23rd Annual
Highway Geology Symposium

GUIDE BOOK FOR FIELD TRIP
NORFOLK, VIRGINIA
APRIL 27, 1972

SECOND HAMPTON ROADS
BRIDGE - TUNNEL
23rd Annual
Highway Geology Symposium

FIELD TRIP

to

The Second Hampton Roads Bridge-Tunnel Crossing

April 27, 1972

Norfolk, Virginia

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FOREWORD

On behalf of the sponsors and the Steering Committee, welcome to the 23rd Annual Highway Geology Symposium field trip. This year's trip not only is in one of the most interesting geological areas of the state, but offers challenge and intrigue to all who have developed the technology to construct a highway facility such as the Hampton Roads Bridge-Tunnel.

The trip first includes a stop at a local fossil pit having strata similar to the older ones of the bay. A boat will be utilized to make an inspection of the tunnel construction and waste areas, and for a general harbor cruise.

It is hoped that you will profit from the trip by sharing in our experiences.

Michael A. Ozol
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INTRODUCTION

The field trip for the 23rd Annual Geology Symposium is focused on the second crossing of Hampton Roads by a bridge-tunnel that will strengthen the tie between Hampton and Norfolk, Virginia. The crossing will be at the contact of the James River with the Chesapeake Bay (see Figure 1).

The field trip will begin with an orientation period at the Chamberlin, which will include movies of the existing structure showing the tube placement, etc. From the hotel, a bus will carry the group to a local fossil pit that displays the local geology. From the fossil pit, the group will journey to a tour boat which they will board for the afternoon trip to the construction involved in the new tunnel.

HISTORY OF THE CHESAPEAKE BAY

In the 17th century, John Smith entered the mouth of one of the world's finest estuaries — the Chesapeake Bay — and wrote: "The North Cape is called Cape Charles in honor of the wealthy Duke of York. Within is a country that may have the prerogative over the most pleasant place of Europe, Asia, Africa or America, for better and pleasant navigable Rivers: heaven and earth never agreed better to form a place for man's habitation. Here are mountains, hills, plains, valleys, rivers and brooks all running most pleasantly into a fair bay composed but for the mouth with fruitful and delightful land. In the Bay and rivers are many isles both great and small, some woody, some plain and most of them low and not inhabited."

The present Chesapeake Bay is about 10,000 years old. Its origin came during Pleistocene times. During a period in the late Miocene or early Pleistocene, the seas had receded and dry land extended almost to the present day continental shelf. In late Pleistocene times, little or no land existed in the area of the Eastern Shore peninsula, as a result of the advance of the Atlantic Ocean. During this advance of the ocean, the combined action of waves and shore currents formed spits and barriers across the shore from Maryland to North Carolina. The resulting enclosed area contained lagoons and marshes similar to the Pamlico and Albemarle Sounds of North Carolina. After the retreat of the sea, this barrier was continuous to the extent that it forced the Potomac and Susquehanna drainage southward to its present outlet into the Atlantic Ocean. When the sea advanced westward again, it drowned the complete area except for the Eastern Shore peninsula. Thus the Chesapeake Bay represents the drowned valleys of the Susquehanna River. The Bay at present has a length of 190 miles and is from 4 to 40 miles wide. The tidal shoreline of the Bay and its tributaries has been estimated at 4,600 miles. The Bay and tributaries have a surface area of about 4,300 square miles. The coastal plain contains 7 major rivers — the Patuxent, Potomac, Susquehanna, Patapsco, Rappahannock, York and James — which feed into the Bay from the west. These are in addition to 40 other main tributaries that are fed by 102 main branches and creeks.

These waterways have a combined navigable length of approximately 1,800 miles.
Figure 1. Location plan for second Hampton Roads bridge-tunnel crossing.
HAMPTON ROADS BRIDGE-TUNNEL PROJECT

The First Hampton Roads Bridge-Tunnel

The first Hampton Roads Bridge-Tunnel, between West Ocean View Street in Norfolk and the Hampton shoreline near Old Point Comfort in Hampton, was constructed during the period November 1954 through November 1957. The project was financed by part of a $95 million bond issue and replaced the Newport News and Old Point Comfort ferries. The crossing consists of 23 tubes totaling 6,830 feet in length, 2 man-made islands, open approaches each approximately 600 feet in length and 2 approach trestles -- the North trestle 3,280 feet in length and the South 3,150 feet. The existing crossing is operated with state highway funds and with tolls that will retire the original bond issue by the end of 1971. The upcoming elimination of these tolls and the increased traffic volumes indicated to state highway officials the need for a second crossing.

