MANTECH Publications

Journal of Transportation Engineering and Its Applications
Volume 8, Issue 2, May-August, 2023

Elastic and Elasto-Plastic Analysis of Embankements by Finite Element Method

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Abstract

Earthen embankments are widely used for roads, railways, river training works, canal works, dams etc. The economy and safety of these embankments can be accomplished by adopting proper methods of design, construction and maintenance. The failure of these structures is likely to result in huge loss of life and damage to property. It may also result in damage of the structure fully or partially. Geotechnical materials range from rock to clay. Their behavior is very complex. A full deformation analysis is the only viable approach for prediction of the nature of soils. The constitutive models that are used to characterize the behavior of geologic materials include linear elastic, nonlinear elastic, elastoplastic and elastoviscoplastic models. The development of constitutive models has assumed considerable importance in recent times due to the emergence of powerful numerical method. Finite element method is the most popular and widely used numerical method for solving engineering problems.

Keywords- *earthen embankments; geotechnical materials; deformation analysis; constitutive models; finite element.*

INTRODUCTION

Embankments are the ancient forms of civil engineering construction in the long history of human civilization. They have been constructed from time immemorial for major purposes of flood prevention, water storage, irrigation, and transportation. The design and construction of

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the embankments can be achieved with relative ease when the foundation soil conditions are good. The principal factors influencing the stability of an embankment are weights of the embankment materials, stresses resulting from the adopted slopes, placing method sand settlement, and the pore pressures which result from consolidation and protection.

GEOSLOPE is a finite element program developed to analyze a wide spectrum of problems in geotechnical, hydro geological and mining engineering projects GEOSLOPE has implemented Computer Aided Drafting (CAD) functionality using the Microsoft Windows graphical user interface. GEOSLOPE provides the following geotechnical engineering software products.

- SLOPE/W for slope stability
- SEEP/W for seepage
- CTRAN/ for contaminant transport
- SIGMA/W for stress and deformation
- TEMP/W for geothermal analysis
- QUAKE/W for dynamic earthquake analysis

For the analysis of embankment, SIGMA/W was used in the present study. SIGMA/W is general finite element software product for stress and deformation analysis of geotechnical engineering structures. Its comprehensive formulation makes It possible to analyze both simple and highly complex problems. A variety of different stress-strain constitutive relationships, which range from simple linear-elastic to non- linear elastic-plastic models, can be used. The many constitutive soil models allow to represent a wide range of soils or structural elements. Loads can be applied and removed in stages and SIGMA/W can be used to compute the changes in pore-water pressures that arise from stress state changes when coupled with SEEP/W. These features enable SIGMA/W to analyze almost any stress or deformation problem in geotechnical, civil and mining engineering project.

Scope of the Study

Embankments are important civil engineering structures used in railways, highways and dams. They are essential everywhere including in earthquake prone areas. It is very essential to understand the performance of embankment under different loading conditions. Design and construction are closely related. An embankment is stable if the resultant of all the forces

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acting upon it does not result in its movement as a whole or of any part of it the factors that affect the stability are the cross-sectional shape, the height of the embankment, the characteristics of the material of which the embankment is constructed, the method and rate of construction and the percolation through the embankment, all of these factors are interrelated. Hence in the present study an attempt has been made to understand the variation of displacements and shear stress by varying the various parameters of embankment.
Embankment

EMBANKMENT

Types of Embankments

Embankments can be classified into two types, homogeneous type and zoned type.

Homogeneous embankment

A homogeneous embankment is one, which consists of practically uniform material throughout. There is no designed plan of material distribution other than the requirement that the coarsest or most pervious material is placed at the outer slopes. This is affected by distribution control in the construction of a rolled fill.

Zoned embankment

A zoned embankment is a rolled fill embankment which consists essentially of an inner or impervious section supported by two or more outer sections of relatively pervious materials. As is apparent, this type of structure is dependent upon the availability of materials that vary in character either between separate borrow pits or by stratification within the same pit to such an extent as to permit the selection and distribution of the materials used in the embankment in accordance with the predetermined plan.

DEFORMATION ANALYSIS

Every solid body deforms under the action of applied forces. To every kind of stress there is a corresponding strain. If the stresses are not high, the strained body will recover its original shape and size when the stresses are released. The property, which a body possesses of recovering from strain, is called elasticity. We call a body perfectly elastic if it recovers completely. If the body does not recover completely, the strain that remains when the stress is removed is called permanent set and the body is said to be in a plastic state. If forces are

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applied to any solid body and these forces are gradually increased, it is observed experimentally that until some definite limit in the magnitude of these forces is reached the body will be perfectly elastic. The limit is called the elastic limit. Beyond this elastic limit, the material will be in the plastic state, and permanent set will be produced.

Stability Analysis

In the analysis for the stability of embankments five modes of failure are investigated. They are:

- Bearing capacity failure
- Sliding failure
- Spreading failure
- Foundation soil squeezing failure
- Rotational failure

The embankments must be stable against all these modes of failure. Fig.1 shows typical failure modes of embankment.

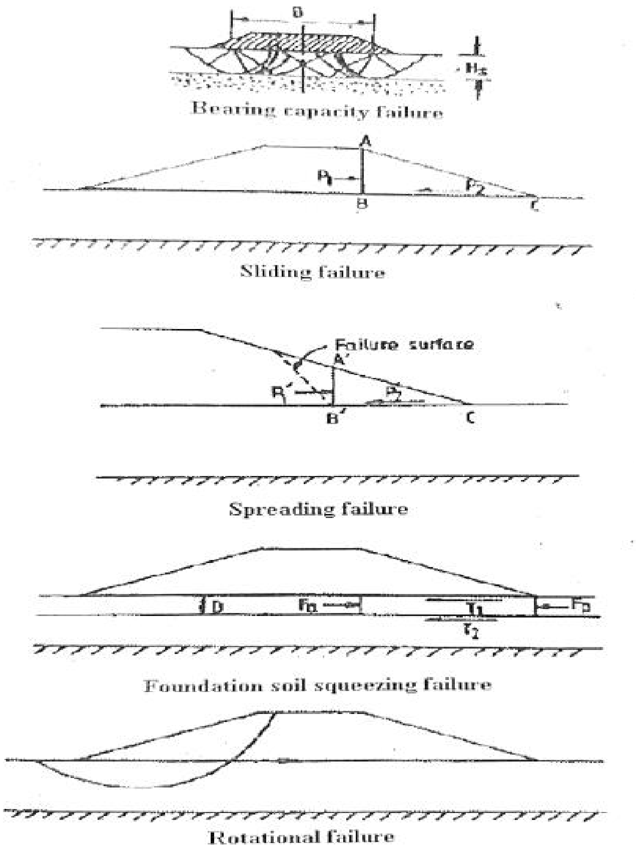

Fig. 1 Modes of failure of embankment

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FINITE ELEMENT ANALYSIS (FEA) – GEOSLOPE

Geotechnical materials range from rock to clay. Their behavior is complex and is affected by such factors as the geologic history of formation, environmental factors, stresses history, drainage condition and stress path. The constitutive models are used to characterize the behavior of geologic materials. The development of constitutive models has assumed considerable importance in recent times due to the emergence of powerful numerical methods. The numerical methods such as Finite element method, Boundary element Method have revolutionized the ability to predict the behavior of various engineering systems in general and geotechnical engineering problems in particular.

