed in the elevator shafts.

Placement of the cantilever sections of the trashrack structures was started in May 1962, and placement of the trashracks followed. Each trashrack structure consisted of 19 placements, a marginal beam bracket, and a cover slab. Access to the work was at first by ladders and catwalks; and work was suspended January 15, 1963, because of ice on the catwalks causing hazardous working conditions. Work was resumed in June 1963, in blocks 6 and 12. Monkey slides were installed on the upstream face of the dam in each block which contained a trashrack structure and in blocks 5 and 6 for the outlet pipe trashrack structures. All trashrack structures including marginal beam brackets were completed in November 1963. The cover slabs and marginal beams were precast and placed on the trashracks.

Metal trashracks were placed on the river outlet trashrack structures in June 1963, and this work was completed for the penstock trashrack structures in June 1964.

Placement of the gate hoist structures for the penstock fixed-wheel gates started in November 1963, and was completed in February. The structures were made in 10 placements from elevation 3652.30 to elevation 3724.58. Trashrack guide extensions, stoplog guides, and fixed-wheel gate guides were in the eight blocks containing penstocks. Vista canopies were placed adjacent to the elevator towers in blocks 9 and 16.

191. SURFACE DRAINAGE GUTTER. Constructed early in 1963, a surface drainage gutter runs along the downstream face of the dam just below the compacted backfill which is at elevation 3157.0. The invert of the gutter is 2 feet wide and it runs left and right of a stilling basin in block 12. The invert of the stilling basin is at elevation 3153.00 and the gutter is at elevation 3155.50 at that point. A 30-inch corrugated metal pipe drain brings the water from the pump chamber to the stilling basin, and the left branch of the gutter carries it to block 7 and then along the service bay to a 30-inch corrugated metal pipe in a drop inlet at the A-line of the powerplant. From there, the water flows through the machine shop bay to a “flap valve in the left training wall which discharges into the tailrace. The right branch of the gutter carries water along the face of the dam to block 21 and into a 30-inch corrugated-metal-pipe drain in a drop inlet near the intersection of the 1- and B-lines of the powerplant. The 30-inch drain carries the water through a flap valve in the right training wall to the tailrace. Behind each of the flap valves is a 30-inch gate valve. The flap valves are at elevation 3146.0 and, in case the tailrace becomes too high for surface drainage, the 30-inch gate valves can be closed and the water discharged into the powerplant sump through an 8-inch emergency bypass from a point in the 30-inch corrugated-metal pipe in the machine shop to the powerplant sump. An 8-inch gate valve is located on the emergency bypass line in the powerplant sump.

192. ELEVATORS IN DAM. The elevators were supplied and installed by Pacific Elevator and Equipment Co. of San Francisco, Calif., under specifications No. DS-8443. Installation was started on the elevator in block 8 as soon as the hoistway and machinery room were made available to the contractor on March 23, 1963, and work under the contract was accepted as substantially complete December 26, 1964. Completion date of the contract was extended by 177 days to cover delay to the contractor caused by failure of the Government to make the elevator hoistways and machinery rooms available as specified. Cost of furnishing and installing the two elevators in the dam was $284,919, which included $5,919 for extra work and materials provided by the contractor. Invitation No. DS-8443 also provided for furnishing and installing two elevators in the powerplant, which is discussed separately in section 217.

193. GANTRY CRANE. The 165-ton outdoor gantry crane operates across the top of the dam from the left abutment to near the right abutment. The crane is used for installation and maintenance of penstock gates, hoists, stoplogs, and river outlet bulkhead gates. After difficulties were experienced with the main hoist gearing on the 300-ton powerplant cranes (sec. 227), the supplier of the 165-ton crane was required to check and repair the main hoist gearing in the shop. This reduced the field repair at the
construction site and was the least costly to the suppliers of the equipment. The material was received in Flagstaff during April of 1963; it was found that some minor shipping damage had occurred, but this was repaired at no cost to the Government during the erection of the crane by the prime contractor.

The erection of the 165-ton crane was performed by Merritt-Chapman and Scott Corp. under specifications No. DC-4825; erection was started in March 1963 in the prime contractor's fabrication yard. Installation of the crane rails began in July 1963 in block 1 of the dam; all rail had been laid and blockout concrete placed in October. The crane was erected on block 3 of the dam.

The structural steel was erected by the ironworker crew of Merritt-Chapman and Scott Corp., and the cleanup, adjustments, and installation of mechanical equipment was performed by their crew of millwrights. The erection engineer arrived at the installation site on November 4, 1963. The erection engineer, working with a qualified crew, did not have any problems of note on the mechanical portion of the erection. Counterweights were placed, the crane was painted, and the crane moved to the left abutment for testing. The formal load tests were conducted starting on November 14 and were completed November 18, 1963.

194. SERVICE ROADS AND BRIDGE. Excavation for the right abutment service road to the dam was started in February 1964, and the right abutment service road bridge was completed in April 1964. Excavation for the left abutment service road to the dam was started in April 1964. The service roads and parking areas were completed, including bituminous surfacing, in September 1964. Installation of guard rail followed. Gates were installed by the contractor at the entrances to the spillway intake structures, and Government forces installed a gate near the entrance to each abutment service road.

195. TERRAZZO AND TILE. Areas that would be toured by the general public were designated to receive terrazzo floor finishes, structural wall tile, or ceramic wall tile in the dam. Marus Marble and Tile Co. of Greensboro, N.C., was awarded a contract under specifications No. DC-6057 to place 1-1/2-inch bonded concrete underbed on stairs and landings in the elevator towers of the dam between elevations 3697.77 and 3734.02; to place thin bonded terrazzo finish on the floors in the right abutment adits to the powerplant; including lobbies, and on the stairs, stair landings, lobbies, and restroom floors of the elevator towers in the right abutments adits to the powerplant, including lobbies, and on the stairs, stair landings, lobbies, and restroom floors of the elevator towers in the right abutments adits to the powerplant; to install ceramic wall tile in the restrooms located in the elevator towers between elevations 3697.97 and 3734.02; and to place terrazzo floor and install ceramic tile at various locations in the powerplant. This last item is discussed separately under a section on the powerplant.

Start of work under specifications No. DC-6057 was delayed from April 21, 1964 (the date the contractor received notice to proceed) until September 28, 1964, when the contractor was able to start work. This delay was caused by failure of the Government to provide the floor areas to allow orderly performance of the required terrazzo work. The structural and ceramic wall tile was supported on the terrazzo base coves and could not be installed until after the terrazzo floors were placed. By a finding of fact, an extension of time of 227 days was allowed the contractor for completion of his contract. All work was completed April 23, 1965, under specifications No. DC-6057, with a cost of $53,500 allotted for the dam.

196. LOG BOOM. A 1,228-foot-long log boom, with a 15-foot boat passage near the middle, was constructed across the reservoir approximately 1,500 feet upstream from the dam. This log boom serves the purpose of intercepting floating debris before it reaches the dam and aids in control of boats on the reservoir. The boom consists of 40-foot sections constructed of pairs of logs fastened together side by side. The sections are fastened together with lengths of 1-inch wrought iron log chain, and the boom is anchored to the canyon wall at each end. Five anchor points were constructed in each canyon wall spaced between elevations 3520 and 3703. The anchors consist of a 1-1/4- by 12- by 24-inch iron plate, provided with a ring, mounted against a vertical concrete pad. The plate is secured to the canyon wall with two 1-inch-diameter by 10-foot-long bolts grouted into the rock.

The log boom was constructed at a cost of $34,874 by R. H. Jackson and Associates of Golden, Colo., under specifications No. 400C-291. Work was started June 23, 1965, and all work was completed October 25, 1965. Two orders for changes were processed which increased the amount of anchor chain, increased the thickness of the anchor plates, deleted the crack-free requirement on four logs in the boat passage section, and extended the time for completion of the contract by 28 calendar days.
197. PLAQUES. A contract was awarded to Alton Iron Works of Albertson, N. Y., under invitation No. (D) 45-1113-A, for furnishing and installing two plaques at Glen Canyon Dam, along with plaques at other locations. Both plaques were fabricated from sheet aluminum and were machined and polished at the contractor's Albertson, N. Y., plant and were anodized by Perma Plating Co., Brooklyn, N. Y. Both plaques were 7 feet 6 inches in diameter and were mounted one each on the two elevator towers. The one mounted on the block 17 tower was the Great Seal of the United States and the one mounted on the block 8 tower was the U.S. Department of the Interior seal. The plaques were installed on January 26, 1967, by Young Electric Co. of Salt Lake City, Utah, representing Alton Iron Works. Cost of the two plaques was $7,000.

D. SPILLWAYS

198. GENERAL. The spillways (fig. 101) are designed to discharge, at reservoir elevation 3711, 276,000 cubic feet per second. By passing an additional 15,000 cubic feet per second through the river outlets and 9,000 cubic feet per second through four units of the powerplant, a total flood release of 300,000 cubic feet per second can be obtained. The entrances for the spillways are located about 600 feet upstream from the dam, and each consists of an unlined approach channel and reinforced concrete crest structure with piers. Each crest is set at elevation 3648, and discharge through the tunnel is controlled by two 40- by 52.5-foot structural steel radial gates with counterweights.

The spillway tunnels for the greater part of their length are 41 feet in diameter. The transition section downstream from the intake structure changes from a flat-arch-roof section 89 feet wide by 52 feet high to a circular section 48 feet 3 inches in diameter. From this point there is further transition of the circular section to the 41-foot-diameter tunnel. The tunnels are designed to flow partially full or at never more than 0.7 of the height.

199. EXCAVATION. Drilling equipment was moved to the right spillway intake area in July 1957, and excavation began. Excavation in the left spillway intake was started in October 1957. Excavation in opencut in both spillway intakes was completed in April 1958, and excavation for the spillway tunnels was started from the top.

At the same time, spillway raises were started in the diversion tunnels. The right spillway raise was a 7- by 14-foot pilot hole which was holed through at 585 feet on July 1, 1958. The left spillway raise, an 8- by 9-foot pilot hole, was pushed from the bottom for 550 feet and then holed through from the top. The length of this pilot hole was 567 feet. Excavated material from spillway tunnel excavation was then dropped through the raises into hoppers and discharged directly into trucks. Excavation at the upper portals of the spillway tunnels was completed to the point where both were ready for arch steel in May 1958.

The heading of the right tunnel reached elevation 3476 during the second week of January 1959, when work was suspended because of interference with diversion through the right tunnel. Forty-two sets of arch steel had been placed at the time.

The heading of the left tunnel reached elevation 3220 early in April 1959 and remained at this elevation until after the river closures. Meanwhile, tights were removed and preparations were underway for lining of the left tunnel beginning at elevation 3224 and working up. A large jumbo was erected for use in scaling and removing tights. Track was laid and the jumbo lowered into the tunnel. Reinforcing steel and drainage pipe were being placed for the tunnel lining at the time of the strike on July 6, 1959. Track was also being laid in the right tunnel for the lowering of men and equipment for resumption of drilling at the time of the strike.

Preparation for resumption of excavation of the right spillway tunnel was started in June 1960. A 20- by 20-foot disposal or haul road tunnel was driven from the intake channel to the canyon wall at elevation 3635 so that the excavated material, after being raised from the heading, could be pushed through by a bulldozer and dropped to the bottom.

Two skips running on tracks were used to bring the muck out of the tunnel and were dumped from a ramp into trucks which hauled the excavated material to the tunnel. It was pushed out of the tunnel by a bulldozer and fell down the canyon wall. Excavation was started the latter part of August and was completed in January 1961, except for the lower elbow section.

200. CONCRETE CONSTRUCTION. Following the strike, work was resumed in the left spillway tunnel on January 4, 1960. Reinforcing steel was placed beginning at elevation 3224, and drainage and grout pipe were installed. Reinforcing steel and grout and drainpipe were placed to elevation 3525, station 21+68, and the first concrete lining was placed the
week of April 18, 1960. An attempt was first made to use the gravity flow system, but mechanical difficulties were encountered and this system was abandoned and all lining was placed by pumpcreting. Placements 1a, 2a, and 3a were made and the special concrete finish applied in the elbow sections. The form was replaced by a straight-section form and placements 1b and 2b made to station 22+96.96, elevation 3328.4. On July 16, 1960, a hoist cable failed while the form was being pulled up for placement 3b. The form was dropped about 50 feet and wedged itself into the concrete elbow lining already placed.

Considerable time was lost in freeing the form, raising it to the level of the 3b placement and repairing it. New ribs and pans had to be ordered and delivery was not made until September. Placement 3b was finally made the week of November 6, 1960. At the end of 1960 the lining had progressed to elevation 3391.14, station 22+53.05. Lining was resumed in January 1961, with placement 3c and continued through placement 13c, station 21+05.04, elevation 3594.18, which was made in August. From this point on, the invert was lined first with placement 1d being made in September and continuing through placement 4d in October to station 20+45, elevation 3638.12. A porous concrete pad was placed under the 8-inch drains in the intake area, and 18 B-holes were grouted in the crest area.

The first walls and pier sections were then placed from rock to elevation 3635 for the spillway intake structure. Placement of the intake structure was suspended because of severe cold weather on December 11, 1961, when the right and left walls were at elevation 3672.5 and the pier at elevation 3657.5. Work was resumed in February when the weather moderated, and lining of the tunnel and placement of the intake structure were completed in June 1962 except for the unexcavated cap in the elbow section just above the left diversion tunnel.

Pedestal bases for the radial gates were then grouted in place and the four pedestals placed. Sillplates were grouted in place and the counterweights placed in the wells. Erection of radial gates 1 and 2, installation of wallplates, and installation of hoist equipment on the bridge deck were then started. Completion was in January 1962, and the radial gates were tested satisfactorily and accepted for operation in March.

A cofferdam was constructed in August 1962 downstream of the outlet channel of the left spillway, and the area was dewatered in preparation for construction of the flip bucket. Air and water lines were run from the spillway outlet to the plug section of the left diversion tunnel in preparation for placing the tunnel plug. Excavation of rock and concrete was started in September in the outlet channel of the left spillway, and the first placement for the deflector bucket was made in October. This work was completed in January 1963. Concrete was hauled in a 20-ton truck in which a chute had been installed. The concrete was dumped into a 4-cubic-yard bucket and moved to the forms by a mobile crane.

During installation of anchor bars for the left deflector bucket, it was found that large stress relief joints or voids existed behind the protective wall in the outlet channel between stations 37+10 and 37+30 and between stations 37+65 and 37+96. Grout or vent holes were drilled horizontally in these two areas at an elevation about 1 foot below the bottom of the anchor bar hole. Prior to grouting in the anchor bars, grout was injected into the new holes, drilled below the row of anchor bars, at a pressure of 10 pounds per square inch, until grout returned from the new grout holes drilled below the next higher row of anchor bars. The combination of anchor bar and grout holes served as vents to preclude any possibility of developing excessive pressures. In November the pressure was increased to 20 pounds per square inch, which did a better job of grouting of the anchor bars. The voids were grouted between elevations 3144 and 3187.

Preparation for construction of the right deflector bucket began in the latter part of July 1963, with the drilling of holes for anchor bars in the concrete protective wall. However, this work was suspended until completion of the lining of the elbow section of the right spillway tunnel. Work on the right deflector bucket was resumed in December 1963, and the final placement was made early in February 1964.

Preparations for lining of the right spillway tunnel were started in February 1961, when the access road to the intake channel was reconstructed to permit passage of cars and trucks. Tights were removed from the floor of the intake channel, and the laying of tracks was started. Part of the wall between the intake channel and the canyon was removed and work continued through June when it was suspended. Preparations for lining were resumed in September when surveys were made at the lower end of the tunnel excavation and assembly of the form for placement 1a was started. Work was again suspended during the week of October 15, 1961, when the form for placement 1a was nearly complete, and the contractor decided to delay start of lining of the right tunnel until all concrete had been
placed in the crests and piers of the left spillway intake. The first two lining placements were made in August 1962, from station 24+17.67 to 23+82.04, invert elevation 3196.90 to elevation 3224.33. A special concrete finish was applied to the lining through the elbow section as required by the specifications. A whirley crane was used to handle material and concrete for the lining and the intake structure, and it was placed on the rock ledge above the left side of the intake structure. In order to reach the right wall of the intake structure, it was necessary to extend the tracks. The left wall of the intake was started in October 1962, and was completed in February 1963. The tracks of the whirley crane were extended over the left wall of the intake structure in March 1963, and the right wall of the structure was started in that month. Meanwhile, the lining of the upper spillway tunnel was progressing and this work was completed in October 1963.

The lower elbow section of the right spillway tunnel was excavated in March and April 1963. The first lining placement was made in the invert from station 26+11.72 to station 25+85.50 in September 1963. Two invert sections were lined and then one arch lining placement was made at the lower end of the elbow section. After four invert sections were placed, followed by the four arch lining placements, the remaining four placements were made by placing the entire circumference of the arch at one time. This work was completed in November 1963.

The concrete work for the intake structure of the right spillway was completed in November 1963. The trunnion bases for the radial gates were placed, and assembly of the gates was started on the ledge above the intake.

Hoist equipment was installed on the bridge of the intake structure, counterweights were installed, and the gates erected. Radial gate No. 3 was satisfactorily tested on February 27, 1964, and gate No. 4 was satisfactorily tested on March 10, 1964. Painting of all gates was completed in August 1964.

201. RADIAL GATES. The four 40- by 52.5-foot radial gates were furnished under invitation No. DS-5192 and manufactured by Vereinigte Osterreichische Eisen and Stahlwerke A.G. (VOEST). In the field erection, the workmanship was considered very good. Very minor drifting was required for assembly and no misplaced holes were found. A small omission was noted on the gate arms in that drain holes were not drilled and the holes for guide shoes on top of gates No. 3 and 4 were not drilled. This was a very small percentage of the holes required and the installation contractor made corrections in the field.

Merritt-Chapman and Scott Corp. proposed several changes in the erection procedure shown on figure 268. The prime contractor had well-qualified survey crews and engineering supervision with recent experience on erection of large radial gates. As the erection procedure allowed some latitude in the method of erection, the contractor was allowed to proceed with erection of the first gate, subject to acceptable installation. The contractor's erection methods were sound and all operating checks were satisfactory. The remaining gates were also assembled without unusual difficulties and it was not necessary to use the final adjustment of babbitted joint allowed by design.

The radial gate hoist is a two-drum electric-motor-driven mechanical hoist located on the radial gate operating deck. Two 1-1/2-inch stainless steel wire ropes from each hoist drum are connected to lifting brackets near the bottom of the gate. The four gate hoists installed on the left and right spillways were furnished by Moffett Engineering, Inc., of Berkeley, Calif., for a contract price of $104,000. The four radial gate hoists were installed by the prime contractor in the fall of 1962, and were accepted for operation on March 10, 1964. The hoists were placed on embedded anchor bolts and, by use of double nuts, the drum units and gear cases were aligned and leveled. A transit was used for alignment and a precise machinist level was utilized on line shafting joining the drum units and gear cases. The various components and gearing were checked with the hoists running by using dial indicators. No significant difficulties were encountered and good operation of the hoists was obtained.

E. PENSTOCKS AND OUTLET WORKS

202. PENSTOCKS. Water for power generation is delivered to the turbines through eight penstocks (figs. 129 and 130) having a common intake centerline elevation of 3470 feet, which is 245 feet below the crest and 330 feet above the turbine level. They descend through the dam on a 60° incline, bend at the base on a 60-foot radius, and cross over to the powerplant on concrete piers (fig. 269). Centerline length ranges from 406 feet in an outer unit to 449 feet in a center unit; the steel shell thickness ranges from 7/8 inch in the upper sections to 1-13/16 inches in the lower sections. The diameter of the upper, inclined portion is 15 feet, reducing to 14 feet for the lower, horizontal section.
Figure 268.—40 by 52.5-foot radial gate for spillway—Trunnion pin assembly.
The penstocks intakes are protected from ice and debris by massive 200-foot-high trashrack structures (fig. 270). The lower intake section contains six reinforced concrete bays for an overall height of 75 feet. Each bay is a 15-foot inside-diameter, semicircular structure composed of five chords. Each chord constitutes a trashrack opening of about 9 by 12 feet, which is covered and protected by framed metalwork.

Closure of the penstock intakes is accomplished by stoplogs and fixed-wheel gates. The respective sets of stoplogs are spaced several feet in front of the gates and have a total vertical height of 250 feet. Each set is divided into four groups: 9 lower logs, 7 intermediate logs, 7 top logs, and a final upper section of 20 smaller logs. The eight fixed-wheel gates cover only the intake bell of the penstocks. Each gate is 13.96 by 22.45 feet and weighs about 115 tons. Closure control is provided by a large hydraulic hoist. All of the mechanical features along the face of the dam are serviced by a 165-ton gantry crane.

Figure 269.—View looking down on Glen Canyon Dam and Powerplant. Note penstock installation between dam and powerplant. P557-420-7212, July 5, 1962.

Figure 271 shows the penstock transition at the intake of penstock No. 2 at the face of the dam in block 16.

203. PENSTOCK INSTALLATION. The eight penstocks, referred to as No. 1 through 8, are located in dam blocks 18, 16, 15, 13, 12, 10, 9, and 7, respectively. Installation of the penstocks was subcontracted to Chicago Bridge and Iron by the prime contractor, Merritt-Chapman and Scott Corp. The penstocks were furnished by Vinnell Steel of Irwindale, Calif., under invitation No. DS-5052. Initial fabrication was performed at the Irwindale plant. From Irwindale, 10-foot sections, or cans, were shipped by rail to a Flagstaff, Ariz. plant which was established by Vinnell to complete the fabrication (fig. 272). At Flagstaff, the cans were welded into 30-foot sections. Before being shipped to the jobsite by truck, the welds were X-rayed and the sections were placed in an oven for relieving stresses from the welding and were hydrostatically tested. Installation began in December of 1960, with the lower horizontal sections to be embedded in the mass concrete of the dam. The mass concrete was at elevation 3127.5 when the sections were set in place.

During the initial installation of the horizontal and the lower vertical bend sections to be embedded in the mass concrete of the dam, a framework of angle iron was used to support these sections to line and grade until the girth seams could be welded. This supporting framework had been anchored in concrete before any of the penstock sections were brought to the installation site. For extra stability and protection against misalignment by possible concrete bucket collisions with the penstocks, this framework was embedded in the concrete along with the penstock sections. On sections installed on the incline, no supports were used other than the key plates holding two sections together and the actual welded joints as the work progressed. The sections along the incline were for the most part 20 feet in length and installed at a 60° angle from the horizontal plane. In general, no more than one penstock section and a portion of another section would be exposed above the mass concrete. In rare cases when the work was slack for the welders, there would be two complete penstock
CONSTRUCTION

Figure 270.—View of upstream face of Glen Canyon Dam showing trashrack construction. Trashrack structure No. 8 is in foreground. P557-420-9734NA, May 27, 1964.

sections and a portion of a third section exposed. Figure 273 shows some inclined penstock sections being installed in mass concrete.

All welding performed on the penstock installation was done in accordance with the requirements of the 1951 edition of the "American Petroleum Institute—American Society of Mechanical Engineers (API—ASME) Code for Design, Construction, Inspection and Repair of Unfired Pressure Vessels for Petroleum Liquid and Gasses." All welders doing this work were required to be qualified in accordance with the above code. All the field welded girth joints, except for the closing joints, were radiographed for the entire length of the joint. Defects disclosed by the radiographic tests were repaired in accordance with the code and again inspected by radiograph.

Welding of the penstock closing joints across the A-B contraction joint was not accomplished until all joint movement had subsided. A collar which was 6 inches wide and made from 1/2-inch plate, was welded on the upstream edge of the downstream penstock section. The upper 3 inches of this collar extended beyond the downstream penstock section, forming a sleeve in which the upstream penstock section was merely slipped in and set to line and grade. An asbestos-felt cover was wrapped around the penstock 5 feet on either side of the joint. Grout connections were furnished on the inside of the upstream penstock sections and after the joint was welded from the inside, grout was pumped through the connections to fill any voids. After alinement, the key plates and alinement bars were removed.

The last penstock section to be placed near the intake was fabricated with a dish-shaped bulkhead at the upstream end. This bulkhead was not removed until the fixed-wheel gates were operable and in place, sealing the water passage. Removal of the bulkheads was started by the completion contractor during July 1964. Removal continued as turbine erection

Figure 271.—Forms and reinforcement steel for the penstock transition concrete and trashracks being installed in block 16 on penstock 2. P557-420-7365, July 27, 1962.
DAM, POWERPLANT, AND APPURTEA NT STRUCTURES

and the outside diameter of the penstock. The saddles were placed at the minimum tolerance and the penstocks fabricated and wrapped at the maximum outside diameter permitted. Each of these sections to be buried in a select backfill material were wrapped.

Installation of the expansion joints and the sleeve couplings in the backfill area between the dam and powerplant created a few problems. These problems were mostly caused by improper storage both on and off the jobsite. The expansion joint components were stored for periods ranging from 8 months to 2 years 8 months in temperatures ranging between 18° F. below zero and 160° F. metal temperature. This probably resulted in the sleeves and shells taking a more or less permanent set, loss of roundness in some sections, and loss of wax lubricant in the 1-1/4-inch flax packing material. Portions of the flax packing had also been exposed to blowing sand just prior to installation. The penstock sections were stored for an average time of 19 months. The ends of the penstock, where an out-of-round condition existed, were reshaped by jacking 6-inch pipe with ratchet bottle jacks at points determined by inside measurements. With the ends under jacking operations, the expansion couplings were installed and bolted. Bolting was accomplished in the following manner. Two impact wrenches were used 100° apart to snug up the nuts, with the distance from the flange of the follower ring to the outer edge of the shell being measured frequently to keep the flange parallel to the end of the shell. The packing was compressed by this method from 3/8 to 1/2 inch. No attempt was made to compress the packing fully. This was left to be done if required when the penstock was filled with water.

The procedure for tightening the sleeve-type couplings was done in the following manner:

First, the torque wrench was set at 150 foot-pounds and all bolts were progressively tightened until most of the slack had been taken up. This would take two or three passes, and it was discovered after a complete pass that the first bolts had very little torque remaining. For simplicity the torque remaining on the bolts will be referred to as “remaining torque” throughout this discussion.

