THE CARRIER REPAIR SITE—PUGET SOUND NAVAL SHIPYARD

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One year from now the Navy's largest graving dock will be completed and ready to comfortably dock the largest carriers now in service, under construction or on the drafting board. Many of you will have read one or the other of the articles or papers in the various engineering magazines and proceedings of the ASCE. This structure is remarkable in many aspects and I intend to deal with some of them.

Viewing the installation from a low-flying plane, a layman would see a rectangular shaped hole below the water level which is the pattern at the bottom of the graving dock and some large cranes and high towers at yard grade. You know very well that behind that inconspicuous facade, a very complex engineering structure is being hidden. As in so many civil engineering structures, very little shows the casual observer how much engineering had to be done to finish the job satisfactorily.

The dry dock's inside measurements are 1180 feet from the head end to the outboard face, 180 feet wide at the coping, 198 feet wide at the floor level and 61 feet deep.

A general view of the Puget Sound Naval Shipyard indicates its congestion and the dry dock had to be located in an extremely crowded area. At first, it seemed impossible to squeeze a large dry dock, with its laydown area and an outfitting pier into it without doing a lot of demolition and excavation. A dry dock is a big hole in the ground. It was, therefore, a logical decision to build the dry dock out into the water and add valuable acres (13¼) to the Shipyard area.

Various sites were considered. In the framework of an Advance Planning Report, an extensive study of the site and subsoil conditions were undertaken. The actual site was selected by weighing

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operational, economical and structural aspects. The jutting out into the Sound was limited because of a sharp drop of the bottom of the soft material at the southeast corner. Also, predominant in these considerations was the question, which type of dry dock would be appropriate for this site and how could the type and construction procedure be integrated.

Original mud line at the site is 50 feet below mean sea level, 60 feet below yard grade. Beneath the mud line a stratum of soft organic silty clay extended to a depth of as much as 35 feet. This is underlain by 5 to 10 feet of relatively clean sand followed by a very compact, heterogeneous mixture of silt, sand and gravel (glacial till) containing pockets of clean coarse-grained material.

Dry docks have been built in the past as gravity or hold-down or relieved-type structures. The advancement of soil mechanics has made prediction of the behavior of soils more reliable than, lets say twenty to thirty years ago. This dry dock is unprecedented as to the combined features of length, width and depth. Therefore, the selection of the type had to be resolved very carefully for economic and structural reasons and this led to a radical design for the graving dock.

The bottom of the harbor in the vicinity of the Shipyard is approximately at the same elevation as that proposed for the dock floor. Therefore, every foot of construction depth would require excavation and fill or concrete. The width between copings being 180 feet (originally 205 feet were considered by the Navy) would have caused large moments in the center of the slab if the weight of the walls would have been used as a help against the uplift. The slab of a gravity structure would have been 43 feet thick which would have required nearly one-half million cubic yards of concrete forgetting the substantially increased quantity of excavation also required, the cost of the concrete slab above would have been as much as the completed carrier repair site as it is now being built. The conventional method of holding down the dry dock by piles was ruled out because of the layer of soft clay on top of very hard material and in the belief that not enough penetration could be economically obtained for sufficient grip on piles. Prestressed cables anchored deep into the glacial till would have reduced the thickness of the slab to a reasonable amount, but the walls would still have had the same thickness as in a gravity structure. Furthermore, the installation of prestressed cables could have been accomplished only in a dewatered site. The logical choice was, therefore, a relieved dock.

The construction procedure was designed so that its features could be used for the operation of the completed dock. An earth dam with a sheet piling core driven to the glacial till which served as a cofferdam during construction would also serve as a cutoff during the operation of the dock. The earth dam would also serve as an integral part of the mole fill around the dock.

