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Engineering geology and earthwork problem associated with highway construction in soft soil at Sg. Rasau, Dengkil, Selangor

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Abstract: This paper presents an overview of the earthwork problem encountered in the construction of an embankment for the highway project in alluvium deposits near Sg. Rasau, Dengkil, Selangor. The alluvium deposits mainly consist of clay and silty clay composition containing considerable amounts of organic material and decayed wood (peat and organic soils).

The characteristics and engineering properties of this soft soil are presented with respect to its earthworks and geotechnical performance. Soil information are used to illustrate the construction and the potential performance problems encountered.

The engineering properties have shown that this soft soil was not suitable for the construction and the introduction of another material was suggested to improve the highway performance. The studies showed that the highway has improved by applying excavations of unsuitable material, sand replacement, pile supported embankment method and surface soil reinforcement method.

INTRODUCTION

The soft soil formation embrace some square kilometers in the state of Selangor, western Peninsular Malaysia, at about 101°25'E–101°45'E and latitude 2°30'N–3°00'N (Fig. 1). The Kuala Lumpur International Airport is located to the south of the formation.

In order to better understand the problems that are likely to be encountered, it is necessary to know the soil distribution and their general engineering properties. In this paper, the extent of the soft soil is shown and the soil and engineering properties of this residual soil are discussed.

GROUND CONDITION ON SITE

As a precursor to the discussion on the soil distribution, its is useful to examine the topography and geology of the study area. The construction of the highway lies to the south of Selangor on the western side of Peninsular Malaysia. The majority of the site lies on the flat, swampy coastal lowlands and sedimentary residual soils (Kenny Hill formation). The nature of the hills is such that erosion has formed valleys, which have been infilled with recent soft coastal sediments (Fig. 2).

Site geology

Soft soil

The low-lying swampy areas are extensively covered with peat of an average thickness of 2 m, although thickness of up to 6 m has been recorded. This peat normally can be differentiated as dark brown spongy amorphous peat and spongy fibrous peat. This peat is rootless and associated with decayed wood. Immediately below the peat is a layer of very soft to soft compressible clay, which has been generally described as marine clay. This soft clay is light grey in color and very soft to very stiff silty clay to sandy silty clay. The soft soil deposits are categoried as the Pengkalan Member of the Beruas Formation (Gobbert and Hutchison, 1973; Bosch, 1988). Over much of the area of soft ground on the site, the total depth of peat and very soft clay is less than 5 m to 7 m. Depths of 15 m up to 25 m of these sediments have, however, been identified along the line of the perimeter road.

Within the marine clay there is evidence of crustal features on desiccated surfaces at depth due to marine transgression and regression cycles, as recorded in other areas of the west coast of Peninsular Malaysia. An irregular sequence of clay, silt and sand of alluvial and colluvial origin, termed the lower sediments, occur beneath the marine clay.

Residual soil, colluvium and bedrock

The high ground rises between 30 m to 60 m. This high ground is mainly covered by residual soils, derived from the weathering of foliated metasedimentary rock which occur as a series of parallel hills aligned in a south-easterly to north westerly direction with dips between 70° and 90°. The metasedimentary rocks are inferred to be the Kenny Hill Formation comprising essentially sandstone, shale, phyllite and quartzite. The denudation of residual soil has led to the formation of the present valley systems which are colluvial deposits occurring in the low lying area mostly confined to the soft sediments/residual soil contact. This contact zone between the soft sediments and the residual soils is quite complex and an overlying deposit of colluvium generally masks its location.

The colluvium is generally encountered as soft to stiff silty clay overlying medium dense to dense very clayey gravel or sand. The residual soil is typically firm to stiff, becoming very stiff and hard sand silty clay with increasing depth. Residual soil eventually grades into moderately to completely weathered rock, a hard dense clayey sand or sandy silt but generally only at depths greater than 20 m.

Groundwater

In the plain and valley, groundwater is near to ground surface generally being found at between 0.1 m and 0.5 m depth. It is slightly lower at the upper end of some valleys but even then is not more than 1 m deep.

PHYSICAL PROPERTIES

The soil data in this paper is predominantly sources from pre-construction and construction soil investigations conducted for the North South