FINITE ELEMENT ANALYSIS SYNOPSIS

The two steps of finite element analysis are as follows. Modeling the issue comes first, followed by formulating and resolving the related finite element equations. When modeling, the mesh must be created, the material properties must be specified, the suitable constitutive soil model must be selected, and the boundary conditions must be specified.

GEOSLOPE

In order to study a broad range of issues in geotechnical, hydro-geological, and mining engineering projects, the finite element program GEOSLOPE was created. Utilizing the Microsoft Windows graphical user interface, GEOSLOPE has developed Computer Aided Drafting (CAD) capability.

The following is provided by GEOSLOPE. software for geotechnical engineering

- SIGMA/W for stress and deformation
- SEEP/W for seepage
- CTRAN/W for contamination transport
- TEMP/W for geothermal analysis and
- QUAKE/W for dynamic earthquake analysis
- SLOPE/W for slope stability.

For the analysis of embankment, SIGMA/W was used in the present study.

Sigma/W

For the analysis of stress and deformation in geotechnical engineering constructions,

SIGMA/W is a general finite element software program. Its thorough structure enables the

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analysis of both straightforward and extremely complicated issues. It is possible to apply a variety of stress-strain constitutive relationships, ranging from straightforward linear-elastic to non-linear elasto-plastic models. The many constitutive soil models allow a variety of soils or structural components to act to be represented. When connected with SEEP/W, Sigma/W can be used to compute the changes in pore-water pressures that result from changes in stress states. Loads can be introduced and removed gradually. These features enable SIGMA/W to analyze almost any stress or deformation problem in geotechnical, civil and mining engineering projects.

Using Sigma/W

Three executable programs are included with SIGMA/W: DEFINE for model definition, SOLVE for result computation, and CONTOUR for result visualization.

Defining Problem

Problems can be defined with the DEFINE application by drawing them on the screen. Setting up the drawing space is the first step in defining an issue. Setting the page's size, scale, and coordinate system origin does this. Once the drawing area has been established, the issue can be sketched out using lines, circles, and arcs. Then, in order to define the finite element model, we must identify material attributes, discretize the problem domain into finite elements, and then apply boundary conditions. The SOLVE program can read a DEFINE data file that is created when the problem is saved. Once this is finished, the issue can now be resolved.

Solving Problem

The DEFINE program is used to create a data file, and the SOLVE software is then used to resolve the issue. The computations may be terminated at any time, or the iteration may be stopped and resumed at a later time. A graph of the iteration convergence can also be shown.

Contouring and Graphing Results

The analytical results calculated by SOLVE can be graphically displayed by CONTOUR. Exaggerated displacements, colored yield zones, tables of data, contours, graphs, and Mohr's circle diagrams can all be used to display the results. It is possible to contour and graph in either space or time any computed data parameters. The drawing can be improved and tagged

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with visuals in addition to data visualization.

Applications

A finite element software program called SIGMA/W can be used to analyze the stress and deformation of earth constructions. Its thorough structure enables the analysis of both straightforward and extremely complicated issues. The following are some examples of typical cases that SIGMA/W can be used to examine.

- **Deformation Analysis -** The most common application of SIGMA/W is to compute deformations caused by earthworks such as foundations, embankments, excavations and tunnels.
- **Building an embankment or excavating a hole:** Finite elements can be added or subtracted from the finite element mesh to mimic building an embankment or excavating a hole. It is possible to replicate the process throughout time by activating or deactivating elements at different points in the process.
- **Excess Pore-Water pressures -** The effect of excess pore-water pressures generated during fill placement is often a major consideration in slope stability during construction. SIGMA/W can be used to estimate these types of pore-water pressures. Excess pore-water pressures computed using the SIGMA/W may be imported into SLOPE/W for slope stability analysis.
- **Soil-Structure interactions-** SIGMA/W can accommodate soil-structure interaction problems by including structural elements in two-dimensional plain strain analyses. These elements are beam elements which have flexural stiffness, and bar elements which have only axial swiftness with no flexural stiffness. These structural elements are particularly useful when analyzing cases such as sheet-pile walls.
- **Consolidation Analyses -** SIGMA/W can be used together with SEEP/W to perform a fully-coupled consolidation analysis. hen these two integrated products are run simultaneously. SIGMA/W calculates the deformations resulting from pore- water pressure changes while SEEP/W calculates transient pore-water pressure changes. This procedure is used to simulate the consolidation processing both saturated and unsaturated soils.

Elastic Analysis of Embankment

The capability of a soil to support a load from a structure or to support its own overburden, or

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to sustain a slope in equilibrium is governed by its shear strength. The shear strength of a soil is of prime importance for the design of structures, it is highly complex because of various factors involved in it, namely, the heterogeneous nature of the soil, the water table location, drainage facility, type and nature of construction, stress history, time, chemical action or environmental conditions.

Stress Strain Curve

A typical shear stress-shear strain curve is shown in Fig. 2. At first, when the shear stress is modest, the soil exhibits a linear stress-strain curve, behaving like an elastic material. Increases in shear stress and strain lead to the development of considerable plastic shear strain, which is known as yield, at a certain stress level. With an increase in plastic shear strain, soil becomes more resistant to shearing, and this process is known as strain hardening or work hardening. the shear strength of the soil is the greatest shear stress that can be withstood by the soil due to the strain hardening, which increases resistance to a specific maximum shear stress. The soil this yield level is considered to be unstable and the soil is said to fail. In some soils, the maximum shearing resistance decreases after this point and the soil is said to be stain softening or work softening. After a continued large strain, the shearing resistance attains a constant level and the corresponding shearing resistance is called the residual shear strength.

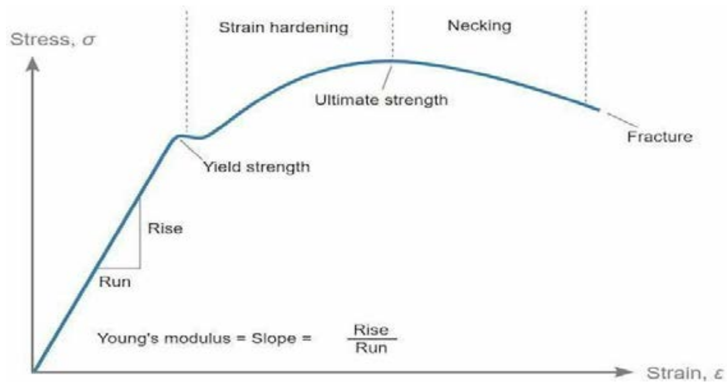

Fig.2 Typical Stress strain curve

Determination of stress increase at points under the embankment

Construction of a foundation causes changes in the stress, usually a net increase. The net stress increase in the soil depends on the load per unit area to which the foundation is subjected, the depth below the foundation at which the stress estimation is desired and other

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factors. Bossiness (1883) solved the problem of stresses at any point in a homogeneous, elastic, and isotropic medium as the result of a load applied on the surface of an infinitely large half-space. This has been explained by Das (1999). Fig. 3 shows the cross section of an embankment of height H. Parameters B1, B2, and, are shown in Fig. 6.3.