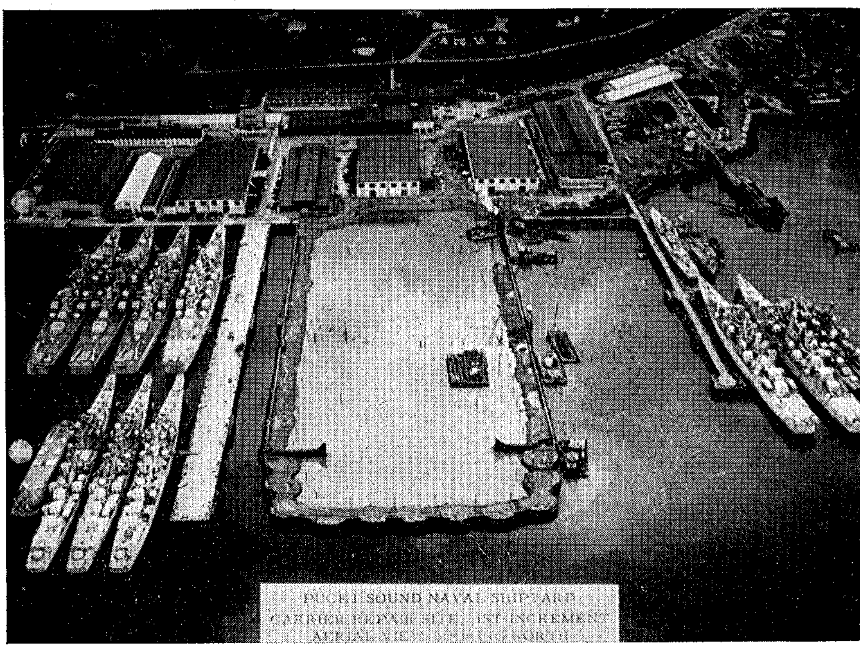
In order to provide a practically incompressible foundation for the dry dock and the laydown area, the soft material overlaying the gravel glacial till had to be dredged, altogether 550,000 cubic yards. The stability of the banks at the periphery of the dredged area was analyzed, the result being that an average slope of one vertical on 1¾ horizontal had to be maintained.

The cofferdam, which protects the site during the construction period, consists of earth dams at the east and west side, with eleven (11) circular cells arranged as a half ellipse at the south end and the existing group at the north end. The cross section of the earth dam was designed for placement of the fill material by sluicing it off barges or other similar methods. Placement by dump barges was only permitted for fill below Elev. 70 and before the sheet piles were set into place. Thus, impact against the sheet piles was prevented and the height differential at the sides of the sheet piles could be held to a minimum. It was computed that underwater slope of the fill material would be 1 to 2¾, a prediction which subsequently was borne out in the actual construction.

Fill material for the earth dam and the cells was carefully selected and rigidly specified and inspected. The fill had to stand on relatively steep slopes during underwater placement, provide high shear resistance for stability of the dams and cells, be free draining during drawdown, and to be incompressible in the foundation of the moles. Material was specified to be reasonably well graded in the following ranges: no sizes larger than 3 inches, not more than 60 per cent passing the No. 4 sieve, not more than 10 per cent passing the No. 100 sieve. The gradation selected was supplied with little or no processing from the abundant glacial outwash materials in nearby areas.

The dam with its cutoff wall was designed for the various stages and water levels during construction and where the sheet piling was used to its full cantilever value. It retained the construction roads at a level 12 feet below the final yard grade. For the final stage, the sheet piling becomes an integral part of the bulkhead or is tied back to deadmen.

The cells of the entrance cofferdam have a diameter of 60 feet. Their height above the dredged bottom is about 90 feet or at about

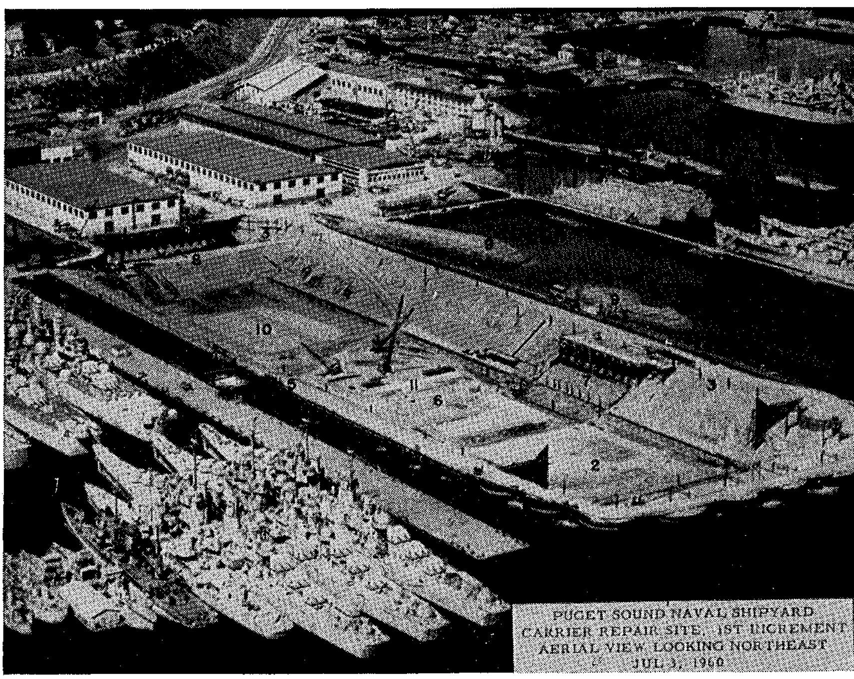


Cofferdam Completed

Elev. 123. At the land side a berm was provided 27½ feet below the top of the cofferdam.