Tunnel

The tunnel portion of the project consists of prefabricated tubes, cut-and-cover box sections, ventilation buildings, and open approaches. The 23 prefabricated tubes were sunk in place in a dredged trench and backfilled to provide a 5-foot minimum cover over the tunnel. At each end of the prefabricated tube section, box sections, which are each about 90 feet long and were constructed by the cut-and-cover method, connect the prefabricated tube section to the ventilation building structures. The open approaches carry the tunnel roadway to the trestle sections.

The tunnel roadway descends on a 4.0 percent grade from a roadway elevation of -16.4 mean sea level (msl) at the north trestle to a low point of elevation -105.4 msl in the tunnel, ascends on a grade of 0.5 percent under the main channel, and then continues on an ascending grade of 4.0 percent to a roadway elevation of -16.4 msl at the south trestle. The width of roadway through the tunnel and open approaches is 23 feet between curbs, and the minimum vertical clearance between the roadway and the ceiling in the tunnel is 14 feet.

Electric power for ventilation, drainage, and lighting is provided by submarine cables from each shore, and water for fire protection and cleaning is piped over each trestle. The roadway within the tunnel is a flexible bituminous concrete pavement on a reinforced concrete slab, and the interior finish consists of ceramic-tiled walls and a porcelain-enamelled aluminum pan ceiling.

Trestle

The tunnel approach trestles, both north and south, are precast, prestressed beams, 30 feet long, supported on precast, prestressed concrete pile bents. The width of roadway is 30 feet between curbs, thus permitting traffic in either direction to bypass disabled vehicles. Two foot wide safety walks are provided on each side of the trestles, and the concrete parapet walls are surmounted by aluminum posts and railings.
Operation

The bridge-tunnel crossing is operated by the Department as a two-way traffic facility. Current daily traffic volumes comprise about 15,000 vehicles. The administration of the project is carried on at a building located at the toll plaza in Hampton, Virginia, where collection and recording equipment are housed. Shelters at the end of each open approach on the islands house trucks and service equipment such as washing vehicles. Garages and storage for maintenance equipment and materials are provided adjacent to Interstate Route 64 in Hampton, about one-half mile west of the toll plaza. Bus service over the project is provided by public bus lines.

The Second Hampton Roads Bridge-Tunnel

The second Hampton Roads Bridge-Tunnel will be located inshore (west) of the existing (Interstate Route 64) crossing. The project will start on Willoughby Spit in the vicinity of the old ferry terminal, where it will connect to proposed Interstate Route 64. The 300-foot approach highway will be transitioned to the trestle in accordance with a clearance diagram furnished by the Department. The south approach trestle, about 6,000 feet long, will terminate at the enlarged South Portal Island. The roadway on the island will be transitioned to the south tunnel portal, and descend through the south open approach structure. The roadway will then descend through the south ventilation and gatehouse structure to the precast trench tunnel. The trench tunnel will pass beneath the Hampton Roads main ship channel and ascend to an enlarged North Portal Island, where it will reach the grade of the trestle after passing through the north ventilation and tide gate structures and the north open approach structure. After crossing the 3,250-foot north approach trestle, the project will terminate on the Hampton shore approximately 650 feet beyond the existing toll plaza, where it will join existing Interstate Route 64.

The second bridge-tunnel crossing will be operated as a dual-lane, unidirectional traffic facility. Under emergency conditions, each tunnel can be operated as a two-way, single-lane facility.

The plan of both the first and second Hampton Roads crossings and the profile of the proposed second crossing are illustrated on Figure 2.
Figure 2. General plan and profile of second Hampton Roads bridge-tunnel crossing.
GEOLOGICAL PROVINCES OF VIRGINIA

Virginia boasts of having rocks from the oldest to the youngest, running the geologic time scale from PreCambrian to recent. The state contains many classic examples of sedimentation, stratigraphy, structural geology, and metamorphic and igneous activity. Based on rock type, Virginia is divided into 5 physiographic provinces.

The Coastal Plain is on the east and consists primarily of unconsolidated sands, gravels, clays and marls.

The Piedmont borders the Coastal Plain on the west and consists primarily of deeply weathered metamorphics.

The Blue Ridge Mountains lie to the west of the Piedmont and are made up of crystalline rock. The Appalachian Valley, better known as the Shenandoah Valley of Virginia, consists of highly folded and faulted sedimentary rocks. The 5th province, the Appalachian Plateau, is in the far southwest corner of the state, where shales, sandstone and coals are found (see Figure 3).

GEOLOGY OF THE AREA

The Hampton Roads area is located in the Coastal Plain. The surface of the Coastal Plain of Virginia generally slopes eastward towards the Atlantic Ocean. It continues to the east beneath the Atlantic Ocean, where it forms the continental shelf that extends approximately 200 miles offshore.

