ENGINEERING GEOLOGY OF THE DORCHESTER BAY AREA

PERTAINING TO URBAN DEVELOPMENT

OF THOMPSON ISLAND

by

DAVID J. HUGHES

Submitted in Partial Fulfillment

of the Requirements for the

Degree of Bachelor of Science

at the

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

September, 1968

Signature of Author..........................
Department of Geology and Geophysics, 19 August, 1968

Certified by.. ................................. Thesis Supervisor

Accepted by.. ................................. Chairman, Departmental Committee on Theses
ENGINEERING GEOLOGY OF THE DORCHESTER BAY AREA

PERTAINING TO URBAN DEVELOPMENT

OF THOMPSON ISLAND

by

DAVID J. HUGHES

Submitted to the Department of Civil Engineering on August 19, 1968 in partial fulfillment of the requirements for the Degree of Bachelor of Science.

ABSTRACT

Thompson Island has been selected as a possible site for an urban complex in Boston Harbor. The significance of geologic parameters is discussed, with emphasis on depth to bedrock and thickness of unconsolidated sediments. The need for additional information is stressed. Tidal information is presented and a safe elevation is determined for the proposed complex. Engineering aspects of deriving new land by filling in shallow water are discussed, including types and locations of fill materials. Finally, a cost per square foot of new land is obtained for several fill schemes.

Thesis Supervisor: Ronald C. Hirschfeld
Associate Professor of Civil Engineering

- i -
TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abstract</td>
<td>i</td>
</tr>
<tr>
<td>Table of Contents</td>
<td>ii</td>
</tr>
<tr>
<td>List of Figures</td>
<td>iii</td>
</tr>
<tr>
<td>Acknowledgements</td>
<td>iv</td>
</tr>
<tr>
<td>Introduction</td>
<td>1</td>
</tr>
<tr>
<td>Chapter 1 . . . Bedrock Properties and Elevations</td>
<td>2</td>
</tr>
<tr>
<td>Chapter 2 . . . Unconsolidated Sediments within Boston Harbor</td>
<td>9</td>
</tr>
<tr>
<td>Chapter 3 . . . Bottom Topography, Water Depths, and Tides</td>
<td>17</td>
</tr>
<tr>
<td>Chapter 4 . . . Fill Materials and Procedures Location of Borrow areas</td>
<td>20</td>
</tr>
<tr>
<td>Chapter 5 . . . Cost of Filling Land around Thompson Island; Restrictions on Fill Areas</td>
<td>25</td>
</tr>
<tr>
<td>Conclusions and Recommendations</td>
<td>39</td>
</tr>
<tr>
<td>Bibliography</td>
<td>40</td>
</tr>
<tr>
<td>Appendix. . . Memo from Professor Moavenzadeh to Mr. Charles Hilgenhurst</td>
<td>42</td>
</tr>
<tr>
<td>Figure Number</td>
<td>Title</td>
</tr>
<tr>
<td>---------------</td>
<td>----------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>1</td>
<td>Simplified Stratigraphic Column</td>
</tr>
<tr>
<td>2</td>
<td>Bedrock Types under Boston Harbor</td>
</tr>
<tr>
<td>3</td>
<td>Bedrock Contours under Boston Harbor</td>
</tr>
<tr>
<td>4</td>
<td>Map of Available Geologic Profiles of Boston Harbor</td>
</tr>
<tr>
<td>5</td>
<td>Hypothetical Section Showing Relationship of Unconsolidated Sediments</td>
</tr>
<tr>
<td>6a</td>
<td>Section in Dorchester Bay from Old Harbor towards Thompson Island</td>
</tr>
<tr>
<td>b</td>
<td>Section along Causway from Moon Island to Long Island</td>
</tr>
<tr>
<td>c</td>
<td>Section through Fox Point to Squantum Point</td>
</tr>
<tr>
<td>d</td>
<td>Section in Dorchester Bay; Mt. Vernon to Thimble Island</td>
</tr>
<tr>
<td>e</td>
<td>Section extending southwards from Castle Island</td>
</tr>
<tr>
<td>7</td>
<td>Locations of Sections in Figure 6</td>
</tr>
<tr>
<td>8</td>
<td>Water Depths at Thompson Island</td>
</tr>
<tr>
<td>9</td>
<td>Comparison of Anticipated and Developed Profiles through Runway Embankments at Logan Airport, showing effects of Soft Mud</td>
</tr>
<tr>
<td>10</td>
<td>Locations and Distances to possible Sources of Sand</td>
</tr>
<tr>
<td>11</td>
<td>Negative Loading.</td>
</tr>
<tr>
<td>12</td>
<td>Estimated Bedrock Contours under Thompson Island</td>
</tr>
<tr>
<td>13</td>
<td>Unconsolidated Soils Come to Rest with Sloping Sides</td>
</tr>
<tr>
<td>14</td>
<td>The Cost of Sloping Land Fills</td>
</tr>
<tr>
<td>15</td>
<td>The Use of Dyking to Contain Fill Materials</td>
</tr>
<tr>
<td>16a</td>
<td>Cost per sq. ft. of land filled with sand to elevation +18.5</td>
</tr>
<tr>
<td>b</td>
<td>Cost per sq. ft. of land filled with sand to elevation +24.0</td>
</tr>
<tr>
<td>c</td>
<td>Cost per sq. ft. of land filled with clay to elevation +18.5</td>
</tr>
<tr>
<td>d</td>
<td>Cost per sq. ft. of land filled with clay to elevation +24.0</td>
</tr>
</tbody>
</table>
ACKNOWLEDGEMENTS