The selection of the dewatering procedure was left to the contractor, subject to the Navy's approval. We made, however, a thorough study of the amount of water to be removed during construction and of the groundwater pressure in the slopes and bottom. The elevation to which the water had to be drawn and the location of controlling piezometer was specified in the contract. The actual water pumped after the initial dewatering was 7,000 to 9,000 gpm as compared to the anticipated underseepage estimated conservatively to be 15,000 gpm.

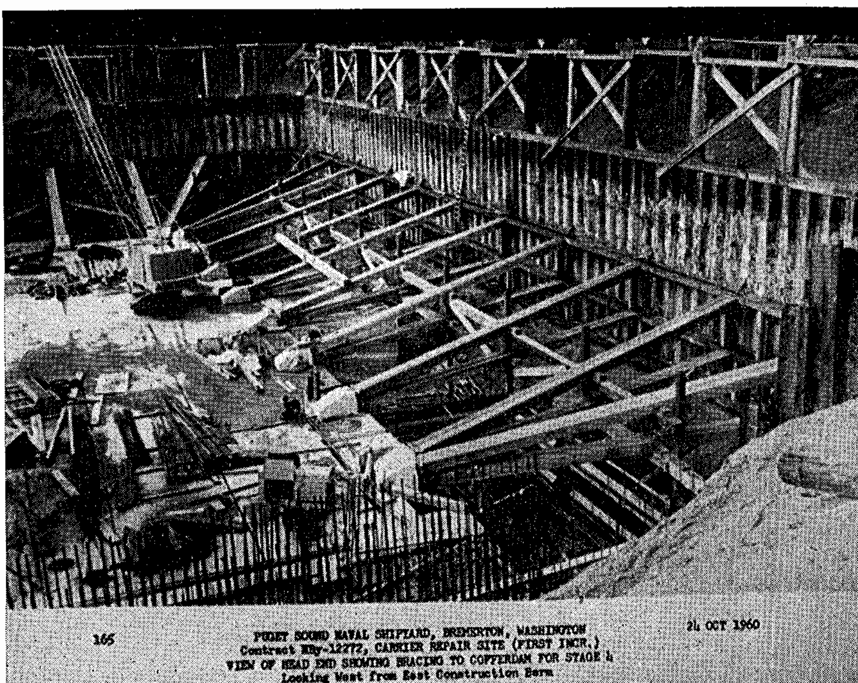
In addition to the main cofferdam, several secondary cofferdams were designed, one at the head end and a second at the pumpwell. The head end cofferdam was required to shorten the length of the excavation at the north end and to reduce the demolition of adjacent structures to a minimum. The pumpwell cofferdam was required to cut a shaft into the main cofferdam because of the shape and the depth of the pumpwell. The deepest section of the pumpwell



GENERAL VIEW—NOTE PUMPWELL LOCATION

is more than 80 feet below mean high water. Both cofferdams are spur braced and their layout and construction procedure is conventional. However, construction procedure, the size of members and their connections were specified and were not left to the discretion of the contractor unless he could submit an alternate which could be approved as its equal.

Assured a safe and dry cofferdam around the construction site, the design of the more important features of the Carrier Repair Site, the drydock itself, could be undertaken. The design philosophy of a relieved graving dock is radically different from that of a conventional gravity dock. In the latter type of dock design the quantity of materials is tantamount to the safety of the structure against a tremendous hydrostatic uplift. The dimensions of the slab and walls are such that flooding and drainage tunnels, service galleries and mechanical tunnels, etc., can easily be carved into it without impairing their strength. The keel block loads, insignificant



