GEOTECHNICAL INVESTIGATIONS FOR TRIDENT DRYDOCK

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ABSTRACT: The results of geotechnical investigations at the Trident drydock site are presented. Site studies disclosed complex geologic conditions. Compact soil deposits ranging from sands and gravels to hard silts and clays were encountered. Piezometric conditions were disclosed within an aquifer sand and gravel stratum which had a major impact on design studies for the cofferdam and drydock. In the vicinity of the drydock, the piezometric elevation ranged from about 25 to 35 ft (7.6 to 10.7 m) above mean sea level. Soil engineering properties of the major strata are summarized and aquifer piezometric head contours are shown.

The site investigation focused on defining groundwater conditions in the aquifer and determining its response characteristics to pumping. Specially designed, remote reading, dual-sensing piezometers, were installed to monitor piezometric heads in the aquifer over water. Their installation is summarized and instrument details are included. The use of heavy-weight drilling mud to control artesian flow during drilling and sampling is described.

A 12-in. (30.5 cm) diameter test well was installed on land near the shore, opposite the drydock location. Two pump tests were conducted. With a moderate pumping rate from a single well on shore, significant artesian pressure relief was achieved within the aquifer throughout the future drydock area. Data on aquifer piezometric levels before and during the pump testing are shown. Computed permeability and transmissivity are presented, along with plots of drawdown with time and distance.

It is concluded that the glacial till and underlying aquifer sands and gravels have high strength and low compressibility, providing excellent foundation soils for the drydock. With the ability to lower the aquifer piezometric levels demonstrated by the pump tests, it is established that drydock construction at this geologically challenging site is technically feasible.

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Introduction

This paper describes the results of geotechnical field investigations undertaken for the design of a drydock for Trident class submarines at the Naval Submarine Base, Bangor, Bremerton, Washington. The drydock is part of a major construction program undertaken in connection with the development of a refit and training facility to support the U.S. Navy's Trident class submarine. The site is located on the Hood Canal in northwestern Washington, as indicated in Figure 1.

The site investigation program included test borings, field instrumentation and testing, pumping tests and geophysical surveys. Earlier test borings at the site had disclosed an aquifer with unusually high artesian head conditions, which caused concern for the feasibility of designing and constructing the proposed drydock. The field investigations gave particular emphasis to defining the groundwater conditions and the response of the aquifer to pumping. A special piezometer was developed and utilized for measuring piezometric heads offshore.

This paper is one of a series written on the geotechnical engineering aspects of the Trident drydock design and construction. Cellular cofferdam design, construction and performance for the facility, are reported elsewhere (2 and 3).

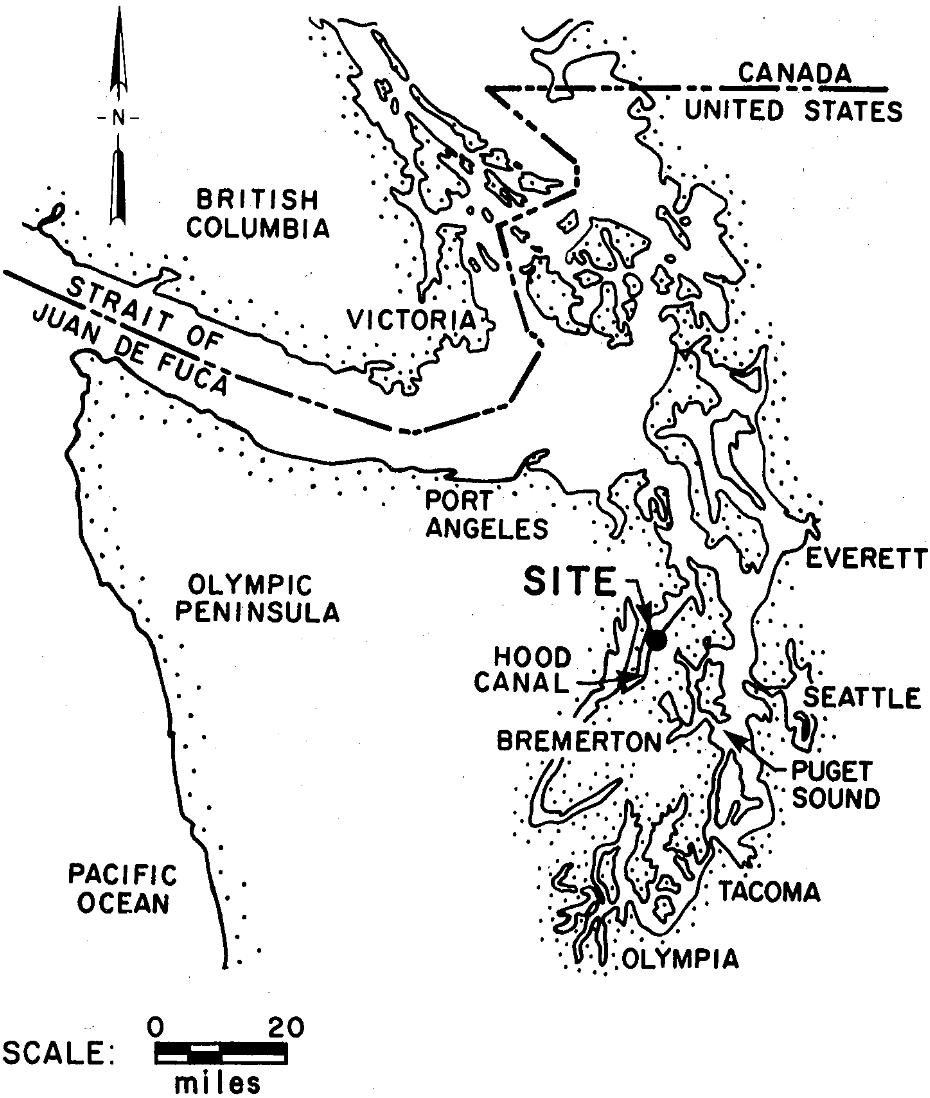

Fig. 1. Project Locus

Facility Description

The drydock, together with the refit piers, form what is termed the Trident Refit Delta, as indicated in Figure 2. Access from land to the Refit Delta is provided by two trestles, one each at the north and south ends. The drydock, which is oriented approximately parallel to the shoreline, is located from 400 to 700 ft. (122 to 213 m) offshore.

As shown on Figure 2, the existing ground surface within the Hood Canal drops in a westerly direction over the drydock site and varies from El. -25 ft (-7.6 m) to El. -62 ft (-18.9 m). Project datum, El. 0, is MLLW. (Refer to Appendix II for explanations of symbols and abbreviations). EHW is at El. 14.6 ft (4.5 m) and MTL at El. 6.4 ft (1.9 m).

The drydock was designed to be constructed at this offshore location in-the-dry within a deep steel sheetpile cellular cofferdam. The subgrade elevation for the drydock floor ranged from El. -61 to El. -64 (-18.6 to -19.5 m) which is approximately 75 ft (22.9 m) below the Hood Canal water surface at MHHW. The required excavation depth for the drydock floor ranged from 2 to 36 ft (0.6 to 11 m) below the ground surface of the Canal.

