# Design Considerations of Pavements on Expansive Clay Soils in Sudan

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## ntroduction

Expansive soils are one of the most problematic materials that are widely encountered in significant land areas in several parts of the world, e.g. in parts of Africa, Australia, India, United States and Canada.

In these countries one of the problems having great impact on the construction and maintenance costs of highways is expansive soils effects. Whenever insufficient attention is given to the deleterious properties of expansive soils, the results will be premature pavement failure evidenced by undulations, cracks, potholes and heave.

As far as Sudan is concerned expansive soils cover large areas in Central, Eastern and Southern states. As these areas include most of the nation's population centers and development schemes an adequate and sustainable road communication system is always needed.

This paper summarizes the general guidelines for designing and building pavements on expansive clay soils worldwide and a critical review of the practice here in Sudan.

## Expansive Soils

These are clayey soils, mudstones or shales that are characterized by their potential for volume change on drying and/or wetting. Usually the clay content is relatively high and the clay mineral montmorillonite dominates. They are characterized by their high strength when dry; very low strength when wet; wide and deep shrinkage cracks in the dry season; high plasticity and very poor trafficability "stickiness" when wetted. These characteristics affect the performance of light structures such as pavements built on these soils. Methods were developed for the identification and classification of expansive soils both locally and worldwide. In Sudan all grayish and/or brownish clays with plasticity index greater than 25% can be identified as expansive. The classification or rating (from low potential to high heave potential) usually depends on the clay content and plasticity (Figure 1, Van der Merwe classification).

## Factors Controlling the Performance of Pavements on Expansive Soils

Building roads in the areas covered by expansive subgrades is always given priority mainly due to the very poor trafficability of unpaved roads during the rainy season. The villages, farms and towns in these areas are totally isolated during the rainy season. Figure 2 shows the existing and planned road network in Sudan and the areas covered by expansive soils. The figure shows that almost 38% of the already built network is founded on expansive subgrades. The major highways such as Khartoum-WadMedani-Kassala, WadMedani-Sennar-Kosti, Sennar-Singa-Damazin and Khartoum-Kosti are wholly laid over highly expansive subgrades.

The subgrade characteristics that affect the performance of pavements laid over expansive subgrades are:

1. The very low wetted strength. Expansive soil measure very low CBR values when fully saturated. Values as low as 2% are common . These soils are therefore characterized as poor subgrade and will need some kind of treatment.
2. The potential for heave specially when lightly loaded as is the case for pavement loading. The traffic load here is transitional and moving, therefore, is not effective in suppressing heave whenever the subgrade is wetted.
3. Shrinkage of wetted subgrades. The subgrade soil on the pavement shoulders is subjected to environmental changes resulting in sequences of wetting and drying. Drying causes shrinkage of the subgrade soil and is reflected on the pavement surface as longitudinal cracks.

The shrinkage cracks in the soil on the sides of the pavement. These cracks are deep (greater than 1.0 m) in arid areas and could allow seepage of water to the subgrade.

Expansive soils are encountered in low terrain and relatively high embankments are often needed to raise the level of the road. In many cases these embankments are built from the surrounding expansive soils. For the structural layers there is always scarcity in good natural construction materials that can be used as subbase and base courses.

Designing an economical and good performing pavements on expansive soils is always a challenge. This challengs is greater in arid areas.

## Available Methods of Subgrade Treatment

Several methods for dealing with expansive soil problems when designing pavements on expansive soils were shown in the literature. These include

a- Realignment: this option is possible only if the areas covered with expansive soils are of limited extent, therefore, the route of the roadway can be changed. Therefore the option is not always available nevertheless an economical alignment is always needed.

b- Excavation and Replacement: This approach is economically practicable if the expansive soil layer is thin and suitable backfill material is available in the vicinity of the road.

c- Prewetting or Ponding: This approach has been successfully practiced in the United States and South Africa {5}. The amount of water needed for ponding is such that the moisture content would be raised to about 2 to 4% above the plastic limit{12} . This option is questionable in arid climates due to expected shrinkage problems and also where the expansive soil is deep.

d- Use of improved subgrade layer: The improved subgrade is usually a non expansive soil of acceptable strength and low permeability. This has an advantsge of reducing the subbase thickness and protecting the subgrade from moisture changes. The Kenyan Road Design Manual {4} recommended a minimum thickness of 30cm for the improved subgrade or capping layer.