HEAD END COFFERDAM BRACING

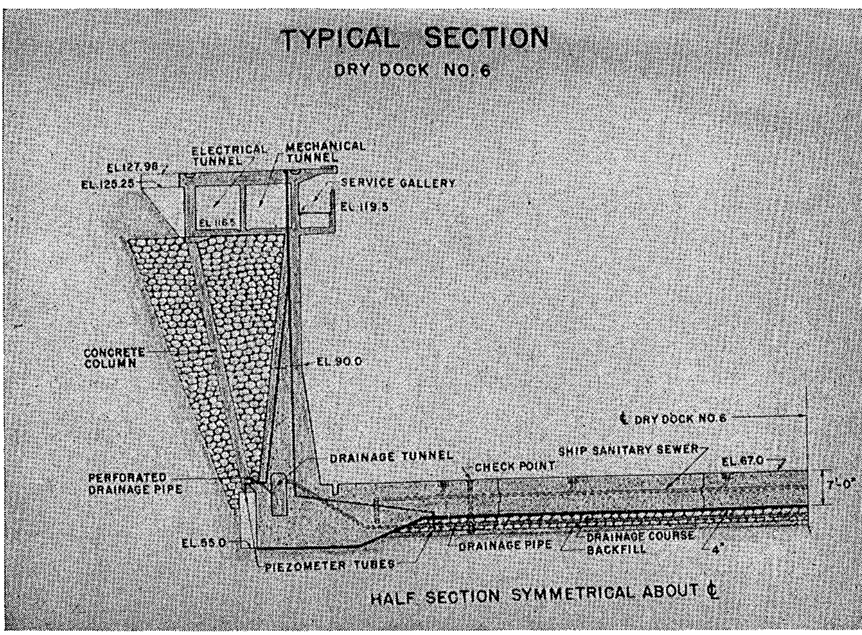
on massive concrete slabs, become major criteria in a relieved dock's slab design.

In a relieved graving dock design, the approach is quite different from that of a gravity dock. The size of each member must be selected economically to withstand the loads acting on it and just increasing materials will add nothing to the safety of the structure. However, they must be thick enough to provide a minimum of maintenance and simplify construction.

Let's therefore, start with the design of the slab. The ship considered was a nuclear carrier with a displacement of 95,000 tons and the unit pressure under a keel block equals 32.8 kips per square foot. It is well known that for any slab on an elastic subgrade, there is a direct ratio between the thickness of the slab and the moments induced by loads on it. The thicker the slab the greater the bending moments, but at least the soil pressure decreases. In this case the coefficient of subgrade reaction was evaluated as 260 kips per square foot per foot, i.e., a soil pressure of 6 kips per square foot would cause a deflection of roughly a quarter of an inch. The final thickness of a 7 foot slab was thus based on an optimum between strength, soil pressure and economy. Due to the great width of the dry dock, many computations could be simplified by assuming an infinite or semi-infinite length of the slab. The bottom slab is a relatively simple member to design as long as it is approximately 20 feet away from the wall. However, its intersection with the wall, the wall itself with its tunnels at the top and bottom make it a much more complicated structure.

The wall does not only retain the fill, but must also provide a drainage tunnel, support the service gallery and the mechanical and electrical tunnels and also the heavy loads from the portal crane tracks. The width between the copings was originally planned to be 205 feet, but was reduced to 180 feet for economic reasons by the Navy. Between the dock railing and the first crane rail, there is a distance of 3 feet to allow clearance for personnel between railing and crane. This requirement makes an overhang imperative as the wall is a natural support for the track. Below the yard grade there are separate mechanical and electrical tunnels which house all the utility lines except oxygen. Originally the wall design was considered to integrate these tunnels and the support of the crane rails into a counterforted structure, but this thought was abandoned as it required a greater width of the bottom slab at the base of the wall. A greater width at the base would have necessitated a larger distance between the two cutoff sheet pile walls and either Pier B or Mooring A would have been demolished. The final solution is that shown by dock's cross section in which sloping precast concrete columns support the outer wall of the utility tunnels.