Second, after the remaining torque had increased to 40 or 50 foot-pounds, the wrench setting was reduced to 110 foot-pounds and two or
three more passes made until the remaining torque had increased to 60 or 70 foot-pounds.

Third, the torque wrench setting was reduced to 90 foot-pounds and two or three more passes were made. These passes were different than the passes made previously. After three-fourths of each pass was made, the torque was reduced to 80 foot-pounds and the remaining one-fourth of the pass was torqued at 80 foot-pounds. This was repeated until the remaining torque had increased to 80 foot-pounds.

Fourth, the torque was spot checked at 80 foot-pounds and the few bolts that were deficient in torque were within 10 foot-pounds of the desired value.

Last, after 5 to 7 days the torque was again checked and all bolts were brought to 80 foot-pounds.

In addition, owing to the fact that the penstock sections are not perfectly aligned nor perfectly round, the spacing between the coupling ring and gland ranged from 3/8 inch to 1-3/16 inches. Because of this condition, it was felt necessary to put 1/2-inch shims between the ring and the gland when spacing became less than 1/2 inch, to prevent the rubber gasket from being completely forced under the anchor ring. After the required torque had been obtained, the overall width of the couplings measured close to 26 inches, plus or minus 1/4 inch.
204. PENSTOCK FIXED-WHEEL GATES. The 13.96 by 22.45-foot fixed-wheel gates were furnished by Vereinigte Österreichische Eisen und Stahlwerke Aktiengesellschaft of Lenz-Donau, Austria, under invitation No. DS-5577. The frames and anchors were fabricated by Rockwell Engineering Co. under invitation No. DS-5469, and the hoists and stems by Pacific Coast Engineering under invitation No. DS-5601. The control cabinets were furnished by Auto-Control Laboratories under invitation No. (D) 190,638-A. The gates and related equipment were installed by the prime contractor under specifications No. DC-4825 (fig. 274).

The fixed-wheel gates, hoist, and controls are located in the penstock trashrack structure of each of the eight penstocks and are used for emergency closures of the penstock and for maintenance purposes. The eight 13.96 by 22.45-foot fixed-wheel gates are installed on the upstream face of the dam. Each gate is connected through a series of intermediate stems to a hydraulic hoist located at the top of the trashrack structure. The control cabinets are installed adjacent to the hoist. Each fixed-wheel gate is a flat structural steel assembly with brass-clad rubber seals mounted on the downstream skinplate. The seals prevent leakage by contacting seal seats embedded in the concrete on the downstream side of the gate slot. Wheels at each side of the gate bear on tracks, also embedded in the concrete on the downstream side of the gate slot. Guide rollers mounted on each side of the gate bear against guides embedded in the concrete of the gate slot. The nominal gate travel is 26 feet 5 inches.

The hoists are an oil-operated, cylinder type and are installed on the slope of the intake structure. The hoists are supported on steel support beams. Each hoist piston has packing and piston rings, is 30 inches in diameter and has a stroke of 26 feet 5 inches. A series of intermediate stems with an assembled length of 172 feet 9-3/4 inches connects the piston stem to the gate stem.

The fixed-wheel gates were assembled at the paint yard, approximately one-fourth of a mile from the left abutment of the dam. Two concrete pedestals were constructed for each gate and were placed in two lifts with 4- by 4- by 1/2-inch angle stubs embedded in the bottom lift. These stubs were capped with the plate accurately leveled and the second lift was then placed.

The gate body for penstock No. 8 was assembled first on the pedestals nearest the dam, and the remainder of the gates were assembled in reverse numerical order. Spaces between the various gates were sufficient to permit installation of the splice plates as well as the fixed wheels and their covers. Access to the upstream and downstream faces of the gate was obtained by use of easily assembled tubular scaffolds. Planks of sufficient length to reach from one scaffold to the next one provided access to the sides of the gate.

When the four sections comprising each gate were stacked and pinned together, a preliminary check of the seal bases for being "in plane" was made. It was not found necessary to change the position of any of the sections after thorough pinning and bolting. The connecting plates were installed, and after all bolting was accomplished, the gates were plumbed to within one-fourth inch of vertical. Stainless steel piano wire, 0.018 inch in diameter, was drawn taut over accurately machined triangular-shaped blocks by means of small turnbuckles. All measurements were made on the seal bases. These piano wires were also used to set the fixed wheels to the required projection.

Before the fixed wheels were installed and after the roller guide assemblies and seals were in place, the
CONSTRUCTION

wheel pockets were primed and given the necessary coats of CA-50 coal-tar paint. The paint was applied by brushing and was kept away from areas which would be in contact with the fixed-wheel assemblies. The fixed wheels were then installed and brought out to the proper relation to the piano wire mentioned above.

The prime contractor built a road from the paint yard to the rim of the canyon directly above the left abutment of the dam. A slide, consisting of two parallel runs of 36 140-pound I-beams, was anchored to the almost vertical canyon wall. A car was fabricated to keep the gates from rubbing while being lowered to the dam. The contractor fabricated a short gate stem for use while handling the gates. He also fabricated a short boom for the dragline and a lifting beam for use by both cableways to left the 125-ton gates. The short stem was installed in gate No. 8, and the crane was positioned above the slide and used to lower the gate to the roadway of the dam.

The two cableways moved the gate to the upstream side of the dam, a distance of about 30 feet, where the 165-ton gantry crane could reach it. The short stem was removed and returned to the paint yard for use in gate No. 7. The regular stem for gate No. 8 was installed. The gate was picked up by the 165-ton gantry crane and set in block 7 gate structure above penstock No. 8. Seven intermediate sections of stem and the No. 8 hoist cylinder completed the installation. This procedure was repeated without mishap until all of the eight gate assemblies were completed.

The installation of the gate, the seven intermediate stems, and the hoist require about 10 hours with two to three men and an operator. The welding and other work required 20 working hours for the pipefitters to install the high-pressure oil. The first gate was placed in the gate structure on April 20, 1964, and the last gate was installed and fully tested on June 2, 1964.

The tests were begun in accordance with the appropriate operating drawings and instructions. However, the gate would not stop when the stop button was pressed and the throttle valve was one-fourth open. With this condition, the restoring feature would not operate.

A design engineer from the Denver office determined that valve C of the high-pressure oil piping needed a stronger spring, and new springs were obtained. The new, heavier springs corrected the faulty operation of the gates. However, two of the valve bodies were sensitive to the tightening of all the socket-head body bolts; i.e., one bolt if fully tightened would render the plunger or spool inoperative. An 0.008-inch-thick shim in the joint under the bolt obviated this condition.

One of the checks made during the tests was to have an inspector, the contractor’s chief of party, and a rodman enter the bellmouth, allow the gate to be closed, and use a feeler gage 1/32-inch thick to check the seals where daylight was observed. The feeler gage could be inserted between the rubber seals only on one gate. The most daylight appeared at the molded corners and not where the brass-bound rubber seals were placed.

The results obtained in the operational tests are as follows: Any of the eight gates will close in less than 2 minutes and 8 seconds; they will open in less than 20 minutes. While closing, they will stop in a distance from 3 to 6 inches. The restoring feature cuts in when the gate settles about 11 inches.

In addition to the inadequate springs in valve C of the high-pressure oil piping, the makeup of the hanger stud assembly gave trouble when the hanger collar seized on the top of the piston and acted as a double nut while unscrewing the hanger stud. The lead plug was not positive enough to keep the collar stationary on the hanger stud. It was decided to install a 3/8- by 1-inch cup-point set screw in place of the plug. A 3/8-inch hole, 1/4 inch deep, was drilled into the hanger stud 5-3/8 inches from the end of the stud, the collar positioned, and the new set screw installed. This resulted in 4-7/8 inches of threads below the collar, which is the requirement. All eight hanger studs were modified in the above manner without further difficulties being experienced.

The workmanship on fabrication of the gate assemblies and on the erection and assembly of the gates was excellent.

205. STOPLOG GUIDES. The stoplog guides in the penstock trashrack structure were supplied by Bennett Industries of Peotone, Ill., under schedule 2 of invitation No. DS-5354, and were installed by Merritt-Chapman and Scott Corp., under specifications No. DC-4825.

Discrepancies in the assembled guide sections were discovered. The major error was that the ends of the cast iron guide sections were not in the same plane as the ends of the steel plate seat sections. This was contrary to the specifications and, if the guides were installed on the dam in this condition, tight joints could not have been obtained.
The first attempts to correct this discrepancy were started on September 6, 1962, with a vertical milling machine and an alinement table long enough to hold three complete guide sections fitted together. The first three sections after the ends had been machined were fitted together, checked and failed to meet the specified tolerances in the overall lengths and in the makeup joints. Further work with the equipment on hand failed to correct the fabrication errors.

The manufacturer brought in a heavier duty milling machine on September 24, 1962. Three guide sections machined on this new milling machine were fit together with all tolerances within the specified measurements. Corrective work on each of the 368 guide sections was completed on November 7, 1962. The general procedure used in the corrective work was as follows:

1. For each guide section where the steel plate seat portion was shorter than the cast iron guide portion, weld was applied to the end for a buildup which equaled or exceeded the cast iron portion.

2. Each section was placed on the milling machine and the end was machined normal to section. Where heavy cuts were made, a light finishing cut followed the heavier cut.

3. Three consecutive sections after having been machined on each end, were fitted together on the alinement bench where each joint was measured with a feeler gage. The maximum acceptable gap was 0.004 inch.

4. Two piano wires were stretched along the guide and the seat portions for a check of plumbness and straightness.

5. After acceptance, the lower two of the sections were stockpiled. The upper section was then moved to the other end of the alinement table and was assembled to two more consecutive machined sections. This procedure was repeated for the remaining sections.

A crew averaging four men accomplished the corrective work. One man operated the milling machine; one man operated a forklift truck and carried sections to the milling machine, the alinement table, or stockpiles; one man assisted the machinist or assembled the machined sections; and one man applied weld buildup to the uncorrected sections. After the corrective procedures were developed, these men did an excellent job considering the long hours and consecutive days of work.

Because of the sections being shortened in the corrective process, the installation of the sections required that the contractor insert stainless steel shims between some of the sections to make up the required distance. This was necessary since the anchor bolts had been installed in the mass concrete of the dam according to drawings. For accuracy of the placement of the guide sections, the sections were installed in blockouts and on the anchor bolts and then later concreted in place.

During installation, slotting of the splice plates was necessary at various locations due to either a misplacement of the embedded anchor bolts or in some cases due to the shortened sections before or after the addition of shims between the sections. No other unusual problems were experienced by the contractor during the installation of the guide sections.

206. DRAFT TUBE BULKHEAD GATES. Twenty-four 12.42-foot-wide by 15.95-foot-high bulkhead gates are provided for use in unwatering the eight turbine draft tubes. The gates are stored in slots, resting on latches, under the upper guide lug on each side of the gate. A lifting frame is provided for raising and lowering a gate with the 10-ton gantry crane. The bulkhead seats, gates, guides and frame were manufactured by the Ogden Iron Works of Ogden, Utah, under invitation No. DS-5341 and were installed on the downstream face of the powerplant by the prime contractor, Merritt-Chapman and Scott Corp., under specifications No. DC-4825.

An extra work order and an order for changes were executed during the life of the supply contract. Chain guides and pins were furnished with the bulkhead gate lifting frame for use in storage as extra work. Mill scale was removed from the structural surfaces of the steel to which the naval brass seats were secured and a coat of white lead and linseed oil was applied; and additional flathead steel cap screws and hexnuts were furnished for gates 4 and 5. The contractor also requested and was given permission to use naval brass in accordance with Composition 1, Federal Specifications QQ-n35, in lieu of that required in the specifications, and the use of flathead naval brass bolts instead of rivets on seat parts IL, IR and 2.

Timely delivery was made in four separate shipments of six gates each and two separate shipments.
of guides. Protection of the gates and guides was adequate during shipment and no unusual damage was incurred in transit. Shop painting of the metalwork was not required and all finished surfaces of ferrous metalwork were coated with a rust-preventative compound prior to shipment.

At the jobsite, the rust-preventative compound was removed, the surface prepared, and the gates and guides were painted with two coats of type IV red lead primer and two coats of phenolic-resin aluminum paint. The good paint system obtained was retained, because the installation contractor lowered the gates into place from the painting yard at the top of the canyon to the powerhouse gate slots using the traveling cranes, or highlines, for convenience in handling and to avoid damage and paint repairs.

The close tolerances of 1/16 of an inch, plus or minus, top to bottom, required careful installation techniques by the contractor. After installation of the lower seal plate, the gate guides were rough assembled from top to bottom. Special templates were tack-welded to the lower seal plate on each side at the bottom, and steel frames were cantilevered from the concrete for the upper template. Three holes, just larger than No. 16 piano wire, were drilled in the templates for alinement, one each for the outside faces and one for the centerline of the inside of the slots for width and depth. Another set was drilled for the face of the lower steel frame. Piano wires were attached between the two templates using a device tensioned by a ratchet-type reel. Plates were set by precise surveying methods and were checked periodically.

During installation, it was found that the 1/2- by 2-inch naval brass flathead bolts, which secured the brass seal plates to the steel frames, were defective due to fractures, either at the body or head or in the threaded section between the head and the nut. About 15 percent of the bolts were found to be defective prior to installation, and further breakage discovered during erection amounted to about 20 percent of all bolts. As a result, all of the naval brass bolts were replaced with monel metal bolts. However, laboratory tests in Denver failed to confirm either that the bolts were defective or that they failed as a result of factory overtightening. The supplier was therefore not held responsible for the costs involved in replacing the bolts.

Other difficulties were experienced in installation due to insufficient depth in the concrete blockouts and improper location of anchor bolts. Minor difficulties were also experienced as a result of some of the guide sections being distorted or warped which required special jack screws being made to spring the sections into position. Some warpage and twisting of the stationary gate seals and support frames was also noted. As the horizontal frame sections did not match the vertical sections at the top, the contractor jacked the upper frame section into place and welded at the assembly joints. Installation of the gates, seals, and guides was satisfactory and no difficulties were experienced during the testing and initial operation of the gates.

When the gates were placed in service for the first time, it was difficult to raise them due to a collection of sand, silt, and rubbish at the bottom of the gates, probably due to the testing and operation of the hollow-jet valves. The gates were freed with tube-introduced compressed air along the face of the gates. After the gates were raised for the first time, this waste material was flushed out and no further trouble was encountered.

207. RIVER OUTLETS. Nonpower drawdown of the reservoir is provided by four outlet pipes (figs. 109 and 110), each 8 feet in diameter and located 96 feet below the penstock elevation level. Although similar in construction to the penstocks, each major element of the installation differs in some respect. There are two trashrack structures for the four outlet pipes, each structure containing two pipes closely spaced at the same elevation. Upper closure is made by 96-inch ring-follower gates (fig. 275) inset some 50 feet inside the dam and by 10-1/3-foot square bulkhead gates seated in guides at the inlet face of the pipes. No stoplogs are provided for the river outlet intake structures. Embedded their length in concrete, the outlets discharge downstream from the powerhouse through 96-inch hollow-jet valves.

Methods utilized for installation of the outlet pipes were essentially the same as those used for the penstocks. Being at the lower elevation of the two sets, horizontal pipe sections of outlets No. 1 and 2 (fig. 276) were first placed in block 6 of the dam and in the mass concrete downstream from the dam in February of 1961. Initial sections of outlets No. 3 and 4, which had intakes in block 5, were placed during the following month, and all sections extending downstream from the dam had been embedded by the end of July 1961. The four 8-foot-diameter pipes were positioned and welded as the blocks rose in elevation. Installation of the outlet pipes was completed in April 1962, when the bellmouth sections for outlets No. 3 and 4 were placed in block 5.
Figure 275.—General view of equipment used in testing of river outlet No. 4 at various flow conditions. Test station is located in the ring-follower gate chamber in dam block 5 at elevation 3387.5. P557-420-11016, May 24, 1965.

Figure 277 shows the outlet pipes partly embedded as of March 20, 1961.

208. RIVER OUTLET BULKHEAD GATES, GATE FRAMES, AND LIFTING FRAME. The bulkhead gate is a flat structural steel assembly with rubber seals mounted on the downstream skinplate. This gate was furnished by Johnson Machine Works, Inc., of Chariton, Iowa, on invitation No. DS-5493. The rubber seals of the gate contact the seal seats embedded in concrete on the upstream face of the dam around the bellmouth of the outlets. The seal seats were supplied by Fulton Shipyard, Antioch, Calif., under invitation No. DS-5370. The gate is closed, opened, and transported by the 165-ton gantry crane at the top of the dam. The crane raises and lowers the gate with a lifting frame which follows the gate guide slots and is coupled to the gate stem by a grappling hook. This lifting frame was supplied by Charles C. Steward Machine Co., of Birmingham, Ala., under purchase order No. (D) 90,637-A. The bulkhead gate was received at Flagstaff, Ariz., on December 22, 1961, the embedded seal seats on February 2, 1961, and the lifting frame on August 14, 1963.

The bulkhead gate, embedded seal seats, and lifting frame were installed, erected, and assembled by the prime contractor. Installation of the seal seats and anchorage was performed in conjunction with the placement of the concrete. The work was substantially completed with the dry testing of the gate operating cycle in October 1963. The assembly of the bulkhead gate consisted of attaching rubber seals and clamp bars with the stainless bolts. Since the assembly work was performed by an experienced crew of millwrights, no difficulties were encountered during the assembly. The seal seats were placed on the anchor bolts in the blockouts and were adjusted to their proper position using templates and fine piano wire stretched tight for measuring control. The positions of the embedded frames and location of wire templates were determined by the contractor's survey crews. The contractor's survey crews were well qualified for this type of construction layout, and many of the alignment problems often associated with this type of installation did not develop.

209. RING-FOLLOWER GATES AND CONTROLS. The four 96-inch ring-follower gates
were supplied by Goslin-Birmingham Co. under invitation No. DS-5269 and the two control cabinets were furnished by Kendo, Inc., of Denver, Col. under invitation No. DS-5498.

The ring-follower gate is of cast and welded steel construction and consists of a body, a leaf, and a hydraulic hoist which is an integral part of the gate. The slide-type gate with a leaf includes a follower ring having a circular opening equal to the diameter of the pipe to provide an unobstructed water passage when the leaf is in the open position. The hoist cylinder is 27 inches in diameter and has a travel of 8 feet 8 inches.

The two control cabinets are of steel construction and enclose the control system for two ring-follower gates in each cabinet. The control system was installed in the gate chambers of the river outlets in the dam and was used to operate the four ring-follower gates. The opening and closing of the gates is controlled from a pushbutton station located in each cabinet. The ring-follower gates were received at Flagstaff, Ariz., beginning in May of 1961 and shipment was substantially complete by October 16, 1961. The control cabinets were received at Flagstaff on September 28, 1962.

The ring-follower gate installation was performed by the prime contractor under specifications No. DC-4825. Installation started with placement of main body and lower bonnet in block 6 in February of 1962, and the embedded parts were completed in block 5A in April of 1962. The ring-follower, gate leaf, upper bonnet cover, and hoist were installed in outlets No. 1 and 2 in May 1962, and outlets No. 3 and 4 in June of 1962.

In January of 1963, after the installations had been completed, the contractor was operating gate No. 4 for testing and adjustment. During the final checkout, ring-follower gate No. 4 was taken to the closed position but failed to close completely by approximately 2 inches. This gate was being operated by a remote switch to the control cabinet by the crew inside the river outlet pipe. The safety pressure switches had been calibrated and set in accordance with the appropriate drawing. During the long period of erection of the gates, a large amount of residue from sandblasting of outlet pipes upstream of the ring-follower gates had collected in the bottom bonnet of the gate; also drainage water and cement grout had caused sandblast sand residue to solidify to some extent. When the ring-follower on the gate leaf was brought down toward its closed position, the hydraulic thrust collapsed the ring in the bottom of the gate. Measurements on the diameter found the ring was 1 inch out-of-round and warped approximately 3/8 inch. Several methods were tried in an effort to push the ring to its original shape while the leaf was in position in the gate body. All efforts to restore the ring of the leaf follower to roundness while in the gate body failed. The gate was disassembled and the leaf was taken to the installation contractor's shops for repair, during the week of February 11 to 18, 1965. A failure was noted on the downstream stiffener, 3 feet 11 inches up from the bottom and to the left, and at the fabricator's welded joint near the bottom.

During the next 2-1/2 days, the contractor fabricated a structural steel pressing jig and sandblasted away all the coal-tar enamel coating from the section. The true center of the waterway was located by using the top normal machined surface as a reference plane. Radial distances from the center to the inside of the shell were recorded for each 10°.

This measurement was used to determine the amount any segment had to be moved to obtain the desired roundness and to check on any gains made during the pressing operations.

The initial pressures exerted on the section were 50 tons applied near the right springline and 20 tons applied on the inside bottom surface. Measurements taken on the loaded section indicated the horizontal diameter was shortened by 3/8-inch and the lower vertical radius was lengthened by 0.050 inch. When released, the section assumed the original configuration before the pressure had been applied. During this press, it was noted that the weaker top portion bowed out

Figure 277.—Installation view of outlet pipes. Partially buried in concrete, two of the outlet pipes poke their way skyward at Glen Canyon Dam. P557-420-5806, March 20, 1961.
and away from the center point. For added strength to this portion, the contractor added a 1/2-inch-thick plate, 8 inches wide and 9 feet long, across the top of the section on both the upstream and downstream side. For a more evenly distributed load to the top of the section, braces were added between the pressing jig and the two upper quarter points.

In a 3-day period, various pressures were applied to the section to a maximum of 130 tons on the right springline and 32 tons on the lower inside surface. Higher pressure did not seem practical since the top portion had a tendency to bow out. During the last press of this period, the brass seat was removed and the lower half of the section was heated with propane torches. Temperatures of approximately 550° F. were produced along the bottom, 250° to 300° F. at the lower quarter points and decreasing to 113° F. at the springline. These operations accomplished a gain of less than one-fourth inch on the horizontal and vertical diameters.

As the follower could not be pressed back into shape, the contractor cut the stiffeners around the circumference of the ring-follower. This method proved to be successful and the ring was brought back to original shape and rewelded. The gate leaf was again installed and the repair work was completed on March 28, 1965. At a later date, the ring-follower gates were put in service and the repair was satisfactory in that leakage was very small on this gate. Subsequently, the pressure limit switch on the other gates was lowered to a safer value which would just operate the gates during initial installation and testing.
With the exception of incorrect pilot-operated check valves, the installation of the controls proceeded without unusual difficulties. The supplier replaced these incorrect check valves at the site without cost to the prime contractor. The control cabinets for gates No. 1 and 2 were badly damaged on May 23, 1962, when the roof over the gate chamber failed as fresh concrete was being placed in block 6A of the dam. The control cabinet was returned to the supplier's plant, repaired, and returned at the expense of the prime contractor.

The ring-follower gates and controls were first placed in service by passing water through the outlet works in January 1965.

210. HOLLOW-JET VALVES. The four hollow-jet valves and controls (figs. 127, 128, 278, and 279) are used to regulate the flow of water from the river outlets. The hollow-jet valves are of cast and welded steel construction and consist of a circular body and a movable needle which forms an annular passage and seats in the throat. The hollow-jet valve is hydraulically operated by a cylinder within the passage which is concentrically positioned by eight radial splitters. Each control cabinet is of steel construction and encloses the control system for two hollow-jet valves. A cable-driven dial-type position indicator for each hollow-jet valve is located on the cabinet control panel to show the percent of opening. The 96-inch hollow-jet valves were manufactured by the Goslin-Birmingham Manufacturing Co., Inc., of Birmingham, Ala., under invitation No. DS-5363. The controls were supplied under invitation No. DS-5503 by the Rucker Co. of Oakland, Calif.

The four hollow-jet valves were installed at the site by the prime contractor starting on January 15, 1962, and work progressed using conventional erection procedures until completion in April of 1963. The controls were supplied, assembled, and tested by the supplier; only a small amount of field piping work was required to complete the installation. One difficulty noted involved the placement of the flow regulation valves which were inaccessible after assembly of control cabinets. It will eventually be necessary to provide an opening in the cabinets for ready access to adjust the valves. After the first season of operation, the valves were inspected for damage and very little cavitation was noted.
CHAPTER XIV. Construction—POWERPLANT

211. GENERAL. Glen Canyon Powerplant was constructed 400 feet downstream of the axis of the dam. This reinforced concrete structure is 649 feet long by 113 feet wide and is 150 feet high above the mass concrete required for a foundation. The structure contains eight 112,500-kilowatt generating units, each driven by a 155,500-horsepower vertical-shaft turbine. The total plant generating capacity is 900,000 kilowatts, or about 81 percent of that authorized for the entire Colorado River Storage Project.

Eight unit bays and a service bay span the width of the canyon with an elevator tower on the west end of the plant and a machine shop downstream of the service bay. The control and office area are housed in a two-story structure placed above the superstructure of units 1 and 2. Placed to a top elevation of 3124.5, the substructure concrete was reinforced around the turbine pits, as well as below the draft tubes, down to elevation 3093.0. Unreinforced mass concrete was placed below this elevation and also upstream of the turbine pits up to elevation 3118.75. The reinforced concrete intermediate structure is from elevation 3124.75 to elevation 3188.50 and contains gallery systems both upstream and downstream of the unit bay crosswalls, and the transformer deck on the downstream side of the powerplant. The superstructure is a structural-steel frame with reinforced concrete walls above elevation 3188.50, and lightweight precast concrete roof slabs for all units except unit 3. Second-stage concrete was used for encasing the turbine spiral cases and for supporting the generators.

First-stage concrete, including the entire closed shell of the powerplant structure, was constructed under the prime contract, specifications No. DC-4825, by Merritt-Chapman and Scott Corp. Second-stage concrete, surfacing concrete, and related work were accomplished by the completion contractor, Ets-Hokin Corp. under specifications No. DC-5750. The generators were furnished and installed under a separate contract, invitation No. DS-5522, with General Electric Co., and the elevators were furnished and installed by Pacific Elevator and Equipment Co., under invitation No. DS-5843.