Indebtedness is gratefully acknowledged to: the Urban Systems Laboratory for financial support, under account number 70857; to Professor R.C. Hirschfeld for the opportunity to work on the project and for invaluable guidance and criticism; to Professor J.B. Southard for referring the author to Professor Hirschfeld and for general encouragement; to Mr. Richard Edmunds for invaluable assistance in research and in preparation of illustrations; to Mr. Dan Schodek for criticism and assistance in field studies; to the other members of the Urban Systems Laboratory for many enlightening discussions; and especially to Mrs. Gail Stevens for tremendous assistance in typing and for her constant encouragement.
INTRODUCTION

The city of Boston is bound to the north, south, and west by well-developed suburbs. To the east, however, lies Boston Harbor and the Atlantic Ocean. Within the harbor are many undeveloped islands. Realizing the potential value of these islands for future urban complexes, the Boston Redevelopment Authority has contracted the Urban Systems Laboratory of the Massachusetts Institute of Technology to study the feasibility of development of these islands.

This paper is an interim report of the author's geologic study of the Thompson Island and Dorchester Bay area. It is expected that the proposed development of an island would require extensive land fill to increase the usable land area, and much of this report deals with the engineering aspects of such a land fill operation. Hence the title, "Engineering Geology......"

Due to time limitations the entire harbor could not be studied in detail. The Thompson Island site was chosen for two reasons. First, its proximity to Boston makes the site a logical starting point for a transportation link with the other harbor islands. Such a transportation link would be a tremendous asset to subsequent development of the other islands. Secondly, the Boston Redevelopment Authority is already considering this site for a proposed World's Fair in 1976, with the exposition site to be converted to a new community following the fair. Thus, our information is directly applicable to their current interests.

Some environmental studies performed recently by other members of the Urban Systems Laboratory suggest that Thompson Island is not an ideal location for an urban complex. However, the methods used in this study are applicable to other sites, where similar problems are present to greater or lesser degrees. The final report of the Urban Systems Laboratory study is expected to appear some time this winter.
CHAPTER 1

BEDROCK PROPERTIES AND ELEVATIONS

Most of Boston Harbor is underlain by a dark, fine grained rock known as Cambridge argillite (also known as Cambridge slate or Cambridge siltstone). The Cambridge argillite is the upper formation of the Boston Bay Group (see Figure 1). The other important formations in this group are known as the Squantum tillite, the Roxbury conglomerate, and the Mattapan volcanics.

The Cambridge argillite is a thinly bedded mudstone exhibiting only local slaty cleavage. It is similar to pelite, shale, argillite, and slate but cannot be specifically identified with any of these. The argillite contains numerous diabase sills and dykes, many of which have become cores for drumlins found in the Boston area.

The Squantum tillite is composed predominately of large, poorly sorted rock fragments in an abundant clay matrix. It is generally considered to be a glacial deposit, though some phases seem to be water deposited conglomerates. (Billings, 1929)

The Roxbury conglomerate formation contains a conglomerate member plus several beds of other sedimentary rocks. The conglomerate phase contains pebbles of quartzite, granodiorite, granite, rhyolite, and melaphyr (altered andesite or basalt) set in a sandy matrix. The remaining sedimentary members are local beds of shale, slate, argillite, sandstone, quartzite, melaphyr and volcanic tuff.

