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Geotechnical Problems Associated with Development of Low-Lying Areas in and around Colombo

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Synopsis

Increasing attention is being paid by the developers in recent years for reclamation and development of low lying marshy areas in and around the City of Colombo. The paper discusses the geotechnical problems associated with such development and uses a pedological approach to generate a soil series and several subseries based on morphology and genetic history of the subsurface profiles. Evaluation of the engineering response of the different subseries to various civil engineering activities has also been attempted in the paper. In conclusion, the author emphasizes the urgent necessity of undertaking detailed soil mapping of the low lying areas to ensure appropriate land use and economy in construction.

Introduction

The confines of the City of Colombo have been dictated over the years by the constraints of growth to the North and the East imposed by the nature. The city has been hemmed in by the low lying marsh of Muthurajawela on the north and towards the East its growth has been thwarted by extensive marshlands from Peliyagoda to Kotte and further down South. Hence the expansion of the City of Colombo has taken place over the years in the direction that offered the least resistance—that is to the South. By 1977 a little more than the 10 per cent of the city area remained available for development and most part of it was in marshy terrain. The Colombo Master Plan envisaged reclamation of this entire area by the year 2001. With the rapid onslaught of development activities snowballing over the recent years, the attention of the developers are now being increasingly focused on the expanse of marshlands adjoining the Northern and Eastern boundaries of the City. Thus the low lying areas of Bloemendhal Orugodawatte, Peliyagoda, Dematagoda and Kotte are now coming into prominence for development. The main thrust of development in these areas will be in the low-cost housing sector, warehousing and light industries. These developments will impose additional loads on the grounds which in most part is highly compressible and presently settling under its own weight. The engineering problems associated with development of such low lying areas pose a special challenge to the abilities of the geotechnical engineer. Although isolated cases of investigation of the subsoil condition in these areas have been documented from time to time, comprehensive information as to the nature and engineering characteristics of the subsoil in marshyland and engineering consequences of development on such ground is not available for use by the prospective developers. The paper presents the findings of a limited study of the problem using a pedological approach for classification of subsoil profiles.

Muthurajawela Soil Series

An aggregate of 162 boreholes have been considered in the study spread over the marshlands of Muthurajawela, Peliyagoda, Bloemendhal, Orugodawatte, Maligawatte and Attidiya. In analysing the large volume of data obtained from the boreholes, a pedological approach towards classification of soil has been attempted using morphological and genetic factors contributing to the development of the observed soil profiles. The principal genetic factors taken into consideration are climate, vegetation, parent material; slope and age. Morphological factors like sequence and the depths of various horizons have also been duly considered. Based on the above, development of a soil series (designated as "Muthurajawela Series") has been suggested. The Muthurajawela Series has been further subdivided into several subseries to account for variation in sequence and depth of various horizons.

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Brief details of the subseries are as follows:

Table 1

Subseries designation	*Phase Type*	*No. of horizons identified*	*Remarks*
M I	MI — 1	2	Depth of Organic horizon 1.25 m
	MI — 2	2	1.25 m. Depth of organic horizon 4.0 m
	MI — 3	2	Depth of organic horizon 4.0 m
M II		4	Two organic horizons
M III		3	One organic horizon
M IV		1	No organic horizon

The most dominating factor in these subseries from the point of engineering behaviour is the presence of one or more organic horizons in all the subseries except in subseries M IV.

Subseries M I is generally observed in virgin marshlands where no development activity has yet been initiated. It consists of two distinct horizons, the upper horizon is predominantly organic in nature (Peat or, Peaty clay) and the following horizon basically a transported sandy profile with varying admixture of silt and clay sized particles.

