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# Analytical Investigation on the Benefit of Sisal Fibre Reinforcement of Expansive Clayey Subgrade using Fem

**Binu Sara Mathew, Gayathri Mohan, Kuncheria P. Isaac, Susan Rose**

***Abstract:** Well-built and maintained highways play a major role in nation's development. The subgrade soil is integral part of pavements which provides support to the pavement. The subgrade soil and its properties are important in the design of pavement structure. Expansive soils are those soils, which have high swelling and shrinkage characteristics, extremely low CBR value and shear strength. The soil of Kuttanad region of Alappuzha district of Kerala in India is example of expansive soil entirely different from the normal well drained soils in their morphological, chemical and physical characteristics. Thus construction of roadbeds on or with these soils, which do not possess sufficient strength to support wheel loads imposed upon them either during construction or during the service life of the pavement is a commonly encountered problem. Hence extensive research is being done on improvement of strength properties of these types of soils. Ground improvement technique use locally available material to the maximum and hence found economical. It includes stabilization technique and reinforced earth technique. Lime when added to the soil, can substantially increase the stability, impermeability, and load-bearing capacity of the subgrade. Presently, the soil reinforcement technique is well established and is used in variety of applications like improvement of bearing capacity, filtration and drainage control. Conventional methods of reinforcement consists of continuous inclusions of strips, fabrics, and grids into an earth mass. An experimental investigation was done earlier by the same authors to study the effect of stabilization with lime, sand and sisal fibre on compaction characteristics, CBR value, swelling property, and elastic modulus of expansive soil. The optimum quantity of fibers was decided based on CBR value. The static triaxial test was conducted on unstabilized and stabilized soils at a confining pressure of 40 kPa. In this study, a finite element analysis was done to quantify the benefits of stabilization of clay. The stress-strain data from tri-axial test were used as input parameters for evaluating the vertical compressive strain at the top of subgrade soils using elasto-plastic finite-element analysis. It was observed that the elastic modulus value almost doubled as a result of stabilization. The vertical compressive strain at the top of unreinforced and reinforced subgrade soils obtained as an output from the finite element model was used for estimating the improvement in service life of the pavement or decrease in layer thickness and consequent reduction in construction cost. It was observed that a 14% reduction in construction cost and 7.3 times improvement in TBR value can be attained due to sisal fibre stabilization. Hence it can be concluded that the stabilization with sisal fibre after lime stabilization is as an efficient and economic method of stabilizing expansive subgrade soil.*

***Keywords:-** CBR, TBR, subgrade, fibre, stabilization, Kuttanad, Alappuzha.*

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## I. INTRODUCTION

### *1.1General*

Highways constructed and maintained properly play a major role in nation's development. Among pavement components, subgrade soil is an integral part of pavement, as it provides support to the pavement. Hence subgrade soil and its properties are important in the design of pavement structure. India is a country with varying terrain, soil, climatic and environmental conditions and about 33% of the total land area in India is expansive soils, which is categorised as a poor soil. Expansive soil is typical clay that demonstrate extensive volume and strength changes at varying moisture contents due to their chemical composition. This change in soil volume cause significant structural damage to foundations, including those of pavements. Construction of civil engineering structures on such soil is highly risky because such soil is highly susceptible to differential settlements, having poor shear strength and high compressibility and of very low CBR value and hence considered as a poor subgrade. Most of the places in the district of Alappuzha in the state of Kerala have problems due to the presence of weak clayey soils that are expansive in nature. Kuttanad, a unique agricultural region in Alappuzha district, lies below mean sea level and is submerged under water for more than a month in every year during rainy season. Construction of pavements or buildings in this region has always been a real challenge and various ground improvement techniques are still being experimented to arrive at a cost effective solution for the same. Ground improvement techniques generally use locally available material to the maximum and hence considered as an economical solution. The selection of the correct ground improvement technique at an early stage in the design of structures has an important effect on the choice of foundation. Reinforced earth technique is considered as an effective ground improvement method because of its cost effectiveness, easy adaptability and reproducibility. Earth reinforcing techniques continue to make considerable progress, as a result of continued research, technology developments and of the increasing awareness of its environmental and economic advantages. Presently, the soil reinforcement technique is well established and is used in variety of applications and a modification of this technique, viz., random inclusion of various types of fibres is also considered as an effective soil reinforcement technique. These fibres act to interlock particles and group of particles in a unitary coherent matrix.