The bedrock of the Coastal Plain is composed of partially consolidated sedimentary rock that dips to the east at steeper angles than that of the surface. The rocks consist of Cretaceous, Eocene and Miocene marine sands, commonly containing a large percentage of glauconite, gravels, clays, shell marls, and diatomaceous sediments. In turn, these sediments are sporadically overlain by Pleistocene, Recent and possibly Pliocene sand and gravel deposits that may constitute marine terraces.

The Cretaceous sediments were derived from weathering and erosion in areas to the west. During the times of advancing seas, the sediments were deposited throughout the coastal regions. These sedimentary rocks are composed mainly of sand and clay with minor gravel lenses. In some locations, the rock formations contain numerous plant fossils. Cretaceous material may exceed 1,500 feet in depth in the Norfolk-Hampton area.

Following the Cretaceous period was the Paleocene. There is no evidence or exposures indicating that any Paleocene sediments were deposited, which suggests a period of erosion and/or withdrawal of the seas. However, it has been argued that possibly the lower and older Eocene sediments (of the next period) may represent the Paleocene Period.
The Eocene Period began approximately 60 million years ago during another period of advancing seas. Depths of the sediments from the Eocene range from 150 feet in the west to 850 feet between Norfolk and Cape Charles. The sediments are composed of glauconitic sand beds with discontinuous interbedded clays. The formation abounds in fossil remains such as shark teeth and whale bones.

The absence of Oligocene material in the column indicates another era of either nondeposition or active erosion and recessed seas.

To the east, around Norfolk, the Miocene sediments reach thicknesses greater than 900 feet. The compositions of the Miocene formations vary from sand to diatomaceous clays with some glauconitic clays and some very shelly marls. As can be expected, the formation abounds in fossils of whales, seals, porpoises, mullusks, shark, ray and other fish.

The most recent system of rocks to be deposited came during the Pleistocene period. The lithology of this formation may simply be described as unconsolidated, yellow, crossbedded sand and gravel up to 100 feet thick near the Eastern Shore. Shallow seas were probably responsible for the deposition.

Silt, sand and gravel comprise the most recent material deposited in the Coastal Plain. This regolith was derived from wind, beach, lagoon and stream deposits (see Figure 4).

The surface is only slightly dissected by streams. Swamps and marsh lands are common, with the Great Dismal Swamp being the largest. Because the coastline is so deeply cut by branching bays and estuaries, the appearance has been described as that of a "fringe of peninsulas". Bluffs up to 100 feet high commonly border the estuaries. Fine natural harbors, sandy beaches, and barrier beaches are abundant along the coastline.
Figure 4. Geological cross section — Richmond to Norfolk.
RICE MEMORIAL MUSEUM AND FOSSIL PIT (STOP NO. 1)

The pit shows an excellent section of the local geology. The museum adjacent to Rice Pit contains many excellently preserved macrofossils collected from the pit. The pit is operated commercially as a borrow pit and as an outdoor educational laboratory for schools and colleges. It is approximately 50 feet deep.

The silty sand facies of the Yorktown is exposed in the pit. The texture of the sediments ranges from clayey silt and sand near the base to silty fine sand in the upper part. Quartz, calcite, and glauconite are the dominant minerals. Calcite ranges from less than 10% of the sediment in the basal part of the pit to more than 30% locally in the uppermost beds. The increase in calcite reflects the increase in the fossil content upward in the section. Bedding is lacking or poorly developed in this facies. Lamination is present locally within the pit, but bioturbation has destroyed much of the original bedding. Cursory sampling of the pit has yielded over 175 species of mollusks, arthropods, foraminifers, bryozoans and other groups. The fauna is dominated by mollusks. A baleen whale was recovered from the upper part of the formation (U.S. Geol. Survey, 1965, p. A-11). The lower beds contain a restricted macrofauna with many burrowing benthos and few predators. Although thin-shelled pelecypods are present throughout the sequence, they are relatively more abundant in the lower sequence. The upper beds contain a diverse community of vagrant benthos, including carnivorous gastropods, echinoids, and pelecypods. Both population density and faunal diversity increase upward through the section. Intensive studies of the fauna are being conducted by personnel of the United States National Museum and United States Geological Survey.

The Yorktown Formation is overlain by 6 to 10 feet of Pleistocene sediments. A gravelly sand less than 1 foot thick rests upon the Yorktown. The gravelly sand grades upward into well sorted medium sand and then into a heterogeneous mixture of sand, silt, and clay. The upper part has been weathered and, during the present period of weathering, the upper few feet of the Yorktown has been altered to a noncalcareous, mottled silty sand. Locally iron oxides have accumulated in the gravelly zone and produced an indurated pebble bed.

