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Consolidation characteristics of polluted sea bottom sediments

Les caractéristiques de la consolidation des sédiments maritimes pollués

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SYNOPSIS The contribution of polluted sea bottom sediments to environmental problems and investigation of possible methods of disposal for such sediments in shallow waters has become a major problem of concern in many parts of the world. This paper outlines the findings of an investigation carried out on Golden Horn bottom sediments. The organic content and the putrescibility index of the sludge samples studied are found to be higher than those encountered in similar places. The geotechnical investigations have shown that these sediments consist of fine grained soils of very high water contents and upon consolidation in a slurry consolidometer, block soil samples of medium consistency with high compressibility could be obtained. Also, it has been experimentally observed that a marked decrease in putrescibility index of the samples took place during consolidation.

INTRODUCTION

The Golden Horn bay in the city of Istanbul is a long and narrow waterway dividing the city, and the area is a site of many historic monuments as well as being a densely populated residential and industrial region. In past centuries (the days of Ottoman Sultans), the region used to be a recreational area with its picturesque surrounding. Since the turn of the century, it has been victim of over-population and uncontrolled industrial development. Today, it has long lost its beautiful image and is a typical case of man's destruction of its environment. It is been largely filled with eroded material from surrounding hills and disposal of waste, and it is highly polluted.

The area has unique soil conditions and the associated geotechnical problems have been reported elsewhere (Peynircioğlu, 1961, 1965, 1973; Togrul, 1975; Kumbasar et al., 1976). The present investigation was carried out to study the contribution of sea bottom sediments on the pollution problem and to study the methods of disposal for these sediments. This paper primarily deals with the consolidation behavior of these bottom sediments and associated changes in their geotechnical properties. Sea bottom sediments from various points along the Golden Horn have been tested in the laboratory and the results are presented herewith.

GEOLOGY

The geology of Golden Horn area has been the subject of many investigations (Ketin, 1953; Maden, 1975; Sayar, 1976). The southern shores Golden Horn are gently sloping to heights of 40-60 m, whereas the northern shores have steeper slopes reaching to 80-140 m heights. The oldest formations of the area consist of graywacks, clayey schists and limestones belonging to Upper Paleozoic. On this base, at

higher elevations sand, gravel, clay and marl series of Neogene age are encountered. The area has been affected by Hersinien and Alpine tectonic movements. Graywacks and clayey schist have been subject to different degrees of weathering on the surface. Aluvial deposits at the basins of Alibey and Kagithane streams flowing into the bay, and aluvial deposits of marine origin encountered along the shores and basin of Golden Horn constitute the youngest sediments of Quaternary age in the area. Along the shores a fill layer decreasing in thickness towards inlands covers the aluvial deposits.

Because the surrounding slopes are not protected, fine sand and silt size particles from the weathered graywacks and schists are carried by erosion into the bay. In addition, large quantities of sewage, solid waste and industrial pollutants have been disposed into the bay for a long period of time.

SOIL PROFILE AND THE GEOTECHNICAL PROPERTIES

In the vicinity of Golden Horn, the ground surface is covered with a fill layer of varying thickness composed of sands, silts, clays, gravels and boulders, bricks as well as organic materials. Underneath the fill layer, a brown highly plastic residual silty clay layer whose thickness decreases from end to the mouth of the bay is encountered. Below this formation, the most typical soil formation of the area, the Golden Horn clay, a gray silty clay of marine origin with shells and a large organic content is found. The thickness of this formation varies from 0-6 m at the end to 35-40 m towards the mouth of the bay. The base rock in the vicinity of Golden Horn consist of clayey schists and graywacks, the upper elevations of which are weathered and have surface slopes varying between 20° - 60°. Figure 1 illustrates a typical soil profile across the Golden Horn.

TABLE I
Average Geotechnical Properties of Soil Layers

	w_L (%)	w_P (%)	w (%)	c_u (kPa)	m_v (kPa) ⁻¹	c_v (m ² /s)
Brown Residual Clay	50	27	34	50	3.0×10^{-4}	4×10^{-8}
Soft Gray Clay	70	35	60	25	6.5×10^{-4}	7×10^{-9}

Table I summarizes the average geotechnical properties of soil formations.

