CONSTRUCTION of the second highest dam in the United States will begin early this year. It is the Glen Canyon Dam, a key structure of the Bureau of Reclamation’s Colorado River Storage Project. The project was authorized by the Congress in the spring of 1956 to develop the land and water resources of the Upper Colorado River Basin, a 10,000-sq. mi. area containing a rich potential of agricultural, industrial, and recreational assets.

Glen Canyon Dam, to be about 700 ft. high above its foundation—second in height only to the 726-ft. Hoover Dam—will be built on the Colorado River in north-central Arizona, about 15 river miles upstream from Lees Ferry and 12 river miles downstream from the Arizona-Utah state line. It is about 370 mi. upstream from Hoover Dam on the Lower Colorado River.

Glen Canyon Dam is designed to serve multiple purposes by creating a reservoir for conservation storage, power generation, silt retention, recreation, and fish and wildlife conservation. It will be a concrete arch structure having a volume of 4,770,000 cu. yd., a crest length of 1,500 ft., and a maximum thickness at the base of 300 ft. The reservoir will have a capacity of 28,040,000 ac. ft. and will extend 186 mi. up the Colorado River and 71 mi. upstream on the San Juan River. Glen Canyon reservoir and other storage units in the Upper Colorado River Basin will provide holdover reserves of water to meet terms of the 1922 Compact of the Colorado River. Glen Canyon Powerplant, to be built concurrently with the dam, has been designed to include an installed capacity of 900,000 kw.

Problem of access

By virtually any construction standard, access to the remote Glen Canyon area imposes major problems in the transportation of supplies and equipment from established areas to the site. As an illustrative example, although it is approximately 1,200 ft. from one rim of the canyon to the other at the dam site, it was necessary, until recently, for vehicular traffic to go 225 mi. to get from one side of the canyon to the other.

Flagstaff, Ariz., a railhead, is 135 mi. from the dam site; the railhead at Marysvale, Utah, is 200 mi. from the dam site, via Kanab, Utah, the nearest town.

First major construction at the dam site began Oct. 2, 1956, following award of a $2,452,340 contract to Mountain States Construction Co., Denver, for construction of the right (west) diversion tunnel. The 2,741-ft. tunnel has a diameter of 48 ft. 6 in. in its upstream portion and a diameter of 46 ft. 6 in. in its downstream portion.
The principal quantities required for the dam, spillway, outlets, and power features are shown in the accompanying tabulation. Most of the materials listed will be supplied and installed by the general contractor during the period of the contract, which is expected to extend for about 7 years. In addition to these materials, the Bureau will purchase the larger items of special machinery and equipment under separate advertisements to be issued as soon as designs have been completed.

In the following summary, plans for construction of the Glen Canyon Unit of the storage project are briefly discussed to indicate the scope of the development and the many challenging construction problems to be resolved.

Glen Canyon dam site

Glen Canyon covers a 176-mi. section of the Colorado River Basin from the lower end of Cataract Canyon, 14 mi. above Hite, Utah, to Lees Ferry, Ariz. This canyon is one of the spectacular cuts by the Colorado River. Throughout most of its length, Glen Canyon is a narrow river gorge confined by massive sandstone walls variable in height, the maximum being 1,200 ft. above river level. At Lees Ferry, the lower terminal of the canyon, the nearly vertical walls recede, and the river flows for a short distance in a relatively open valley before entering the narrow gorge of Marble Canyon.

Above the rim of Glen Canyon and extending for some distance on either side is a gently rolling upland plain dotted with isolated buttes and mesas and cut at intervals by deep narrow canyons leading into the Colorado River. The entire area is a vast expanse of wasteland, uninhabited except for a few ranchers on the northwest side of the river and scattered Indian families on a reservation to the southeast.

The Glen Canyon area is a small but typical part of the Colorado Plateau Province, a vast area of nearly horizontal sedimentary rocks that have been elevated without materially disturbing the component layers. It is essentially a country of broad, cliff-edged mesas cut by narrow, steep-walled canyons.