In the absence of reliable data about the depth of bedrock, effort has not been made to establish a third horizon below horizon II. The three phase types established in this subseries are based on the varying thickness of the upper organic horizon and is intended to characterize specific engineering response as explained in the following. The depth range of two horizons are as follows:

Table 2

Horizon	*Description*	*Depth range (Metre)*
I	Fibrous Peat/Organic clay (Pt/OH)	I-1 up to 1.25 m I-2 more than 1.25 m upto 4.0 m I-3 Greater than 4.0 m
II	Sandy loams/Sandy clay (SM/SC to CL)	Not fully penetrated

Subseries M II is also commonly observed in virgin marshlands and has four distinct horizons. Horizons I and II of this subseries are identical in nature with subseries M I, the distinguishing feature being the presence of a second organic horizon (Horizon III) overlying a silty sand deposit (Horizon IV). The observed depth range of various horizons are as follows:

Table 3

Horizon	*Description*	*Depth of range (Metre)*
I	Fibrous peat/Organic clay (Pt/OH)	0.30 - 2.75
II	Sandy loam (SM/SC)	1.00 - 4.75
III	Amorphous granular peat/ Organic clay (Pt/OH)	1.25 - 3.25
IV	Poorly graded silty sand (SP)	Not fully penetrated

In this subseries genetics of the two upper horizons are identical to that of series M I while the organic matter of the third horizon gives evidence to the presence of swamps and marshlands in these areas in Pleistocene and geologically recent times.

M III subseries is the result of the superposition of a transported fill layer on M I subseries. This profile is expected whenever reclamation activity has been carried out in a low lying area. The depth range of various horizons in this subseries is as follows:

Table 4

Horizon	*Description*	*Depth range (m)*
I	Fill material, generally lateritic soil (silty loam to silty sand) MH to SM, SC	0.3 - 8.9
II	Fibrous peat or organic clay (Pt/OH)	0.4 - 5.7
III	Transported floor plain deposit (silty sand) SM - SC	Not fully penetrated

M IV subseries is represented by a single horizon of siltys and going up to bed rock. This is characterized by the absence of any organic horizon.

Engineering Properties of the Organic Horizons

Engineering behaviour of the different soil subseries described above is mostly dominated by the extent and the engineering properties of the organic horizons present in each subseries. It is therefore necessary to examine the engineering properties of the organic horizons in a greater detail.

The native vegetation of the long standing swamps in the low lying areas has given rise to, on decomposition and accumulation over a period of years, organic soils whose solid constituence consists predominantly of vegetable matter in varying stages of decomposition or preservation. This cumulose deposit which generally overlies the alluviam is an intra-zonal hydromorphous soil and is commonly referred to as Peat or Muck, the latter indicating a higher degree of decomposition of vegetable matter or intermixing with mineral soil constituents in contrast to pure vegetable peats that have well preserved plant remains.

The organic soil observed in these horizons may be broadly divided into three basic groups, namely, coarse fibrous, fine fibrous, and amorphous granular peat. The material available in surface horizons, namely, Horizon I of subseries M I and M II is generally the coarse fibrous variety. Where, however, fill material has been placed on the organic layer, as in Horizon II of subseries M III, there is considerable impregnation of lateritic and other inorganic concretions in this zone intermixed with coarse vegetable fibres and silt and clay sized particles. The coarse fibrous variety is quite often followed by a layer of fine fibrous peat where the decomposition is more advanced and the interstices of fine vegetable fibres contain appreciable quantity of colloidal organic matter. Amorphous granular peat is generally observed in the second organic horizon (*e.g.* in horizon III of subseries M II) where the colloidal fraction of the organic matter increases substantially and the fibrous character of the soil is lost. The state of decomposition in this horizon is so advanced that its biological identity is lost. The resulting mass is a thick slurry of finely comminuted plant remains. This is generally referred to locally as "Humus Peat".

Due to the predominantly fibrous constitution of the organic matter, peat has a sponge-like nature associated with very high moisture content, very high void ratio and high drying shrinkage. The order of moisture content observed in this deposit ranges from 85 to 265 per cent. Higher moisture content is associated with the coarse fibrous variety and the lower values are observed in the amorphous variety.

The bulk density is observed to be in the range of 1.15 g/cc to 1.56 g/cc, the corresponding dry densities being 0.31 g/cc and 0.36 g/cc. Amorphous granular peat shows a higher bulk density than the coarse variety.