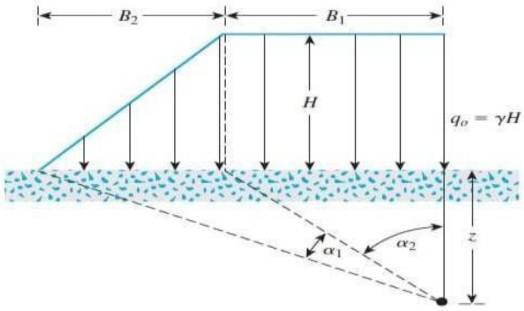

Fig.3 Embankment loading

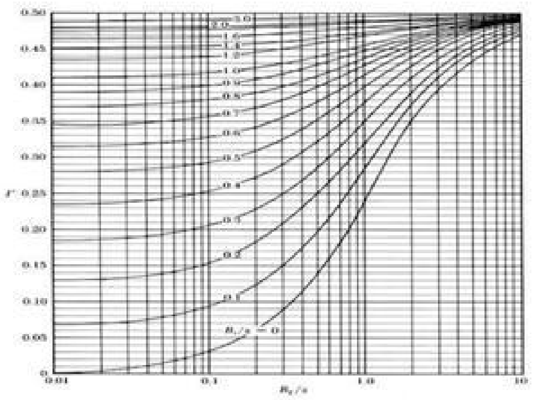

Fig.4 Osterberg's chart for determination of vertical stress due to Embankment loading

For two-dimensional loading condition, the vertical stress increase is expressed as:

Fig.5 shows the cross section of an embankment of heightH. For this two-dimensional loading condition, the increase in vertical stress is calculated using the above equationgives:

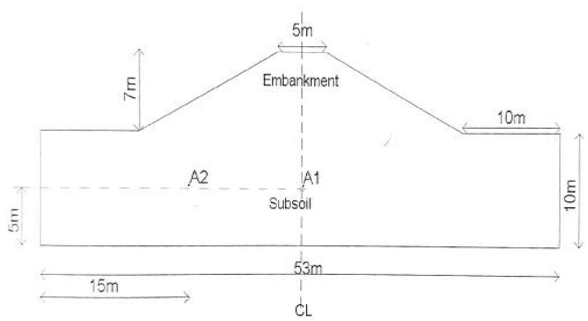

Fig. 5 Typical cross section of Embankment resting on subsoil

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Immediate Settlement

All soils undergo immediate settlement also called elastic settlement. This is due to the initial readjustment of positions of soil grains to equilibrium under the action of load. It is generally accepted that the estimation of immediate settlement is based on elastic theory. Thus, immediate settlement S; in meters, is calculated from the equation given below (Raj P.P. (1995). Fig.6 shows the cross section of rectangular footing on resting foundation soil considered for the analysis.

$$S_e = q_0 . B' . \frac{1-\mu_s^2}{E_s} . F_1$$

q = Intensity of contract pressure (kN/m²)

B'= Least lateral dimension of loaded area (m)

Es = Modulus of elasticity (kN/m²)

F1= Influence factor which depends on the shape and rigidity of footing

µs = Poisson's Ratio

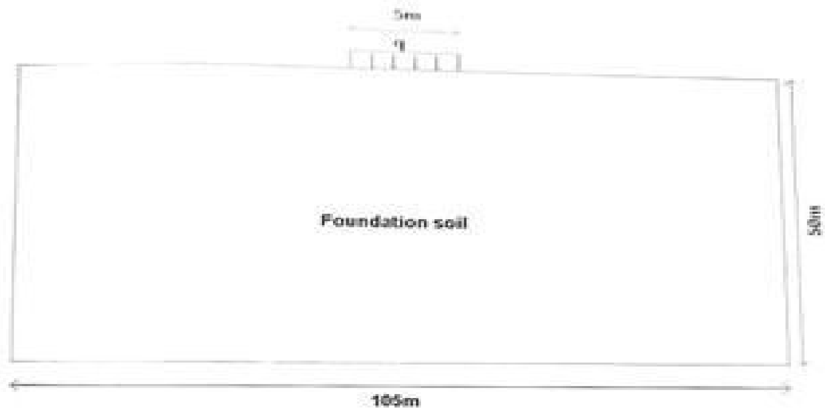

Fig.6 Typical cross section of rectangular footing on foundation soil

Convergence Study

In order to decide the number of elements, the embankment shown in Fig.7 is considered for convergence study. The number of elements is increased from 13 to 19240 elements. The number of elements is so chosen that the aspect ratio in all the cases was equal to one. The boundary conditions, geometry of embankment, loading conditions are maintained the same.

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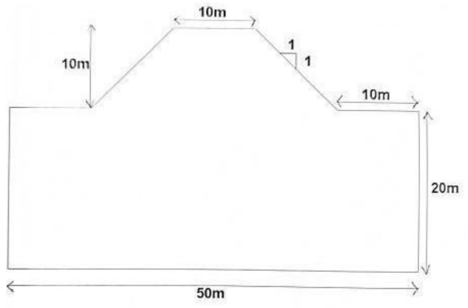

Fig.7 Geometry of the embankment considered for convergence study

The material properties used are:

Mass density: 14kN/m3 Young's Modulus: 3000 kN/m² Poisson's Ratio: 0.40

Element type: 4 noded quadrilateral plane strain element.

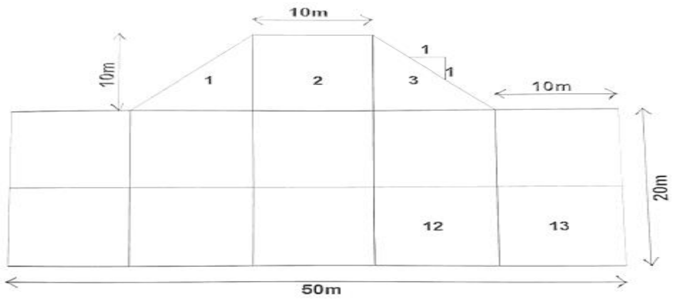

Fig.8 Geometry of the embankment with 13 elements

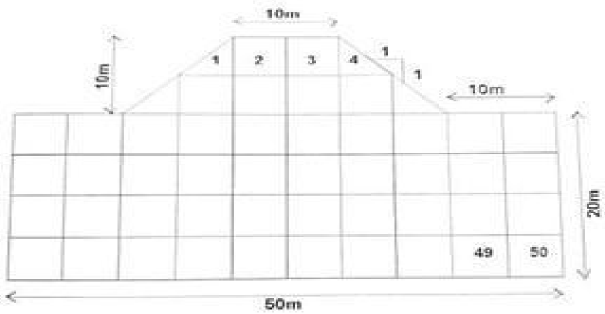

Fig.9 Geometry of the embankment with 50 elements

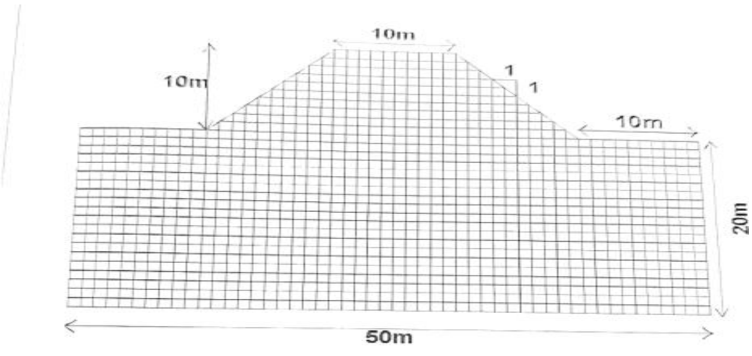

Fig.10 Geometry of the embankment with 1210 elements

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The variation of horizontal displacement, settlement and shear stress and the corresponding number of elements are shown in Fig.11, 12 and 13. Displacements and shear stress are compared at three different points A, B and C as shown in key sketch.