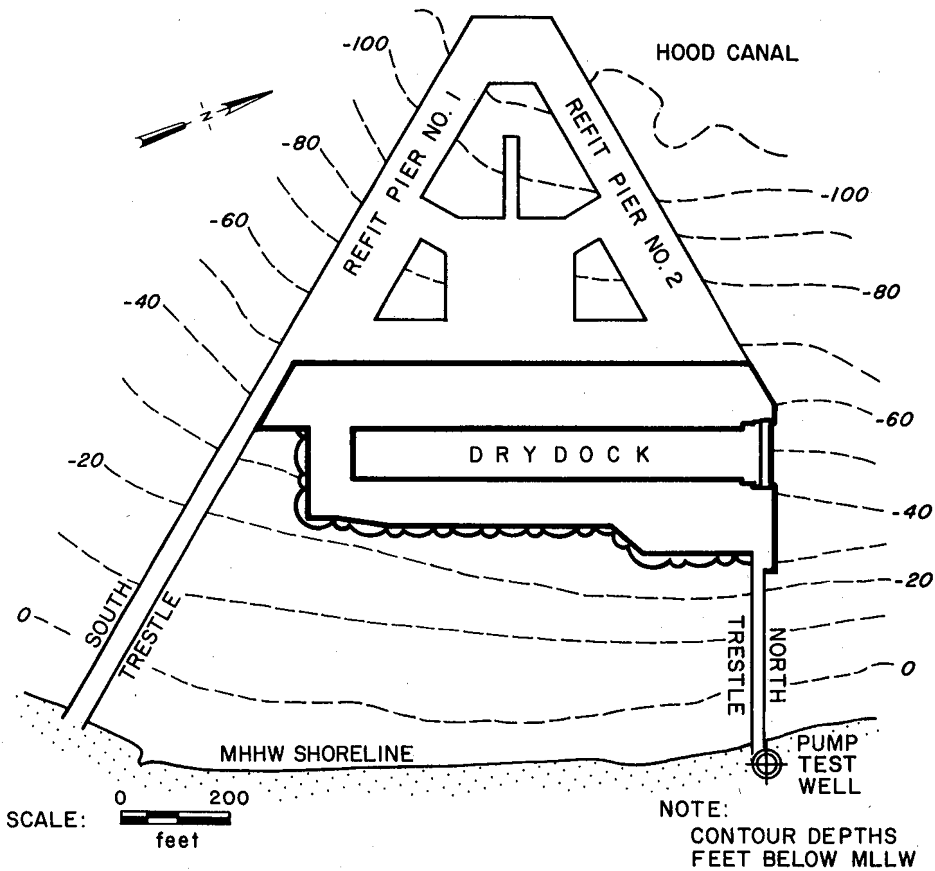

Fig. 2. Site Plan

SITE GEOLOGY AND PLANNING FOR EXPLORATIONS

The typical subsurface soil profile in a direction perpendicular to the shoreline is shown in Figure 3. For the project, the most significant strata are the glacial till and aquifer sands and gravels. The glacial till and other near surface, relatively impervious strata on land provide confinement for high artesian heads in the underlying aquifer. The artesian aquifer was revealed by earlier test borings, which encountered elevation heads over 50 ft (15.2 m) above the low tide level (MLLW) in the Hood Canal. Under artesian pressure, soil and water were blown up the drill casings, in a continuous shower. An example of cobble-sized materials which were washed up on to the drill barge through the drill casings is shown in Figure 4.

Due to these high artesian conditions, there was concern regarding the feasibility of design and construction of a drydock at the site. Would it be possible to reduce pressures within the aquifer sands and gravels to permit site dredging, drydock floor subgrade excavation and construction of the drydock in-the-dry? Could a permanent pressure relief system be designed for in-service drydock conditions to limit uplift pressures on the facility and to provide for adequate seismic stability of the offshore slope upon which the Refit Delta was to be built? What effect would temporary and permanent pressure relief have on water supply wells which were installed within the aquifer at locations on land?

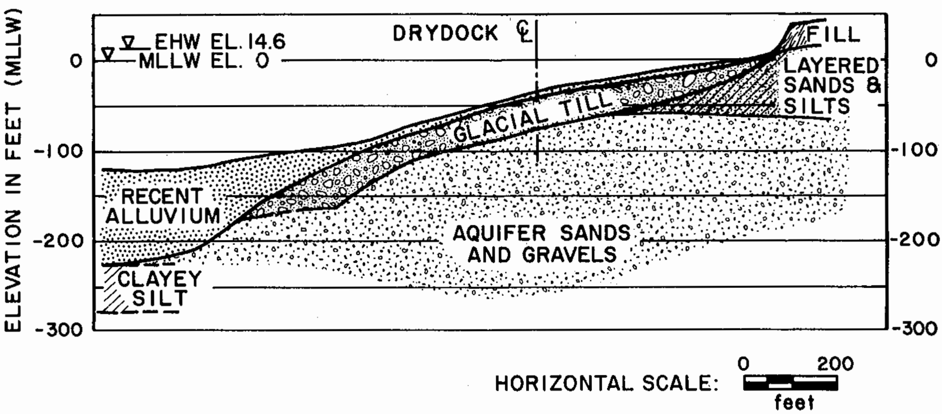

Fig. 3. Generalized Soil Profile Perpendicular to Shoreline

Fig. 4. Cobbles Washed Up Drill Casings By Artesian Flow

A major emphasis of the drydock subsurface exploration program was the definition of piezometric elevations and groundwater flow characteristics within the aquifer in addition to providing other soil and groundwater information required for project design. Along with a comprehensive test boring program, pumping tests were conducted to determine the permeability, transmissivity and other characteristics of the aquifer related to groundwater flow and technical feasibility for artesian pressure relief.

Field Investigations

Test Borings

A total of 57 test borings were drilled at the site from November 1974 through May 1975 by Warren George, Inc. of Jersey City, New Jersey. The borings included 17 drilled on land and 40 drilled within the Hood Canal throughout the Refit Delta area in water depths ranging from 10 to 120 ft (3 to 37 m). Field explorations for design of the two pile supported refit piers and the south trestle were performed by others and are not reported herein. Four types of borings were conducted for the drydock design studies:

- Type A - Borings designed to obtain pore pressure and flow rate data in strata exhibiting artesian pressures. These borings were cased full depth and drilled with water. A total of 31 such borings were made. Substantial soil disturbance was anticipated in these borings owing to artesian flow up the drill casings. However, in order to obtain the necessary information on the aquifer, blow count data and sample quality were deliberately sacrificed.

- Type B - Uncased borings designed to obtain good quality soil samples and blow count data. Heavy-weight drilling mud, ranging from 90 to 105 lb. per cu. ft. (1.44 to 1.68 kg. per cu. cm), was used to counter-balance artesian pressures and to prevent borehole collapse and soil disturbance. Drilling mud consisted of a mixture of bentonite or attapulgite clay and barium sulphate, used to control the unit weight. Drilling mud returning from the borehole was processed through a screening device ("shale shaker") to remove sand and gravel particles. Bentonite was used for the borings on land where fresh water was used to mix the mud. Attapulgite was used offshore where salt water was used in the mix. A total of 20 Type B borings were drilled.

- Type C - Conventional shallow, cased borings drilled with water and terminated in or slightly below the glacial till deposits which overlie the aquifer. Falling head permeability tests were made in these borings. Five such borings were made.

- Type G - Uncased borings drilled on land, with steel casings grouted into the completed boreholes for use in geophysical seismic testing. A total of six such borings were made.

