Characterisation of the Reclaimed Soils in the Foreshore Area of Manila Bay, Philippines.

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Abstract: Manila Bay is one of the finest natural harbours in the world, with Metro Manila developed along the east side of the Bay. Metro Manila is heavily developed and, since it is confined between Manila Bay and a freshwater lake, Laguna de Bay to the east, available real estate is limited. One of the ways of providing valuable real estate to the area has been to reclaim the foreshore area by dredging marine sediments from the Bay to the shallows on the foreshore of the Bay. A significant amount of reclamation has already taken place and more is planned. Development on this reclaimed land includes commercial, residential and transportation projects.

The entire Philippine Archipelago is within an active seismic area and there are active faults present close to the Bay. A recent example is an earthquake in December of 1999, which measured 6.8 on the Richter scale and caused minor damage to some office buildings within the reclaimed area.

Investigations have recently been carried out for a 12-km extension to the existing Manila Light Rail Transit system, some of which is constructed on reclaimed land. To minimise land use, the new guideway will be elevated throughout most of its length, generally with single columns between spans. Each column will be supported on a single large diameter caisson, carrying the loads through the reclaimed fill to the weak tuff bedrock below.

The site investigations comprised boreholes, SPT's, CPT's, pressuremeter tests, and laboratory tests.

In this paper, the geology of the Manila Bay area is discussed briefly and the results of the site investigations are presented. The reclaimed and underlying materials are then classified in terms of their index properties and strength and settlement characteristics. A case history describing a structure founded on diaphragm walls and barrettes is also referred to, in order to illustrate the foundation conditions and some of the difficulties of construction in these materials.

Introduction

Fig. 1 shows Manila in plan. The Bay area can be seen to the West of Metro Manila and Laguna de Bay can be seen to the east. The approximate extent of the reclaimed land is shown in heavy outline.

Investigations for a 12-km extension to the existing Manila Light Rail Transit system, Line 1 have recently been carried out. The proposed alignment of this LRT Line 1 Extension runs on the reclaimed land and this is also shown in Fig. 1. In order to minimise land use, the new guideway will be elevated along most of its length, generally with single columns between spans, very similar to the RTP 2000 line currently under construction in Vancouver. Each column will be supported on a single large diameter caisson, carrying the loads through the reclaimed fill and weak Bay Mud to the underlying weak tuff bedrock.

The site investigations consisted of wash bored holes with SPT's and Shelby samples taken for laboratory testing. In addition, some CPT's were carried out in the overlying reclaimed and Bay

