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Pavement Design for Roads on Expansive Clay Subgrades

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Abstract: This paper aims to develop a design guide to help highway engineers in Sudan improve design and construction of pavement on expansive subgrades, thereby extending road life. Expansive soils as road subgrade in Sudan have been contributing to pavement failures and subsequently causing increased annual maintenance expenditure. The pavements design methods are found to be the primary cause of these failures. Thus, it is quite important to establish design criteria that can improve the road performance and durability. This design method was derived on basis of the technical design methods recommended by previous researchers and adopted by certain African countries as practical solutions of swelling problems of soil. To check the validity of the suggested design method, two cases of existingroads in Khartoum were studied. The results obtained clearly indicated that the suggested design method is effective and applicable in Sudan.

Keywords:Pavement; Design guide; Expansive soils; Swelling.

1. INTRODUCTION

The performance of pavements depends upon the quality of subgrades. A stable subgrade and properly draining pavement help produce a long-lasting pavement. Subgrade soil provides support to the remainder of the pavement system. The quality of the subgrade will greatly influence the pavement design and the service life of the pavement. Roads running in expansive soils areas are known for bad condition and unpredictable behaviour for which the nature of the soil contributes to some extent. The failures of pavement, in form of heave, depression, cracking and unevenness are caused by the seasonal moisture variation in the subgrade soil.

For many years researchers have studied the expansive subgrades in an effort to determine the most appropriate methods of design and construction practices where these soils cannot be avoided. Furthermore, there has been significant amount of research on subgrade improvement techniques to construct a uniform and stable pavement on expansive soils

2. LITERATURE REVIEW

Many design methods are used as practical solutions for the problems of expansive soils when exist as road subgrade. These design methods which recommended by previous researchers for minimizing the damaging effects of moisture changes and related volume changes in expansive soils beneath roads. Many of these methods are embodied in the design specifications of certain African countries.

Chemical stabilization as reported by Little [1], involves mixing or injecting the soil with chemically active compounds such as Portland cement, lime, fly ash, calcium or sodium chloride or with bitumen. Chen [2]conducted research using various stabilizers including lime, Portland Cement and lime/cement mixtures to conclude that lime shows the greatest improvement to compressibility, California Bearing Ratio (CBR) and swelling. In the field it is extremely difficult to effectively mix moist clay and lime due to natural moisture content. Ramanujam and Jones [3] explained that the main disadvantage of subgrade cement stabilisation is the high stiffness created and a tendency for overlying pavement to crack.

Sheet piles, impermeable membranes or barriers are concrete diaphragm walls or polythene membranes are used to prevent moisture movement from surrounding areas into pavement structure. Horizontal barriers of impervious materials are recommended to prevent the rising of water by capillary action while vertical barriers can be used to prevent water from road side edges to enter the pavement. Sterinberg[4]used a 2.4 m deep vertical membrane beneath the edges of a road in Texas and successfully reduced the variations in moisture content within the protected zone compared with soil outside the protected zone.

Pre-wetting and Ponding methods attempt to cause the majority of heave to occur before construction commenced. Water is supplied by irrigation or by forming a pond covering at least the area of subsequent construction. Steinberg [5]and Poor [6]believe that ponding water on a foundation reduces the future swell, often assisted by moisture barrier installation. The idea of deliberately ponding water on the subgrade prior to the construction of pavement may seem a little unusual. However, Das [7]discusses the benefit of inducing heave.

Geosynthetics including geotextiles, geogrids, and geomembranes are materials used to improve soil conditions. Geotextiles play a role in separating materials, reinforcing, filtering, draining and/or providing a moisture barrier [8]. The functions of this material include keeping subgrade clay and subbase materials separate, increasing load bearing capacity, protecting fine-grained soils from transportation and channelling undesirable water away. This is supported by Zornberg and Gupta [9]who stated that geotextiles reinforce the subgrade or base materials by providing lateral restraint, tensile membrane support and increasing the bearing capacity. Black and Holtz [10]reported that subgrade sections beneath geotextiles become more consolidated with time than areas without the geotextile.

Certain African countries such as Kenya, South Africa, Tanzania and Botswana have manuals for pavement design and construction specifications of roads on expansive soils. Kenya Road Design Manual, Ministry Of Works and Construction (MOWC), [11] considers soil stabilization, using 4 to 6% of lime will reduce the swelling and increase the soaked CBR of expansive soils. Extended sealed shoulders using impermeable materials are required by the manual where removal or stabilization are not employed, in order to minimize the effect of seasonal changes on pavement. The manual recommends that side drains should be kept as far from the road as possible, or avoided entirely, as they have acted as water sources and promoted swelling. In order to minimize the swelling due to moisture changes, the manual recommends surcharging the natural expansive soil using 1 to 3m of non-expansive fill.

