August 2022

# Magazine Article by J.S. Seybold Regarding the Construction of the Garrison Dam, October, 1949

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# CIVIL ENGINEERING

REPRINT

OCTOBER 1949

THE MAGAZINE OF ENGINEERED CONSTRUCTION

Garrison Dam

MOTOR GRADERS maintain road while trucks haul fill for Garrison Dam. See article by J. S. Seybold.

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MWD of Southern California Doubles Capacity of Water Softening Plant — Diemer

Aerial Survey Methods Solve Highway Location Problems in Tropics — Pryor

PLAN TO ATTEND ASCE FALL MEETING IN WASHINGTON, D.C., NOV. 2-4

#15

RIVERDALE, N. Dak., built on terrace on left bank above dam, includes both temporary and permanent housing. When project is completed town will house operation and maintenance personnel. White lines indicate dam site. Just below downstream toe is railroad and highway embankment and construction bridge, which carries single-track railroad and 26-ft roadway.

# Constructors Roll Nearly One Million Yards a Week Into Garrison Dam


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WHEN COMPLETED Garrison Dam will be one of the world's largest water controlling structures—in fact the world's largest earthfill dam built by dry-land methods. Its reservoir will stretch 200 miles up the Missouri Valley and drain an area of 180,940 sq miles. Its five power units will produce 400,000 kw. Excavation for the intake, powerhouse, outlet works, and spillway will provide almost all of the 68,000,000 cu yd of fill required in this rolled-earth structure. Eight tunnels about 30 ft in diameter are being constructed as part of the structure. Of these, five will serve as penstocks and three will be used for flood control. Before constructing any of the tunnels, a test tunnel was dug to obtain design data. Garrison Dam is the second unit in the Pick-Sloan Plan for the control of the Missouri River. When completed in 1954, it will share with the Fort Peck Dam, the first unit in the plan, the task of regulating the flow of the river for flood control, power and navigation.


GARRISON DAM, key unit in the Pick-Sloan comprehensive plan for the conservation of water resources of the Missouri Valley, although a rolled-earth structure, contains 1,500,000 cu yd of concrete. Hoover Dam, the world's highest dam, a concrete gravity structure, contains only slightly more than 3 million cu yd of concrete. How Garrison compares in various respects with the five largest dams in the United States can be seen from Table I.

The first stage of construction involving some 14,000,000 cu yd of fill, was carried on by a joint-venture contractor group called Garrison Builders. The present contract, covering the second-stage construction, is being carried out by Peter Kiewit Sons' Co. and Morrison-Knudsen Co., Inc. jointly. This contract includes the placing of 16,630,000 cu yd of embankment fill, or a total excavation of about 19,500,000 cu yd, and is scheduled for completion by the end of 1950. See Fig. 1.

Garrison Dam is located on the Missouri River about 12 miles south and slightly west of Garrison, N.Dak., from which it takes its name. The dam is being constructed as a multiple-purpose project for flood control, irrigation, hydroelectric power production, improved flow regulation in the interest of navigation and sanitation, recreational development and wild life preservation.

The Missouri River at the dam site drains an area of 180,940 sq miles. The reservoir created by the dam will have a capacity at maximum normal operating pool (El. 1850) of 23,000,000 acre-ft, which includes 4,900,000 acre-ft of dead storage (to El. 1775), 13,850,000 acre-ft for multiple-purpose storage (to El. 1838), and 4,250,000 acre-ft for flood control (between Els. 1838 and 1850). At minimum flood-control pool (El. 1838) the reservoir will have an area of 335,000 acres and at maximum normal operating pool (El. 1850), an area of 390,000 acres. The reservoir will extend along the Missouri River in a northern direction approximately 200 miles to within 9 miles of the mouth of the Yellowstone River, about 13 miles east of the Montana–North Dakota state line.