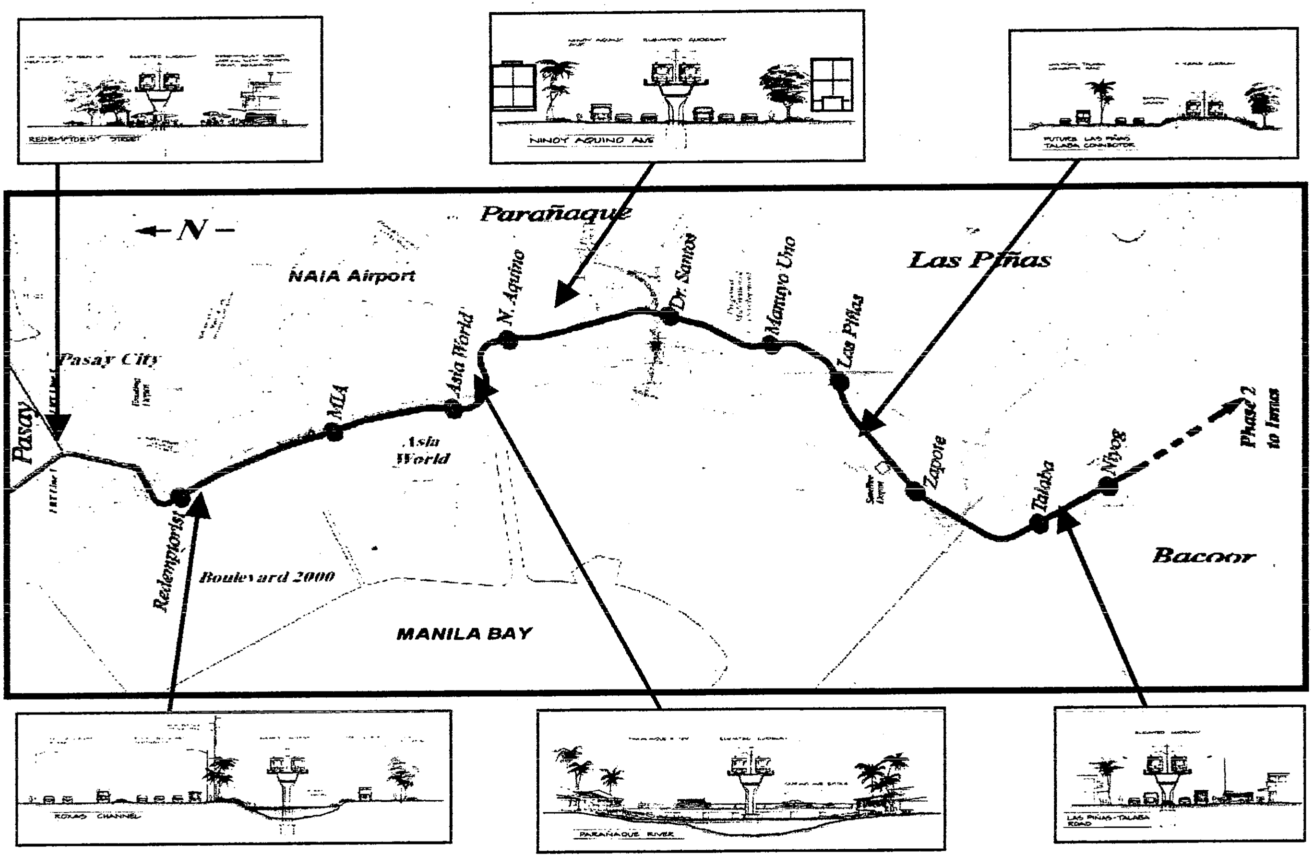

Fig. 1 Plan Showing the Layout of the LRT and the Extent of the Reclaimed Land

Mud layers, and pressuremeter tests were carried out in the underlying tuff.

The area to the west of the alignment is reclaimed land, which is planned to be developed into residential and commercial developments. Several high-rise structures, both office towers and apartment blocks have already been built in these reclaimed areas. Extensive use is made of large diameter bored piles and barrettes for the foundations to large structures. "O-Cells" were carried out by Loadtest, Inc. to test the skin friction and end bearing of a set of barrettes for a high-rise building, founded in the weak tuff bedrock. These tests will be discussed in the paper as the results are of interest in evaluating the bedrock as the founding layer beneath the reclaimed land and the soft Bay Mud layers.

Photo 1 shows a view of the canal in which the LRT1 Extension is proposed to run. In the background is the Coastal Mall, which is located on the reclaimed land. The Coastal Mall is founded on driven piles. Photo 2 shows a large section of undeveloped land. The Church in the background is also founded on driven piles.

