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Geotechnical Aspects for Roads on Expansive Soils

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Abstract: ***This paper presents some issues of geotechnical investigation for roads built on expansive soils. The aim of the study is to provide road engineers with guidance on site investigation; field and laboratory identification of expansive soils. A clear understanding of the expansive subgrade soils behavior and their geotechnical characteristics has been of more interest to the study in order to assess properly the source of the swelling problem. Two case study sites, representative known problem-areas in Khartoum were carefully selected for geotechnical site investigation. The field exploration consisted of excavating trial pits and collecting soil samples from the subgrade. These soils were subjected to laboratory testing for measuring the particle size analysis, consistency, strength and swelling characteristics. The soils were found to have over 50% clay particles, high plasticity index more than 30% and high free swell index of 160% to 250%. The compacted samples were found to have swell potential of 7% to 15% coupled with high swelling pressure in excess of 90 kPa and low strength, CBR values less than 4%. General conclusions have been drawn from the study findings.***

Keywords: Expansive soils, geotechnical, investigation, swelling, subgrade.

1. Introduction

Expansive soils are generally characterized by the presence of clay minerals of the montmorillonite (smectite) group. Such soils give rise to problems in civil engineering works because of their capacity to undergo large volume changes with changes in moisture content, which expand and shrink when the moisture in the soil changes.

Expansive soils prevail over a large area of Sudan and have caused significant damages to irrigation systems, water lines, sewer lines, buildings, roads and other structures located on these soils. The Damage caused by expansive soils was estimated by Charlie et al [1] to exceed $6,000,000 (30,000,000 Sudanese pounds) annually. However, the scarce knowledge about the behavior of road's subgrade in swelling soils is obvious behind the damages of pavements mainly due to the uplift forces and heave following wetting of the soil. Therefore the early identification and understanding of such soils is necessary to avoid costly problems.

The aim of the study is to improve the understanding of the behavior of these soils as road's subgrade and to clarify the proper procedure of geotechnical site investigation for road engineers.

2. Literature Review

Soils with a high percentage of swelling clay have a very high affinity for water partly because of their small size and partly because of their positive ions, [2]. The swelling behavior is usually attributed to the intake of water into the montmorillonite, an expanding lattice clay mineral in expansive soils. According to Chen [3], montmorillonite is made up of a central octahedral sheet, usually occupied by aluminum or magnesium, sandwiched between two sheets of tetrahedral silicon sites to give a 2 to 1 lattice structure. The three-layer clay mineral as shown in Figure 1 has a structural configuration and chemical makeup, which permits a large amount of water to be adsorbed in the interlayer and peripheral positions on the clay crystalline, resulting in the remarkable swelling of soil, [4]. Identification of the presence of expanding clay minerals in expansive soil, montmorillonite is carried out by using different methods such as x-ray diffraction, electronic microscopy, differential thermal analysis and wet chemical analysis, [5].

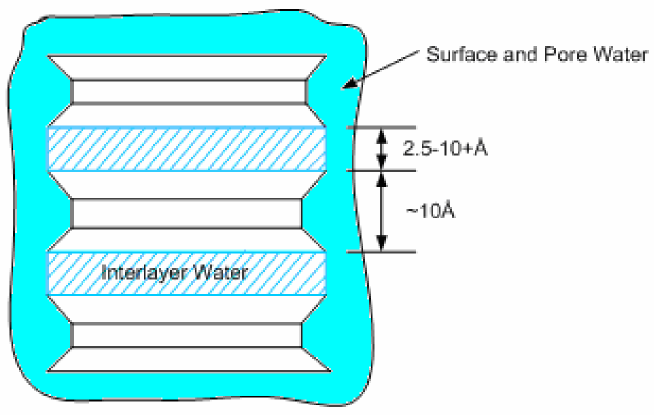

Figure 1: Structure of montmorillonite clay mineral, [4]

As reported by Nelson and Miller [6], there are various geotechnical techniques to identify the swelling soils. Surface examination, geological and geo-morphological description are more useful indicators of expansive soils. The surface examination has been considered first because of its importance in the determination of the subsurface exploration. Field estimates of shrink-swell potential can be made by observing desiccation cracks (Figure 2). The development of desiccation cracks in the ground surface is apparent during the dry periods. The degree of swell potential determines the size of the cracks, [2]. Great swell potential is indicated by large and more frequent polygon arrangements of cracks while low shrink/swell means that potential for shrinkage cracks developing is low. Soils containing expansive clays become very sticky and plastic when wet and adhere to soles of shoes or tires of vehicles. They are also relatively easy to roll into small threads. It is essential that the surface examination by visual-manual descriptive of the soil to be followed according to ASTM [7]. This standard insists, among other things, the reporting of the colour, moisture condition, consistence, structure and particle sizes.