Air, water and power for the construction work under the prime contract in the powerplant area were furnished from stations on the canyon rim. Air was furnished by supply piping from compressors on the rim. Water was obtained from the wells at Wahweap via the main distribution system. Power was supplied by line from the rim and a temporary distribution system which was installed and moved as the construction work progressed. Construction materials were brought to the work area by high-line cableway or were trucked through the powerplant access tunnel. Reinforcement was bent and bundled for each lift or placement at the steel yard on the east rim. Reinforcing steel was supported by angle iron and on cast concrete blocks of size to provide required cover. Most of the piping was precut and partially assembled when the piping arrived at the site for installation.

212. EXCAVATION. Excavation for the powerplant structure began in January 1959, with the removal of talus on the left side of the canyon in the machine shop and service bay area. A berm for the machine shop roof at elevation 3239 was excavated, intersecting a minor joint at approximately elevation 3240. As the joint nearly paralleled the face of the canyon wall, rock bolts were placed throughout this section. A rock slab was removed on the left side downstream of the m-line between elevations 3290 and 3195. Foundation benches were cut out of the rock by line drilling methods as the excavation progressed. Benches for the river outlet valve structure and training wall area were cut at elevations 3170, 3161.5, 3151.5, 3141.5, 3131.5, 3118, 3112, and 3108. At the time of the strike on July 6, 1959, powerplant excavation had reached elevation 3110 on the left side.

Drilling and shooting for the powerplant structure began on the right side of the canyon in March 1959. The elevation 3118 bench had been exposed at the time of the strike and excavation had reached elevation 3097. Rock bolts, 6 and 8 feet in length, were used at appropriate locations on both sides of the canyon. Loose rock in the nearly vertical walls of rock excavations was pried off by highscalers working from ropes. Periodic inspections were also made for the purpose of removing any additional rock which became loosened after the initial scaling. Performed concurrently with excavation for the dam, conventional methods and equipment were used for the rock and common excavation in the powerplant foundation area. Briefly, the drilling work was performed by wagon drills and a large bench-type work area was blasted for each round. Large, steel-tracked shovels and draglines loaded the muck into large dump trucks for dumping on the upstream and downstream cofferdams. The upstream cofferdam was located so that a work space was available between the foundation of the dam and the upstream cofferdam, until the excavation level reached the inner canyon bed level.

Following an extended strike of 6 months’ duration, excavation work for the dam and powerplant foundations resumed in January 1960. Line drilling, shooting, and mucking for the powerplant excavation began on the left side with the elevation 3110 berm.
Some unsafe rock was removed between elevations 3160 and 3184, between the ex- and g-lines, and berms were exposed on the left side to elevation 3060 under unit bay 8.

Powerplant excavation on the right side of the canyon was resumed at elevation 3097 in the middle of March 1960. Except for the haul, excavation of unit bays 1, 2, and 3 was completed at about elevation 3093 early in May 1960. Bedrock in unit bay 4 was at approximately elevation 3035 which was about 58 feet lower than unit bay 3. Bedrock in unit bay 5 was at approximately elevation 3030. Free-draining gravel material from the excavations was stockpiled at the downstream cofferdam for later use in the tailrace area and between the dam and the powerplant.

During May of 1960, steel dowels were placed in unit bay 1 at elevation 3083, in the theoretical bench at elevation 3109, and in the upstream section of unit bay 3. The ground mat installation also began during this period.

213. FOUNDATION. Once diversion had been completed and the dam keyway excavation had progressed to river level, excavation for the foundations of the dam, penstock supports, powerplant, service bay, machine shop, and river outlet area progressed concurrently. The powerplant was constructed across the downstream portion of an inner gorge in the river bottom rock that extended upstream a short distance from the dam foundation. It was necessary to excavate rock to provide a foundation for the substructure of units 1, 2, and 3. For the remaining units, 4 through 8, mass concrete was placed to provide a foundation. Excavation for the mass concrete foundation was held to a minimum in the river bottom rock, providing keying upstream of the longitudinal centerline of the units.

Originally line drilling and benches would have been used for the service bay foundation but, due to bedding of the sandstone, the benches could not be held. In lieu of the benching, anchor bars were grouted into the canyon wall along with some rock bolting.

A stress relief joint and rock slab in the vicinity of the service bay area mass concrete extending into the left abutment keyway of the dam required remedial measures to assure adequacy for the structure foundation. The rock slab was anchored to the canyon wall from near the a-line to just downstream of the intersection of the 2-inch expansion joint between the dam mass concrete and the service bay with 1-3/8-inch anchor bars on 5-foot centers both ways between approximate elevations 3095 and 3182. The anchor bars were embedded a minimum of 10 feet in sound rock past the relief joints. The anchor bars and relief joints were grouted in 5-foot lifts as the mass concrete elevation increased. The additional line of 1-3/8-inch anchor bars, as required on the drawings downstream to the a-line and bx-line, were installed in the same sequence as the anchor bars upstream of the a-line.

Two drainage systems were constructed at the concrete-rock contact from downstream of the 2-inch expansion joint to approximately 3 feet upstream of the d-line with gravel and perforated sewer pipe and open-joint sewer pipe. After the anchor bars and grouting had been completed, 3-inch drain holes were drilled through 4-inch pipe embedded in the concrete, through the sewer pipes into the rock, a minimum of 1 foot past the grouted stress relief joint. The purpose of the drain holes was to assure that water pressures would not build up under the rock slab. This phase of the work was accomplished beginning in September 1960 and was completed with the drilling of the required drain holes in March of 1961. Additional anchor bolts were required for the canyon wall but are associated with the dam and are therefore presented in section 161. A series of 1-1/2-inch bolts and drain holes were required to be installed as a part of the canyon wall bolting. These were located between the canyon wall and the service bay and machine shop superstructure walls upstream of the m-line. The work in this area was performed during the fall and winter of 1961 in advance of the remaining wall bolting, as it was necessary that it be completed prior to constructing the superstructure concrete walls.

During June of 1960, movement amounting to 0.08 foot was detected in the foundation rock in unit bays 1 and 3 and in the area of the penstock supports for penstocks 1, 2, and 3. Check points were established throughout the area and were observed for further movement. Additional movement of about 0.07 foot was noted in August, generally towards the east at the upstream edge of penstock support 3C, at the edge of a bench some 58 feet high.

Several steps were taken to stabilize the foundation material. Construction was suspended in unit bays 1, 2, and 3 until all mass concrete in the powerplant was brought up to the level of the unit bay 3 foundation; construction was also suspended on the supports for penstocks 1, 2, and 3 until the adjacent dam and powerplant concrete was brought up to the level of the foundation of the supports for penstock 3; and the size of the fillets on the dam was increased to fill the void between the toe excavation face and the downstream toe of the dam, extending an enlarged fillet from the near vertical cut for the bases of supports for penstock 4 in block 13 to the right abutment. In addition, it was necessary to support the rock wall between penstocks 3 and 4 with concrete buttresses between the powerplant and dam. Four concrete support buttresses

484
POWERPANT

were constructed, one each between stations 5+00 and 5+34, 5+37 and 5+74, 5+88 and 6+93, and 6+39 and 6+60. Completed by January 1961, the buttresses averaged about 30 feet in thickness.

214. CONCRETE. (a) Mixing and Placing Methods.—Concrete for the powerplant area was manufactured in the central batching plant, located on the elevation 3540 bench, excavated out of the right canyon wall upstream of the dam and approximately 700 feet upstream of the powerplant. The concrete was delivered to the construction area by high-line cableway using concrete buckets. The first concrete in the powerplant area was placed on May 5, 1960, for penstock support 2B, using one of the main 50-ton high-line cableway with a 12-cubic-yard concrete bucket. The 50-ton cableways were used in the powerplant area to place concrete until late November 1960 when the third high-line cableway, with 25-ton capacity, was placed in service. The remaining concrete placed in the powerplant area was placed using the third high-line cableway with an 8-cubic-yard bucket. The concrete in the downstream part of the tailrace slab and the river outlet area could not be reached using the highline. For these locations, the structural concrete was transferred to a hopper and was placed using a crane and a smaller bucket. Mass concrete for the river outlet was placed using a pumpcrete machine, located within the reach of the highline used to deliver concrete from the concrete batching plant. Concrete mixes varied from 6-inch maximum size aggregate for the mass concrete to 3/4-inch maximum size aggregate, depending upon the complexity of the particular placement and taking into account cover for embedded items, spacing of reinforcing steel, massiveness of the placement, and amount and spacing of the embedded materials. Generally, the typical sizes of aggregate used were as follows:

<table>
<thead>
<tr>
<th>Location</th>
<th>Maximum size of aggregate, inches</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass concrete</td>
<td>6</td>
</tr>
<tr>
<td>Substructure massive walls</td>
<td>3</td>
</tr>
<tr>
<td>Intermediate structure massive walls and columns</td>
<td>3</td>
</tr>
<tr>
<td>Structural concrete, superstructure walls, parapets, floors, cover slabs</td>
<td>1-1/2</td>
</tr>
<tr>
<td>Stairs, blockout concrete, and miscellaneous small placements</td>
<td>3/4</td>
</tr>
<tr>
<td>Bulkhead gates blockouts for guides and seats</td>
<td>Grout</td>
</tr>
</tbody>
</table>

Details of concrete materials, methods, and equipment used in the manufacturing, control, mix designs and compressive strengths are covered in appropriate sections of this publication. Additional information is presented in the following subsections.

(b) Forms.—Wooden forms were used for the mass concrete in the powerplant area until the mass concrete was of sufficient height above rock, then steel panel forms were used. Powerplant area structural forms, both exterior and interior finish surfaces, were made of 3/4-inch exterior plywood sheathing on 2-by 6-inch studds spaced on 16-inch centers and with double wales of 3- by 6-inch timbers on 16-inch to 3-foot centers.

Tongue-and-groove sheathing was required to be used for the exterior surfaces of the superstructure concrete on the south elevation of the machine shop, the west elevation of the powerplant, and the remaining surfaces of the cable and elevator tower, for architectural appearances. Forms were tied together with 1/2-inch steel rods and 3/4-inch she-bolts. Form tie spacing ranged from 16-inch centers to a maximum of about 3 feet, taking into account various factors such as size, shape, and depth of the placement. The contractor was quite generous in his use of form ties, resulting from having several form failures early in the concrete construction phase. All wood forms were constructed at the carpenter shop located on the east rim. The quality of the forms constructed at the carpenter shop was outstanding, resulting in excellent concrete surfaces. Exterior concrete forms were usually stripped within 24 hours after placement, with repairs being made as required and she-bolts holes being plugged shortly thereafter.

(c) Placement Schedule.—The first mass concrete in the powerplant substructure was placed on May 31, 1960, in the upstream section of unit bay 1 between the 5- and 3-lines to elevation 3105. Placement in unit bays 3 and 5 followed. Concrete placement methods and equipment closely followed the procedures used in the concrete construction for the dam, and the mass concrete in the powerplant structure was completed in December 1960 with a placement in unit bay 8.

Placement of the reinforced substructure concrete began in June 1960 and continued in the logical sequence of construction, followed by initiation of intermediate structure concrete construction in September 1960. By this time, the pattern of concrete placement was established in a routine sequence of unit bays 1, 3, 7, and 5, followed by unit bays 2, 4, 6, and
8. The mass concrete for the outlet works encasement downstream of the dam also became a part of the sequence placements between the dam concrete and the powerplant as the work progressed. During the early part of 1961, concrete placing in the powerplant averaged about 13,000 cubic yards per month. This average dropped to about 1,700 cubic yards per month during the last 6 months of the year, due partly to concentration of effort on placement in the dam and partly to the greater forming and reinforcing steel work requirements in the structural concrete of the powerplant. Concrete construction in the machine shop and service bay followed on an appropriate schedule. Intermediate structure concrete was completed in November 1961 with a placement in unit bay 8.

Placement of the superstructure concrete began in unit bay 1 in October 1961. In November 1961, the contractor was advised that the powerplant cable and elevator tower above elevation 3233.33 and unit bays 1 and 2 above elevation 3231.69 were being redesigned to provide fallout protection. No work was performed above those elevations until the details of the revisions were furnished, and all superstructure concrete was completed early in July 1962. The high bay windows in the powerplant unit bay outside walls were also deleted for additional fallout protection and security purposes.

(d) Cooling.—The powerplant unit bay mass concrete was placed in 5-foot lifts and was not cooled. The mass concrete for the service bay, machine shop, and river outlet was required to be cooled to 60°F. One-inch outside-diameter aluminum tubing on nominal 5-foot spacing was embedded in the mass concrete, and refrigerated water was circulated through the cooling coils at a rate of approximately 4 gallons per minute for a period of 12 days. Upon completion of placement of the mass concrete, the concrete temperature was lowered to the required 60°F. Thermocouples and insert thermometers placed in embedded tubing were used to control the progress of the cooling. In March of 1961, following completion of the required cooling, the contraction joint, cooling pipe, and thermometer tubing downstream of the m-line were grouted. The machine shop and service bay cooling pipe was grouted during June of 1961.

The service bay mass concrete cooling was accomplished using the chilled water supply system used for cooling the mass concrete in the dam. A small refrigeration plant with chiller and cooling tower was set up downstream of unit 8 near the m-line to cool the machine shop and river outlet mass concrete. This same plant setup was first used to cool the dam mass concrete prior to placing the main refrigeration plant chilled water system in service.

(e) Curing.—Concrete curing was performed as required by the specifications. The exterior surfaces of the mass concrete and powerplant structure concrete were cured using gray membrane curing compound. Horizontal construction joints, floors, and stair treads were cured with water for at least 14 days. Finished floors were covered with plywood for protection during the construction phase; but even so, gouging and spalling of these surfaces required considerable repairs by the prime contractor. Interior surfaces of walls, columns, ceilings, soffits, vertical construction joints, and construction joints were cured by leaving the forms in place for at least 4 days. Mass concrete that contained pozzolan was required to be cured for a minimum of 21 days or until covered with concrete. Dry-packed she-bolt holes were cured by covering with masking tape.

(f) Tailrace Slab.—The contractor was instructed to construct a reinforced concrete slab (fig. 280) in the tailrace of the powerplant by order for changes No. 7, in lieu of riprap required by the specifications. The tailrace area was laid out in 17 sections, designated A through Q, with 10 slabs placed in sections A through H, and 9 slabs in sections I through Q. The tailrace slabs were about 30 feet square and were 8 inches in depth for a distance of 150 feet from the powerplant and 12 inches deep for the remaining length of the slab. Following dewatering and backfill compaction, the work was started in September 1961 in section A-1, downstream from unit bay 8, and was completed in April 1962. For placing sections farthest downstream which were beyond cableway reach, it was necessary to transfer the concrete bucket to a crane.

Placing of concrete in the powerplant was suspended on December 11, 1961, due to severe winter weather, and was not resumed until the middle of February 1962, when the weather moderated. Placement of the tailrace slab was resumed late in December, and portable wooden shelters were constructed to protect the slab placement. Electrically driven forced-air heaters were used to assist in the protection against low temperatures. The tailrace slab collapsed 3 years later in April 1965, after the river outlets were operated for an extensive period (see section 57).

215. POWERPLANT SUPERSTRUCTURE. Furnished by the prime contractor, structural steel for the powerplant superstructure had been prefabricated and was ready for erection upon delivery at the site. The structural steel was fabricated and erected by
subcontractor Judson Pacific-Murphy Corp., a subsidiary of Yuba Consolidated Industries, Inc.

The first shipments of steel consisting primarily of welded steel plate arrived at the jobsite in April and May 1959, amounting to some 2 million pounds. Further deliveries were deferred for about 6 months and an additional 2.82 million pounds of steel was shipped over a 3-month period ending in March 1960. Subsequently, a change in the structural steel requirements added 383,000 pounds and increased the structural steel erected into the powerplant to the final total of 5.2 million pounds.

Erection of steel began in unit bay 1 in June 1961 (fig. 281), and was completed in July. This work was then temporarily suspended until September for completion of intermediate concrete construction. A rubber-tired mobile crane was used to handle the steel members, which were field erected with bolted connections. The crane boom was equipped with a boom extension for erection of the control and office area superstructure over unit bays 1 and 2. Work was resumed in September 1961, and the erection of the superstructure steel was completed in January 1962. Items of special interest on the superstructure include exposure of the outside steel column flanges with concrete exterior walls placed between the columns. Given the option to use precast or cast-in-place walls, the contractor elected to construct the walls in place. Also, cast-in-place roof slabs were used for the machine shop and service bay portions of the structure for protection from falling rock as these bays are adjacent to the canyon wall.

The roof of the unit bays, except unit bay 3, consisted of precast concrete decking, waterproofing membrane, and lightweight cover slabs. These precast concrete decking units were covered with a vapor barrier and a five-ply membrane, and the lightweight cover slabs were 3 inches in thickness. Some difficulties were experienced in protecting the membrane from...
damage during installation of the cover slab and related roof work. Unit bay 3, which would also be a visitors' observation deck, was constructed with a 4-inch regular concrete deck slab, placed on the structural steel, and a five-ply membrane and 3-inch-thick cover slab of regular concrete.

In an amendatory agreement dated May 7, 1962, in order to insure readiness of the powerplant for work under the completion contract, the contractor agreed to complete the walls, floors, structural roof slabs, and all interior installations for unit bays 1, 2, and 3 of the powerplant structure by June 15, 1962; and the same work in unit bays 4 through 8, the service bay and the machine shop bay of the powerplant structure, and the paving of the powerplant parking area by August 15, 1962. As the completion date for all work in the powerplant was established by the specifications as September 23, 1962, meeting the earlier completion date involved additional cost to the contractor for additional materials, labor, equipment and other expenses, and the contractor was reimbursed $128,000 for expediting this work. All work pertaining to unit bays 1, 2, and 3 was accepted on July 15, 1962; the remaining work under the amendatory agreement was substantially complete and accepted on August 15, 1962; and all remaining work involved in the powerplant construction was completed and accepted on September 23, 1962.

216. SECOND-STAGE CONCRETE. Concrete placed under the completion contract included blockout concrete, a control cable entry structure and certain lined sections, and miscellaneous concrete in the powerplant and various other locations. This concrete work also included bonded concrete surfacing, the 4-inch floor surfacing, and 3-1/2-inch terrazzo underbed on the several floor surfaces in the powerplant and other structures. This concrete was batched at a plant in Page, Ariz., transported to the powerplant in transit mixers, and placed by conventional methods. There were several instances where the underbed in the generator floor and on the generator balcony was placed too high, despite properly set screeds, and it was necessary for the contractor to bush these surfaces to allow for an adequate thickness in finish terrazzo. Owing to delays in scheduling the terrazzo work, these rough areas caused inconvenience and additional maintenance.

The completion contractor elected to use prepacked methods for placing second-stage concrete about the embedded parts of turbines (fig. 282), which was allowed under an alternative provision of the specifications. This concrete was placed by a subcontractor, Lee Turziillo and Cleveland Cement Co., Inc., a joint venture.

As this method is not often used, the aggregate placing and grouting methods utilized for this work are described below in greater detail than usual for second-stage concrete.

Prior to placing aggregate, the first-stage concrete was sandblasted and initial cleanup performed. Reinforcing around the draft tube liner was followed by the installation of the grout pipe and grout observation well piping. The grout pipe was installed on 5-foot centers for adequate grout coverage.
Figure 282.—Unit bay 1—Second-stage concrete outline.
The aggregate was dumped from buckets through a rubber "elephant trunk" into the areas on each side of the liner. The aggregate was then blown into place and into close contact with the liner. Aggregate was also dumped on the inside of the draft tube liner and placed through two 12- by 16-inch holes located approximately 10 feet from the upstream edge of the pier noses and about 15 feet apart in the bottom of the liner. Aggregate was also placed from the inside of the liner into the invert section between the first-stage concrete and the steel liner. The forms in the three outlet sections of the draft tube were left off until this portion was filled. Forms were installed and filling continued. The holes in the steel pier noses were adequate for filling with aggregate. Good results were obtained but placing of the aggregate was very slow.

Placing of the aggregate was usually done during one 8-hour shift and the aggregate was blown into place on the following two shifts. As preplacing progressed to springline and above, there were no difficulties in filling the blockout around the draft tube liner. In placing the aggregate in units 1 through 8, the time varied from 15 days maximum for unit 1 to a minimum of 2 days for unit 5. The average was about 7 days or twenty-one 8-hour shifts. Approximately 750 cubic yards of aggregate were placed around each liner. Very little breakage was noted during the placing of the aggregate.

Placing aggregate around the draft tube liner in unit 1 was started on December 11, 1962, and continued from elevation 3098.50 to elevation 3124.00. Three-inch maximum aggregate was used except for some 25 to 30 cubic yards of 1-1/2-inch maximum size used under the flat section of the draft liner. During the placing of aggregate around the unit 1 draft tube liner, the ambient temperature was low enough that a film of ice formed over the rock after washing. Forced draft air heaters were used to keep ice off the aggregate prior to the start of grouting. The heaters were used on the outside of the liner during the placing of the aggregate and inside the draft tube liner prior to grouting. The heaters inside the liners were not completely satisfactory even though the throat of the liner was covered.

The grouting operation of unit 1 was started on January 10, 1963, when the daily mean temperature had been 31°F. for several days prior to grouting. Temperatures were as low as 14°F. before grouting was completed on January 12, 1963, with a daily mean temperature of 17°F. The surface area at elevation 3124.00 was covered and kept heated in accordance with specifications requirements for winter protection. Temperatures of the draft tube liner were obtained by using a surface thermometer and recorded over a period of 10 days. When temperatures were obtained above 60°F., a fog spray was to be installed for cooling purposes. With the extremely low ambient temperatures it was not necessary to use fog spray for cooling purposes on unit 1 draft tube liner. Temperatures peaked at 60°F. in about 72 hours. Procedures were similar on the other units, except that fog sprays were needed to reduce temperatures in other units. Unit 8 liner was grouted on July 18, 1963, with an ambient temperature of about 92°F.

Two gages were installed in the draft tube liner during the grouting operation. With all holes plugged to hold the head of water there was at no time any pressures built up above 10 pounds per square inch. Generally, 6 to 8 minutes of pumping on each hookup would raise the grout lift approximately 20 inches. There were eight 5-inch holes in the draft tube liner to facilitate aggregate or concrete placing. The holes were plugged with wooden plugs when grouting was started. The 41 tapped holes were also plugged with steel plugs. The forms at each of the three openings between the draft tube liner first-stage concrete could not be made watertight and there was no assurance that there was a head of water ahead of the grout at all times.

Attempts were made to keep grout off the top of the construction joints. The pumping was stopped so that approximately two-thirds of the rock would be embedded. It was noted that excess grout on the surfaces would tend to peel off in wafers even though the surfaces were flooded for curing. Escape of gas through the top of the grouted lift continued for 3 or 4 days from the buildup of hydrogen gas resulting from the aluminum powder in the grouting admixture. After the cores were taken there was some evidence of entrapped air in the core.

Equipment used for pumping were grout pumps and a 2-cubic-yard shop made agitator mixer. Two-inch grout lines were used, with a pumping distance of approximately 500 feet and approximately 50 feet of 1-1/4-inch hose to each hookup. A wye connection with two lines from a 2-inch supply line was used. As many as four hookups were made at a time with two pumps operating. Fair results were obtained by alternating pumping and progressively working over the area. Some difficulties were experienced because of the operating condition of some equipment and use of inexperienced personnel. Several 6-inch cores were obtained from predetermined locations in units 1, 2, 3, and 6. Cores drilled indicated that good results were obtained in filling the voids, based on only short sections of core recovered, and that there was good bond to the aggregate.
The aggregate was dumped from buckets through a rubber "elephant trunk" into the areas on each side of the liner. The aggregate was then blown into place and into close contact with the liner. Aggregate was also dumped on the inside of the draft tube liner and placed through two 12- by 16-inch holes located approximately 10 feet from the upstream edge of the pier noses and about 15 feet apart in the bottom of the liner. Aggregate was also placed from the inside of the liner into the invert section between the first-stage concrete and the steel liner. The forms in the three outlet sections of the draft tube were left off until this portion was filled. Forms were installed and filling continued. The holes in the steel pier noses were adequate for filling with aggregate. Good results were obtained but placing of the aggregate was very slow.

Placing of the aggregate was usually done during one 8-hour shift and the aggregate was blown into place on the following two shifts. As preplacing progressed to springline and above, there were no difficulties in filling the blockout around the draft tube liner. In placing the aggregate in units 1 through 8, the time varied from 15 days maximum for unit 1 to a minimum of 2 days for unit 5. The average was about 7 days or twenty-one 8-hour shifts. Approximately 750 cubic yards of aggregate were placed around each liner. Very little breakage was noted during the placing of the aggregate.

Placing aggregate around the draft tube liner in unit 1 was started on December 11, 1962, and continued from elevation 3098.50 to elevation 3124.00. Three-inch maximum aggregate was used except for some 25 to 30 cubic yards of 1-1/2-inch maximum size used under the flat section of the draft liner. During the placing of aggregate around the unit 1 draft tube liner, the ambient temperature was low enough that a film of ice formed over the rock after washing. Forced draft air heaters were used to keep ice off the aggregate prior to the start of grouting. The heaters were used on the outside of the liner during the placing of the aggregate and inside the draft tube liner prior to grouting. The heaters inside the liners were not completely satisfactory even though the throat of the liner was covered.

The grouting operation of unit 1 was started on January 10, 1963, when the daily mean temperature had been 31°F. for several days prior to grouting. Temperatures were as low as 14°F. before grouting was completed on January 12, 1963, with a daily mean temperature of 17°F. The surface area at elevation 3124.00 was covered and kept heated in accordance with specifications requirements for winter protection. Temperatures of the draft tube liner were obtained by using a surface thermometer and recorded over a period of 10 days. When temperatures were obtained above 60°F., a fog spray was to be installed for cooling purposes. With the extremely low ambient temperatures it was not necessary to use fog spray for cooling purposes on unit 1 draft tube liner. Temperatures peaked at 60°F. in about 72 hours. Procedures were similar on the other units, except that fog sprays were needed to reduce temperatures in other units. Unit 8 liner was grouted on July 18, 1963, with an ambient temperature of about 92°F.