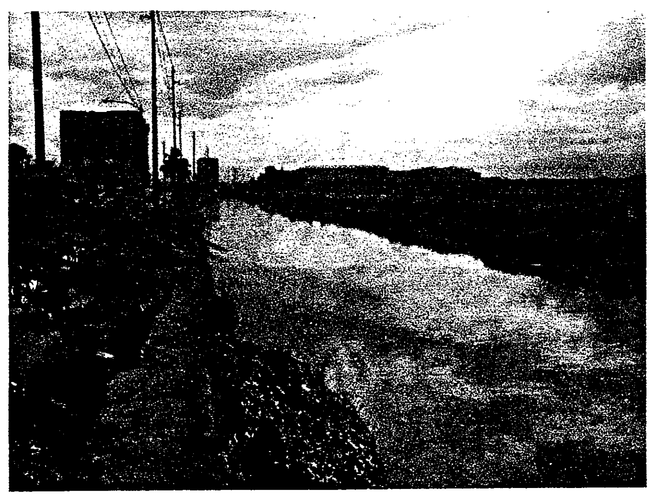

Photo 1. View South Along Canal. Coastal Mall is in the Background

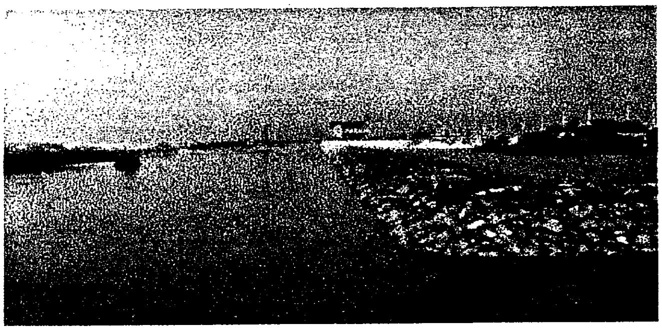

Photo 2. General View of Reclaimed Land

General Geology of Metro Manila

An idealized section of the geology of the area is shown in Fig. 2. The "bedrock" in the area of the Line 1 extension is the Guadalupe Tuff formation, known locally as "Adobe".

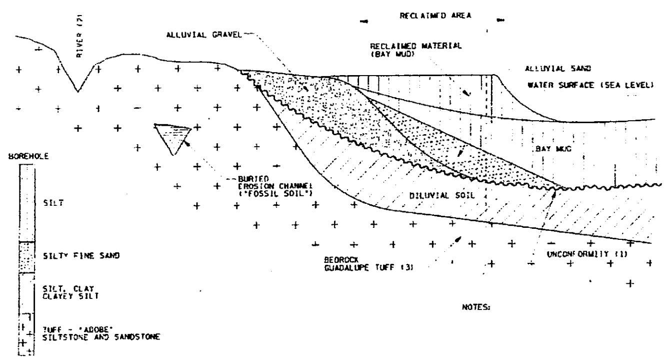

Fig 2. Generalised Geology of the Bay Area

The tuff was deposited under marine conditions as ash and clastics from volcanic activity. These ash deposits are pozzolanic, which has resulted in the tuff being weakly cemented. The tuff varies in grain size from gravel (conglomeritic), through "sandstone" and "siltstone" to claystone.

Note that the terms "sandstone", "siltstone" and "claystone" are terms locally applied to the various types of tuff. The properties of "sandstone" tuff or "siltstone" tuff are not those of a typical sandstone or siltstone. The first three types are relatively strong, with strengths (UCS) of approximately 1 MPa to 7 MPa and less susceptible to weathering than the claystone, which has strengths of approximately 0.6 MPa to 1.5 MPa. The claystones also show "shattered" and slickensided structure, which are typical of active (and potentially expansive) clays.

Since the volcanic activity was sporadic, and because the tuff was deposited under water, the surface of the tuff could undergo some weathering before the next layer of ash was deposited, or some alluvial deposits could be deposited before the next layer of ash was deposited. Both of these processes would result in softer layers, of clayey or sandy material, within the stronger tuff. Soil layers deposited and covered by the next phase of tuff deposition are referred to as locally as "fossil soils". In a borehole close to the Asia World Station, a significant thickness of these paleo-deposits was encountered, which can probably be attributed to an ancient riverbed, which was filled with alluvial soil layers before being covered by the next layer of tuff.

The surface of the tuff appears to dip toward the Bay, so that as one moves away from the Bay it could be expected that the tuff is closer to the surface. Although this may be true in general, there are exceptions and there are known to be areas away from the Bay, which have significant (reported to be of the order of 30 m) of soil layers overlying the tuff.