The Mattapan volcanic formation includes rhyolites, trachytes, andesites, tuff, and breccias. This formation is not always present; in some areas the Roxbury conglomerate rests directly upon the basement complex. This condition exists in East Dedham and along the South Shore
<table>
<thead>
<tr>
<th>Layer</th>
<th>Age</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Consolidated Deposits</td>
<td>Pleistocene</td>
<td>Outwash, sand, gravel and clay Till</td>
</tr>
<tr>
<td></td>
<td>Pennsylvania (?)</td>
<td>Mattapan volcanics 0-2000 ft.</td>
</tr>
</tbody>
</table>

---

**Figure 1.** Simplified Stratigraphic Column
*(after Billings, 1929)*
of Boston Harbor.

The rocks of the Boston Bay Group underwent mild folding during the period of the Appalachian orogeny. The axes of these folds strike generally east-west and dip slightly to the east. Subsequent erosion and faulting have resulted in a rather complicated bedrock surface under the Boston Basin. (see Figure 2.)

The depth to the upper surface of bedrock is very important in determining the cost and nature of building foundations and utilities placement. If the bedrock is shallow, buildings may be supported on piles, allowing the use of relatively cheap, locally abundant clay for the purpose of land fill. (It should be mentioned that this combination of piles and clay may result in "negative loading" - a problem which arises when the clay consolidates over a long period of time. See p. 25.) If, however, the bedrock is buried under thick layers of highly compressible sediments, such as clay and mud, the cost of placing piles becomes prohibitively expensive, and one is forced to consider floating foundations placed in a non-compressible fill such as clean sand or gravel. In addition, since a thick layer of mud or clay is likely to compress under the added burden of fill material, settlement problems are likely to be encountered in areas where fill is to be placed upon thick deposits of clay or mud overlying deep bedrock.

Unfortunately, very little information is available concerning depth to bedrock within the harbor area. Upson and Spencer (1964) suggest the existence of several Pleistocene river valleys, or buried bedrock valleys, under the Dorchester Bay area. (see Figure 3.) This would place the bedrock surface 250 feet or more below sea level in parts of Dorchester Bay, and Phipps (1964) cites a depth of 360 feet to bedrock under Spectacle Island. On the other hand, outcrops of the Squantum formation exist above sea level in the Squantum Point area (Squaw Rocks and Chapel Rocks). Mr.
Figure 2. Bedrock Types under Boston Harbor
(After Billings 1929)
Figure 3. Bedrock Contours Under Boston Harbor, in feet below Boston City Base.
(After Phipps, 1964)
Clifford Kaye of the U.S. Geological Survey, noted authority on the geology of Boston, explained that he personally places little confidence in the bedrock valley theory. He added that the bedrock is indeed quite deep in parts of the harbor, but the bedrock contours are too irregular and too uncertain to accurately predict the existence or the location of such bedrock valleys.

Some boring records for the Old Harbor and the Neponset River estuary are available in the handbook published by the Boston Society of Civil Engineers (1961). Other information is available for the old Squantum Naval Air Station (Jackson and Moreland, 1955), Governor's Island (Lee, 1942), and numerous sewer lines placed by the Metropolitan Districting Commission. (see Figure 4.) I know of no borings or geophysical surveys on Thompson Island or in the immediate area. More information relative to the Thompson Island site should be obtained with the aid of geophysical surveys and borings in selected locations. (see Appendix)
Figure 4. Map of Available Eologic Profiles of Boston Harbor.
CHAPTER 2

UNCONSOLIDATED SEDIMENTS WITHIN BOSTON HARBOR

The most prominent sedimentary feature of the Boston Basin is the existence of a vast deposit of soft clay known as the Boston Blue clay. This blue clay is a still water deposit whose thickness ranges from 2 feet to over 200 feet. It is often separated from bedrock by thin layers of sand, gravel, or glacial till, and in some areas there are thin layers of sand, gravel, or silt within the clay.

The upper layer of the blue clay has been oxidized to form a generally firmer yellowish clay, referred to by Boston engineers as "the stiff crust." This oxidation is believed to have taken place at a time when much of the harbor bottom was above sea level. There has since been a general subsidence of the entire Boston Basin area, with a subsequent rise in sea level. (Marmer, 1944)

Above the yellow clay lies a thin (5 feet to 10 feet in most places) layer of organic silt covered by mud. This mud is of the black, carbonaceous variety. The high organic content of this mud is generally attributed to the many sewer outfalls in and near Boston Harbor. (Mencher, Copeland, and Payson, 1968) This mud is extremely soft and compressible and is generally incapable of supporting structures or landfill. (See p. 21.) This mud often contains trapped gases, making it a reflector of seismic waves. This property makes some methods of seismic study impossible, notably the electronic pinger method developed by Dr. Harold Edgerton of M.I.T. (Payson 1963)

The normal thickness of these mud deposits is less than 15 feet. However, in the Dorchester Bay area these mud deposits average about 20 feet in thickness (Barlow, 1966), and the thickest mud beds (40 feet) in the inner harbor are found in the Neponset River Channel, just west of Thompson Island.
Figure 5 shows a hypothetical sedimentary section which might appear in Boston Harbor. While this section is "typical" of the harbor deposits, it should not be taken to represent any particular area. Figure 6 shows some actual sections drawn from borings previously taken within the harbor. These sections are located on a map in Figure 7.