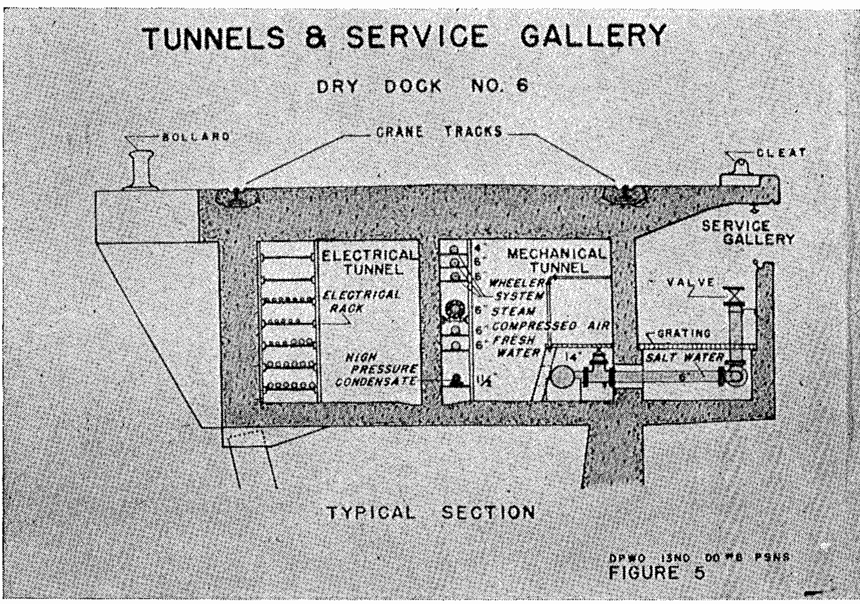
The dewatering of a dry dock requires a conduit near the base of the wall. Tunnels were placed in each longitudinal wall within the intersection of slab and wall, where the material was stressed the least. The top of the tunnel was placed above the dock floor but the floor elevation had to be consistent with the arrangement of the underdrainage system, which will be described later. Due to the hydraulic requirements for the dewatering tunnels, the slab thickness at the base of the wall was increased from 7 to 12 feet and the same dimension was adopted for the over-all thickness of



Dock Wall—Cross Section

the wall at its base. The top of the wall, below the utility tunnels, was selected from a functional standpoint for ease of construction. In between these elevations, the section was shaped to suit economy and appearance.

The service tunnel structure has four walls including the parapet of the service gallery. Each of them has a different thickness depending on its function. The standard Navy Yard twenty-foot track-gage set the center to center distance of the supporting walls, the wall between the electrical and mechanical tunnel thickness was considered a practical minimum, for the height of about 9 feet serves as a distributing member for loads on the top slab. The wall between the mechanical tunnel and the service gallery acts also as a support for the crane rail and was accordingly dimensioned. The parapet of the service gallery, designed for water pressure acting on the outside and with a pull from utility lines, has a thickness of 10 inches for its height of 4½ feet. The wall under the outer crane will serves also as a retaining wall against the fill. This wall needed a rigid support, therefore, the precast columns, inclined and supported



SERVICE GALLERY—CROSS SECTION

at the lower end by brackets extending outward from the bottom slab was the answer. Thus, the dry dock wall, the gallery structure and these precast columns became a monolithic structure elastically restrained by the bottom slab. The design was developed to incorporate the actual behavior of the structure as much as feasible and reasonable. As mentioned before, the wall between the electrical and mechanical galleries acts as a distributing plate for the portal crane loads at the crossovers and in case of heavy truck crane loads equal to 30 kips per foot. The twin box structure also acts as distributing girder against horizontal loads. The distributing capacity of the gallery structures is of such a magnitude that isolated horizontal loads did not need to be considered individually in the design of the wall below.

The head end wall of the dry dock was designed as a slab restrained on three sides. Due to the varying moment of inertia and the stiffening effect of the mechanical gallery at the top, the design of the head end wall required the development of thirty simultaneous

General View—December 31, 1960

equations, the solution of which was developed with the help of a digital computer.

The wall at the entrance of the dry dock was designed as a gravity structure subject to the water pressure. This part of the structure is honeycombed by the filling culvert, the dewatering culvert, drainage discharge, salt water intake and traveling screen, and appurtenances for these conduits. Secondly, the size of a gravity structure was very convenient for the integration of the drydock structure with the adjacent Pier 9 and the connection to the temporary circular cell cofferdam at the entrance of the drydock.

