Difficult Caisson Sinking for Vancouver Water Tunnel

Open dredging used to sink 24-ft.-diameter caisson 130 ft.—Large boulders encountered at 100 ft. drilled and blasted by diver—Landed on sandstone, sealed and pumped out as start of 400-ft. shaft

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BOULDERS removed by blasting in a 100-ft. depth of water and final jetting through 15 ft. of shale were the special problems encountered in sinking a caisson 130 ft. to rock by open dredging as part of the pressure tunnel being built by the Greater Vancouver Water District under the First Narrows at the entrance of the harbor at Vancouver, B. C. Completed and unwatered, the caisson provided the start of a 400-ft. shaft required to reach rock through which the 3,100-ft. tunnel could be driven. The original plan to sink under air was successfully changed to open dredging, although extreme care and judgment were required to found and seal the caisson on rock. An outline of the project, its relation to the Vancouver water-supply system and the progress of the work appeared in *Engineering News-Record,* Jan. 12, 1933, p. 56.

The tunnel will replace the present system of submerged mains used to bring the city's water supply across the Narrows from sources north of the harbor. It consists of two 400-ft. shafts and 3,104 ft. of 7½-ft.-diameter tunnel. The south shaft is in Stanley Park, Vancouver, where sandstone bedrock is within a few feet of the surface; the north shaft is located on the tide flats across the Narrows. Borings indicated that these tide flats consist of tightly packed sand and gravel (brought down by Capilano Creek) about 100 ft. deep, overlaying the weathered surface of shale bedrock. No core was recovered for 130 ft. below high water. As a result of the 100-ft. depth of water-bearing gravel above bedrock at the location of the north shaft, it was necessary to sink a caisson to a satisfactory foundation, seal it and finally excavate through the seal to continue the shaft in the rock. The problem was hazardous, necessitating careful judgment on the determination of a satisfactory foundation that would safely permit an open shaft to be sunk through the seal and into the rock below.

It was originally intended that the caisson should be sunk under compressed air, but in view of the high pressures that might be required before the caisson reached rock the contractor asked for and received permission to try open-dredging methods, offering to make a $50,000 reduction in price and, if the method failed, to proceed under air at his own expense.

The caisson design in the contract drawings was cylindrical in shape, with an internal diameter of 14 ft. and 3-ft. concrete walls heavily reinforced. To avoid, if possible, the use of additional weight to overcome skin friction, the contractor decided to increase the walls to 5-ft. thickness, making the outside diameter 24 ft. (Fig. 1). In view of this increased thickness the quantity of reinforcing was reduced. To decrease skin friction, it was decided to excavate the sand and gravel at the caisson site for about 30 ft. previous to constructing and to backfill the excavation with pea gravel, which would tend to reduce the friction as a result of having particles of about uniform size.

After this had been done, an island of heavy gravel was built up 8 ft. higher than the surrounding flats to facilitate setting up the cutting edge and placing the first concrete above high tide. A framework of timber piles trussed together with heavy timbers was built to form a working platform and to act as guides during the early stages of sinking.