From data obtained in the Boston Common area, Kaye (1961) concludes that four layers of glacial drift were deposited, separated by three layers of marine clay. He takes the bottom layer (Drift I) to be till of the Kansan or Nebraskan era, Drift II to be till, clay and gravel outwash of the Illinoian era, Drift III to be drumlin till of the Early Wisconsin era, and Drift IV to be outwash of the Late Wisconsin era.

Using this information the following stratigraphic history has been inferred (Phipps, 1964). The initial advance of the ice sheet deposits the ground moraine. The ice sheet retreats and local outwash sand, gravel and clay are deposited and subsequently oxidized, followed by widespread deposition of clay. The ice sheet readvances, depositing till, and retreats, allowing another extensive layer of clay to be deposited. The final outwash layer is deposited, possibly by another advance of the ice sheet. The land is then elevated and eroded, bringing us to the present.

Thompson Island itself is of glacial origin. The northern half of the island, that occupied by the Thompson Academy, is a drumlin resting in till. The southern half appears to be a gravel outwash which extends at least to the mouth of the Neponset River. The surficial deposits surrounding Thompson Island are mostly mud with some sand and gravel. There are large pebbles and cobbles on most of the beach surrounding the island, and there are extensive clam beds on the southern and western beaches.
Figure 5. Hypothetical Section Showing Relationship of Unconsolidated Sediments.
Figure 6a. Section in Dorchester Bay from Old Harbor towards Thompson Island.
(After Phipps, 1964)

Figure 6b. Section along Causeway from Moon Island to Long Island
(After Phipps, 1964)
Figure 6c. Section through Fox Point to Squantum Point. (After Phipps, 1964)

Figure 6d. Section in Dorchester Bay; Mt. Vernon to Thimble Island. (After Phipps, 1964)
Figure 6e. Section extending southwards from Castle Island
(After Phipps, 1964)
Figure 7. Locations of Sections in Figure 6.
(The shellfish are of no commercial value due to the pollution of the harbor. The U.S. Department of Public Health prohibits shell fishing in polluted waters, including specifically the beaches on Thompson Island.) Again, there is virtually no information cataloged on the Thompson Island site except what can be obtained visually. It is hoped that the seismic survey described in the appendix will be carried out in order to provide the necessary information.
CHAPTER 3

BOTTOM TOPOGRAPHY, WATER DEPTHS, AND TIDES

The upper surface of the Boston Blue clay is highly irregular, showing a relief of over 100 feet within the harbor. The bottom topography around Thompson Island is somewhat less irregular, with broad tidal flats to the east and south, and shallow water to the southwest of the island. There is a deep channel to the west and northwest (from the Neponset River) and a valley between Thompson Island and Spectacle Island. (see Figure 8) With the exceptions of this channel and valley, the bottom surrounding Thompson Island stands on a very shallow, even slope.

The highest tide ever recorded in Boston Harbor reached 15 feet above mean low water. (Mean low water equals +0.8 feet, Boston City Base.) This tide was caused by the simultaneous occurrence of an unusually high astronomical tide and a strong onshore storm breeze. (Minots Ledge storm, 6 April 1951)

The Beach Erosion Board of the U.S. Army Corps of Engineers has studied the effect of prolonged high wind upon the tide in Boston Harbor. (Metcalf and Eddy, 1963) They estimate a sustained wind of 100 miles per hour will produce a storm tide of 6.0 feet +1.5 feet (local variations). For an 80 mile per hour sustained wind they estimate a storm tide of 4.0 feet +1.0 feet. Metcalf and Eddy also report the highest waves expected in the inner harbor are 1.5 to 2 feet, crest to trough.

Tidal information is of utmost importance in determining the minimum "safe" elevation for a filled land surface. Ideally, tides and waves should never be allowed to inundate the area chosen for development. However, the cost of filling land to a higher elevation is sometimes greater than the cost of damage from occasional flooding.
Figure 8. Water Depths at Thompson Island. (in feet, 0 = mean low water.)
Two other effects need to be considered before a safe elevation can be determined. First, waves approaching a sloping beach front may run up the beach to an elevation considerably higher than that of the approaching wave. The run-up factor is very dependent upon local topography and is best determined empirically rather than predicted. Generally the run-up factor is higher for a gentle slope than for a steep slope. This factor varies from about 1.5 to 3 for most beaches.