The void ratio is also observed to vary over a wide range depending on the variety of the peat. The coarse fibrous variety shows a void ratio upto 5.2 while the amorphous variety has a typical order of 1.5 to 1.8.

The unconfined compressive strength varies in the range of 0.22 kg/cm^2 to 0.27 kg/cm^2.

The compressibility characteristics of this layer is also observed to vary over a fairly wide range depending on the proportion of organic matter. Consolidation tests carried out on fibrous samples of peat show a compression index as high as 1.48 while amorphous granular samples yield a much lower value of the order of 0.3. The compression ratio $\frac{(C_c)}{(1+e_o)}$ determined for different varieties of peat falls in the range of 0.11 to 0.24.

Consolidation of peat is associated with abnormally large decrease in permeability under sustained loading, a decreasing co-efficient of compressibility and thixotrophy, as well as surface activity of organic material, All this makes the process of consolidation in peat a very complex phenomena which militates against a precise settlement analysis based on the Terzaghi's theory of consolidation. This apart, secondary compression plays a significant role in peaty soil. The actual order of secondary compression depends on the variety of peat and may be of a very high order in the fibrous variety where an extremely slow drainage process continues over a very long period of time with movement of water from the micro pores to the macro structure of the vegetable matter.

The range of engineering properties of different horizons of each subseries are given in Table 5.

Table 5

Range of Engineering Properties in the organic horizons

Engineering Property	*Horizon I of Subseries M I and M II*	*Horizons III of Subseries M II*
Field Characteristics:		
Total density (Yt) in g/cc	1.16 to 1.54	1.59 to 1.68
Dry density (Yd) in g/cc	0.31 to 0.84	0.83 to 0.99
Natural Moisture Content in %	85 to 265	63 to 101
Natural Void Ratio in %	1.5 to 5.2	1.0 to 1.4
Physical Properties:		
Colour	Greyish black to dark black	Greyish black to dark black
Texture	Fine to coarse fibrous	Amorphous Granular
Specific gravity	2 to 2.4	2 to 2.4
Mechanical Analysis		
Gravel (4.75mm to .20mm)	0 to 4.5%	0
Sand, Coarse (2.0 mm to 4.75 mm) %	0 to 4.9	0 to 2
Medium (0.425 mm to 2.0 mm) %	2 to 20	1.1 to 9
Fine (0.075 mm to 0.425 mm) %	3 to 52	10 to 30
Silt and Clay (less than 0.075 mm) %	38 to 95	61 to 89
Index Properties:		
Liquid Limit (LL) %	49 to 160	49 to 103
Plastic Limit (PL) %	40 to 95	31 to 45
Plasticity Index (PI) %	18 to 100	18 to 58
Classification:		
Unified Classification System (1498-1970)	Pt	OH
Textural	fibrous peat	organic clay

Engineering Response of Different subseries

The following types of structures have been considered in the study:

Table 6

	Type of Structure	Type of footing	Column/Wall loads
1	Low cost houses single to four storeyed	Strip footing	25 – 164 kN/m
2	Office – 3 to 4 storeyed	Pad footing	1380 – 1900 kN
3	Light Industrial	do.	65 kN
4	Heavy Industrial	do.	175 kN

The various options considered in the study for placement of foundation and/or ground treatment in each soil subseries are as follows:

(1) Preloading the area after reclamation has been carried out to the desired level and placing foundation within the fill material after preload has been removed. The preloading period considered is six months.

(2) Placing foundation below the upper organic horizon.

(3) Providing pile foundation when the preceding two options are not feasible.

The engineering response of each subseries has been analysed and described in the following.

Engineering Response of Subseries M I

1. For Horizon I (peat layer) thickness up to 1.0 metre, shallow foundations can be provided on the reclaimed land after preloading. This is based on the assumption that the height of reclamation and the height of preload are both limited to 2.0 metres.