In the bottom of the bay itself, a very thick accumulation of fine silts and clays due to erosion from the surrounding slopes and two small streams that used to flow into bay (a recently built earth dam now controls their flow), plus discharge of sewage lines, solid and industrial wastes constitutes a slurry like sediment which has very high organic content and rich in pollutants. From the end of the bay up to about one third of its length the thickness of the bottom sediments reach to less than 1 m from the water surface and it decreases towards the mouth of the bay. Golden Horn bottom sediments are in the consistency of a slurry to very large depths, increasing in density and consistency gradually, and with their high contents of organic materials and pollutants they not only hinder navigation but also pose grave environmental problems.

POLLUTION CHARACTERISTICS OF SEA BOTTOM SEDIMENTS

Several investigators studied the environmental aspects of Golden Horn sea bottom sediments (Karpuzcu and San, 1975; Baykurt, 1976; Orhon, et.al., 1978). Measurements of samples from these sediments indicate very high concentrations of organic materials (between 10% - 30%) and heavy metals (Cu: 40-50 ppm, Zn: 150-200 ppm, Hg: 10-20 ppm, Pb: 60-70 ppm, Cr: 70-80 ppm). In this investigation, primarily the effect of bottom sediments on pollution of the sea water and sediment-water interactions were studied. In this respect, particular attention was paid to determination of soluble phosphorus and nitrogen transport and organic matter concentrations as well as benthic oxygen demand potential. Table II summarizes the pollution

TABLE II

Pollution Characteristics of Bottom Sediments

Solids Ratio (%)	31-66
Organic Content (%)	9-32
Putrescibility Index (mg O ₂ /g dry wt.)	13-94
Putrescibility Index After Consolidation (mg O ₂ /g dry wt.)	7-13
PO ₄ -P (mg/g dry wt.)	0.10-0.40
NH ₃ -N (mg/g dry wt.)	0.30-7.50

characteristics of bottom sediments. Also, laboratory model test were carried out to study the pollution potential of these sediments on the water above them. In these experiments, the variations in concentrations of suspended solids in water, free oxygen and putrescibility index have been measured for a period of 6 months under laboratory testing conditions. The analysis of the results of these experiments are beyond the scope of this paper, but it can be safely concluded that the pollution potential of these sediments (with respect to sediment-water interaction) is markedly decreased with consolidation pressure and time.

SLURRY CONSOLIDATION OF SEA BOTTOM SEDIMENTS

Taking into account the possibility that the sea bottom sediments may be dredged and deposited behind dikes on shores, the consolidation behavior of bottom sediments from Golden Horn and the associated changes in their engineering properties have been investigated. The bottom sediments are first consolidated in a slurry consolidometer. The settlement-time and void ratio-pressure relationships are experimentally determined. Then the block soil samples obtained

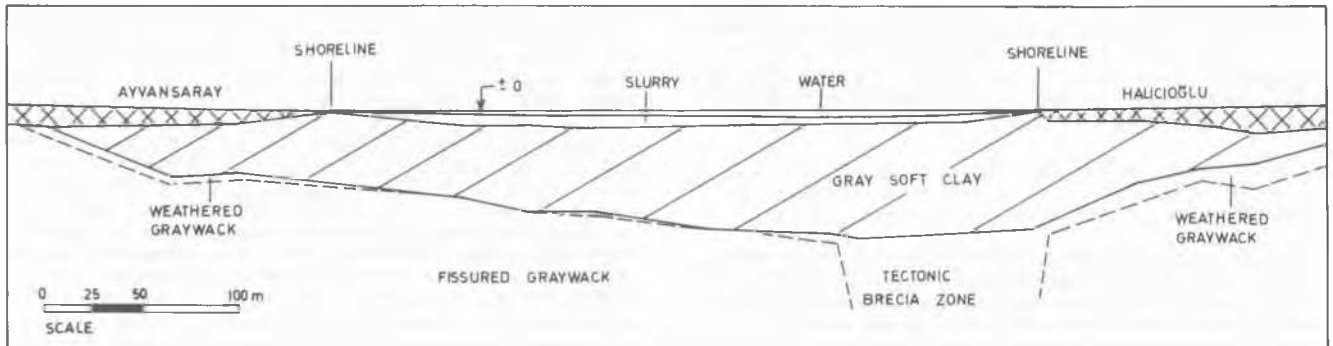


Fig.1 - A Typical Cross-Section Across the Golden Horn (Maden, 1975)

after slurry consolidation are subjected to testing to determine their shear strength and compression behavior.