The sediments, fauna, and stratigraphic relationship of the Yorktown sediments in Rice Pit and in surrounding areas indicate that the lower end of the Peninsula was covered by normal marine waters 50 to 150 feet deep during the late Miocene. During late Miocene and early Pliocene time the Yorktown sea became progressively shallower as the sea level fell and the basin filled with sediment. The upper part of the Yorktown formation was truncated by Pleistocene marine erosion. A thin veneer of Pleistocene sediments was deposited during the late Sangamon or early Wisconsin Stage.

SOIL AND HYDRAULIC STUDIES

Soil Study

The stratification of the silt-clay and upper sand deposits was explored during the design of the first Hampton Roads crossing by 46 borings, as shown in Figure 3.
Figure 5. Boring plan and profile of second Hampton Roads bridge-tunnel crossing.
Undisturbed samples of soil were secured and tested in the laboratory to obtain data on the soil properties. An additional program, consisting of 10 borings, was undertaken in the course of the studies for the second Hampton Roads crossing to further verify the soil profile along the alignment of the crossing and to obtain further information on soil characteristics and their effects on design and construction.

The soil profile revealed by these borings was in close agreement with that based on the first boring program. In the areas of the north approach trestle, the North Portal Island, and the north 2,000 feet of the precast tube tunnel, the soils are sandy. These soils do not present any special problems in the design or construction of the project.

To the south, however, there is a thick layer of compressible organic silt clay. Generally, this silt clay is overlain by a deposit of sand. The elevation of the bottom of the silt clay ranges from -30 at the south trestle to -190 at the deepest portion of the channel. Dense, sandy soils are found below the silt clay. The silt clay presents problems, particularly at the South Portal Island.

The properties of the silt clay strata were investigated by means of field vane shear tests and laboratory tests of undisturbed samples, consisting of unconfined compression tests and consolidated-undrained triaxial tests. On the basis of these test results, a shear strength profile was developed, with shear strengths varying from 300 to 500 psi from the top to bottom of the silt clay layer.

The compressibility characteristics of the silt clay were investigated by means of laboratory consolidation tests in conjunction with evaluations of settlements observed at the existing South Portal Island. The investigation indicated that the silt clay layer is highly compressible, and hence imposed loads will result in substantial settlements. Furthermore, the rate at which consolidation occurs is very slow; therefore, any design which is dependent on preloading of the compressible soil will require some means of accelerating the consolidation.

Hydraulic Study

The first Hampton Roads crossing was designed to provide protection against floods and hurricanes to an elevation -14 feet above mean sea level (msl) for the trestle approaches and portal islands. The ventilation buildings are watertight to an elevation of -17.25 msl, and tide gates are provided at each portal to prevent flooding of the tunnel in the event of a major inundation. An analysis of recent studies made by the U. S. Army Corps of Engineers and the U. S. Weather Bureau on the subject of hurricane and storm characteristics in the Hampton Roads area has confirmed and validated the design criteria for the existing crossing. An evaluation of the operational records for the first Hampton Roads crossing and for the Chesapeake Bay crossing has likewise confirmed and validated the original design criteria for flood, hurricane and storm protection.
In 1960, the South Portal Island riprap protection was reinforced, and in 1965 the underwater slope protection for the tunnel required minor repairs for 1,600 feet offshore of the North Portal Island. In 1969, the South Portal Island seawall was restored to its original elevation to compensate for local settlement of 0.8 to 2.0 feet occurring since the project was opened in 1957.

Annual inspections of the project, reviews of operational records during hurricanes and storms, and records of maintenance costs over a period of 13 years clearly indicate the adequacy of the original hydraulic design criteria and justify their adoption for the second crossing.

SITE CONDITION

The existing South Portal Island is located partially in the lee of Fort Wool and is protected against storms by a riprap dike and a concrete seawall along its northeast face. The North Portal Island is sheltered from storms by Old Point Comfort. Outshore (east) of the existing crossing, there are telephone and government communication cables between Fort Monroe and Willoughby Spit via Fort Wool. The Hampton Roads channel passes between the portal islands and is abutted by numerous leased oyster-fishing grounds in the shallow waters surrounding the trestle approach structures. Borrow material required for the construction of the existing South Portal Island was obtained from Willoughby Bank by hydraulic methods. (See Figure 6.)

The second bridge-tunnel crossing will be located 200 to 300 feet inshore (west) of the existing crossing. A 6,000-foot bridge-trestle structure will connect Willoughby Spit to an enlarged South Portal Island. The new 7,270-foot precast tunnel will pass under the Hampton Roads channel between the islands, and will provide a horizontal clearance of approximately 3,800 feet between the six-fathom channel lines and a vertical clearance of 58 feet below mean low water.