South Africa Manual of Technical Recommendations for Highways (TRH12), Committee Of Land Transport Officials (COLTO) [12] suggests raising the moisture content of the clay prior to place fill in order to minimize swelling. The Fill placed over these expansive clays assists in counteracting the swelling pressure. Removal and replacement of swelling clays is recommended where they are shallow. Longitudinal drains at the bottom of embankments should be avoided and culvert inlets and outfalls should be carefully maintained. Compaction of swelling clays should be carried out at 2 or 3% above the optimum moisture content (OMC). Lime stabilisation has been used to reduce swelling of expansive clay soils.

Tanzania Manual, Ministry Of Works Tanzania (MOWT)[13] recommends excavating 600mm of expansive clay and replacing with fill materials. The materials used for replacement should be impermeable with plasticity index less than 15%. Sealed shoulders minimum 2m wide, side slopes of 1:6 where embankment is less than 2m high, (1:4 if greater). Side drains are to be avoided in areas of expansive soils. Where essential they are to be kept a minimum 4m from the bottom of the embankment on roads. Subgrades of expansive soils are to be kept moist and covered with earthworks as soon as possible.

Botswana Road Design Manual, Ministry of Transportation and Communication (MOTC) [14]recommendprewetting of the natural expansive soil as was done by Netterberg and Bam [15]. Extended sealed shoulders are required using embankment slopes where removal or stabilization is not employed.

3. PAVEMENT DESIGN

The main objective of this study is to derive an effective pavement design to solve the problems of swelling on pavement structure. This may be achieved by justifying some improvements to current design techniques to suit roads in Sudan. Experience has shown that design and construction of roads on expansive soils, particularly in underdeveloped countries, required more investigations and expensive construction materials. The following is a detailed descriptionof the developed design guidelines.

3.1 DESIGN PARAMETERS

The design parameters of road construction on expansive soils are:

1. Traffic load application is given in terms of Equivalent Single Axle Load (ESAL).
2. Subgrade strength is measured in terms of the California Bearing Ratio (CBR) or the Resilient Modulus (MR) of the soil. Compaction of subgrade soil will increase its density and strength and prevent excessive settlements under traffic loading. Expansive clays are liable to show serious decrease in strength when compacted at high moisture contents. They should be compacted at low to optimum moisture content zone to increase strength.
3. Swelling Potential is defined in terms of two main components "swell percent" and "swelling pressure". Holtez[16] defined swell percent as the percentage of total volume change of a soil when tested in an oedometer cell such that its moisture content varies from the air-dry to the saturated condition under a vertical surcharge pressure of 1 psi (≈ 7kpa). The swell percent is usually measured under a small vertical surcharge pressure (7 to 20 kPa). The swelling pressure is equivalent to the pressure, which must be applied to prevent swelling (or volume change) of the soil sample when water is fed into it. In design it is quite important to measure the swell percent and swelling pressure of the subgrade expansive soil.
4. Construction material properties: most of the empirically based design methods such as AASHTO, Transport Research Laboratory (TRL) and CBR methods account for variations in materials properties and allow the overall thickness to be reduced. This will increase the strength of the materials above the minimum values required by the specifications.

3.2 DESIGN GUIDELINES

The suggested design is derived from previous studies[7, 17, 18] recommendations and the experience of design adopted by similar countries to Sudan, COLTO [12]and MOWT [13]. The guidelines for flexible pavement design of roads on expansive soils will briefly be described as follows:

A. **Removal of subgrade**: Very weak subgrade, may be considered to have CBR values less than 3% and resilient modulus (MR) less than 20 MN/m2, which generally include high plasticity clays. The support to pavement by these soils is not uniform and unstable. If the expansive soil layer is so deep, it is recommended to be removed to a depth not less than 1.5m below ground level. This depth depends on the overburden pressure to counteract the swelling of the subgrade soil.

B. **Subgrade Improvement**: On expansive subgrades an economical option may be used to fill material available locally to improve the effective subgrade support to the pavement and thereby reduce the thickness of pavement required. A thick layer of fill will provide a more uniform support to the pavement and counteracts the swelling. It is recommended to provide a layer of suitable (preferably granular) fill materials of min. thickness 600 mm as recommended by MOWT [13]. The pressure of this fill layer should be more than the swelling pressure to prevent any tendency of the subgrade soil to swell. This layer should be compacted in layers of 200mm each at optimum moisture content till it attains the density of 95% of maximum dry density and CBR not less than 10%.Based on Zornberg and Gupa[9]recommendations and the practice adopted by Skok[17] and Rowe and Badv[18], it is recommended to use geotextiles incorporated within fill layers to increase the stability of the fill, increase the shear strength and provide a more uniform support for the pavement.