The dam site lies in a narrow straight-walled section of Glen Canyon about 1 mi. below the mouth of Wahweap Creek. At this site, the sides of the canyon rise abruptly from the bed of the river in nearly vertical walls 650 ft. high. Both abutments and the foundation area at the site are in the Jurassic Navajo sandstone. The Navajo formation is a massive, highly cross-bedded, buff to red, medium- to fine-grained sandstone made up essentially of white and pink quartz grains and a few grains of other minerals.
Eight generators will have a combined capacity of 900,000 kw. The double spillway will handle 276,000 sec. ft. Diversion during the construction period will be through the spillway tunnels. Mass concrete will rise in columns, as large as 55 x 170 ft. in section at the base. Cement content is now anticipated to be 2 sacks of portland cement and 1 of pozzolan per yd. Concrete will be placed at 50 deg.

GLEN CANYON DAM, RESERVOIR, AND POWERPLANT

Physical Data

<table>
<thead>
<tr>
<th>Type</th>
<th>Concrete arch</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height above river bed</td>
<td>580 ft.</td>
</tr>
<tr>
<td>Height above lowest point in foundation</td>
<td>700 ft.</td>
</tr>
<tr>
<td>Crest length</td>
<td>1,500 ft.</td>
</tr>
<tr>
<td>Crest width (width of roadway)</td>
<td>35 ft.</td>
</tr>
<tr>
<td>Base width</td>
<td>300 ft.</td>
</tr>
<tr>
<td>Concrete in dam</td>
<td>4,770,000 cu. yd.</td>
</tr>
<tr>
<td>Crest elevation</td>
<td>3,713</td>
</tr>
<tr>
<td>Maximum discharge through spillways</td>
<td>276,000 sec. ft.</td>
</tr>
</tbody>
</table>

RESERVOIR

Capacity | 28,040,000 ac.-ft. at normal water surface elevation 3,700
Area | 164,000 ac. at normal water surface
Elevation maximum water surface | 3,711
Length | 186 mi.

POWERPLANT

Capacity | 900,000 kw.
Number of units | 8
Capacity of each generator | 112,500 kw.
Capacity of each turbine | 153,000 hp.

The climate in the vicinity of the dam site is dry. Summers are hot and winters are relatively mild. Maximum recorded temperatures for June and July are 114 deg., a minimum temperature of 2 deg. has been recorded in December and January. Snowfall is light and will not create any construction problem. For the past 20 years of record at Lees Ferry, the average annual snowfall was about 4 in. Annual precipitation is 6 in.

For construction of the dam, the contractor will be required to erect and maintain a complete concrete plant. The plant will include equipment for processing, conveying, and stockpiling concrete aggregates; storage and handling facilities for both cement and pozzolan; mixing and batching facilities; refrigerating equipment for cooling aggregates and mixing water; and a cableway or other means of conveying the concrete to and placing it in the dam.

Aggregates to be used in the concrete for the dam will probably be obtained from Government-owned property known as the Wahweap deposit, located on Wahweap Creek about 7 mi. upstream from its junction with the Colorado River. The aggregate will require washing and some wastage to obtain the desired quality and grading. As the aggregates are potentially reactive with alkalis in cement, low-alkali cement will be called for in the dam.

It is anticipated that the mass concrete for the dam will contain about two sacks of portland cement and one of pozzolan per yard. Concrete will be placed at 50 deg. on the dam.
sack of pozzolan per cubic yard. About 3,000,000 bbl. of cement and 225,000 tons of pozzolan will be used.

The dam is to be divided into columns or blocks by radial and circumferential contraction joints. Blocks will range in size from 55 x 170 ft. in the downstream portion at the base to 70 x 120 ft. in the upstream portion. To insure monolithic action of the dam and to secure the desired stress distribution in the structure, the contraction joints will be grouted. For the injection of grout into the joints, a system of pipes is to be embedded in the concrete adjacent to the contraction joints.