Two gages were installed in the draft tube liner during the grouting operation. With all holes plugged to hold the head of water there was at no time any pressures built up above 10 pounds per square inch. Generally, 6 to 8 minutes of pumping on each hookup would raise the grout lift approximately 20 inches. There were eight 5-inch holes in the draft tube liner to facilitate aggregate or concrete placing. The holes were plugged with wooden plugs when grouting was started. The 41 tapped holes were also plugged with steel plugs. The forms at each of the three openings between the draft tube liner first-stage concrete could not be made watertight and there was no assurance that there was a head of water ahead of the grout at all times.

Attempts were made to keep grout off the top of the construction joints. The pumping was stopped so that approximately two-thirds of the rock would be embedded. It was noted that excess grout on the surfaces would tend to peel off in wafers even though the surfaces were flooded for curing. Escape of gas through the top of the grouted lift continued for 3 or 4 days from the buildup of hydrogen gas resulting from the aluminum powder in the grouting admixture. After the cores were taken there was some evidence of entrapped air in the core.

Equipment used for pumping were grout pumps and a 2-cubic-yard shop made agitator mixer. Two-inch grout lines were used, with a pumping distance of approximately 500 feet and approximately 50 feet of 1-1/4-inch hose to each hookup. A wye connection with two lines from a 2-inch supply line was used. As many as four hookups were made at a time with two pumps operating. Fair results were obtained by alternately pumping and progressively working over the area. Some difficulties were experienced because of the operating condition of some equipment and use of inexperienced personnel. Several 6-inch cores were obtained from predetermined locations in units 1, 2, 3, and 6. Cores drilled indicated that good results were obtained in filling the voids, based on only short sections of core recovered, and that there was good bond to the aggregate.
Grout was batched into transit mixers on the rim near the south portal of the powerplant access road tunnel and transported through the tunnel to the agitator mixer. Grout temperatures usually ran from 73°F to 76°F, but occasionally temperatures of the grout during the summer months ran as high as 94°F. The higher temperatures presented problems of getting grout pumped to locations where needed. Temperatures were kept below 90°F by the use of crushed ice in the mixing water. The grout lines from the pumps were covered with burlap and kept wet when pumping. Grout slump was checked with a grout flow cone.

When the forms were stripped in the draft tube liner sections between the steel liner and the first-stage concrete, the surfaces resembled a terrazzo finish. The weight of aggregate against the forms appeared to keep the grout from completely covering the aggregate in contact with the forms. External form vibration was exercised but with poor results where much aggregate was overhead. Good results were obtained from external form vibration on the vertical faces. As soon as forms were stripped the imperfections such as surface irregularities were repaired and the she-bolt holes plugged. In order to obtain an F3 (specially formed) finish, the contractor hand-stoned mortar into the terrazzo-looking surfaces. The mortar application was kept on continuous water cure for a minimum of 7 days and good results were obtained with no discoloration.

After the preplaced aggregate was grouted and cooled, the liner was sounded for drummy areas. The 41 one-inch holes in the liner section were water tested at a pressure of 10 pounds per square inch. Only a few holes were interconnected. Only a very small amount of neat grout was used; possibly one-half cubic foot was used to fill the voids in unit 1 draft tube liner. All draft tube liners, units 1 through 8, were water tested during the grouting operation the spiral case was being prestressed at 225 pounds per square inch. Temperatures were recorded from the time grouting started until the spiral case was embedded and water was circulated in sufficient quantity to maintain a 5°F minimum temperature rise.

The second placement, from elevation 3124.00 to elevation 3131.75 was conventional concrete with blockout section around the upper draft tube liner. The blockout section from elevation 3124.00 to elevation 3131.75 and to the springline of the spiral case at elevation 3140.00 was filled by the prepacked method.

After joint cleanup, installation of reinforcing steel and embedded items, the grout intrusion piping was installed. This installation included piping for void grouting of the apex between the spiral case and the stay ring. Three-inch maximum aggregate was placed high around the spiral case, leaving enough area adjacent to the case to dump 1-1/2-inch maximum size aggregate. The 1-1/2-inch maximum aggregate was kept to a minimum of approximately 50 cubic yards. Better results were obtained by keeping the 1-1/2-inch aggregate confined to as small an area as possible to facilitate moving the rock into place by blowing. The aggregate was placed in contact with the stay ring and the underneath side of the spiral case by the use of compressed air.

The same procedure as outlined previously for grouting the draft tube liner in unit 1 was used in pumping the grout into the prepacked sections around the spiral cases of units 1 through 8. In one instance on unit 2, a fairly large section did not take grout and it was necessary to repack the aggregate and regroute the voids. The ungrouted area was investigated, additional jacks were placed, and the vents and returns indicated that the grouting was adequate. Grouting of the third placement in unit 1 that was started June 14, 1963, and required 26 hours to complete. Unit 2 required 28 hours and unit 3 required 21 hours to grout. The blockout around the upper draft tube liner from elevation 3124.00 to elevation 3131.50 was pumped first and then the grout pipe around the edge of the turbine blockout closing in on the high points of the spiral case was pumped alternately and progressively to get a complete seal. All of the grout pipe in each segment was hooked for grouting if no grout return occurred from other hookups. After all grouting was completed, the 1-1/2-inch line that was installed in the apex between the stay ring and the spiral case was hooked to grout any possible voids. The 1-1/2-inch supply line was left with a hydrostatic head of grout of about 10 feet above elevation 3140.00.

During the grouting operation the spiral case was being prestressed at 225 pounds per square inch. Temperatures were recorded from the time grouting started until the spiral case was embedded and water was circulated in sufficient quantity to maintain a 5°F minimum temperature rise.

217. ELEVATORS IN POWERPLANT. Two elevator shafts were provided in the right abutment or control area end of the powerplant. One was for a 10,000-pound-capacity passenger elevator and the other was for a 2,000-pound-capacity passenger elevator. The elevators were furnished and installed by Pacific Elevator and Equipment Co., of San Francisco, Calif., under solicitation No. DS-8443. Installation of the elevators was started as soon as the hoistway and machinery rooms were made available on May 15,
1963, and all work under the contract was accepted as substantially complete December 26, 1964. Completion date for the contract was extended 177 days to cover delay to the contractor caused by failure of the Government to make the elevator hoistways and machinery rooms available as specified. The cost of furnishing and installing the two elevators in the powerplant was $130,640. This contract also provided for installation of two elevators in the dam, which is discussed in section 192.

218. TERRAZZO AND TILE. Major areas designated to receive terrazzo floor finishes in the powerplant were the main generator floor, the visitors’ walkway balcony floor, and the floors of the rest rooms and first aid rooms. Terrazzo floor finishes could not be placed on the main generator floor or visitors’ walkway until the completion contractor was out of the way. However, it was necessary to finish the floors and walls before the completion contractor completed his work in those areas where fixtures and partitions would be mounted on them. Mainly, these areas were the floors and walls of the rest rooms and first aid rooms located throughout the powerplant and office area.

As it was impractical to award a contract for such a small amount of dispersed work, the placing of terrazzo floors and installation of ceramic tile on the walls of the rest rooms and first aid rooms was included with other terrazzo and tile work in the dam under specifications No. DC-6057 which was awarded to Marus Marble and Tile Co., of Greensboro, N.C. Major work under these specifications was previously discussed in section 195.

219. ROOF REPAIRS. The flat powerplant roof for units 1, 2, and 4 through 8 consisted of precast concrete roof slabs supported on the concrete walls and wide-flange roof purlins. These slabs were covered with a vapor barrier and a five-ply membrane waterproofing. This membrane waterproofing was covered with lightweight reinforced concrete cover slabs 21 feet 7 inches by 19 feet 9 inches. The joints between the slabs were filled with corkboard capped with joint compound. Wood cants and monel metal flashings were used at the edge of the roof and at expansion joints at bay lines.

After the powerplant roof was completed, leaks developed from undetermined causes. Repairs were made by Superior Roofing Co., Inc., of Salt Lake City, Utah, under specifications No. 400C-292. Work was started July 6, 1965, and was completed August 31, 1965.

Principal features of work in unit bays 1, 2, and 4 through 8 consisted of removing joint compound and sponge-rubber strips from existing expansion joints and tooled grooves, cleaning grooves and joints to be refilled with corkboard, joint compound and calking compound, and furnishing and placing bonded sheet neoprene cap strips over prepared joints complete with wood cants as required. Roof repairs for unit bay 3, the service bay, and the machine shop bay were less urgent and were deferred until a later season.

Order for changes No. 1 was issued to change the method of preparing and refilling joints to be covered with bonded sheet neoprene cap strips, increase the width of the neoprene cap strips in some locations, and add joints to be covered with neoprene sheets; and (2) to apply sealer, additional primer, and liquid top coat along the edges of the neoprene roof strips to obtain a satisfactory bond of the topcoat. An additional 20 calendar days were allowed for completion of the contract because of these changes and additions.

220. GLASS DOORS. After self-guided tours of the dam and powerplant were started, it was decided that at a number of locations on the tour route full length glass panel doors should be substituted for the existing all-metal doors.

Cedar Glass Co., of Page, Ariz., was awarded the contract under specifications No. 400C-353 for the replacement of existing all-metal doors. Aluminum glass panel entrance doors were installed as follows: Two pair were located in the dam at the downstream adits to the powerplant, four pair at powerplant walkways at elevation 3188.5, two pair at elevator towers at the top of the dam, one pair at the tunnel entrance from the visitor center at the top of the dam, and one pair at the entrance to the unit 3 powerplant observation deck. Two pair of steel doors with glass lights approximately 23 by 34 inches were installed in the wall openings between rooms 1101 and 1102 of the powerplant office area. All work was completed and accepted November 26, 1967.

221. FLOOR REPAIRS. There were several instances where the U-3 (steel-troweled) finish on the concrete floors in the powerplant was damaged by contractors’ forces as a result of inadequate precautions to protect these finished surfaces. Some of the floor areas were damaged with pock marks, spalls, and gouges varying in size from less than 1 inch up to 9 inches in circumference and depths up to nearly an inch. Some of these areas were repaired using conventional methods with good results. However, late in 1962, the contractor desired to find a satisfactory method of repair that could be applied more easily and produce a color that would more nearly match the existing concrete finish.
Several brands of epoxy cement mixtures were tried before finding one that proved satisfactory. The epoxy cement was furnished in 1-gallon containers of a part A and a part B, separately. Owing to the rather high material cost, the small containers and small mixes were recommended to eliminate waste. The areas were thoroughly cleaned with wire brushes to remove laitance or any other foreign material in small areas, or by bushing in the larger areas, and the area blown clean. Applied only to spauied areas that were thoroughly dry, equally mixed proportions of epoxy material smoothed with the patching trowel tended to leave the desired smooth finish, but the epoxy "pulled" enough to leave a slight depression in the center of the wet material.

The best results were obtained by leaving the patching material slightly high in the depressions, followed by dry grinding with a power stone of No. 120 grit. The epoxy was ground any time from 48 to 72 hours with good results, and the No. 120 grit stone removed the high spots with no damage to the surrounding U-3 finish. In practice, this method of grinding apparently speeded up the repair work slightly because not so much time was required in smoothing out the newly placed material. The epoxy was applied with an air temperature of 40° to 50° F. in early 1963. The patched area could be opened to normal foot traffic after several hours. In a few days, the patch area had blended with the surrounding areas and was difficult to detect except in the larger repair areas or when the floor was wet. Following an extended period of observation, both the bond and appearance are satisfactory on the repairs made on floors on the interior of the powerplant. Repairs made in areas subject to outside weather conditions are peeling from the concrete surface and will eventually require additional repairs.

222. PENSTOCK SUPPORT AREA. Excavation for penstock support footings was started in April 1960. By order for changes No. 5 the contractor was directed to excavate a minimum of 5 feet into sound rock for these footings. Concrete placement started in May 1960, with placement of 5-foot lifts for supports No. 2-B and 2-C. The first two lifts were 5 feet in height, and after that the H-frame lifts were 10 feet in height. Construction of the penstock supports proceeded along with concrete construction in the dam and powerplant. Beside the A supports which were on the face of the dam, there is one support each for penstocks No. 1 and 8, two supports for penstocks No. 2, 3, 6, and 7, and three supports for penstocks No. 4 and 5. The C and D supports were constructed to elevation 3136.84, and the B footings, over which a vault was later constructed, extended to elevation 3140.0. During construction of the footings, backfill was kept to within 50 feet of the top of all footings at all times. All penstock support footings were completed in November 1961. The concrete vaults in the B supports were completed during 1962 (fig. 283).

The horizontal penstock sections were placed and bolting of the expansion joints and sleeve-type couplings was completed in September 1962. The area around the supports was backfilled (fig. 284) with free-draining material excavated from the riverbed and stockpiled at the downstream cofferdam. Backfill was delivered to the area by conveyor through the powerplant, was spread by a tractor with dozer blade, and was kept within 50 feet of the top of the supports as the supports were constructed.

When backfill in the penstock support area reached elevation 3110 a 2-foot gravel blanket was placed over the area to elevation 3112. Drainage pipe was laid within the gravel blanket and backfill operations were continued. Select backfill material was placed under the horizontal penstock sections. Compaction of the backfill in this area and construction of the drainage
system was done under order for changes No. 6. Compaction to 70 percent of laboratory maximum dry density was accomplished by four passes of a crawler-type tractor weighing approximately 40,000 pounds.

223. POWERPLANT ACCESS TUNNEL. The powerplant service, or access, road tunnel was excavated from both ends beginning in August 1957. Frazier-Davis Construction Co. of St. Louis, Mo., subcontractor for all tunnel work, excavated the lower (upstream) section of the tunnel and subcontracted the upper (downstream) section to Gibson-Roberts, Inc., of Yardley, Wash. By the end of 1957, the tunnel had progressed 907 feet from station 95+00 at the upper end and 1,129 feet from station 1+12 at the lower end.

The original plan for the tunnel called for a 560-foot section of the roadway to be in opencut along the talus from station 47+00 to station 52+60. Because of the jointed nature of the rock at the intermediate portal locations, it was thought better to relocate the opencut roadway into the canyon wall and the opencut section was therefore eliminated. The realigned tunnel was increased in length by 667.76 feet and an equation was necessary at station 64+01.23 BK=57+33.47 AHD. The horizontal distance through the tunnel equals 10,056 feet. The tunnel contains 18 adits at approximately 500-foot intervals and they vary in length from 80 to 200 feet. All adits are 12 feet wide by 10 feet high to the A-line and have an arched crown extending 2 feet at the centerline.

The tunnel is 20 feet wide at the A-line and, from a point 12 feet 6 inches above the A-line floor the top section is arched on a 10-foot radius. Excavation was accomplished by blasting methods. Generally, eighty-two 1-1/2-inch-diameter holes, 12 feet deep, were drilled on 2-1/2-foot centers and a burnt cut used as a burden breaker. An average of 350 pounds of 50 percent blasting powder was used in a full face round. Powder holes were drilled from a two-floored, rubber-tired, drilling jumbo. After the dayshift had drilled and blasted, muck was removed by the swingshift with an overhead loader. The muck was loaded into front-dump trucks and wasted into the canyon through the adits. After the muck was removed, the tunnel walls and ceiling were scaled to remove any loose rock. The average depth per round was 11.4 feet.

The two tunnel crews, one working from each end, met at station 54+11.3 on June 24, 1958. Because the rock encountered in the tunnel was much more jointed than was anticipated and had a greater tendency to break up, the number of steel ribs actually required was five times the number originally estimated, and the number of roof bolts was 14 times those estimated.

The drainage system consisted of an 18-inch corrugated metal pipe culvert from either side of the upper portal down the centerline of the tunnel and out the first adit at station 89+98.

Crushed rock base and bituminous surfacing was placed on the tunnel roadway in April 1959. Excavation and placing of crushed rock base for the access from the Bitter Springs Highway to the downstream (upper) portal of the service road tunnel had been completed in 1957.

Concrete lining was placed at the lower (upstream) portal of the tunnel from station 1+10 to station 1+30 during April 1959, and the walls at the upper (downstream) portal were lined from station 95+00 to station 94+72 during that month. The arch and exterior face were completed early in 1960 and concrete was placed above the portal to hold some loose rock in place. The difference in elevation between the two tunnel portals is nearly 750 feet, and the varying grade through the tunnel reaches a maximum of 8 percent.
A. INSTALLATION OF TURBINES AND GENERATORS

224. HYDRAULIC TURBINES AND GOVERNORS. (a) General Description.—The hydraulic turbines were furnished by Baldwin-Lima-Hamilton Corp. of Eddystone, Pa., under invitation No. DS-5234. This was the largest single turbine contract in the Bureau of Reclamation history at the time (1960). The eight hydraulic turbines installed in Glen Canyon Powerplant are the vertical-shaft Francis type, with field-welded plate steel spiral cases and elbow-type draft tubes. Each turbine has a capacity of 155,500 horsepower, at full gate opening, when operating at 150 revolutions per minute under a net head of 450 feet. At a head of 510 feet and an output of approximately 150,000 horsepower, the required warranty efficiency was 90 percent.

The governors for regulating the speed of the turbines are of the oil-pressure, cabinet, actuator type with electric-driven speed-responsive elements. They were furnished by Pelton Division of Baldwin-Lima-Hamilton Corp. under invitation No. DS-5562. Each governor is a complete unit, its principal parts consisting of the actuator with its relay valve, indicators, and controls, restoring mechanism, motor-driven pumping units, pressure tank, sump tank, and oil piping used for regulating the speed by controlling the gate opening of the turbine. The governors are rated at 441,700 foot-pounds at an oil pressure of 250 pounds per square inch, corresponding to the capacity of the turbine servomotors.

The turbine installation work was primarily the responsibility of the completion contractor, but the supply contract provided for certain field installation work by the turbine manufacturer in the assembly, alinement, and hydrostatic testing of embedded parts. This division of the work between the supply and completion contractors was sometimes difficult to handle in the field in that there were early problems in differentiation in responsibility for the work between crews. However, as the same subcontractor was employed by both the completion contractor and the turbine manufacturer, the problems were a matter of cost distribution rather than actual work conflict.

(b) Installation Procedure.—Installation of the draft tube liners and placement of second-stage concrete were the responsibility of the completion contractor. The draft tube liners were field welded in sections erected in place in the draft tubes. This method of individual welding of plates was selected by the subcontractor, Chicago Bridge and Iron Co., as the most economical method, both with respect to fabrication and field erection. Basically, the draft tube liners consist of two portions, conveniently referred to as upper and lower sections. The shorter upper section is flanged at the top for bolting to the discharge ring, while the lower end makes a field-riveted joint at the connection to the lower section of the draft tube liner. The makeup section, or upper piece of the lower draft tube liner, was then placed in approximate position followed by the lowering of the upper draft tube liner section into the factory level. Portions of the turbine parts were manufactured by S. A. Cockerill-Ougree of Seraing, Belgium. These parts consisted of the runner and runner caps; main shaft and sleeve; servomotors, rods, levers, links, pins, operating ring and wicket gates; head cover; distributor ring; stationary and rotating seal rings; guide bearing, bearing support and bearing cover; oil catcher; stuffing box, gland, and lantern rings, walkways, stairs, and handrailings. These are essentially all of the nonembedded parts. Early difficulties were experienced in casting some of the turbine parts but these were resolved by the subcontractor as the work progressed. In addition there were significant delays in delivery of the rotating parts of the turbines which caused field problems in meeting installation schedules. An item of note was that Baldwin-Lima-Hamilton's bid was based on a combination of foreign and domestic subcontracting of the elements of the turbines, which drew protests from foreign and domestic bidders and was submitted to the Comptroller General of the United States for a ruling before award of the contract.
approximate position, but the makeup section was not assembled at this time. A platform and instrument-supporting structure was fabricated at the site from pipe and steel plate in tripod form and was welded in place at the upper end of the lower draft tube liner. Figures 285 and 286 show the distributor ring and spiral case, respectively.

The purpose of this structure was to support a plumbline wire and an engineer’s level used during the leveling of the stay ring flange. The discharge ring was in two sections; the upper flange was designed for bolting to the lower flange of the stay ring, while the lower flange mated with the flange on the upper draft tube liner. The upper draft tube liner was placed in position as a unit and the discharge ring was placed in position on jack supports. The discharge ring was closely leveled and centered to the plumbline wire, checked for roundness, cleaned, and then prepared for placing of the stay ring. The stay ring was brought in by sections, placed on its supporting jacks and temporarily bolted to the discharge ring. The centerlines and match marks placed in the shop were used to position the stay ring to lines established by the survey crews. The stay ring halves were made up with large shrink bolts which were heated and stressed to a predetermined amount to make a tight joint between stay ring halves. The spiral case and extension sections were placed in the turbine pit in approximate position on jacks and blocking.

At this point in the installation the work was turned over to the supplier, Baldwin-Lima-Hamilton Corp., for field welding and hydrostatic testing of the spiral cases. Although there was a change in contract responsibility, the field crews remained the same since Chicago Bridge and Iron Co. subcontracted the turbine assembly erection work from both the completion contractor and the turbine manufacturer. Through the turbine supplier, Chicago Bridge and Iron Co. made a proposal to change the spiral case installation to an all-field-welded, no stress relieving, assembly of spiral cases. This proposal involved a very complete welding procedure supervised by Chicago Bridge and Iron Co.'s welding engineers. The use of radiographs on all welded joints provided quality control of production welding. Baldwin-Lima-Hamilton Corp. assumed complete responsibility for the adequacy of this method up through the hydrostatic testing of the spiral case.

It was reported that this was the first time the Bureau had allowed this method of installation of spiral cases. From an installation point of view, the method proved to be very satisfactory, primarily due to the high quality of welding and supervision supplied by the subcontractor. When the spiral case had been assembled, the spiral case was alined and leveled by the use of turnbuckles, jacks and supports, as required by the turbine manufacturer. The head cover flange of the stay ring was leveled by the use of micrometer level attachments to a surveyor's instrument. This level and
alinement was maintained during hydrostatic testing and placement of concrete.

The next step in the erection was the hydrostatic testing of the spiral case. The opening at the stay vanes was closed by the use of a temporary test ring supplied for this purpose. The tests of the spiral case proved that the fieldwork was completely watertight, and the stressing of the case through the working range of pressure proved the structural quality of the work. Upon satisfactory completion of the hydrostatic test, the pressure in the cases was brought to 225 pounds per square inch and maintained until the case was embedded and the concrete was cured. On completion of the hydrostatic test and checking of the tie-downs, alinement, and levels, the spiral case was turned back to the completion contractor for the remainder of the erection and assembly of the turbines.

The pit liner was placed on the spiral case with particular attention given to location of servomotor bases. This was difficult and time consuming during installation of the first three units, as the bases were refitted in the field to the range of desired tolerances; the problem was corrected at the fabrication shop on the last five units. The external piping and grout piping with vents were installed, a final check of all items to be embedded was made, and the unit was released for concrete placement. After the concrete had been placed and cured around the spiral cases, a final set of micrometer levels was taken on the stay ring flange. The adequacy of this method of anchoring and placing of concrete around the spiral case and pit liner was confirmed by these final level readings.

The bottom ring was placed, centered, leveled and bolted down, but not doweled at this point. The lower platform of the boring rig was placed in position on the top flange of the draft tube liner. This platform later proved to be too large to be removed after lower stationary seals had been placed and required extensive repair work in unit 1. The lower and upper stationary seal rings were placed in the unit at this time to be later hung from brackets on the head cover. The head cover with four wicket gates spaced 90° apart was placed in the unit on the stay ring flange. The head cover was carefully positioned to the unit centerline and was aligned so that the four index wicket gates were plumb and with the proper clearances. The remaining wicket gate bores were checked with a tribar and were sanded or buffed for proper clearance. The head cover and bottom ring were then drilled and reamed for dowels. The guide bearing housing, guide bearing and packing box were aligned to plumb wire centerline and drilled and reamed for dowels. The bottom platform of the boring rig was aligned at this time and bolted securely. The head cover, wicket gates, guide bearing, guide bearing housing, and packing box were removed from the unit. The next operation was the placing of the portable boring rig for machining of the stationary seal rings. The basic four-wire plumbing, combined with rotation checking, was adapted to plumb the main shaft.

The stationary seal seats were machined and the seats were bolted in position. The inside diameter of the wearing rings was machined to give proper clearance with the rotating seals of the runner.

The head cover and boring rig were removed from the unit. The main shaft and runner were assembled on the generator deck using the coupling bolts stretched by 0.012 inch to give proper stress in the bolts. The throat ring was installed on top of the upper draft tube liner. The runner and main shaft were then placed in the unit on the ledge provided by the throat ring.

The main shaft was plumbed and the runner was centered in the seal rings using shim stock in the runner clearance space. The wicket gates were placed in the bottom ring in their respective positions and the head cover installed over them. The remaining parts were then assembled in the turbine pit. The servomotors gate shifting ring, gate links, and guide bearing housing were assembled and adjusted. The turbine was then at a point it could be released for generator erection.

Table 4 lists the chronology for the turbine erection.

<table>
<thead>
<tr>
<th>Unit No.</th>
<th>Started turbine installation</th>
<th>Completed turbine installation</th>
<th>Unit placed in service (first generation)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>9-18-62</td>
<td>1-16-64</td>
<td>9-4-64</td>
</tr>
<tr>
<td>2</td>
<td>9-20-62</td>
<td>3-9-64</td>
<td>9-22-64</td>
</tr>
<tr>
<td>3</td>
<td>9-27-62</td>
<td>4-14-64</td>
<td>12-11-64</td>
</tr>
<tr>
<td>4</td>
<td>10-16-62</td>
<td>6-26-64</td>
<td>2-10-65</td>
</tr>
<tr>
<td>5</td>
<td>10-24-62</td>
<td>9-18-64</td>
<td>7-19-65</td>
</tr>
<tr>
<td>6</td>
<td>10-26-62</td>
<td>11-24-64</td>
<td>10-13-65</td>
</tr>
<tr>
<td>7</td>
<td>11-5-62</td>
<td>5-3-65</td>
<td>1-21-66</td>
</tr>
<tr>
<td>8</td>
<td>11-2-62</td>
<td>5-11-65</td>
<td>2-28-66</td>
</tr>
</tbody>
</table>
The installation of the governors was under the direction of a factory erection engineer who performed all of the work inside of the cabinets including the operation of the governor during the first start. The completion contractor's work consisted of moving the equipment to the powerplant, alining and leveling it in position, and then placing a grout pad at the base of the cabinets.