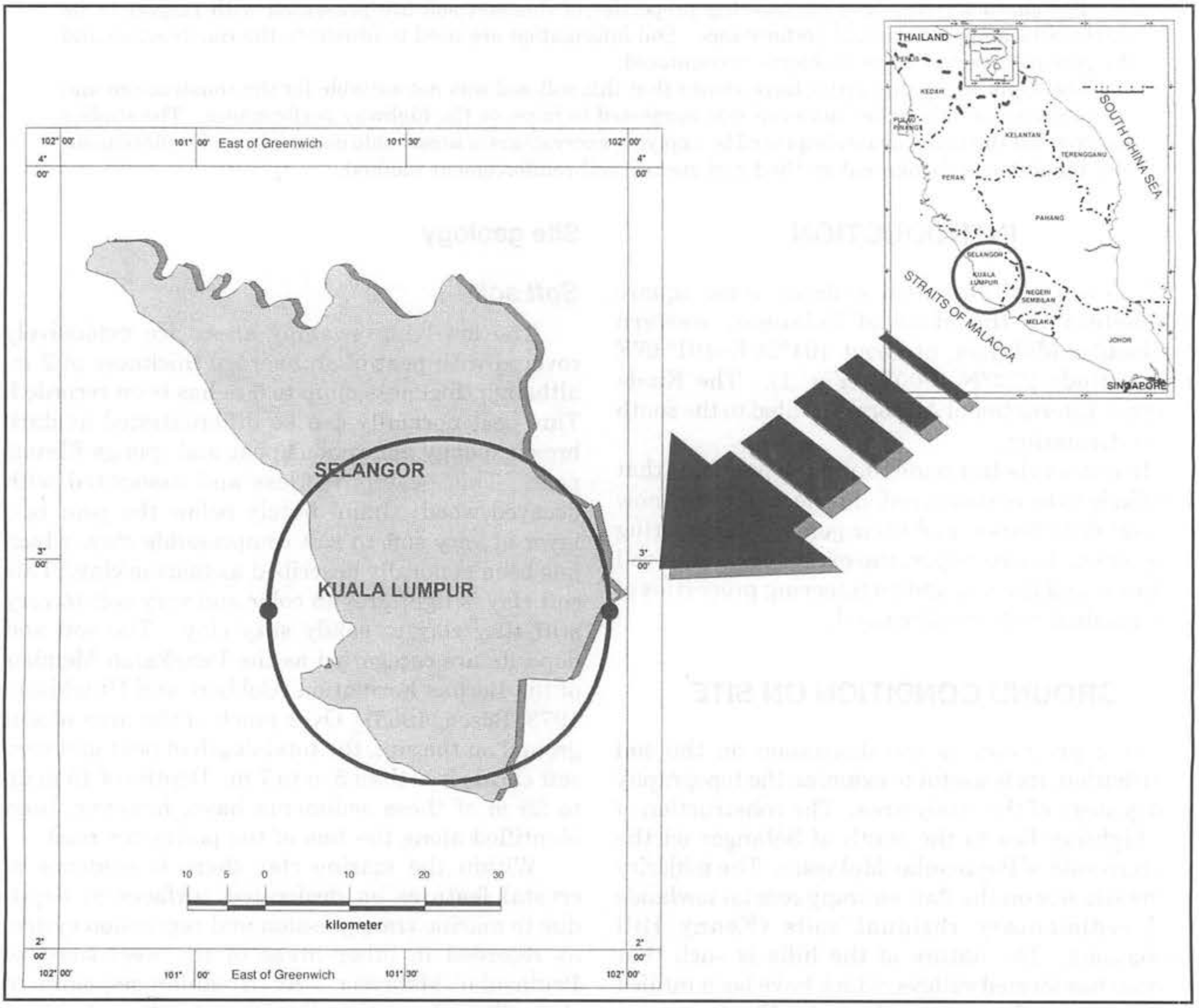

Figure 1. Location of study area.

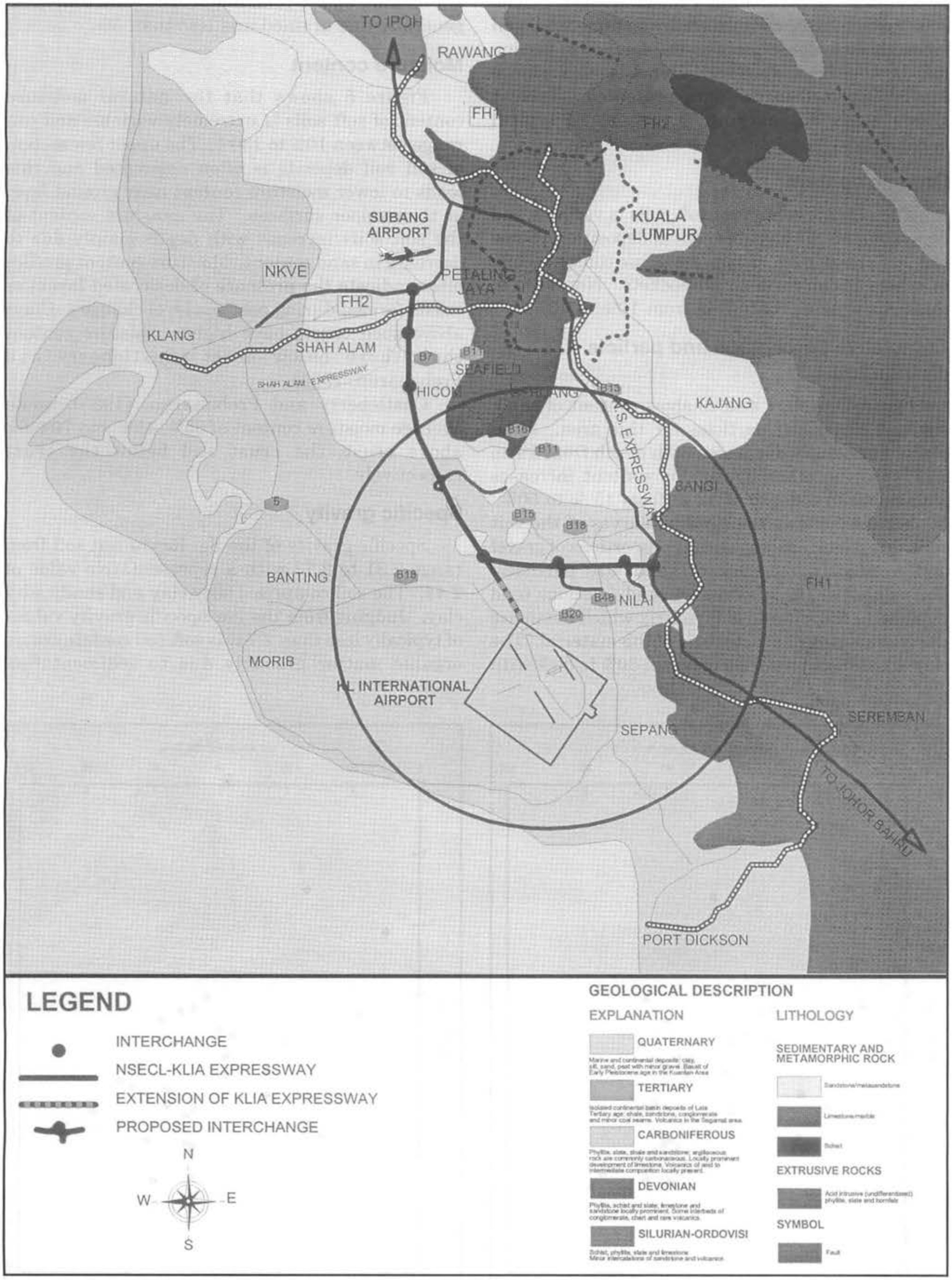

Figure 2. Location and geological map of study area.

Expressway Central Link Project (ELITE). The soil testing was conducted by commercial soil laboratories. Consequently, the quality of testing may be not of research level. Hence, some variance can be expected in the data presented. Table 1 shows some engineering properties of typical boreholes.

Organic content

The organic content of soft soils is variable and dependent on the environment of deposition. Some soft soil shows disseminated organic content while in others it can form small pockets. Normally in this area organic content is from 10% to 40%.

Cumulative percentage and particle size distribution

Figure 3 (a, b, c and d) show content of sand, silt and clay sized particles for this area. Sand content generally decreases with depth from 3% to 30%. On the other hand, clay content increases with depth to a depth of 12 m from 15 % to 50%.

Figure 4 shows the grading curves of the soft soils. The soils have significant proportions of gravel and a small percentage of sand size particles. Consequently, the gravel and sand fractions tend to 'float' in the silt and clay matrix which dominate the engineering characteristic of the material. The clay-sized fraction varies between 30% to 80% with silt making up the remainder. The sand content is generally fine grained and less than 5%.