The top of the tunnel structure is to be located at the same elevation as that of the existing tunnel, thus providing an equal or wider channel width, in accordance with recommendations of the U. S. Army Corps of Engineers. The Hampton Creek channel, approximately 1,000 feet west of the center line of the existing trestle, was relocated during the construction of the first crossing and will not be affected by a second one. Similarly, the Willoughby Spit channel will not require modification, as it is sufficiently remote from the construction area.
RIGHT-OF-WAY REQUIREMENTS

At the north and south termini of the project, the new approach roadways can be constructed within the rights-of-way of the existing project and the currently planned construction of Route I-64 on Willoughby Spit. Consequently, no additional property will be needed for construction on land. Design and construction requirements indicate that a permanent easement should be acquired between the Willoughby and Hampton shores, to be 500 feet west of the center line of the new crossing and 500 feet east of the center line of the existing crossing. This easement would provide adequate space for construction and, upon completion of the project, will permit operational control to prevent damage to the trestles and submarine power cables.

DREDGING AND BORROW AREAS (STOP NO. 2)

Conferences with the U. S. Army Corps of Engineers, the U. S. Navy, the U. S. Coast Guard, and local contractors have established that adequate dredging spoil and borrow areas are available for the project. The U. S. Government has a disposal area at Craney Island (about 3 miles from the project) which can accommodate pumped or bottom dump material.

The Highway Department, during the course of its studies for Interstate Route 64, investigated a borrow area at Sewells Point Spit. An evaluation of the borings and soil tests made during this investigation has indicated that sufficient quantities of sand suitable for construction of the South Portal Island could not be obtained economically in this area. It should be noted that these materials are suitable for ordinary backfill and, if required, could be used for fill over the precast piles. Additional borings have indicated that adequate quantities of suitable borrow material for the new South Island may be obtained from Willoughby Bank, the source of sand fill for the South Portal Island of the existing crossing.

OSTER AND FISHING AREAS (STOP NO. 3)

The locations of leased oyster beds and public fishing areas in the vicinity of the project, as well as the dredging limits and disposal and borrow areas for the second crossing, are shown on Figure 6. The Department secured from the State Department of Marine Resources, and other qualified sources, prior to construction, a survey of oyster-bed ownership and yield. With this information, considerable construction economies can be effected by reducing the contractor's risk and liability, which otherwise would be reflected in the bids for construction contracts.
NORTH AND SOUTH PORTAL ISLANDS

North Portal Island (Stop No. 4)

The existing North Portal Island will be enlarged to accommodate the new crossing by hydraulic fill placed on the existing sand bottom. The fill will be contained to prevent siltation with preplaced stone dikes between an approximate bottom elevation of -17 msl and a top elevation of the island at -12 msl.

The extent to which the island is to be widened is the minimum distance between the existing and proposed tunnels such that the existing tunnel fill will not be disturbed during construction. The resulting approximate width of 235 feet between tunnel center lines provides adequate space for the new structures and roadways within a length almost identical to that of the existing island.

South Portal Island (Stop No. 5)

The existing South Portal Island will be enlarged by construction of a new island immediately adjacent to the existing one to accommodate the new tunnel. The site of the new South Island, unlike that for the North Island, is underlain with a soft silt deposit forming the upper portions of the natural bottom of Hampton Roads as shown in Figure 7 (in back envelope). After completion, the new and existing islands will be connected to form a single one.

Methods of Construction

As the construction of the new island will impose large additional loads on the compressible subsoils, three schemes of construction were studied to determine the method that would result in the minimum cost and minimum risk to the existing tunnel. These schemes, as discussed in the following sections, are (1) the sheetpile trench method, (2) the dredge and fill method, and (3) the sand drains and surcharge method. The 3 methods are illustrated in Figure 8.

Sheetpile Trench Construction

With the sheetpile trench method of construction, the new tunnel and open approach structures would be located about 80 feet inshore (west) of the existing center line of the tunnel on the South Portal Island. Construction of the new facilities would be carried out within an open sheetpile trench parallel to the existing tunnel and within the confines of the existing dredged and filled island. This method would limit the need for extending the existing island and hence limit the new loads resulting from sand fill on the compressible substrata. However, the cofferdam method requires the alignment of the new tunnel to be so close to the existing tunnel that the trench excavation would uncover the top of the existing tube. Therefore, any further consideration of this method was abandoned because of the high risk of disturbance.
Figure 8. Construction methods for South Portal Island on second bridge-tunnel crossing.
Dredge and Fill Construction

