NUMERICAL ANALYSIS OF CONTROLLED MODULUS COLUMN FOUNDATION SYSTEM SUPPORTED EMBANKMENTS

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ABSTRACT

The objective of this research is to present the numerical analysis of deep foundation system namely controlled modulus columns (CMC) for support of embankments. This paper describes the analysis modeling used for CMC foundation system using the finite element method. The elasto-plastic finite element model used to simulate the embankment soil foundation has been verified against field data. The results obtained from this study showed that the effect of CMC could be negligible when the soil strength increased in terms of its angle of internal friction. With low values of internal friction angle, the CMC reduce the potential of surface deformation about 12%. The values of surface deformation decreased with column diameter until it reach constant value at (0.5m) where less than this values the reduction in deformation could be negligible or have insignificant effect. The maximum deformation was observed at the middle of embankment, also the deformation at the embankment foundation reduce by about (17%) when take into consideration the CMC in soil embankment foundation.

الخلاصة:

ان الهدف من هذا البحث هو لتقديم التحليل العددي لنظام اسس التعليات الترابية المسمى (CMC)لدعم التعليات الترابية. هذا البحث يصف التمثيل التحليلي المستخدم لـ (CMC) باستخدام طريقة العناصر المحددة . ان نموذج المرونة اللدونة بطريقة العناصر المحددة استخدم لتمثيل نظام التعلية الترابية وتم مقارنتة مع نتائج حقلية. ان النتائج التي تم الحصول عليها من هذه الدراسة اظهرت ان تاثير CMC يمكن اهماله بزيادة مقاومة التربة بدلالة زاوية الاحتكاك الداخلي. ولقيم قليلة لزاوية الاحتكاك الداخلي فان CMC يقلل نسبة التشوه السطحي بحوالي 12%. ان قيم التشوه السطحي تقل مع قطر العمود حتى يصل الي قيمة ثابتة حوالي(0.5 m) حيث ان اقل من هذه القيمة يمكن اهمال النقضان الحاصل بالتشوه او يصبح تاثيره غير ملحوظ. واعلى قيمة للتشوه لوحظت تحت منتصف التعلية, كذلك ان التشوه في اساس التعلية يقل بحوالي (17%) عند الاخذ بنظر الاعتبار الـ (CMC) في اساس التعلية الترابية.

KEY WORDS

Embankment, finite element, (CMC) Controlled Modulus Column, numerical analysis, stress distribution, deformation, Elasto-plastic,

INTRODUCTION

When the embankment is founded on soft soil deposits several problems arises such as settlement or stability problem due to lack of bearing capacity, and or in case of loose saturated fine sand subjected to liquefaction due to ground shaking. To overcome these difficulties, a wide range of deep foundation systems has been developed for construction of embankments on soft soils ***(Porbaha et. al, 2002 a)***. The objective of this research is to present new deep foundation system namely controlled modulus columns (CMC) for support of embankments.

The behaviour of a test road embankment constructed on soft soil deposits at Haarajoki, Finland is simulated with a multi-laminate constitutive model accounting for structural anisotropy and destructuration effects. Structural anisotropy is achieved by directional distribution of the state variables which are responsible for the bonding of natural soft soil material. The numerical calculations are completed with a finite element method program capable to perform coupled static/consolidation analysis of soils. Problems related to the initiation of in situ stress state, conditions of preconsolidation. Despite simple assumptions concerning field conditions and non-viscous formulation of the constitutive model, the obtained final results are of a sufficient accuracy for geotechnical practice ***(Neher and Cudny, 2003)***.

The objective of this research is to present the numerical analysis of deep foundation system namely controlled modulus columns (CMC) for support of embankments. This paper describes the numerical modeling used in the analysis of CMC foundation system using the finite element method. Under uniform surcharge traffic load the problem can be studies by plain strain conditions. The approach to the problem allows taking into consideration the settlement tolerance associated with these conditions; and the variability in different soil characteristics.