Upon completion the rolled-fill earth embankment will be about 12,000 ft long with the crest at El. 1875. The lowest part of the dam is 210 ft below the crest. The dam will have a crown width of 60 ft and a maximum base width in the flood plain of about 2,500 ft exclusive of the upstream impervious blanket. Embankment slopes, Fig. 2, vary

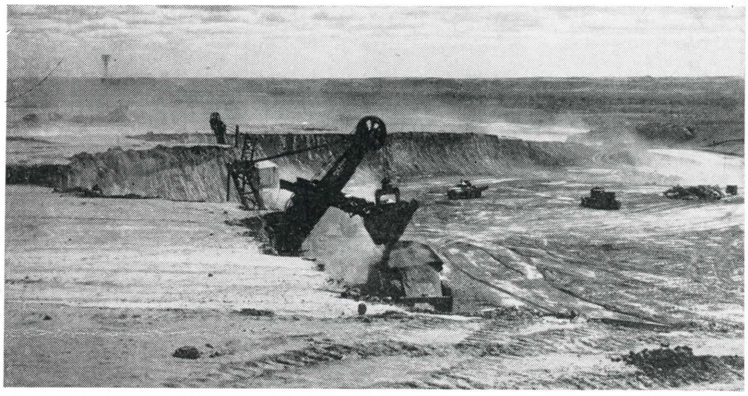
TABLE I. LARGEST DAMS IN UNITED STATES, IN ORDER OF STORAGE CAPACITY

| Dam | Height Ft | Length Ft | Volume Cu yd | Storage Capacity Acre-Ft | Reservoir Area Sq Miles | Type |
|---|---|---|---|---|---|---|
| Hoover Dam | 726 | 1,244 | 4,400,000 | 32,359,000 | 246 | Gravity (concrete) |
| Garrison | 210 | 12,000 | 68,000,000 | 23,000,000 | 609 | Rolled earthfill |
| Fort Peck | 250 | 21,026 | 128,000,000 | 19,417,000 | 383 | Hydraulic fill |
| Grand Coulee | 550 | 4,173 | 10,493,000 | 9,517,000 | 127 | Gravity (concrete) |
| Kentucky | 206 | 8,422 | 8,518,700 | 6,003,000 | 408 | Gravity (concrete) |
| Shasta | 602 | 3,500 | 8,710,000 | 4,493,000 | 46 | Gravity (concrete) |


*(Reprinted from October 1949 issue of* CIVIL ENGINEERING, *published and copyrighted by the American Society of Civil Engineers)*

CONSTRUCTION of Garrison Dam (right) continues around the clock in two 10-hour shifts, with time between shifts for maintenance of equipment and lunch periods. Flood lamps are fixed on structural steel towers 70 ft high, mounted on skids for ease in moving.

FIVE SCOOPFULS from electric shovel (right) load 25-cu yd bottom-dump truck with material excavated in spillway area. Almost all material for embankment comes from excavation. Shovel is Bucyrus 120 B and truck is butane-fueled Euclid.



from 1 on $2^1/_2$ at the top to 1 on 8 at the bottom. A highway will be constructed across the crown of the embankment.

### Seepage Control and Drainage

Selected impervious material will form the upstream portion of the dam. Slope protection will consist of 3 ft of rock over 1 ft of spalls over 1 ft of bank-run gravel. This protection extends from the top of the dam to El. 1800, below which a bank-run gravel blanket will be carried down a 1 on 10 beach slope to El. 1770. The downstream portion of the dam will contain random rolled-fill material, and the exposed slopes will be protected with vegetative cover. Seepage will be controlled by an impervious blanket extending 1,250 ft upstream from the toe of the embankment and by sheetpiling and impervious-backfilled trench-cutoffs under the upstream portion of the embankment. A horizontal pervious drainage blanket under the downstream portion of the embankment, a downstream toe drain and relief wells below the downstream toe serve a similar purpose.

Flat slopes and the resulting broad base width were chosen for reasons of stability considering the 80 to 120 ft of alluvial clay and clayey glacial till which forms the foundation in the west terrace. The same broad base width will be carried across the river and east terrace to reduce seepage through the 40 to 100 ft of pervious sand forming the foundations and to provide an ample safety factor for stability. The internal section will consist of a large impervious and random embankment with a thin horizontal blanket of pervious material beneath and generally downstream of the center line to collect through seepage. The more impervious material will be placed in the impervious zone and the less impervious in the random zone. Sufficient volumes of semipervious and pervious material are available from excavated areas for use at the outer downstream portion of the random zone, which connects with the pervious drainage blanket below. This drainage blanket is 10 ft thick across the valley, decreasing to 5 ft at both abutments where the more impervious foundation and lower dam height combine to reduce seepage. Above El. 1845 the drainage blanket will be omitted entirely.

