GLOBAL JOURNAL OF GEOLOGICAL SCIENCES VOL. 4, NO. 1, 2006: 65 - 71
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STRATIGRAPHIC INFLUENCE ON SOME ENGINEERING PROPERTIES OF THE FOUNDATION SOILS IN PARTS OF SOUTH WEST OF LAGOS METROPOLIS, NIGERIA

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(Received 19 March, 2005; Revision Accepted 5 December, 2005)

ABSTRACT

A geological and geotechnical study of the foundation soils in parts of southwest Lagos metropolis was carried out to determine the cause(s) of building failure in the area. Geotechnical sub surface exploration program at twelve different sites were used.
Analysis of results indicates that the foundation soil is a series of geologically recent alluvium deposits that can be classified into three strata. The derived engineering parameters of the soils reflect the effects of their stratigraphic outlay.
The normal consolidation recorded for the soils of the middle stratum as compared to pre-consolidation of the soil of the upper stratum indicates that the over consolidation is not due to removal of overburden. The variation in OCR value, and other engineering parameters such as cohesion, void ratio, Atterberg indices both laterally and vertically are due mainly to the localised influences of their stratigraphic outlay through the effects of ground water fluctuations and desiccation. This has considerable effects on settlement characteristics and the bearing capacities of the soils. The study offers a reasonable basis for the general diagnosis and prediction of specific engineering properties and behaviour of foundation soils elsewhere in the metropolis where similar stratigraphic units can be clearly discerned.

INTRODUCTION

Lagos metropolis with land area of about 500 sq. km (Balogun 1980) is a major center of commercial and industrial activities in Nigeria due to its proximity to the seaport. The relatively flat terrain of most parts of Lagos and the occurrence of swamps in over twenty percent (20%) of its land area, have resulted in an acute shortage of available land for building development. The rapid rate of urban development has also led to the high rate of reclamation of marginal land for building development.
The superficial sediments in such marginal land are commonly soft cohesive deposits of recent geological age, which are generally incompetent as foundation soils. Hence the failure of structures, which are not supported with the appropriate foundation designs, is a common feature.
Geotechnical description of the foundation soils based on interpretation of site investigation reports is found in literature (Farrington, 1961, 1980, Ajayi et al 1983, and Balogun 1980). There is however paucity of information on the influence of geological condition on the engineering properties of the investigated foundation soils.
Surulere area in the southwest of the metropolis represents an example where the derived engineering parameters of the soils show good correlation with discernible stratigraphic mapable units. This study offers a good understanding of the engineering properties of the soil from geological perspective.

SITE LOCATION AND DESCRIPTION

The area of study is located within the mainland part of Lagos metropolis, Lagos State. The area falls within the geographical co-ordinates of latitude 6° 28' – 6 °31' North and Longitudes 3 °19 – 3 °22' East. The area includes Surulere, Itire, Ikate, Aguda, Ijeshatedo and Iganmu (Fig. 1).

GEOLOGICAL SETTING

Lagos metropolis is within the **Southwest Nigeria part** of the Dahomey basin (Jones & Hockey, 1964; **Adegoke & Omatsola 1981**). The Quaternary deposits of this basin directly underlie most part of Lagos metropolis and thereby constitute the foundation soils. Allen (1964, 1965) indicate that deposition of the late Quaternary deposits on the continental shelf and the Niger delta occurred under the influence of fluctuating Pleistocene eustatic sea level.
Lithological and geotechnical description of the on-shore Quaternary deposits are found in literature (Farrington 1961, Ajayi, et al 1983). The subsoil condition at depth interval of 15m to 35m for most parts of Lagos consists of an organic clay stratum that is over consolidated (Ajayi, 1980) This clay stratum has been shown (Ajayi et al 1983) to correspond to the offshore ridge at depth between 15m and 31m below present sea level, and which has been dated (Allen, 1965) as being at least 3380 +/- 150years
The subsoil condition from ground surface to a depth of about 15m varies for different parts of Lagos.