From Fig.11, Fig.12 and Fig.13, it is clear that convergence is achieved at 305elements at all the three points.

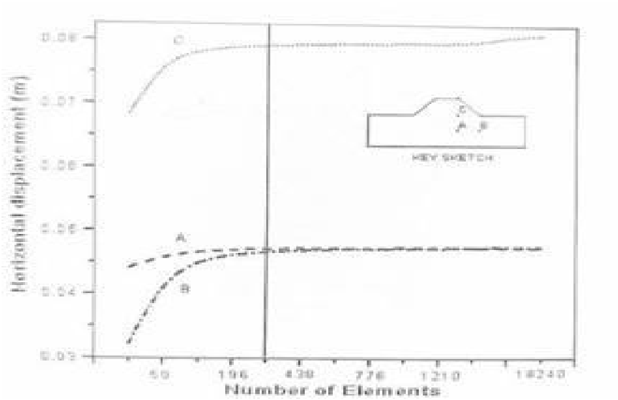

Fig.11 Variation of Horizontal displacement with number of elements

From Fig. 11, it can be observed that there is no considerable change in the variation of horizontal displacement at point A and B. At point C increase in number of elements increase the horizontal displacement.

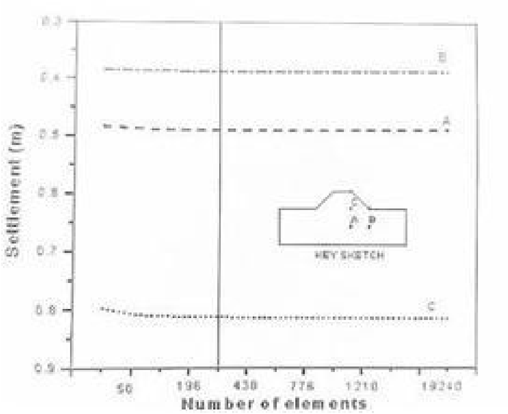

Fig.12 Variation of Settlement with number of elements

From Fig. 12 complete convergence of settlement is observed at all the three points A, B and C. The increase in the magnitude of settlement is not considerable.

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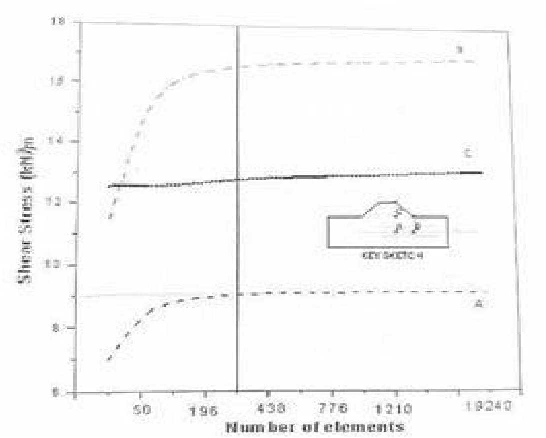

Fig.13 Variation of Shear stress with number of elements

From Fig 13, convergence is observed in the shear stress at number of elements equal to 305, The magnitude of shear stress increase initially with the increase in number of elements up to 305 at points A and B. With further increase in number of elements beyond 305 the change in magnitude of shear stress is not considerable. At point C the variation in magnitude of shear stress is not considerable.

Parametric Study

The cross-sectional shape, height of the embankment, properties of the material used to construct the embankment, material used to construct the foundation, method and speed of construction, and percolation through the embankment are the elements that determine stability. These elements are all connected. The length of the free field, the height of the embankment, the slope of the embankment, the depth of the subsoil, the modulus of elasticity of the material of the embankment, and the mass density of the material of the embankment are some of the parameters that are varied in the current study

The material properties used are:

Weight density: 14N/m

Young’s Modulus: 3000 kN/m^2

Poisson's Ratio: 0.40

Element type: 4 noded quadrilateral plane strain element

Following parameters were studied and analyzed

- Effect of the free field length

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- Effect of thickness of subsoil
- Effect of height of embankment
- Effect of Unit weight of soil
- Effect of variation of slope of embankment
- Effect of Young's modulus of embankment

Summary

The stress strain characteristics of real materials areextremely complex. In the present work linear elastic analysis was carried out to understand the deformation behavior of earthen embankment using a finite element software module SIGMA/W from GEOSLOPE software. A comparison was made between the finite element solution of typical geotechnical problems using GEOSLOPE and a solved problem from existing literature and the two results are comparable. Convergence study was made to decide the optimum number of elements required to calculate the displacements and shear stress. Also, variation of horizontal displacement, settlement and shear stress with respect to various parameters like length of free field, height of embankment, slope of embankment, depth of subsoil, Young's modulus of material of embankment and weight density of embankment were studied and compared.

Embankments with Mitigation Measures

In situ soil characteristics of a construction site are different from those desired and, almost always, far from ideal for a designated need. With increased urban development sites, the favorable foundation conditions became depleted. The civil engineer has occasionally been forced to build structures at locations picked without consideration for the quality of the soil. Thus, it is becoming more and more crucial for the engineer to be aware of the extent to which soil qualities may be enhanced or other options that may be considered for the construction of a desired project at the specified site.

One of the following four approaches may be used to ensure the structure performs satisfactorily if inadequate soil conditions are discovered at the site of a proposed construction.

- By pass the unsuitable soil by means of deep foundations extending to a suitable bearing material.

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- Redesign the structure and its foundations for support by the poor soil, a procedure that may not be either feasible or economical.
- Remove the poor material and either treat it to improve and replace it or substitute for it by a suitable material Treat the soil in place to improve its properties.

In this study an attempt was made to understand the variation of displacement and shear stress by adopting the following ground improvement techniques for embankments and contours were plotted for assessing the distribution of displacements and stresses in the soil media.

Soil Reinforcement

Reinforced earth is a composite construction material in which the strength of an engineering fill is enhanced by the addition of strong inextensible tensile reinforcements in the form of strips. Reinforced soil is somewhat analogous to reinforced concrete in that, in the former the bond is through adhesion / friction of soil to reinforcement and in the latter, it is through chemical bond. The similarity, if any, ends here. Whereas the reinforcement concrete is designed to carry the tensile forces in the structure, it is likely that an entirely compressive stress field will exist in the reinforcement of a reinforced soil structure. The tension in this occurs due to the manner in which it functions and not because there is any tensile force in the structure.

The scientific basis for the modern concept of soil reinforcement lies in the idealization of the problem of soil reinforcement in the form of a weak soil reinforced by high- strength thin horizontal members.

A wide variety of materials have been in use as reinforcing material, Early structures were formed using organic materials such as timber, straw orreed for reinforcement. As these materials are less durable, new materials such as steel, concrete, glass fiber, rubber, aluminum and thermos-plastics have been used successfully. Durability of reinforced soil is the basic requirement. Hence sufficient judgement has to be exercised while selecting the reinforced material. Resistance to corrosion is the significant factors, which affects the durability. High alloy steel, aluminum, glass-fiber reinforced plastics and geo synthetics are non- corrosive and have general long life.

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Salient features of reinforced soil

Reinforced soil processes many novel characteristics that render it eminently suitable for construction of engineering structures.

