Mono Craters Tunneling Struggle with Water and a

Major feature of the project to develop a supplemental water supply for the City of Los Angeles has been the driving of the 11-1/3-mi. bore through the crest of the Sierra Nevada.

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The driving of the 11-1/3-mi. Mono Craters tunnel represents the principal construction feature in the Mono Basin project being carried out by the Los Angeles Bureau of Water Works and Supply to bring supplemental water supply through the crest of the Sierra into the Owens River, so that the present aqueduct can be operated at its full capacity of 480 sec. ft. throughout the year. Tunneling operations were started in 1934, and during the four year construction period the work has developed the following features of unusual interest: shaft sinking and tunnel driving through heavy, glacial material with large flows of water; carbon dioxide gas flows averaging about 1,000 c.f.m. requiring extensive ventilating equipment; and the trucking of bulk cement in 1,500 lb. sacks. A general description of tunnel driving and lining operations is presented in this article.

Features of the Mono Basin project, the need for this supplemental supply, sources and method of diversion were reviewed briefly in Western Construction News, June, 1936. A collecting system of conduits in the basin will deliver into a storage and regulating reservoir to be formed by the Grant Lake dam. The discharge from this reservoir will flow through the Mono Craters tunnel and enter the water-shed of the Owens River for delivery into the existing aqueduct system of the City of Los Angeles.

The tunnel has a finished cross-section providing an area of 74 sq. ft., which is nearly equivalent to a circular section of 9 ft. 8 1/2 in. in diameter. The gradient is 0.0005, which provides a capacity of 365 sec. ft., based on a coefficient of n = 0.012.

The tunnel excavation is more than 90% completed, only about 5,000 ft. remaining (see profile) to be driven on Oct. 31, 1938. At the rate of progress made in the two remaining headings for the past few months, the tunnel should be holed through in March of next year.

Points of access and headings

Construction work began in September, 1934, at the west portal (heading 1), and subsequent excavation has been carried on in a total of six headings. The accompanying profile drawing shows the points of access and the designation of the headings. Work at the east portal began in November, 1934, and headings 5 and 6 (see profile) were holed through July 7, 1936, after driving 9,927 ft. toward shaft 2.

The sinking of shaft 2 was begun Feb. 9, 1935, and tunnel grade was reached four months later, June 12, 1935. The depth is 299 ft. from collar to tunnel invert. Driving was begun in heading 4, August 28, and in heading 5, Sept. 7, 1935. A total of 2,808 ft. was driven in heading 5 before hoisting through to heading 6.

Shaft 1 sinking was begun Dec. 3, 1934, and tunnel grade was not reached until May 12, 1937. The depth is 896 ft. from collar to tunnel invert. This shaft penetrates volcanic ash and rhyolite for 563 ft. and from 563 to 871 ft. the formation was unconsolidated glacial material. The water table was struck at a depth of 492 ft. As the shaft was driven deeper into the glacial material the increasing head of water made it extremely difficult to hold the sand encountered in the bottom of the shaft against leaking up. Several runs of sand and gravel into the shaft occurred at various times. Each run would relieve the pressure for a time but there was a tendency for the gravels immediately surrounding the shaft to be gradually sealed up by fines with a resulting diminished flow of water and increased pressure until another run-in would occur.

Shaft sinking problems

Drifts were driven out from the shaft at the 632, 709 and 739-ft. levels to accept some of the water courses and relieve the pressure at the shaft. These drifts undoubtedly relieved the pressure somewhat but were not entirely satisfactory due to the tendency of the materials to seal up with fines and obstruct the drainage.

The shaft was lined with reinforced concrete from the 530-ft. depth to the bottom. Both shaft 1 and shaft 2 have three compartments, the two skips being 5 ft. x 5 ft. 2 in., and the main water and utility compartment 5 ft. x 20 ft.