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Randomly distributed fibre reinforcement can be advantageously employed as a ground improvement technique for embankment and subgrade.

### *1.2 Need of Present Investigation*

Good quality road materials are getting scarce and at the same time they are not affordable in many locations because of high cost of haulage from distant sites where they are available. With the aim of constructing pavements of moderate thickness on poor subgrade, soil stabilization and new techniques of construction have been continuously explored. In such cases, natural soils are either treated or reinforced with different kinds of materials to improve their engineering properties. A plenty of natural materials such as jute, coir, sisal, bamboo, wood, palm leaf, coconut leaf truck, coir dust, cotton and grass, etc., have been experimented as a soil reinforcement material so as to improve engineering properties of poor soil. Sisal fibre is a natural fibre, available in plenty in Kuttanad of Alappuzha District. Limited studies have been carried out on the use of this fibre as a soil reinforcement. An experimental investigation was earlier conducted by the same authors using the waste sisal fibres (Binu and Gayathri, 2012) to arrive at the optimum fibre content and aspect ratio. The study was carried out after stabilizing clay with 5% lime and 7.5% of sand by dry weight of soil. The optimum value of fibre aspect ratio and fibre content were obtained as 80and 0.75% respectively and the same is used for the present study also. It is also essential to investigate the efficiency of reinforcement of Kuttanad clay with sisal fibres and its effect on the extension of service life of pavements.

### *1.3 Objectives of the Study*

The objective of the present study is to carry out an analytical study to quantify the benefits of stabilization of Kuttanad clay. The results of the experimental investigations conducted earlier to arrive at the optimum fibre content and aspect ratio have been adopted in the present study. Hence the objective of the study is to conduct an analytical study to bring out the benefit of stabilization of Kuttanad clay using sisal fibres in terms of Traffic Benefit Ratio (TBR) which gives the extension in the service life of pavement due to fibre reinforcement. The study was carried out using Finite Element Modelling (FEM) in ANSYS.

## II. MATERIALS USED FOR THE STUDY

The engineering properties of the soil used for the study was determined by standard procedures specified by relevant IS 2720 [part 2], and is shown in Table 1. Lime has proved to be an effective additive for reducing the Atterberg's limits of clayey soil, and in increasing the stability of soil after compaction and hence 5% hydrated lime was used as an additive for the present investigation. For enhancing the surface friction between clay and sisal fibre, 7.5% of river sand was also added along with optimum quantity of sisal fibres.

**Table 1 Properties of Kuttanad Clay (Binu and Gayathri, 2012)**

| Properties | Values |
|---|---|
| Field Dry Density (g/cc) | 1.32 |
| Field Moisture Content (%) | 88 |
| Specific Gravity | 2.7 |
| Sand content (%) | 8 |
| Silt content (%) | 52 |
| Clay content (%) | 40 |
| Liquid Limit (%) | 100 |
| Plastic Limit (%) | 36 |
| Plasticity index (%) | 64 |
| Maximum Dry Density (g/cc) | 1.23 |
| Optimum Moisture Content (%) | 34 |

Sisal fibre used for the present study was collected as a waste material extracted during colouring process from the manufacture of mats, carpets and rugs from 'Extraweave' Company in Aleppey. The properties of sisal fibres, collected from company are shown in Table 2 and the photograph of sisal fibre plant and fibre are shown in Figs. 1and 2 respectively.

**Fig. 1 Photograph of Sisal Fibre Plant**

**Fig. 2 Photograph of Sisal Fibre**



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**Table 2 Properties of Sisal Fibre (Extraweave company, Alappuzha)**

| Property of Fibre | Value |
|---|---|
| Colour | White |
| Average diameter (mm) | 0.25 |
| Average tensile strength (N/mm$^2$) | 405.9 |
| Density (g/cc) | 1.45 |
| Unit weight (kg/m$^3$) | 962 |
| Specific gravity | 0.962 |

## III. FINITE-ELEMENT MODELING

### *3.1 General*

ANSYS, a finite element software package intended for the two dimensional analysis of deformation and stability of structures was used for the present study. A two-dimensional axi-symetric, elasto-plastic finite-element analysis of the mechanistic pavement model resting on both unreinforced and reinforced subgrade soil was carried out using ANSYS software in order to quantify the benefits of soil stabilization. The extent of deformation, strain, and the stress at the top of subgrade were captured from subsequent run of the model. The layered pavement response due to traffic loading was extracted mechanistically so as to investigate the benefits of reinforcing the subgrade soil in the flexible pavement design.