The construction of the existing South Portal Island was accomplished by the dredging and disposal of 90 feet of compressible, and hence unsuitable, foundation materials, which were replaced with sand fill by hydraulic methods. Since completion of the construction 13 years ago, settlements have been within the predicted acceptable values, and have resulted in minimal corrective measures to the island and its protection, with no significant damage to the structures. Enlargement of the existing island by dredge and fill methods would require that the center lines of the existing and new islands be 300 to 400 feet apart in order to avoid problems of slope stability during the dredging of the enlarged island. This method of construction, with suitable separation of the islands, will present no undue hazards to the existing structures, but will require the removal and disposal of about 1,000,000 cubic yards of silt and replacement with approximately 1,500,000 cubic yards of hydraulic sand fill. Disposal at sea of unsuitable material is no longer economical and disposal in the Corps of Engineers Craney Island disposal area 5 miles distant requires a substantial rehandling charge. Further, the hydraulic fill to a depth of 20 feet below the new structures will require vibro-compaction for a distance of 25 feet each side of the tunnel center line. The total estimated cost is $5 million.

Sand Drains and Surcharge Construction

Widening of the existing island utilizing this third method of construction will require placing hydraulic fill between the existing bottom (elevation -15 msl) and the top of the island (elevation -12 msl) within the enclosure of previously placed stone dikes. This procedure will limit silting and will provide a dry land surface from which sand drains can be installed prior to surcharging to elevation -37 msl. After completion of the consolidation period, the surcharge will be removed and used as tunnel backfill. Settlement analyses were made using the Boussinesque Theory, and these were verified by the Finite Element Method using computer techniques. These studies indicate negligible additional settlement under the existing structures when the center lines between islands are 250 feet apart. This method would require 1,350,000 cubic yards of fill, 250,000 cubic yards of surcharge removal, 525,000 lin. ft. of sand drains, and instrumentation. Estimated cost: $4.05 million.

Upon evaluation of the above factors it was decided to use the surcharge and sand drain method of construction. No dredging and disposal of unsuitable material is required in this method. However, the dredge and fill method is a positive and relatively foolproof plan while the sand drain construction and operation require considerable care and control of technique to produce completely satisfactory results. The South island was constructed under a separate advanced contract to permit, under a subsequent contract, the trench to be dredged and deposited to construct the North Island and the tubes to be fabricated while the 12 months of surcharge on the South Island progressed.

The problems, after the selection of the surcharge and sand drain method, became the criticality of design, care in installing the sand drains, and the evaluation of field instrument readings.
SOIL PROFILE — LABORATORY AND IN SITU TESTING

In general terms, the soil profile at the South Island site consists of a thin layer of loose silty sand at the bay bottom at about elevation -15. This is followed by a layer of clayey silt with seams and pockets of sand down to elevation -90. The lower portion of the silty clay contains some organic matter. Below the silty clay are layers of dense silty sand and sand.

The clayey silt is slightly over consolidated at the upper portion and normally consolidated lower down. It varies gradually in consistency from soft at the top to stiff at the bottom.

The presence of this clayey silt layer presents problems of stability and settlement.

Cohesion

Laboratory tests of undisturbed samples of the clay silt were made in 1954 for the first bridge-tunnel. Additional laboratory tests as well as field vane tests were made in 1969. The 1954 tests consisted of unconfined compression tests and triaxial tests. Only the 1954 unconfined compression test results were used for the design.

In the 1969 test 2 consolidated, undrained triaxial tests were made at chamber pressures equal to 1/2 the overburden pressure. These yielded results lower than those of the unconfined compression tests of the same sample tubes.

A plot of peak cohesion results versus depth showed that soil cohesion increased with depth. From this finding, plotting values of cohesion were assumed for design. The basis of the assumption was to follow the average lower limit of the test results, neglecting extreme values.

From a plot of Atterberg limits and natural water content versus elevation and stress-strain curves for laboratory and vane shear tests, it appeared that the clayey silt was quite sensitive, particularly in the upper layers.

Consolidation

Consolidation tests were performed during both the 1954 and 1969 investigations. Consolidation curves were produced by plotting preconsolidation pressure and existing overburden pressure versus depth and coefficient of consolidation, C_v, at applicable pressure ranges, versus elevation.

From these tests it appeared that:

1. The clayey silt is somewhat over consolidated from its surface at -15 to elevation -50 and normally consolidated below that.
2. The time rate of consolidation is much higher for the soils above -50 than for those below.

For consolidation by means of sand drains, it is conservatively assumed that the horizontal coefficient of consolidation is equal to the vertical. Field permeability and pumping tests were performed during the initial stages of construction. It was planned that if it was confirmed that the horizontal coefficient of consolidation was substantially greater, the sand drain spacing would be revised. The sand drains were installed by jetting for minimum displacement, minimum smear.