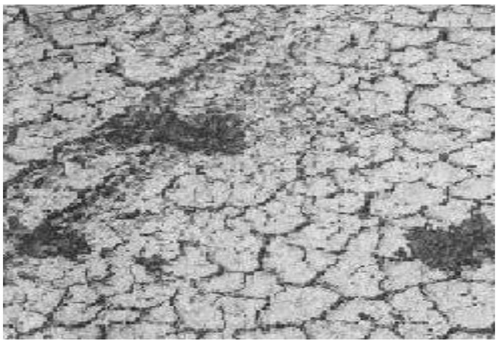

Figure 2: Expansive soil showing desiccation cracks.

Geological description is usually obtained by the study of the site history and geological maps. Information on the maps can give valuable idea of the soil composition as the preliminary information for further investigation, [8]. The geo-morphological description includes a host of many things such as ground water table situation, soil physical properties such as colour, consistency, surface texture, structure and texture groups etc. Most of the relevant physical and mechanical properties to give indicators of swell potential are obtained by performing geotechnical index property tests such as Atterberg limits, unit weights and grain size distribution. Other direct tests to determine the swell potential include volume change tests (free swell and swell in oedometer test), swelling pressure test and mineralogical compositions by x-ray diffraction (XRD) test.

The indirect methods to determine the swelling characteristics of the soils are essentially based on mathematical correlations of certain physicochemical properties and mineralogical composition. They empirically correlate soil index parameters such as water content, dry density, Atterberg's limits, clay content etc. to expansiveness. Nayak and Christensen [9] gave statistical relationships for swell percent (S) and swelling pressure (P) as:

$$S = (2.29 \times 10^{-2})(I_P)^{1.45} \times C/w_i + 6.39 \quad (1)$$

$$P = 2.5 \times 10^{-1})(I_P)^{1.12} \times C^2/w^2_i + 25 \quad (2)$$

where, S: is the swell percent, P_s: is the swelling pressure in KN/m^2, I_P: is plasticity index, C: is the clay content, w_i: is the initial water content.

Identification and measurement of swelling characteristics is an important factor for pavement design and construction on expansive soils. Identification of swell potential based on Casagrande's plasticity chart is shown in Figure 3 as proposed by Chleborad et al [10]. It is observed that soils of high potential for swelling are plotted in the zone typical for montmorillonite. The U-line indicates the upper bound for natural soils, thus no soil should plot above U-line. Another way of identifying the expansive soil is to use the activity method proposed by Cartel and Bentley [11]. The proposed classification chart is shown in Figure 4. The activity term in the Figure is defined as follows:

$$A_c = \frac{PI}{C - 5} \quad (3)$$

where PI: is plasticity index, C: is colloids (or clay) content.

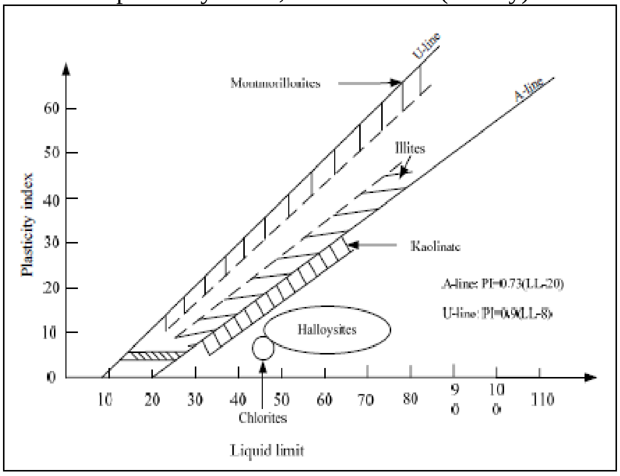

Figure 3: Plot of clay minerals on Casagrande's chart, [10].