Moisture content

Figure 5 shows that the natural moisture content of soft soils is extremely variable and can range between 10% to 130%. The upper few meters of soft soil deposits is often desiccated and this leads to lower moisture content near ground level or their upper surfaces. The moisture content of the soft soils increase with depth mainly due to decrease in sand content. Moisture content profiles often indicate the presence of desiccated layers or crusts formed during past sea level changes. Clays above such crusts have higher moisture content than those below crust (Castleberry and Prebaharan, 1985).

Castleberry and Prebaharan, (1985), quote average moisture content of 35%, 45% and 70% for above crust, the crust and below the crust respectively.

Specific gravity

Specific gravity of the Sg. Rasau soft soil from range 2.31 to 2.73 with a representative value of 2.44. The soil comprises silty clay and sandy silty clay. Judging from the low specific gravity values of typically less than 2.7 this soft soil contains more organic matter probably due to sedimentation

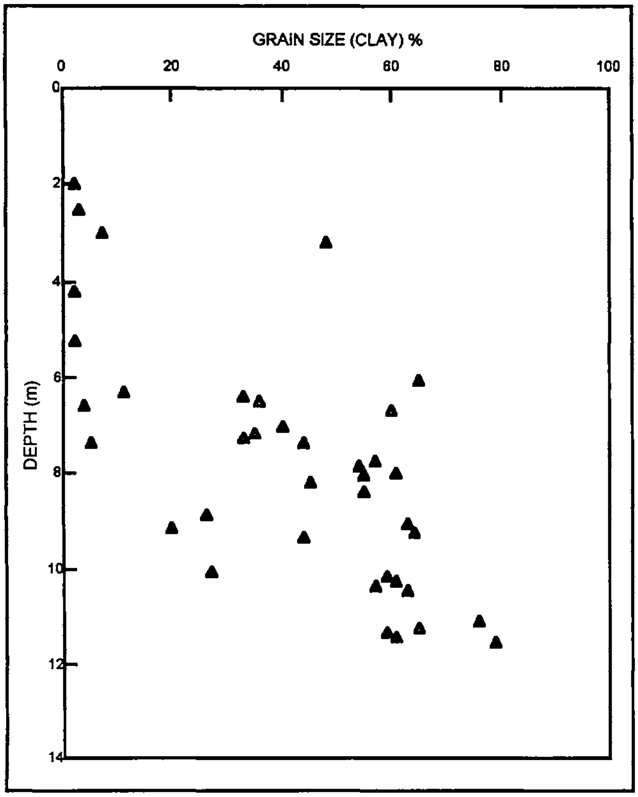

Figure 3a. Clay (%) versus depth (m).

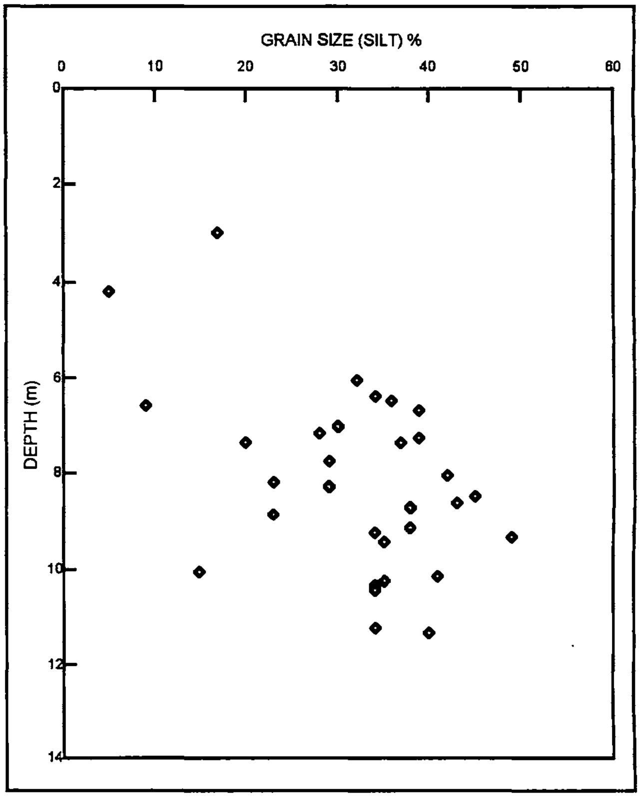

Figure 3b. Silt (%) versus depth (m).

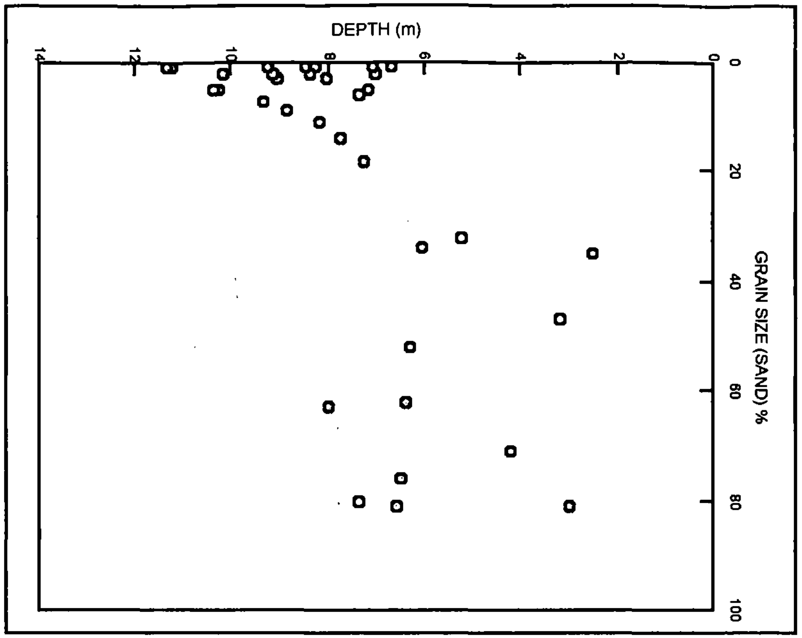

Figure 3c. Sand (%) versus depth (m).