e- Surcharging Expansive Soils: It is well known that placing a substantial thickness of non-swelling material over expansive clays reduce heave. The Kenyan Road Design Manual recommends that the total thickness of pavement plus the improved subgrade to be at least 60cm. This approach is not effective over soils of high swelling potential.

f- Using Sand Trenches: The function of a vertical sand trench is to act as a water balance reservoir. The predominant pavement distress was found to depend on the moisture conditions of the subsoil. For dry subsoils shrinkage cracks provide good passage for free water resulting in differential volume change in the soil beneath the pavement. In such case water proofing membrane must be installed along the trench and then backfilling is required with bituminous sealing along the trench surface. In such condition the function of the trench is to prevent the access of free water to:

i. the cracked pattern. On the other hand very wet subsoils on edges will swell and shrink with seasonal moisture changes while the moisture of the subsoil beneath the center of the pavement remains constant. This differential trend leads to formation of longitudinal cracks of the pavement edges {1}. In this

ii. condition the function of the trench is to reduce the

iii. seasonal moisture changes of the subsoil under the pavement edges. This approach was undertaken by the State Department of Highway and Public Transportation,

g- Texas {13}. Sand trenches were extended to 2.70m. deep

h- and good results were obtained. The approach needs careful detailing and is difficult to construct.

i- Preventing Moisture Changes in Pavement Layers: This is attainable by: a) The pavement should be as impermeable as possible by using a proper bituminous seal cover; b) shoulders should be impervious with proper width (about the active zone) and if necessarily sealed or even surface dressed and sloped 1:4 outwards; c) drainage culverts should not be of pre-cast units so as to avoid the problems from joints; d) side ditches should be as far away as practicable from the pavement; and e) Bedding and surrounding soils of culverts shall be of well compacted non-swelling material of good resistance against scour.

j- Mechanical Stabilization: This is achieved by mixing a non-expansive soil with the expansive clay. The non-expansive soil is usually sand or sandy and/or gravelly material. Generally mechanical stabilization of heavy clays is not practical, as large percentage of non-expansive material will be needed to be added.

k- Cement Stabilization: Cement stabilization is widely used in road construction. The process involves pulverization of natural material, spreading of cement and mixing with the clay soil, watering and immediate compaction. Cement stabilization is best suited to granular materials. Cement was also found to reduce plasticity, swelling potential of clay soils and markedly improve soil strength. A study was conducted in the Building and Roads Research Institute (BRRI) in Sudan {8} on two clay soils from central Sudan. It was found that the addition of up to 10% of ordinary Portland cement by weight to these soils markedly reduced their plasticity index (from almost 40% to less than 10%). In India {16} addition of up to 15% of cement was needed to markedly improve the engineering properties of Indian black cotton soils.

l- Lime Stabilization: The stabilization of clays by hydrated lime $Ca(OH)_2$ has been demonstrated by many engineers and agencies to be very successful. The technique has been widely used in road engineering. Lime stabilization had very limited use in Sudan although the studies and research on lime stabilization of expansive clay soils showed very promising findings {6}.

**Subgrade Treatment in Sudan**

In the last two decades, several roads have been designed and/or constructed on expansive clays in Sudan. Table {1} summarizes the treatments recommended by the designers of selected roads.

**Evaluation of Subgrade Treatment Methods in Sudan**

From the summary given in Table {1} it is noticed that:

a. The CBR of the embankments should be greater than 5% and imported fill should be used when the subgrade materials are of CBR< 5%. Usually This treatment needs a thin protective layer of impervious non expansive materials to be laid on the side slopes but it was not recommended.
b. A cappimg layer or improved subgrade is always required on the top of the embankment when the CBR of the embankment material is less than 8% . The capping materials are gravely sand, mechanically stabilized clay with gravel or sand , or lime stabilized clay. It is noteworthy to mention that gravely sand or mechanical stabilized clay may be a problematic pervious layer.
c. Some designers required the use of a layer of selected materials of CBR

>15% on the top of the embankment mainly to reduce the thickness of the Subbase and to act as a capillary cut off between the embankment and the upper permeable subbase materials.

d. Sand trenches were proposed for Sennar - Singa – Damazin Road {10} but not implemented as they are laborious and time consuming.