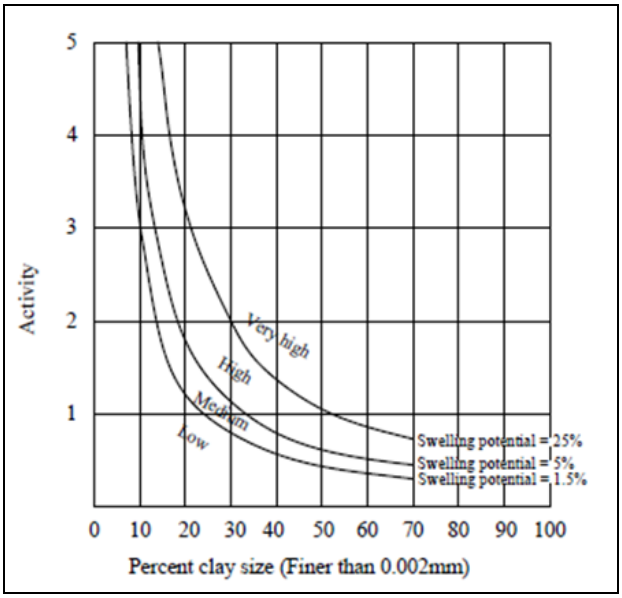

Figure 4: Classification chart for swelling potential, [11]

Charlie et al [1] reported typical damages to show the type, extent and causes of damages and provided information on design methods used in Sudan to reduce potential damages. They investigated more than 30 sites and found that over one third of Sudan's area may have potentially expansive soils and recommended all potential construction sites in the clay plain be evaluated for expansive soils. Problem of expansive soils results from a wide range of factors such as swelling and shrinkage of clay soils result from moisture change, type of clay minerals, drainage– rise of ground water or poor surface drainage and compression of the soil strata resulting from applied load. Other factors include, pressure of the backfill soil, soil softening, weather, vegetation and the amount of aging, [3], [12] and [2]. All these factors should be considered to come out with the appropriate design criteria for pavement design. With proper knowledge of the above indicatives, the potential for structural damage can be dramatically minimized or avoided. The engineering community is becoming more aware of the existence of expansive soils and their locations. As a result, more problems are diagnosed correctly, whereas in earlier years many expansive soils problems were incorrectly attributed to settlement.

3. Geotechnical Investigation

Geotechnical investigation practice for roads on expansive soils is important prior to construction. Site investigation varies from location to another, but within a particular area, local practices appear to be fairly similar. Soil exploration methodologies are usually step-by-step processes that develop as information accumulates. According to Nelson and Miller [6] and shown in Figure 5, the staged procedure involves three steps; reconnaissance, preliminary investigation and detailed investigation. The reconnaissance stage is mainly to review available information and perform a surface reconnaissance survey. The preliminary investigation is to conduct detailed surface mapping, preliminary borings, and initial laboratory testing and analysis for soil identification and classification. The detailed investigation is essentially to conduct soil borings for recovery of specialized samples for testing and analysis, conduct specialized field tests, and partial excavation. Results from each stage should be integrated and evaluated for their impact on design requirements and construction procedures. Field observations made during the reconnaissance survey and preliminary investigation phases can provide valuable data, and can be obtained easily, even by relatively inexperienced professionals.

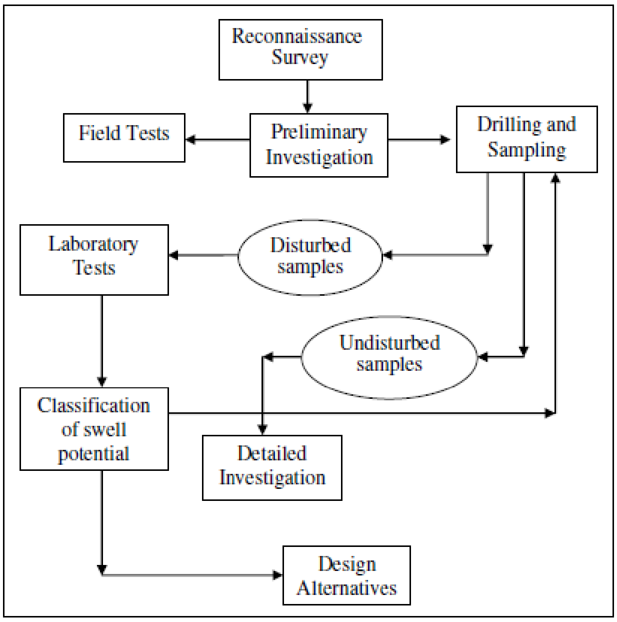

Figure 5: Flow chart for site characterization, [6]

4. Case Study

The primary objective of this study is to identify the key geotechnical information in the field investigation of roads on expansive soils. To achieve this objective, the field investigation was carried out on two major roads in Khartoum state. The experimental investigation was carried out by site exploration and laboratory investigation. Two major road sites, which are distinctly different in their geotechnical characteristics, were selected for this study; Algaba road in southern part of Khartoum and Shambat road in western part of Khartoum North.