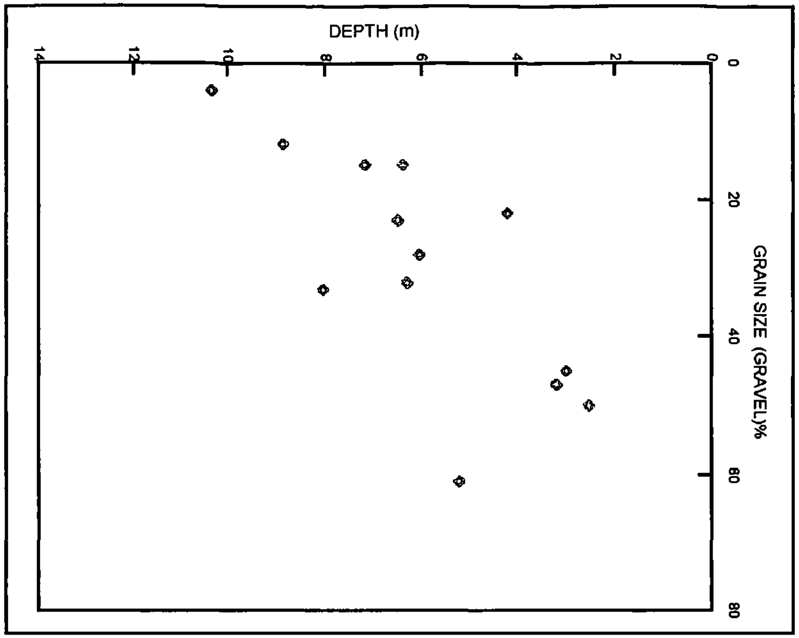

Figure 3d. Gravel (%) versus depth (m).

Table 1. Some engineering properties of typical boreholes.

Depth	Bulk Density	Moisture content	Plastic Limit	Liquid Limit	Plastic Index	Clay	Silt	Sand	Gravel	Specific Gravity	σ_3	σ_3-σ_1	C_u	Pc	e_o	Cc	Cr	Cv	Organic content
1.	1.39	118	44	97	53	–	–	–	–	–	20	16	–	110	1.36	0.28	0.15	0.27	
2.	1.44	102	–	–	–	66	31	3	0	2.44	40	16	–	–	–	–	–	–	
3.	1.42	96	39	96	57	–	–	–	–	2.40	40	18	16	56	2.32	1.28	0.38	0.21	
4.	1.42	100	–	–	–	51	33	14	2	2.45	–	–	–	30	2.44	0.97	0.28	0.38	
5.	1.37	112	–	–	–	19	36	37	8	2.54	–	–	–	70	2.67	1.06	0.29	2.30	–
6.	1.73	19	24	82	58	66	32	2	0		55	42	26	300	0.89	0.34	0.18	2.27	43
7.	1.81	35	37	99	62	74	20	6	0		65	124	66	–	–	–	–	–	69
8.	1.92	30	30	77	43	57	29	14	0		75	105	98	–	–	–	–	–	–
9.	1.57	59	28	78	50	54	45	1	0		75	22	13	60	1.52	0.73	0.29	0.35	11

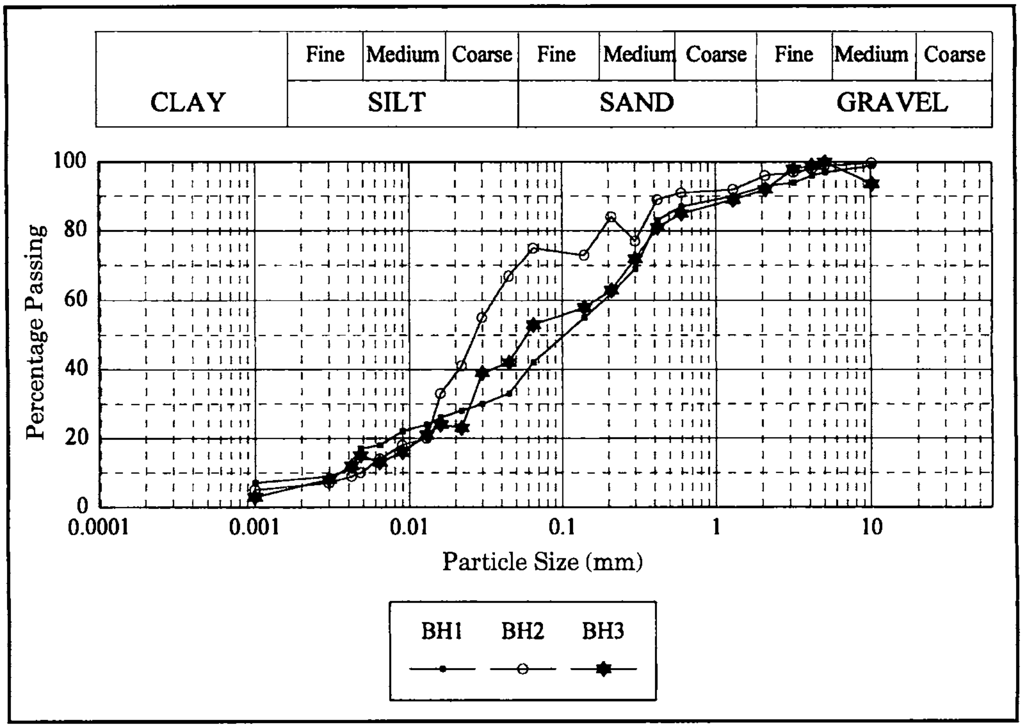

Figure 4. Grading curves of the soft soil.

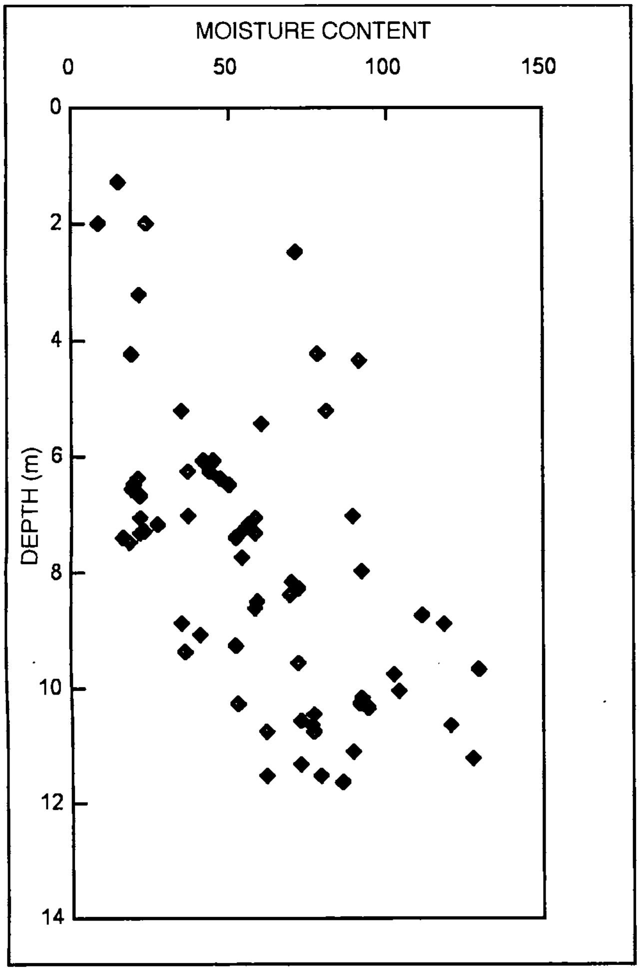

Figure 5. Moisture content versus depth (m).