METHOD OF STUDY

Geotechnical subsurface exploration program at twelve different sites comprising of thirty-one shell and auger boring were utilized for this study. Twenty-three borings were terminated at depths of 20m to 35m, and the other nine borings were terminated at depths of between 10m and 15m. Soil samples were colleted at intervals of 1m to the terminal depths of the borings. The subsoil drainage conditions of the area were also determinated from the borings.
Undisturbed soil samples were obtained within the zones of cohesive material with the aid of U-4 sample tubes. Laboratory tests carried out on selected soil samples includes: grain size analyses, consistency limits, natural moisture contents, quick un-drained tri-axial compression and oedometer consolidation tests.

RESULTS AND DISCUSSIONS

a. Subsoil Profiles

Correlation of the boring logs indicates that the subsoil from ground surface to about 35m depth consists of recent alluvium deposits that can be classified into three main strata. The first stratum, which occurs from ground surface to about 9m depths varies in lithologic composition. The stratum is composed of lateritic sandy clay in the northern part and soft to firm deposit of silty clay in the southern part. In waterlogged and swampy

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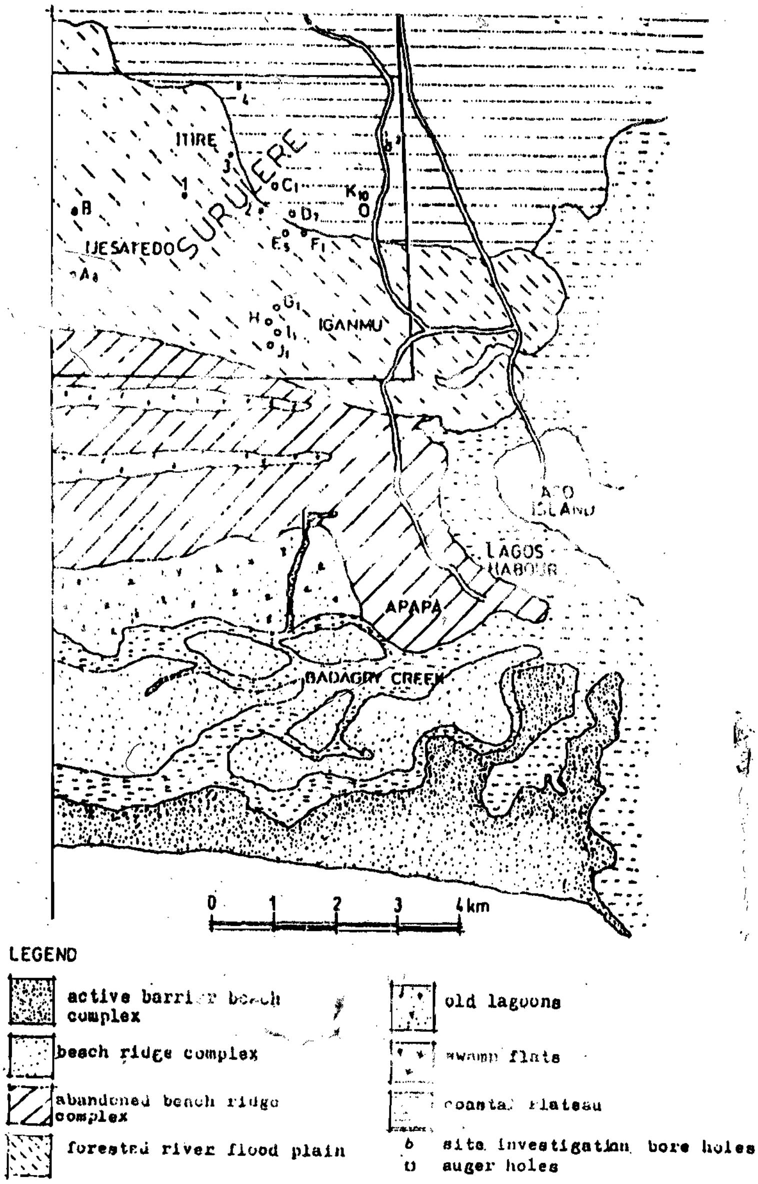

Fig.1 Geomorphology of Western Nigeria coastal zone showing area of investigation /in box/ within the forested river floodplain and coastal plateau /modified from Adegoke et al. 1980/

sections, the stratum is composed mainly of soft amorphous peat.

The second layer is composed of sandy silty clay deposits, which in some areas terminate at a depth of about 16m and others extends up to a depth of about 25m. Thin bands of dense sand often occur within this layer.