The layers overlying the tuff are shown schematically in Fig. 2. The older diluvial clayey layers are typically stronger than the younger Bay Mud. The Bay Mud layers are generally normally consolidated. The reclamation has taken place by dredging the Bay Mud and depositing it over the Bay Mud layers as shown in Fig. 2. The reclaimed material is thus often silty or clayey sand, usually with high proportion of fine materials in the matrix.

The following table summarises the relative ages and some of the properties of the various geological strata.

Geological Time						
Quaternary	Alluvial epoch	Holocene	Present to 11,000 years ago	Alluvial layer	Chiefly soft mud layer, N=0 to 3, qu=0.15 to 0.5 kg/cm², wn = 40 to 120%, roughly normal consolidation.	
	Diluvial epoch	Pleisto-cene	11,000 years ago to 2,000,000 years ago	Diluvial layer	Silt, clay, sandy silt, sand	N = 5 to 10
Tertiary		Pliocene	2,000,000 years ago to 25,000,000 years ago		Clay, sandy clay, silt, sand	N = 10 to 50
	Tertiary neocene	Miocene			Cemented clay or sand, shale, sandstone, tuff, shell fossils and volcanic material prominent, N ≥ 50	

Table 1. Summary of Ages and Properties of Subsurface Strata

The silty sand deposits are generally loose below the water table and are thus susceptible to liquefaction during earthquake events.

Seismicity

The entire Metro Manila area is in Seismic Zone 4, as specified in the National Structural Code of the Philippines (4th Edition, 1992).

The pga for the 1 in 475 year earthquake for the Manila area is 0.4g and for the 1 in 100 year event is 0.185g.

On July 16, 1990 an earthquake of magnitude 7.8 occurred near the town of Rizal on Luzon Island in the Philippines at 4:26 AM local time. Fig. 3 shows the epicentre of the earthquake and the relative locations of Dagupan City and Manila.

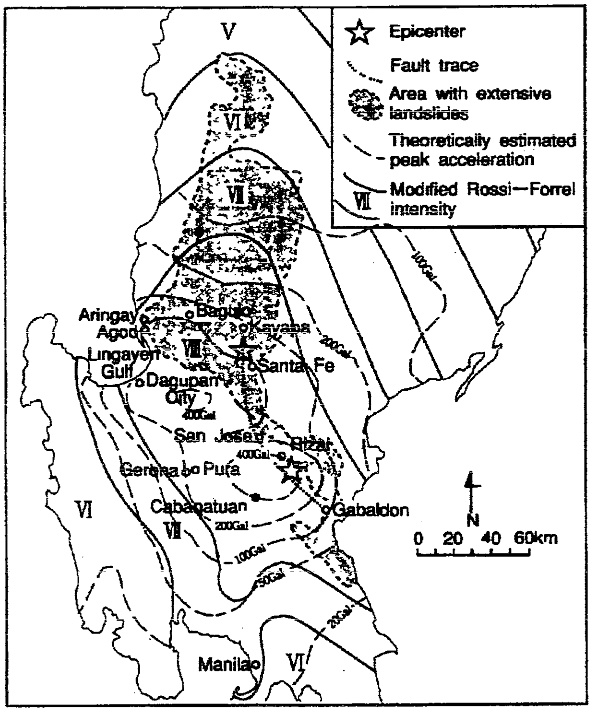

Fig 3. Summary Map of Luzon Earthquake

At nearby Dagupan City, the estimated Modified Mercalli Intensity at Dagupan City was 8.7 (2), which corresponded to an average PGA of approximately 0.45g to 0.5g (3). Significant liquefaction occurred and significant lateral spreading towards the rivers was recorded (1).