A substantially complete cutoff against foundation seepage is provided across the entire valley. Steel sheetpiling is being used for the deeper pervious strata and a cutoff trench for the shallower pervious strata. The basis for changing from a cutoff trench to sheetpiling and the location of the cutoff line were established by economic studies. For the sheetpiling a $^3/_8$-in. web, 16-in. wide section, weighing 23 lb per sq ft of wall, has been selected and has been driven without difficulty to depths of 110 ft to penetrate 8 to 10 ft into the clay till beneath the river sands.

### Driving Cutoff Piling

On the east and west bank, respectively, a total of 2,398 ft and 1,412 ft of wall has been driven, and on the right bank 4,475 ft of cutoff trench

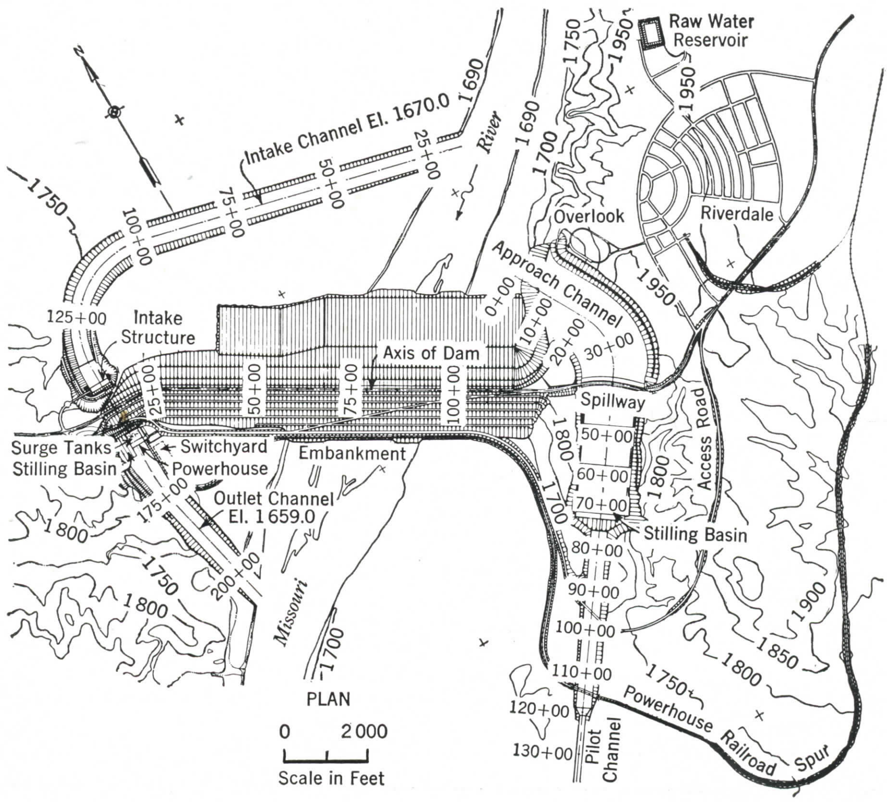
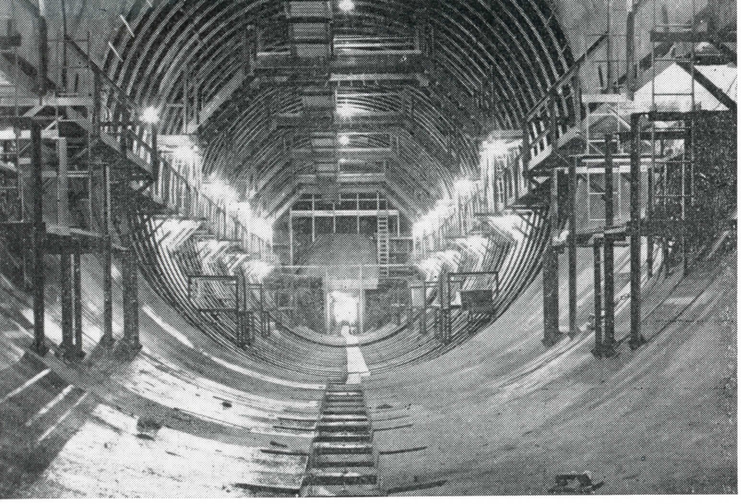
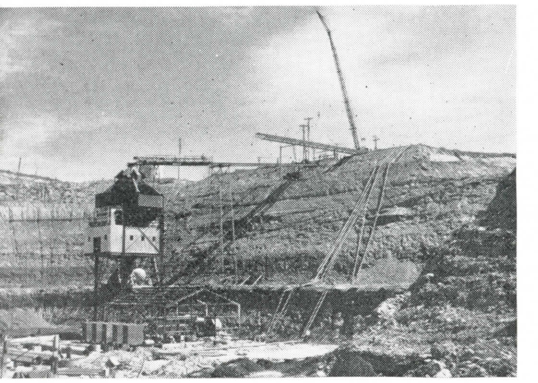