The third layer is a deposit of stiff dark brown organic clay occurring from depth of between 16m and 25m and extending up to 35m.

The derived generalized subsoil condition is shown in Fig. 2

b. Depositional Consideration

The process of stratigraphic outlay of the foundation soils may be deduced from the fact that organic clay sediments which constitute the third layer in the study area is part of the organic clay stratum that occurs at depth of 15m to 35m in most parts of Lagos metropolis and which has been described in details by Ajayi, 1980.

A correlation of this clay stratum with the dated continental shelf sediments (Ajayi et al, 1983) with modifications by Salami 1990 indicates deposition in an inundated environment that existed throughout Lagos metropolis during the early Holocene (about 3380 YBP). Apparently, erosional activities of the succeeding period led to deposition of the eroded materials from the upland on top of the organic clay stratum.

These deposited materials constitute the sandy silty clay of the second stratum, as well as the lateritic sandy clay and the soft silty clay of the first stratum. The organic matters of the eroded materials were later deposited in the relatively calm waterlogged environment of the southern part to form the amorphous peat.

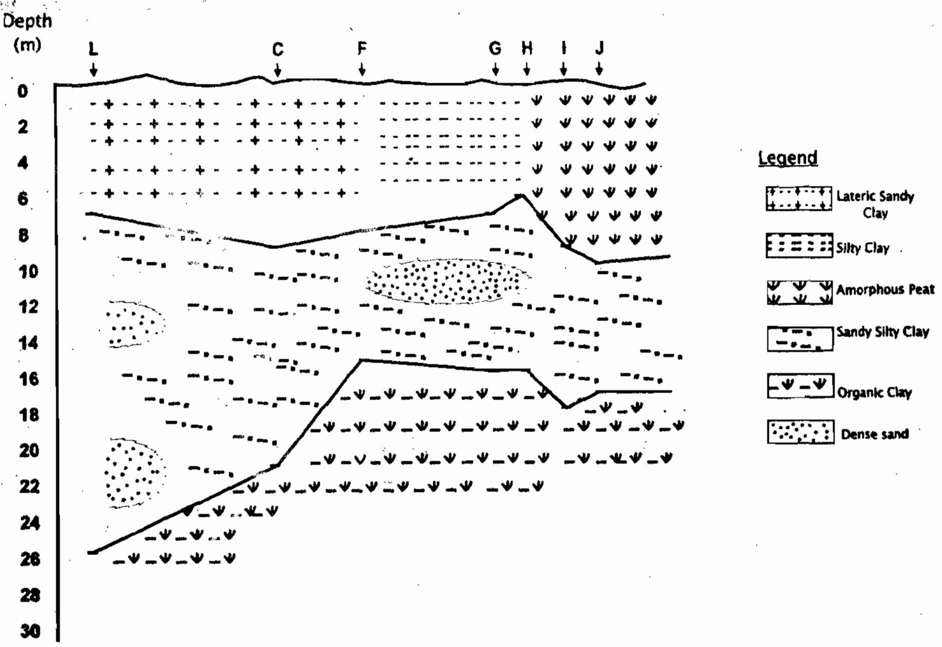

Fig. 2: Generalize subsoil profile of the study area

c. Geotechnical Properties

The laboratory test results obtained are presented in Table 1.

(i) Index properties

The index properties of the foundation soils that constitute the first stratum vary widely depending on their composition.

The average value of the natural moisture content for the soils generally increase from 18.4% for the lateritic sandy clay in the northern part, to 22.6% for the silty clay in the southern part. Exceptionally high value of 302% was recorded for the amorphous peat that occurs in the waterlogged parts of the area.

The average values of liquid and plastic limits, plasticity and liquidity indices increase for the soils in the same trend.