**Increase in Cohesion with Consolidation**

On the basis of the relationship of the cohesion test results with overburden pressure and preconsolidation pressure, it was assumed that

\[ C = 0.3 \ p. \]

The initial cohesion is the product of existing preconsolidation, whether under existing overburden pressure or other geological preconsolidation pressure. When the soil consolidates under the imposed load to a value higher than its initial cohesion, an increase in consolidation will take place.

**Field Observations**

The devices used to monitor the consolidation of the in situ foundation material were:

- Casagrande Piezometers
- Pneumatic Piezometers
- Deep Settlement Points
- Control Stakes
- Inclinometer Casings

**Slope Stability Analyses**

Slope stability analyses were performed for various stages of the proposed construction. These consisted of complete solutions of the Swedish Slide Circle and manual solutions of sliding wedges.
The minimum factors of safety are tabulated below:

<table>
<thead>
<tr>
<th>Maximum Fill Elevation</th>
<th>Minimum F. S., which includes fill to the maximum elevation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Slide Circle</td>
</tr>
<tr>
<td>+5</td>
<td>1.09</td>
</tr>
<tr>
<td>+12</td>
<td>1.15</td>
</tr>
<tr>
<td>+20</td>
<td>1.37</td>
</tr>
<tr>
<td>+30</td>
<td>1.44</td>
</tr>
<tr>
<td>+37</td>
<td>1.27</td>
</tr>
</tbody>
</table>

It should be noted that an approximate slope stability analysis by means of Taylor’s charts indicates that the fill to +12 requires the same average cohesion value as did the excavation for the existing South Island. It was reported that the excavation was made without any problems of instability.

For fills above elevation +12, the increase in cohesion due to consolidation of the sand-drained area was considered in the stability analysis.

The factors of safety tabulated above are considered adequate in view of the fact that the fill is to be kept under careful observation. It should be noted that the lowest factors of safety occur at early stages in the construction. For this reason, remedial action such as extending berms will be possible if the need is indicated.

**TRESTLE DESIGN — SECOND CROSSING**

**Clearance and Design Criteria**

The horizontal roadway clearance between bottoms of brush curbs for the proposed trestles will be 36 feet, providing 2 lanes of 12 feet each, plus shoulders on each side. The normal roadway section will be crowned at a rate of 3 1/16-inch per foot, which will also be the maximum super-elevation rate. The profile of the proposed trestle has been established to provide the same vertical clearance between the bottom of the structure and mean low water (MLW) as that for the existing trestle (13 feet - 3 inches). The roadway grade will be level, except at the land abutments and approaches to the islands. Cross drainage will be provided to assure a safe and comfortable driving condition.
Span Lengths

Studies were made using an American Association of State Highway Officials (AASHO) HS20 loading plus alternate military loading for 50-foot, 75-foot and 100-foot trestles. The spans consisted of prestressed concrete beams supporting a cast-in-place concrete deck founded on 54-inch diameter prestressed concrete cylinder piles. The results of these investigations, plus experience on the first Hampton Roads crossing and other projects, and soil investigations in the area, all indicate that a maximum pile loading of 200 tons is both feasible and prudent. Based on this pile capacity, investigations indicate that the 50-foot span requires 2 piles at each bent, the 75-foot span requires 3 piles, and the 100-foot span requires 4 piles. A design study was made, setting the prestressed beams at a spacing of 6 feet - 9 inches. This spacing is the approximate maximum for a 100-foot AASHO Type 4 beam and a 75-foot AASHO Type 3 beam. The same spacing was used for the 50-foot span since the Department's highway design criteria specify 6 feet - 9 inches as the maximum spacing of stringers for a total slab thickness of 7 1/2 inches.

TUNNEL DESIGN — SECOND CROSSING

Description

The tunnel portion of the project consists of precast tubes, open approaches, and ventilation buildings. The portal-to-portal length of the tunnel is approximately 7,270 feet, of which the precast tubes comprise about 6,875 feet. The depth below mlw to the top of the tunnel at its lowest point will be about 79 feet.

Design Criteria

The tunnel design criteria are itemized as follows:

1. The maximum grade in the tunnel is 4 percent.

2. Since stopping sight distance does not govern along the vertical sag curves in the tunnel, the proposed length of 200 feet for the 2 vertical curves is compatible with a 50 mph design speed based on driver comfort.

3. Flooding of the tunnel and the open approaches during periods of extreme high tides is prevented by constructing the side walls of the open approaches to a height 14 feet above mean sea level and by providing portal tide gates.