- It employs prefabricated elements - which facilitates easy handling, storage and assembly.
- It mostly uses easily available ordinary granular soil as fill material.
- The soil placement can be done by modern equipment or manually.
- A reinforced soil structure is flexible in nature, which permits larger differential settlements than conventional rigid structures and hence construction is feasible even over poor subsoil.

Finite Element Analysis- Modelling

In the present study, reinforced soil was considered as a heterogeneous system in which the soil and the reinforcement are separately represented. The analysis was carried out by assuming the material to be linear elastic and two- dimensional plane strain problem. The main intention was to understand the distribution of stresses and deformations and to understand the mechanism of action of reinforcement strips in soil mass. Hence, the work was restricted to elastic analysis. Here, the reinforcement was treated as a structural element whose ends are restrained for movement in horizontal direction. The moments of inertia and cross- sectional area are specified in terms of unit thickness. Study was based on continuum consideration. But in real soil the mechanism of load carrying capacity is through friction between soil and reinforcement. Hence, a higher value of Young's modulus and thickness of reinforcement were selected in the present study. The soil was modelled as a linear elastic material with young's modulus and poison’s ratio as basic inputs. The performance of the reinforced embankment with 2.5m spacing of reinforcement and 1m spacing of reinforcement were compared with the benchmark model without any mitigation measures.

The material properties of soil used were:

Young's Modulus: 20000 KN/m^2

Poisson's Ratio: 0.30

Unit weight: 14 kN/m^3

The structural properties of reinforcement used were:

Young's Modulus: 2×1010kN/m^2

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Thickness of reinforcement: 0.01 m
Moment of Inertia: 8.33×10^{-6} m4
Cross sectional area: 0.01 m^2

Embankment without Mitigation Measures

For the embankment without any mitigation measures, the fluctuations of displacement and shear stress in the embankment subsoil system were analyzed. Displacement contours and shear stress contours were plotted to analyze the deformation of the embankment; this was used as a benchmark model to compare the impacts of reinforcement. Fig.14 depicts the embankment's geometry.

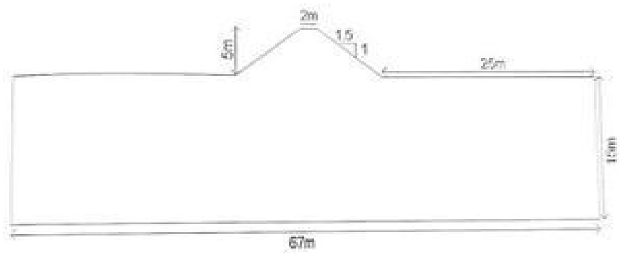

Fig.14 Embankment without any mitigation measure

Fig.15 indicates the distribution of horizontal displacement contour. The contours are plotted at an interval of 0.0005 m. It can be observed that the horizontal displacement in embankment portion is less when compared to the displacement in subsoil, Maximum horizontal displacement occurred approximately in the middle of the subsoil below the embankment portion below the toe.

Fig.16 indicates the distribution of settlement contour with contour interval of 0.005 m. From the figure it can be observed that the settlement in embankment portion is maximum. The settlement contours are continuous, The provision of embankment provided saucer shape to settlement contour with more curvature near embankment and gradually decreasing with depth.

Fig.17 indicates the distribution of shear stress contour with contourintervalof2kN/m2.Itcanbeclearlyobservedthatthe shear stress distribution is continuous. There is a stress concentration at point A i.e. the junction between the embankment and subsoil.

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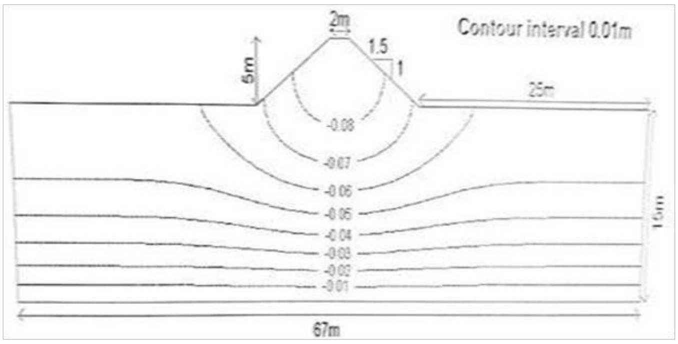

Fig.15 Distribution of horizontal displacement in embankment without mitigation measure.

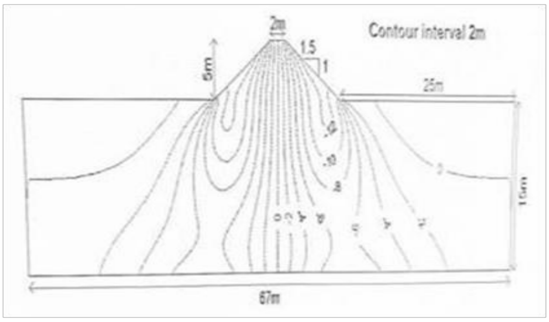

Fig.16 Distribution of Settlement in embankment system without any mitigation measure

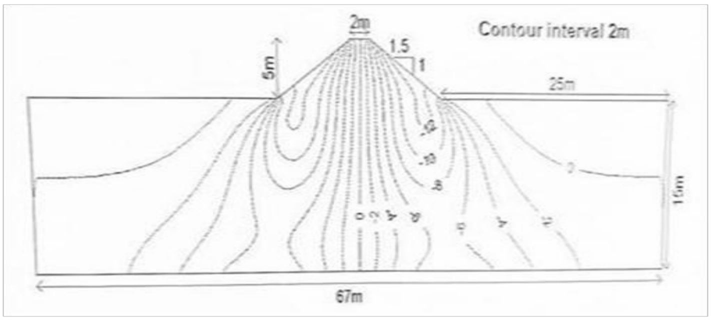

Fig.17 Distribution of Shear stress in embankment system without Any mitigation measure

The variation of horizontal displacement, settlement and shear stress was studied by placing reinforcement for the following:

1. Reinforcement in embankment at 2.5mspacing.
2. Reinforcement in subsoil at 2.5mspacing.
3. Reinforcement both in embankment and subsoil at 2.5m spacing.

In general, following observations were made:

Horizontal displacement

- Provision of reinforcement reduced the magnitude of horizontal displacement.

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- Performance was the best when reinforcement was provided both in embankment and in subsoil.
- Provision of reinforcement induced discontinuity in the horizontal displacement

Vertical Settlement

- Presence of reinforcement reduced the magnitude of settlement.
- Performance was the best when subsoil as well as embankment were reinforced.
- In comparison to subsoil, the vertical settlement of reinforcement was not very significant.

Shear Stress

- Because of the reinforcement and the irregular geometry of the embankment, the maximum shear stress somewhat increased in magnitude. The increase was most pronounced in the portion of the embankment.
- Because of the reinforcement, a discontinuity in the shear stress distribution was clearly visible.

The distribution of horizontal displacement, settlement, and shear stress contour with the reinforcement spacing 1m only in the embankment portion, only in the subsoil, and both in the embankment and subsoil were studied in an effort to study the effect of reinforcement spacing. The results were compared with benchmark model contours.

The variation of horizontal displacement, settlement and shear stress was studied by placing reinforcement for the following:

1. Reinforcement in embankment at 1mspacing.
2. Reinforcement in subsoil at 1mspacing.
3. Reinforcement both in embankment and subsoil at 1m spacing.