Soil samples were normally obtained by driving a 2-1/2 in. (6.4 cm) I.D. split-spoon sampler with a 300 lb. (136 kg) hammer falling 30 in. (76.2 cm). The larger than normal split-spoon and relatively heavy hammer were used due to the dense and coarse nature of soils at the site.

All completed test borings were sealed with cement grout to prevent flow of artesian groundwater.

Soil Instrumentation

Soil instrumentation consisted of piezometers installed within completed boreholes, primarily in the aquifer sands and gravels. In addition to providing a measure of static groundwater levels, the piezometers were used to monitor the effects of test pumping. A total of 24 piezometers were installed on land and over water.

- "Dual-Sensing" Piezometers Within the Artesian Stratum

  Over water, 11 dual-sensing piezometers were installed within the aquifer sands and gravels. The dual-sensing piezometer is a unique instrument developed especially for the project. The design allowed all offshore piezometers to be read remotely from a central location on shore. A typical installation is shown in Figure 5a. These piezometers utilized a specially designed and fabricated head assembly to provide for two independent methods of measuring water pressure. The head assembly, attached by a diver to the piezometer riser pipe near the mudline, included both a pneumatic pressure transducer and a simple hydraulic tubing connection. A detail of the dual-sensing head is shown in Figure 5b. Use of the sensing head at the mudline was possible because of the permeability and high flow rates within the aquifer.

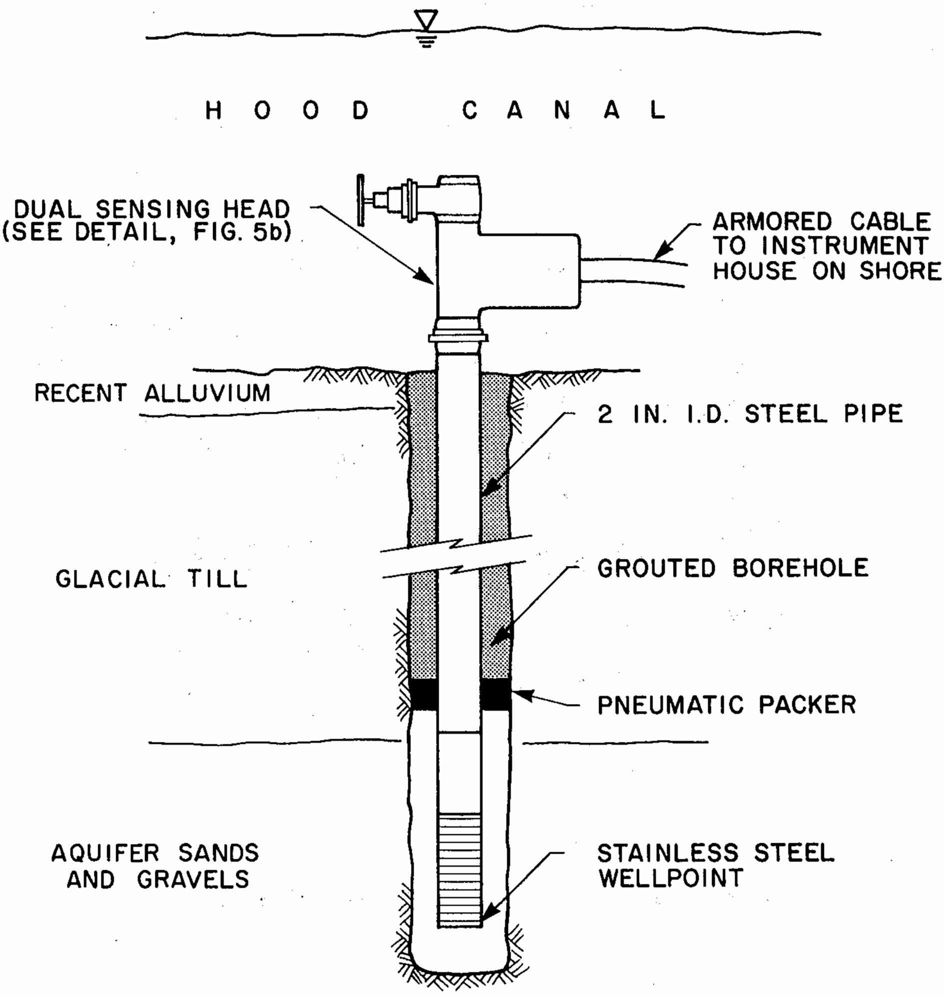

Fig. 5a. Dual-Sensing Piezometer Installation

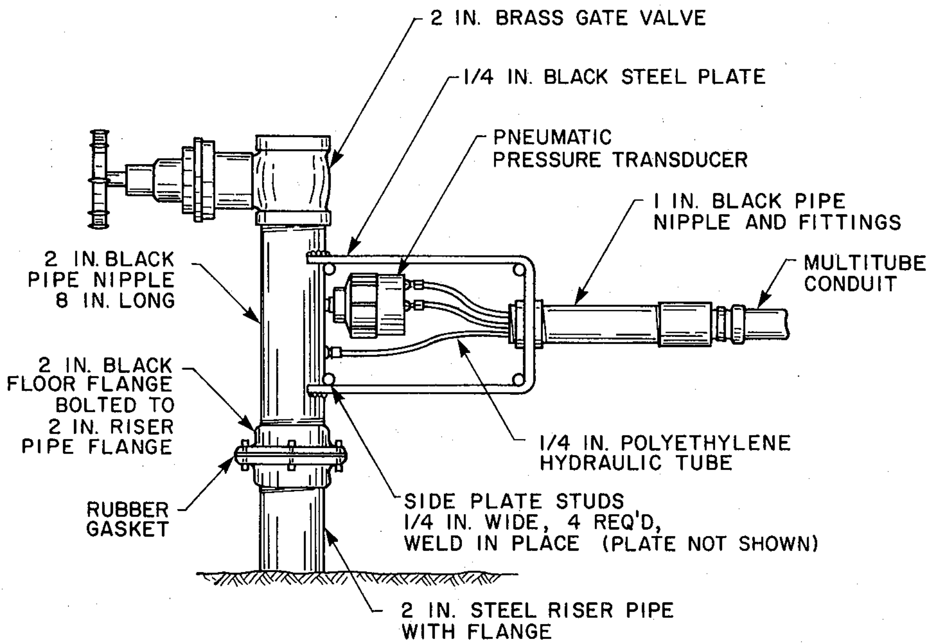

Fig. 5b. Detail of Dual-Sensing Piezometer Head

The instrument readout cables, encased in armored conduit, were laid on the bottom of the Hood Canal and connected to the instrument house on shore. Cable runs of up to 1200 ft (366 m) were required.

The piezometers were installed in Type "B" holes, which were advanced using heavy-weight drilling mud. This installation is highly unusual, but was made possible by taking advantage of the artesian groundwater conditions. At each location, the wellpoint, riser pipe and packer were installed into the mudded borehole and grouting performed. After grout set-up, the wellpoint and riser pipe were purged with water until artesian flow was generated. The resulting continuous flow cleansed the piezometers of the drilling mud and all units performed satisfactorily. After purging, all remaining drilling tools and casing above the mud line were removed. A diver then threaded the drill casing stickup at the mud line and affixed the bottom flange. The dual head assembly was then attached. The valve at the top of the unit shown in Figure 5b was opened during the attachment process to facilitate its assembly under active flow conditions. After assembly the valve was closed.