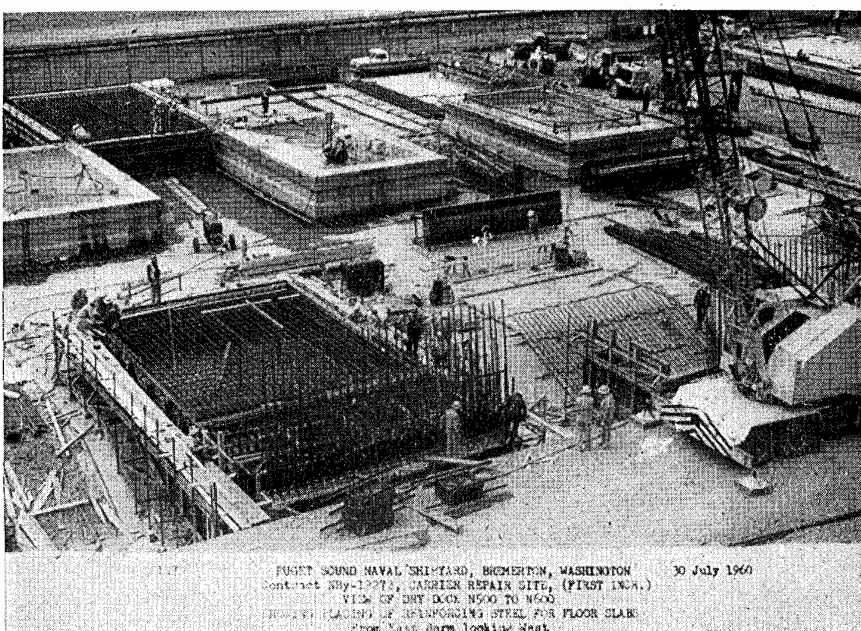
The pumpwell of the dry dock is subject to uplift and hydrostatic and earth pressures during the flooding of the drydock. Yet the bottom slab is subject to economic considerations as a thick slab which will increase the cost of excavation and dewatering during construction. The bulk of the weight of the pumpwell is contributed below Elev. 76 where the foundation for the pumps, the concrete around the discharge culverts and other conduits under water pressure, required heavy concrete thickness. The width of the pumpwell was reduced to a minimum by designing and using large pilasters which cantilever at the main pump motor floor.

The location of the pumpwell was a compromise created by four considerations. First, to have it as near as possible to the point of discharge; second, as near to the center of the drydock for ease in dewatering; thirdly to fit it into the crane track layout, and fourth, the construction procedure requirements due to the greater depth of the pumpwell's subgrade.

A large part of the design of this project, and not the least one, was its coordination with the multitude of fittings, utilities, crane tracks, stairs, mechanical and electrical cross tunnels into the structural design of the walls and slab. First, consider the sub-division of the slab and the walls themselves. A modular length of 12 feet was arbitrarily chosen for the spacing of the construction joints. The 7 foot slab was originally divided into 24 by 48 foot blocks, however, after the reduction of the width of the dry dock the 48 feet were reduced to 40 feet but in the longitudinal direction the 12 foot modulus was retained. The walls were poured in 48 foot lengths with a horizontal joint just below the utility tunnels and one intermediately halfway between top and bottom. The vertical construction joints in the walls were offset 12 feet from the transverse construction joints in the slab. The spacing of the precast columns of 16 feet fitted both the 24 foot length of the slab and the 48 foot lengths of the wall pours.

To handle a ship being brought into the dock cleats and bollards are needed for the lines and capstans to pull the ship into the dock and its proper lateral position. The cleats located along and close to the coping offered no particular problems. However, the bollards and capstans are located beyond the crane tracks. Inasmuch as the foundations for both could be incorporated into the tunnel structure, the shear and bending resistance of slabs, walls and utility tunnels was utilized, thereby considerably reducing the weight of their foundations to withstand a pull of 100 kips acting 30° above the horizontal.

The support of the turnout of the tracks was similarly treated. However, the transition between the rigid support of the track on the wall structure and the elastic support on fill was provided by an approach slab, similar to that used by highway slabs at bridge abutments.



Floor Slabs—Large Detail

In addition to the fittings and turnouts previously mentioned, there are sewage systems, sand traps, manholes, equipment hatches, piezometers and other installations such as the stairs to the service gallery and the dry dock floor and the proposed elevator to be fitted into the structural design.