In general, following observations were made:

Horizontal displacement

Significantly less horizontal displacement results fromcloser- spaced reinforcement or the addition of more reinforcement. Infect, the subsoil's horizontal displacement is essentially nonexistent.

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Settlement

The amount of settlement has been decreased by increasing reinforcement or decreasing the gap between existing reinforcement.

Shear stress

The amount of shear stress has increased due to a reduction in reinforcing spacing or the addition of more reinforcement. The shear stress will become discontinuous if reinforcement is provided.

DENSIFICATION

One of the most common soil improvement countermeasures is densification. The significant small and medium irrigation infrastructure are earthen embankments. They used earth that was dug up from somewhere to construct on the subsoil. In order to achieve the required outcomes, it is crucial that the subsurface has the necessary strength and deformation properties, and that the embankment is compacted. The majority of the embankments in India are not particularly robust and are constructed on flimsy sub-soil. Densification of a foundation soil can, however, be economically accomplished in a limited space at the proper site.

To understand the behavior of a densified embankment, elastic analysis was done. The following three typical cases of embankment behavior were compared in the current study.

- An embankment with no protective measures.
- A thick wall in front of the toes of the embankment.
- A thick wall inside the embankment toes.

To explore the effect of wall thickness, three distinct dense wall thicknesses 1m, 2m, and 4m were taken into consideration. The contours of horizontal displacement, settlement, and shear stress were drawn. By placing graphs along the horizontal section and vertical section of the contour, variations in horizontal displacement, settlement, and shear stress were compared for different wall thicknesses. Clause explains embankment without mitigating measures.

The material properties of soil considered were:

Young's modulus: 2x10^4 kN/m^2

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Poisson's ratio: 0.30

Unit weight: 14kN/m^3

The material properties of dense wall considered were:

Young's modulus: 2x107 N/m^2

Poisson's ratio: 0.20

Unit weight: 24kN/m^3

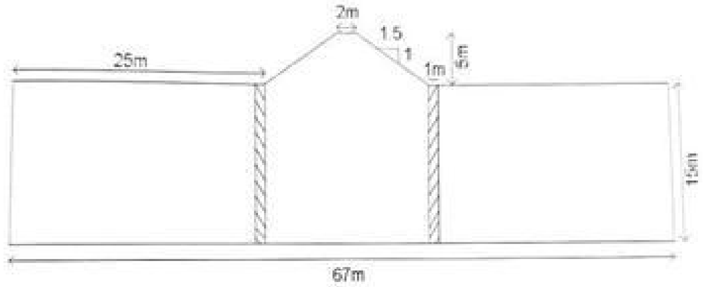

Fig.18 Geometry of the embankment with dense wall outside the toes

The variation of horizontal displacement, settlement and shear stress was studied by placing thick dense wall outside the toes for the following:

1. Embankment with 1m thick dense wall outside of thetoes
2. Embankmentwith2mthickdensewalloutsideofthetoes.
3. Embankmentwith4mthickdensewalloutsideofthetoes.

In general, following observations were made:

Horizontal Displacement

- Presence of wall minimizes the horizontal displacement in the subsoil below the embankment. The magnitude of horizontal displacement is very less when the embankment is provided with 2m thick dense wall.
- Presence of wall creates discontinuity in the horizontal displacement. Presence of wallcreates
  negative displacement in the soil on its outside near the base

Settlement

- Increase in thickness of wall reduces the magnitude of settlement. But, the amount of reduction in magnitude of vertical displacement is not appreciable.

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- Presence of wall creates discontinuity in settlement.

Shear stress

- Shear stress increases with increase in thickness of wall.
- Presence of wall creates discontinuity in shear stress.
- Stress concentration point in case without wall is at the toe. Whereas, with wall it is inside the subsoil below the toe on both sides of the wall. There is a change in the sign of shear stress on both sides of wall.

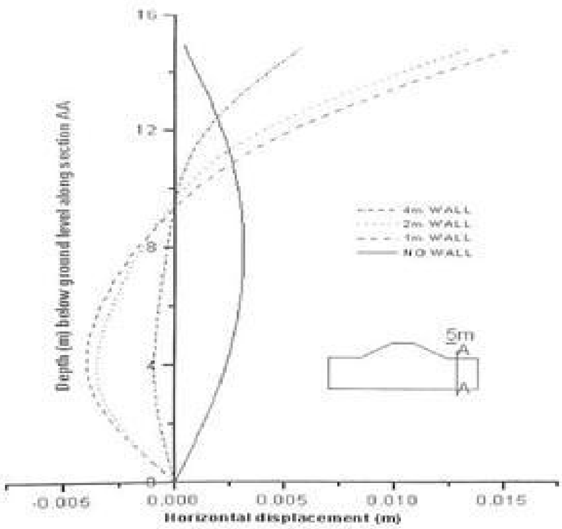

Fig.19 Variation of Horizontal displacement along vertical section AA (Embankment with walloutside)

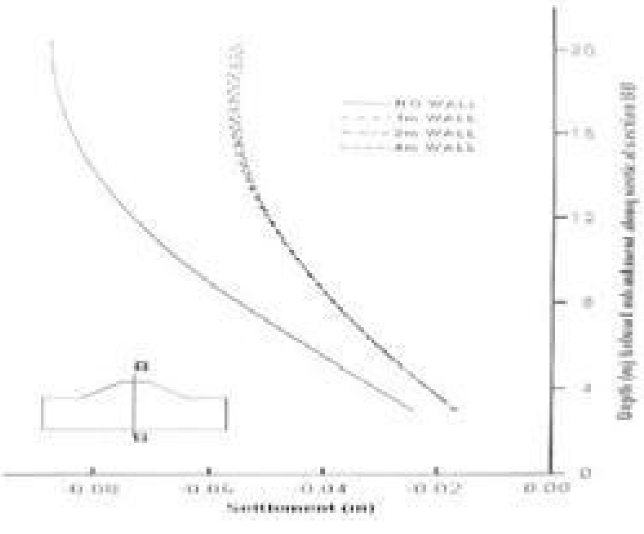

Fig.20 Variation of Settlement along vertical section BB (Embankment with wall outside

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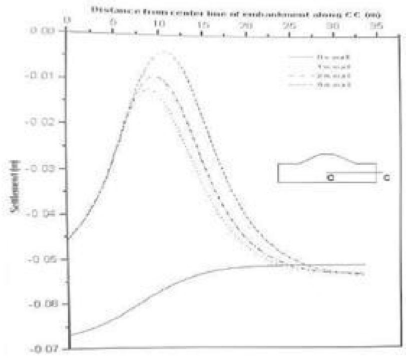

Fig.21 Variation of Settlement along horizontal section CC at center of subsoil (Embankment with walloutside

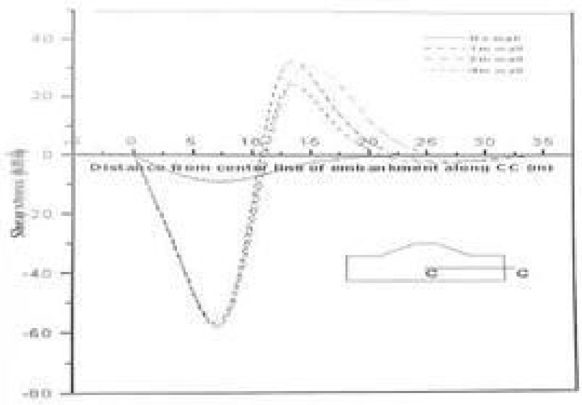

Fig.22 Variation of Shear stress along Horizontalsection CC at center of subsoil (Embankment with walloutside)

The variation of horizontal displacement, settlement and shear stress contour is studied for embankment with 1m thick dense wall on inside of the embankment toes for the following:

1. Embankment with 1m thick wall inside of the toes.
2. Embankment with 2m thick dense wall inside of the toes.
3. Embankment with 4m thick dense wall inside of the toes.