Table 1: Summary of Geotechnical Property of the Foundation Soils In South West of Lagos Metropolis

	1st Layer			2nd Layer
	Lateritic Sandy	Silty Clay	Amorphous peat	Sandy Silty Clay
Natural Water Contents (m.c) %	13 – 22	16 – 51	90 – 594	15 – 31
Liquid Limit (LL)%	39 – 51	39 – 104	51 – 674	24 –38
Plastic Limit (PL)%	13 – 16	11 – 31	44 - 211	7 – 13
Liquidity Index (LI)%	0.1 – 0.27	9.1 – 8.5	48 – 148	0.59 – 0.81
In-situ void ratio (e_o)	0.45 – 0.60	0.54 - 1.532	5.06 – 17.0	0.46 – 0.88
Bulk Unit Weight (γ_b)Mg/m^3	2.04 – 2.69	1.84 – 2.11	0.95 – 1.38	1.85 – 2.12
Dry Unit weight (dγ) Mg/m^3	1.69 – 2.35	1.09 – 1.81	0.14 – 0.78	20
Specific Gravity (S.G)	2.67 – 2.69	2.05 – 2.65	2.26 – 2.47	
Cohesion (Cu) kN / m^2	25 – 190	11.24 – 103.6	4.0 – 10.0	20 - 40
Angle of internal friction (Φ)	5- 15^0	0- 14^0	0^0	
Cu / p_o Ratio		6.55	0.21 – 0.58	0.16 – 0.27
Compression Index Cc	0.04 – 0.11	0.04 – 0272	1.25 – 6.7	0.76 – 138
Coeff: of Consolidation (Cv) (m2 /yr) Stress range (kPa) 12.5 - 25			0.5 – 20	
25 – 50			0.3 – 1.0	
50 – 100		1-27	0.1 – 1.0	
100 – 200	1- 3	1-23	0.3 – 0.4	1 – 6
200 – 400	1- 2	1- 3		1 – 3
400 – 800	1-2	1- 2		1 – 4
Coeff of volume change (Mv): Stress range (kPa) 50 – 100	0.067 – 0.091	0.092 – 0.19		
100 – 200	0.045 – 0.077	0.062 – 0.198		
200 – 400	0.032 – 0.06	0.018 – 0.126		
400 – 800	-	-	-	-
Consolidation ration (OCR)	1.54 – 8.0	1.19- 2.3	0.58 – 1.0	0.74 – 1.14
Ultimate bearing capacity (kPa)	452	357	36	
Safety factor	3.0	3.0	2.0	
Max. safe bearing capacity (kPa)	151	119	18	
Allowable bearing pressure (kPa)	131	20 – 89	1.5	

As shown in Fig. 3, the lateritic sandy clay and the silty clay plot above the Casagrande's A-line and within B-line and C-line indicating low to medium plasticity. In contrast, the amorphous peat plots below the A-line and well after the B-line indicating organic and plastic nature of the soil. In addition, the natural moisture content of the amorphous peat is generally above the liquid limit indicating normal consolidation.

Moderate in-situ void ratio values of 0.53 and 0.70 were recorded for the lateritic sandy clay and the silty clay respectively, whereas, high value of 10.31 was recorded for the amorphous peat. Average bulk unit weight for the soils decrease from about 2.14 (Mg/m^3) for the low plastic soil, to a low value of about 1.20 (Mg/3) for the organic and highly plastic amorphous peat.

The sandy silty of the second layer has average natural moisture content of 20% and plots above the Casagrande's A-line indicating low plastic nature. Average in-suit void ratio of the soil is about 0.60. The organic clay of the third layer plots below the Casagrande's A-line.

(ii) **Shear Strength Characteristics**

Average cohesion (Cu) values recorded for soils within the first stratum range from 58.5kN/m^2 for the lateritic clay to 48.35kN/m^2 and 6.8kN/m^2 for the silty clay. The amorphous peat in the waterlogged section has low cohesion (Cu) value of 6.8kN/m^2. Over consolidation of the lateritic sandy clay and the silty clay is indicated by the plot of Cu/Po-Ip for the soils above Skempton's line, whereas the plot of Cu/Po-Ip for the amorphous peat below the Skemton's line indicates under-consolidation (Fig. 4).

The sandy silty clay of the second layer has average Cu value of 30kN/m2. the plot of the values of Cu/Po-Ip close to the Skempton's line for this soil suggest normal consolidation.