FIG. 1. PLAN OF GARRISON DAM (right) covers area of about five square miles. Channel at upper left will divert Missouri River through intake structures during diversion and closure operations in 1952. Crown width of dam is 60 ft and maximum base width in flood plain is 2,500 ft exclusive of upstream impervious blanket extending additional 1,250 ft.



TEST TUNNEL (left) completed in January 1949, at site of penstock tunnel No. 4, contains instruments to record magnitude and distribution of earth pressures. Catwalks give access to instruments and measurement points. Slots in concrete lining at invert expose sections of steel ribs for strain-gage measurements.



CRANE (above) places section of aggregate conveyor for mixing and batching plant to serve tunnels in west abutment. Refrigeration plant is also under construction here.

has been excavated and backfilled. The total length of the pile wall and cutoff trench will be 11,132 ft, including 1,580 ft driven across the present river channel. By using a leading spade jet to full depth and a hairpin jet on each side of the pile being driven, serious difficulty has been avoided in driving the deeper piles to full grade. The construction of the driving tower requires that each pile be placed and driven to full penetration before the traveling tower is advanced. This method probably necessitates a greater number of correction piles than would be required if it were possible to stick and partially drive a section of wall before driving the piling to final grade, but an advance of 30 to 35 piles, averaging 105 ft, has been maintained, which meets the scheduled requirements. Selected check piles have been pulled for inspection and none has shown damage. After the piles have been driven in their trench, and after the trench has been carefully cleaned and the muck resulting from jetting operations removed, selected impervious material is carefully hand tamped around the piles.

A blanket 1,250 ft wide extends along the upstream toe from Sta. 42 + 00 on the west terrace to the east abutment, where it will tie into the blanket covering the lignite seams in the entrance to the spillway approach channel. Varying in thickness from 14 to 24 ft where it adjoins the dam, the blanket decreases to from 5 to 14 ft at its upstream extremity. The blanket is highly impervious as compared to the underlying sands. At least 5 ft of thickness of the blanket is rolled to the same placement specifications as the impervious section of the dam; the remainder is constructed of uncompacted impervious material placed in 12-in. loose layers compacted by the traffic of placing and spreading equipment.

For conservative control of underseepage, a relief well system is planned, extending across the main reach of the deep pervious foundation from the west bank of the river to the east abutment. Present design contemplates using wood stave pipe of 8-in. inside diameter in 24-in. gravel pack wells, discharging into an open ditch approximately 175 ft downstream of the center line of the present highway which runs along the toe of the dam. The wells on the island and east terrace will be about 200 ft on centers and penetrate approximately 80 percent of the depth of the valley sands, which range from 80 to 107 ft. A drain will extend along the toe of the dam for 10,700 ft to carry through seepage from the 10-ft pervious drainage blanket and to tap the pervious sands and gravels to afford relief and drainage of under seepage from the foundation.

In the river, island and east terrace sections, the cover of the toe drain will extend down approximately 30 ft in some places, and to support this depth of cover a reinforced-concrete-encased clay pipe has been designed, employing tee branches with perforated plates to admit drainage to the pipe. To prevent movement of the silt and clay random material into the underlying pervious drainage blanket of the downstream section of the dam, a 3-ft semipervious transition layer of Fort Union sand will be used. Careful selection of materials to be used in the top of the pervious blanket will prevent migration of the semipervious material into the pervious blanket.

