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CASE STUDY OF SUBSURFACE CONDITIONS OF FLOOD PLAIN IN WESTERN KENYA

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ABSTRACT

An investigation was carried out to assess the subsurface suitability of the River Nzoia floodplain in Budalangi Division of western Kenya for supporting shallow foundation structures. An analysis of the conditions in the area during flood seasons was conducted using soil mass characterisation, geotechnical testing, slope stability analyses, terrain evaluation and analysis of ground conditions in buildings in the area. The analyses reveal that significant slope failure occurs when the percentage of water exceeds 50% in slopes cut at angles greater that 24°. The suitability of the ground for supporting shallow foundation structures has been established from the results of fieldwork and from laboratory studies.

Keywords: Floodplain, foundation structures, site conditions, geotechnical testing, normal stresses

1. INTRODUCTION

The sites have been classified into five categories according to Zaruba and Mendl [7]. The categories are; Very suitable sites, providing foundation soils that do not present any problem and a small width of footing is possible. Suitable sites differing from those in the above category in that a problem does arise during excavation such that a wide footing is necessary. Conditionally suitable sites, where the layout and the particulars of the structure must be adopted to the site conditions. Sites of low suitability, where foundations present so many difficulties that the construction costs increase steeply and Unsuitable sites, where only exceptionally high costs can make a given construction work possible

Budalangi Division, one of the most devastated floodplains in western Kenya is underlain by loose sedimentary deposits that have been deposited by floods. It is a flat- lying area that borders Lake Victoria. The area described here is bounded by longitudes 33° 57′ E and 34° 00 E′ and latitudes 0°03′ S and 0°06′ S. Approximately 28,000 people live in this floodplain. However their spatial distribution is quite uneven, with some places being completely deserted. An explanation to this is the flood- related problem associated with this floodplain.

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A strong possibility of reclamation of the floodplain in the near future, the need to establish the causes of failure in structures as well as the need to establish the sites suitable for building shallow foundation structures (schools, roads and houses) have acted as a source of inspiration for presenting this case study of one of the most devastated plains of Kenya. Some of the characteristic problems of structures are; cracking of buildings, tilting of structures, breakdown of roads and failure of artificial and natural slopes. Problems affecting human settlement include destruction of homesteads by floodwaters and abundant malaria-causing parasites. Geotechnical design teams will use results of this engineering geologic investigation to develop appropriate design elements to address each of these suitability issues.

2. MATERIALS AND METHODS

The sampling sites comprised of areas along which road development will soon take place, building sites and areas where cracks in buildings and tilting of structures were observed. The sampling procedure was random. Investigations in the swamps were not particularly successful in the area in that groundwater levels and the instability of the surrounding ground greatly restricted the sampling sites. During the course of investigation, a total of thirty four samples were collected from depths ranging from 0.7m to 1.0m The samples were collected by augers and U_{100} samplers. Sampling depths correspond to those mainly adopted for buildings. In the laboratories, most of the samples were found to be identical, thirty-four samples were narrowed down to eight samples that mainly differed in colour and grain size. Several properties of soils were investigated in the laboratory according to the approved international standards namely, British Standards (BS), American Standards of Testing and Materials (ASTM) and International Society for Rock Mechanics (ISRM) standards [1,2,3,4,5,6]. Geotechnical laboratory investigation included particle size analysis by sieving and sedimentation, analysis of consistency limits, free swell analysis, analysis of consolidation/settlement characteristics and soil strength analysis using shear-box and triaxial methods.

The particle size analysis test has the scope of grouping constituent particles into separate ranges of sizes. The ultimate purpose was to determine the relative proportions of dry weight of each size range especially the clay fraction that has direct bearing on the engineering properties of soils. The test procedure incorporated two separate and different phases namely, sieving and sedimentation. Sieving was used to separate gravel and sand size particles into different size ranges by employing a series of sieves of standard aperture openings [1,2]. Sedimentation was employed in analysis of particle sizes of much smaller silt and clay fractions. The results of particle size analysis were presented in form of tables and graphs. The tables show the percentages of particles finer than certain sizes [1,2,3]. In the graphical method the results are presented in the form of a particle size distribution curve (grading curve) in which, percentages finer than any given size are plotted against the particle size on logarithmic scale.

Moisture content in soils can influence their engineering behaviour and in the laboratory, it was measured at various test conditions as an index test. Consistency limits tests reflect

the influence of water content grain size, and mineral composition upon the mechanical behaviour of clays and silts. There is a range of moisture contents within which a clay soil exhibits a plastic consistency. To account for this behaviour, use was made of consistency limits to measure and describe the plasticity range in numerical terms.