Bearing capacity values of foundation set at 1m below ground surface are summarized in Table 1. These were calculated

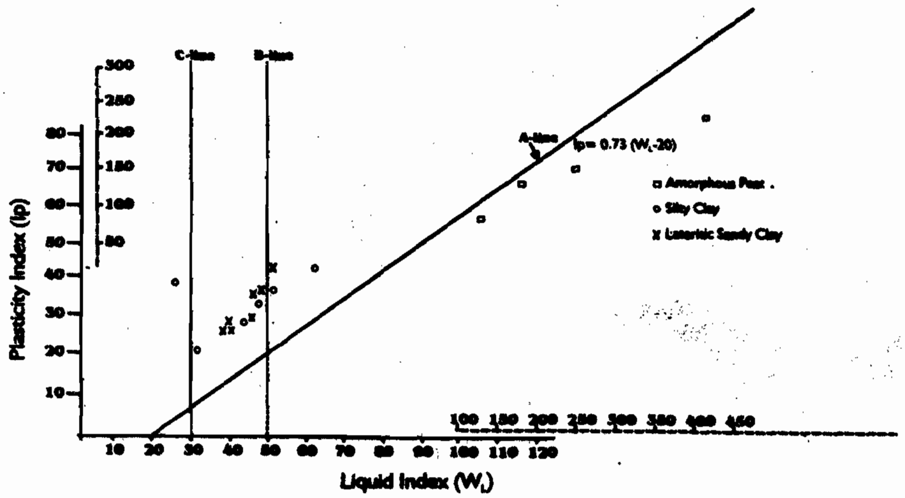

Fig. 3. Plot of Plasticity Index (Ip) versus Liquid Limit (WL)

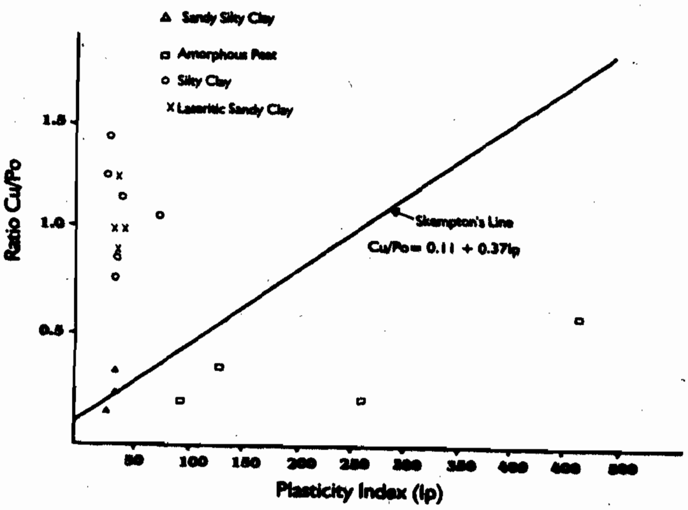

Fig. 4. Plot of Cu/Po versus Plasticity Index (Ip)

with the general bearing capacity equation of Terzaghi and Peck (1967).
The high variation in Cu values for the lateritic sandy clay and the silty clay would lead to the use of safety factor of 3. The amorphous peat has low variation in Cu values hence the use of safety factor of 2 is recommended.

(iii) Compressibility

The soils within the upper stratum exhibit variation in compressibility both laterally and vertically. The lateritic sandy clay has high OCR value that ranges from 1.54 to 7.9, and pre-consolidation pressure (σ_p) of 125 kPa to 215 kPa. These indicate heavy over-consolidation. The soft to firm silty clay is slightly over consolidated with pre- consolidation pressure (σ_p) that ranges from 28 kPa to 98 kPa and OCR values of between 1.8 and 2.3. The amorphous peat is under consolidated as indicated by OCR values between 0.58 and 1.0.
The parallel occurrence of the mean preconsolidation line and the mean overburden pressure line for the silty clay indicates constant difference in values of preconsolidation and overburden pressure with depth (Fig. 5). Such constant difference is attributed to over consolidation due to changing ground water level (Crooks and Graham 1973). These generally results in desiccation.
However, localized decreases in OCR values with depth were observed for both the lateritic sandy clay and the silty clay indicating decrease in effect of desiccation with depth (Fig. 5).
The sandy silty clay of the middle stratum is normally consolidated as indicated by average OCR value of 0.96.
Laboratory tests of the samples of the organic clay layer stratum that constitutes the third layer within this study area indicate over-consolidation of the soil with OCR value of between 1.1 and 2.5.

iv. Settlement Characteristics

Consolidation settlements ΔH for the lateritic clay are calculated using values of Coefficient of compressibility (Mv) and the equation ΔH = H. ΔP. Mv.