The second effect to be considered is the rising trend in mean sea level at Boston. It is not certain whether the mechanism for this is the melting of the ice caps, subsidence of the coast, or both, but the effect is the same in either case. (Marmer, 1944) The observed rate of rise is currently about 0.02 foot per year, or about 1 foot in 50 years. (Metcalf and Eddy, 1963)

Tides of 15 feet or more (BCB) represent a worst case situation (simultaneous occurrence of high astronomical tide plus storm tide) which occurs very infrequently. During the period 1921 to 1960, the tide in the harbor reached +14.0 feet (BCB) seven times, but it reached +15.0 feet (BCB) only once. (Metcalf and Eddy, 1963) If we add to this 1.5 feet of free board for wave run-up plus a 2 foot allowance for the change in sea level over the next 100 years, we obtain an elevation of 18.5 feet (BCB) necessary to provide good protection from the sea. If, on the other hand, we choose to provide complete protection from the sea, we must allow for the simultaneous occurrence of maximum astronomical tide (about 13 feet), maximum storm tide (an additional 6 feet for 100 mph winds), and maximum wave run-up (about 3 feet for steep slopes). To this we must add the 2 feet for changing sea level. Thus, an elevation of +24 feet (BCB) would provide absolute protection from the sea. The question which remains is whether the cost of an additional 5.5 feet of filled land is justifiable compared to the expected cost of repairing occasional flood damage.
CHAPTER 4

FILL MATERIALS AND PROCEDURES
LOCATION OF BORROW AREAS

The exact type of material needed for a particular land fill depends upon the use to which the new land is to be put. In an area which is to support high rise apartments with massive utilities services, small amounts of settlement in land fill can seriously damage the utilities connections, particularly if the settlement is non-uniform. However, in areas designated for playgrounds or one story dwellings, the expected load upon the filled land is much smaller, and settlement would not be expected to have a serious effect. Generally, coarse granular materials such as clean sand and gravel are much less compressible than materials such as clay, silt, mud, etc., and are less likely to cause settlement than are the latter materials. Thus, Boston Blue clay would be adequate fill material for a proposed airport or recreational area, but not for an urban complex.

Another source of potential settlement is the condition of the base material and sub-soil upon which fill is to be placed. An area containing thick beds of soft clay and mud overlying deep bedrock will settle more than an area containing sand and gravel overlying shallow bedrock. Soft black mud is particularly undesirable as a surface deposit since it is easily displaced by the weight of the fill material. (see Figure 9.) In general, it is advisable to remove thick mud deposits before placing fill. (Casagrande, 1949)

For the purpose of filling land in a water environment it is usually less expensive to transport the fill material hydraulically from another water environment (or to barge the material if pumping is not feasible) than to transport the material overland. (Prof. F. Moavenzadeh of
Figure 9. Comparison of Anticipated and Developed Profiles through Runway Embankments at Logan Airport, Showing Effects of Soft Mud. (After Casagrande, 1949.)
M.I.T. is currently investigating new techniques used by the Penn Central Railroad to transport earth and ores, but these studies are not yet complete. However, it is not always possible to find adequate amounts of fill material near the area to be filled. There is a large supply of clay located in and near Boston Harbor, where it may be placed at a cost little more than the cost of dredging the harbor bottom (though dredging may be prohibited in certain areas). However, there seem to be no extensive sand or gravel borrows within the harbor area. From his surveys of the New England coastline, Mr. Carl Hard of the U.S. Army Corps of Engineers reports there are no large sand or gravel deposits closer than Cape Ann to the north or Plymouth to the south. He added that there are closer borrow areas, but they probably do not contain enough material for our purposes (we estimated 10 million cubic yards of fill for the Thompson Island Site), and at the current rate of consumption by builders, sand and gravel companies, etc., these nearby borrow areas are very likely to be exhausted in the near future. (see Figure 10)

Hydraulic transport of fill material essentially requires a pipeline from the borrow area to the fill site. Over long distances this pipeline can become expensive and difficult to maintain. Mr. Hard suggested that we barge the fill material from one of the large borrow areas, loading the barges by the hydraulic dredge method. He added that we might avoid the task of dredging the surface mud from the Thompson Island site by dumping the fill in a small local depression off shore (to form a temporary storage area), pumping the fill on to Thompson Island, and finally pushing it into place with bulldozers, displacing the mud as the fill is placed.

This "displacement technique" was discussed separately with Dr. Aldrich of Haley and Aldrich, Inc., and Mr. James Reynolds of Hayden, Harding, and Buchanan, Inc. Both
Figure 10. Locations and Distances to Possible Sources of Sand. (After Massachusetts Airport Development Co., 1968)
gentlemen felt there was considerable danger of trapping pockets of mud which could later cause severe local settlement. In addition, the rapid displacement of large quantities of mud could result in a "mud wave," which might impair some of the local waterways (small boat channels) and cause severe local pollution of the water, if only temporarily. Mr. Reynolds recommended dredging the mud (the problem of where to dispose of the mud remains to be solved) and dumping barged fill directly into place.