C. **Surface and Subsurface Drainage**: Adequate surface and subsurface drainage is necessary for satisfactory and prolonged performance of the pavement. Proper surface slopes in both longitudinal and transverse directions should be maintained. The transverse slope or cross-fall should be directed towards the side drains of impermeable walls and bed. The surface slopes should allow rapid removal of rainwater.Subsurface drainage is a key element in the design of pavement systems. The two basic design strategies promoted are (1) to prevent water from entering in pavement and (2) to quickly remove any water that does infiltrate. The changes in moisture content of subgrade soil are caused by fluctuations in ground water table seepage flow, percolation of rain water and movement of capillary water. In subsurface drainage of road it is required to keep the variation of moisture in subgrade soil to minimum. Therefore, it is recommended to use a drainage layer or filter layer directly below the subbase course. A filter layer of porous materials such as well-graded gravel or crushed stones (chipping) of minimum thickness 200mm is recommended. This layer is with proper slopes in both longitudinal and transverse directions. It is mainly designed to intercept capillary water and consequently reduces wetting effects of the subbase. A collection pipe of 150mm diameter or more is recommended in the far end of the drainage layer (parallel to the road edges or side drains). The pipe should be perforated in the upper half. The longitudinal slope of the pipe should be about 1:30. Outlet pipes will be needed to carry water to the side ditch (side drains). The trench or filter columns of porous materials, 200mm min. width is to be located over the pipes to the level of the base.

D. **Bituminous Surfacing (BS):** In order to eliminate the ingress of water into the pavement structure, it is preferred to adopt impervious surfacing of low void content, such as dense asphalt concrete mixture. Coarse aggregates for BS course shall consist of crushed rock. They shall be clean, hard, and durable, of cubical shape, free from dust and soft or friable matter.

E. **Base andSubase Courses:** Design details of the remaining upper pavement layers of base and subbase should be designed as per pavement design methods based on the CBR of subgrade soil and traffic loading.

4. CASE STUDY

To investigate and verify the validity of the suggested design guide for roads on expansive soils, two cases of roads projects were chosenfor study, Alazhari and Alarda roads. The field work program was conducted for pavement evaluation. Photographs were taken for road surface and design data were collected to assist in pavement evaluation.

4.1 ALAZHARI ROAD

Alazhari Road is selected as a case study due to the problems and damages caused by the subgrade of expansive soils and the subsurface water. This road is one of the main roads in Khartoum State that connects two cities, Omdurman with Khartoum North through Shambat Bridge. The study conducted for the western part of AIazhari Road in Omdurman of 750 m length. The road suffered from severe distresses of potholes, rutting and heavy depressions as shown in Plate (1). The causes of these failures may be due to improper design, excessive loads and poor drainage leading to poor subgrade conditions.

Rehabilitation of the road was carried out in 2007. The consultant, University of Khartoum Consultancy Corporation (UKCC) conducted a geotechnical investigation and pavement redesign. The results obtained from pavement evaluation indicated that the failure of the road was attributed to improper pavement design, heavy traffic loads and poor drainage of the road. The redesign done by UKCC recommended removal of the natural subgrade of expansive soils to 1.5 m depth and replaced by selected filling materials. Table 1 presents the data collected of the pavement design as recommended by the consultant, UKCC. After five years of the rehabilitation, it was found that the road performance is so good and only small cracks can be seen on the surface. This indicates that the last rehabilitation is successful and the design is proper.