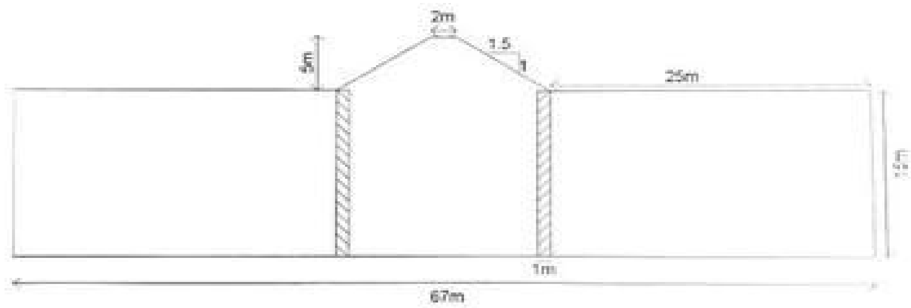

Fig.23 Geometry of the embankment with thick dense wall inside the toes.

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In general, it can be observed that the increase in thickness of wall decreases the magnitude of horizontal displacement and settlement and increase in magnitude of shear stress. The wall in embankment acts like column. Hence, larger the size of column more will be the capacity of column.

Horizontal displacement

The variation of horizontal displacement was studied by plotting graph along vertical section AA shown in Fig.23 and the following observations were made Presence of wall on the inside of toe will considerably reduce the magnitude of horizontal displacement in the embankment and subsoil below the embankment in front of wall. The location of maximum displacement will shift upwards.

Settlement

The variation of settlement was studied by plotting graph along the horizontal section BB and vertical section CC shown in Fig.24 and Fig.25. The following observations were made. Presence of wall on the inside of toe will considerably reduce the magnitude of settlement. Provision of wall creates discontinuity in the settlement.

Shear stress

The variation of shear stress was studied by plotting graph along horizontal section DD shown in Fig.26 and the following observations were made. Provision of wall on the inside of toe induces stress concentration at the base of the wall. Hence, the wall has to be firmly anchored to the hard rock. It can be observed that the magnitude of shear stress is higher on inner side of the wall when compared to outside of wall.

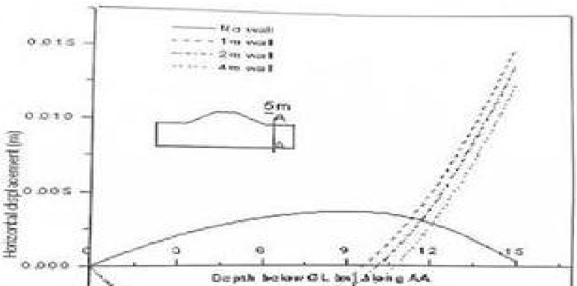

Fig.23 Variation of the Horizontal displacements along vertical section A.A. (Embankment with wall inside)

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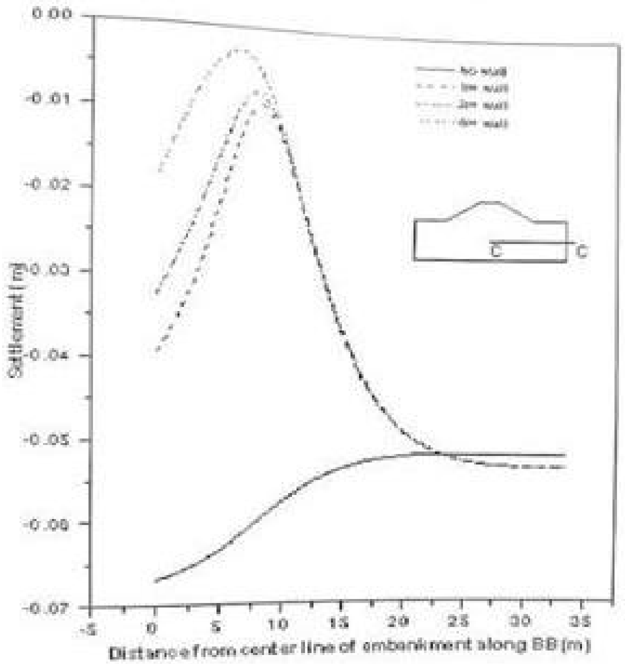

Fig.24 Variation of Settlement along horizontal section CC at center of subsoil (Embankment with wall inside)

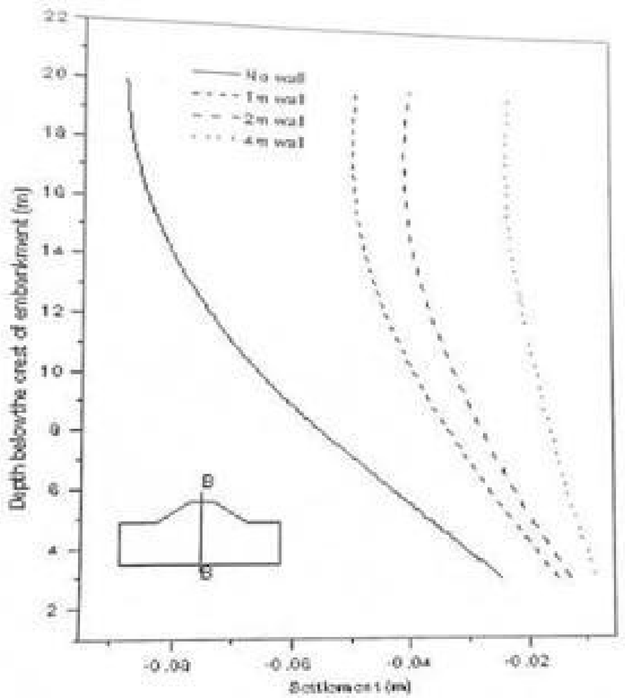

Fig.25 Variation of Settlement a long vertical section CC at center line (Embankment with wall inside)

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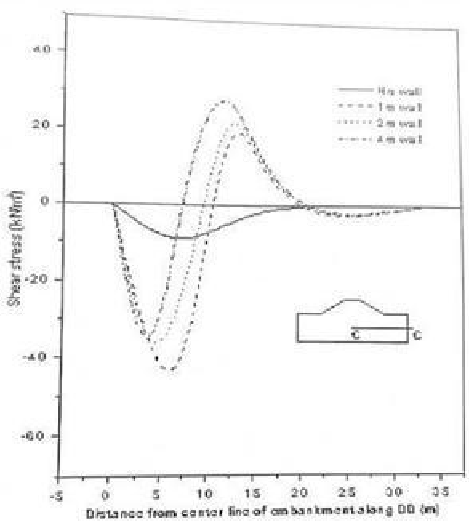

Fig.26 Variation of Shear stress along horizontal section CC at center of Subsoil (Embankment with wall inside)

ELASTO-PLASTIC ANALYSIS

Elastic constitutive models are quite straightforward. Young's modulus and poison's ratio are the only two material parameters needed for linear elastic models, however they are insufficient to capture many of the crucial aspects of actual soil behavior. Only atomic bonds are stretched during elastic deformation, therefore the work put into deforming a body can be fully recovered upon unloading. Regardless of the loading path, the strain can be used to specifically describe the elastic state. The notion of plasticity can be used to expand these models in order to make improvements. Understanding elastoplastic behavior and applying it to finite element analysis using GEOSLOPE for some geotechnical applications are the goals of this effort.