The over-all excavated dimensions are 7 x 20 ft. The concrete lining in shaft 1 was made octagonal through the grillage and shaft 2 with flat plates. The shafts are 30 ft. from the east portal and contain a percolation sump pocket larger than any on the project. The two shafts are driven in the form of a pair, with one heading of each shaft driven simultaneously.
The lining was designed to withstand a hydrostatic pressure of 50 lb. per sq. in. Material at the bottom of the station and muck pocket were cut is a soft sandstone with an underlying gouge in the seams giving it an increased tendency to squeeze. On account of the difficulty of holding this lining around the station and muck pocket were made considerably smaller than originally planned and as actually constructed at shaft 2.

Shaft 2 the station was cut 30 ft. opposite the shaft, the center line of which is 50 ft. off the tunnel center line. A surveyors drift 7 ft. wide was cut from the ends of the shaft parallel to the tunnel, 45 ft. both directions, with a single cross cut over to the tunnel. A pump station and sump were set out from the shaft opposite the tunnel, and an equipment pit 13 ft. wide and 50 ft. long at right angles from the tunnel on the opposite side of the tunnel from the shaft. The tunnel was widened to 16 ft. for a length of 200 ft. to provide room for the battery charging station and switching facilities.

At shaft 1 the repair drift and surveyors drift were eliminated and the width of the station reduced to 13.5 ft. The muck pocket capacity was made 30 cu. yd. The pump stations were also located a few hundred feet from the shaft.

**Materials encountered**

The material encountered in heading 1 for 17,300 ft. was volcanic rock, principally rhyolite, and then a sandstone or shale to the holing through point. The rhyolite offered no particular difficulties until well under the craters where the heavy water pressure and large quantities of carbon dioxide gas gave considerable trouble. Numerous fracture zones were encountered where the water and gas, both under pressure, would tend to carry in sand and small fragments. A considerable amount of the driving was done with the face fully breastboarded and the sides and arch spiled tightly. Heading 2 (west from shaft 1) was either in unconsolidated glacial material of the type that caused the difficulty in sinking shaft 1, or in soft sandstone and shale.

Heading 3 has been mostly sandstone and shale, some areas of which had a tendency to squeeze the same as the material at the station for shaft 1. This type of material gave no great difficulty in driving but had to be relieved frequently until it finally attained a degree of stability. Squeeze posts were used back of the steel sets in these areas and relieving was done by removing some of the material between the lagging. About a mile east from shaft 1, heading 3 has passed into a diorite with indications that it may soon enter granite.

Heading 4 has been driven through granite from a point 6,000 ft. west from shaft 2, and is still in granite at 12,500 ft. Most of the granite, however, is blocky and requires support. Driving west from shaft 2, the bottom of which is in hard basalt, the tunnel was in basalt and andesite for 3,650 ft. from which it entered unconsolidated glacial material which continued until the heading entered granite at 6,000 ft. A large portion of heading 6 west from East Portal was driven through lake bed material which gave considerable difficulty by "heaving." Several feet of this material gradu-
hilly squeezed up from the floor and had to be removed from time to time. This area had become fairly well stabilized by the time the concrete lining was ready to be placed in the summer of 1937. The total tunnel excavated to Oct. 31, 1938, was 54,808 ft. Of this amount, two-thirds is timbered. The last 18,000 ft. driven, however, is all timbered except 2½%.

The maximum month's progress was 1219 ft. made in heading 1 in April, 1935. The maximum days progress was 90 ft. in 16 hr. on July 15, 1935, on which date one shift was lost on account of the tunnel being flooded by a cloudburst at West Portal.