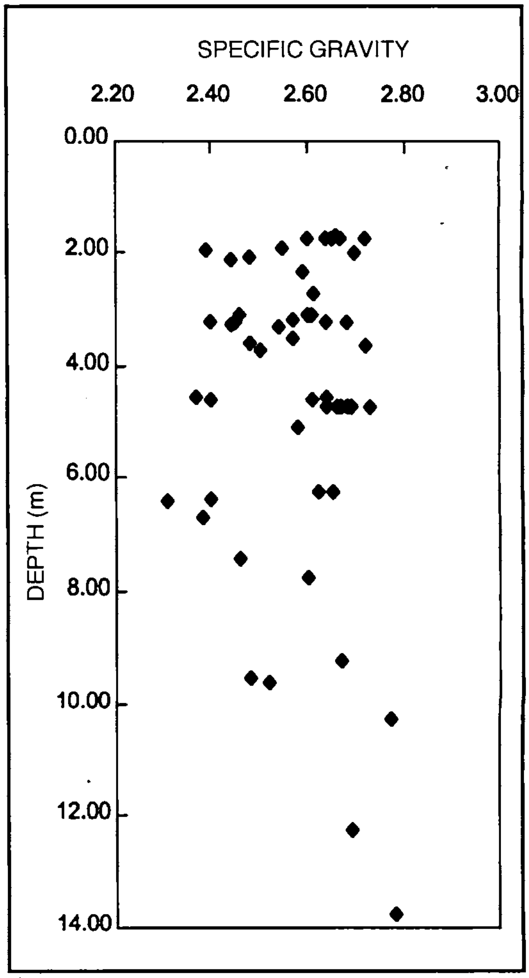

Figure 6. Specific gravity versus depth (m).

because the Sg. Rasau soft soil referred here was obtained a few hundred meters inland. Figure 6 shows that the specific gravity increases with depth.

Atterberg limit

The typical range of plastic limit (PL) is between 10% to 80% while for the liquid limit (LL) it is between 10% to 120% and for plastic index (PI) is from 3% to 80%.

The variation of the Atterberg limit indices with depth are given in Figures 7, 8 and 9. The liquid limit increases with depth reflecting the decrease in sand content with depth.

Plastics index versus depth show an increase with depth. It increases with depth from 40% to 80%, down to a depth of 8 m. The plasticity index below a depth of 8 m is consistent at 50% to 80% with a representative value of 65%. The plasticity index is a little high due to high liquid limit. Liquid index gradually decreases with depth.

Compressibility parameters

Figures 10, 11 and 12 show the variation between the following compressibility parameters: compression index (Cc); recompression index (Cr); and the coefficient of consolidation (Cv) versus depth (Nishida, 1956). There is a general trend for the compressibility parameters to increase with depth. This increase is consistent with the effect of the

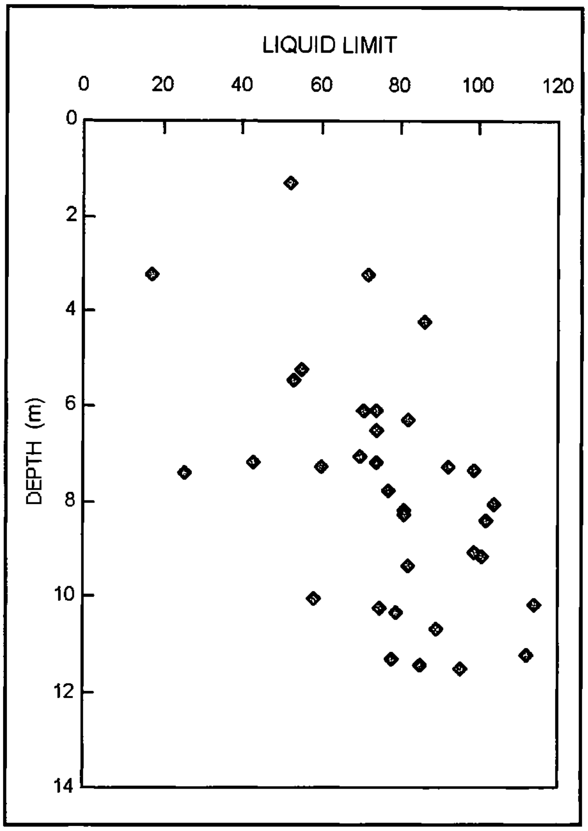

Figure 8. Liquid limit (LL) versus depth (m).

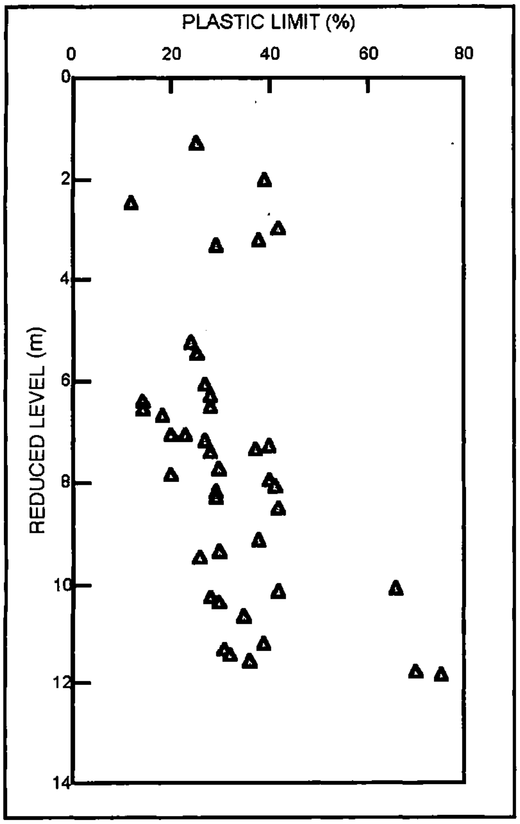

Figure 7. Plastic limit (PL) versus depth (m).