In addition to providing two semi-independent methods of measurement, the piezometer unit was designed to permit relatively simple replacement of the sensors if malfunction occurred. If necessary, the entire head assembly or components could be replaced by a diver. This resulted in considerable cost savings to the field work since the drilling contractor did not have to include contingencies for drilling supplemental boreholes to replace conventionally installed piezometers if malfunctions occurred.

All 11 piezometers operated satisfactorily throughout the 5-1/2 month period of use. Only one temporary malfunction occurred when a drilling barge spud became entangled in a cable and dislodged one of the dual head assemblies. The unit was quickly replaced by a diver and functioned properly thereafter.

In each case, the pneumatic and hydraulic piezometer readings showed excellent agreement. During portions of the pumping tests described later, water levels were drawn down below the level of the readout station and readings were provided by the pneumatic sensors only.

- Pneumatic Piezometers in Glacial Till

Three pneumatic piezometers were installed over water in shallow boreholes terminated within or just below the glacial till stratum. The piezometers were installed within conventionally drilled boreholes and sealed with bentonite pellets.

- Hydraulic Piezometers in the Artesian Stratum

Hydraulic piezometers were installed on land at ten borehole locations. Packers and cement grout seals were provided in a manner similar to that shown for the dual-sensing piezometers.

At locations where the piezometric head was above ground surface level, readings were made by means of a pressure gauge mounted at the top of the riser pipe. At other locations, or when heads were drawn down due to pumping, water levels were determined by soundings.

Measured elevation heads at all piezometers, both on land and over water, were influenced by tidal changes. Piezometric data were adjusted to a base corresponding to tide El. 0, using correlations established separately for each instrument. Piezometer fluctuations as a fraction of tide variation ranged from nearly 1.0 for the pneumatic units installed in the glacial till over water, to an average of about 0.6 for the aquifer piezometers over water, to about 0.3 for the hydraulic piezometers on land nearest the shoreline.

Pump Tests

The high artesian pressures within the aquifer sands and gravels were recognized as having significant impact on the design and construction of the proposed drydock. Accordingly, a test well was installed on land into the artesian stratum in order to conduct pumping tests. The well consisted of a 12-in. (30.5 cm) diameter casing with a 40-ft (12.2 m) long, 10-in. (25.4 cm) diameter wellscreen installed within the aquifer. The well location is shown on Figure 2 and a profile of the test well is shown in Figure 6.

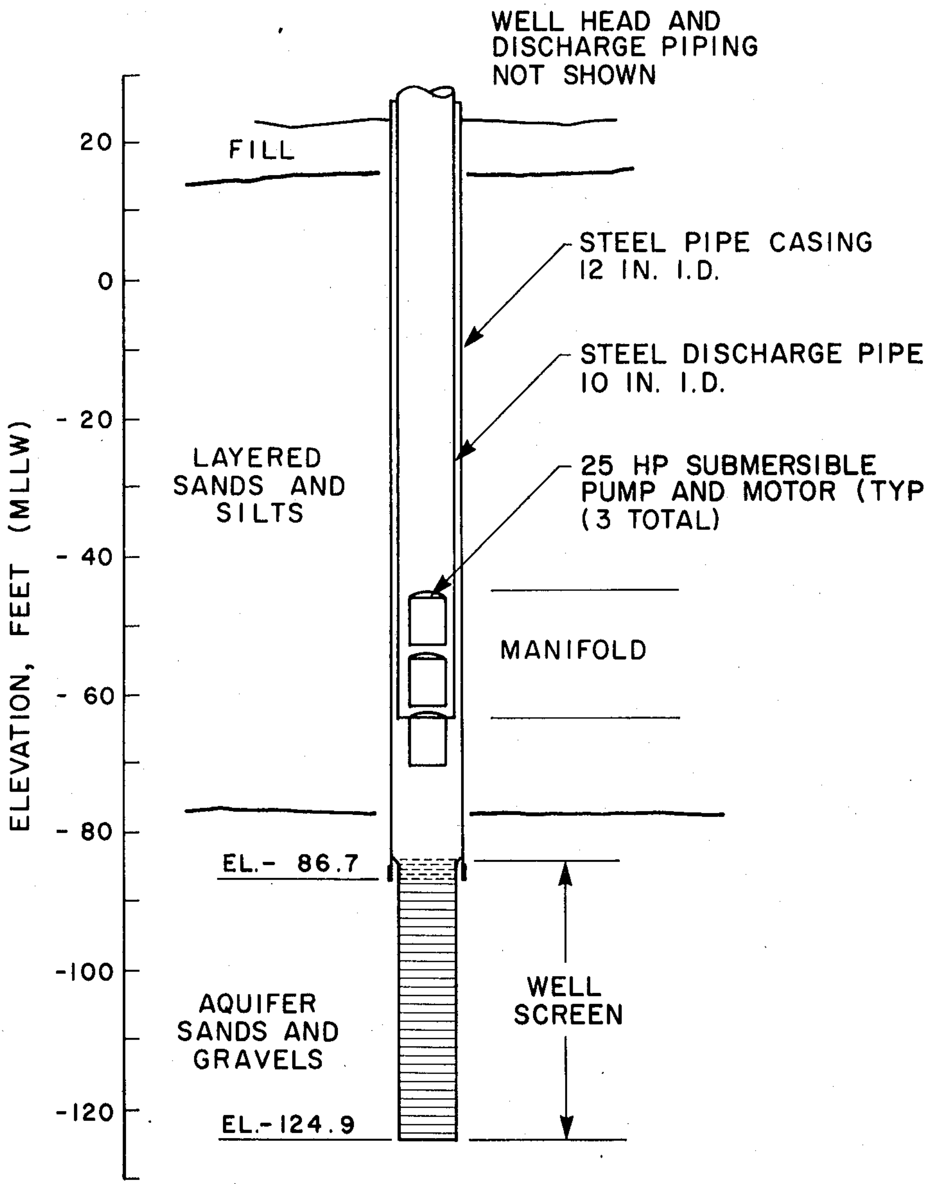

Fig. 6. Profile of Pump Test Well

Geophysical Survey

Geophysical measurements were made to develop information on in-situ soil properties needed for possible dynamic analyses of the drydock structure. The program included the measurement of both compressional and shear wave velocities of subsurface materials on land, by crosshole and uphole techniques, using steel casings grouted into the Type G boreholes. Seismic refraction and reflection measurements were also made over-water within the drydock area for purposes of correlating soil properties on land and over water.

Soil Conditions

A complex sequence of soil types and stratigraphy exist at the site. Distinct boundaries between adjacent soil zones are often not present. Although relatively simplified titles have been given the major soil zones, a zone may represent a complex interbedding of various soil types. Soil conditions at the site are illustrated in the generalized profile in Figure 3. Following are comments on geologic origins and descriptions of the major soil zones, in order of increasing depth below ground surface. Selected properties of the glacial till and aquifer sands and gravels are listed in Table I and grain size curves are shown in Figure 7.