It is clear from the recommendations of the designers that there is general agreement that the encountered soils are very poor subgrades and there is a desperate need to improve their strength and also reduce their potential for heave. However, most of these treatments concentrate on the improvement side. In many cases the CBR of the subgrade is less than 4% and no better material is available nearby. The embankments therefore are built from nearby borrows. The only advantageous treatment which can improve strength, reduce plasticity and swelling potential is the addition of lime. Although this option has been recommended by some of the designers it never found place in practice. Lime stabilization of heavy clays has been practiced in the road industry in many countries around the world. A study of lime stabilization of expansive soils in Sudan confirmed the technical viability of the treatment for use as road pavement materials. The factors that encourage the introduction or implementation of lime stabilization in Sudan are:

1. Highly expansive soils cover wide areas in Sudan. {Figure 3}
2. The availability of raw materials in Sudan. {Table 2}
3. Encouraging results have been achieved in the Laboratory. {Table 3}
4. The road network is expanding over extended areas of expansive subgrade. {Figure 2}

However, the following constraints are expected when implementing or using lime as stabilizer:

- Difficulties of mixing specially in relatively wet climates
- Lack of experience and the need of skilled labors.
- Poor Production of hydrated lime in the available kilns and the use of expensive imported lime.

Most of the abovementioned constraints may be overcome by good planning and stage implementation. Experts can be called for from abroad and consequently experience transfer will be acquired . Trial sections can be made and their functional and structural conditions can be assessed and the expected promising results will encourage the construction of industries for lime production of high quality and low cost. Such high quality production of lime can be used in sugar factories.

## Conclusion and Recommendation:

All the reviewed road designs confirmed that it is a must to treat expansive subgrade with particular attention.

Recently in Sudan one of the Government's prospective plans is the development of its productive capacity. The key factor in this respect is the establishment of an adequate road communication net work covering the whole Country and forms part of the Trans-African Highway.{Figure 2}

Taking into consideration that about 2800 Km. of this net work will be constructed over extended areas of expansive subgrade with the scarcity of road building materials together with the availability of lime deposits , the technique of lime stabilization is very much recommended to be practiced.

## References

1- "Dagg M. , and Russam K. "The Relations Between Soil Shrinkage and the Development of Surface Cracks in an Experimental Road in Kenya", African Soils Vol. 13,PP. 5-25, 1968.

2- Galander Engineering Consultants/Kocks Consult GMBH "ElMujlad – Higlieg Road", Soils and Materials Report.

3- Geological Research Authority "Brief Geology and Mineral Potential Opportunities In Sudan", unpublished, 1993

4- Kenyan Road Design Manual, 1980.

5- Krazynski L.M. "Expansive soils in Highway Construction - Some Problems and Solutions", Prepared for the IV International Road Federation, African Highway Conference, Nairobi, Kenya, Jan. 1980.

6- Mohamed A.J., and Walker R. D. "Effect of Lime, Moisture and Compaction on a Clay Soil", Highway Research Record Number 29, Highway Research Board, PP. 1 - 12, 1963.

7- National Highway Authority , Laboratories Directorate "Namma – Abyei Road, Soils and Materials Report", July 1999.

8- Osman M. A., and Mustafa A. K. "Compaction Properties of Two Black Cotton Soils In Sudan" Proceedings Seminar on Expansive clay soil problems in the Sudan, Hydraulic Research Station , Wad Medani, Sudan, 1983.

9- Resource Surveys and Engineering Company / Norconsult International A.S. "EdDueim – EsSufi Road , Soils and Materials Report", August 1994.

10- Roads and Bridges Public Corporation, Louis Berger International Incorporated, Campsax International A/S "Sennar- Singa - Damazin Road , Report on Design",1977.

11- Roads and Bridges Public Corporation, Roughton and Partners Consulting Engineers "WadMedani – Sennar - Kosti Road", Final Report On Design and Construction Of the, 1982.

12- State Department of Highways and Public Transportation, Texas, "Ponding of Expansive Subgrade, 1969", Prepared for the IV International Road Federation, IRF , in African Highway Conference , Nairobi, Kenya, Jan. 1980.

13- State Department of Highways and Public Transportation, Texas, "Study on Sand Drains, 1975", Prepared for the IV International Road Federation, IRF, in African Highway Conference , Nairobi, Kenya, Jan. 1980.