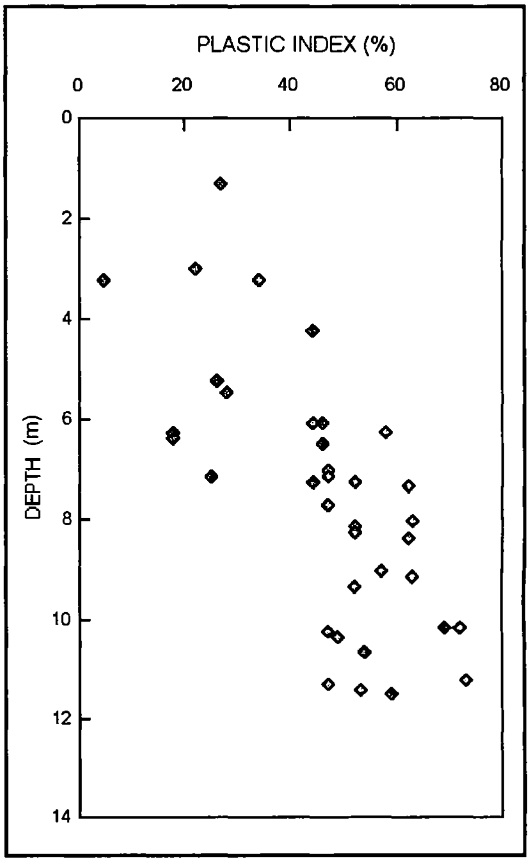

Figure 9. Plastic index (PI) versus depth (m).

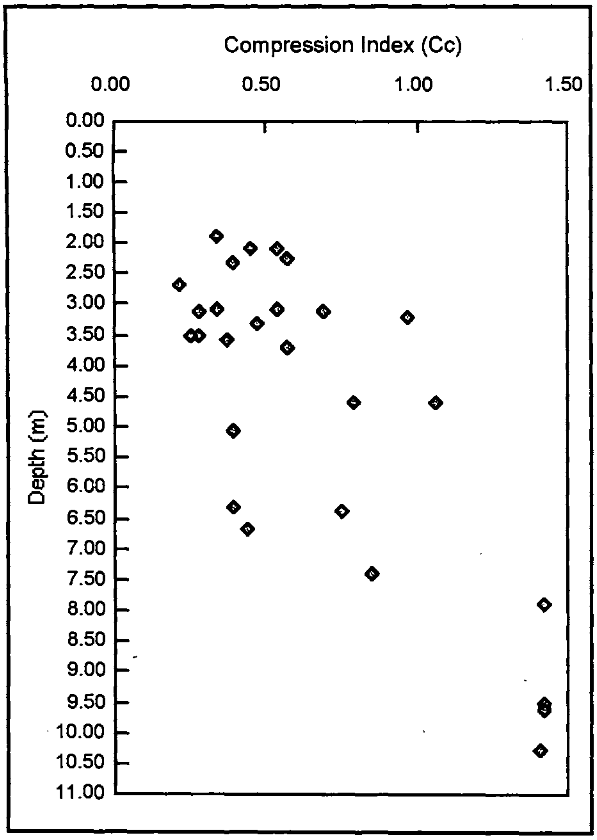

Figure 10. Compression index (Cc) versus depth (m).

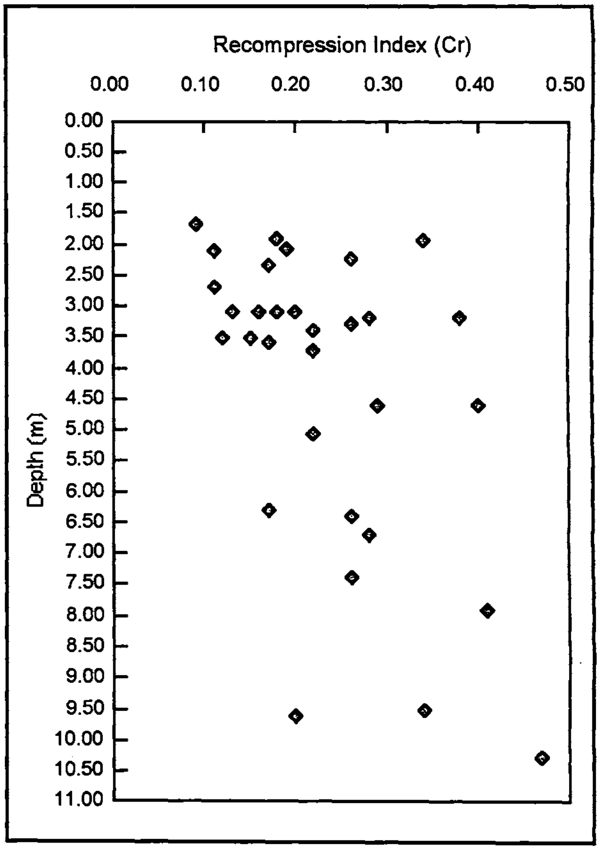

Figure 11. Recompression index (Cr) versus depth (m).

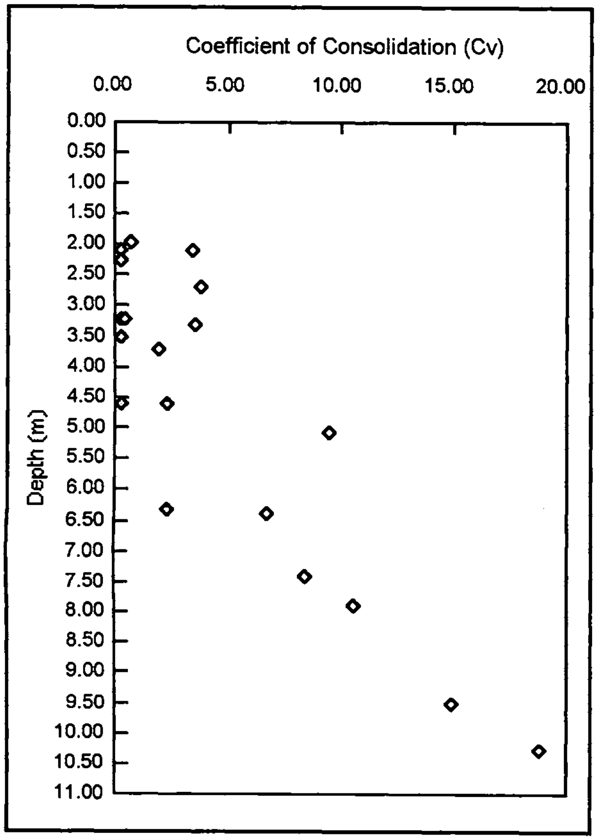

Figure 12. The coefficient of consolidation (Cv) versus depth (m).