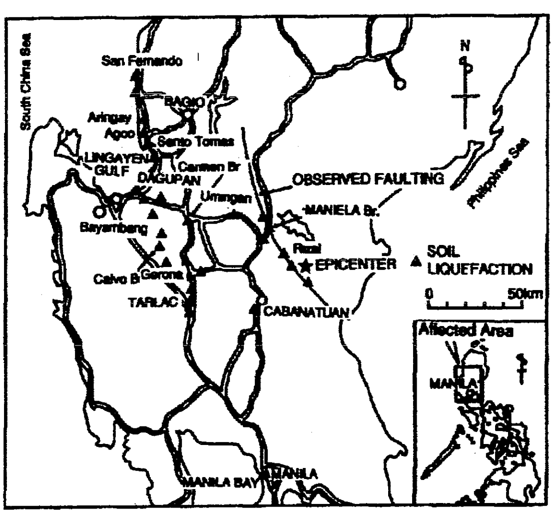

Fig 4. Map Showing the Liquefied Sites During the Luzon Earthquake of July 16, 1990

The estimated Modified Mercalli Intensity in Manila, was 6.5 (which corresponded to an average peak acceleration of approximately 0.075g to 0.1g), where relatively little damage occurred as a result of the earthquake, although some liquefaction was recorded, as shown in Fig. 4.

Design Considerations for the LRT Guideway

The track is planned to be mainly on elevated guideway, founded on individual large diameter bored piles socketed into the underlying tuff, as shown in Fig. 5. For the stations and other special structures, foundations on groups of bored piles are planned.

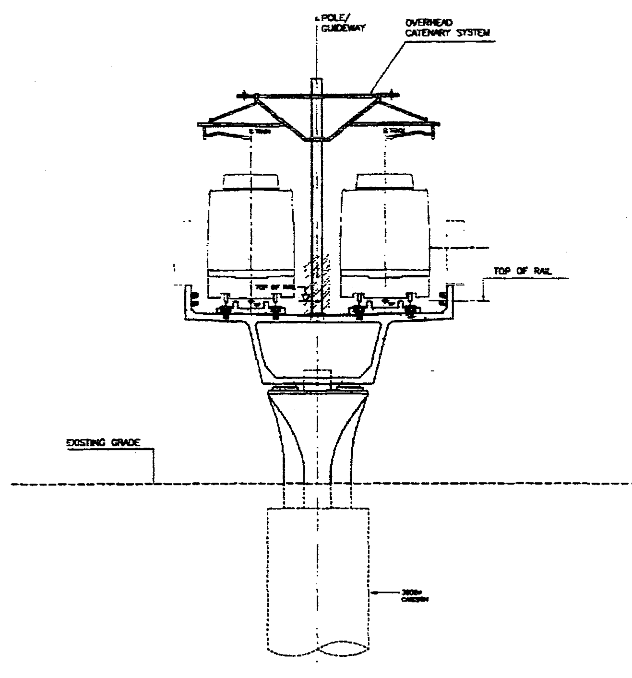

Fig. 5 Typical Section Showing Elevated Guideway

The underlying tuff layers will provide vertical and horizontal support for the piles and the soft layers of Bay Mud and reclaimed material will not be relied on for lateral or vertical support. Negative skin friction effects for the overlying soft soil layers will be taken into account. Where deep soft materials and/or shallow water table conditions are encountered, temporary casings are planned for use during installation of the bored piles.

For conditions of lateral spreading, the piles will be designed to carry dynamic loading imposed by the liquefiable soils and any non-liquefiable soils layers overlying a liquefiable layer. The design assumes passive loads for the non-liquefied soil layers and $0.3\sigma_0$ for the liquefied soil layers.

For the at-grade sections, concerns about lateral spreading under earthquake conditions have lead to ground conditioning, in the form of stone columns being used. The detail for the at-grade sections at Dr. Santos station is shown in Fig. 6.