14- STIPE/Technocon Engineering Consultants "Renk – Malakal Road , Soils and Materials Report", March 1999.

15- Sumaya A. Mohamed "Lime Stabilization Of Expansive Soils for Use as Road Pavement Materials", June 1998.

16- Uppal H.L. "Stabilization of Black Cotton Soil for use in Road Construction" Indian Roads Con. Road Res. Bull. 5, PP. 105-154, 1959.

## Table {1}: Design of Roads on Expansive Subgrades

| Road Classification | Roadway | Subgrade P.I % | Subgrade CBR % | Design Treatment |
|---|---|---|---|---|
| Constructed | Medani – Sennar - Kosti | 36 | 3 | 0.50 m. Embankment of Subgrade material with CBR >4% |
| | Sennar – Singa – Damazin | 38 | 3 | Top layer of natural subgrade to be wetted and re-compacted wet of optimum moisture content<br>0.30 m. Improved Subgrade of CBR >9% {Only Friable Silty Clay improved with 50% Sand}<br>Cement or Lime Stabilization were suggested but not practiced<br>0.15 m. Selected Materials of CBR > 15% ; |
| | Mujlad – Higlieg | 11-28 | 3 | 0.60-1.0 m Embankment of CBR > 5%<br>With Embankment of CBR < 5% Improved Subgrade was needed by:<br>- gravel/sand mixtures<br>- gravel or sand mixed with clay<br>- lime stabilization |
| Designed | Namma – Abyei | 28 | 4 | >1.0 m. Embankment of Subgrade Material with CBR >5%<br>Trial Sections of embankment covered by lime stabilized clays were suggested |
| | Renk - Malakal | 32 | 3 | >0.50 m. Embankment of Subgrade Material with CBR >5%<br>0.20 m. Capping Layer of CBR > 8% from:<br>- low plastic clays mixed with natural fine gravel (wind blown)<br>or<br>- high plastic clay stabilized by lime |
| | EdDuem – EsSufi | 8-36% | 2-3% | 0.60-1.0 m Embankment of CBR > 5%<br>Selected Materials of CBR > 15% still needed and improvement suggestions are:<br>- gravel or sand on upper layer<br>- mixing of local silts and clays with imported gravel or sand<br>- mixing of local silts and clays with lime. |

## Table {2}: Lime Deposits in Sudan {3}

| Location | Estimated Quantities |
|---|---|
| 1. Jebel Aulia<br>N 15° 03′<br>E 32° 23′ | Not Measured |
| 2. Sennar Area<br>N 13° 19′ - 13° 30′<br>E 32° 23′ - 33° 25′ | 1175 M. Ton<br>{Marble of $CaCo_3$ = 98.6%} |
| 3. Kosti Area | Not Measured<br>{Marble of $CaCo_3$ = 64.8%} |
| 4. Jebel Murat<br>N 20° 07′<br>E 30° 44′ | Not Measured<br>{Marble of $CaCo_3$ = 96%} |
| 5. Atbara Mable<br>N 17° 40′<br>E 33° 50′ | 60 M. Ton<br>{Marble of CaO = 52%} |
| 6. Durdeb Area<br>N 11° 30′<br>E 36° 05′ | 17 M. Ton {one of the two deposits}<br>{Marble of CaO = 54%} |
| 7. Maman Area<br>N 16° 15′<br>E 36° 10′ | Not Measured<br>{Marble of High Quality} |
| 8. Coastal Area<br>N 19° 10′ - 19° 25′<br>E 37° 10′ - 37° 20′ | Not Measured |
| 9. ElRuseires Area | Not Measured<br>{Marble of CaO = 56%} |
| 10. Jebel Rashad Area<br>N 11° 27′<br>E 31° 14′ | Not Measured<br>{Marble of CaO = 54%} |
| 11. ElFasher Area | Not Measured<br>{Two deposits of $CaCo_3$ = 96%} |

## Table 3: Results of Lime Stabilized Expansive Clay

| Name of the Road | Results | | | | |
|---|---|---|---|---|---|
| 1. Singa – Damazin {Km. 56}, {15} | **Lime %** | 0 | 1 | 2 | 4 |
| | CBR% @ O.M.C | 2.6 | 10.8 | 64.0 | 118.5 |
| 2. Mujlad – Higlieg {Km. 143}, {15} | **Lime %** | 0 | 2 | 4 | 6 |
| | CBR% @ O.M.C | 2.9 | 11.5 | 90.0 | 132.0 |
| 3. Namma – Abyei , {7} | **Lime %** | 0 | 3 | 5 | 7 |
| | CBR% @ O.M.C | 3.4 | 58.0 | 71.0 | 72.0 |