(c) Operational Tests.—The purpose of the operational tests was to determine that all phases of the installation work had been performed properly, all control devices had been checked and adjusted, and the equipment was ready for operation. As the generators and other equipment were involved in the turbine and governor operational tests, all testing was coordinated through the test coordinator. Preliminary tests were made before admitting water to the turbine. The plumb of the combined main shafts was checked from four plumblines at approximately 90° apart and the runner concentricity was rechecked. The governor and turbine wicket gates were operated several times, the gate squeeze was set, and the rate of movement and operation of all automatic and safety devices were checked and adjusted as required. The timing of the wicket gates was set and their position recorded for use during other tests. The wicket gate timing could then be set without unwatering the spiral case. The runner clearances and shaft movement were measured under blocked servomotor conditions with full governor pressure applied.

(d) Repair Work.—During the first months of operation of the turbines, it was noted that the stainless steel cladding on the runners was inadequate. Baldwin-Lima-Hamilton was notified of the deficiencies on February 25, 1965. On June 18, 1965, representatives of the Bureau, Baldwin-Lima-Hamilton, and one of the latter's subcontractors met at the Glen Canyon Powerplant. The purpose of the meeting was to inspect the runners and to develop a procedure to accomplish the repair work. It was determined the coating deficiency was the primary responsibility of the subcontractor supplier.

One of the problems at this time was to determine the thickness of the stainless steel coating, in

<table>
<thead>
<tr>
<th>Unit No.</th>
<th>Operational hours prior to repair</th>
<th>Labor man-hours</th>
<th>Dates of repair</th>
<th>Pounds of Welding rod applied</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>9,659</td>
<td>380</td>
<td>November 3, 1965</td>
<td>December 20, 1965</td>
</tr>
<tr>
<td>2</td>
<td>11,300</td>
<td>600</td>
<td>January 18, 1966</td>
<td>March 30, 1966</td>
</tr>
<tr>
<td>3</td>
<td>10,488</td>
<td>480</td>
<td>March 30, 1966</td>
<td>June 13, 1966</td>
</tr>
<tr>
<td>4</td>
<td>11,227</td>
<td>560</td>
<td>June 13, 1966</td>
<td>September 7, 1966</td>
</tr>
<tr>
<td>5</td>
<td>3,060</td>
<td>223</td>
<td>December 10, 1965</td>
<td>January 17, 1966</td>
</tr>
<tr>
<td>6</td>
<td>6,941</td>
<td>576</td>
<td>September 7, 1966</td>
<td>January 5, 1967</td>
</tr>
<tr>
<td>7</td>
<td>8,762</td>
<td>596</td>
<td>May 5, 1967</td>
<td>July 15, 1967</td>
</tr>
<tr>
<td>8</td>
<td>6,440</td>
<td>588</td>
<td>January 6, 1967</td>
<td>April 26, 1967</td>
</tr>
</tbody>
</table>
place, on the runners. The defects were apparent in units that had been in operation for some time; but in units that were not in service, or had only a small number of hours of operation, it was very difficult to determine coating thickness. An inspection determined that the repair work fell into two areas. Some areas were the responsibility of Baldwin-Lima-Hamilton and others were the Bureau’s responsibility. All parties agreed the work was required on all eight runners, but no workable basis was available to determine the amount of repair in advance. A device was developed by a Bureau employee to measure the thickness of the stainless steel cladding in place. The repair work was performed by Chicago Bridge and Iron Co., the installation subcontractor, on a time-and-material basis. Table 5, on the preceding page, gives the time and material involved in the repair in the Government’s area of responsibility.

During early operations, the method of securing the throat ring to the upper draft tube liner was also found to be unsatisfactory. The bolts were sheared off during operation and the throat ring in unit 1 was discovered to be completely free during an inspection. The supplier was required to skip weld the throat ring to the upper draft tube flange—in addition to bolting—on all units and no further difficulties were experienced from this cause.

225. GENERATORS. (a) General.—The General Electric Co. of Schenectady, N. Y., furnished and installed the eight generators for the Glen Canyon Powerplant (fig. 287) in accordance with invitation No. DS-5522. The contract provided for furnishing, installing, and testing eight 125,000-kv.-a., 90 percent power factor, 13,800-volt, 150-r.p.m., 60-cycle, vertical-shaft, hydraulic-turbine-drive, alternating-current generators, as well as the associated direct-current excitation system with controls, control of generator cooling water system by flow modulation, and specified spare parts for the generation units. Fabrication of the eight generators was started at the company plant on January 3, 1962, and installation at the site on unit 1 began on December 26, 1963. Assembly and testing, except for final acceptance tests, were completed on February 28, 1966. Construction proceeded concurrently on the other generators. Unit 1 was placed on the line for the first time September 1, 1964; unit 2, September 18, 1964; unit 3, December 10, 1964; unit 4, February 9, 1965, unit 5, July 8, 1965; unit 6, October 6, 1965; unit 7, January 14, 1966; and unit 8, February 25, 1966.

(b) Rotor Assembly.—The first generator shaft was lifted onto the rotor erection pedestal in the erection bay by one of the 300-ton overhead cranes on December 26, 1963. The rotor spider was next placed on the rotor shaft and bolted to the shaft flanges. A suitable scaffolding was erected around the spider for a working area and to carry the bundles of laminations for the rotor stacking. The overhead crane was also used to handle the 500-pound bundles of laminations. As the laminations were stacked, four presses were made to insure a tight mass. This was accomplished by placing pipe sleeves over the rotor rim bolts for the length of the unstacked portion. Rim stud nuts were then tightened on the pipe
sleeves. During the final press, the rim studs were tightened with an impact wrench and all the rim stud nuts were lock welded.

Field poles were delivered as required for each unit and were checked for dielectric insulation resistance prior to installation. Those pole pieces that were low in value were internally heated, using electric welders or high-current rectifiers, until the proper dielectric value was obtained. The individual pole pieces were placed on the rotor with the powerplant overhead crane. They were held in place by vertical keys driven tight; the surplus key stock was cut off and stop plates were installed on both ends of the keys. Series field connections between the poles were silver-soldered and final connections were made to the slip rings by a bus system. The rotor was spray-painted with insulating varnishes before being installed in the stator bore. Figure 290 shows a closeup of the rotor for unit 8.

(c) **Stator Assembly.**—Each stator was shipped in three sections on flatcars to Flagstaff, Ariz., then transported to Glen Canyon by special truck. Stator erection began by placing the foundation pedestals to proper elevation. The three sections were placed in approximate position, bolted together, rounded to proper diameter, and then bolted and horizontally doweled to the foundation pedestals.

Each stator section was shipped with the armature coils in place. At each location where the stator sections bolted together, eight makeup coils were installed by armature winders. The 14 coils originally installed at the factory were lifted and replaced after the eight makeup coils were added at each junction. All makeup and lift coils were heated to 85°C surface temperature for 1 hour, which rendered the insulation flexible. Series coil connection phase jumpers and the bus sections in the splits were silver-soldered. The completed coil assembly with buses and jumper was given two coats of insulating varnish. The completed stator assembly was centered in the pit with reference to the center of the turbine shaft and was set to a grade elevation 0.035 inch high to allow for settlement of the assembled machine.

(d) **Assembly of Major Parts.**—The major assembly work began after the rotor, stator, lower bearing bracket, and upper bearing bracket assemblies were completed. The lower bearing bracket and upper bearing bracket were assembled in the field and all connections were hot-bolted together. The lower bearing bracket, with the lower cover plates in place, was placed on the foundation plates, centered, leveled, and bolted into place. This was used as a working platform for the stator erection. After the stator was rounded out, centered, and winding completed, the brake jacks were placed and leveled to the proper elevation, which prepared the unit for placing of the rotor assembly.

The completed rotor (fig. 288) was connected to the 580-ton-capacity lifting beam, which was supported by the four 150-ton hooks on the two 300-ton overhead cranes. The assembled rotor was lifted off the pedestal and suspended in the erection bay where workmen cleaned the coupling face. The rotor was then moved to the stator bore and carefully lowered into position, resting on the brake jacks. In placing the rotor, masonite guide slats were used to keep the rotor from contacting the stator bore.

![Figure 288. Rotor for generating unit 8 being lowered into stator. P557-420-11335, July 21, 1965.](image-url)
The brake jack locking cams were released and the rotor assembly was allowed to become suspended on the thrust bearing. The coupling was lined up by adjusting the upper bearing bracket position and was then made up by the contractor. All coupling bolts were stretched 0.010 inch. The alignments were checked by the turbine erector, the generator erector, and the inspector.

After the generator shaft alignment was completed, the shaft was blocked into position and then the upper and lower guide bearings were adjusted for proper clearance. As the major parts assemblies were being installed, the air housing was assembled and welded.

The generator exciter came in two parts, a field assembly and the rotor armature. The rotor armature and exciter ventilating fan were bolted on the generator shaft, and the field assembly was placed in position. The generator contractor installed the amplitune voltage control unit, the field rheostat assembly, and the controller of the cooling water modulating system. The completion contractor installed the cooling water piping, the generator neutral grounding transformer, and the permanent magnet generator. Figure 289 shows various stages of generator erection.

(e) Contractor’s Field Organization.—The field organization of the contractor normally consisted of a superintendent of erection, an assistant superintendent of erection, an office manager, a foreman millwright, a foreman electrician, a foreman ironworker (rigger), eight millwright journeymen, six electrician journeymen, one ironworker journeyman (rigger), one carpenter journeyman, one pipefitter journeyman, two laborer-truck drivers, and two armature winders. This crew produced 69,640 man-hours of labor in the installation of the eight generating units, or an average of 8,705 man-hours for each unit. The reported gross field cost for the installation labor, including administration and supervision, was about $388,522.

(f) Contractor’s Construction Plant.—At the time of generator installation, construction of the powerplant had progressed to the stage where the contractor was able to proceed with a relatively small construction plant. The specifications provided that the Bureau would provide overhead crane service, rotor lifting beams, compressed air service, and 480-volt electric power service.

The construction plant consisted of one general purpose truck, one pickup, one motor bus, two fixed air compressors, two engine lathes, two portable electric welding machines, two pedestal grinding stands, two fixed drill presses, two sets oxygen-acetylene gas combination cutting welding units, two high-current electric bracing tong units, one portable boring bar combination unit, one heavy duty alternating-current direct-current rectifier unit, one 35-kilovolt high-voltage testing transformer, twenty-four 50-ton dual-lift screw jacks, eight 50-ton center-hole hydraulic pullers, numerous assorted sizes and lengths of wire rope slings, four heavy-duty pneumatic impact wrenches, six sets of chains hoist
and pullers from 3 to 10 tons, one engineers transit, two engineers precision levels, three sets small tools consisting of electric and pneumatic portable drills, grinders, sounders, nibblers and impact wrenches, sockets, wrenches 3 inches down to one-fourth inch, end wrenches, machinist levels, micrometers, gauges, scales, etc., and one power-driven wood saw, one power-driven hacksaw, and a sufficient supply of special tools and instruments as required by the electrical, machinist, and millwright crafts.

The contractor made available, for a fee, one alternating-current high-potential testing transformer with control and power supply for the Government to perform the required alternating-current high-potential proving tests.

(g) Work Procedures and Practices.—The completion contract provided under specifications No. DC-5750 that the generator contractor would furnish the lower bearing bracket anchor bolt, lower bearing bracket foundation plates, stator foundation pedestal anchor bolts, stator foundation pedestal, which would be installed and to proper level by the completion contractor. The lower bearing brackets were shipped partially assembled. Two arms were hot-bolted to the center hub in the field. The physical dimensions of an overall width of 22 feet 11 inches made it impractical to preassemble this subassembly at the factory. The lower cover plates were assembled on the bearing bracket before placing it on the lower bearing bracket foundation plates. The bracket assembly was placed on the foundation, brought to elevation by checking from the turbine crown plate, and centered by using a tightwire from a tripod above the generator foundation to the turbine shaft true center. After the alignments were completed, the bearing bracket was doweled to the foundation, brought to elevation by checking from the turbine crown plate, and centered by using a tightwire from a tripod above the generator foundation to the turbine shaft true center. After the alignments were completed, the bearing bracket was doweled to the foundation plates, which were then grouted in place. The brake jacks and brake jack piping were placed in position on the lower bearing bracket, taking advantage of the clear working space.

The stator foundation pedestals were installed under specifications No. DC-5750. Care was taken to give the final grade on these pedestals with the reference to the top of the stator section. By doing this research on the stator section, shims were eliminated between the stator and the foundation pedestals.

The three stator sections were placed in the pit on the foundation pedestals. Premilled vertical shear horizontal keys were placed in the three splices to control the 17-mil penetration of the stator laminations when the sections are fastened together. (It was anticipated that these keys would be inspected for tightness after 3 or 4 years of operation. If not tight, the split through bolts should be retorqued as looseness at this point will develop a soft lamination assembly in the stator, eventually resulting in coil damage from either coil or iron migration.)

The stator section split bolts were tightened until the 17-mil penetration of the lamination was obtained. The stator section was rounded by establishing the true center of the unit using a tripod extending above the stator with the lower bearing bracket as the base. A tightwire was installed from the tripod upper bearing to the center of the lower guide bearing chamber in the bearing bracket. Micrometer readings were taken from this tightwire to the predetermined points on the inner circumference of the stator. Five measuring points were prepared about 6 inches from and on each side of the split. Measuring points were then prepared about every 20° around the inner circumference. At each location one point was about 3 inches from the top of the laminations, one up about 3 inches from the bottom, and a third in the middle of the lamination assembly. At the splits other points were located between the middle point and the upper and lower points. Five dual lift jacks were placed around the outside circumference of each stator section. Near the baseplate line, each jack was brought up to a light compression again at the stator frame. After each set of micrometer readings were taken of the stator inner circumference, the jacks were readjusted to bring the stator into proper conformation at the bottom ring, midsection, and top where it was practical to obtain this condition. Where eccentricity existed between the top and bottom ring, adjustments were made by raising the stator and shimming the pedestal contact to plumb the lamination form. The maximum shim installation was 25 mils on one pedestal.

Before releasing the jack holding the stator in position, the horizontal dowels were drilled and placed in the pedestal-stator junction and all foundation and mounting bolts were torqued to proper tension. A working platform was constructed on the lower bearing bracket to facilitate the installation of the lap coils.

(h) Handrails.—As originally constructed, the handrails on the top of the generator air housing enclosed only about one-sixth of the deck, providing a guarded passage from the access stairway landing to the exciter platform stairway and to part of the collector ring brushes. As maintenance workers needed access to the remainder of the deck, during routine maintenance operations, it was necessary to provide additional handrails to encircle the entire deck. Specifications No. DC-6441 provided for furnishing and installing this additional aluminum handrail and for removing a portion of the existing handrail. Larsen Rigging and Equipment Co. of Salt Lake City, Utah, began work
February 7, 1967, on this modification and all work was completed and accepted February 24, 1967.

(i) Some Operational Problems.—Soon after initial operation of unit 1, oil was observed at the lower guide bearing. After various experiments the contractor added another vapor guard. This was done on all units and substantially diminished the oil leakage. An oil slinger was added on unit 8 and extended operation indicates that this will also be added to the other seven units.

A problem occurred with vibration of air deflector baffle plates in the air housing, resulting in cracking of some of the plates. The contractor extensively reinforced the plates in all units.

B. INSTALLATION OF MISCELLANEOUS MECHANICAL AND ELECTRICAL EQUIPMENT

1. Miscellaneous Mechanical Equipment

226. GENERAL DESCRIPTION. The turbo-generating units require a substantial amount of mechanical equipment in support of the plant operation. Two 300-ton cranes in the main generator room and a 75-ton crane in the machine shop are required to maintain the units. A complex oil storage and handling system is necessary to lubricate the mechanical equipment, as well as a separate system to service the insulating oil requirements of the electrical equipment. Large water pumps are also needed to dewater the various sumps, others to circulate the generator cooling water, and even larger booster pumps are required for domestic water supply purposes. A compressed air system was required for specific and general service use in operation and maintenance of the plant, and a carbon dioxide fire extinguishing system was necessary to protect the generators and the oil handling rooms.

227. 300-TON POWER PLANT CRANES. Overhead in the main generator room in the powerplant are two 300-ton traveling cranes (fig. 290) with a span of 71.5 feet. Each of the cab-operated cranes has two trolleys with 150-ton-capacity main hoists and 30-ton-capacity auxiliary hoists. The lifting capacity of the two main hoists on each crane may be combined with a lifting beam to produce a total capacity of 600 tons when the trolleys on each crane and the bridges of the two cranes have been locked together. These electric cranes are for use in installing and maintaining the turbines and generators and for handling materials in the service area. Each main hoist has a lift of 80 feet and is equipped with 12 parts of 1-3/4-inch-diameter wire rope and a sister hook drilled for a horizontal lifting pin. The auxiliary hoists are standard single-hook with four parts of 1-inch-diameter wire rope and have a lift of 100 feet. The 300-ton cranes were purchased under invitation No. DS-5260 by Yuba Consolidated Industries, Inc., of Benicia, Calif., and were installed by the prime contractor.

Erection of the 300-ton crane began in December 1961, in the Merritt-Chapman and Scott Corp. fabrication yard at the site. This yard work consisted of the structural steel assembly of the main bridge girders and placement of the trucks. The assembled bridge girders were placed on the powerplant crane rails by high-line cableway before the roof of the powerplant was installed. Most of the installation of equipment could then be performed with the bridges in place on the rails.

On April 11, 1962, the erection engineer representing Yuba Industries reported to perform acceptance testing of the cranes. The cranes were adjusted and run-in for the formal acceptance testing. Tests on the No. 1 crane started April 16. Because of a faulty hoist motor brush position, the test load dropped a sufficient distance to throw out the windings of the main hoist motor. The hoist motor was repaired and returned in July. The testing resumed and an auxiliary motor was damaged. The contactors were then found to be defective on both cranes and were replaced. The test on the No. 2 crane was started July
25 with a 187.5-ton load and this test was completed in August.

By order for changes No. 15, the 300-ton cranes were tested in accordance with paragraph C-4 of invitation No. DS-5260 instead of in accordance with the requirements of subparagraph 182(b) of the construction specifications.

1. All main and auxiliary hoists were tested at no load, half load, and rated load to determine electrical characteristics and hoisting and lowering speeds.

2. When conducting the bridge speed test under subparagraph (d)(4) of paragraph C-4, only one main hoist had a test load of 150 tons on the hook. The other hoist was unloaded.

3. The cranes were tested consecutively so that final adjustment could be made to assure all four hoists operating as nearly alike as possible.

The auxiliary motor on the No. 1 crane was repaired and returned, and tests on both cranes were completed November 1962. Separate technical reports on the cranes were made.

228. 75-TON MACHINE SHOP CRANE. The 75-ton machine shop crane is a cab-operated, indoor traveling-type crane with a span of 67.5 feet. This electric, overhead crane travels on a runway extending the length of the machine shop and is used for handling materials and equipment in the shop. The trolley is equipped with a 75-ton-capacity main hoist and a 15-ton-capacity auxiliary hoist. With rated load the main hoist operates at speeds up to 6.6 feet per minute. The main hoist has a lift of 40 feet and is rigged with eight parts of 1-1/4-inch-diameter wire rope and a sister-type hook bored for a lifting pin. The auxiliary hook is a standard type with the total lift of 55 feet with four parts of 0.785-inch-diameter wire rope. The bridge speeds are variable up to 85 feet per minute.

This crane was supplied by the Legnano Electric Corp. of New York and Torino, Italy, under invitation No. DS-5252 and was installed by the prime contractor. The formal load testing of the 75-ton crane was started on February 21, and was completed on March 2, 1962. The load test pointed up motor defects on the bridge and trolley. The replacement of motors was extended in time until the prime contractor’s forces were moving out, and the supplier had the repair work performed by the completion contractor.

The prime contractor had installed the 75-ton crane in the powerplant machine shop during the month of January 1962. As the connections were turned bolts in fitted holes, the assembly was not difficult and very little drifting and no reaming was required. The major mechanical problem encountered involved the operation of the hydraulic bridge brakes. After several unsuccessful attempts to adjust the bridge brakes, a close check revealed that the crane supplier had installed master cylinders at the cab-operated pedal and also at the brake shoe locations on the trucks of the bridge. This situation could not be corrected without extensive revisions of the entire brake system design. Although the brake system would stop the crane under full load at full speed, the mechanical advantage of a large master cylinder to smaller servo-cylinders was not in the system, and a large amount of pressure on the brake pedal was required to stop the crane. However, after further study, it was determined that the brake system would serve the purpose intended and basically met the specifications. The installation was therefore accepted.

229. 10-TON GANTRY CRANE. The 10-ton crane is an outdoor, traveling gantry type and was installed on the transfer deck on a track allowing travel along the length of the powerplant. This crane is for use in operation and maintenance of the turbine draft tube bulkhead gates. The gantry is equipped with a 10-ton base-mounted hoist. The hoist has a lifting speed of 14 feet per minute and a total lift of 80 feet and the gantry travels at a speed of 35 feet per minute. Both hoist and travel motions are controlled from a pushbutton station on the hoist platform of the gantry. The crane was fabricated by Crane Hoist Engineering Co. of Bell, Calif., under invitation No. DS-5398, and was installed by the prime contractor. The 10-ton gantry crane was placed on the rails of the transformer deck of the powerplant in March of 1962 and the counterweight was placed in April of 1962. During a trial run, when the crane was being used to install the draft tube bulkhead gates, the worm gear reducer drive unit was damaged and it was determined that this unit was not of sufficient capacity to meet the specification requirements. The worm gear reducer was replaced by one of greater capacity received on August 21, 1962.

230. OIL STORAGE AND HANDLING SYSTEMS. The lubricating and governor oil storage facilities consists of two vertical 4,000-gallon tanks. These tanks were furnished by American Steel and Iron Works of Denver, Colo., under invitation No. DS-5265 and were installed by Merritt-Chapman and Scott Corp. The tanks were installed, except for final cleanup and painting, during the spring of 1961 in the
DAM, POWERPLANT, AND GENERATING EQUIPMENT, ETC.

machine shop at elevation 3123.67. No unusual difficulties were encountered during this installation phase.

Other components of the oil handling system were installed by the completion contractor, Ets-Hokin Corp., under specifications No. DC-5750, as follows:

(1) A portable oil purifier was furnished by DeLaval Separator Co. of Chicago, Ill., under invitation No. (D) 90,578-A. The purifier is capable of handling 1,200 gallons per hour of transformer oil and 600 gallons per hour of governor and lubrication oil.

(2) One 50-g.p.m. transformer oil transfer pump and one 30-g.p.m. lubricating oil transfer pump were furnished by Colorado Pump and Supply Co. of Denver, Colo., under invitation No. (D) 90,583-A.

(3) One filter paper drying oven was furnished by L. A. Greene-Bowser, Inc., of Cookeville, Tenn., under invitation No. (D) 90,624-A.

(4) The metal piping to the generator housing, turbine pit, and governor cabinet was furnished and installed by a subcontractor, Detweilers, Inc., of Idaho Falls, Idaho, under specifications No. DC-5750.

Installation of the equipment and piping was substantially completed between August and September of 1963, with no difficulties being encountered except for some minor initial troubles in testing the oil purifier. A few of the top disks in the purifying bowl were damaged due to probable mismatching of parts by the manufacturer, but these were corrected in the field.

The most significant difficulty encountered with the oil system occurred after installation by the completion contractor, when clean oil became contaminated in the supply piping between the purifier and the units. Initially, the contractor had cleaned the oil piping according to the requirements of the specifications. This procedure provided that the piping was to be dismantled after erection, cleaned, and then reerected. The steps in the cleaning procedure were to use a rotary wire brush, blow out the piping with compressed air, swab with a cloth impregnated with solvent, and then swab with dry cloths. The cleaning and erection process for this piping extended over a period of approximately 3 months from August to November 1963. During that time the open ends of completed portions of the piping runs were covered with a heavy tape, which appeared to be adequate to keep out foreign matter. The first oil was not introduced in the piping system until April 1964, when the piping was subjected to a pressure test. Several of the flanged joints had minor leaks which were promptly corrected.

In preparation for filling the oil requirements of generating unit 1, oil was circulated from the storage tanks through the purifier, down the main headers, and back to the storage tanks. Samples taken during a period of 5 to 6 weeks, while this filtering operation was in progress, revealed visible metallic particles which had the appearance of oxidized iron flakes. Moisture had apparently entered the piping at the taped openings or through loose flanged joints, during the time between the cleaning procedures and the first time oil was put in the system. In order to fill the unit oil sumps on schedule, a small terminal purifying unit was used just ahead of the unit piping for each unit. This terminal filtration procedure was also used in filling the transformers with insulating oil.