2. When the Horizon I depth increases to 1.25 metres, (phase type M I – 1) the anticipated settlement becomes excessive for all structures except single storeyed residential units, even when the area is preloaded. The importance of peat layer thickness for effective preloading can be understood from the above.

3. For peat layer thickness in excess of 1.25 metres (phase types M I – 2 and M I – 3) preloading does not remain effective unless the height of preloading is increased to 2.5 metres with provision of sand drains. It is estimated that with provision of 15 cms diameter sand drains at 1.5 metres spacing and preloading for six months, all types of structures can be provided up to 2.0 metres thickness of peat. Stiffening of foundations will however, be required in all cases. Residential buildings up to three storeys can be provided on stiffened shallow foundations up to 3.0 metre thickness of peat and double storeyed buildings can be considered up to peat thickness of 4.0 metres.

4. When the thickness of peat in Horizon I exceeds 4.0 metres (phase type M I – 3), shallow foundations cannot be considered even after preloading the area. Provision of pile foundation has to be considered in such cases.

5. The analysis further shows that for the combined thickness of fill and peat layer (Horizon I) limited to 2.75 metres, it is possible to bypass the organic horizon and to place shallow foundations of most of the structures in Horizon II (SM – SC/CL). However, in many cases, stiffening of the foundation will be necessary. For heavy industrial structures and warehouses, further analysis should be carried out to examine the feasibility in a particular case.

Engineering Response of Subseries M II

1. This subseries has two peat horizons, Horizon I and Horizon III with a horizon of transported sediment interspersed in between. In this case, both the horizons I and III will contribute to ground subsidence under the weight of the fill used for reclamation even before construction activity commences. In M I subseries, it has already been observed that limiting thickness of horizon I beyond which preloading ceases to be effective is about 1.25 metres. In subseries M II the corresponding limiting depth will be even less due to the presence of peat in horizon III. Therefore, it does not remain practicable to place foundations on the filled ground even after preloading. Provision of sand drains will also be relatively costly in this case due to the longer length of drains required (average length about 8 metres).

2. The combined thickness of fill and Horizon I determines the feasibility of placing foundation in Horizon II below the surface peat layer. Considering a limiting combined thickness of 2.75 metres, if the height of the fill is taken as 1.50 metres, then the limiting thickness of Horizon I becomes 1.25 metres.

Since the foundation placed in Horizon II will contribute to settlement of peat Horizon III, there is obviously, a minimum thickness of this cushion layer (Horizon II) below which the excessive settlement of Horizon III will prevent positioning the foundation in Horizon II. Considering the minimum thickness of Horizon II as 4.0 metres, the following options are available for placing foundations in Horizon II.

Table 7

Horizon	*Depth of Horizons (Metre)*				
Horizon	*Case 1*	*Case 2*	*Case 3*	*Case 4*	*Case 5*
I (Pt)	1.25	1.25	1.25	1.25	1.25
II (SM/SC)	4.0	4.0	5.0	5.0	5.0
III (Pt/OH)	1.0	1.25	1.0	1.25	1.50

Analysis based on the above considerations indicate that in cases 1, 2 and 3 placing foundation in Horizon II is possible only for single storeyed residential and light industrial structures. However, for single storeyed structures this option may not be very attractive considering the depth of foundation involved. In case 3, however, double storeyed structures can also be founded on Horizon II with stiffened foundation. Case 5 represents the limiting case where provision of shallow foundation does not remain feasible except for single storeyed residential buildings. Deep foundations are therefore, to be considered for thickness of peat exceeding 1.25 metres in Horizon III.

Engineering Response of Subseries M III

In this subseries the feasibility of placing foundation in the filled ground (Horizon I) depends on the relative depths of Horizons I and II.