When compared to their linear counterparts, nonlinear elastic models in which the material properties change depending on the level of stress or strain offer significant advantages.

The majority of nonlinear elastic models assume isotropic behavior because of the numerous parameters involved, including young's modulus, poison's ratio, cohesion, internal friction angle, dilation angle, etc. Elastic-plastic theory is arguably the greatest framework for developing constitutive models that accurately mimic real-world soil dynamics. Perfect plasticity, strain hardening, and strain softening plasticity are three categories of plastic behavior. Since these models presuppose elastic behaviors before yield, they can take

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advantage of both elastic and plastic behavior's advantages. One layer of atoms slipping over the next causes the plastic deformation, which is a permanent shift in atomic locations. Only when the shear stress on a plane of the body surpasses the critical value is this possible. Local imperfections in the material, known as dislocations generated during soil disturbance and handling, are extremely sensitive to the tension required to cause plastic deformation.

Strain Curve for Stress

The linear behavior up to the yield stress is represented by the idealized elastic-perfectly plastic model, after which the material flows at constant stress. When loading occurs, the yield surface's location in stress space remains constant. The behavior is completely elastic when the stress level approaches the yield surface. Plastic straining happens when the stress condition exceeds the yield surface. The stress condition is not allowed to penetrate the yield surface.

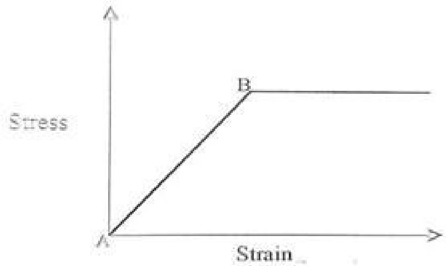

Fig.27 Linear Elastic and Perfectly Plastic Stress Strain Curve

If the element of soil considered above is a part of the soil mass in a boundary value problem, the plastic straining of the element is restricted. Strain increase indefinitely only when sufficient elements of soil are failing so that a collapse mechanism develops.

Conclusions and Scope for Future Work

In the current work, the finite element package GEOSLOPE-SIGMA/W was used to investigate the behavior of embankments. It was found that this package offers a strong method for the deformation analysis of flat strain systems. Due to its thorough formulation, it can be used to assess both straightforward (linear elastic model) and complex (elasto- plastic model) issues. It has no precise restriction on problem size in terms of nodes, elements, or material types and is naturally suited for tackling arbitrary geometry or material property

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variations. A planar strain analysis can successfully model reinforcement using structural elements.

CONCLUDING REMARKS

Based on the finite element analysis of embankments, following conclusions were drawn in the present study.

1. The horizontal displacement, element and shear stress varied considerably when the fire field length was within 5H from the toe of the embankment, where H is the height of the embankment. Hence the boundary effect was felt up to 5H.

2. The horizontal displacement and shear stress in embankment initially increased with the increase in thickness of subsoil and the values converge at around 3H suggesting little influence of subsoil thickness on these parameters after 3H. Whereas, settlement increased with the increase in depth of subsoil.

3. The horizontal displacement, settlement and shear stress increased considerably with the increase in height of embankment Hence height of the embankment can influence the performance of subsoil as well as embankment considerably.

4. With an increase in soil unit weight, the horizontal displacement, settlement, and shear stress all rose linearly.

5. The horizontal displacement decreased, shear stress and settlement increased with the increase in slope angle at the toe of the embankment. However, at other points the variation was less pronounced.

6. The horizontal displacement and settlement decreased linearly with the increase in young's modulus of embankment. But, no change in magnitude of shear stress was observed when young's modulus was increased.

7. From the analysis of embankment using soil reinforcement as mitigation measure, it was observed that the decrease in spacing of reinforcement decreased the deformation of the embankment. It was observed that the performance was the best when reinforcement was provided both in embankment and subsoil. The following are the observations:

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- **Horizontal displacement:** Provision of reinforcement reduced the magnitude of horizontal displacement. In fact, the magnitude of horizontal displacement was almost zero in subsoil when the vertical spacing of reinforcement was reducedto1 m. Reinforcement induced discontinuity in the horizontal displacement.

- **Settlement:** Provision of reinforcement reduced the settlement, Performance was the best when subsoil as well as embankment were reinforced.

- **Shear stress:** The magnitude of maximum shear stress slightly increased due to the provision of reinforcement. The increase in magnitude was more in the embankment portion due to the presence of reinforcement and irregular geometry of embankment, Discontinuity was clearly observed because of the presence of reinforcement.

8 From the analysis of embankment using dense wall as mitigation measure both in the inside of the embankment toes and in front of the embankment toes, it was observed that the magnitude of shear stress increased and decreased horizontal displacement and settlement with increase in thickness of wall. The following are the other observations:

- **Horizontal displacement:** Presence of wall inside of the embankment toes created discontinuity in the horizontal displacement. Wall created negative displacement in the soil on the outside near the base.

- **Settlement:** Increase in thickness of wall reduced the magnitude of vertical displacement. But, the reduction in vertical displacement was not appreciable.

- **Shear stress:** The magnitude of shear stress increased with the increase in thickness of dense wall Provision of wall created discontinuity in the shear stress concentration point changed from the toe in case of benchmark model to inside of the subsoil below the toe on both sides of the wall. There was change in the sign of shear stress the bothsides of the wall.

9. From the verification embankment problem using elasto- plastic soil model the results from GEOSLOPE compared well with the analysis by Zeinkiewicz et al (1975). Attempts

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were also made to understand the variation of deformation with various parameters of embankment and following observations were made.

- The horizontal displacement and settlement increased with the increase in unit weight of soil.
- With an increase in internal friction angle of up to 15 degrees, both horizontal displacement and settlement decreased. Additionally, an increase in internal friction angle had no effect on settlement or horizontal displacement.
- The horizontal displacement increased with the increase in slope angle up to 40 degrees. Further, increase in slope angle decreased the horizontal displacement. The settlement decreased with the increase in slope angle up to 40 degrees. Further, increase in slope angle increased settlement.

10. From the verification footing problem using elasto-plastic soil model the results from GEOSLOPE compared well with the analysis by Zeinkiewicz et al (1975). Attempts were also made to understand the variation of settlement with various parameters of embankment and following observations were made.

- Settlement increased linearly with the increase in unit weight ofsoil.
- Settlement decreased with increase in internal friction angle.
- Settlement decreased with increase e in cohesion, But, with increase in cohesion beyond 15kN/m2 the variation in the magnitude of settlement was marginal.

SCOPE FOR FUTURE WORK

- Embankments can be analyzed considering the effect of ground water table.
- Inhomogeneity between the embankment and subsoil can be considered i.e., the material property can be varied at different levels with layered idealization.
- Embankments can be analyzed using layeredsoils.
- Soil structure interaction problems canbe considered.
- Dynamic analysis can be carried out to understand the performance of embankment under earthquake load

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