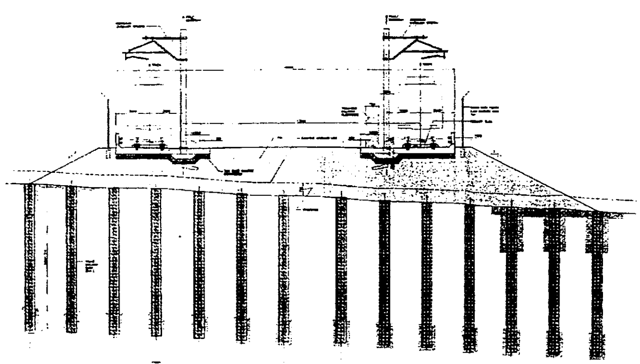

Fig. 6 Section Showing Stone Columns Proposed for Dr. Santos Station to Minimise the Effects of Lateral Spreading Under this At-Grade Section.

Site Characterisation

Manila has two pronounced seasons: the wet season starts in May and tapers off in August after which relatively dry periods are encountered with occasional rains. During the wet season, monthly rainfall intensity could reach as high as 1,300 mm. The average mean temperature for Manila is about 28°C. Average height of the ground above sea level is about 1.5 m with areas in the reclamation up to about 2.5 m.

The site investigation was mainly geared to identify the need for ground improvement and the properties of the tuff as founding material, for both vertical and lateral loads.

A typical soil profile for the reclaimed area is shown in Fig. 7. It is often difficult to clearly identify the boundary between the in-situ Bay Mud and the reclaimed material, which comes from the same source. In the soil profile shown in Fig. 7, this boundary appears to be at 3.5 m. The water table is tyically high, of the order of 2.5 m below ground level. CPT tests confirmed the N values used and it has been decided to proceed using only SPT values for future phases of investigation.

Photo 3 is a photograph of the reclaimed material showing the nature of the sandy reclaimed material and the abundance of shells. Fig. 8 is a set of grading curves for both the clayey and sandy materials.

In Fig. 9, the Liquid Limit against Plasticity Index Plot is presented. It can be seen from this plot that all the cohesive materials plot close to the "A" line, so that the materials described in the logs as "clay" are, in fact, silty clays and all the materials described as "silt" are clayey silts.