Mr. Kaye of the U.S.G.S. pointed out that perhaps some of the material from the gravel outwash around the southern end of Thompson Island might be utilized for fill. While there is record of this gravel layer in the boring log prepared by the Boston Society of Civil Engineers (1961), the extent and volume of the gravel bed are unknown. When asked about the feasibility of using this material, Mr. Reynolds of Hayden, Harding, and Buchanan commented that if the gravel were clean (less than 10% silt), the overlying mud might be dredged off and the gravel pumped into place at a cost considerably less than that of barging fill from Cape Cod.

Unfortunately, there are many uncertainties about this gravel outwash. Extensive surveying and boring would be necessary to accurately determine the volume and location of this bed. In addition, large samples need to be obtained and inspected to determine whether or not the gravel is clean enough to be used as fill. (These two steps are generally advisable before removing fill material from any source, but they are easier and less expensive in areas where the proposed fill is not covered by thick mud deposits.) Finally, a thorough investigation into the effect of removing material from this bed is necessary to insure that no damage to the present Quincy shore line would result if this source were used.
CHAPTER 5

COST OF FILLING LAND AROUND THOMPSON ISLAND:
RESTRICTIONS ON FILL AREAS

Before determining the cost of land fill in the harbor it is necessary to establish the type of fill to be used and the desired final elevation of the filled surface. In Chapter 3 two minimum safe elevations were obtained; +24 feet (BCB) was found to give absolute protection from the sea even under worst possible conditions, while +18.5 feet (BCB) was found to provide adequate protection except under occasional severe storm conditions. Separate costs will be computed for these two elevations.

As mentioned in Chapters 1 and 2, granular fill material is generally superior to clay and mud fill materials, but granular material is also much more expensive to place. Clay fill generally requires piles to support building foundations. As the clay consolidates its volume decreases. If the clay shrinks around a pile, it may come to rely upon the pile for support, instead of lending frictional and buoyant support to the pile. This effect, known as negative loading, may cause failure of the pile unless the pile was designed to support the additional load. (see Figure 11) On the other hand, well placed granular fill will usually support foundations and utilities without piles. Thus, the final decision to use sand or clay should not rest solely upon the initial cost difference of placing the fill. For the purposes of this report, both granular fill and clay fill will be considered.

The cost of placing clay fill is essentially the cost of dredging it from the harbor bottom. Hydraulic dredging costs $0.50 per cubic yard if the dredged material is to be pumped less than 10,000 feet. If the material is to be pumped between 10,000 feet and 20,000 feet an auxilliary
Figure 11. Negative Loading.
booster must be used, raising the price to $1.20 per cubic yard. The cost of placing granular fill barged from a borrow area 40 miles away (approximate water distance to Plymouth, Massachusetts) is about $2.50 per cubic yard. These figures were quoted by Mr. John Podger of Metcalf and Eddy, Inc., and are based on that firm's recent study concerning an extension of Logan Airport. The figures include the cost of dredging, transporting, and placing the fill, plus the contractor's profit and contingencies. They do not, however, include any fees paid to the owner of the borrow site (if privately owned). Some approximate cost estimates were obtained from other engineering firms, but Metcalf and Eddy appear to have the most definitive analysis of current prices.

When the added burden of fill material is placed upon a thick clay deposit, the clay can be expected to consolidate, shrinking as water is squeezed from the pore spaces. The amount of settlement can be calculated with the aid of the following equations (Terzaghi and Peck, 1967, pp. 72,73):

\[
S = H \frac{C_C}{1 + e_0} \log_{10} \left( \frac{P_0 + \Delta P}{P_0} \right)
\]

where \(S\) is the total amount of settlement (change in the thickness of the clay deposit, in cm), \(H\) is the total unloaded thickness (cm) of the clay deposit, \(e_0\) is the natural void ratio, \(P_0\) is the pressure (gm/cm\(^2\)) upon the clay before the fill is deposited, \(\Delta P\) is the incremental pressure (gm/cm\(^2\)) added by the fill material, and \(C_C\) is given by

\[
C_C = 0.009 (L_w - 10\%)
\]

where \(L_w\) is the liquid limit of the clay. (The last equation holds only for clays which are naturally loaded, that is, for clays which have never experienced a pressure
greater than the expected load, \((P_0 + \Delta P)/P_0\). This is a fair approximation for the Boston Blue clay, but not for the yellow clay. The yellow clay behaves much like a preconsolidated clay and shows little or no settlement under moderate loads.)