Figure 2 illustrates the void ratio-consolidation pressure variations observed in slurry consolidation tests. It is observed from the

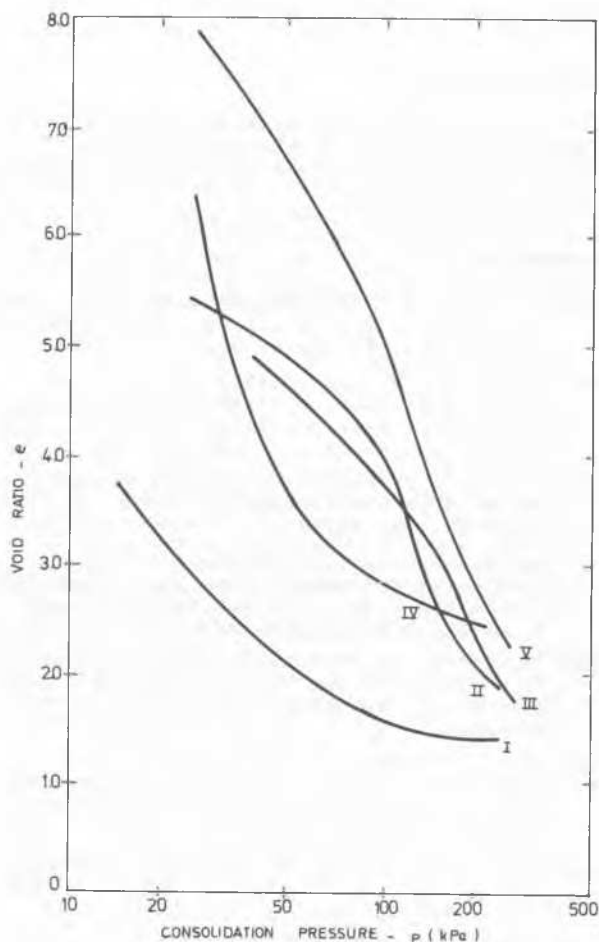


Fig.2 - The Void Ratio-Consolidation Pressure Variations Observed in Slurry Consolidation Tests

results of these tests that under 100 kPa consolidation pressure the average values of coefficient of volume change, m_v is about $2 \times 10^{-3} (\text{kPa})^{-1}$ and coefficient of consolidation, c_v is about $5 \times 10^{-8} \text{ m}^2/\text{s}$. An interesting (may be peculiar) observation from the results of these tests has been the change in degree of saturation during consolidation. In contrast to what would be expected, the degree of saturation has decreased during the slurry consolidation of these sediments rather than increasing. This is attributed to high organic content of these sediments and the release of gases by decay of organic material as well as the oxygen uptake of the mud from the water in the slurry during the consolidation period (about 2 months). It has been experimentally determined that a marked

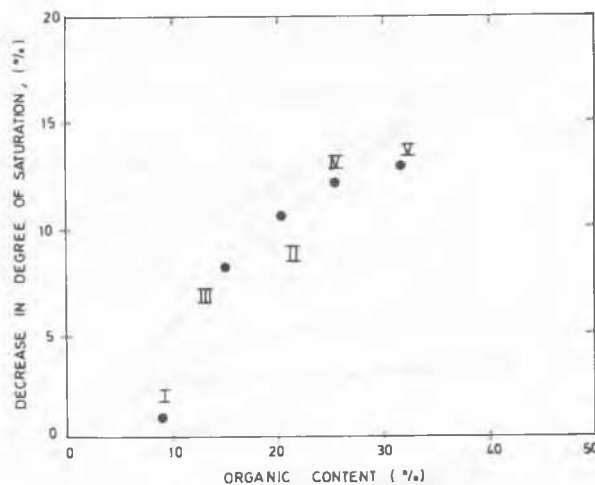


Fig.3 - The Decrease in Degree of Saturation During Slurry Consolidation

decrease in putrescibility index of the specimens took place during consolidation. Figure 3 illustrates the decrease in degree of saturation during consolidation with respect to organic content.

The block soil samples obtained from the slurry consolidation of bottom sediments have been tested to determine their shear strength and compression properties. Due to the limited number of specimens that could be prepared from these samples, their shear strength were determined only by unconfined compression and vane tests. Even though there is some scatter in data due to presence of fibrous materials in the specimens tested, the undrained shear strength/consolidation pressure (c_u/\bar{p}) ratio seems to vary linearly with the plasticity index, the average value being about 0.23. The slurry consolidated samples were also tested in the oedometer device to investigate their compression behavior. Figure 4 illustrates void ratio-consolidation pressure relationships obtained in these experiments. From the results of oedometer tests, it is observed that the average compression index for these slurry consolidated soils is around 1.0. Variation of average values of coefficient of consolidation and coefficient of volume change with consolidation pressure during recompression of slurry consolidation are shown in Fig.5.