It is expected that relatively small quantities of embankment material will be supplied from borrow pits. The excavation of the intake and intake channel, powerhouse and outlet works, and spillway will yield most of the materials needed. The haul across the river on the construction bridge is limited to the gravel and pervious materials from the intake channel excavation required in the east-bank pervious zone. Otherwise, the random and impervious materials excavated on each bank are estimated to be of sufficient volume to construct the respective embankments. Approximately 4,000,000 cu yd of commercial-grade lignite will be excavated and salvaged in the construction of the dam and appurtenant works. The exact amount to be salvaged depends on the feasibility of utilizing beds 3 ft or more in thickness.

### Eight Tunnels in Right Abutment

The outlet works, located in the right abutment, consist of eight tunneled conduits, five for power and three for reservoir regulation, and an intake structure and stilling basin. The intake and outlet channels, which connect the outlet works with the river above and below the dam, average 350 ft in bottom width.

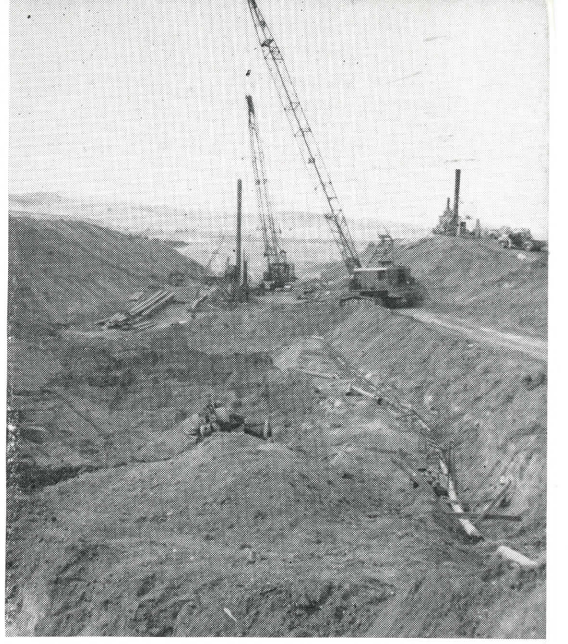
Specifications for the embankment require the contractor to spread the fill in approximately horizontal layers. All pieces of rock or lignite and cobbles greater than 6 in. in maximum dimension are removed from the impervious, random, and semipervious sections of the embankment. Pieces of rock greater than 9 in. in maximum dimension are removed from the pervious section of the embankment. Lignite is not allowed in the pervious zone. Zones of the embankment in which lignite is permitted contain no more than 2 cu ft of lignite in 10 cu ft of embankment, evenly dispersed within the layer. Because of the methods of excavation used, very little lignite has been placed in the embankment as the excavation operations generally tend to concentrate the lignite in unit loads which are wasted. Excavation operations in the thicker lignite beds, which are the exception, conform to the usual methods employed by strip mines, and all material is salvaged.

In general, the natural moisture content of the Fort Union material and overburden is satisfactory for the required compaction. Some additional water is added, and in some cases wet areas have been found in the pits which require wastage of small quantities of material. Field tests are carried on currently with the contractor's embankment work and any lift found unsatisfactory is given an additional processing by additional rolling or other remedial treatment. At times, it has been necessary to allow sections of the dam to dry either naturally or by working with special equipment. The conventional-type sheepsfoot rollers used, have a drum approximately 5 ft in diameter and weighing not less than 3,500 lb per lin ft when ballasted. Pressures of not less than 640 lbs per sq in. are exerted by the rollers.

Impervious and random material are placed in layers not over 9 in. in uncompacted thickness, and are compacted by at least ten passes of the rollers. Pervious material is placed in layers not over 12 in. in uncompacted thickness and compacted by four passes of tractor treads. Some of the Fort Union material when excavated and spread is found to be quite blocky. Specially built heavy tooth rollers of the knife or spike type are used to break down such material for compaction by standard rollers. The Fort Union material has been found quite satisfactory for the impervious section of the dam. Certain of the more sandy phases of Fort Union formation and overburden are more successfully placed in the random section.