- <u>Recent Alluvium</u>

  Recent alluvium forms the uppermost stratum of soils underlying the Hood Canal. The alluvium consists of very loose to medium compact gray sands and gravels with traces

TABLE 1

SELECTED CLASSIFICATION AND ENGINEERING PROPERTIES OF MAJOR SOIL STRATA

PROPERTY	GLACIAL TILL	AQUIFER SANDS AND GRAVELS
Water Content, percent	6 - 21	-
Liquid Limit, percent	15 - 25	Non plastic
Plastic Limit, percent	9 - 17	
Penetration Resistance, blows per foot	50 - 200 (1)	70 - 400 (1)
Permeability, x 10^{-4} feet per minute	2 - 67 (2)	150 (3)
Angle of Internal Friction, degrees	-	43 (4)
Compression Wave Velocity, feet per second	-	6500 - 7500 (5)
Shear Wave Velocity, feet per second	-	1300 - 2200 (5)

NOTES:

(1) 2-1/2 in. I.D. sampler, 300-pound hammer, 24 in. drop.

(2) From borehole permeability tests.

(3) Based on pump test analysis.

(4) From triaxial tests on reconstituted samples.

(5) Cross-borehole seismic refraction tests.

(6) 1 ft = 0.3 m

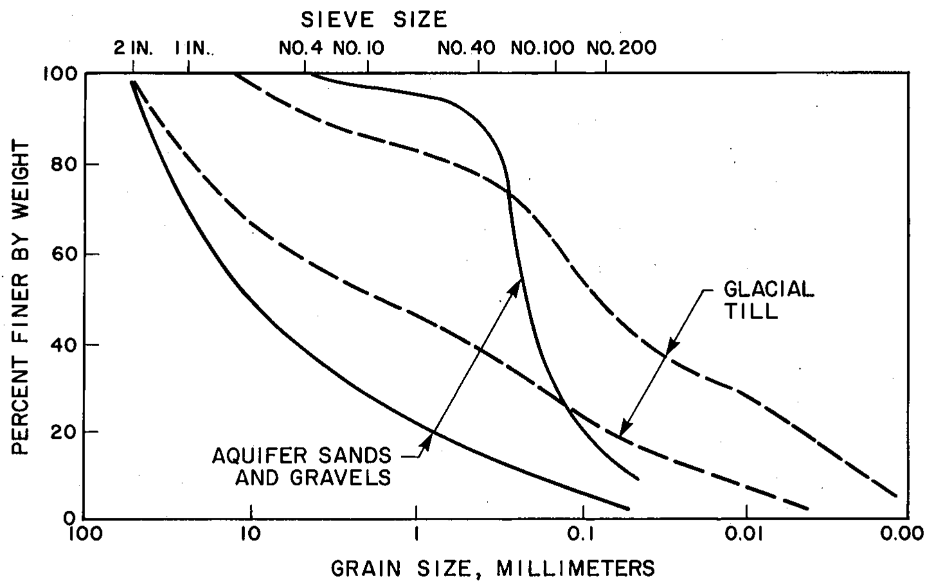

Fig. 7. Range of Grain Sizes: Glacial Till and Acquifer Sands and Gravels

of silt, shell fragments, decomposed wood, and occasional small cobbles. Generally, the alluvium is encountered as a layer of fine sand with an underlying, thinner deposit of sandy gravel. Throughout the immediate area of the drydock, this stratum does not exceed a 10-ft (3.0 m) thickness. Its thickness increases toward the west, and over 100 ft (30.5 m) of the deposit was encountered beyond the apex of the Refit Delta. Penetration resistance in the recent alluvium generally ranges from 2 to 30 blows per foot.

- Glacial till

Glacial till was encountered directly below the recent alluvium offshore. The glacial till provides confinement for artesian groundwater within the underlying aquifer sands and gravels offshore. The till occurs primarily as a very compact gray silty coarse to fine sand to sandy silt, with trace to little coarse to fine gravel and traces of clay. Pockets of silt, sand, or gravel were frequently encountered within the stratum. Penetration resistances in the till ranged from approximately 50 to 200 blows per ft (0.3 m). Obstructions to drilling were encountered in only one boring in the stratum, indicating that it was relatively free of cobbles and boulders.

Throughout the drydock area and most of the Refit Delta, the till layer is relatively uniform in thickness, ranging from about 20 to 40 ft (6.1 to 12.2 m). As shown on the soil profile, the glacial till reduces markedly in thickness and pinches out beyond the limits of the Refit Delta. Also, the glacial till layer thins out in a direction approaching the shore from the drydock location. The absence of the glacial till in areas is attributed to past wave erosion in the Hood Canal during post glacial periods of lower sea level.

- Layered Sands and Silts

This zone is the most variable soil unit and consists of interbedded deposits of medium to very compact sands and gravels and stiff to hard gray silt with layers and lenses of silty fine sand and traces of organic material and shell fragments. Together with the glacial till, the silt layers form the aquiclude to the major artesian aquifer on land. Pervious strata within the deposit also exhibit artesian pressures. The layered sands and silts range from about 80 to 180 ft (24.4 to 54.9 m) in thickness within the limits of the boring program on land. The thickness of the sands and silts decreases in a westerly direction, and beyond about 300 to 400 ft (91.4 to 121.9 m) from shore, the stratum is not encountered. Penetration resistances are variable and range from 30 to over 100 blows per ft (0.3 m).

- Aquifer Sands and Gravels

Aquifer sands and gravels, confined beneath the glacial till and layered sands and silts strata are relatively pervious granular soils which conduct groundwater with high artesian pressures. Artesian conditions within the study area are the result of groundwater flow from higher elevations on land. The aquifer is recharged from infiltration, where the confining strata are not present. This deposit is the water supply aquifer at the base.

These materials consist of interbedded, very compact gray sands and gravels, with occasional lenses and layers of silt and traces of organic material, clay and shell fragments. The aquifer likely contains pockets and layers of openwork gravel and cobbles.

Gradation tests showed that the sands and gravels have a relatively significant content of fines, with the silt content generally ranging from 5 to 15 percent. Penetration resistance typically varies between 50 and 150 blows per ft (0.3 m) and is influenced by the coarse gravel and cobbles present.

Only a limited number of test borings were sufficiently deep to penetrate through the aquifer. It is believed that near the Refit Delta, this stratum varies from about 200 to 250 ft (61 to 76 m) in thickness, with the bottom of the aquifer at approximately El. -270 ft (-82.3 m) to El. -310 ft (-94.5 m).

- Clayey Silt

It appears that a clayey silt stratum forms the lower boundary of the aquifer sands and gravels. Due to its depth, the material was encountered in only a few borings located far offshore near the apex of the Refit Delta. The deposit consists of interbedded hard silts and clays with occasional layers of sand and gravel. The top of the silt was encountered at approximately El. -300 ft (-91.4 m).

The depth to bedrock at the site, extrapolated from the map of Hall and Othberg (1), is in the order of 2,000 to 2,400 ft (610 to 731 m) below sea level. The deepest borings known to have been made on the Navy base, which are test wells for water supply studies, extended to approximately El. -1000 ft (-304.8 m) without encountering bedrock.

Groundwater Conditions

Aquifer piezometric elevations within the site area are presented in Figure 8. Contour data shown were obtained on a specific date and are representative of the piezometric levels measured throughout the period of observations. The contours indicate a relatively steady decline in elevation head in a direction from the land toward the proposed drydock. The artesian heads range from El. 30 ft (9.1 m) to El. 40 ft (12.2 m) over almost the entire refit delta complex and then drop rapidly to insignificant levels near the apex of the delta. These data reveal that groundwater is flowing within the aquifer across the site, in a direction approximately perpendicular to the shoreline, with essentially complete venting near the apex of the Refit Delta.