The cutting edge was formed by

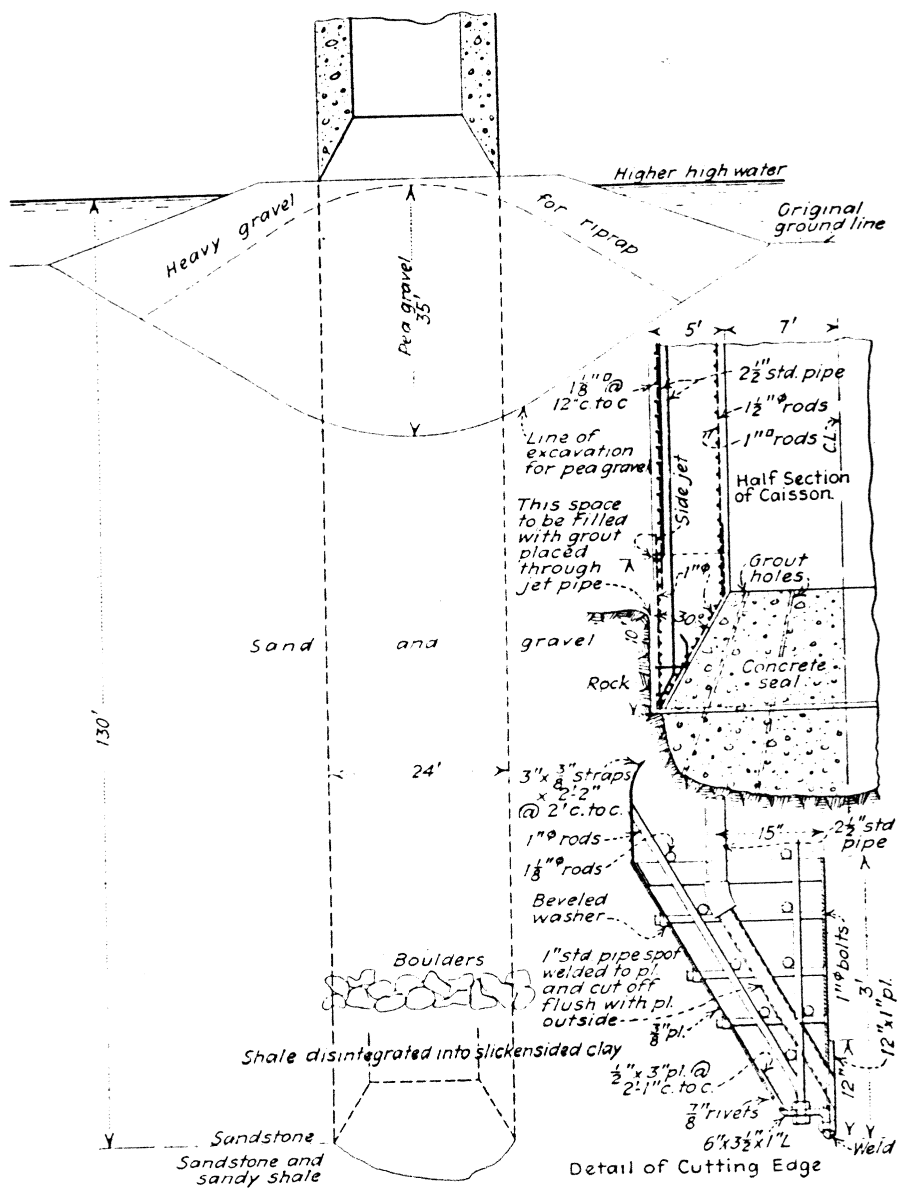


Fig. 1—Materials encountered in sinking, caisson section and details of cutting edge.

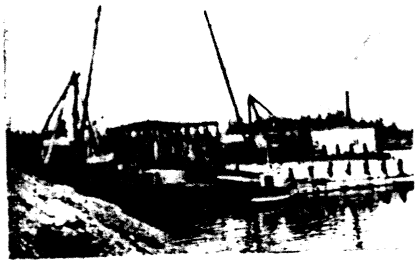


Fig. 2—General arrangement of surface plant. Larger derrick at left handled excavation and concrete. Smaller derrick at right moved aggregate and steel.

sloping the inner wall of the caisson out at 30 deg. with the vertical to form a bell, and it was shod at the bottom with a light structural-steel shoe (Fig. 1). This shoe consisted of plates and angles riveted and welded together. The actual cutting edge was 6 in. wide, and the plates protected the concrete on both sides to a height of 3 ft.

Before sinking operations were started the caisson was built to a height of 30 ft. To provide additional bearing while this concrete was being placed, the steel shoe was filled with gravel up to the top of the plates as soon as placed, and later the entire bell was filled with gravel. The concrete was about 1:2:3 mix, with 2 per cent calcium chloride added to give early strength. Sectional steel forms were used for both walls. When the forms were stripped after each 8-ft. pour, the top ring was left in place to form a base for the next form set-up. The surface of each pour was thoroughly cleaned and roughened with picks; as a result, when the caisson was finally pumped out, it was entirely watertight from top to bottom.