Driving Operations

The drill carriages (see illustration) used in the tunnel were made in the Department shops. Standard equipment in sufficiently compact units was not available at the time of beginning tunnel construction. The frame of the carriage is made of 4½-in. extra heavy pipe mounted on 24-in. gauge trucks. Four of these pipes constitute the horizontal members and extend forward to serve as cantilever supports for the four drifter drill mountings. Each drill is mounted on a short length of pipe attached by clamps to one of the four longitudinal pipes of the frame. This mounting permits each drill to swing in two planes by merely loosening nuts on the clamps. Centrally mounted in the frame is an air receiver of 15 in. dia. and 5 ft. long with six outlet connections, one each for the four drifter drills and two extras for jackhammers. The working platforms on either side which fold up against the carriage when not in use have plank floors 24 in. wide. The planks are less slippery than metal would be. The longitudinal pipes of the main frame form excellent storage space for the wooden tamping sticks and blowpipes. The front of the carriage is mounted on four-wheel trucks with a kingpin, while the rear, where there is less weight, is carried on a single pair of wheels. Ingersoll-Rand and Gardner-Denver automatic drifter drills with 3½-in. piston and 50-in. shell are used.

The accompanying diagram shows the typical arrangement of drill holes. This diagram is based on a 38-hole round. The number of holes varies considerably, but usually runs between 24 and 40. The usual advance per round is 5 ft., although in sound rock 6 ft. and sometimes 7 ft. are pulled when possible.

The mucking machines used are Conway Type 50A. Hauling is done by Atlas battery locomotives using 48 cell Exide batteries of 340 ampere hour capacity at 110 volts. In addition, trolley locomotives are used as boosters for 9,600 ft. in from the west portal. Track gauge is 24 in. and 40 lb. rails are used.

The tunnel is hauled by shuttle trains. Cars are of the side dump mine type of 70 cu. ft. capacity. Switches are installed every half mile, alternately 200 and 300 ft. in length. For switching behind the mucking machine a California switch is used, constructed with four rails making them 24-in. gauge tracks. Empty and loaded muck cars use the outer tracks, but the drill carriage and mucking machine can be taken to and from the face only on the center track due to clearance limitations.

The mucker operates on 440 volt 60 cycle current, with power taken into the tunnel at 2200 volts in marine and mono cables. Transformers are located every thousand feet.

Method of supports

With the exception of the immediate vicinity of the two portals where 8 x 8-in. timber sets were used, 6-in. I-beam and H-beam sets have been used almost entirely. Five inch 12½-lb. I-beam sets were employed at first, and later 6-in. 12½-lb. I-beams and finally 6-in. H-beam. Both 20 and 30-lb., were adopted as standard. In very heavy ground where the 30-lb. sets are required, steel spreaders are used across the invert. These spreaders are 6-in. 20-lb. H-beams, curved to a radius of 19 ft. 4 in. It has not been necessary to replace any tunnel sets where the spreaders were used. The supporting sets are normally placed on 3-ft. centers, although in many places they are much closer, sometimes a few inches apart.

The soft condition of a considerable portion of the material encountered necessitated the driving of spiling. The spiling driven was usually 4 x 6 in. or 6 x 6 in. timber driven ahead of the face at least 7 ft. or more, depending on the tendency of the material to run. Spiling is ordinarily driven by the mucking machines serving as a sort of battering ram. An 8 x 8-in. timber with a collar and plate on each end is held against the end of the spiling being driven while the other end is rammed by the machine. One of the battery locomotives with a special coupling for holding the ramming timber has been used satisfactorily for the purpose.

In extremely hard ground where spiling must be drivenblind, 10.5-lb. steel channels have been successfully used. The channels are driven with the legs alternately outward and overlapped so that the channels interlocking apart while driving.

Control of gas

As the tunnel driving proceeded, the craters, carbon dioxide gas encountered in increasing quantities. The gas of 13,000 ft. from West Portal the intake of this gas became too great to be handled with the ventilation equipment then installed. Tunnel driving in heading 4 then temporarily suspended (May 1936) while a ventilation shaft was driven to the portal. This shaft had a depth of 353 ft. and was sunk 100 ft. from the portal. This shaft has a 70 cu. ft. capacity. Switches are installed at the 10 ft. interval. The sinking of the shaft was accomplished in a period of 82 days, from May 13, 1936, to June 23, 1936.