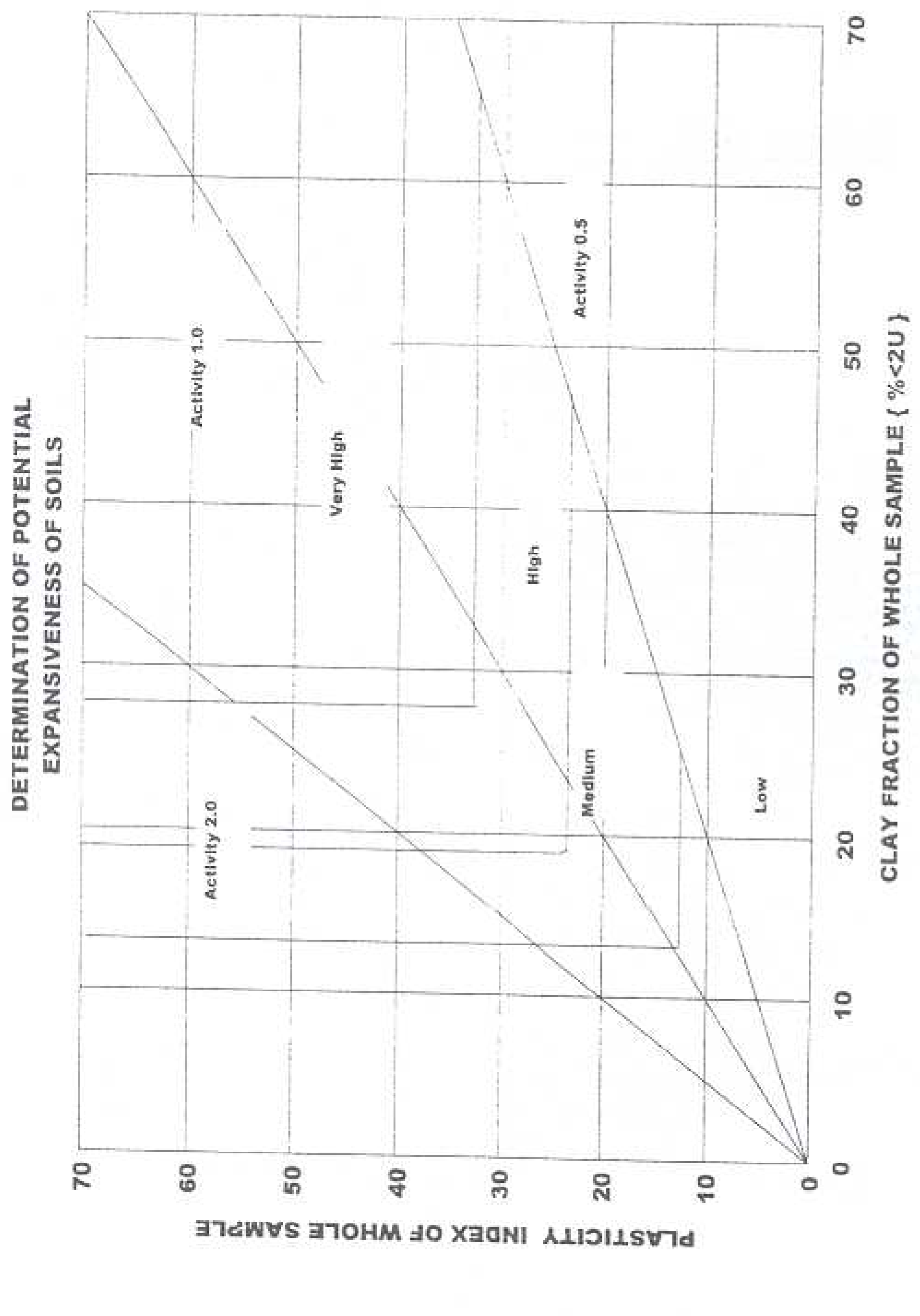
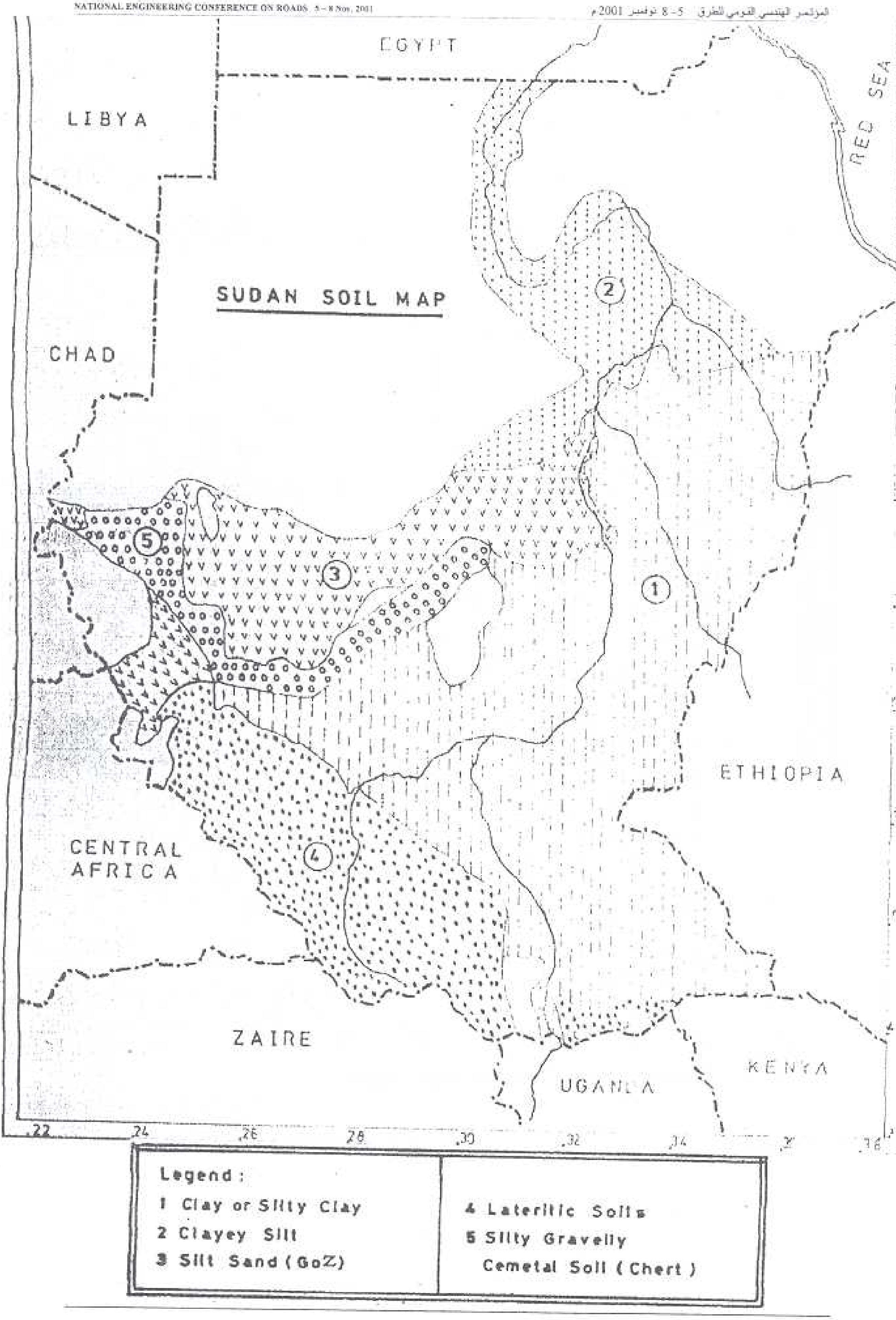



Fig. ( 1 ) ( VAN DER MERWE,1964 )


EGYPT
LIBYA
RED SEA
SUDAN SOIL MAP
CHAD
ETHIOPIA
CENTRAL AFRICA
ZAIRE
UGANDA
KENYA
1
2
3
4
5
22
24
26
28
30
32
34
36
Legend:
1 Clay or Silty Clay
2 Clayey Silt
3 Silt Sand (GoZ)
4 Lateritic Soils
5 Silty Gravelly Cemetal Soil (Chert)