Excavation was done with a $1\frac{1}{2}$-cu.yd. clamshell bucket or a $2\frac{1}{2}$ cu.yd. orange-peel bucket. Little trouble was experienced for about 100 ft. of penetration, but at that depth a mass of large boulders was encountered. The first boulder, which weighed 5 tons, was successfully slung by a diver and removed, but the rest were too tightly embedded under the cutting edge to be removed either by means of slings or pins. Blasting was the only solution to this serious problem.

Holes for the charges were drilled by divers using a heavy jackhammer drill. The back pressure caused by the head of water in the caisson was about 48 lb. per sq.in., but it was found that even with large hose at least 175-lb. pressure was needed at the compressor for effective operation of the drill. To prevent damage to the concrete in the caisson walls, the charges were kept small, half a stick of 40 per cent dynamite being the maximum charge. The shots were fired electrically, one hole being drilled and shot at a time. As a further precaution to reduce the bursting effect of the sudden concussion on the caisson walls, a compressor was allowed to discharge out of an open pipe at the bottom of the caisson.

By this method several cubic yards of boulders were removed, and the caisson was sunk slowly, but without damage, an additional 8 ft. to the surface of what had once been bedrock. This material consisted of shale weathered and disintegrated by glacial action into a soft slickensided mass, almost a sandy clay. The caisson, therefore, had to be sunk through this material before a safe foundation could be reached.

In building the caisson a number of $2\frac{1}{2}$-in. pipes, with a 1-in. outlet at the cutting edge, had been left in the concrete spaced evenly around the circumference. A second ring of pipes had outlets in the caisson wall about 10 ft. above the cutting edge. It had been intended that these pipes should be used for two purposes: (1) during sinking operations the lower ones could be used as water jets to assist in excavating the material below the cutting edge and the upper ones as outlets through which to force air or water to reduce skin friction; (2) as grout pipes to fill any spaces that might be left between the caisson and the rock. It was found, however, that as water jets the lower ring were useless because they continually plugged so tightly with sand that it took an hour or more to clean each one out. The upper ring of outlets pointed upwards and did not plug so readily, but when air was forced through them the bubbles apparently did not rise close to the caisson wall but showed on the surface of the ground anywhere from 2 to 200 ft. distant.