231. UNIT LUBRICATING OIL SYSTEM. The unit lubricating system is a key section of the overall oil handling system and extends from the headers servicing the units to the governors and to the generators and turbines. The generator thrust bearing is an immersed type with inherent oil circulation, and the capacity of the oil reservoir is 2,100 gallons. A self-contained high-pressure oil system is provided for the thrust bearing shoes to force oil between the bearing surfaces prior to starting and during shutdown of the generator in order to maintain a full thickness of oil film between the bearing surfaces. The upper guide bearing and lower guide bearing of the generator, also of the immersed type, have oil reservoirs around the bearings to allow for circulation of oil during rotation of the main shaft. The turbine guide bearing is lubricated by a pressure oil circulating system with two motor-driven oil pumps—one alternating-current pump for normal operation and one direct-current pump for emergency operation. The oil leaving the bearing drains back to an oil reservoir in the turbine head cover. There are provisions made for controlling the low temperature of the oil to assure lubrication on quick starts of the unit. During the first start of the units, the cleanliness of the oil from this system was questioned by the erection engineers of the turbine and generator manufacturers. This problem was resolved by the use of a small portable filter placed at a point where oil enters the bearing.
Oil storage, purifying, and transfer facilities are provided for handling the oil for the main power transformers, each with a capacity of 7,600 gallons. The system was placed so unfiltered oil cannot enter the filtered oil lines. The transformer oil storage room contains two 10,000-gallon transformer oil storage tanks, one for filtered oil and the other for unfiltered oil. Return piping from the main power transformers is not provided. The oil purifier room contains a 60-g.p.m. transformer oil transfer pump, supplied by Colorado Pump and Supply Co. under invitation No. (D) 90,583-A. When a transformer is to be drained or filled with oil, it must be moved on tracks into position near the oil unloading pit and flexible hose connections made between the transformer and the pump. The transformers are provided with filter press connections, so a portable purifier can be used on the transformer deck.

232. AIR COMPRESSOR INSTALLATION. Compressed air is provided for the operation of generator air brakes, charging of the governor pressure tanks, operation of air tools from service outlets located throughout the powerplant, operation of turbine grease pumps, operation of generator cooling water system controls and air conditioning system controls, and depressing the draft tube during synchronous condenser or motoring (spinning reserve) operation. The major items of Government-furnished equipment were installed by the completion contractor.

The high-pressure air supply consists of one stationary 20-c.f.m., 375-p.s.i., two-stage, water-cooled air compressor with aftercooler, and a horizontal air receiver, 18 inches by 6 feet, to supply air for changing the governor pressure tanks and to furnish standby emergency air supply for switchgear equipment on the generator floor. This equipment was supplied by Compressor Service Co., Los Angeles, Calif., and I. G. Downs, Inc., on invitations No. (D) 90-581-A-1 and No. (D) 90-581-A-2.

The service air, generator brake air, and draft tube depressing air systems consist of three stationary 100-p.s.i. air compressors. One is a 100-c.f.m., single-stage horizontal, water-cooled compressor with one air receiver, 48 inches by 12 feet; and two are 500-c.f.m., two-stage, horizontal, water-cooled compressors with two air receivers, 48 inches by 12 feet.

The brake air system has two air receivers, 30 inches by 7 feet, checked off from the main service air system so that proper pressure will be available for the generator air brakes. This equipment was supplied under the invitations previously mentioned.

The draft tube depressing air system has four air receivers, 66 inches by 18 feet, checked off from the main service air system. This depressing air system is provided in order that the units may operate as synchronous condensers or motoring, using a minimum of power. Initial unwatering to depress the water level in the draft tube below the level of the turbine runner is supplied by the stored air in the receivers.

No particular difficulties were encountered during the conventional methods of installation and testing used. The completion contractor's installation work consisted of moving the equipment to the powerplant, placing it on prepared foundations, and providing initial servicing and equipment for operations.

233. AUXILIARY AND SERVICE WATER SYSTEMS PUMP INSTALLATIONS. There are a large number of pumps installed in the equipment operating in the powerplant. The major water handling units are the generator cooling water pumps, the drainage and unwatering pumps, and the domestic water supply booster pumps.

Nine 2,200-g.p.m. generator cooling water supply pumps were furnished on invitation No. (D) 90,601-A by Aurora Pump Division of New York Air Brake Co. of Aurora, Ill. The centrifugal pumps take water from the draft tubes under a positive suction pressure and deliver it to the generator air coolers. Eight of these pumps were installed along with the unit piping in 1963, with one pump to be used as a spare. No significant installation difficulties were encountered.

Drainage and unwatering sump pumps were installed in both the powerplant and dam by the completion contractor. Two 2,900-g.p.m. deep-well turbine pumps were installed in the dam for unwatering the foundation sump. The two pump units are controlled by a float switch with automatic alternator. If one pump fails to keep the sump water level below a set point, an alarm sounds and the second pump will start. Two 500-g.p.m. and two 100-g.p.m. pumps were installed in the powerplant sumps. The pumps were furnished under invitation No. (D) 90,585-A by Fiese and Firstenberger Manufacturers, Inc., of Fresno, Calif. The operation is by automatic floatswitch control.

Four 920-g.p.m. centrifugal multistage booster pump units were installed to pump water to the Page water plant. Furnished by the G. M. Wallace Co. of Denver, Colo., under invitation No. (D) 90,622-A, the
234. STATIONARY CARBON DIOXIDE FIRE EXTINGUISHING SYSTEM. The carbon dioxide fire extinguishing system was installed to provide automatic fire protection for the generators and oil handling rooms. These systems were installed by the completion contractor and were furnished by the Cardox Division, Chemetron Corp., under invitation No. (D) 90,606-A. The generator system is made up of an initial and a delayed discharge of gas. The initial discharge of the gas is initiated by thermal switches in the generator air housings. The electrical controls cause operations of the discharge heads in the cylinders at the cylinder bank and open the proper selector valve to direct the gas to the generator where the signal originated. This system can be operated manually from remote control switches, but the routing valves must also be operated manually. The delayed discharge is operated manually at the cylinder bank as required to control the amount of carbon dioxide in the generator. Each bank of initial and delayed discharge cylinders protects two generators through selector valves automatically, or manually, operated to discharge gas to a unit.

A separate group of cylinders was provided for the oil purifier room. Discharge is automatic subsequent to operation of water sprinklers in the room activated by fusible links. The flow of water through a waterflow switch closes a contact of an electric timer switch. After a 5-minute delay, a weight-operated valve is actuated by the electric timer and shuts off the supply of water to the sprinkler system, simultaneously actuating a solenoid valve to control the discharge of carbon dioxide to the oil handling rooms.

235. POWERPLANT MACHINE TOOLS. The following new machine tools were furnished by the Government and were installed in the powerplant by the completion contractor:

- 15-inch pedestal drill press
- 11-inch by 11-inch power hacksaw
- 300-ton hydraulic shop press with 5-ton arbor press
- 2-inch pipe and bolt threading machine
- Electric heat treating furnace
- 24-inch vertical drill press

The completion contractor also installed the following used machine tools which were obtained from the Naval Gun Factory, Washington, D.C.:

- 16-foot boring mill with a 320-kilowatt semiportable motor-generator set
- 36- by 144-inch-centers lathe
- 20- by 72-inch-centers lathe
- Milling machine
- 4- by 8-foot surface plate
- 6-foot radial drill
- No. 2 cutter and tool grinder
- 10- by 1-1/2-inch pedestal grinder
- 12- by 2-inch pedestal grinder
- 16- by 30-inch-centers lathe
- 36-inch heavy-duty shaper
- 35-ton hydraulic straightening press
- 6- by 18-inch surface grinder

The installation of the machine tools consisted of leveling, locating floor anchoring if required, and servicing in accordance with manufacturer's instructions. The installation of the new tools was performed without difficulty. Some difficulties were experienced with the used tools, primarily due to lack of detailed manufacturer's instructions and parts lists and lack of repair parts on obsolete equipment.

2. Miscellaneous Electrical Equipment

236. GENERAL DESCRIPTION. The eight generators for Glen Canyon Powerplant were installed in a single row at finish floor elevation 3168.50. Located just downstream from the generators, an electrical gallery at this same floor elevation contains the generator switchgear. The 12 power transformers are located outside the building on the deck 20 feet above the switchgear in the electrical gallery. The isolated-phase bus, mounted on the downstream wall of the powerplant, provides the electrical connection between the power transformers and the generators. Each pair of generating units is connected to a single bank of three single-phase power transformers. Power is generated at 13.8 kilovolts by each of the eight generating units and is transformed to 345 kilovolts at units 1 and 2, 3 and 4, and 5 and 6, and to 230 kilovolts at units 7 and 8. Station-service power is taken off the bus of units 3-4 and 5-6. All major items of electrical equipment were furnished by the Government and were installed by the completion contractor under specifications No. DC-5750.

237. GENERATOR SWITCHGEAR AND BUS STRUCTURES. One station-type switchgear assembly for each generator was furnished by General Electric Co. under invitation No. DS-5828 and the eight
assemblies were installed by the completion contractor. Each assembly contains a 7,000-ampere air-blast circuit breaker, disconnect switch, current transformers, forced air cooling equipment, and provisions for connection to the isolated phase bus and generator protective cubicles. The switchgear for units 1, 3, 5, and 7 also include bus potential transformers used for synchronizing transformer metering and relaying.

Manufacture and shipment of the switchgear were scheduled in pairs to accommodate the installation of associated isolated phase bus, power transformers, and shunt reactors. The switchgear equipment was shipped assembled in two major components: the circuit breaker and disconnect switch in one part, and the bottom frame the other. A third section, the potential cubicle, was also shipped for four units. The first major shipment, which was the complete switchgear for units 1 and 2, arrived at Flagstaff railhead on August 29, 1963. The equipment for units 7 and 8 arrived in September 1963; unit 4 in November 1963, unit 3 in December 1963, and units 5 and 6 in July 1964.

The equipment was trucked to a temporary site storage area by the completion contractor and then moved into the powerplant after the base channels were set and grouted. Because of limited head room at the opening to the electrical equipment gallery at the generator floor level, it was necessary to move the breaker cubicle into position with small pipe rollers. Each breaker was then raised, the bottom frame placed on the base channels, and the breaker lowered to the bottom frame. The contractor fabricated a special lifting beam and A-frame to facilitate this installation work.

The switchgear was assembled in the energization sequence schedule for the switchyard and transformer circuits; namely units 1, 2, 7, 8, 3, 4, 5, and 6. This installation work started on March 10, 1964, and proceeded through August 1964, under the supervision of the manufacturer’s erecting engineer. Final functional and timing checks of each breaker were performed just prior to placing the unit in service.

The switchgear and generators are connected to the power transformer by the isolated phase bus furnished by Westinghouse Electric Corp. under invitation No. DS-5828. The generator surge protection equipment, metering and relaying potential transformers, a bus ground switch, and connection terminals were included as part of the isolated phase bus.

The first shipment of bus arrived at the railhead on September 6, 1963, for use on units 1 and 2. The shipment for units 7 and 8 arrived on September 30, and other shipments arrived in November 1963 and June 1964. Several shipments sustained severe shipping damage, which was repaired in the field by welding or replacement of parts. The bus was shipped in sections convenient for handling and loading and the ends were covered and taped. Most of these protective covers were torn open during shipment and extensive cleaning of the interior of the bus housings was necessary.

In order to deliver power at 230 kilovolts from units 5 and 6 pending completion of the Pinnacle Peak 345-kilovolt additions, an additional section of bus for a temporary connection between units 6 and 7 was obtained on an order for changes to invitation No. DS-5828. This bus section was received and installed in May 1965.

Installation of the bus structures was accomplished by the completion contractor under specifications No. DC-5750. Services of the manufacturer’s erecting engineer were utilized for approximately 65 percent of the installation work. In addition to repair of shipping damage, the erector corrected fabrication errors and omissions. Owing to the large size of the prefabricated sections, the bus and supporting frame were erected with a rubber-tired mobile crane utilizing conventional structural steel erection methods.

During erection of the bus, considerable difficulty was encountered in obtaining an adequate seal at the gasketed joints in the bus housing. Probably because of temperature cycling, the gasketed joints would not remain airtight. The positive pressure dry air supply system was therefore overloaded and ineffective, resulting in a number of air compressor failures during the first 6 months of operation. After many attempts to correct the leakage, the manufacturer proposed a redesign of the air supply system which included a high-volume low-pressure blower, a dehumidifier, and larger supply headers. A trial installation was made and found to be satisfactory. Modification of all units was completed by February 1967, and this work was performed under the equipment warranty.

All the bus structures were high-potential tested after completion of installation, and successfully withstood the 50-kilovolt tests. The original installation of the bus for units 7 and 8 included taps to shunt reactors which were in service until August 1965. When the reactors were no longer required, the bus sections were removed and permanent end caps were placed on the taps near the power transformers.
238. POWER TRANSFORMERS. Nine 100,000-kv.-a. single-phase power transformers, rated 345 kilovolts on the high side and 13.7 kilovolts on the low side, were furnished by Pennsylvania Transformer Division of McGraw Edison under schedule No. 1 of invitation No. DS-5780. Transformers for the fourth circuit (fig. 291), rated 100,000 kv.-a., 230 kilovolts to 13.8 kilovolts, were furnished by Westinghouse Electric Corp. under schedule No. 2 of invitation No. DS-5780.

The first shipment of the 345-kilovolt transformers from Pennsylvania Transformer arrived at the railhead in June 1963. One 276-kilovolt lightning arrester was damaged and required replacement. During September three more transformers arrived, and again one 276-kilovolt lightning arrester was damaged. The last three transformers required on schedule No. 1 arrived in late November and early December. The three 230-kilovolt transformers furnished by Westinghouse arrived at Flagstaff on October 4, 1963. The only visible shipping damage was a small crack in a weld near the base of the transformer. The tank still held nitrogen pressure and no internal damage was anticipated. The transformers were stored at the railhead until installation was started in June 1964. The 230-kilovolt Westinghouse transformers were hauled to the powerplant on conventional lowboy trailers.

Figure 291.—High-tension bushing being raised into place on transformer K7A. P557-420-9847, June 10, 1964.

Assembly of the 230-kilovolt transformers for units 7 and 8 began on June 6, 1964, under the supervision of a Westinghouse erecting engineer. The internal inspection of the transformers revealed that one set of high-voltage bushing current transformers had broken loose from the support brackets and fallen to the top of the winding. It was necessary to replace the current transformers and make extensive field repairs to insulating barriers and spacers and lead insulation. As was the case under similar conditions in transformer KU5A in the switchyard, the transformer access manhole was not large enough to permit removal and replacement of the damaged current transformer. As a part of the replacement procedure a new manhole was cut in the top of the transformer. New manholes were not installed on the other two transformers, but the necessary materials were furnished so that the manholes can be installed if they are ever required. Completion of assembly of the transformers was delayed nearly 2 months by the damage; however, this did not result in any delay of equipment energization.

The 345-kilovolt transformers furnished by Pennsylvania under schedule No. 1 of invitation No. DS-5780 were also stored at the railhead until installation. The first units were hauled to the powerplant in early July 1964. Because of weight and height restrictions, a special hauling carriage was required for these transformers. The carriage was designed and built by Reliance Trucking Co. These transformers were shipped with a temporary shipping cover welded to the tank. After oil filling, this cover was removed and the upper section of the tank, which provides space for the bushings and current transformers, was welded to the lower part. After the bushings were installed and connected, the oil filling was completed.

The high-voltage bushing draw-leads on three of the nine 345-kilovolt Pennsylvania transformers were too short to reach the bushing terminal. It was therefore necessary to lengthen the leads by cutting them off and splicing on a new piece. Replacement of the leads was not difficult and was considered as a part of the normal assembly of the transformers.

In the final stage of erection of the third transformer on July 30, 1964, a one-half-inch lock washer was accidently dropped into the tank. Many hours of searching did not locate the washer. Since it
was necessary to establish liability prior to energizing the transformer, a fourth transformer was immediately assembled and substituted in the K1A bank in order not to delay the on-line schedule of the first generator.

Responsibility was ultimately placed with the construction contractor, and it was proposed that the transformer could be placed in service without untanking to locate the missing lockwasher if the contractor would extend the manufacturer’s warranty for 5 years and bear the costs of an extensive combustible gas analysis program. The contractor’s decision to accept this proposal was made on January 12, 1965, and the transformer was placed in the K3A bank and energized in conjunction with unit 4 start-up procedure on February 8, 1965. During the first 3 years of operation, no difficulties attributable to the lockwasher appeared.

Assembly of all Pennsylvania transformers was completed December 8, 1964; however, the last unit was not energized until February 1966. All insulating oil for transformers was degasified by vacuum treating as it was pumped into the transformers. With this method, dielectric strengths approaching 40 kilovolts were obtained.

239. SHUNT REACTORS. Twelve 8,000-kv.-a. shunt reactors (fig. 292) were furnished by General Electric Co. under invitation No. DS-5828 for installation on the 13.8-kilovolt bus at transformer K7A. All of the reactors were shipped in the latter part of November 1963, scheduled to arrive at the site in time to meet the installation schedule. However, six reactors sustained major shipping damage in route and were returned to the factory without having reached their destination. The damaged units were beyond repair and were scrapped. The replacements were not shipped from the factory until June 1964.

The services of an erecting engineer, who was already at the site for installation of other equipment at Glen Canyon, were utilized for the installation of all reactors. The first six reactors were installed by the completion contractor on the unit 7 side of transformer K7A and connected to the isolated phase bus. Shortly after the units were energized, excessive temperature rises were noted in the vicinity of the installation. Extensive cracking was observed in the concrete deck supporting the reactors. The reactors were removed from service on September 7, 1964, and the supplier was requested to proceed at once with modifications to limit the temperature rise.

Installation of the six reactors on the unit 8 side of transformer K7A was delayed until an aluminum shield, 8 feet in diameter and 3/8 inch thick, could be fabricated and placed under the concrete base of the reactor. The assembly was completed and test energized on October 29, 1964. Extensive checks of the temperature rise of the supporting concrete and reinforcing steel with the reactor bank energized, showed that the addition of the circular shields was ineffective. The supplier modified the shielding by filling in the gaps and extending the shield beyond the reactors. Further temperature rise measurements indicated that while the rate of increase had slowed, the total rise at ultimate use would still be beyond specification limits. However, operational requirements were such that the lower half of the reactor banks could be disconnected; and since the temperature rise with this method of operation was not excessive, no further modifications were required.

Extensive tests of the area under the unit 7 side reactor bank were conducted to determine the extent of structural damage. Analysis of test cores by the Bureau’s Denver laboratory and the space-frame analysis by the designers indicated no structural defects. Therefore, only replacement of the deck cover slab was required of the supplier. This was necessary in

Figure 292.—Closeup view of two shunt reactors. P557-420-9943, July 13, 1964.
order to restore the membrane waterproofing under the slab, and the work was performed shortly after reactor removal.

The reactor interphase bus links were also found to be overheating during normal operation due to excessive eddy currents. This problem was corrected by redesign of the links so that the short axis of the links was perpendicular to the axis of the reactor.

As provided in the completion contract, the reactors were removed from service in August 1965, and were disassembled and loaded for shipment to the Bureau’s Pinnacle Peak Substation.

Although no major problems were experienced with the main control boards, the scales and charts of the recorders furnished were initially incorrect. Representatives of Minneapolis-Honeywell corrected this deficiency.

Westinghouse obtained the sequence operations recorder from Rochester Instruments Corp. Installation of this unit was completed under the supervision of a representative of Rochester Instruments, and the unit was placed in operation a short time after initial operation of the powerplant. The annunciator system was supplied by Panellit Division, Information Systems, Inc., and the oscillograph by Hathaway Instruments, Inc.

240. MAIN CONTROL, GRAPHIC, RELAY, AND DISTRIBUTION BOARDS. The main control boards (fig. 200) were fabricated by Westinghouse Electric Corp. under invitation No. DS-5751 and were transported by motor freight. Individual panels were complete with meters, relays, switches, and internal switchboard wiring. Shipped in the latter part of 1963, the boards were installed in the powerplant control room early in 1964 (fig. 293). Interpanel switchboard wiring and some minor modifications were done at the site by Westinghouse.

Interboard control cable was furnished, installed, and terminated by Anderson Electric Co., subcontractor for electrical work under specifications No. DC-5750. Internal board wiring and cable connections were checked and the relays and meters furnished with the boards were calibrated and set. The Denver office were at Glen Canyon to make desired corrections to the control scheme design and wiring details. Temporary connections made at this time included the 230-kilovolt east and west bus overvoltage protection and connection of the reactor bank to the low side of transformer K7A.

Soon after initial operation of units 1 and 2, work began for temporary operation of the Glen Canyon-Pinnacle Peak line No. 1 at 345 kilovolts. This required changes in current transformer connections of transformer K7A, changes in differential and breaker failure relay tripping, and other related changes. The
Pinnacle-Peak line No. 1 controls and relays were also placed in operation and functionally checked at this time.

The need for unit dropping became apparent early in system operation, and a temporary unit dropping scheme was designed. Relays were mounted on a plywood panel which was installed at CCA13 utilizing spare circuit breakers at the rear of the unit control panels. Numerous modifications of the scheme have been made since that time due to changing conditions and the need for improvements.

New boards for the permanent relay system for the Glen Canyon-Flagstaff lines No. 1 and 2 were purchased under invitation No. DS-6227 from Keystone Electrical Manufacturing Co. The spare line relay panel on board CCC was connected to provide relay protection on the Glen Canyon-Flagstaff line No. 1 during the installation of these new boards. Installed by the completion contractor under a change order, substantial additions of control switches, meters, indication, wiring and cable were involved.

Addition of 69-kilovolt lines required additions and modifications of the control boards. The work was performed by the completion contractor under a change order. New indicating meters and control switches were installed on spare panels of the CCB board. Relays in the CCD board, originally provided for future 138-kilovolt lines, were used. The added control equipment was furnished by the Government under minor purchase orders.

241. STATION-SERVICE POWER SYSTEM. The primary 4,160-volt intermediate voltage switchgear, the secondary 440-volt unit substations, and the lighting distribution unit substations required for the station-service power system were furnished by Allis-Chalmers Manufacturing Co. under invitation No. DS-5732. This equipment was shipped to the jobsite during March, April, and May of 1963.

Installation of the equipment was started in October 1963, and continued as surfacing for the floors of the powerplant was completed. Assembly of the switchgear, the transformers, and disconnects by the completion contractor was performed under the technical supervision of the manufacturer's erecting engineer. Final checkout of the operational functions of the equipment was completed by the erecting engineer and Bureau test personnel in June 1964. The only significant difficulty encountered in assembly involved mismatch of rigid bus connections between components, which was corrected by factory refabrication of the bus without delay of installation work.

The primary power supply for the station-service system is provided by three 3,750-kv.-a. power transformers furnished by Westinghouse Electric Corp. under invitation No. DS-5828, and two 500-kv.-a. induction voltage regulators, furnished by General Electric Co. under another schedule on invitation No. DS-5828. The voltage regulators arrived at the railhead at Flagstaff, Ariz., on September 18, 1963. They were hauled to the powerplant by the completion contractor and set in position on the transformer deck during the following week. The three power transformers furnished by Westinghouse arrived on August 7, 1963, and were hauled to the transformer deck by the completion contractor shortly thereafter.

The interconnecting nonsegregated phase bus for the regulators, transformers, and 4,160-volt switchgear was also furnished by Westinghouse under invitation No. DS-5828. This equipment was received at the Flagstaff railhead on January 10, 1964, and installation was accomplished in early February. Other major items of station-service equipment included the unit auxiliary powerboards, air-conditioning powerboards, and miscellaneous power distribution panel boards, which were furnished by Federal Pacific Electric Co. under invitation No. DS-5787. The major portion of this equipment arrived at the jobsite in September 1963.

Installation of the powerboards by the completion contractor was scheduled to coincide with the required in-service dates of the major unit equipment. As installation progressed, equipment deficiencies appeared which required field modification. Some deficiencies were corrected by the completion contractor as required to place equipment in service and other corrections were arranged for in advance by the manufacturer.

The powerplant station-service system was energized from a temporary 12-kilovolt source on July 15, 1964, after successful high-potential testing of the equipment. This temporary source was used for all plant auxiliaries until December 30, 1964, at which time the transfer was made to the permanent connections on the unit 3 and 4 isolated phase bus. By this time the 25-kilovolt cable from the switchyard to the powerplant had been installed by the completion contractor under specifications No. DC-5750 and was available as a standby power source.

242. COMMUNICATIONS. The automatic switchboard and control room operator's turret were
furnished and installed by Stromberg-Carlson under invitation No. DS-5976. The dial telephones, extension bells and the code call relays and signaling devices were also furnished by Stromberg-Carlson and were installed under a change order by the completion contractor.

Installation of the automatic switching equipment was started on February 14, 1964, and was completed on March 6, 1964. As negotiations with the completion contractor for installation of extension equipment and interconnecting wiring were not complete, telephones were initially installed on a temporary basis at critical key locations by Government forces. Service from these lines was discontinued as the permanent installations were made. Interconnection to an outside line was first made by tielines to the attended switchboard at the administration building in Page. When the offices in the powerplant were occupied, a new Bell System switchboard was installed. Interface equipment was also provided to allow direct out-dialing for emergency and power dispatching purposes. An additional trunk adapter was purchased and installed by Government forces to allow for increased direct dial access to the Colorado River storage project microwave system.

A terminal cabinet and a 100-pair cable were installed by Mountain States Telephone Co. in the powerplant telephone equipment room. The cable was routed through the control cable tunnel to telephone company terminal facilities near the switchyard.

For the early stages of operation of the powerplant, interconnections for communications and metering were made to the Arizona Public Service Co. microwave system by way of a Government-furnished 25-pair cable. This cable was installed from the control room area to a terminal pole near the 69-kilovolt area of the switchyard by the completion contractor on a change order. Terminations were made in the powerplant at a telemetering equipment rack furnished by Arizona Public Service.

The permanent terminal cabinet and 100-pair cable from the Colorado River Storage project microwave terminal facilities were furnished and installed by Stromberg-Carlson under specifications No. DC-5853. Digital telemetering transmitters, load control thermoverters, and associated tone transmitters and receivers were furnished by General Electric Co. under invitation No. DS-5921 and were installed and connected by the completion contractor. Transfer trip relaying tone transmitters and receivers, furnished as a part of the microwave system, were also installed and connected by the completion contractor.