CONCLUSIONS

Sea bottom samples taken from representative sections of Golden Horn are studied for their pollutional and geotechnical properties. The organic content and putrescibility index of these sediments are found to be considerably higher than those commonly encountered in similar places. Also, the high magnitude of soluble phosphorus and nitrogen transported to the main body of water from the sediments is found to closely depend upon the hydraulic regime of the medium. Experimentally determined geotechnical properties indicate that these sediments generally consist of fine grained

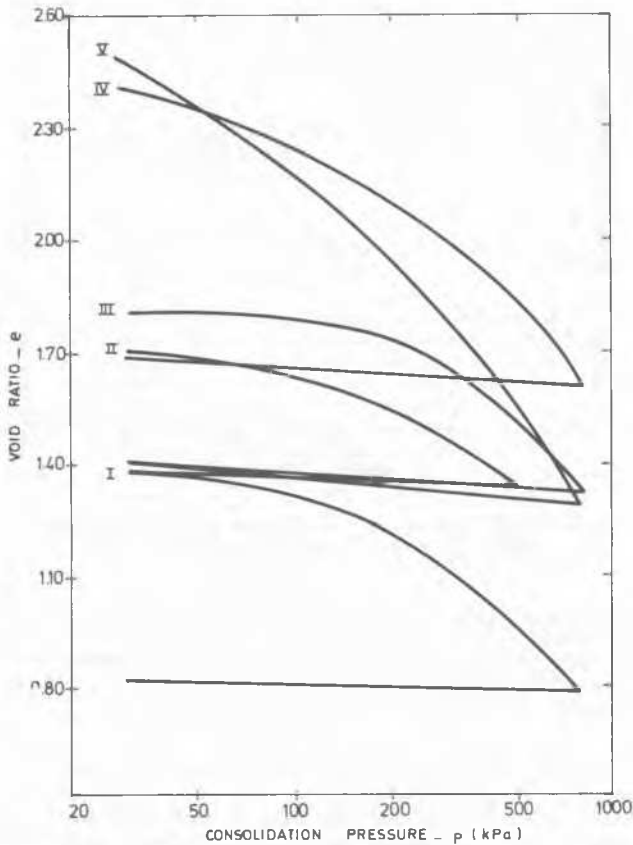


Fig.4 - The Void Ratio - Consolidation Pressure Variations During Recompression of Slurry Consolidated Samples

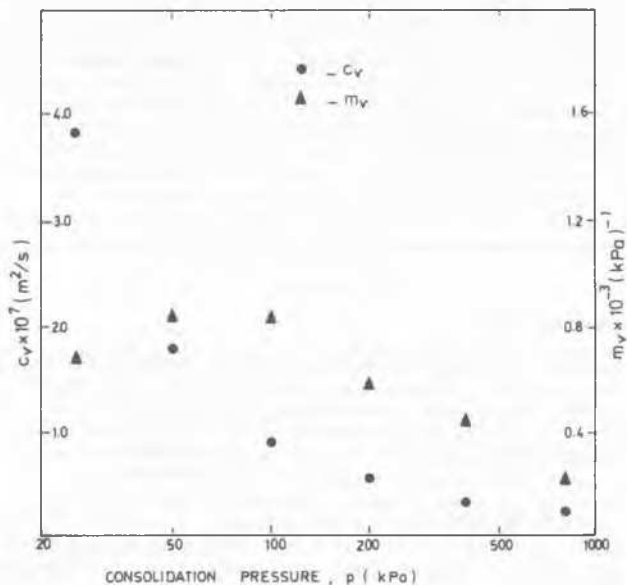


Fig.5 - Variation of Average Values of c_v and m_v With Consolidation Pressure p

soils. Their consolidation behavior studied by slurry consolidation have shown that, under suitable drainage conditions relatively thick layers of these bottom sediments can be consolidated in reasonable periods of time. Experimental results indicate that upon consolidation under final pressures of between 200-300 kPa, soil layers of medium consistency with high compressibility can be obtained if the dredgings of these sediments are stored behind dikes on shore.

ACKNOWLEDGEMENT

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