The liquid limit, LL, is the moisture content at which a soil passes from plastic state to liquid state as determined by this test. The procedure for determining the liquid limit made use of a cone penetrometer. In this method measurements were made of the amount of penetration into the soil of standardised specific mass. At liquid limit, the penetration is usually 20mm. Plastic limit is the moisture content at which a soil sample ceases to behave as a plastic solid and becomes friable and crumbly. Plasticity index is the moisture content between plastic limit and liquid limit. The results of consistency limits test were presented both in form of tables and graphs. The tables showed the cone penetration at various percentage moisture contents. The graphs showed the amount of penetration with moisture content.

Free swell test served to indicate the possible expansive properties of soils. Free swell is the increase in volume of a soil from a loosely dry powder form when it is poured into water, expressed at a percentage of the original volume. Shear-box and triaxial tests were carried out to determine the shear strength of soils. The tests were performed on both undisturbed and remoulded soil samples. The results of shear tests were presented in the form of tables and graphs. The oedometer test served to determine the consolidation settlement characteristics of the soils. The purpose of the test was to establish the amount by which the soils would compress when loaded and allowed to consolidate.

3. RESULTS AND DISCUSSION

From particle size distribution curves, it was established that most of the soils in the floodplain have a silt/clay fraction exceeding 80% leading to high water retention (Table 1). On the plasticity charts, the soils were found to be of medium to high plasticity. Free swell tests indicated that a few soils have a low degree of expansion with a majority having medium to high degree of expansion (Table 2). Remarkable non- uniformity in shear strength is clearly a characteristic feature of this floodplain (Table 3). Consistent abundance of silty sands near Lake Victoria provide unequivocal evidence of single source of soils. Clearly, black cotton soils cover the major part of the floodplain. There is hardly any doubt that the black cotton soils below most buildings crack due to swelling and shrinkage during alternating wet and dry seasons (Table 4).

Table 1. Particle size distribution

No. of samples	Description of soil	Clay %	Silt %	S and %	Gravel
5	Brown lateritic sandy loam	52- 64	15- 34	<8	0
15	Black cotton soil	77- 85	<14	<3	<1
2	Red sandy loam	63-80	18-30	<9	<7
8	Dark grey silty sand	13-52	>81	15-25	<1
4	Grey sandy clay	44-68	43-52	8-20	<4

Table 2. Free swell test results

Number of samples	Description	Degree of expansion	Free swell %
10	Soils not likely to expand on wetting	Low	<50
24	Soils likely to expand on wetting	Moderate	50- 100

Table 3. Shear test results

Sample No.	Depth (m)	Triaxial test		Direct shear test	
		C (kN/m^2)	Φ^o	C (kN/m^2)	Φ^o
1	0.8	58	17	45	20
2	0.9	14	12	33	18
3	1.0	8	14	10	24
4	1.0	25	15	18	20

Table 4. Plasticity test results

Number of samples	Description of soil	LL%	PL%	PI	Linear shrinkage
5	Brown leteritic sandy loam	48	24	23	5
15	Black cotton Soil	50	30	20	21
2	Red sandy loam	25	14	11	11
8	Dark grey silty sand	nd	nd	nd	N/A
4	Grey sandy clay	50	30	20	13

***nd means not done**

The areas covered by non-cohesive soils require stabilization of the ground before building shallow foundation structures. The soils cave in easily and have a relatively deep slide, in this kind of soil only deep structures are tolerated. The slopes can be made at angles of less than 20°. Settlement of structures occurs due to deformation of near surface layers and also due to the presence of ground water. In the Mohr diagrams, their C is very small, but their increase in strength owing to increasing pressure is manifested by considerable value of Φ. When the foundation width and depth increases, σ also increases as the slip surface extends to greater depth. The danger of exceeding the bearing capacity of sand occurs with narrow and shallow foundations of walls especially after groundwater table has risen. The wall sinks into the ground, tilts and collapses.

Some buildings in Maumau (formally known as Idokho) area show settlement while others do not, indicating that settlement depends on the direct contact pressure between the foundation base and soils at that particular point. Some buildings in Budala (Bunaba) area show a lot of cracks on the floor, more cracks are observed at the centre than at the sides. This indicates that despite the fact that the soil was uniformly loaded, there is more settlement at the centre than at the sides.

Black cotton soils are feared owing to the large settlements of structures and possible destruction of buildings by volume changes. From the laboratory analysis, it was indicated that the soils are unconsolidated and therefore a maximum allowable loading of 200 kN/m^2 is necessary. Many stiff clays begin to behave in a ductile manner when normal stresses amount to 200 kN/m^2.

Ground water level was carefully investigated with special attention paid to wetter periods. Loss of cohesion in cohesive soils results from infiltration of rainwater into surface layers. The normal stress σ is small near the surface and thus only a section of the strength curve in the Mohr diagram is valid, where the curve bends down towards the coordinate origin. This section of Mohr curve displays a very small magnitude of τ_0 but Φ =40°- 45°. Considering the statical loading by penetrating water, the safe angle of slope should be less than 20°. Steeper slopes deform, suffer from cracks which are penetrated by water and the

surface layer collapses.