Contraction joints are to be interlocked by keys formed to provide a maximum cross-sectional area for resistance to shear after grouting. The contractor will have the option of placing the concrete in the dam in either 5- or 71/2-ft. lifts. The rate of placing concrete in any block will be restricted so that not more than one horizontal lift can be placed in 72 hr. A maximum vertical difference of 25 ft. in the top surface of adjacent blocks will be permitted.

Temperature control measures will consist primarily of precooling the various parts of the concrete mix to obtain concrete placing temperatures of not more than 50 deg. F., and of artificially cooling the concrete by an embedded pipe system to temperatures of between 40 and 50 deg. Precooling measures will include cooling the aggregate either by immersion in an ice-water bath or by refrigerated air blasts, cooling the mixing water and by adding slush or chip ice to the mix.

In addition to the refrigerating capacity required to carry out this precooling, there must be added the cooling load from the embedded pipe system which is needed to cool the concrete so that the contraction joints in the dam can be filled with cement grout before the reservoir water load is placed against the dam. About 950 ml. of pipe or tubing will be embedded in the concrete of the dam to accomplish the artificial cooling.

Foundation treatment

The general plan for grouting the foundation rock will consist of low-pressure shallow grouting at the upstream face of the dam, followed by grouting a high-pressure deep curtain in the same area. The low-pressure grouting will be done through holes drilled on 20-ft. centers to a depth of 25 ft. prior to placement of concrete. After concrete has been placed to a sufficient height, the deep high-pressure grouting will be done through holes drilled from the foundation gallery at 10-ft. centers and at depths varying up to 250 ft.

Drainage of the foundation will be provided by a series of holes drilled into the foundation rock from the floor of a main foundation gallery and from the roof and floor of the foundation tunnels which will extend into each abutment. A second foundation gallery parallel to and downstream from the main foundation gallery will be located in the dam and drainage holes will be drilled from this gallery if future foundation drainage conditions require them. Drainage from the foundation galleries will be collected in a sump off the lowest point in the gallery system and pumped out of the dam.

Powerplant construction

Glen Canyon Powerplant is to be constructed about 470 ft. downstream from the axis of the dam. It will be a reinforced concrete structure 665 ft. long, 113 ft. wide, and 150 ft. high above foundation. The powerhouse superstructure will be a structural steel frame having reinforced concrete enclosure walls. The roof will be built of prestressed concrete slabs and cast-in-place concrete. Specifications will offer the contractor the alternative of placing either precast panel walls or cast-in-place walls in the superstructure.

Construction of the powerhouse will be carried out in two stages. First-stage construction, which is to be part of the prime contract for the dam, will include placement of 87,000 cu. yd. of structure concrete, 10,700,000 lb. of reinforcing steel, and 4,250,000 lb. of structural steel. In addition, 60,000 cu. yd. of mass concrete are to be placed beneath the powerhouse.

Second-stage construction, which will be carried out under a separate completion contract, will include placement of 30,000 cu. yd. of concrete and 3,000,000 lb. of reinforcing steel. The completion contract, to be awarded after completion of the major portion of the prime contract, will call for installation of the generating equipment, exposed piping and electrical conduits, architectural finish, heating and ventilating equipment, and other finish work.

The powerplant is designed for an ultimate installation of eight 112,500-kw. generating units. Capacity of each turbine is 155,500 hp.; rated head is 450 ft. Water will be conveyed to each generating unit through a 15-ft. steel penstock embedded in the dam. The penstocks emerge at the toe of the dam and span the intervening distance between the toe and the powerhouse on concrete piers.