243. BATTERY CHARGERS. Two static-rectifier type battery chargers were furnished by Federated Engineering Development Corp. under schedule No. 3 of invitation No. DS-5787. Shipment of the chargers was greatly delayed by priority work in the supplier’s plant. The late delivery had no adverse affect since procurement of the station battery was rescheduled to coincide with the delayed delivery. The chargers were received and installed in late February 1964, and the first unit was placed in service in May.
CHAPTER XVI. Construction—SWITCHYARD, TRANSFORMER CIRCUITS, AND CONTROL CABLE TUNNEL

244. GENERAL. Glen Canyon Switchyard (figure 216) is located on the right canyon rim starting about 600 feet downstream and 700 feet above the powerplant, within a fenced area approximately 800 feet by 1,200 feet. Seven of the eight transformer circuit towers for the powerplant to switchyard transformer circuits are located inside this fenced area, between the switchyard and the canyon rim. The other transformer circuit tower and a ground wire mast are located on the left canyon rim across from the switchyard. An access road was constructed from U.S. Highway No. 89 to the entrance at the northwest end of the switchyard, and a parking area was constructed at the entrance outside of the fenced area. The high-voltage switching and termination facilities located in the switchyard are described in Chapter IX.

An inclined tunnel was constructed from the powerplant to the switchyard, primarily for use as a control cable duct. This tunnel is about 7 feet square and 1,300 feet in length. A shallow type C cable trench extends from the powerplant control cable tunnel entry structure the entire length of the yard with a branch trench into the 25-kilovolt area. Control and power cables are buried from the cable trench to all equipment.

All electrical equipment for the switchyard was furnished by the Government. All other materials, including steel structures, overhead conductors, hardware, insulators, and control and power cables were contractor furnished. Initial excavation and grading was performed by the prime contractor under specifications No. DC-4825. The construction of the major portion of the switchyard was accomplished under the completion contract, specifications No. DC-5750. The 59-kilovolt facilities and the microwave power supply were constructed under specifications No. DC-6238 and the 5-kilovolt visitor center bay under specifications No. DC-6274. The effect of the expedited completion schedule for specifications No. DC-5750 was quite pronounced, since large areas of the switchyard were behind the original schedule at the start of the expedited program.

Grading for the switchyard and structure foundation construction was subcontracted to Fago Brothers Construction Co. of Scottsdale, Ariz. Work began on the grading phase early in July 1962 and the general grading had been essentially completed by the end of the year, except for the area adjacent to the control cable tunnel entrance structure. Work in this area was completed after the entry structure concrete was completed in July 1964. The salvaged gravel surfacing was spread, plus additional gravel, to stabilize the switchyard surface for access during the foundation construction phase. Order for changes No. 1 also provided for a 12-inch blanket of pit-run gravel on the switchyard embankments for erosion control. No drainage collection system was provided on the canyon side, and repair of this gravel blanket is necessary after occasional heavy rainstorms. A curb and outfall line system was planned for construction among future completion items. The switchyard access road and parking area embankments and bituminous surfacing were completed in October of 1964. The switchyard gravel surfacing was completed during October of 1966 and application of soil sterilant followed.

Most of the concrete foundations for the switchyard structures were designed for either pad- or rock-type foundations. The type of foundation used for the various structures was determined by the type and quality of material encountered. Concrete for the switchyard foundations was batched at the completion contractor's batching plant, located near the upper...
portal of the powerplant access tunnel, and was delivered to the switchyard by transit mixer. Conventional practices were followed in constructing the wooden forms and placing reinforcing steel and concrete for the structures and with curing of concrete by membrane curing compound.

The batching plant at the tunnel portal was provided by the subcontractor on the powerplant concrete. At times it was difficult to obtain concrete for the switchyard due to the heavy demands by the powerplant subcontractor. Placement of switchyard concrete foundations began during April 1963, and after changes in subcontractors was completed in November 1963 by the prime contractor, Ets-Hokin Corp. The remaining switchyard concrete, including conduit encasement, pullboxes, cable trench, cable trench crossings, and switch operating platform supports, was completed by the end of July 1964. To provide for temporary 230-kilovolt operation of the 345-kilovolt Flagstaff transmission line No. 1, additional structure foundations were constructed by the completion contractor in November 1964 as provided for by order for changes No. 5.

Structural steel for the switchyard was furnished by Muskogee Iron Works of Muskogee, Okla., and erection was performed by the completion contractor. Switchyard steel was assembled on the ground with loose-bolted connections. The larger structures were assembled in box sections on the ground. After erecting with mobile cranes, the structures were plumbed and all connections torqued. No unusual difficulties were encountered, although some misfabricated members required replacement or reworking. When holes were required to be redrilled or repunched, the galvanizing was repaired using zinc dust-zinc oxide priming paint. Erection of the switchyard structural steel began in the 25-kilovolt yard during August 1963, the 345-kilovolt yard during mid-September, and the 230-kilovolt yard during the last part of October. At the end of the year, all major steel structures in the switchyard had been erected.

246. HIGH-VOLTAGE BUSES. The east and west 345-kilovolt buses are 954,000-circular-mil all-aluminum duplex strain type, and taps from the bus to switches and jumpers between disconnects and breakers are also duplex cable. The connection of unit 5 to the west bus is accomplished with 3-inch iron-pipe-size aluminum rigid pipe welded to form a continuous length. Bus support clamps and connectors are of the bolted type. Corona-free hardware was installed on all 345-kilovolt bus, and corona control rings were used with all compression dead-end assemblies. Particular care was taken to avoid abrasion or contamination of the stranded cable in order to minimize corona.

The 230-kilovolt bus is also a combination of strain and ground mounted rigid 3-inch aluminum pipe bus. Conventional compression fittings and hardware and bolted fittings are utilized. The strain bus and jumpers are single-conductor, 1,272,000-circular-mil all aluminum. In order to dampen vibrations in long lengths of rigid pipe bus, 1,272,000-circular-mil stranded cable was inserted in the full length of the pipe.

The 25-kilovolt strain bus for the tertiary of the 345- to 230-kilovolt autotransformer is 2,500,000-circular-mil all-aluminum with compression dead-end assemblies. Taps to the bus are made with bolted connectors. All other 25-kilovolt strain bus, between the pothead structure and the switch structures, and jumpers from the buses to disconnects and circuit breakers are 1,272,000-circular-mil all aluminum. The main and transfer buses are 2-inch iron-pipe-size aluminum pipe as are connections between line and bypass disconnects. The contractor experienced considerable difficulty in producing the uniform short-radius bends which were necessary in this bus.

The 25- to 69-kilovolt transformer circuit is 954,000-circular-mil all-aluminum cable installed with compression dead-end assemblies. Essentially all other 69-kilovolt bus work is 2-inch iron-pipe-size aluminum pipe supported by post-type insulators.

All bolted taps and connectors to the various buses were made up with torque wrenches in accordance with the recommendations of the hardware manufacturer. Close inspection was maintained to assure that the aluminum conductors were properly cleaned prior to making up connections.

In order to temporarily utilize the 345-kilovolt Flagstaff line at 230 kilovolts as an interconnection to Arizona Public Service Co., a tie circuit between the 230-kilovolt west bus and the 345-kilovolt west bus was installed under a change order on the completion contract.

This temporary tie was utilized from December 1964, through October 2, 1965. A second temporary bus connection tying the 230-kilovolt east bus to the 345-kilovolt west bus was installed by Government forces using live-line bare-hand techniques, in April.
1965. The temporary connection to the 230-kilovolt west bus was removed at that time.

247. TRANSFORMER CIRCUITS. Four transformer circuits were constructed from the powerplant takeoff to the switchyard takeoff structures. Circuits No. 1 through 3 are designed for operation at 345-kilovolts and circuit No. 4 at a voltage of 230 kilovolts. In order to provide the required clearances for the four transformer circuits, it was necessary to excavate 3,475 cubic yards of rock at the canyon rim. This work was provided for by order for changes No. 5 and was accomplished by the prime contractor under specifications No. DC-4825. The work started late in November 1960 and continued intermittently until completion in March of 1961.

The completion contractor under specifications No. DC-5750 was required to construct the transformer circuits including furnishing and erecting the takeoff structure at the powerplant and the tower structures, and furnishing and stringing the required conductors, insulators, and hardware. Before work could begin on the west rim structures, it was necessary for the subcontractor to salvage and remove the temporary visitors’ parking area and overlook facilities. Work began early in August 1962, and the tower footings were excavated in conjunction with construction work for the switchyard. Foundations for the transformer circuit towers were constructed in rock in accordance with the construction drawings. The foundation outlines were line drilled and the material was loosened by shooting with 60 percent powder. Placement of foundation concrete began during February 1963 and was completed in October of 1963.

The transformer circuit rim towers were fabricated from extra-high-strength, high-strength, and standard-strength steels. The higher strength steel members were furnished painted with zinc dust-zinc oxide paint and the standard steel members were galvanized after fabrication. The remaining towers were fabricated with standard steel galvanized after fabrication. A hydraulic crane with a telescoping boom was used in the assembly of the tower sections on the ground. A 60-ton mobile truck crane with full boom and jib was used to erect the tower structural steel. To provide the reach for erecting the west side rim towers, it was necessary to construct temporary embankment pads adjacent to each tower. These embankments were later removed and the area dressed. The tower sections were assembled with loose bolts and, after erection and plumbing the bolted connections were torqued as required for the various bolt sizes.

The structural steel for the transformer circuit towers was also furnished by Muskogee Iron Works of Muskogee, Okla. Some fabrication errors required repunching and redrilling by the erectors. Resulting injuries to galvanized or paint coatings were repaired using zinc dust-zinc oxide priming paint. Erection of the transformer circuit steel towers began during December 1963, and by the middle of June 1964, was essentially completed.

Stringing and sagging of the transformer circuits was accomplished during late spring and summer of 1964 by the contractor’s line crew and equipment being used on the construction of the 345-kilovolt Glen Canyon-Flagstaff transmission line No. 1 under another contract. Circuits No. 1, 2, and 3 were 2,167,000-circular-mil ACSR (aluminum conductor, steel reinforced) conductor, Circuit No. 4 was 954,000-circular-mil ACSR conductor and the overhead ground wires were 1/2-inch galvanized steel cable.

Stringing was done from the transformer deck to the rim towers, and the spans were attached to the towers with double sets of tension insulator strings. Hot-line hardware was used on the switchyard spans, along with corona rings and corona-free fittings in the high-voltage circuits.

248. CONTROL CABLE TUNNEL. The control cable tunnel extends from the powerplant on a 7- by 7-foot section approximately 1,300 feet long excavated in the canyon rock on a slope of 29°32', terminating with concrete entrance structures. The upper portal is at the north end of the switchyard; the lower portal connects to the powerplant cable tower with a bridge section 53.5 feet long. The control cable tunnel serves as a duct for switchyard control cables, ground wires, communication cables, and a 25-kilovolt auxiliary power supply cable from the switchyard. The tunnel was constructed with galvanized cable trays, steel stairs, and a lighting system.

Excavation for the control cable tunnel, provided for under the prime contract, specifications No. DC-4825, was subcontracted to Frazier-Davis Construction Co., who in turn subcontracted the excavation to Cannon Diamond Drilling Co., of Compton, Calif. Work began with an opencut section in the switchyard area during September 1957, and was holed through into the canyon, approximately 100 feet above the river during March of 1958. A track-mounted, pneumatic overhead mucker was used to load the loosened material into a cable-hoisted muck
CONSTRUCTION

car for hauling to the upper portal area. The excavated material was dumped into trucks and was wasted. Jack-leg drills were used to drill the powder holes, and about 10 feet of tunnel was excavated each two-shift day.

During January and February of 1963, the lower portal and portal invert concrete was placed by the prime contractor. The control cable duct between the tunnel and powerplant was a structural steel truss bridge, 52 feet 8 inches center-to-center bearing, with insulated metal wall panels and an open steel grating floor. Assembled at one of the rim storage yards, the bridge was set in place on the bearing plates early in April of 1963, using one of the 50-ton high-line cableways. Late in April, the pitched reinforced concrete roof was cast in place on the bridge.

Work performed by the completion contractor on the control cable tunnel included placing concrete for the tunnel walls arch and upper entrance structure, furnishing and installing the steel stairs, cable trays, and completing the required electrical installations.

Concrete for the control cable tunnel was batched at the upper portal area using a skip-loading mixer and a wheelbarrow scale. A specially built rubber-tired car, operated by a cable hoist at the upper portal, was built to transport materials, men, and equipment to the work area in the tunnel. The contractor excavated rock for the wall keys and placed concrete for an enlarged curb to support the wooden wall forms and provide a track for the access car. The enlarged curb concrete was placed beginning in early October 1963 and was completed in early December. Both sides of the wall concrete were placed simultaneously from the bottom between January and March 1964.

Conventional arch concrete was placed during April and May 1964 to the A-joint crossing. The A-joint was left unlined 15 inches on each side except where concrete inserts were required to be installed in the walls. From the joint to the transition to the entrance concrete, the arch was lined with 4 inches of pneumatically applied mortar, which was reinforced with welded wire fabric. Subcontracted to the American Gunite Co. of Salt Lake City, Utah, arch mortar was placed in two 2-inch passes during May of 1964. Concrete for the entry structure was placed during July of 1964.

Installation of the steel stairs and cable trays began in early June from the lower portal of the tunnel and was completed on the downstream side by mid-July. Pulling of control cables under the expedited program schedule followed and was completed by the end of July with installation of the remaining cable trays and cables later.

Techni-Builder, Inc., of Phoenix, Ariz., was awarded a contract under specifications No. DC-6351 (SF) to furnish and install a handrail on one side of the control cable tunnel stairway and to furnish and install chain-link, mesh-covered, safety gates on approximately 25-foot spacings throughout the length of the stairway. Installation was started December 6, 1965, and was completed December 10, 1965.

249. MINOR ADDITIONS. The 69- and 2.4-kilovolt microwave power supply additions to the Glen Canyon Switchyard were constructed under specifications No. DC-6238. Tide-Bay, Inc., of Tacoma, Wash., was awarded a contract for the work under these specifications and began work June 7, 1965. All work was completed December 4, 1965. The switchyard area had been graded, surfaced with 6 inches of gravel surfacing, and fenced by others under specifications No. DC-5750, prior to work under specifications No. DC-6238.

Reinforced concrete foundations were constructed for a 69-kilovolt power transformer, a 25-kilovolt transformer circuit tower, and a 69-kilovolt transformer structure, all in the 69- to 25-kilovolt transformer area of the switchyard. In the 69-kilovolt area, concrete foundations were also constructed for a bus structure, a circuit breaker, a current transformer support, and a potential transformer support, all 69-kilovolt, as well as a microwave supply terminal structure. Four reinforced concrete 69-kilovolt approach tower footings were constructed at P.I. station 1+98.8 of the Glen Canyon-Page 69-kilovolt transmission line.

Both the 69- to 25-kilovolt and the 69-kilovolt areas were located at the north end of the Glen Canyon Switchyard. Structural-steel structures furnished and erected under this addition included two bays of 69-kilovolt bus structure, one transformer structure, one potential transformer support, two current transformer supports, one approach tower, all 69-kilovolt; one 25-kilovolt transformer circuit tower, and one microwave supply terminal structure. Also included were field alterations to an existing 25-kilovolt fuse and bus support, field alterations to a 25-kilovolt bus structure, and furnishing and installing switch-operating platforms. Transformers, circuit breakers, and switches used in this modification and addition were Government-furnished.
Other major items installed or furnished and installed included various sizes of exposed electrical rigid metal conduit; nonmetallic conduit embedded in concrete; lightning arrestors and grounding systems; aluminum strain and jumper buses; rigid aluminum buses; bus supporting insulator assemblies; outdoor bracket-type lighting units; terminal boxes; two 69-kilovolt approach spans of 69-kilovolt transmission line complete with conductors and overhead ground wires; and one span of the microwave two-wire power supply line.

Provision for removing and restringing one span of messenger-supported communication cable in the switchyard was deleted from the specifications requirements and was handled by operation and maintenance personnel to minimize communications interruptions. Other minor modifications and additions were made to the Glen Canyon Switchyard under specifications No. DC-6274, to supply electrical power to the visitor center at Glen Canyon Dam. These involved constructing reinforced concrete foundations for a 5-kilovolt bus structure and a 1,500-kv-a. transformer; installing a 22,900- to 2,400-volt, 1,500-kv-a., 3-phase transformer; and furnishing and erecting a 5-kilovolt bus structure complete with disconnecting fuses, lightning arresters, rigid aluminum bus, insulator assemblies, and grounding system. The power is transmitted to the visitor center through a concrete-encased buried duct bank. A lateral off the main duct bank was constructed to a dead end near the upstream side of the west abutment of the Glen Canyon Bridge to provide for future requirements.

A. SWITCHYARD ELECTRICAL EQUIPMENT

250. GENERAL. All major switchyard equipment was furnished by the Government and with few exceptions was delivered to the completion contractor at the railhead in Flagstaff and trucked to the site as provided in the specifications. All of the equipment was at the site sufficiently in advance of dates required to allow an orderly equipment installation program.

251. AUTOTRANSFORMERS. Three 100,000-kv-a., 345-230-25-kilovolt autotransformers were furnished by Westinghouse Electric Corp., under invitation No. DS-5784. The original scheduled shipping date for the units was August 1963. However, all three transformers failed during impulse testing at the factory and were rejected. The transformers were rebuilt, successfully tested, and shipped in March 1964, arriving at the railhead in Flagstaff on April 6.

The transformers were hauled by the completion contractor's hauling subcontractor, Reliance Trucking, to the switchyard and set on their foundations on April 14 and 16, 1964. Assembly of the transformers under the supervision of the manufacturer's erecting engineer began May 12, 1964. Two of the transformers were found to have suffered shipping damage to the bushing current transformers on the high-voltage bushing, caused by failure of the current transformer support arrangement. Assembly and checkout of the undamaged unit was completed on May 25.

Repair and replacement parts were ordered immediately for the damaged units. It was found that the transformer manhole was not large enough to permit removal or reinstallation of the bushing current transformers. Modification and enlargement of the manhole was accomplished as a part of the repair procedure. The necessary parts arrived June 26 and installation was completed July 8. Normal assembly procedure of the two transformers was then continued and was completed July 16. Doble testing of the transformer bushing revealed one bushing which had an open capacitance tap. This bushing was removed and replaced with a bushing intended for transformer K7A. A new bushing was shipped from the factory on July 30 for subsequent installation in transformer K7A.

After the transformer had been assembled, Westinghouse advised that a change in field assembly procedure required that the 230-kilovolt bushing lead be wrapped with paper tape. This was accomplished at the time the faulty bushing was replaced on KU5A2, but the other two units had to be partially drained and refilled specifically for this work.

Other difficulties encountered included a defective oil pump motor on transformer KU5A2, a defective oil pump on KU5A3, and nuisance tripping of all oil pump motor starters. The defective pumps and motors were replaced by Westinghouse and the overload heaters were changed to the ambient-compensated type.

A vacuum degasifier was utilized in handling all oil for the autotransformers in addition to normal filtering equipment. This was not provided for in the specifications but was arranged for under a change order.

252. POWER CIRCUIT BREAKERS. The six power circuit breakers for the 345-kilovolt area of the switchyard were furnished by General Electric Co. under invitation No. DS-5721. These are among the first airblast type 345-kilovolt circuit breakers manufactured by General Electric. Originally shipment
of the breakers was scheduled for May, June, and July 1963. This schedule was delayed approximately 1 month for modifications made at the factory to improve original designs. The breakers were at the site considerably ahead of scheduled installation dates. Two of the breakers received considerable shipping damage, but it was confined primarily to cracked and broken welds which were field repaired during assembly of the breakers.

A number of modification kits were applied to the breakers, primarily connected with the air supply system. Early operating experience indicated that the air compressors for the breakers could be a source of maintenance difficulty. Special test equipment is required for installation and maintenance of these breakers. An electrolytic hygrometer was supplied by General Electric for checking moisture content of air and insulating gas in the breaker during installation work, and a direct-writing oscillograph was borrowed from the Parker-Davis project for making timing tests on the breaker.

An additional bushing current transformer was added to each pole of four of the breakers under specifications No. DC-6238. In order to avoid wasting large quantities of SF₆ (sulfur hexafluoride) insulating gas in the current transformer column when they were opened for adding the current transformer, the gas recovery cart furnished for use with SF₆ breakers on the Parker-Davis project was brought to the switchyard and adapted for conserving and reinstalling the gas.

Four 230-kilovolt oil circuit breakers and four 34.5-kilovolt oil circuit breakers were furnished by Pennsylvania Transformer Division of McGraw Edison Co. under invitation No. DS-5816. The 230-kilovolt breakers were received in May and the 34.5-kilovolt breakers in August of 1963. The breakers were hauled from the railhead to the switchyard in November 1963.

The 34.5-kilovolt circuit breakers sustained considerable shipping damage which was repaired in the field prior to final checkout. During storage, lamps were placed in the tanks to prevent condensation. In two breakers the lamps were in contact with the fiber tank liners and burned them. These liners were replaced by the completion contractor prior to final oil filling.

The 230-kilovolt circuit breakers were assembled by the completion contractor under the supervision of the manufacturer’s erecting engineer. One 230-kilovolt bushing was broken by the contractor and was replaced at his expense. Installation, testing, and final checking of the four breakers was completed February 28, 1964, after 23 working days. An additional 4 days was required for oil filling.

These 230-kilovolt circuit breakers did not prove satisfactory for the conditions of operation at Glen Canyon, and after unsuccessful attempts to modify relaying schemes and establish special operating procedures to limit the duty on the breakers, a program of replacement of the breakers was instigated. Circuit breakers originally purchased under invitation No. DS-6287 for Mead Substation were diverted to Glen Canyon and were installed by Government forces. The first breaker was installed in December 1966, and the last in February 1967.

Two 69-kilovolt oil circuit breakers were furnished by Pennsylvania Transformer Division of McGraw Edison under invitation No. (D) 90,700. The breakers were received May 28, 1965, and installed by Tide-Bay, Inc. under specifications No. DC-6238. These breakers were shipped completely assembled and required only routine inspection and insulation checks prior to oil filling.

253. DISCONNECTING SWITCHES. All 345-, 230-, and 25-kilovolt disconnect switches in the switchyard were furnished by Schwager-Wood Co., Inc., under invitation No. DS-5860. The switches arrived at the site in early October 1963. Assembly and installation of the switches by the completion contractor started in December 1963 and continued through July 1964.

Some factory assembly and fabrication errors were encountered which required redrilling or punching mounting holes or replacement of hardware items. In addition to the assembly difficulties, it was found that ground switches would not operate properly. A manufacturer’s representative was at the site on two occasions to correct the difficulties. Interphase operating rods, counterweights, and contact shoes were ultimately changed in order to obtain satisfactory operation.
254. VISITOR CENTER COMPLEX. The site selected for the Carl Hayden Visitor Center is on the west rim of the canyon between the right abutment of the dam and the right approach to the highway bridge. This location provides an excellent view of the lower reaches of the reservoir, dam, powerplant, tailrace, and highway bridge. A portion of the rotunda is cantilevered out from the canyon wall to afford a more spectacular view. The selected area was the site of the west cableway tower facilities during construction of the dam.

255. DESCRIPTION. The visitor center building (fig. 294) consists of a steel-framed one-story wing with basement, steel-framed rotunda, and a concrete elevator shaft. The building foundation consists of reinforced concrete columns, piers, pilaster, and foundation walls. The concrete roof of the elevator shaft is covered with sheet neoprene roofing. The building wing and rotunda have wooden roof decking covered with insulation and neoprene roofing, a combination of aluminum walls and entrances, and precast concrete panels with facings of exposed aggregate. Interior finishes consist of terrazzo, vinyl and mosaic tile floor finishes; hardwood paneling; ceramic wall tile; gypsum wallboard, suspended acoustical ceiling tile and ventilating acoustical ceilings; and miscellaneous finishes. The building is complete with air conditioning, electrical power, control and lighting systems, and plumbing system.

Other features of the visitor center are a concrete-lined tunnel and elevator shaft from the top of the dam, including a lighting system; concrete paving, terraces, retaining walls, sidewalks, curbs and gutters, bituminous surfacing, drainage facilities,
roadway and parking area lighting systems; a water supply system, including a storage tank and 4-inch water supply line; and an electrical supply system from the Glen Canyon Switchyard.

256. CONTRACT ADMINISTRATION. The visitor center complex was constructed under specifications No. DC-6274 by Allen M. Campbell Co., General Contractors, Inc., of Tyler, Tex. A significant portion of the specialty work was performed by 12 subcontractors.

Although the contract was awarded on June 30, 1965, and notice to proceed was received by the contractor on July 12, the contractor was not able to start work until August 16 because of the statewide strike of operating engineers which prevented initiation of construction work at the site. A later findings of fact established that this delay was excusable from computation of allowed contract time.

A. CONSTRUCTION

257. FOUNDATION PREPARATION. Overburden was stripped from the general area. Drilling for excavation of the basement of the building was completed and the basement was blasted and excavated. During removal of the blasted basement rock, fill was placed and compacted in the parking areas and drilling and blasting was completed on miscellaneous features, such as sidewalks and the water tank at the base of "Beehive" rock. Excavation of foundations for major walls outside the building and major trenching was then completed using conventional methods and equipment. Concrete from the old high-line tail tower tracks had to be blasted and removed to construct the access road to the upper parking area, and high rock spots in the parking area were also drilled and blasted.

During the excavation of the trench for the 4-inch waterline, a previously covered portion of the old tail tower rail support concrete was found to be considerably thicker than had been anticipated. A rock knoll between U.S. Highway No. 89 and the ramp to visitor center parking area No. 3 also obstructed the view and created a traffic hazard. At another location, two catch basins and some exterior lighting standards were located such that the foundation excavation encountered other sections of the old tail tower support concrete. The excavation in these instances was performed as extra work by the contractor.

258. TUNNEL EXCAVATION. Rock bolts were placed at the portal of the tunnel between the dam and the visitor center, and excavation of the tunnel was then performed, using conventional drilling and blasting methods. Owing to the relatively small size of the tunnel, a small rubber-tired conventional four-wheeled trailer was used as a drilling jumbo, which also served to carry tools and materials. On completion of the excavation in rock for the basement of the building, a pilot hole for the elevator shaft was driven from the top and was holed through satisfactorily. Line drilling and excavation of the elevator shaft to the A-line was then performed. The elevator pit was then excavated and tights were removed in the tunnel, shaft, and basement. Excavated material from the tunnel and elevator shaft was wasted into the reservoir from the top of the dam.