4.1 Project description

Algaba road of 3km length connects the southern part of Khartoum with Omdurman by Al Ingaz Bridge. A portion of this road located at Almugran in Khartoum, 900m length had been plagued by cracking, rutting, and potholes. The road is a major transport facility for trucks and buses that transport goods and passengers from Omdurman to Khartoum south. This particular roadway section required frequent maintenance to maintain a heavy traffic pavement surface, and recently had received a 50mm overlay. However, within one year of construction, the overlay was badly cracked and rutted, again need repair. These conditions of pavement prompted the urgent need for a geotechnical investigation.

Shambat road is a major road located at the western part of Khartoum North of 2.5km length. This road has been experiencing considerable pavement failures since construction. Maintenance costs have been significant, and it appears that failures may simply be due to weak subgrade soil. The distresses of cracks, potholes and heave were likely associated with problems in the subgrade soils along the alignment. Potential causes could have included expansive soil, compressible soil, poor drainage. Distresses related to expansive soils exist throughout the road alignment, but significant damages concentrations are located in certain sections of about 1.2km length. A lack of adequate surface drainage is another critical factor leading to problems with expansive subgrade soils in this road.

4.2 Geotechnical information

The land topography in Khartoum state areas is almost flat. The soils originally are sediments filling and Nubian stones. The sediments filling are composed of alluvial deposits that include clay, calcareous sandstones, lime-stones, mud, and organic materials. In general, the alluvial deposits contain significant amount of the active clay minerals of montmorillonite, the most troublesome expansive clay mineral. Since montmorillonite minerals are very fine with large specific surface areas, their presence contributes to high degree of expansiveness of soil. Usually, the degree of expansiveness is proportional to the amount of montmorillonite or other expansive clay minerals present in the soil. The two sites of the investigated roads are the most famous areas in Khartoum of expansive clays of high swelling potential. Therefore roads and light structures in these areas suffered from severe failures.

4.3 Field Exploration

The field exploration composed of excavating trial pits to 2m depth below ground level. The trial pits were excavated manually using pick-axes and shovels. Three trial pits were excavated at each road site and undisturbed soil samples were collected using hand tools such as shovels. The samples were carefully packed in plastic bags and transported to the soil mechanics laboratory at university of Khartoum for testing. Disturbed samples were also taken from the trial pits, sealed, packaged, logged and transported to the laboratory. No water table was encountered within the depth reached by manual excavation, 2m. Generally, the ground water table in Khartoum is much deeper even during the rainy season.

4.4 Laboratory investigation

The laboratory investigation program for identification of swelling soils and their geotechnical characteristics has been performed to address the research objectives. The expansive soil is identified by their mineralogical composition and index properties. The tests were conducted to measure the soil physical properties, strength and swelling characteristics. Sieve analysis, hydrometer, Atterberg limits (liquid and plastic limits) tests were carried out for soil classification in accordance with BS 1377 [12] and Unified Soil Classification System. Oedometer tests were performed for measuring swell potential and swelling pressure of compacted soils. Whereas the free swell was measured in a graduated cylindrical glass jar of 100ml capacity.

4.5 Results and discussion

The tests results for the samples obtained from the subgrade soil of Algaba road (G_1 to G_3) and Shambat road (Sh_1 to Sh_3) are presented in Tables 2 and 3. Wet sieving and hydrometer tests were performed to obtain the particle size distribution of fine particles. The results of the samples are plotted in Figures 6 and 7. The results indicated that the soils have high clay content in the range 52% to 70% and small amount of sand and silt. The liquid limit and plasticity index values are very high and varied from 59% to 74% and from 30% to 40% respectively. Identification of the clay mineral type by using Casagrande's plasticity chart of Figure 3 and based on liquid limit and plasticity index values, the soils are plotted in the zone typical for montmorillonite. The activity of clay which was determined using equation 3 varied from 0.59 to 0.71 as given in Table 2. The results of the index tests clearly illustrated that the soils are cohesive of high plasticity with high to very high expansive potential and very active due to the presence of montmorillonite clay minerals.

Table 2: Index properties of soils samples

Sample	*Particle Size (%)*			*Atterberg's Limits (%)*			*Activity A_c*
	Sand	*Silt*	*Clay*	*LL*	*PL*	*PI*	
G_1	18	16	66	69	33	36	0.59
G_2	25	19	56	61	30	31	0.61
G_3	10	20	70	72	32	40	0.62
Sh_1	19	24	57	68	31	37	0.71
Sh_2	28	20	52	59	29	30	0.64
Sh_3	20	18	62	74	35	39	0.68