### *3.2 Input Data for Finite-Element Modelling*

The Finite-Element (FE) analysis of the pavement system was carried out by using the standard package ANSYS, employing the multilinear-isotropic elasto-plastic hardening model which defines the constitutive relationship of the materials involved. Properties of different pavement layers required for carrying out the FE analysis are the modulus of elasticity, Poisson's ratio, and the stress-strain(x$10^{-6}$) data. The initial tangent modulus is needed only to initialize the iterative procedure. Chandra et al. 2008 has reported that confinement in the pavement due to shoulders and surrounding soils is in the range of 26–40 kPa. Hence, triaxial tests were conducted on both unstabilised and stabilised subgrade soils at a confining pressure of 40 kPa so as to determine the modulus of elasticity which are shown in Figs. 3 and 4 respectively. Elastic modulus was calculated from straight portion of stress- strain curve and was found to be 790 and 2317 kPa for unstabilised and stabilised soil respectively.

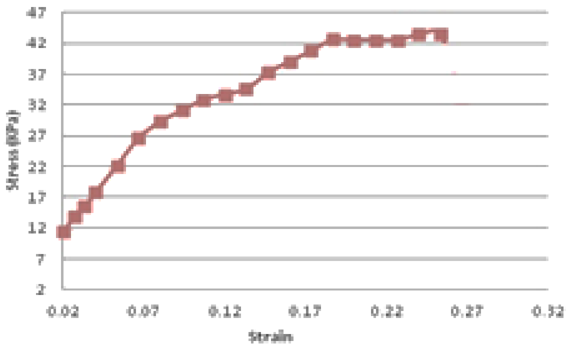


**Fig. 3 Stress Strain Curve for Clay**

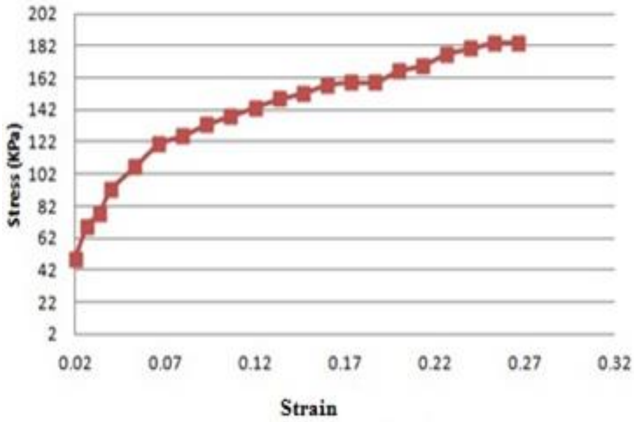


**Fig. 4 Stress Strain Curve for Stabilised Clay**

Actual cumulative stress-strain data generated from unconsolidated undrained triaxial test was used in the present FE analysis. Rajesh, 2006 has determined experimentally the Poisson's ratio of Kuttanad clay as 0.4 and the same was adopted for the present study. Elastic modulus and Poisson's ratio for the pavement layer materials as shown in Table 3 were selected from the study conducted by Chandra et al. (2008).