Although there is considerable variation within the data from the Type A borings due to localized soil conditions and testing influences, there is a definite trend of increasing piezometric level with depth at individual borings as shown in Figure 9.

Measured elevation heads within the mid-depth of the glacial till at the three pneumatic piezometers over water, when adjusted to correspond to tide El. 0, ranged from El. 5 ft (1.5 m) to El. 9 ft (2.7 m). This indicated that most of the head loss due to upward seepage occurred near the bottom of the till.

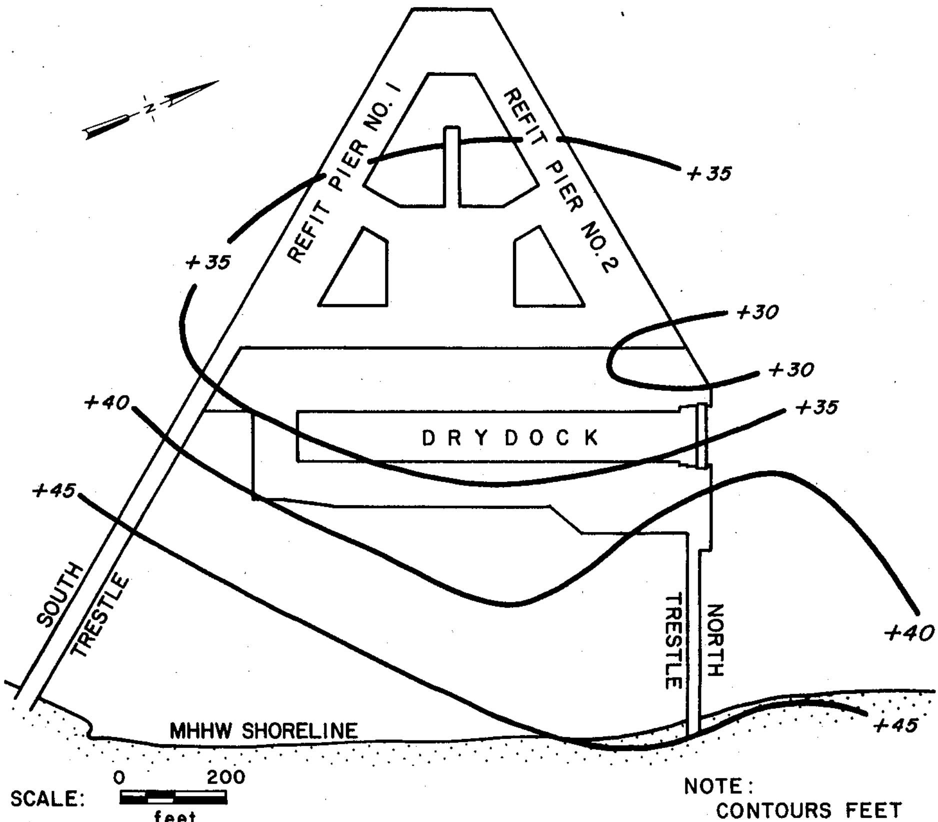

Fig. 8. Aquifer Piezometric Elevations
Prior to Pump Test

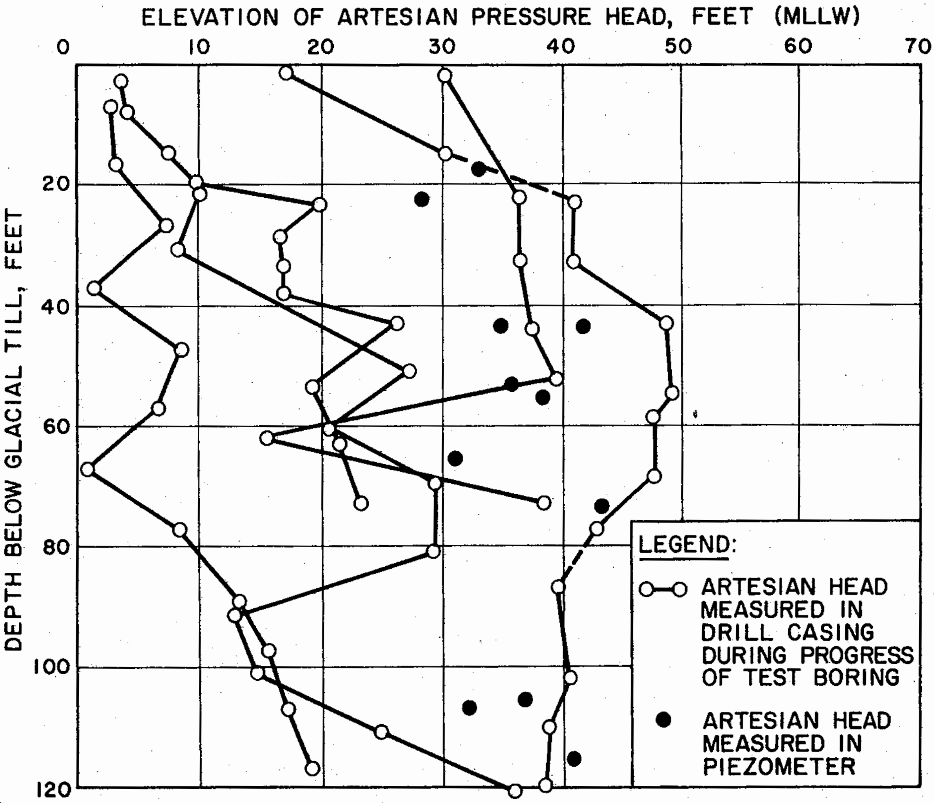

Fig. 9. Piezometric Level with Depth Below Glacial Till

While drilling Type A borings within the aquifer sands and gravels, water flowed continuously from the boreholes under artesian pressure. Flow rates varied and were a function of the working elevation from which the drilling was conducted, local stratification and characteristics of the aquifer at the borehole, tide level and pumping activities at the site. Measured flow rates generally varied from 1 to 100 gal per min (3.8 to 378 liters per min) and ranged up to a maximum of 350 gal. per min (1323 liters per min) from 6 in. (152 mm) diameter casings.

Results of Pump Tests

Two pump tests were performed during the field work. The first, test 1A, was conducted during a 5-day period in December 1974. It was performed to obtain initial data on the feasibility of aquifer pressure relief after the first few piezometers were installed offshore. The more comprehensive test, 1B, was of 15-days duration and performed in April 1975. This test is described below, and summary data for both tests are provided in Table 2.

By the time of test 1B, 11 piezometers had been installed within the aquifer over water throughout the Refit Delta area. Numerous other piezometers and observation wells, located on land, were also monitored.