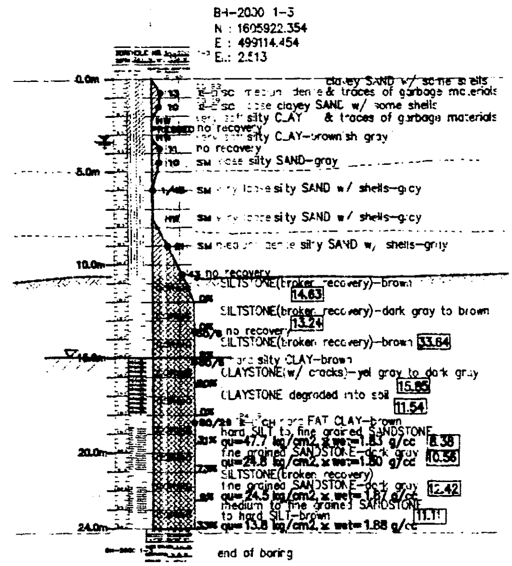

Fig. 7 Typical Soil Profile in Reclaimed Area

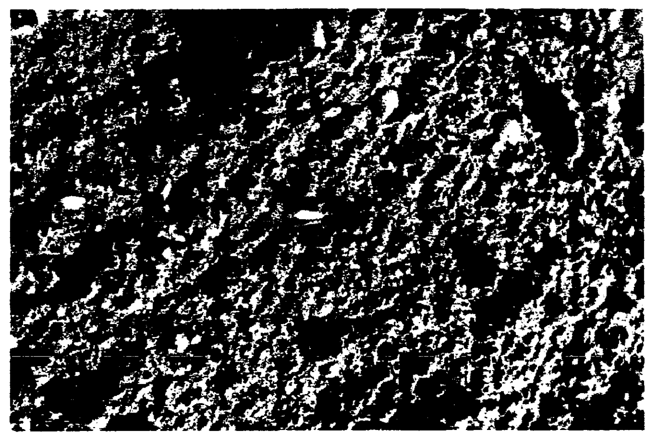

Photo 3. Close up of Sandy Reclaimed Material

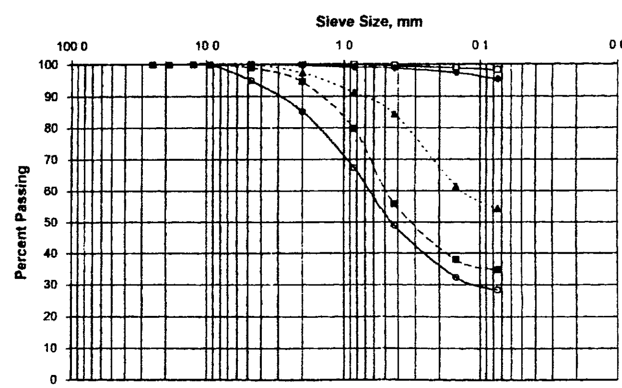

Fig. 8 Typical Grading Curves for the Clayey and Sandy Reclaimed Materials

In Fig. 10, a plot of Liquid Limit against C_c is shown. It can be seen that the C_c values are high, as are the e_0 values (1.8 to 2.8), which indicates highly compressible clay.

This is to be expected as the clays are described as very soft to soft. There is not a clear relationship between the Liquid limit and the compressibility of the clays in the reclaimed area.

The soils in the reclaimed area below the water table are susceptible to liquefaction, according to the Chinese liquefaction criteria.

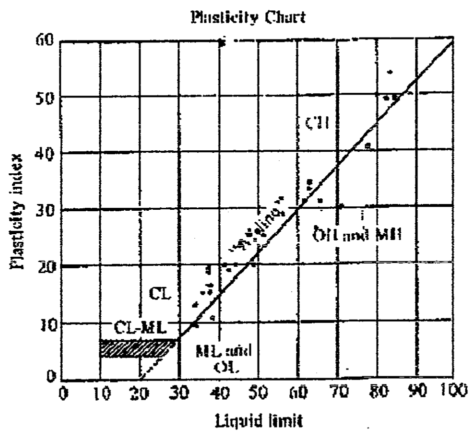

Fig 9. Plot of Liquid Limit against Plasticity Index for Reclaimed Materials

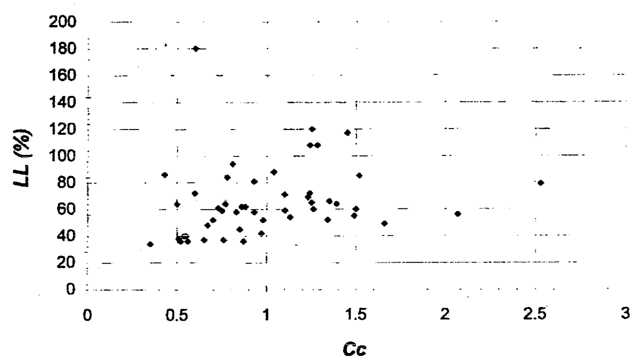

Fig. 10 Plot of C_c against Liquid Limit for Reclaimed Materials

Case History of O-Cell Testing of Tuff Layer

In addition to the UCS tests that were carried out on the tuff formation, pressuremeter tests were carried out. These pressuremeter tests were specifically carried out in order to have representative p-y curves for the lateral load analyses of the bored piles, which are socketed into the tuff formation.

Many of the high-rise structures in Metro Manila supported the structures on massive reinforced structural mats that are placed on grade in the same tuff formation. This results in four to eight basement levels being required to transfer the net foundation loads to the competent tuff layers. In addition, the deep basement results in large compensation of the loading. More recently, use has been made of large diameter bored piles, as well as barrettes and diaphragm walls to transfer the loads through the weak upper layers to the underlying tuff, for structures that require fewer basement levels. These types of foundations are heavily loaded and static load tests are difficult to carry out in the time and space available, and are often prohibitively costly.