**Table 3 Elastic Modulus and Poisson's Ratio for Pavement Layers (Source: Chandra et al. 2008)**

| Parameter | Subbase | Base | DBM | BM |
|---|---|---|---|---|
| E(Mpa) | 70.12 | 99.20 | 269.67 | 403.33 |
| Poisson's Ratio | 0.30 | 0.30 | 0.25 | 0.25 |

### *3.3 Dimensions of Finite Element Model and Loading*

Dimensions of finite element model should be sufficiently large so that constraints imposed at the boundaries have very little influence on the stress distribution in the system. Helwany et al. (1998) discretized a three layer pavement system with a right boundary at a distance of about eight times the loaded radius and adopted a uniform tyre pressure of 550 kPa acting on a circular contact area with a radius of 160 mm. Kwon et al. (2005) considered 76 mm thick asphalt concrete layer and 254 mm thick unbounded aggregate base course resting on the subgrade soil. A uniform tyre pressure of 828 kPa was considered in this study to simulate an overloaded tyre-pavement loading which was applied over a circular area with a radius of 102 mm. For the present study, a uniform pressure of 575 kPa was applied on a circular contact area with a radius of 150 mm as shown in Fig. 5. This uniform pressure was supposed to be caused by a single axle wheel load of 40.8 kN (4,080 kg).

### *3.4 Boundary Conditions for FE Model*

For application of a finite element model in the pavement analysis, a five-layered system of infinite extent was reduced to a system having finite dimensions. Figure 5 shows a typical 2D axisymmetric Finite Element model of the pavement resting on subgrade soil.


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Roller supports were provided along the axis of symmetry to achieve the condition that both the shear stresses and radial displacements are equal to zero. Similarly, the roller supports were provided along the right boundary which was placed sufficiently far away from the loaded area so as to have a negligible deflection in the radial direction. At the bottom boundary, roller supports were provided, permitting free movement in the radial direction and a restraint was provided to any movement in the vertical direction. In the present study, the right boundary was placed at a distance of 1,750 mm from the outer edge of loaded area, which is more than seven times the radius of the applied load of 150 mm. Eight noded structural elements were used for discretization of layers in the flexible pavement. Boundary conditions adopted for the study are schematically represented in Fig. 5.

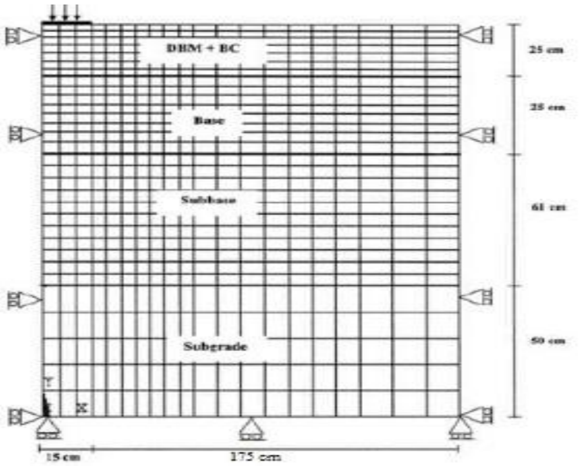


**Fig. 5 Boundary Condition for the FE Model**

### *3.5 Benefits of Subgrade Stabilization*

A mechanistic-empirical design approach was used in the present study to evaluate the benefits of reinforcing the weak subgrade soils in terms of reduction in layer thickness and extension in service life of the pavement. The proposed methodology has a better capability of characterizing different material properties and loading conditions, and has the ability to evaluate different design alternatives on an economic basis. Same pavement section was considered for both unstabilized and stabilized subgrade. Hence soil stabilization would result in more service life of the pavement due to stabilization and has been expressed in terms of Traffic Benefit Ratio (TBR). Structural failures considered in the design of flexible pavements as per Indian practice are of two types, namely surface cracking and rutting. Cracking is due to fatigue caused by repeated application of load in the bounded layer generated by the traffic. Rutting is developed due to accumulation of pavement deformation in various layers along the wheel path. Horizontal tensile strain developed at the bottom of the bituminous layer or the vertical compressive strains developed at the top of the subgrade, respectively, have been considered as indices of fatigue and rutting of the pavement structure. Since the scope of the study is limited to stabilising the subgrade soils only, rutting has been considered as a failure criterion in this study. Failure criterion for flexible pavement as per IRC 37-2001 is the development of rut depth of 20 mm. The rutting prediction model is given in Eqn. 1.