The parameters \(e_0\) and \(L_w\) may be found from tables, and \(\Delta P\) may be calculated from the wet and dry densities of the fill material. However \(P_0\) cannot be calculated without knowledge of the density and thickness of deposits overlying the clay. Also, the thickness of the clay bed (\(H\)) must be known in order to determine the expected settlement. Thus, settlement may not be accurately determined without detailed geologic information.

If the geology of the area can be inferred from the geology of adjacent areas, some estimate of settlement can be obtained. Figure 12 is an attempt to estimate bedrock contours under Thompson Island from material presented in Figure 3. However, the northern part of Thompson Island is a drumlin resting in glacial till. Many of the drumlins in Boston Harbor are reinforced by rock cores (diabase dykes) which extend down into bedrock. (LaForge, 1932) In addition, glacial till is often found directly above bedrock. (see Figure 6d) If this is true at Thompson Island, the estimated bedrock contours in Figure 12 would seem grossly incorrect. The additional uncertainty regarding sediments overlying bedrock make any settlement calculations hopeless. Until geophysical surveys (or borings) are performed on the Thompson Island site, no meaningful settlement calculations can be performed.

Unless the fill is contained by dykes or dams, it will come to rest on a natural slope determined by the properties of the material used. (see Figure 13) Generally, sand can be safely placed on a slope of 1 to 4; hydraulic clay will stand on a slope of 1 to 20, provided
Figure 12. Estimated Bedrock Contours Under Thompson Island.
Unconsolidated material will not stand with vertical sides...

But will form a broad cone, with sloping sides.

1:4 slope as described in text.

Figure 13. Unconsolidated Soils Come to Rest with Sloping Sides.
all soft surface mud is removed before the fill is placed. (Casagrande, 1949) These slopes will be used to determine the cost of filling land around Thompson Island. Where fill costs are determined on a contour basis (as in Figure 16), the cost of the material necessary to maintain a slope must be included in the cost of the particular strip of land it supports. (see Figure 14)

Artificial dyking could be built in areas where it is desired to contain the fill on steeper slopes. Dykes are usually built on a slope of 1 to 4, yielding no improvement over the free standing slope of sand fill. This would, however, be a substantial improvement over the free standing slope of hydraulic clay fill. (see Figure 15)

Figures 16 (a,b,c, and d) show the calculated cost per square foot of filled land contoured around Thompson Island. Figures 16a and 16b represent barged sand at $2.50 per cubic yard filled to elevations +18.5 feet and +24 feet (BCB) respectively. Figures 16c and 16d represent hydraulic clay at $0.50 per cubic yard filled to similar elevations. These costs (Figure 16) include dredging a layer of mud 5 feet thick (average) from the fill area before the fill is placed, again at a cost of $0.50 per cubic yard. No allowances have been made for settlement of the sub-soil or for compaction of the fill (clay).

It is expected that any fill operation within the harbor will have some effect upon water circulation there. When asked specifically about water pollution, Mr. Hard of the Army Corps of Engineers stated that he did not expect any pollution problems to result from land fill around the harbor islands, provided we did not close off any waterways between the islands and the mainland. He suggested, however, that we consult the Department of Waterways when we had more specific plans for land fill areas. In addition, we expect some advice from other members of the M.I.T. faculty concerning the matter of pollution in the harbor.
The cost of section A₁ should be included in the cost of filling area A, not in filling area B. Thus, the large area C₂ is absorbed in the cost of fill area C only, not in the rest of the entire fill.

Figure 14. The Cost of Sloping Land Fills.
Figure 15. The Use of Dyking to Contain Fill Materials.
Figure 16a. Cost per Square Foot of Land Filled with Sand to Elevation + 18.5.
Figure 16b. Cost per Square Foot of Land Filled with Sand to Elevation + 24.0.
Figure 16c. Cost per Square Foot of Land Filled with Clay to Elevation + 18.5.
Figure 16d. Cost per Square Foot of Land Filled with Clay to Elevation + 24.0.
Mr. Hard added that the Corps of Engineers was more concerned that we do not obstruct or interfere with the navigable channels within the harbor. He specifically advised us to stay clear of the "President Roads" area. Plans call for future widening and deepening of this channel. He also suggested that we respect the many channels used by private boats and pleasure craft.

This last point may be significant with respect to the channel bordering the west side of Thompson Island. Due to the steep slope of the off shore region, fill material may tend to slump down into the channel, with severe consequences for any building bordering the filled shore line. Dykes or retaining walls would help prevent this situation, but their cost may not be justified in view of the comparatively small land area available.
CONCLUSIONS AND RECOMMENDATIONS

The most salient feature of this report is the lack of specific information concerning the geology of Thompson Island. All too often architectural designs are developed (often at great expense) without sufficient prior knowledge of the ground upon which structures are to be placed. Until some type of organized geophysical survey is performed, no reliable engineering information can be obtained.