In view of the highly compressible nature of the amorphous peat, the consolidation settlement was calculated with equation:

$$\Delta H = H_o \frac{C_c}{1+e_o} \log \frac{(P_o + \Delta P)}{P_o}$$

Similarly, consolidation settlement of the slightly over consolidation silty clay was calculated with equation (Holtz & Kovacs 1981)

$$\Delta H = H_o \frac{C_r}{1+e_o} \log \frac{\sigma_p}{P_o} + H_o \frac{C_c}{1+e_o} \log \frac{(P_o + \Delta P)}{\sigma_p}$$

Where ΔH = Consolidation settlement
H_o = Original Thickness
Cc = Compression index
ΔP = Stress increment due to load
Po = Overburden pressure
e_o = Initial void ratio
Cr = recompression index
σ_p = Preconsolidation pressure

The lateritic sandy clay, which is heavily over-consolidated due to its high degree of desiccation, is likely to have relatively small settlement under building loads. This is attributed to the fact that final consolidation stress σ_{cf} is commonly less than it preconsoildation, σ_p, value that ranges from 125 kPa to 215kPa. The silty clay believed to be moderately desiccated is correspondingly slightly over-consolidated. The pre-consolidation stress of this soil most likely plays significant role in the amount of settlement recorded for it. When building load is less than the pre-consolidation stress, the amount of settlement is generally low.
On the other hand, when the load imposed on the soil is more than the pre-consolidation stress (σ_p) high consolidation

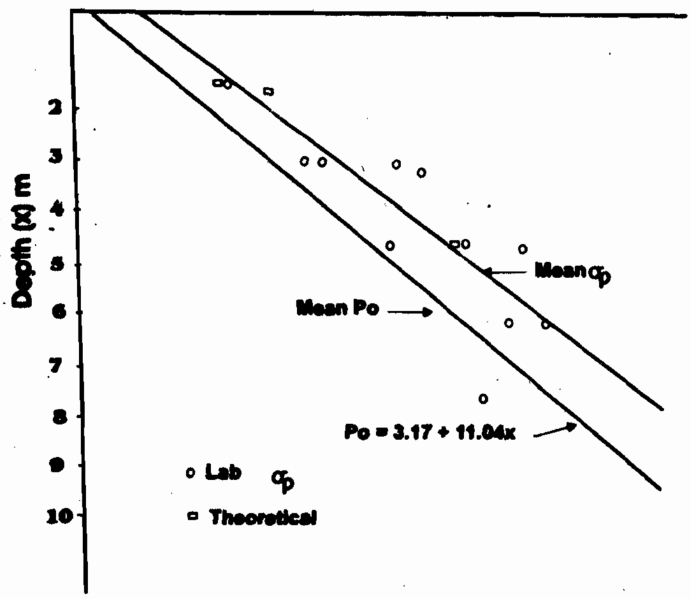

Fig.5: Pre-consolidation pressure (σ_p) versus depth for the silty clay.

settlement is recorded. The under-consolidated amorphous peat has large amount of settlement under load (Fig. 6 and 7).
The significance of the pre-consolidation is that the lateritic soil can support heavy structures of up to 131kPa. The silty clay may support light structure with necessary reinforced shallow foundation designs. The amorphous peat is incompetent as foundation soil, hence building loads must be transferred through the deposit to the underlying sandy silty clay deposit by means of piles.

CONCLUSION

Stratigraphic outlay significantly affects the geotechnical properties of the foundation soils in parts of South west Lagos metropolis. Noteworthy is the normal consolidation recorded for the sandy silty clay of the second stratum as compared to the over consolidation recorded for the soils of the upper stratum (except the amorphous peat).
This phenomenon indicates that over consolidation of the soils of the upper stratum is not due to removal of overburden by erosion, but due to fluctuations in ground water level and desiccation.
Other effects of startigraphic outlay are the lateral variation and the engineering properties of the soils of the upper stratum. The effect on the engineering properties includes increase in index properties from the lateric sandy clay to the amorphous peat as well as decreases in densities, cohesion and OCR values in the same trend. The amorphous peat probably represents the most recent deposits in the area and occurs largely below water table, with minimum influence of groundwater fluctuation and desiccation.