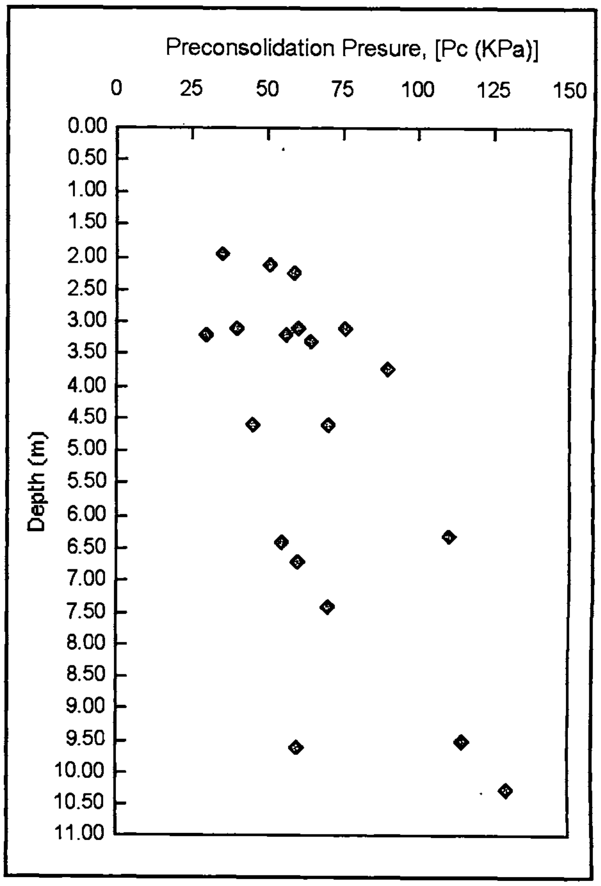

Figure 13. Preconsolidation pressure (Pc) versus depth (m).

increase in moisture content with depth and the decrease in the sand with depth.

The variation of recompression ratio (Cr) with depth shows that there are no obvious trends between the recompression ratio (Cr) and depth. Consequently, the variability in this value is more a function of the soil test than soil properties.

Preconsolidation pressure

The preconsolidation pressure (Pc) is important in determining the settlement of soft soil under external loading. Figure 13 shows the trend between preconsolidation pressure (Pc) and depth. The trend shows a general increase in Pc with increasing depth.

Ho and Dobie (1990) described how uniform incremental loading can be used to determine Pc more accurately than recognized international standards. This trend means that Pc for a soft soil deposits may be determined together with the extent to which it will consolidate. This is extremely useful when any ground treatment is to be undertaken.

PROPERTIES OF THE SOFT SOIL

Unlike other construction materials, soil is non-homogeneous and its properties are highly variable and complex (Cox, 1968; Abdullah and Chandra, 1987; Amin *et al.*, 1987; Ramli Mohamad *et al.*, 1994; Bujang *et al.*, 1995).

The plasticity chart plot, Figure 14, Figure 15 and Figure 16 shows that the soft soil material are variable. Generally the soft soil material can be classified as very low plastic to highly plastic. It also inferred that the soft soil is between silt to clay size. For the Sg. Rasau soft soil, the type of clay is almost similar to those obtained for other clays.

The influence of increasing clay content on the plasticity index is also depicted in Figure 14 in accordance with Skempton (1953), the activity index (AI) is an indicator of clay mineralogy. A high activity index (AI > 1.25) usually denotes montmorillonite, while a low activity index (AI < 0.75) denotes kaolinite.

The results from the study area, shows the soft soil have a high activity index (AI > 1.25), even though the clay mineralogy of the soft soils comprise mainly kaolinite. Figure 14 also shows the relationship between plasticity index, percentage of clay fraction and the activity of the clay. The figure indicates that the clay samples from this soft soil have activities ranging from 0.5 to less than 2.0. The liquidity index falls into medium expansion to very high expansion.

Figure 15 shows that the soft soils have falls ranging from inorganic clays of high plasticity limits to inorganic silts of high compressibility and organic clays. Whereas Figure 16 indicates that the Sg. Rasau soft soils are slightly similar to organic silt and clay from Panama and New London clay.

CONSTRUCTION PERFORMANCE

The above engineering properties imply that road construction on the soft soil will be fraught with "slip circle" failure in the embankment slope and settlement will be occurring.

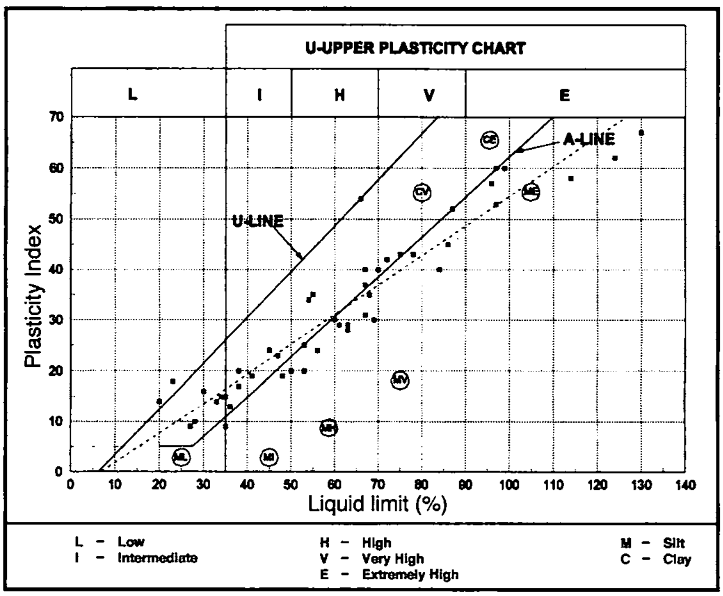

Figure 14. Plasticity Index versus Liquid Limit (%). Casagrande plasticity chart for cohesive soil.