The construction contract for the eight diversion tunnels was let in April 1949. All the tunnels will be used in the diversion and closure operations in 1952. Five of the tunnels, each 35 ft in bore diameter, are designed as penstocks, each supplying an 88,000-hp turbine, now being designed and built by the Baldwin Co. of Philadelphia. The three remaining tunnels are to be used for reservoir regulation, one being 31 ft in diameter and two 27 ft. All tunnels will be lined with 3 ft of concrete. The 1,200-ft tunnels are practically parallel, spaced 75 ft from center to center at the upstream portal. Center lines of the tunnels diverge slightly in order to increase the downstream spacing of the three reservoir control tunnels to 81 and 85 ft to allow for the economical design of the stilling basin.

In the larger power tunnels a 10 WF 72 steel rib section will be used with open lagging for about 300 ft each side of the midpoint. For the first 300 ft at both portals, 8 WF 48 steel sections will be used, also with open lagging. Rib spacing is generally $3^1/_2$ ft center to center, with 24 ft between construction joints. In the smaller control tunnels, 10 WF 49 and 8 WF 35, with the same spacing and construction details, are used respectively in the center and outside quarters. The total overburden is approximately 210 ft, of which the original ground forms approximately 120 ft, and conforms to the dam section. The full section of the dam has been completed over the tunnels and tunnel driving has been started by the contractors,



SHEETPILE WALL IS DRIVEN in sections in core trench excavation on right bank where necessary to cut off deeper pervious strata. Maximum sheetpiling length of 50 ft used here does not require tower for driving.

S. A. Healy Co. and Material Service Corp. Articulated joints will be used at the portals. The tunnels will be completed before diversion is started.

#### Test Tunnel on Site of Penstock No. 4

A test tunnel was built for the purpose of determining the magnitude and distribution of earth pressures to be used in designing the reinforced concrete lining and the steel ribs. The tunnel was constructed to the full diameter of the outlet works tunnels and was sufficiently long, 240 ft, to avoid arch effects and to obtain typical section loading data. Built on the center line of penstock