Placing foundation in Horizon I will be possible only when the depth of this horizon is relatively large compared to the thickness of the following peat horizon. The following combinations have been considered in the analysis:

Table 8

Horizon	*Depth of Horizon (Metre)*			
	Case 1	*Case 2*	*Case 3*	*Case 4*
I (SM.CL)	4.0	6.0	8.0	8.0
II (Pt)	1.0	1.0	2.0	3.0

In Cases 1, 2 and 3 shallow foundations can be provided for all types of structures considered although it will be necessary in most cases to stiffen the foundation suitably. Case 4 represents the limiting case where excessive settlement would render shallow foundations unsuitable.

Engineering Response of Subseries M IV

This is a relatively simple profile with a single horizon of granular material (mostly nonplastic silty sand). Shallow foundations can be provided on this ground for all types of structures except heavy industrial structures and warehouses. For these structures, further analysis will be required to determine in each case the possibility of providing stiffened shallow foundation which can tolerate total settlement of the order of 125 to 150 mm.

Use of Short Bored Underreamed Piles

It has been discussed in the foregoing that limiting depths of organic layers can be determined beyond which the option of preloading and use of shallow foundations does not remain cost and time effective. In such situations provision of pile foundation has to be considered. Piles can generally be founded in Horizon II of subseries M I, Horizon IV of subseries M II and Horizon III of subseries M III. Except in cases of heavy industrial structures, the column and wall loads are generally of a low order and conventional normal diameter piles (400 mm to 500 mm) tend to be prohibitively costly in relation to superstructure cost. Use of small diameter (200 mm to 300 mm) bored cast-in-situ piles with underreamed bulbs should prove very cost effective in such cases. The underream is generally kept at 2.5 times the stem diameter and it improves the end bearing capacity of the piles significantly. Since such piles can be installed manually with simple boring rigs and underreaming tools these seem to be ideally suited for use in low lying marshy areas. The author has experience of use of these piles in similar situations for over ten years and considers that small diameter underreamed piles provide the appropriate technology for development to low lying areas particularly in situations unsuited to shallow foundations. Technical details of these piles are now freely available, and the process can be developed and patented by local construction agencies.

Suggested Further Work

An attempt has been made in the foregoing to present a pedological approach for engineering classification of subsurface profiles in low lying marshy areas. Such information can be profitably used by developers at the feasibility study stage of a project. A few confirmatory boreholes advanced in a project area will facilitate identification of the particular soil subseries governing the area. The engineering response of the subseries to various construction activities may then be ascertained.

Considering, however, the magnitude of development activities envisaged in the low lying areas in the coming years the necessity of a more extensive determination of subsoil condition in these areas seems imperative. Such further endeavours should aim at developing geotechnical and taxonomic maps of the low lying areas which would facilitate evaluation of techno-economic aspects of project proposals. For this purpose, the low lying areas may be divided into several blocks for convenience of mapping and presentation.

A convenient scale for presentation may be 1 : 7500. Taxonomic maps may be prepared for (1) Foundation, (2) Reclamation, (3) Drainage, (4) Materials of Construction and (5) CBR of the areas for road purposes.

Preparation of the geotechnical maps will, however, require considerable magnitude of inputs in terms of equipment, technical manpower and expertise for interpretation of test data and the joint endeavour of all the developing agencies in the government sector need be moblized for this purpose.

The importance of availability of such taxonomic maps to planners engaged in developing low lying areas cannot be over-emphasized. This will not only ensure appropriate land-use and economy in construction but will also help to avoid recurrence of geotechnical problems during the land-use construction stage of projects.

Conclusions

1. With the recent growth of development activities in the low lying marshy areas in and around Colombo the necessity of tackling geotechnical problems associated with such development has assumed greaterimportance.

2. A pedological approach can be made to classify the numerous subsoil profiles of low lying areas into a distinct soil series and subseries characterized by specific engineering response to different civil engineering activities.

3. It is possible to identify limiting depth of organic horizons beyond which preloading technique and use of shallow foundations become economically ineffective.

4. Small diameter bored underreamed piles can provide the appropriate technology for development of low lying marshy areas.

5. Extensive geotechnical and taxonomic mapping of the low lying areas should be undertaken urgently to ensure appropriate land use and economy in construction.

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