Aquifer piezometric conditions at the completion of pumping are shown in Figure 10. The aquifer piezometric levels within the drydock area were reduced from initial values ranging from El. 30 ft (9.1 m) to El. 40 ft (12.2 m), to

TABLE 2

SUMMARY DATA FOR PUMP TESTS

ITEM	PUMP TEST	
	1A	1B
Duration of pumping, days	5	15
Average flow rate, gallons per minute	1,200	1,865
Maximum well drawdown, feet	48	96
Average aquifer transmissivity, sq. ft. per day	6,550	5,350

1 gal = 3.78 l

1 ft = 0.3 m

1 sq. ft = 0.093 sq. m

values less than El. 5 at the northeast corner and about El. 10 ft (3.0 m) near the southeast corner. Thus, with one well pumping onshore, the piezometric head at the drydock was reduced by magnitudes ranging from approximately 30 to 40 ft (9.1 to 12.2 m).

Figure 10 shows that an asymmetric distribution of piezometric head developed about the well during the test. The lower piezometric heads at given distances from the well in the southwesterly direction reflect a zone of apparently higher average permeability than elsewhere. The piezometric head distribution to the east of the test well reflects the higher initial heads in that area and recharge effects resulting from the normal, westerly flow of artesian water within the aquifer. Likewise, boundary effects due to natural discharge of water from the aquifer to the west are indicated.

Data on drawdown and recovery (residual drawdown) as a function of time for selected piezometers are presented in Figures 11 and 12, respectively. The data were chosen to illustrate the piezometric effects that occurred throughout the region, varying from positions close to the well to the extreme south-westerly corner of the drydock. Drawdown versus distance relationships for piezometers over water are presented in Figure 13.

It is seen, in Figure 11, that very rapid piezometric head reductions occurred. For example, almost 8 ft (2.4 m) of pressure relief developed at a piezometer 280 ft (85.3 m) from the well, within six minutes from the beginning of

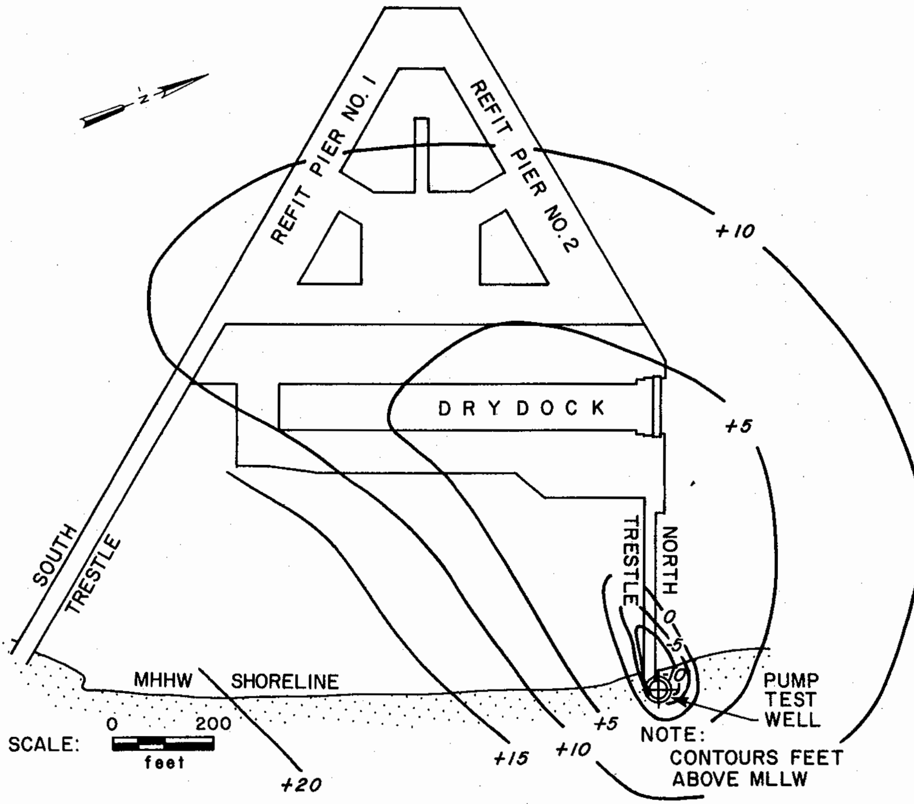

Fig. 10. Aquifer Piezometric Conditions During Pump Test

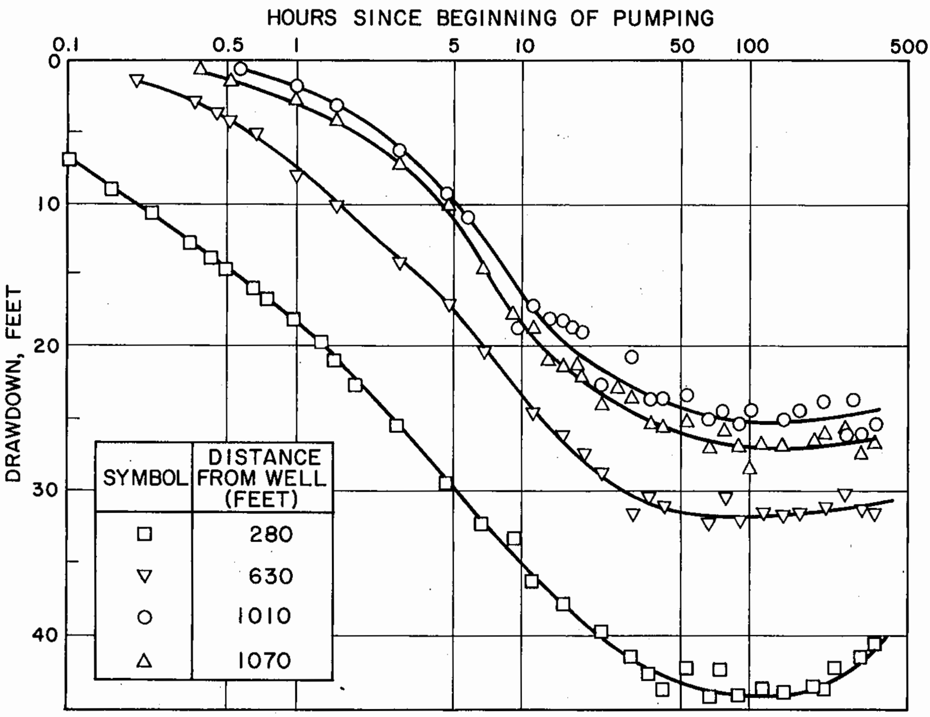

Fig. 11. Drawdown Versus Time During Pump Test

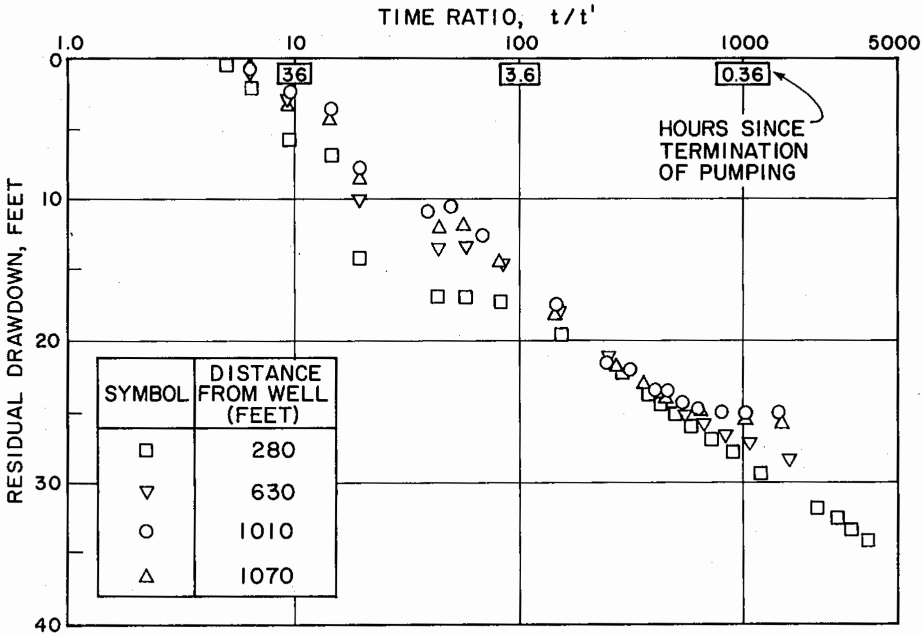

Fig. 12. Residual Drawdown (Recovery) Versus Time Ratio After Completion of Pumping