Artificial slopes in the area are very unstable due to the fact that they were cut at very high angles during the construction of the adjacent dyke. A very unsuitable situation arose during the construction of the dykes in the area. The subgrade of the route was situated lower than the surrounding ground surface, so that the necessary gradient of drainage was unavailable. A roof- like reverse gradient was created to obtain sufficient drainage of the fill slopes. However in some areas, this drainage is so insufficient such that the dykes have been cut through by the violent floodwaters.

The other cause of slope failure in the fissured clay in the area is that the fissures open because of stress relief or desiccation, so that water can penetrate the soil. Groundwater present in the slope decreases the effective stress between the clay particles while the tangential forces do not diminish. The effective stress decreases because of the presence of water molecules between the soil particles, the tangential forces do not diminish because of existence of a free surface of the slope towards which the face materials can collapse

The sand soil in Rukala area is said to be underlain by a clay layer which does not allow drainage from the sand soil, keeping it constantly wet and suitable for farming but unsuitable for building shallow foundation structures. When a clay layer is overlain by a non-cohesive soil, the clay layer deforms in a ductile way while the overlying non-cohesive soil suffers extension cracks and their contribution to shear resistance is small. The density of silty sand is rather low, owing to the silty character and the presence of water in the sand, the soils break easily and even small foundations cannot be excavated without installing drainage prior to excavation.

4. CONCLUSIONS

The floodplain in Budalangi area has most of its area covered by fine-grained soils that have varying geotechnical characteristics. However, the soils can be divided into two main groups namely, loose unconsolidated soils bordering the lake and clays with high plasticity and high swell volumes. The properties of the soils in the floodplain evidently get affected by the high groundwater table. Stability of slopes in the study area is controlled by local geological conditions, the shape of the overall slope in that area, the local groundwater conditions and the technique used to make the slope. The controlling factors vary so widely across the floodplain for different excavation conditions that it is impossible to give general rules on how deep a structure should be to ensure that it will be stable.

There are clear indications that tilting of buildings in the area is more prevalent in areas where the structures occur close together. Cracking of buildings is more prevalent in areas with black cotton soils. As far as the suitability of the ground for supporting shallow foundation structures is concerned, different problems are faced in selecting sites since the conditions differ widely. The soils of the study area afford building sites of varying suitability. The sites can be classified into five main categories according to Zaruba and Mendl [7].

1) **Very suitable sites** - Provide foundation soils that do not present any problem and a small width of footing is possible. These sites are found on the northern side of the Samia-

Wamia range of hills at Port Victoria and also at the foot of the hills**.**

2) **Suitable sites** - These differ from (1) in that a problem does arise during excavation such that a wide footing is necessary in order to distribute stress over a wide area. Sites consisting of red sandy loam, for instance parts of Bukoma, belong to this category.

3) **Conditionally suitable sites** - For this type of sites, the layout and the particulars of the structure must be adopted to the site conditions. This implies for example, the need for reduction of differential settlement by ingenious design of the foundation (including pile foundation). Areas covered by dark gray silty sand such as Rukala, and areas of relatively higher ground but made of sandy clays having dilatation joints such Khayega (Kholokhongo) area belong to this category.

4) **Sites of low suitability** - In such sites, foundations present so many difficulties that the construction costs increase steeply. These include areas, for example, between the first and the second dyke (near the river) and areas with high ground water table and covered by black cotton soils,for instance Maumau (Idokho), Musoma (Bunaba), and Rukunga (Ndekwe).

5) **Unsuitable sites -** In this type of sites it is only exceptionally high costs that can make a given construction work possible and this includes all the "permanent" swamp areas.

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REFERENCES

1. British standards, BS:1377, Code of Practice for Methods of Testing Soil for Civil Engineering Purposes, British Standards Institutions, London, 1975.
2. British Standards, Bs:5930, *Code of Practice for Site Investigation*, British Standards institutions, London, 1981.
3. British Standards, Bs:8004, *Code of Practice for Foundations*, British Standards institutions, London, 1986.
4. Brown, E.T., Rock characterisation, testing and monitoring, International Society of Rock Mechanics, Suggested Methods, Pergamon Press, London, 1980.
5. Brown, E.T., Suggested Methods for Determining Uniaxial Compressive Strength and Point Load Strength index of Rock Materials, International Society of Rock Mechanics, Pergamon Press, London, 1985.
6. Brown, W.T., *Annual Book of Standards*, American Society of Testing and Materials (ASTM), No. 2, **14**(1981), Philadelphia.
7. Zaruba, Q., Mendl, V., *Engineering Geology*, Elsevier Scientific Publishing Co., Amsterdam, 1976.