Table 3: Strength and swelling characteristics of soils

Sample	*CBR (%)*	*FSI (%)*	*S (%)*	*SP (kPa)*
G_1	1.5	180	10.1	105
G_2	2.5	160	9.5	93
G_3	1.2	250	15.0	130
Sh_1	3.2	172	8.7	95
Sh_2	4.0	165	7.0	90
Sh_3	1.6	205	10.5	122

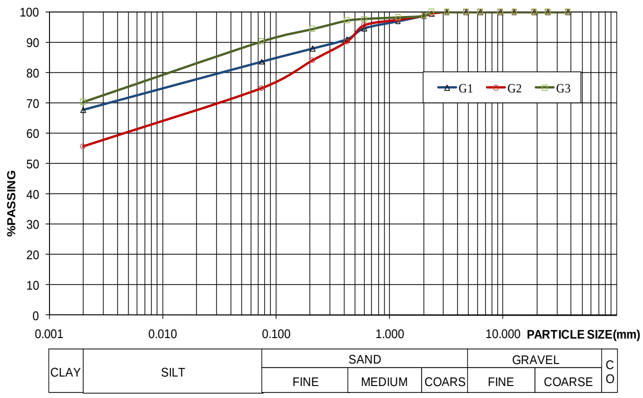

Figure 6: Particle size analysis for samples of Algaba road

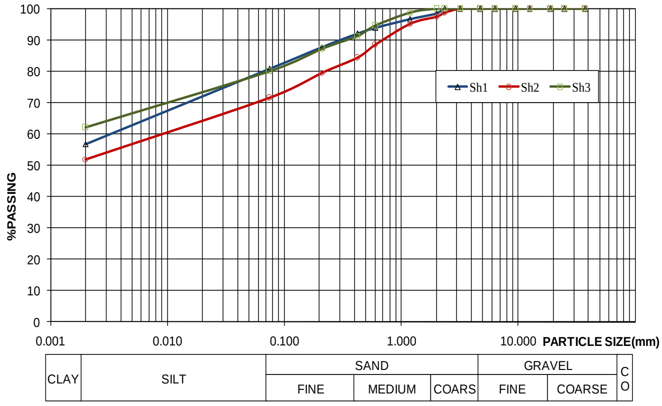

Figure 7: Particle size analysis for samples of Shambat road

The free swell tests on samples from the two sites were performed according to Holtz and Gibbs [13]. As observed in Table 3 high values of free swell index (FSI) in the range from 160% to 250%. The results indicate that the soils are associated with clay, which could swell considerably when wetted. The soils proved to have the ability to absorb and retain a great deal of water and undergo significant volumetric changes with moisture fluctuations (i.e. clay having high to very high swelling-shrinkage potential).

When the oedometer test was conducted on compacted clay samples, tested at seated pressure of 7 kPa it yielded swell potential (S) varied from 7% to 15% and swelling pressure (SP) values between 90 kPa and 130 kPa. This means that the expansive clay can exert high upward swelling pressure. The results of oedometer tests are presented in Table 3.

A subsurface investigation encountered moist expansive clay soils along the entire length of the roads. Based on soil conditions and the measured properties, the soils at both sites are highly plastic and moisture sensitive. The soil profile at Algaba road differed slightly from that at Shambat site. However, both profiles indicated the presence of clay in the soils. A typical subsoil profile of Algaba road shows a top layer of dry dense light grey sandy clay of high plasticity encountered up to 0.7m depth and followed by a layer of stiff black sandy clay with cracks that extended down to the end of the pit at 2m depth. The soil profile at Shambat site consists of dense grayish silty clay of 1.4 m thick that underlain by stiff dark grey silty clay of high plasticity. Apart from differences in colors, both profiles share similar geotechnical characteristics. However, the dominance of grayish color in almost all samples was interpreted to reflect the presence of montmorillonite in the soils.

5. Conclusions

Based on the study results, the following general conclusions can be drawn:

- The study showed that for pavement on expansive soils it is necessary to carry out geotechnical site investigation in order to have sufficient knowledge about the geotechnical characteristics, behavior and treatment of expansive soils as road's subgrade
- Many of the structural problems and premature failures of roads built on expansive soils originate mainly from inadequate or insufficient site investigation, among other factors include poor drainage, age, climatic conditions and neglected maintenance of the roads.
- Effort to maintain roads on expansive soils in Sudan by government authorities have not yield any result because the maintenance carried out was approached wrongly. It is evidently clear from the findings that the presence of expansive soils as road subgrade have contributed to road failure.
- From the experimental results it is concluded that the soils are cohesive of high plasticity with high to very high expansive potential and very active clay due to the presence of montmorillonite minerals. The soils showed high to very high free swell and swell potential coupled with high exerted swelling pressure and low strength.

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