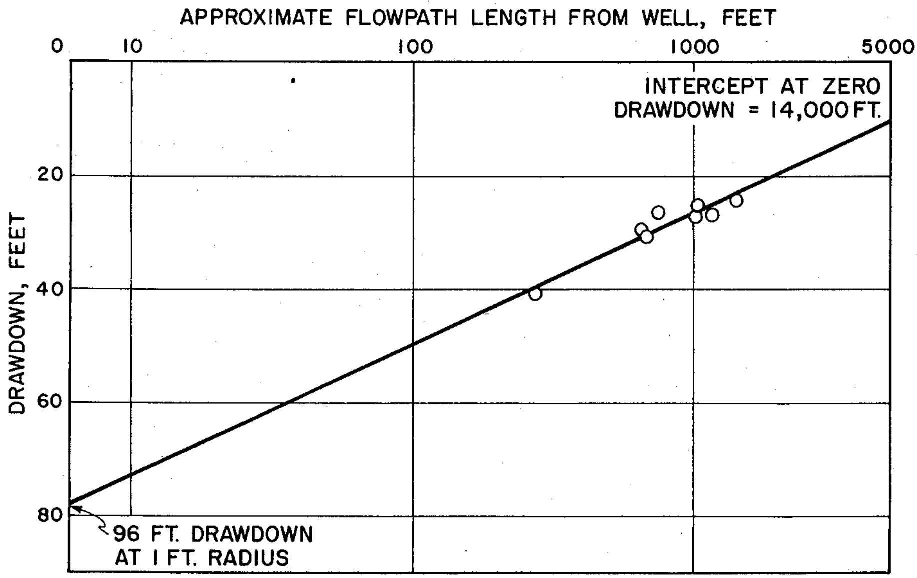

Fig. 13. Drawdown Versus Distance

pumping. This same pressure relief developed within three hours at piezometers over 1000 ft (304.8 m) from the well near the southwest corner of the drydock. Within approximately 50 hours, the four piezometers achieved their maximum drawdown.

Figure 12 shows that piezometric heads at the four piezometers recovered very rapidly. By t/t' = 10, which was 36 hours after completion of the pumping, the residual drawdown had decreased to less than 4 ft (1.2 m) for the piezometers 630 to 1070 ft (192 to 326m) from the well and to approximately 6 ft (1.8 m) at a distance of 280 ft (85.3 m) from the well.

The drawdown-distance relationship presented in Figure 13 was prepared on the basis of the approximate flow path length of the indicated piezometers from the well rather than straight-line distance. This was done to account for the significantly asymmetric distribution of flow toward the well, which is illustrated in Figure 10. The theoretical "radius" of influence in the southwesterly direction at the completion of pumping is 14,000 ft (4,267 m).

Computed transmissivity values from the test ranged from a low of approximately 3,200 to a high of about 8,000 sq. ft. per day (297 to 743 sq. m. per day). An average transmissivity of 5,350 sq. ft. per day (497 sq. m. per day) was chosen for design. Assuming an aquifer thickness of 240 ft (73.2 m) resulted in a calculated average permeability of 150×10^{-4} ft. per min (76×10^{-4} cm per sec.). This corresponds to the permeability of a very fine sand. Thus, even though the stratified aquifer contains significant amounts of coarse sand and gravel, its overall characteristics from the standpoint of seepage and flow are that of a relatively fine-grained cohesionless deposit. Computed aquifer storage coefficients ranged from 0.0004 to 0.0010, which are indicative of artesian conditions.

Conclusions Relative to Feasibility of Artesian Pressure Relief

Pump test 1B disclosed that, with a moderate pumping rate from a single well on shore, significant artesian pressure relief could be achieved within the aquifer throughout the delta area. Pressure reductions occurred rapidly throughout the aquifer both on land and over water. With two exceptions, all piezometers within the aquifer over water stabilized within approximately two days after commencement of pumping. Two piezometers stabilized within 5 to 7 days. Analyses of the test data disclosed that, from the standpoint of flow, the soils within the artesian aquifer exhibited an overall average permeability corresponding to that of a very fine sand.

Pump test 1B confirmed that it would be technically feasible, for both construction and in-service conditions, to relieve the artesian pressures at the drydock site. Unpublished studies by others showed that construction and in-service dewatering would not have an adverse impact on the base water supply.

Conclusions Related to Other Geotechnical Aspects of Design

The field and laboratory data obtained for the glacial till and aquifer sands and gravels disclosed both deposits to be very compact and to exhibit high strength and low compressibility. It was concluded that the soils were excellent foundation materials for the drydock and for the cellular cofferdam required for drydock construction. While being very compact, the glacial till was not considered so dense in-situ as to require blasting for dredging. The apparent limited quantity of cobbles and boulders within the till was also considered favorable from the standpoint of sheet pile driving for the cofferdam.

Summary

Geotechnical investigations at the Trident drydock site disclosed complex geologic conditions. Compact soil deposits ranging from relatively clean sands and gravels to a silty sand to sandy silt glacial till to hard silts and clays were encountered. Piezometric conditions were disclosed within an aquifer sand and gravel stratum which had a major impact on design studies for the drydock. In the vicinity of the drydock, the piezometric elevation ranged from about 25 to 35 ft (7.6 to 10.7 m) above mean sea level.

In addition to defining soil conditions, the site investigation focused on defining groundwater conditions in the aquifer and determining response characteristics of the deposit to pumping. Specially designed and fabricated dual-sensing piezometers, utilizing both pneumatic and hydraulic sensing methods, were installed to monitor piezometric levels in the aquifer over water.

A 12-in. (30.5 cm) diameter test well was installed on land near the shore, opposite the drydock location. Two pump tests were conducted. With a moderate pumping rate from a single well on shore, significant artesian pressure relief was achieved within the aquifer throughout the future drydock area.

Data from the borings disclosed the glacial till and underlying aquifer sands and gravels to be of high strength and low compressibility, thus providing excellent foundation soils for the drydock. With the ability to lower the aquifer piezometric levels demonstrated by the design phase pump tests, it was established that drydock construction at this geologically unique site was technically feasible.

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Appendix II — Notations

EHW	-	Extreme High Water
El.	-	Elevation
MLLW	-	Mean Lower Low Water
MHHW	-	Mean Higher High Water
MTL	-	Mean Tide Level
t	-	Elapsed time since beginning of pumping from the test well
t'	-	Elapsed time since end of pumping from the test well

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