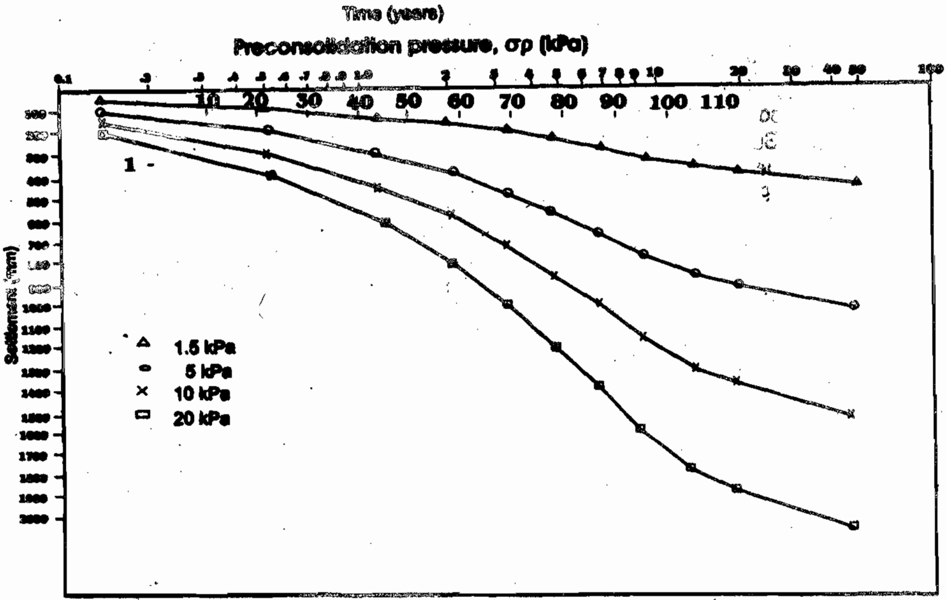

Fig. 6. Plot of Settlement (consolidation and secondary) against logarithm of time for different building stress on 9m thick amorphous peat

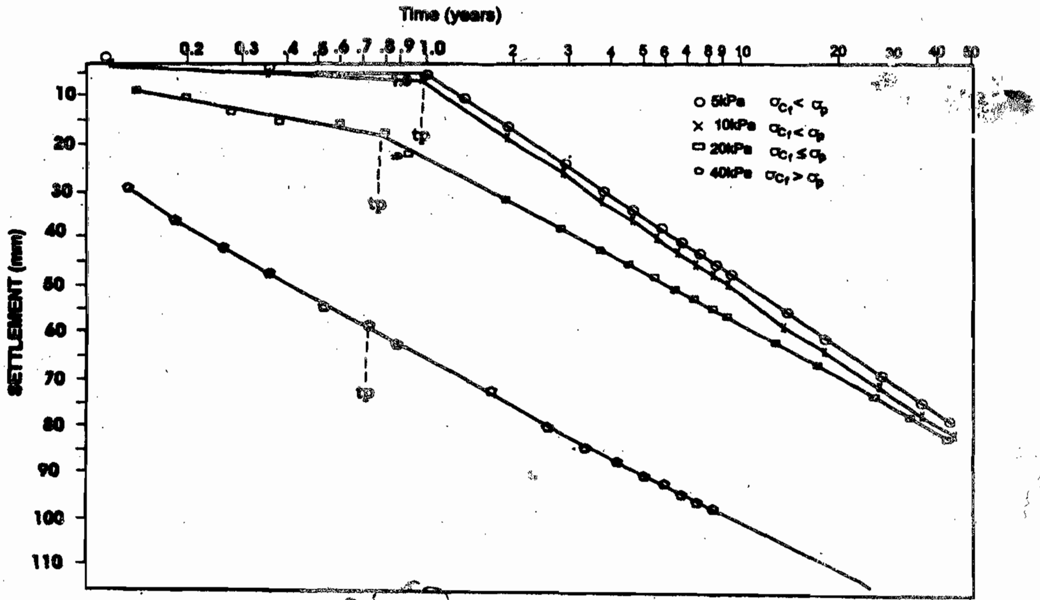

Fig. 7. Plot of settlement against logarithms of time for different building stresses on 9m thick silty clay.

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