The cost of granular fill is probably too great for the average community development. Thus, more information relative to piles and dyking will probably be needed in the near future. Some form of dyking or retaining wall will be definitely needed if the area west of Thompson Island (near the Neponset River Channel) is to be filled. In this area the slope of the bottom (1:10) leading to the channel is greater than the maximum slope on which hydraulic clay will safely stand. For this reason I cannot recommend extending Thompson Island in this direction.

The most reasonable areas to consider for filled land appear to be the broad, flat areas to the southeast and to the southwest of the island. The water here is quite shallow and the bottom is nearly horizontal. It appears that hydraulic clay could be made to stand here without the need for dykes. In addition, the rock outcroppings at Squantum Point and at Moon Head give some hope that the bedrock may be relatively shallow in these areas.
BIBLIOGRAPHY

Barlow, DeWitt D., Jr., Personal communication with Mr. Martin Adler of the Boston Redevelopment Authority, April 20, 1966.


Boston Society of Civil Engineers, (1961), Boring Data from Greater Boston, published by the Boston Society of Civil Engineers, Boston, Massachusetts.


Massachusetts Airport Development Company, (1968), An Investigation of a Possible Harbor Location of an Airport for Boston, (unpublished).


Metcalf and Eddy, Notes From Downtown Waterfront Corporation Flooding Study (unpublished), October 22, 1963.


Reply to Professor Fred Moavenzadeh
Room 1-171

Mr. Charles Hilgenhurst
Director of Urban Design
Boston Redevelopment Authority
City Hall Annex
Boston, Massachusetts

Dear Mr. Hilgenhurst:

In order to have a better understanding of the geologic and soil conditions in the vicinity of Columbia Point and Thompson Island, Messrs. David Hughes and Richard Edmunds of our group met with Messrs. D. Holt and V. Murphy of Weston Geophysical Engineers, Inc., to discuss costs and scheduling of seismic surveys for the area surrounding Thompson Island, in Dorchester Bay. It was agreed that seismic profiles on the perimeter of the island and the [-6] foot elevation contour (referred to mean low water) would adequately define the area of interest, and that profiles spaced every 500' in the mud flats to the southeast would give extensive coverage of that area. (See Figure 1). Weston Geophysical Engineers' rough estimate of costs is:

1) $1,000 preliminary surveying to accurately locate the profiles.
2) $10,000 actual seismic profiles and interpretations.
3) $3,000 for boat rental (required for offshore profiles).

Thus a conservative estimate of $14,000 to $15,000 total for the job was obtained. Mr. Holt stressed that this could vary somewhat depending upon the exact bottom configurations.

For 1000' separation of profiles in the mud flats instead of 500' (Delete dashed line in Figure 1), the total cost was estimated at $11,000 to $12,000.

Mr. Holt commented that under their present workload they could begin work about two weeks after receiving a definite commitment. The total time from beginning to final report should be about one month, though data and preliminary information could be presented on a day-by-day basis as it is received. The information to be received from this type of survey includes depth to bedrock and depth and thickness of clay and unconsolidated deposits. As we have previously agreed, this information is vital in determining the type of foundations.
which are necessary for a building project in this area, the feasibility of driving piles, and the expected settling of filled land.

As noted in figure 2, we already have some definite information concerning depth to bedrock in the Columbia Point Area. The Boston Boring Log gives a fairly extensive account of the sedimentary deposits to be expected in this region. In addition, Boston Edison has extensive seismic information in the Squantum Point area and throughout much of the Neponset River Estuary. I believe Weston Geophysical has done this work, but they are bound by Edison not to divulge their findings. However, perhaps Edison would allow this material to be released to the BRA.

It is essential that information of the type discussed with Weston Geophysical be obtained before reliable engineering work can be done relating to cost and type of fill, foundations, and utilities placement. In view of the magnitude and time schedule for the BRA project, the original proposal for 500 foot spacing of profiles in the mudflats would seem advantageous. This would give more resolution than 1000 foot spacing, and would avoid more expensive and time consuming resurveying of the area, should this information become crucial at a later date. The additional expenditure ($14,000 to $15,000 versus $11,000 to $12,000) seems justifiable at this time.

Please let me know if your office is interested in conducting this survey in the future. We will be very glad to contact Weston Geophysical Engineers for more accurate cost and job definitions.

Sincerely yours,

Fred

Fred Moavenzadeh
Associate Professor
Department of Civil Engineering

cc
FM: cw
Fig. 1 Proposed Seismic Profiles