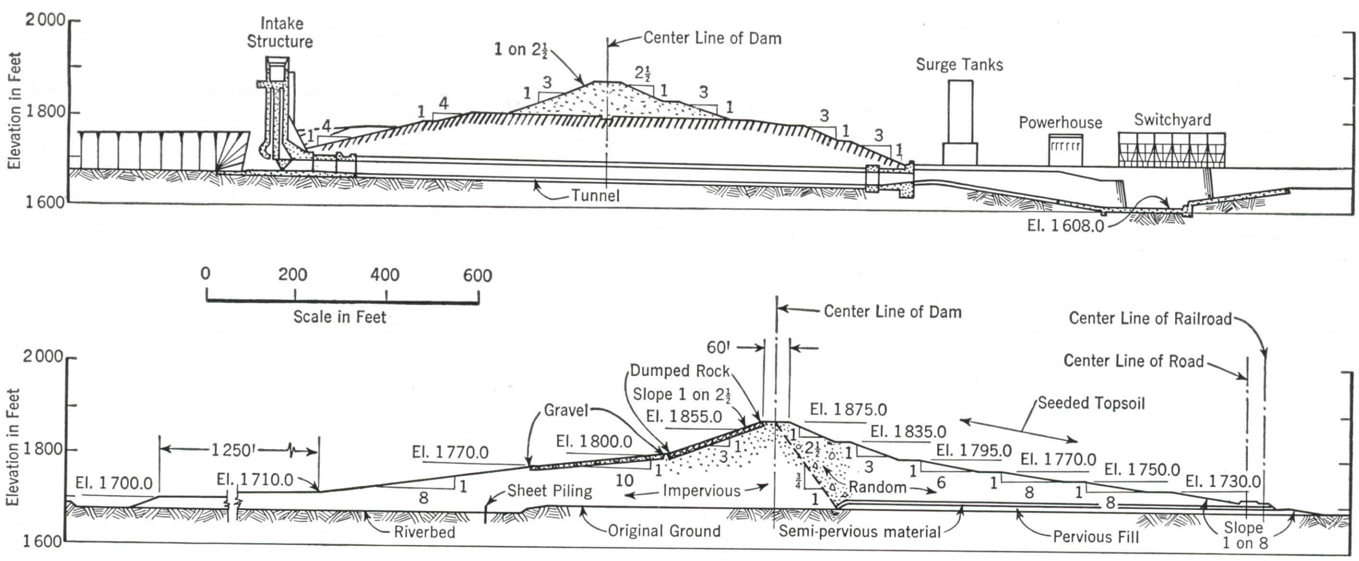



FIG. 2. PROFILE OF OUTLET WORKS (at top) indicates relative locations of intake structure, tunnels, surge tanks, powerhouse and switchyard. Maximum embankment section (below) has slopes varying from 1 on 2½ at top to 1 on 8 at bottom. Protection on upstream slope consists of 3 ft of rock over 1 ft of spalls over 1 ft of bank-run gravel from top to El. 1,800, and below, bank-run gravel to El. 1,770. Exposed downstream slopes between berms will be protected with vegetative cover.

tunnel No. 4 and completed in January 1949, the test tunnel will ultimately be incorporated as a part of the penstock tunnel. The test section is supported by circular steel rib beam sections, with spacing varying from 2 to 4 ft on centers. Of the total 240 ft only 75 ft is lined with reinforced concrete, the steel ribs being exposed throughout the remaining length of the test tunnel. The beginning of the test tunnel is 215 ft from the face of the portal excavation and access is provided by a 7×9-ft tunnel, supported with timber bracing.

#### Measurements Provide Design Data

Numerous strain-gage measurements on the steel ribs and on sections of ribs exposed in slits in the concrete-lined portion of the tunnel are taken, along with measurements of changes in rib diameter and shape, and soil pressure measurements from pressure cells set back of the concrete lining. Observations for supplementary data consist of the following: Carlson strain meter measurements within the concrete lining; SR-4 strain-gage measurements on reinforcing steel and rib steel within the concrete lining; direct measurements of swell of the soil mass around the periphery of the tunnel; rebound of soil strata due to tunnel excavation and excavation outside the portal; and changes in moisture content of the soil at various depths from the face of the excavated surfaces.

Experience with the test tunnel to date indicates that it is entirely feasible and safe from the construction standpoint to drive tunnels of the size contemplated in the Fort Union formation at the location selected for the outlet works. Observation for periods ranging from 9 to 11 months on the exposed ribs of the test tunnel and for about 6 months on the concrete-lined portion of the tunnel, has led to the following conclusions: Vertical loads on the exposed ribs as yet do not exceed 20 percent of the weight of overburden directly over the tunnel; horizontal loads vary from about 90 to 100 percent of the vertical loads; both vertical and horizontal loads continue to increase at slow rates, with horizontal loads approaching equality with vertical loads and thereby indicating the probability of ultimate uniformity of loading around the tunnel. The loading can be expected to attain 100 percent of the overburden over the tunnels.

Results to date have been of great value in the design of the eight outlet works tunnels, and the testing program will be continued into the first stage of tunnel construction. One of the first tunnels to be constructed will be adjacent to the test tunnel. This condition of driving a tunnel close to a previously constructed tunnel will result in the maximum unbalance of loading that can occur during the entire tunnel construction program. The data obtained from the test tunnel observations during this period will furnish an indication of the most critical condition to be considered in the design of the tunnel lining. Additional observations which will provide data for consideration in the maximum conditions of design will be available by the fall of 1949, when completion of the embankment in the west abutment section will increase the weight of overburden on the test tunnel.

Two horizontal lignite seams are intersected by the test tunnel, and continue throughout the length of the bore, with a slight dip upstream. The upper and lower seams have a thickness of 7 and 4 ft respectively. The lower seam is about 5 ft above the invert of the tunnel and the seams are separated by about the same distance. All the other material passed through is Fort Union bedrock. The test tunnel was driven by shooting the full face to a depth of 6 ft. No difficulty was encountered. Some water was found, generally concentrated in the upper lignite bed, and was cut off by grouting ahead of mining operations. This was done mainly to improve the working conditions in the tunnel. The tunnels will require 325,000 cu yd of excavation and 110,000 cu yd of concrete lining.