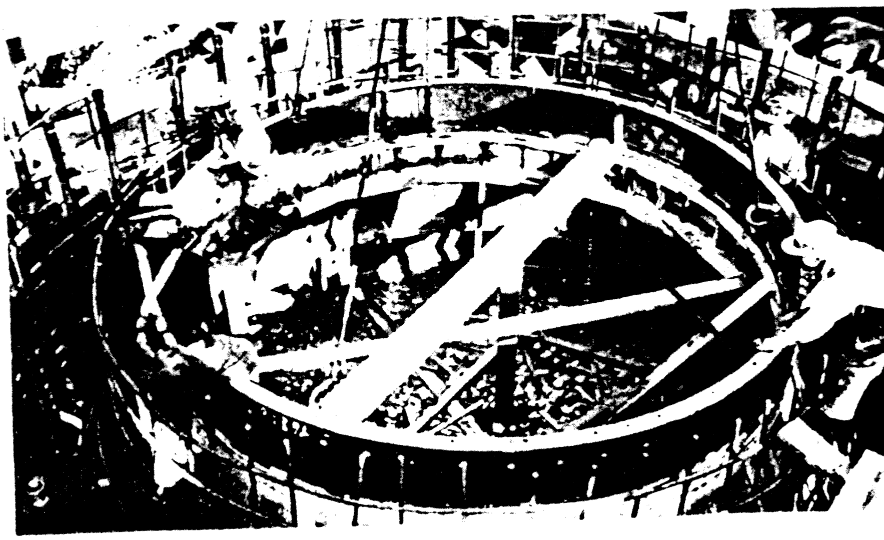
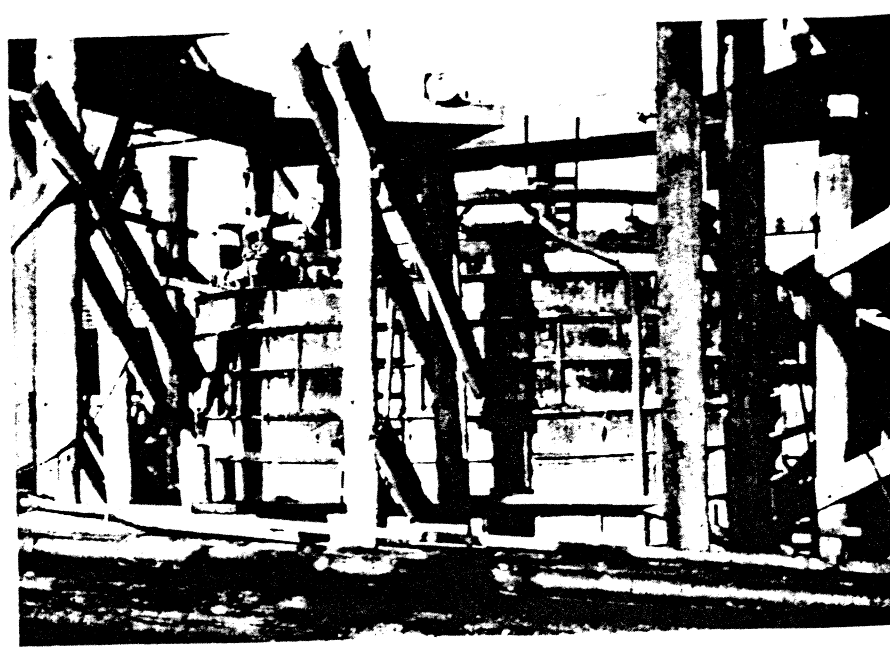


Fig. 3—Assembling the cutting edge and bell steel on the gravel island. Jet pipes to be embedded in the 5-ft. concrete wall appear along the back side.

When it was found that the disintegrated shale could not be readily excavated with an orange-peel bucket, it was decided to build a water jet out of 4-in. pipe with a special cast-steel nozzle, and to operate it as a separate

Fig. 4—Top of caisson, showing steel forms, timber-piling guide frame and manifolds for supplying water to jet pipes.



unit with the derrick. In conjunction with this a sand jack or ejector was used to suck out the fine material washed out by the jet. Water was delivered by a centrifugal pump at 165-lb. gage pressure. Various lengths of bent pipe were used to reach under the bell, and careful watch of jetting operations was maintained by frequent diving inspection. The jet proved very efficient, and the caisson was sunk an additional 15 ft. until the cutting edge was about 125 ft. below high water.

During the period of sinking through the boulders the surrounding material began to slough in under the cutting edge. As the sinking proceeded this sloughing almost always accompanied a movement of the caisson, the flow of the gravel cutting a channel through the softer material below. These movements of gravel caused local settlements up to the surface of the ground, the gravel apparently forming chimneys. As a result, when the action of the jet showed that the caisson was approaching rock, excavation was carried forward carefully in an endeavor to stop the slough, and no excavation was done near where the slough channel showed. Finally, the caisson was dropped the last 18 in. to its final position in one movement and the sloughing was effectively stopped.

About 125 ft. below high water, layers of hard sandstone were encountered with strata of softer material between, and it was in one of these layers of sandstone that the cutting edge was finally founded. Under the center of the caisson excavation was carried down to a depth of 3 or 4 ft. until a ledge was reached that the jet would not cut, although left for an hour in one place. An inspection of the bottom showed that the foundation was adequate as far as bearing was concerned, and that a reasonably watertight seal could be obtained in the rock. The caisson bottom was cleaned up, and a 12-ft. depth of concrete was placed by bottom-dump bucket to form a seal. The bottom-dump bucket was used in preference to a tremie in order to place the concrete as close to the rim of the caisson as possible. The buckets were dumped successively around the edge of the caisson, tending to force any soft material to the center where it would later be removed. Placing operations were successful, but calcium chloride was used in the concrete, and this caused some of it to set up too fast, forming lenses, so that when the shaft was sunk through the seal, laminations of poor concrete were found in places.