$$N_{20} = 4.1656\times10^{-8}\,(1/\epsilon_v)^{4.5337} \qquad (1)$$

where,

$N_{20}$ = Number of cumulative standard axles to produce a rutting of 20 mm

$\epsilon_v$ = Vertical compressive strain at top of subgrade

The vertical compressive strain developed at the top of the subgrade for both unstabilised and stabilised subgrade were evaluated for all these alternatives using elasto-plastic Finite-Element Analysis. The vertical compressive strain at the top of the subgrade was used as the criterion to study the benefit of reinforcing the subgrade soil in terms Traffic Benefit Ratio (TBR) which gives the extension in the service life of pavement due to soil stabilization and was calculated using Eqn. 2.

$$TBR = N_R / N_U \qquad (2)$$

where $N_R$ and $N_U$ are the number of standard axle passes required for producing an allowable rut depth for reinforced and unreinforced pavement sections.

### *3.6 Results of Finite Element Modelling*

The vertical deformation and the stresses at each layer of pavement at the end of loading were plotted for various cases of reinforcements. Equivalent stress contour and directional deformations for clay subgrade and stabilised clay are shown in Figs. 6 to 9 respectively.

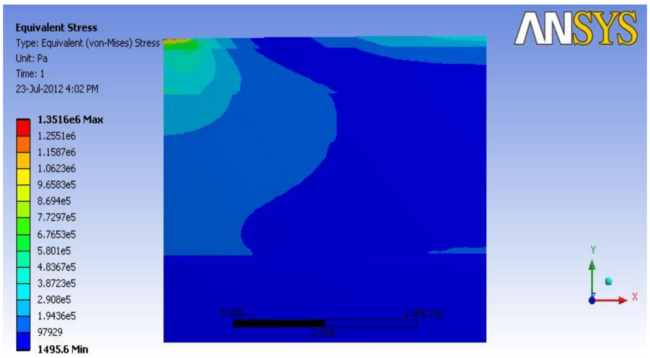


**Fig. 6 Equivalent Stress Contour for Clay**

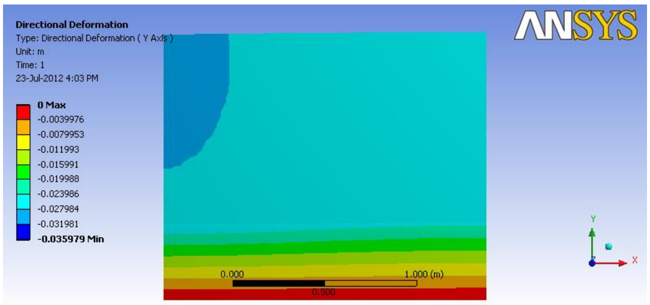


**Fig. 7 Directional Deformation Contour for Clay**

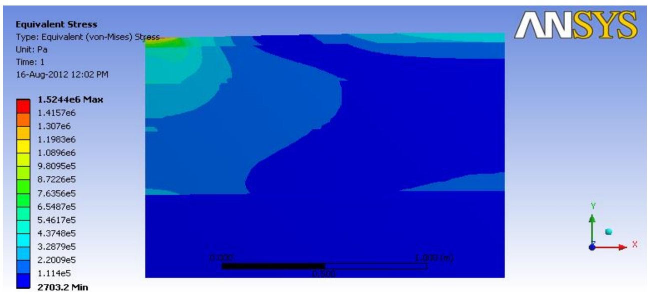


**Fig. 8 Equivalent Stress Contour for Stabilized Clay**


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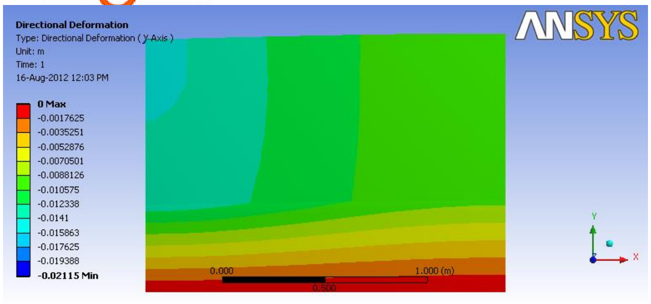


**Fig. 9 Directional Deformation Contour for Stabilized Clay**

The vertical strain at top of subgrade was obtained for the following cases:

i) for varying thickness of pavement section with varying subgrade material (un stabilized and stabilized) at same tyre pressure

ii) for same pavement section with varying subgrade materials(un stabilized and stabilized) at same tyre pressure

Benefit of these cases were analysed in terms of Traffic Benefit Ratio (TBR) and number of standard axle passes to create 20mm rut depth (**$N_{20}$**). Benefit calculation was done for cases of same tyre pressure and varying tyre pressure.