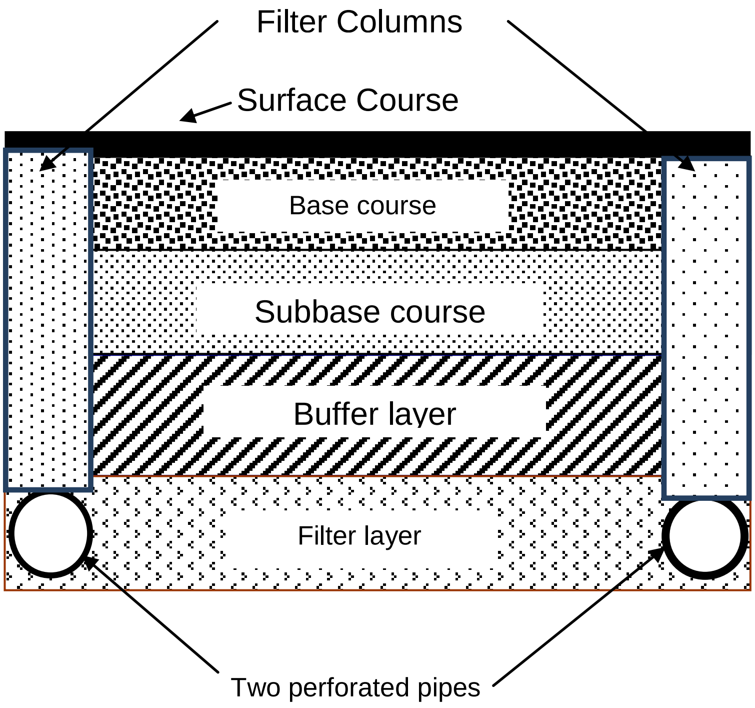

Fig.1. Recommended Pavement Structure for Roads on Expansive Clay Soils

Plate (1): Severe distresses of potholes and rutting appear on Alazhari Road surface

Table 1. The data collected of pavement design as recommended by the consultant, UKCC for Alazhri Road (*Source*: Ministry of Physical Planning and Infra Structures)

Pavement Element	**Description and specifications**
Surface Course	100 mm thick of asphalt concrete mix.
Base Course	Two layers of natural granular soils, each of 15cm thickness.
Subbase Course	Three layers of natural granular soils, each layer of 15cm thickness.
Filter Layer	Drainage layer of crushed stone chipping, 15cm thick. Pulverized pipe of 300mm diameter is situated inside the filter layer.
Embankment Layer	Selected filling materials of various thickness 0.75m to 1.25m, in layers of 25 cm thickness.
Impermeable Membrane	Two horizontal barriers are used with filter layer (crush stone) sandwiched between them.
Subgrde Soil	Silty clay of high liquid limit, 53 to 61%, high plasticity index, 27 to 31% & low strength CBR 1.2 to 3%

4.2ALARDA ROAD

This road is one of the main roads in Omdurman that connects eastern and central part of the town. The road length is 2.75 km and consists of two carriageways, each of 10.5 m width and four lanes divided by central island of 1.2 m to 2.0 m width. A large portion of the road is constructed on expansive clay with high plasticity and very low CBR. This road was maintained several times during the last 10 years and still suffered from severe distresses. As can be seen in Plate (2), the pavement surface shows significant rutting, cracking, heave and heavy depressions. Improper design may be the main cause of pavement distresses. Seepage of sewage water disposed into the subsoil from the neighbor houses may allow water accumulation and subsequent softening of the subgrade in the rutted and heave areas.

Rehabilitation of the road was carried out in 2008. The consultant, Dar consult redesigned the pavement and recommended removal of 1.5m depth of the existing expansive clay soils. The embankment layer of selected filling materials was constructed of 500 mm thick. On top of it a layer of boulders of 400 mm thick was placed with a thin filter layer, 100 mm thick of crushed stone (chipping). In Table (2) below the collected data of pavement design as recommended by the consultant is given. After four years of the last rehabilitation, failures and distresses such as depression and cracking can be seen on the surface in most of the road sections. A major cause of pavement deterioration is inadequate redesign of pavement.

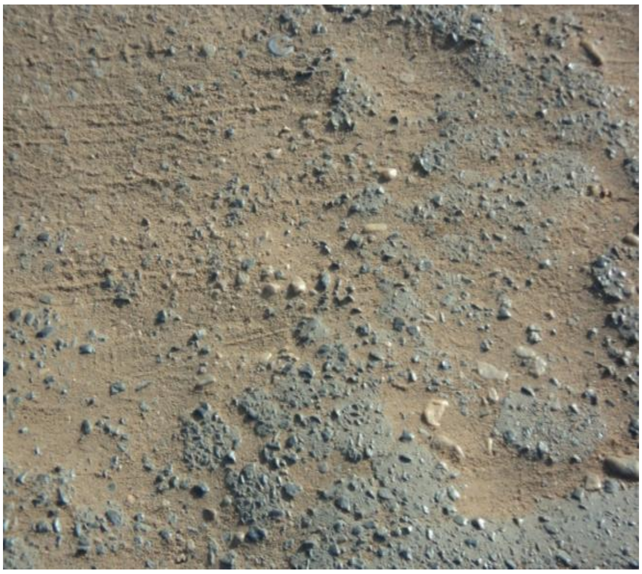

Plate2. Severe distresses of potholes and heave exist on Alarda Road surface

Table 2. The data collected of pavement design and construction for Alarda Road
(*Source*: Ministry of Physical Planning and Infra Structures)