After the concrete had set and the water was pumped out of the caisson, test holes were drilled through the seal. The first hole disclosed the presence of water in the seal, but as the flow did not increase when other holes were drilled, excavation was started and a 6-ft.-diameter shaft, afterwards enlarged to a 10-ft. diameter, was sunk through the seal. In sinking the shaft the concrete was blasted out in the ordinary way except that the rounds were shallow and the charges light. Cut holes were shot and mucked out before the relievers and rim holes were drilled. The concrete in the seal was not cracked or damaged in any way by this blasting.

On reaching the under side of the seal it was found that there was no leakage between the seal and the rock, but that about 1½ gal. per minute came through the laminations of poor concrete in the seal itself. This water probably came from some place where there was a small gap between the cutting edge and the rock. The entire seal was grouted and the flow of water ceased. In the meantime many of the jet or grout pipes that had been built into the walls of the caisson were successfully cleaned out, and grout was forced around the outside of the bottom of the caisson. The remaining 270 ft. of shaft was then sunk in the rock without difficulty.

The work was carried out under contract for the Greater Vancouver Water District, E. A. Cleveland, chief commissioner, and W. H. Powell, engineer. F. C. Stewart is resident engineer. The contractor is the Northern Construction Co. and J. W. Stewart Ltd., with N. D. Lambert as general superintendent and William Smaill as chief engineer.

H. E. Carleton is general superintendent on the tunnel project, and R. M. Wynne-Edwards is in charge of the caisson operations.

Demoistured Air Aids Madden Dam Cement

Handling difficulties caused by the annual eight-months rainy season in Canal Zone are overcome by using sealed steel silos, pneumatic transportation and demoistured air

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THE CONSTRUCTION of Madden Dam in the Panama Canal Zone requires about 700,000 bbl. of cement. The design of a suitable plant for economically handling such a large quantity was complicated by the necessity of receiving the ocean shipments in large increments and storing the cement with adequate protection against very damp climatic conditions.

In the Canal Zone the dry season starts around Jan. 2 and lasts until around May 5. The remainder of the year is the wet season. The annual mean relative humidity in the vicinity of the dam site is about 85 per cent. Relative humidities of 100 per cent may be expected during the mornings of the wet season, as compared with 50 per cent or lower during the afternoons of the dry season. A day without rain during the rainy season is exceptional, precipitation records of the past twenty years show a minimum annual rainfall of 72 in. and a maximum of 152 in.

This article describes the general layout of the cement-handling plant and some of its special features, supplementing the description of the concreting plant at Madden Dam, which appeared in *Engineering News-Record,* Dec. 8, 1932, p. 671.

All cement is furnished by the U. S. government, which holds contracts with several American cement mills. The Madden Dam contractors are required to give the government 90 days' advance notice of their cement requirements, and the government reserves the right to deliver requirements for two weeks in one shipment. Shipments arrive at Cristobal in 12,500-bbl. lots every other week, and during the heavy concreting period of 1933 such lots are being received weekly. The cement is loaded from ships into box cars in quantities of 232 bbl. per car and is carried by the Panama Railroad 30 miles to Madden Siding, where it is turned over to the contractors.

Earlier experiences on the Panama Canal had shown paper bags to be the most satisfactory protection against moisture accumulation in transit, as well as in tropical storage, and they were adopted. The specifications for the bags call for six plies, with the one next to the inner one paraffin-coated. All seams must be glued with a special moisture-resisting compound except over the filler valve.

The storage facilities of the contractors consist of two steel silos, each having a capacity of 6,650 bbl. of bulk cement. This is comparatively small, but demurrage on cars has been taken into account and will be permitted to occur to an amount equivalent to the non-salvageable cost of additional storage capacity.

At Madden Siding eight cars at a time are spotted under a shed alongside