The total blower capacity which was installed at shaft 3 is a little over 2,500 c.f.m. of air. The fans are electrically operated and so connected that they can be operated either into or sucking out of the shaft. In addition to the electric drive, the fans connected to auxiliary gasoline engines installed for emergency in case of interruption in the power supply. As emergency blowers the total capacity is practically equal to that of the electrically operated equipment.

The quantity of gas released into the tunnel has averaged about 1,000 c.f.m. since the tunnel reached the approximate center of the craters. The quantity ranges from about 850 c.f.m. to 1150, according to the barometric flow depends more upon the rate change of barometric pressure than on the magnitude of the pressure itself. This fact can probably be explained by the fact that gas is driven by the pressure of the atmosphere outside the tunnel.

SECTION of tunnel indicating the typical supporting system. To facilitate the handling of water during construction operations one of the pumping boxes is left embedded in the lining.

![Typical Section of Tunnel with Pumping Box](https://example.com/tunnel-section.png)
facing against to not over 2% in the vicinity for being available for mine portal. This pre-
switches in free through the air locks.

"Proceed toward the hoists pressure the gas pres-
content has been to portal and shaft 1, the system of
varied from operations. Water was first encountered
when the bottom is tied with sash-cord. A steel ring
in the top is used to lift the sack over the discharge hopper and the pulling of the tie
cord releases the sack load. A truck and trailer load of 30 sacks can be unloaded in
about 15 min.

SACKS of 1,500-lb. capacity were used in trucking bulk cement to the job. These
sacks are bottomless, and before filling the bottom is tied with sash-cord. A steel ring
in the top is used to lift the sack over the discharge hopper and the pulling of the tie
cord releases the sack load. A truck and trailer load of 30 sacks can be unloaded in
about 15 min.

Pumps at shaft 3 are also located high
enough above tunnel grade that they
cannot be flooded. These pumps, con-
sisting of two 6,000 g.p.m. units, are not
connected to the dewater pipes on the
suction side but pump directly from a
ump into which any or all three of the
14-in. lines can be discharged.

The total flow from shaft 1 has been
somewhat over 5,000 g.p.m. since mid-
summer of 1938 when the seasonal fluc-
tuation reached its peak. There has been
a seasonal fluctuation reaching its peak
each summer just after the snow melts.
The surface water affects the tunnel
flow quite readily, especially in the vicin-
ity of shaft 1. The total installed capacity
of the pumps at shaft 1 is 12,500 g.p.m.
consisting of five 2,500 g.p.m. units de-
signed to operate against a head of 1,000
ft. The pumps at shaft 2 are two 2,500
g.p.m. and one 4,500 g.p.m., 380-ft. head
units.

The dewatering pipes are 14-in. 12
gauge laid against the floor and wall of the tunnel. Two pipes are laid in head-
ing 1 as far as shaft 3 and three lines from
shaft 3 eastward to the 15,000-ft. pump
station. One pipe was carried all the way
to the hoiling through point at 22,400 ft.
One dewatering pipe has been sufficient
each for each of the other headings.

To facilitate the handling of the water
during concrete lining operations, one
of the lines is left in place and buried in the
lining. The nearly circular form of the
finished section provides 10 in. of con-
crete between the buried pipe and the
surface of the concrete.
used later to support forms for placing the arch. The floor is given only a rough screening since considerable material is later spilled on it during the placing of the arch. The final step will be the placing of a troweled mortar finish on the floor.

Control of the tunnel water is a difficult problem in the placing of the concrete lining. A drain consisting of one or more 5-in. perforated sheet metal pipes is placed in a trench in the sub-grade and backfilled with gravel. These drains lead to the pump sumps which are located partly outside the normal excavation line of the tunnel. Forms are placed on the tunnel side of the sumps so that they are kept open and in service after the floor is poured.

Where excessive quantities of water fall from the roof of the tunnel, sheet metal is placed behind the tunnel sets to carry the water around the periphery of the tunnel to lateral drains connected with the longitudinal invert drains.