Pavement Element	Description and specifications
Surface Course	75 mm thick layer of asphalt concrete mix.
Base Course	200 mm thick layer of natural granular soils.
Subbase Course	Two layers of natural gravels materials, each layer of 150 mm thickness.
Filter Layer	100mm thick layer of crushed stone chipping,.
Boulders layer	400 mm thick layer of boulders materials.
Embankment Layer	Two layers of selected filling materials, each layer of 250 mm thickness.
Impermeable Membrane	Vertical moisture barriers (Fondaline Sheets) used for each carriageway on both edges to a depth 2.0 to 2.5m.
Subgrde Soil	Silty clay of high liquid limit (44% - 63%) and plasticity index (25% - 33%), low strength CBR=1.2% - 2%

5. RESULTS AND DISCUSSION

In the two cases studied above, the design and construction specifications adopted are different. Table (3) presents the summary of the results obtained for the two cases studied. A comparison between the design and construction specifications of the two roads studied and the recommended design. As can be seen, most of the pavement elements design of Alazhari road agreeS with the recommended design guide. As mentioned before, in section 4.1 the road after five years of the last rehabilitation is in good condition, which indicates that the design and construction are done properly.

The second case studied of Alarda road when compared with the suggested design guide it shows disagreement in most of the design and construction items. The side drains are not considered in the design and this indicates that the surface drainage is inadequate. Thus, surface runoff water may penetrate the road surface and affect the pavement layers. Impermeable vertical membranes, Fondaline Sheets which are used to prevent water movement from the road sides and central island to the depth 2m to 2.5m. These sheets were cracked due to the soil movements and the sheets covered very shallow depth, 2m to 2.5m. Where the membrane crack and below the sheet depth, water may penetrate through thecracks and cause a progressive inward penetration of the zone of soil movement leading to soil expansion and ultimately failure of the pavement. Therefore, the road damaged and failure are due to improper design and construction.

Table 3. Summaryof the cases study results

Design and Construction Item		Alazheri Road	Alarda Road	Guidelines Design
Removal of expansive soil		1.5 m	1.5 m to 2.0 m	1.5 m
Replacement	Material	Selected Fill	Selected Fill and Boulders	Selected Fill
	Thickness	0.75 m to 1.25 m	0.5 m & 0.4 m	0.6 m to 1.0 m
Surface Drainage System		Side drains	No drains	Side drains of impermeable walls & bed
Subsurface Drainage	Type	Filter layer with pulverized pipe	Filter layer	Filter layer with pulverized pipe & filter column
	Material	Crushed stone (Chipping)	Crushed stone (Chipping)	Coarse/Medium Gravel or Sand
	Thickness	15 cm	10 cm	20 cm
Moisture Barrier or Membrane	Type	Horizontal Membranes Impervious (I)& Pervious (P)	Impervious vertical Membrane	Not needed
	Location	On top (I) & bottom (P) of filter layer	Pavement edges	N.E

6. CONCLUSIONS

On the basis of the results of the study presented in this paper the following conclusions are drawn:

- Expansive soils show large volume changes when the moisture content changes. This can lead to loss of uniform support to the pavement, a reduction of bearing capacity of the soil, heave and cracks in the pavement.
- The suggested design guidelines are quite important that will help road engineers in Sudan to make appropriate design for roads constructed on expansive soils. The design parameters include traffic loading, strength and swelling potential of subgrade soil and construction materials properties.
- The developed design guide recommends removal of natural expansive soils to a depth not less than 1.5m and to improve the subgrade soil by placing suitable fill materials of min. CBR 10% and thickness 0.6 to be constructed in layers of 20cm thickness to counteract swelling. The fill materials thickness depends on the measured swelling pressure of the subgrade expansive soil. It is recommended to use of geotextiles incorporated within the fill layers to increase the stability and strength.
- To achieve adequate drainage, proper surface slopes in both longitudinal and transverse directions should be maintained. The transverse slope should be directed towards the side drains of impermeable walls and bed. For water in subsoil it is recommended to use filter layer of well graded gravel or crushed stones (chipping) of 20 cm min. thickness directly below the subbase course. A perforated pipe of diameter not less than 15 cm and longitudinal slope 1:30 is to be placed in the far end of the filter layer. Filter columns of well graded gravel, 20 cm min. width can be used over the pipes to the level of the base.
- It is recommended to use dense asphalt concrete mixture of impervious surfacing of low void content. Design details of the base and subbase should be as per pavement design methods based on the subgrade soil strength and traffic loading.

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