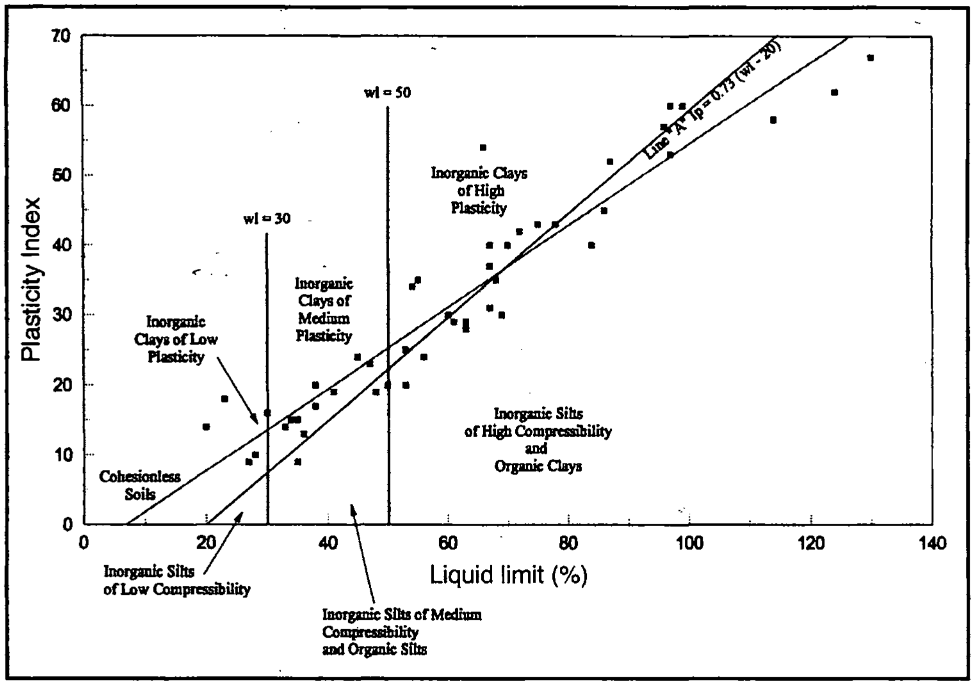

Figure 15. Plasticity chart.

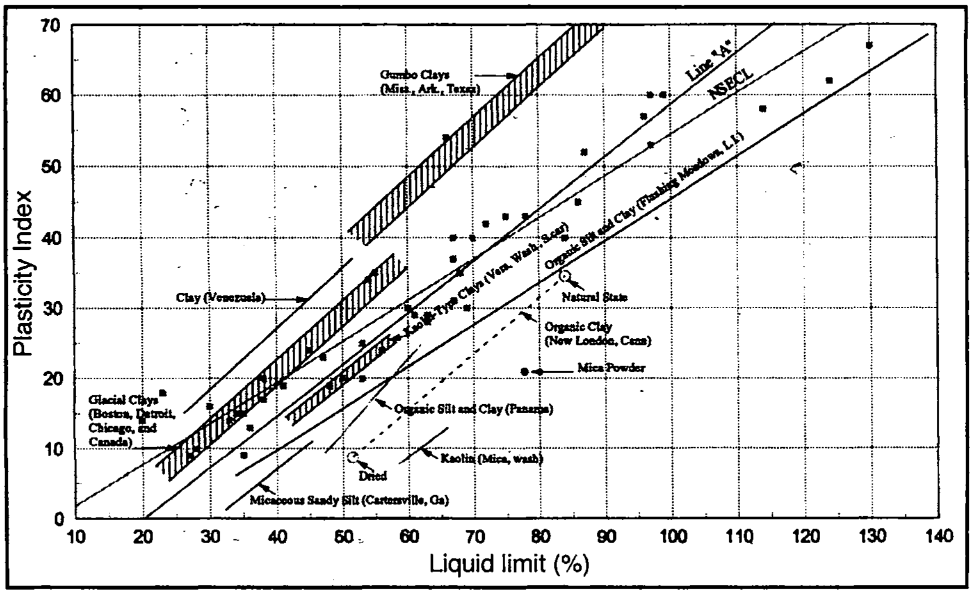

Figure 16. Relation between liquid limit and plasticity index for typical soils.

Method of construction

To improve the highway performance a few methods of construction have been applied such as excavation of unsuitable material, sand replacement and filling, pile supported embankment method and surface soil reinforcement method (Ting *et al.*, 1987; Terzaghi and Peck, 1990).

Surface soil reinforcement method

The method involves laying some reinforcement materials (geotextiles and geogrids) at the surface of the soft soil deposit before filling. The material are useful to ensure site trafficability, to control loss of fill materials and to reduce differential settlement of the embankment. They also provide horizontal restraint at the bottom of the embankment so as to reduce the risk of rotational or transactional failures of the embankment. It has to be highlighted that this method cannot reduce the final total embankment settlement which is related to the compressibility and thickness of the supporting soft soils deposits, and the amount of fill placed on top of the soft soils.

However, in some instances, the settlement can be speeded up by surcharging, thereby reducing the amount of post-construction settlements. Usually, the method is effective for low height embankment and for cases where regular maintenance can be implemented.

Replacement method/filling

The method involves removal of all or part of the soft soil and replacing it with suitable materials. The removal can be executed using excavation machinery. The excavation and backfill are carried out with or without dewatering. This is done immediately or to sand filling in order to keep the material free from laminants.

The first stage of sand filling shall be approximately one meter, which at the same time serves as platform for haulage carrying sand to the excavated area. On reaching adequate stretch of approximately 50 m, the sand layer of sandal shall proceed and the subsequent layer after the first one-meter shall be compacted satisfactorily by means of a vibratory roller. After that testing should be carried out immediately after the action or else the ingress of underground water is rapid and causes the existing water table to raise up and the fill will be soaked up with water and remains fully saturated.

Pile supported embankment method

As the name implies, instead of supporting the embankment load on the soft soil, this load is now supported on piles. Piles are installed and the pile tops are capped with a continuous r.c. slab or pilecaps with a strong geotextile spanning between the caps.

Thus the fill loads are transferred through the piles to a lower, more competent supporting stratum. This results in increasing bearing capacity and a drastic reduction of embankment settlement to an acceptable level, usually within 25 mm.

CONCLUSION

In planning, design and construction highway over soft soil deposits, the following are necessary in order to be able to implement a successful and cost-effective road construction:

i. Knowledge on geology of the area.
ii. Site investigation to determine the subsurface conditions especially the geotechnical properties of soft soil for this area.
iii. Assessment of various methods of construction and limitations of each method.

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