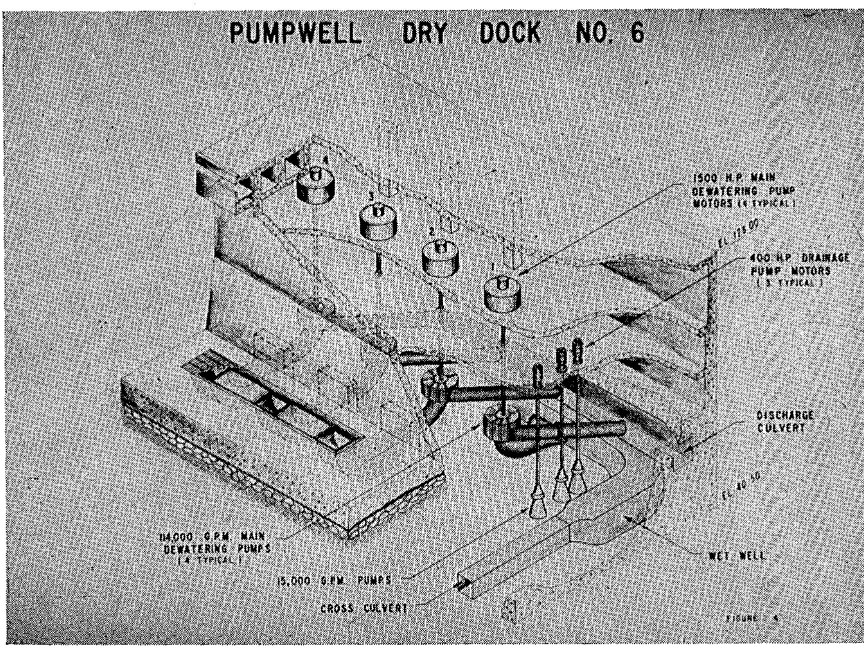
Let us return to a basic problem—water—which must and should always be respected. The best way to deal with it, is to get rid of it. In a drydock you have to depend on water to bring the ship into the dock. Thus, the design of the dewatering and filling of the dry dock play a big role in the dry dock's over-all design considerations. Two-hundred-seventy-acre feet must be moved in and out of the dock chamber. Filling, while it can be done relatively easy, requires serious consideration of culvert openings, the size of the flooding conduit, the velocity of the water on to the dock floor during the initial filling period in order to not disturb the pattern of keel blocks laid out for the ship entering the dry dock. The keel blocks are made of concrete sandwiched between timber and an inrushing wave might move them. Therefore, the initial flow of water into dry dock must be carefully controlled until the blocks are covered and protected against undesirable currents or wave action. Subsequently, the flooding procedure is limited only by the size of the conduits and the velocity within them.

A proven, efficient manner of flooding a dry dock is by means of a cross culvert located in the bottom slab near to outboard end of the dock through openings in the dock floor slab. We provided 18 openings of varying widths distributed evenly across the floor of the dock. The total flooding period was set to be 90 minutes and during an initial period of 20 minutes the water level in the dock was to be raised 10 feet. Therefore, to satisfy these criteria it was necessary to provide the equivalent of an 11 × 11 foot culvert at each side of the dock with a maximum entrance velocity of about 20 feet per second. Gates for that size were not considered to be economical, thus the intakes were split into two 8 × 8 foot openings with flush bottom sluice gates. These culverts were funneled into an outer opening of 14 × 11 feet at face of the entrance to compensate for the trashrack losses. The gates are operated by motorized equipment and can be opened or closed in 8 minutes.

The caisson used to close the dry dock and permit its dewatering was designed by Foster & Cafarelli, Consulting Engineers, New York. The caisson is a steel structure with high specific gravity concrete used as ballast and a minimum of equipment, such as flooding valves and pumps to empty the ballast tanks.

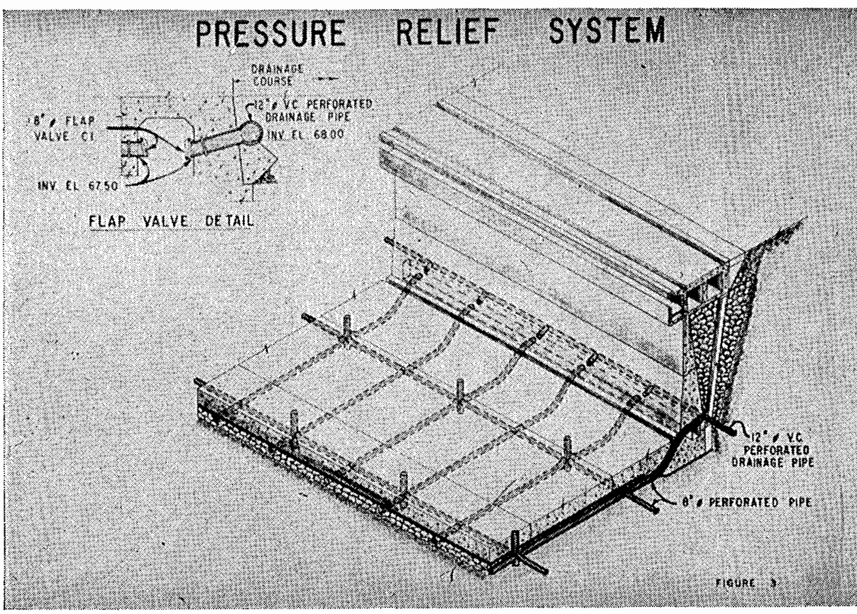
The caisson is reversible and can be used at either the inner or outer seat. Futhermore, when the caisson is in place it serves as a roadway across the width of the dock at its outboard end. The caisson is positioned in its seat by means of lines and the drydock's most southerly capstans.