The concrete placing unit consists of a carriage on which is mounted a ramp, conveyor belt and a 1 cu. yd. mixer. The carriage is provided with its own locomotive power and is mounted on nine 24-in. gauge trucks. The aggregate cars are hoisted by a small electric hoist and each compartment dumps automatically onto the conveyor belt which feeds into the mixer. The switching of loaded and empty cars is done on a California switch in the same manner as the muck cars are handled during excavating.

In pouring the floor, alternate ties are first removed from under the track just ahead of the mixer carriage. Then, as soon as the carriage has passed completely off a pair of rails, they are lifted by chain blocks suspended from the tunnel sets, the ties removed and temporarily stored along the side of the tunnel just outside the curb. Steel forms are used for the inner surface of the curb. The forms are supported on 1-in. steel pins driven into the subgrade. The pins are pulled at the time of stripping the forms. A twist with a wrench loosens them so that they can be easily pulled.

Steel forms are used for placing the arch. These forms are assembled in 30-ft. sections and moved on a carriage mounted on two pairs of trucks. The forms are lifted into place or lowered by hydraulic jacks mounted on each end of the carriage, and when lowered and folded will easily pass through the sections which are set up in position. Concrete is placed through a 6-in. extra heavy discharge pipe from a 1-yeard Ransome gun mounted on trucks and coupled to the mixer carriage.

The floor is ordinarily poured one shift per day, the other two shifts being used for trimming and installing drains. The arch is placed continuously in three shifts of eight hours. The pour averages 250 cu. yd. per day which lines 200 to 300 lin. ft. of tunnel depending on the over-breakage. The tunnel lining averages about 2 cu. yd. of concrete per lineal ft.

Aggregate is produced by the contractor's own screening plant located at Rush Creek 3½ mi. from the portal. Gravel is of granitic origin, is good sound, having a specific gravity of 2.65. Yield of concrete runs about 80 sacks per cubic yard, 75 lbs. of 3,000 to 4,000 lb. per sq. in. box of mix is arbitrarily raised 2% where excessive quantities of water are encountered.

**Batching plant**

The portion of the lining composed from the east portal to a point 6,000 ft. west of shaft 2 was done at the portal. The batching plant has now been moved to the west portal in order to concrete the section from the portal to shaft 1 while driving is continued in Headings 3 and 4.

The batching plant consists of an aggregate and gravel tunnel from which the material is carried by conveyor belts. 60 cu. yd. bin divided for sand and gravel beneath which are the weigh hoppers dumping directly into the aggregate cars. A bulk cement storage plant has been installed to store 2,500 bbl. Cement is weighed automatically by photoelectric cells mounted in such a manner that the screw conveyor feeding into the weigh hopper is stopped automatically when the correct weight of material is in the hopper. When the cement is dumped from the weighing hopper and the car the conveyor is automatically started so that the weighing hopper is always filled and ready to dump. Two men operate the batching plant.

**Cement in 1500-lb. sacks**

A new method of transporting bulk cement has been devised by the engineers of the Monolith Cement Co., which has the contract for furnishing cement. The cement is hauled in canvas sacks holding 1,500 lb. These sacks are hauled at the top with a 15-ton steel ring about 10 in. in diameter and are left open at the bottom. Before filling, the bottom is tied with a piece of sash cord in such a manner that by pulling the loose end the knot will untie.

A crane has been installed over the hopper at the batching plant, and sacks are hoisted off the trucks by the crane. The crane is sloped (see illustration) so that the loaded crane rolls to spot over an opening in the cover of the hopper. By pulling the cord the entire 1,500 lb. of bulk cement is dropped into the hopper from which it is carried to the two elevated cylindrical storage tanks by a series of screw conveyors. A truck and trailer load of cement can be unloaded in approximately 15 min. Thirty 1,500-lb. sacks of cement are hauled in one truck and trailer load, eighteen sacks on the trailer and twelve on the truck.

**Organization**

The project is being done by force count under the direction of H. A. Norman, chief engineer and general manager, Los Angeles Department of Water. H. L. Jacques, engineer in charge, is superintendent of the project, and the writer is in charge of engineering.