The case history described here, illustrates the Osterberg-cell (O-cell) test method [5] used on barrette footings for a 28-storey residential structure located in Metro Manila. Since knowledge of the tuff formation is valuable to the guideway foundations, the information gained from such a test is considered to be important to designs on the Manila reclaimed land. In particular, tests such as these are being considered for the large diameter bored piles proposed for use on the LRT1 Extension.

The O-cell is shown schematically in Fig. 11. The cell is basically a sacrificial jack designed to expand both upward and downward when pressurized hydraulically. The bearing stratum resists the downward force and the upward force is resisted by the weight of the pier and the skin friction along the sides of the pier. The test pier is instrumented with telltales to measure the upward and downward displacement of the cell, so that the load-

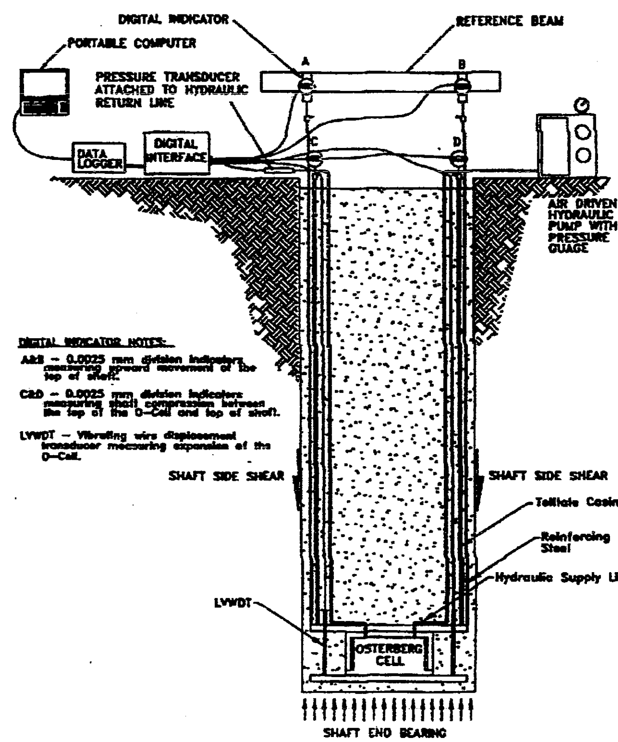

Fig. 11.Schematic of Typical O-Cell Installation in Large Diameter Bored Pile

movement curves can be plotted for both the skin friction of the shaft and the bearing pressure of the base of the pier. One of the benefits of the O-cell is that a reliable settlement analysis can be carried out for a pier from the test results.

The diaphragm wall and barrette excavations for the 28-storey residential structure were both carried out using the same clamshell, using slurry panel techniques resulting in a panel a nominal 0.85 m wide.

The skin friction value for the Tuff was calculated as 92.5 kPa and the bearing value for the Tuff was calculated at 3,675 kPa. The soil below the barrette base appeared to be more compressible than the soil along the side of the barrette. This could be due to installation disturbance or poor cleanout of the base of the barrette. Problems, which can also be identified by the O-cell, are poor cleanout of the base, poor concreting techniques, the effects of improper hydrostatic balance and failure to roughen sidewalls.

References

1. Wakamatsu, K, Yoshida, N, Suzuki and Tazoh *Liquefaction-induced Ground Failures and Their Effects on Structures in the 1990 Luzon, Philippines Earthquake.* 13th ICSMFE, New Delhi, 1994.

2. Mochizuki, T, et al. *The seismic microzoning of source region based on the seismic intensity of 1990 Philippine earthquake (1990).* Proc 10th World Conf. On Earthquake Engineering, Madrid, July 1992.

3. Bolt, B. A. *Earthquakes – Newly Revised and Expanded.* W. H. Freeman and Co. 1993

4. Gervasio, F. *The Geology, Structures and Landscape Development of Manila and Suburbs.* The Philippine Geologist Vol. XXII, No.4, December 1968.

5. Fellenius, B. H. et al. *O-Cell Testing and FE Analysis of 28-m-Deep Barrette in Manila, Philippines.* JGGE, July 1999