#### Intake Structure Contract Let

The intake structure, already under contract to Peter Kiewit Sons' Co. and Morrison Knudsen Co., Inc., will accommodate trash racks, stop-logs, service gates and emergency gates for the eight tunnels. The reinforced concrete substructure is approximately 170 ft in width, 540 ft in length and 200 ft in height. The five power conduits will each have two 12×26-ft vertical-lift-type service gates and, for the emergency closure of each, two 12×26-ft bulkheads will be provided. The three flood control conduits will each have one 18×24.5 ft Tainter-type regulating gate and, for emergency closure of a flood control conduit, one 18×24.5-ft vertical-lift-type emergency gate. Provisions are made for trash racks in the power conduits and stop-logs in the flood control conduits.

The substructure is surmounted by a structural steel and reinforced concrete superstructure approximately 50×50×540 ft. This superstructure will house the gate hoists, gantry crane, overhead traveling crane, power control equipment, gasoline-electric standby generator, water supply equipment, compressed air equipment, and offices. Gates, gate guides and frames, hoists, cranes and other smaller items will be furnished by the Government. Work on the intake structure, expected to be completed by February 1, 1953, includes about 100,000 cu yd of excavation, 300,000 cu yds of concrete, and 22,950,000 lb of reinforcing and structural steel.

#### Spillway in Left Abutment

The chute-type spillway with gates on the crest structure will be built in the left abutment with an alignment almost normal to that of the dam. To control the water entering the spillway, 28 Tainter gates 40×29 ft are to be used. The gate piers will support a bridge for the highway which will traverse the embankment. Water is conducted to the spillway by a curved approach having a bottom entrance width of 1,880 ft and a length of 3,215 ft to the gate structure. The spillway will discharge 600,000 cfs and drop the water approximately 195 ft. The crest elevation will be set at 1825 and the invert elevation of the stilling basin probably at 1636, but this elevation may be changed as a result of the model studies now under way.

A nine-span, 1,350-ft, plate-girder construction bridge has been built over the Missouri River. It carries a 26-ft roadway and a single-track railroad. During the construction period approximately 1,250,000 cu yd of pervious material from the intake channel on the right bank will be moved over this bridge to the filter zone of the dam on the left bank. Likewise all the materials for the tunnels, intake structure, powerhouse and stilling basin will pass over this bridge, which also will be used in closure operations. The superstructure is designed to facilitate dismantling and permit maximum salvage. Each span consists of three 150-ft-span plate girders, two of 75 tons and one of 50 tons for rail and highway traffic lanes respectively.

A total of 30 miles of standard-gage railroad, including classification yards and passing tracks, has been built. Rail facilities extend to the site of the major structures—the powerhouse, outlet works, and intake —and will be carried to the spillway site when concreting operations are begun there. It is expected that in the summer of 1950, peak traffic will exceed 150 loaded cars per day. Cars are delivered to the contractor's receiving tracks and empties returned to the marshaling yards at Riverdale Junction by the Government, but such spotting and moving as is required in work areas is done by the individual contractors.

#### Permanent Town Built

The construction town of Riverdale, a permanent feature, is located on the high terrace on the left bank above the dam. To date 381 family housing units, each with one to three bedrooms, have been constructed together with a trailer court and dormitories. No family housing has been built for contractors' personnel. Operating and maintenance personnel of the completed project will be housed in 100 family-type units classed as permanent.

Temporary units are both of the prefabricated and site-built type. Permanent units are steam heated by a central heating unit but temporary units have oil-fired hot-air furnaces. A church, theater, recreation building, grade and high school, water treatment plant, dormitory hotel for unmarried employees, warehouses, garage and equipment repair facilities, hospital and concessionnaire store block have been built. Police and fire protection are furnished.

#### Progress to Date

Excavation and embankment operations began in the powerhouse and outlet channel area on the right bank in October 1947. Similar work was started in the spillway cut in the east abutment in May 1949. As of September 15, 1949, 24,700,000 cu yd of material had been excavated and 18,000,000 cu yd placed in the embankment. The maximum yardage excavated to date to one day has been 175,000; in a six-day week, 1,021,524 cu yd, of which 90 percent was placed in embankment.

Garrison Dam is scheduled for completion in 1954. In that year also the first of the five 80,000-kw generators is scheduled for installation. Two additional units completing the initial installation will be placed in 1955. Present studies indictae that installation of the remaining two units will be required by 1958. The Corps of Engineers, Garrison District, Riverdale, N.Dak., has charge of construction, headed by the writer as District Engineer.

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