In dewatering the dock we are not as fortunate, as it must be done within a reasonable time. The dewatering pumps are used infrequently and are required to pump against a varying head of 0 to 55 feet. It takes four 54-inch diameter pumps with a capacity of 114,000 gpm and 1500 HP motors to empty the dock in about 4 hours. A crucial point in the dewatering procedure of a dry dock is the removal of the last few feet as it is obvious that this depth of



PUMPWELL ARRANGEMENT

water is not sufficient to feed the intake of one let alone all four major pumps. Generally speaking, the supplementary smaller drainage pumps are used for holding down the ground water and cleaning up the dock floor, however, it would take about 2 hours to remove the last 2 feet of water in the dock with two 15,000 gpm drainage pumps. This dilemma was solved by an arrangement of the intakes whereby the three dewatering pumps having separate intake conduits are fused into one for a shallow depth below the dock floor. This has the advantage that the intake circumference has been artificially enlarged to deliver water to one pump when the dock water level approaches the floor level. However, there are still the last inches of water at the far end of the dock where even this arrangement is inadequate. The fourth pump, therefore, was not connected to the dry dock chamber proper, but to the wet well. This wet well is required by the underdrainage system so that all or any combination of 1—54-inch—114,000 gpm or 3—15,000 gpm pumps can discharge the water entering from the opening in the dry dock walls, required as access to the drainage tunnels, and floor drainage gutters which feed into



DRAINAGE DETAILS

the drainage tunnels either directly or through a cross culvert into the wet wall. The openings and conduits are adequate to deliver at least 75,000 gpm to the fourth pump when it pumps against the highest possible head.

The second, and most important water problem for a relieved hydrostatic pressure designed structure, is its removal from outside the structure. The dry dock pressure relief system consists of two main elements, a drainage blanket beneath the floor and a wedge of drainage material behind the walls. Underdrainage of the dock floor is provided by a 3 foot thick layer of select free draining material, underlain by 1 foot of typical fill material where the floor is placed in cut in natural soils. The drainage layer is a clean, coarse-grained material specified as follows: no sizes larger than 3 inches, 50 to 65 per cent smaller than ¾ inch, 25 to 45 per cent smaller than No. 4 sieve, no particles smaller than No. 40 sieve. The drainage layer plus the 1 foot thickness of granular fill were designed as a two-layer filter against the natural soils to be encountered in cut areas. A grid of 8 inch perforated, closed joint, vitrified clay drain pipe is placed within the drainage course at 48 foot centers. This drainage system discharges through a cast iron line extending through the base of the dry dock wall and a flap valve into the drainage culvert.

A triangular-shaped wedge of the same drainage material surrounds the entire dry dock walls. This drainage wedge is 30 feet wide at the top of the wall and 5 feet wide at the level of the dock floor. Practically the entire active wedge of material exerting pressures on the dock wall falls within the drainage wedge. During the rapid dewatering of the dock interior the ground water levels within the active wedge outside the wall will drop almost as rapidly as water levels inside the dock. The wedges drain to 12 inch closed joint, perforated, vitrified clay pipe placed outside the wall at the level of the base of the dock floor, which is connected to the drainage culvert within the wall. The remainder of mole is built up with the clean, coarse-grained material supplied for the general fill.

This graving dock, while it was sponsored by the Bureau of Ships, U.S. Navy, the design and construction was conducted and supervised by the Bureau of Yards and Docks through the Public Works Officer of the 13th Naval District, Seattle, Washington. The Public Works Officer of the Shipyard acted as the Resident Officer in Charge of Construction and supervised all testing and construction. The Advanced Planning Report and the design of the graving dock proper was undertaken by Moran, Proctor, Mueser and Rutledge of New York and Carey and Kramer of Seattle. The latter firm designing, primarily, the utilities, power and architectural work, whereas the former undertook the remaining design problems including the site investigation.

For more detailed information on the design and construction of this dry dock see "Journal of the Waterways and Harbors Division," Proceedings of the American Society of Civil Engineers, dated March 1960.