Hydraulic features

Spillway tunnels having their en-
trances about 600 ft. upstream from
the dam will be used to pass flood
waters. The inflow design flood was
based on a combination of snow and
rain floods during the months of
April, May, June, and July. Peak dis-
charge is 380,000 sec. ft. and has
occurred June 18, 1921. By storing
about 1,850,000 ac.-ft. of the flood
waters, the maximum discharge
through the spillways will be 276,000
sec. ft. An additional 15,000 sec. ft.
of the flood will be discharged
centers through the outlets and 10,000 sec. ft.
through four units of the powerplant.

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Crests of the entrance channels for
the spillway tunnels are controlled by
240 x 32.5-ft. radial gates for
each tunnel. Tunnels will each be
concrete lined and will have tran-
sitions from the crests to 41-ft. diam-
eter tunnels. Lining of both tunnels
is to be done under the dam contract.
Ski-jump buckets at the downstream
ends of the spillways will raise the
water so that it will be deflected into
the center of the river channel.

Although entrance channels of the
spillway tunnels will be unlined, the
discharge velocities of the water, as
high as 162 ft. per sec., will require
that the elbow areas have a special
finish to minimize cavitation.

From hydrological investigations,
the following flood frequencies have
been determined in analyzing the di-
version of the river:

<table>
<thead>
<tr>
<th>Flood Type</th>
<th>Frequency</th>
<th>Discharge</th>
</tr>
</thead>
<tbody>
<tr>
<td>5-year flood</td>
<td>25%</td>
<td>118,000 sec. ft.</td>
</tr>
<tr>
<td>10-year flood</td>
<td>10%</td>
<td>150,000 sec. ft.</td>
</tr>
<tr>
<td>25-year flood</td>
<td>5%</td>
<td>196,000 sec. ft.</td>
</tr>
</tbody>
</table>

**MAXIMUM 15-DAY VOLUME**

<table>
<thead>
<tr>
<th>Flood Type</th>
<th>Frequency</th>
<th>Discharge</th>
</tr>
</thead>
<tbody>
<tr>
<td>5-year flood</td>
<td>25%</td>
<td>2,723,800 ac.-ft.</td>
</tr>
<tr>
<td>10-year flood</td>
<td>10%</td>
<td>3,180,000 ac.-ft.</td>
</tr>
<tr>
<td>25-year flood</td>
<td>5%</td>
<td>3,350,000 ac.-ft.</td>
</tr>
</tbody>
</table>

Closure of the left diversion tunnel
will be in two stages. Initial work will
install the first section of the tunnel
plug containing three 4x5-ft. high-
pressure slide gates. This will be ac-
complished during the low-flow sea-
son when the flow of the river will be
confined to the right tunnel. The
gates in the plug section will control
the discharge downstream and will
allow storage in the reservoir to begin
when the right tunnel is closed.

Final closure of the left tunnel will
be made when the reservoir fills to the
level at which the river outlets in the
dam can supply minimum down-
stream releases of 3,000 sec. ft. At this
time, the slide gates will be shut, the
gate passages and chambers filled
with concrete, and the final section of
the concrete plug installed.

Closure of the right diversion tun-
nel should be scheduled in time to
store the spring runoff in the reser-
voir. It is contemplated that a normal
spring runoff with minimum down-
stream releases will fill the reservoir
to minimum power storage level.

The river outlets, located on the
left abutment, will provide river re-
leases for downstream commitments
when the powerplant is not in opera-
tion and when final closure is made of
the diversion tunnels. Capacity of
the outlets is 15,000 sec. ft. at mini-
mum water surface elevation. Outlets
consist of four 96-in. steel pipes con-
trolled by hollow-jet valves and have
ring-follower gates for emergency
closure. The intakes are at an elevation
10 ft. above estimated 100-year
silt level, and will be protected from
trash and debris by concrete trashrack
structures on the upstream face of the
dam.

**COLORADO RIVER BRIDGE**

A striking feature of the Glen Can-
yon construction is the Colorado
River bridge about 700 ft. above
river level. The bridge, to be built
865 ft. downstream from the axis of
the dam, is to be a single span steel
arch, having a rise of arch of 165 ft.
and a length of 1,028 ft. It will have
a reinforced concrete deck for a 30-ft.
roadway and two 4-ft. sidewalks, one
on each side of the roadway.