4. The crown slope in the new tunnel is 1/4-inch per foot.
5. The existing and proposed tunnel structures were designed on the basis of the following assumptions:

Weight of Materials

- Water - 64 pcf
- Saturated soil - 110 pcf
- Submerged soil - 70 pcf
- Structural concrete - 147 pcf
- Tremie concrete - 83 pcf (submerged)
- Ballast - 70 pcf (submerged)
- Lateral coefficient active earth pressure - 0.27

Factor of Safety (Buoyancy)

- At sinking (not including ceiling, ledge, sidewalk, roadway pavement or wall finish weights) - 1.06
- After dewatering and removal of bulkheads (prior to placing interior joint concrete and backfill) - 1.02
- Final design condition (tube completed with 5-foot minimum backfill in place - no allowance made for shear or side friction provided by the backfill) - 1.25.

The following photographs illustrate the techniques by which the tubes for the first crossing were fabricated, outfitted and sunk into position.
(1) EASTERN ROARK BRIDGE-TUNNEL One of America's major highway projects, this double-deck expressway is a key link in a $385 million improvement program to stimulate Virginia. It provides a direct traffic link between Newport News and Hampton on north side of Hampton Roads with Norfolk and Portsmouth in the south, and -- by eliminating ferry trip -- cuts travel time from 15 minutes to seven. Meritt-Chapman & Scott Corporation, of New York, built bridge tunnels for Virginia's Department of Highways. Perales, Pruneshoff, Baill & McDonald, of New York, designed project and served as supervising engineers.
[1] \textit{EN ROUTE TO TRINIDAD}: Completed 100,000-ton, steel-clad with watertight bulkheads at both ends, was launched from shipyard pier into Delaware River from five ships, and towed to Harwich Roads where it served as a floating drydock. The shipyard required approximately 10,000 tons of structural steel, 300 tons of concrete, and 30,000 cubic yards of earth for its building.

[2] \textit{SLEEP-UP" BAKERS}: These 130,000-ton, steel-clad, drydocks established by Horlick-O'Byrne & Sons at Lambert's Point, six miles from New York, where 10,000 tons of steel were used, serve as floating drydocks for repair and maintenance work. By the 130,000-ton "sleep-up" drydocks, they are equipped with water supply and drainage, accommodation for power, telephone, and water, and complete facilities for gates and valves.

[3] \textit{TRAFFIC}: The traffic, a 130,000-ton, steel-clad drydock, was built at Lambert's Point, six miles from New York. It is equipped with water supply and drainage, accommodation for power, telephone, and water, and complete facilities for gates and valves.
(6) GOING DOWN. Three steel frames, partly sunk by the time ('floating'), the almost completely submerged tube was maneuvered into position and joined into steel-pleated trench bridge across Wentworth Bridge. To make a structure, time was crucial, when placed too deep, steel-pleated trench bridge would have stopped at Wentworth Bridge.

(7) TWO TUNNELS. After completion of the superstructure, the tunnel was flooded with a flow of 1.8 cubic feet per minute. The length of the tunnel was 10,000 feet and cross-sectional area was approximately 180 square feet. The tunnel was designed to withstand the weight of a U.S. Navy cruiser.
(C) JOINED TOGETHER. Once in position on bottom of dredged trench, tube was melted together by divers and remaining space between inner and outer tubes was filled with concrete. Next, each ring of concrete was built around sea-tight inner belting and tube was covered with a Galvamox blanket of steel. Later, as steel belting in between sections was progressively withdrawn through joints were welded and tube was joints were welded and tube was walled in. This is one section of tunnel formed at this point.

(8) MAN-MADE ISLAND. Two-man-made islands, constructed by Marshall-Wyman & Bonus from time of existing parts of 1953 dredges to bottom of Fontana Dam, were in section between tunnels and the two tunnels, respectively, were: South Island -- began in April, 1954, with 2,000,000 cubic yards of stone, maximum depth 5 feet above, maximum depth 3 feet above. North Island, elegantly designed. One of the best made in a lake, was devised by Northland, Inc.
A feasibility study for constructing Interstate Route 64 totally on land through the Willoughby area was made in 1957. However, the width of the roadway badly damaged private property. Consequently, a long trestle was built across Willoughby Bay. This site also involved the crossing of the waste that was dredged for the sea plane base for the Navy. The fills were surcharged, and several mud waves developed. Originally, the design called for about 15 feet of oyster shells to be placed at the bottom of each embankment to act as a platform for the roadway. Unfortunately, the shells were not available at the time of contract. One bridge had to be moved because methane gas (marsh gas) was encountered about 50 feet down under pressure. An attempt to burn the gas off was made for 3 months, however, the difference in pressure was hardly noticeable. The construction area is shown in Figure 9.

Figure 9. Willoughby Spit construction area.
Figure 6. Site conditions at second Hampton Roads bridge-tunnel crossing.