(i) Benefit calculation for varying pavement section with varying subgrade material at same tyre pressure

Vertical strain at top of the subgrade was estimated by FEM modelling on ANSYS package, by keeping tyre pressure as 575 kPa and the subgrade layer alone was changed as Kuttanad clay and stabilised clay. Number of cumulative standard axles to produce a rutting of 20 mm and the TBR was calculated for these two cases using Eqns. 1 and 2 respectively and are shown in Table 4 and Table 5 respectively.

**Table 4 Benefit of Stabilization on same Pavement Section with Unstabilized and Stabilized Subgrade Layer**

| Material | Strain (micro strain) | $N_{20}$ | TBR |
|---|---|---|---|
| Clay | 0.045 | 53163 | - |
| Stabilized Clay | 0.028 | 389676 | 7.3 |

It can be seen from Table 4 that stabilization has a positive impact on pavement performance since it increases number of wheel passes required to cause rutting failure and the improvement in Traffic Benefit Ratio indicates the improvement in service life of pavements. Clay stabilized with lime, sand and sisal fibre with optimum fibre content and aspect ratio can improve the service life of clay by about 7.3 times.

(ii) Benefit calculation for varying pavement section with varying subgrade material at varying tyre pressure. Inorder to study the effect of varying tyre pressure on the strain values, pressure was varied as 575 775, 975 and 1200 Kpa respectively for the unstabilized and stabilized clay. Hence both subgrade material and tyre pressure were varied and the result obtained from FEM analysis for the same is given in Table 5. From Table 5 it can be seen that, for tyre pressures of 575 and 775 kPa, the TBR is almost the same as around 10, whereas for higher tyre pressures, there is a drastic decrease in the TBR value. Hence it can be concluded that for best results of sisal fibre stabilization, the tyre pressure should preferably be equal to or less than775 kPa.

**Table 5 Effect of Tyre pressure on Strain values of Stabilized and Unstabilized Clay**

| Tyre Pressure | Strain values (Micro Strain) | | $N_{20}$ | | TBR |
|---|---|---|---|---|---|
| | Clay | Stabilized Clay | Clay | Stabilized Clay | |
| 575 kPa | 0.04499 | 0.0272 | 53216 | 521042 | 9.8 |
| 775 kPa | 0.068047 | 0.0410 | 8154 | 81077 | 9.9 |
| 975 kPa | 0.08568 | 0.06571 | 2869 | 9554 | 3.3 |
| 1200 kPa | 0.10536 | 0.0854 | 1123 | 2912 | 2.6 |

## IV. SUMMARY AND CONCLUSIONS

Road construction over weak soil subgrades has been a real challenge for the highway authorities even today. This study is an effort to stabilise Kuttanad clay using locally available materials and to arrive at a cost effective methodology for pavement construction in this region. Based on the earlier experimental investigations, a fibre content of 0.75% by dry weight of soil and an aspect ratio of 80 have been identified as optimum for sisal fibres. A Finite Element Modelling was done in ANSYS using these results for studying the benefit of stabilisation of Kuttanad clay using sisal fibres in terms of its Traffic Bearing Ratio (TBR). The results showed that stabilisation of black cotton soil like Kuttanad clay using sisal fibre is an efficient and economic tool for improving the characteristics as a subgrade soil. From the undrained triaxial test results, it was observed that the elastic modulus of Kuttnad clay increase by 2.9 times due to addition of lime, sand and sisal fibres. By experimenting with the same pavement section over both unstabilized and stabilized subgrade soil, it was observed that the Traffic Benefit Ratio is 7.3 when the clay was reinforced with sisal fibres. Effect of tyre pressure on the benefit of sisal reinforcement was also experimented by varying the former from 575 to 1200 kPa and it was observed that for best results, the tyre pressure should preferably less than or equal to 775 kPa.

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