The mining work was performed by a subcontractor, the Mile Hi Drilling Co. As a general rule 35 holes, each 8 feet in depth on 2-foot centers, were drilled to excavate the 7- by 9-foot tunnel, using a 3-hole burn or burden breaker in a triangular pattern. Each round was loaded with 295 sticks of 35 percent powder. Knock-off bits were used on two jackhammers to drill the powder holes. As a general rule, the tunnel was driven on swing shift, sometimes making two rounds per shift and averaging about 7 feet per round. A hydraulic front-end loader was used to bring out the excavated material. To provide clearance for the loader at the points of intersection, the inside corners of the tunnel were removed resulting in considerable overbreak. As excavation progressed, rock bolts were placed in the roof as a safety measure. The drilling crew consisted of a foreman and two miners who loaded, blasted, and installed rock bolts.

The contractor placed considerably more roof bolts than had been normally anticipated from previous experience in Navajo sandstone. This condition was primarily due to the contractor's conservative attitude towards safety in the softer formations at the upper part of the canyon wall. No particular difficulties were experienced in blasting the tunnel, and overbreak was maintained within reasonable limits.

Drilling of the 5-inch drain hole for the elevator pit was initially abandoned at a depth of about 28 feet due to difficulties in drifting. A new 3-inch pilot hole was drilled through to the canyon which was then reamed to a diameter of 5 inches by pulling the bit from the canyon to the pit with a modified wagon drill.

259. FOUNDATION EXCAVATION. No unusual difficulties were experienced in the rock excavation or earthwork construction for the visitor center. Following rock excavation and general grading, trenching for the various utility lines was completed.
and the pipes were laid. This included the water supply piping, the corrugated metal pipe surface drainage system, electrical power supply duct bank and manholes from the switch yard, and buried area lighting conduits. The manholes for the surface drainage were precast concrete. In addition, a buried control cable and water supply piping were installed for an automatic sprinkling system for certain areas on the visitor center grounds to be landscaped by others under a future contract.

260. CONCRETE PLACEMENT. Concrete placements began with the placing of sections of the concrete integral retaining wall and sidewalk, parapet wall sequences and manhole invert slabs. On December 30, 1965, a fire gutted the batching plant owned by the concrete supplier. Replacement equipment and materials were ordered promptly, repairs were made, and the plant returned to full operation on January 10, 1966. Concrete was placed by conventional methods, including the use of wooden forms and snap-tie fasteners, generally following a logical sequence of construction. Foundations and basement walls were placed, followed shortly by the basement floors. The first floor was not placed until all of the basement walls had been completed. With placement of the elevator machinery room roof, concrete placements were completed in August 1966. Except for those locations directly accessible to a transa-mix truck, the concrete was placed with a mobile crane using a bucket with a rubber tremie. Figure 295 shows the status of the work as of May 24, 1966.

Subsequent to completion of the concrete construction in the building proper and the completion of trenching excavation, embankment was placed about the various major concrete structures and utilities, and the gravel underbed for the paved areas adjacent to the building were completed. Construction of the miscellaneous concrete structures took place over a period of about 1 year, progress being generally slow.

During the colder winter months, the contractor kept the concrete curing temperatures above the minimum specification requirements through the use of plastic sheeting on wooden frames, warmed by space heaters. Construction of the electrical duct bank began during January 1966, and continued intermittently, with placement of concrete being completed during July and the backfill completed during August. Following completion of the tunnel invert concrete in May, no concrete was placed in the shaft or tunnel until September when the tunnel arch lining and elevator lobby arch concrete were placed. The tunnel entrance structure concrete was placed in October and November 1966. The tunnel entrance door installation and tunnel lighting installations were also completed at this time.

261. MISCELLANEOUS. The structural steel for the visitor center was delivered early in the project work and was stored at the site. After the concrete floors were placed and cured, the structural steel was quickly erected without experiencing any unusual difficulties. Terrazzo was placed in November and December 1966, except for the final fine grinding and sealing which was deferred until later. During placing of the terrazzo floors, a rainstorm washed white cement mortar over the nominal protective barriers provided and down over the canyon wall below the rotunda. The resulting white stains on the face of the canyon wall detracted from the appearance of the visitor center and it was necessary for the contractor to remove them. Installation of mechanical and electrical materials roughly followed the sequence of concrete and framing construction. Following discussions with the National Park Service, changes and additions were provided for the audiovisual system for the visitor center and numerous revisions were made in the finish requirements in the exhibit, information, and lounge areas on the main floor of the rotunda.

Numerous delays were experienced by the contractor in obtaining precast concrete panels, primarily due to problems of the supplier. The problems were eventually resolved and the precast panels were delivered to the site. The rate of delivery was somewhat slow and other deficiencies were found in the panels upon delivery to the site. As a result,
satisfactorily made. Acceptance tests were satisfactorily completed during April of 1967. In general, the elevators were constructed using conventional installation methods and no unusual problems were experienced during this phase of construction. The hoist for elevator No. 1 did develop vibrations greater than normally expected. Representatives of the contractor returned to the project during June 1967, and corrected an out-of-round brake drum.

263. PRECAST PANELS. Installation of the precast concrete panels for the building continued intermittently. Framing for the building interior and installation of associated conduit and metalwork continued when the panels were not available for installation. About 95 percent of the panels had been set in place by the end of March 1967. The south entrance precast column panels were rejected due to fabrication defects, and replacement panels were delivered and installed during May, which completed the panel installation. Calking of the panel joints began soon after completion of installation of the panels and was rapidly completed.

As soon as the last panels were in place, work began on installation of the building roof insulation and roofing, which was completed within about 1 month. Some difficulty was experienced with handling of adhesive, which was resolved when the critical limits of the temperature installation range were determined and the work schedule adjusted accordingly. Basically, roof surface temperatures of less than 95°F were necessary at the surface of the black neoprene in order to effect adequate bond with the recommended adhesive. As soon as the building was closed in, work began on installation of the aluminum curtain walls, entrances, wallboard, insulation, and ceiling installations. Interior finish carpentry and electrical installations were followed by the installation of bat and rigid type insulation, gypsum wallboard, walnut paneling and other wall finishes.

264. FINISHING WORK. By the end of June 1967, finish grinding and sealing of terrazzo floor surfaces, installation of plumbing fixtures, and electrical fixtures, and finish painting of the building had been generally completed. Chain link fencing, aluminum handrails, and precast concrete benches were then installed. About a month after the terrazzo had been completed, a small crack appeared in a section of the terrazzo in the rotunda, showing some vertical displacement. Other cracks appeared during the next few weeks and a drummy area of about 1 square yard developed. The area was rebonded by drilling and
grouting with an epoxy sealant, and the cracks were repaired. Although the problem seemed related to differential settlement, no evidence of this could be found on the underside of the rotunda floor and no further cracking occurred during an extended period of observation.

The initial start of the heating and ventilating chiller was made on July 12, 1967. Work began on the checkout and adjustment of the system but was suspended when the chilled water system proved to be deficient in providing the specified volume of water to the air-conditioning units. Two circulating pumps, designated CP-1 and CP-2, were replaced with pumps of greater capacity and the system was satisfactorily tested and completed. All work under the contract was accepted as substantially complete on August 17, 1967.
CHAPTER XVIII. INITIAL POWER GENERATION AND RESERVOIR OPERATION

265. FILLING CRITERIA. The filling criteria for Lake Powell were approved by the Secretary of the Interior on April 2, 1962. Basically, the criteria cover the first filling of Lake Powell up to full reservoir at elevation 3700 feet above mean sea level. Provision was made for sufficient water to be released from Lake Mead and Lake Powell to satisfy water uses below Hoover Dam. The criteria also provided that the United States would make a fair allowance for any deficiency in firm energy generation at Hoover Powerplant.

Until elevation 3490 was first reached, the water stored in Lake Powell was made available to maintain rated head on Hoover Powerplant. A minimum flow of 1,000 cubic feet per second was maintained in the river downstream of Glen Canyon Dam during this initial storage period through the high-pressure gates in the left diversion tunnel. After stored water in Lake Powell reached elevation 3490, the reservoir level was maintained at that level or higher. The storage level in Lake Powell was operated in such a manner that Lake Mead was not drawn below elevation 1123, which is the elevation for rated head on Hoover Powerplant. Over 1,000,000 acre-feet per year was also released while gaining storage to elevation 3490 at Glen Canyon, insofar as inflow and storage permitted.

In summary, the operation of Lake Powell above elevation 3490 and the operation of Lake Mead were coordinated to produce the greatest practical amount of power and energy, but still meet downstream water demands in accordance with the filling criteria. These filling criteria are included in U.S. Senate Document No. 7, 88th Congress, 1st session, along with other related documents.

266. RESERVOIR FILLING. Initial closure of Glen Canyon Dam was accomplished on March 13, 1963, by final closure of the left diversion tunnel gates. The reservoir water surface elevation at the time of closure was 3203.3 feet with a storage of 119,500 acre-feet. Water release through the high-pressure regulating gates in the left diversion tunnel was adjusted to pass a minimum of 1,000 cubic feet per second. This rate of release was maintained for the remainder of the year and the reservoir elevation on December 31, 1963, was 3409.6 feet with a storage of 2,968,000 acre-feet.

Releases were increased by varying amounts to meet downstream requirements from January 30, 1964, through May 11, 1964, when they were again reduced to a minimum of 1,000 cubic feet per second. This flow was maintained through August 17, 1964, when the reservoir attained an elevation of 3490.3 feet and a storage of 6,141,000 acre-feet. Testing of generating unit 1 began on August 20, 1964, unit 2 on September 9, 1964, and testing of the other units followed at approximately 2-month intervals. The downstream water releases were continued as coordinated releases from the available turbines, left diversion tunnel gates, and the outlet works hollow-jet valves until August 30, 1965. By this date units 1 through 5 were on the line and the combined turbine discharges alone were sufficient to meet downstream water requirements.

267. INITIAL OPERATIONAL STAFFING. Key operating personnel were transferred to the project in July 1964, to observe the last phases of construction and equipment installation, assist in final tests, and assume operation of the powerplant upon completion of construction. Operating personnel consisted of a branch chief, an operations foreman, five control room operators, and five assistant operators, providing adequate personnel for efficient operation of Glen Canyon Powerplant on the basis of 24 hours per day and 7 days per week.

268. INITIAL POWER GENERATION AND TRANSMISSION. Initial power transmission was to be made on the Glen Canyon-Shiprock 230-kilovolt transmission line. This line was test energized from Shiprock, N. Mex., to Glen Canyon. Following the initial turbogenerator testing, unit 1 was synchronized to the system on August 31, 1964. Tests were completed and unit 1 was operated 461.5 hours during the month of September 1964. Unit 2 was initially synchronized to the system on September 18, 1964, and was operated 232.0 hours during the remainder of the month. Combined generation of units 1 and 2 produced 46,220,000 kilowatt-hours in September, the first partial month of operation. The official in-service dates for the eight units (dates of first power generation) are as follows:

<table>
<thead>
<tr>
<th>Unit</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>September 4, 1964</td>
</tr>
<tr>
<td>2</td>
<td>September 22, 1964</td>
</tr>
<tr>
<td>3</td>
<td>December 11, 1964</td>
</tr>
<tr>
<td>4</td>
<td>February 10, 1965</td>
</tr>
<tr>
<td>5</td>
<td>July 19, 1965</td>
</tr>
<tr>
<td>6</td>
<td>October 13, 1965</td>
</tr>
<tr>
<td>7</td>
<td>January 21, 1966</td>
</tr>
<tr>
<td>8</td>
<td>February 28, 1966</td>
</tr>
</tbody>
</table>
Table 6.—Lake Powell—Reservoir elevation and water storage (Readings at first of month).

<table>
<thead>
<tr>
<th>Month</th>
<th>Reservoir elevation in feet above mean sea level</th>
<th>Storage, acre-feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>1964</td>
<td></td>
<td></td>
</tr>
<tr>
<td>October</td>
<td>3491.69</td>
<td>6,211,880</td>
</tr>
<tr>
<td>November</td>
<td>3491.91</td>
<td>6,223,320</td>
</tr>
<tr>
<td>December</td>
<td>3491.47</td>
<td>6,200,440</td>
</tr>
<tr>
<td>1965</td>
<td></td>
<td></td>
</tr>
<tr>
<td>January</td>
<td>3491.94</td>
<td>6,224,880</td>
</tr>
<tr>
<td>February</td>
<td>3491.41</td>
<td>6,197,320</td>
</tr>
<tr>
<td>March</td>
<td>3491.91</td>
<td>6,223,320</td>
</tr>
<tr>
<td>April</td>
<td>3491.88</td>
<td>6,221,760</td>
</tr>
<tr>
<td>May</td>
<td>3490.91</td>
<td>6,171,320</td>
</tr>
<tr>
<td>June</td>
<td>3491.82</td>
<td>6,218,640</td>
</tr>
<tr>
<td>July</td>
<td>3510.85</td>
<td>7,270,300</td>
</tr>
<tr>
<td>August</td>
<td>3530.91</td>
<td>8,513,060</td>
</tr>
<tr>
<td>September</td>
<td>3531.34</td>
<td>8,541,100</td>
</tr>
<tr>
<td>October</td>
<td>3530.12</td>
<td>8,460,920</td>
</tr>
<tr>
<td>November</td>
<td>3531.57</td>
<td>8,556,050</td>
</tr>
<tr>
<td>December</td>
<td>3532.56</td>
<td>8,625,960</td>
</tr>
<tr>
<td>1966</td>
<td></td>
<td></td>
</tr>
<tr>
<td>January</td>
<td>3534.63</td>
<td>8,764,840</td>
</tr>
<tr>
<td>February</td>
<td>3535.21</td>
<td>8,804,070</td>
</tr>
<tr>
<td>March</td>
<td>3534.38</td>
<td>8,747,840</td>
</tr>
<tr>
<td>April</td>
<td>3536.73</td>
<td>8,907,370</td>
</tr>
<tr>
<td>May</td>
<td>3538.98</td>
<td>9,061,620</td>
</tr>
<tr>
<td>June</td>
<td>3544.57</td>
<td>9,456,040</td>
</tr>
<tr>
<td>July</td>
<td>3544.91</td>
<td>9,480,520</td>
</tr>
<tr>
<td>August</td>
<td>3540.01</td>
<td>9,133,700</td>
</tr>
<tr>
<td>September</td>
<td>3534.00</td>
<td>8,722,000</td>
</tr>
<tr>
<td>October</td>
<td>3529.46</td>
<td>8,421,360</td>
</tr>
<tr>
<td>November</td>
<td>3527.12</td>
<td>8,269,680</td>
</tr>
<tr>
<td>December</td>
<td>3523.57</td>
<td>8,042,910</td>
</tr>
<tr>
<td>1967</td>
<td></td>
<td></td>
</tr>
<tr>
<td>January</td>
<td>3521.45</td>
<td>7,909,900</td>
</tr>
</tbody>
</table>
Table 7.—*Glen Canyon Powerplant—Power generated and water used.*

<table>
<thead>
<tr>
<th>Month</th>
<th>Unit 1</th>
<th>Unit 2</th>
<th>Unit 3</th>
<th>Unit 4</th>
<th>Unit 5</th>
<th>Unit 6</th>
<th>Unit 7</th>
<th>Unit 8</th>
<th>Thousand kilowatt hours produced</th>
<th>Unit releases, acre-feet</th>
<th>Bypass releases, acre-feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>1964</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>September</td>
<td>461.5</td>
<td>232.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>46,220</td>
<td>152,406</td>
<td>7,934</td>
</tr>
<tr>
<td>October</td>
<td>737.0</td>
<td>742.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>85,470</td>
<td>274,121</td>
<td>0</td>
</tr>
<tr>
<td>November</td>
<td>710.1</td>
<td>692.6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>107,894</td>
<td>346,646</td>
<td>0</td>
</tr>
<tr>
<td>December</td>
<td>672.7</td>
<td>744.0</td>
<td>494.4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>115,633</td>
<td>371,818</td>
<td>24,668</td>
</tr>
<tr>
<td>1964 Total</td>
<td>2,581.3</td>
<td>2,411.1</td>
<td>494.4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>355,217</td>
<td>1,144,991</td>
<td>32,602</td>
</tr>
<tr>
<td>1965</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>January</td>
<td>734.3</td>
<td>744.0</td>
<td>744.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>165,703</td>
<td>530,876</td>
<td>0</td>
</tr>
<tr>
<td>February</td>
<td>622.4</td>
<td>510.2</td>
<td>614.2</td>
<td>368.4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>138,888</td>
<td>445,108</td>
<td>52,710</td>
</tr>
<tr>
<td>March</td>
<td>744.0</td>
<td>742.6</td>
<td>470.1</td>
<td>744.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>128,173</td>
<td>424,256</td>
<td>120,084</td>
</tr>
<tr>
<td>April</td>
<td>588.5</td>
<td>716.7</td>
<td>639.5</td>
<td>709.1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>117,514</td>
<td>393,276</td>
<td>694,306</td>
</tr>
<tr>
<td>May</td>
<td>743.2</td>
<td>743.2</td>
<td>742.7</td>
<td>744.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>170,233</td>
<td>551,516</td>
<td>1,672,428</td>
</tr>
<tr>
<td>June</td>
<td>713.2</td>
<td>709.7</td>
<td>720.0</td>
<td>719.9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>208,825</td>
<td>668,800</td>
<td>1,552,866</td>
</tr>
<tr>
<td>July</td>
<td>740.0</td>
<td>741.5</td>
<td>738.0</td>
<td>741.5</td>
<td>331.2</td>
<td></td>
<td></td>
<td></td>
<td>218,961</td>
<td>707,714</td>
<td>46,162</td>
</tr>
<tr>
<td>August</td>
<td>732.4</td>
<td>711.7</td>
<td>730.8</td>
<td>530.5</td>
<td>692.1</td>
<td></td>
<td></td>
<td></td>
<td>258,122</td>
<td>836,904</td>
<td>98,184</td>
</tr>
<tr>
<td>September</td>
<td>700.2</td>
<td>711.8</td>
<td>712.5</td>
<td>720.0</td>
<td>694.8</td>
<td></td>
<td></td>
<td></td>
<td>250,393</td>
<td>809,726</td>
<td>708</td>
</tr>
<tr>
<td>October</td>
<td>689.2</td>
<td>698.7</td>
<td>715.4</td>
<td>711.4</td>
<td>582.6</td>
<td>231.7</td>
<td></td>
<td></td>
<td>223,871</td>
<td>718,450</td>
<td>4,042</td>
</tr>
<tr>
<td>November</td>
<td>0</td>
<td>718.0</td>
<td>702.7</td>
<td>720.0</td>
<td>474.8</td>
<td>702.8</td>
<td></td>
<td></td>
<td>205,006</td>
<td>656,262</td>
<td>0</td>
</tr>
<tr>
<td>December</td>
<td>133.2</td>
<td>696.1</td>
<td>680.2</td>
<td>713.7</td>
<td>261.2</td>
<td>712.3</td>
<td></td>
<td></td>
<td>187,166</td>
<td>600,288</td>
<td>376</td>
</tr>
<tr>
<td>1965 Total</td>
<td>7,140.6</td>
<td>8,444.2</td>
<td>8,210.1</td>
<td>7,422.5</td>
<td>3,036.7</td>
<td>1,646.8</td>
<td></td>
<td></td>
<td>2,272,855</td>
<td>7,343,176</td>
<td>4,241,866</td>
</tr>
</tbody>
</table>
### Table 7.—Glen Canyon Powerplant—Power generated and water used.—Continued

<table>
<thead>
<tr>
<th>Month</th>
<th>Unit 1</th>
<th>Unit 2</th>
<th>Unit 3</th>
<th>Unit 4</th>
<th>Unit 5</th>
<th>Unit 6</th>
<th>Unit 7</th>
<th>Unit 8</th>
<th>Thousand kilowatt hours produced</th>
<th>Unit releases, acre-feet</th>
<th>Bypass releases, acre-feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>1966</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>January</td>
<td>329.3</td>
<td>405.1</td>
<td>728.8</td>
<td>744.0</td>
<td>240.0</td>
<td>652.9</td>
<td>283.7</td>
<td></td>
<td>166,222</td>
<td>533,384</td>
<td>418</td>
</tr>
<tr>
<td>February</td>
<td>663.5</td>
<td>0</td>
<td>514.7</td>
<td>653.6</td>
<td>528.5</td>
<td>651.9</td>
<td>600.8</td>
<td>66.6</td>
<td>172,985</td>
<td>554,600</td>
<td>626</td>
</tr>
<tr>
<td>March</td>
<td>370.7</td>
<td>0</td>
<td>516.2</td>
<td>462.4</td>
<td>727.4</td>
<td>647.7</td>
<td>638.4</td>
<td>635.4</td>
<td>226,203</td>
<td>641,838</td>
<td>0</td>
</tr>
<tr>
<td>April</td>
<td>630.9</td>
<td>624.6</td>
<td>0</td>
<td>713.2</td>
<td>702.8</td>
<td>697.0</td>
<td>713.8</td>
<td>717.7</td>
<td>299,712</td>
<td>845,376</td>
<td>0</td>
</tr>
<tr>
<td>May</td>
<td>720.4</td>
<td>674.1</td>
<td>0</td>
<td>737.7</td>
<td>735.9</td>
<td>726.7</td>
<td>744.0</td>
<td>742.0</td>
<td>358,023</td>
<td>1,003,028</td>
<td>0</td>
</tr>
<tr>
<td>June</td>
<td>675.6</td>
<td>694.7</td>
<td>213.1</td>
<td>269.3</td>
<td>696.0</td>
<td>699.3</td>
<td>476.2</td>
<td>713.5</td>
<td>275,683</td>
<td>764,672</td>
<td>0</td>
</tr>
<tr>
<td>July</td>
<td>655.2</td>
<td>740.3</td>
<td>686.3</td>
<td>0</td>
<td>727.5</td>
<td>549.1</td>
<td>461.1</td>
<td>468.8</td>
<td>239,646</td>
<td>667,544</td>
<td>0</td>
</tr>
<tr>
<td>August</td>
<td>446.4</td>
<td>736.2</td>
<td>667.8</td>
<td>0</td>
<td>736.4</td>
<td>528.6</td>
<td>458.3</td>
<td>601.1</td>
<td>236,062</td>
<td>666,196</td>
<td>0</td>
</tr>
<tr>
<td>September</td>
<td>587.6</td>
<td>612.1</td>
<td>654.4</td>
<td>531.8</td>
<td>358.0</td>
<td>141.1</td>
<td>680.1</td>
<td>368.2</td>
<td>216,308</td>
<td>617,846</td>
<td>0</td>
</tr>
<tr>
<td>October</td>
<td>612.5</td>
<td>462.1</td>
<td>699.5</td>
<td>614.7</td>
<td>592.5</td>
<td>0</td>
<td>419.0</td>
<td>668.2</td>
<td>197,267</td>
<td>569,188</td>
<td>0</td>
</tr>
<tr>
<td>November</td>
<td>588.4</td>
<td>708.6</td>
<td>635.7</td>
<td>705.7</td>
<td>408.3</td>
<td>0</td>
<td>534.7</td>
<td>600.8</td>
<td>208,040</td>
<td>605,172</td>
<td>0</td>
</tr>
<tr>
<td>December</td>
<td>581.0</td>
<td>648.0</td>
<td>719.3</td>
<td>715.2</td>
<td>537.0</td>
<td>0</td>
<td>177.1</td>
<td>732.8</td>
<td>189,273</td>
<td>554,010</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>6,861.5</td>
<td>6,305.8</td>
<td>6,035.8</td>
<td>6,147.6</td>
<td>6,990.3</td>
<td>5,294.3</td>
<td>6,187.2</td>
<td>6,315.1</td>
<td>2,785,424</td>
<td>8,022,854</td>
<td>1,044</td>
</tr>
</tbody>
</table>
Powerplant, dam, and switchyard station-service power supply was energized through the permanent powerplant facilities on December 30, 1964. A temporary feed had been installed to the switchyard until the permanent equipment was energized. The 25-kilovolt station-service voltage regulator KV1A was put into initial service on March 19, 1965, and the switchyard station-service was also picked up from autotransformer KU5A at that time.

As mentioned previously, power was initially transmitted on the Glen Canyon-Shiprock 230-kilovolt transmission line. The Glen Canyon-Sigurd 230-kilovolt transmission line was energized on October 19, 1964, and the Pacific-Northwest and Pacific-Southwest regions were interconnected through the switchyard the next day.

The Glen Canyon-Flagstaff section of the Glen Canyon-Pinnacle Peak 345-kilovolt transmission line No. 1 was initially energized at 230-kilovolts on December 22, 1964. The Arizona Public Service Co. Bureau of Reclamation loop was closed for power delivery on December 24, 1964. The Glen Canyon-Pinnacle Peak transmission line No. 1 was opened at Winona on May 24, 1965, and was energized from Glen Canyon to Pinnacle Peak Substation at 230 kilovolts for the first time on May 25, 1965. This line was tested on October 2, 3, and 4, 1965, to permit energizing for service at 345 kilovolts. The Glen Canyon-Pinnacle Peak transmission line No. 2 was first energized on July 1, 1966, being delayed due to the difficulties in obtaining satisfactory acceptance tests for an autotransformer at Pinnacle Peak Substation.

The 69-kilovolt transformer KW1A and the 69-kilovolt switchyard were first energized for testing on January 31, 1966. Power delivery to Arizona Public Service Co. and to Garkane over the Glen Canyon-Page transmission line began on February 4, 1966.

269. TRANSFER TO OPERATION AND MAINTENANCE STATUS. During October 22 through 28, 1966, a preparatory inspection for transfer from construction status to operation and maintenance status was made at Glen Canyon Dam, Powerplant, and Switchyard. Major construction was considered complete except for minor deficiencies which would be corrected, and the transfer was made effective January 1, 1967.

270. ELECTRICAL GENERATION AND RELATED STATISTICS. Tables 6 and 7 show initial reservoir storage and power generation statistics from the fall of 1964 until the end of 1966.