Live load design is based on the
loading of a 20-ton truck followed by
a 16-ton trailer, in accordance with
the latest requirements for the Inter-
state Highway System. The concrete
foundations, or skewbacks, support-
ing the arches, are to be placed in
sound rock of the Navajo sandstone
formation at each canyon rim where
glacial joints are at a minimum.

Specifications for the bridge call
for the contractor to furnish and in-
stall 8,000,000 lb. of structural steel,
250,000 lb. of reinforcing steel, 100,-
000 lb. of handrailing, and 1,000
cu. yd. of concrete in the bridge deck.

The bridge is to be built under an
agreement with the State of Arizona
which calls for the Bureau of Recla-
mation to pay from its own funds
$1,800,000 (the amount a temporary
bridge would cost), and the Bureau
of Public Roads $600,000. Arizona
will pay the remaining costs, except
in the event that the cost should run
over $3,200,000, the United States
will pay 75% of the amount of such
excess cost.

Access roads are problem

To overcome the difficult problems
of access to the remote dam site and
to assure a steady flow of materials
and supplies for construction, the De-
partment of the Interior entered into
an agreement with the State of Ari-
izona which called for construction
and maintenance of a 25-mi. access
road 34 ft. wide to the site of the dam and the Colorado River bridge. The agreement with Arizona makes it possible to bring the road up to the standard of a primary highway—beyond temporary construction needs of the Bureau of Reclamation—and is the first step toward a permanent loop off U. S. Highway 89. The terminals are in Kanab, Utah, and Bitter Springs, Ariz., a distance of about 96 mi.

The highway and bridge will permit ready access to the dam site from presently existing improved highways over which construction materials and equipment will be trucked from the railheads. The highway will also provide a tourist route to the scenic recreational area and reservoir created by construction of the dam.

The arrangement with Arizona is made possible by an easement signed by the Navajo Tribal Council for use of land to be crossed in the Navajo Indian Reservation. It is also keyed into participation by the Bureau of Public Roads, which agency will provide additional funds needed to bring the Colorado River bridge to the standards of a primary highway.

Construction of the highway is being carried out under two contracts—a 4½-mi. section, running from Bitter Springs under a $1,156,234 contract held by the Strong Company of Springville, Utah; and a 20-mi. section, completing the highway to the bridge site, under a $1,011,819 contract awarded last August to Transa Homes, Inc., Fullerton, Calif. These portable houses are to be completed with heating, plumbing, and electrical systems and ready for installation and connection to utilities to be provided under future contracts.

Personnel

W. A. Drexheimer, whose offices are in Washington, D. C., is Commissioner of the Bureau of Reclamation. The storage project is in the Bureau's Region 4; E. O. Larson is Regional Director. L. F. Wyie is project construction engineer for the Glen Canyon Unit; his office is at Kanab, Utah.

San Luis Project report to Congress

A BUREAU OF RECLAMATION report on the economic and engineering feasibility of the proposed San Luis Unit of the Central Valley Project in California has been forwarded to the Congress, Secretary of the Interior Fred A. Seaton announced recently.

The San Luis Unit would provide a full water supply to 440,000 ac. of land along the west side of the San Joaquin Valley. Most of this land is presently irrigated by pumping from private wells but the water supply is being rapidly depleted and it is estimated that not more than 150,000 ac. can be sustained in permanent irrigated agriculture without additional water being made available.

The major works reported upon are: the project's approximately $299,000,000—include the million-acre-foot initial capacity San Luis Reservoir, the San Luis pumping plant to pump water from the Delta-Mendota Canal, and a system of main canals through the irrigated area. In addition to the major features of the San Luis Unit, other features—principally the distribution system—would cost an estimated $170,000,000.