The Controlled Modulus Column (CMC) as shown in Figure(1), is a ground modification system that reinforces soil by screwing hollow auger into the soft soil and installing a low pressure cement-based grout column through the hollow auger. The combined effect of densification and reinforcement improves characteristics of the soft ground due to composite action. The CMC system uses a displacement auger powered by equipment with very large torque capacity and very high downward thrust, which displays the soil laterally with virtually no spoil or vibration. The auger is screwed to the soil to the required depth and such it increase the density of the surrounding soil and thus increases its load bearing capacity **(Porbaha et. al, 2002 b)**.

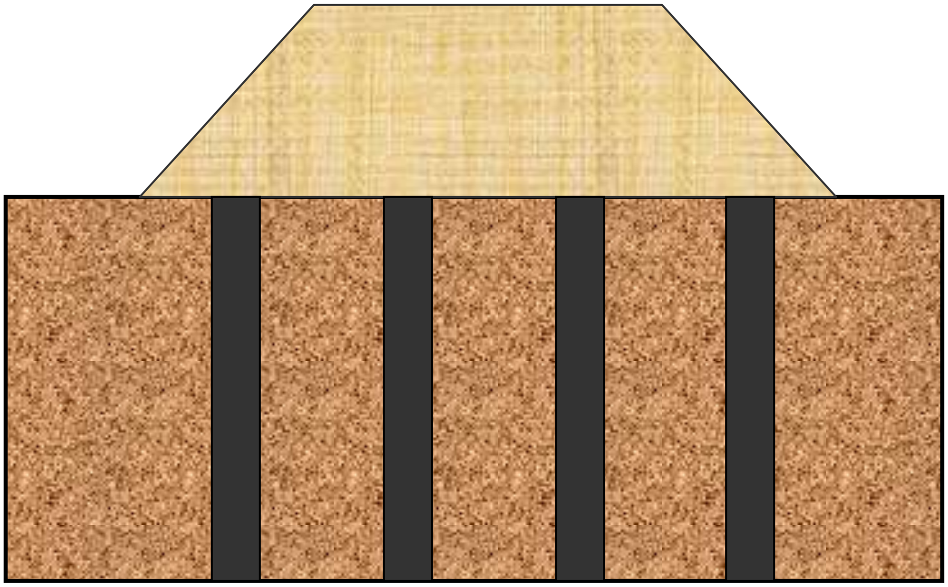

Figure (1): Concept of Column- Supported Embankment.

FINITE ELEMENT ANALYSIS AND MODELING

Work conducted in this part of research aims to numerically analyzing the behaviour of performance embankment structure with CMC system. Numerous researchs used F.E.M to analyze embankments structure over soft soils ***(Andrawes et. al. 1980, Han and Gaber 2002, Li and Rowe, 2002)*** and embankments with vertical band drains ***(Indrartna, et. al. 1992, Hird et. al. 1992)***. ***Porbaha et. al (2002 a)*** simulate the CMC using the axiymmetrical finite difference method to study the behavior of embankment structure with CMC system.

In this paper the method of CMC is described and simulated using finite element numerical analysis as a plane strain conditions with elasto plastic hyperbolic yield criteria. The finite element analysis using the computer program is conducted to discern the stress, strain and surface deformation magnitudes and distribution beneath embankment under varying parameters including column diameter, mesh dimension, soil strength properties. The numerical results are compared with field data.

MODELING OF PROBLEM

The implementation of the model and simulation of embankment soil foundation behavior have been completed using the finite element approach. The finite element mesh and the boundary conditions are shown in Figure (2). Which include 48 elements for soil foundation and 32 elements for embankment. Eight nodded rectangular element has been adopted in this study with 263 nodes and the boundary conditions were adopted as follows: vertical boundaries have zero lateral movements, i.e, roller support and the bottom horizontal boundary was restrained both vertically and horizontally.

The finite element program developed in this research is primarily based on the program P6.2 presented by ***Smith and Griffiths (1998)*** for the analysis of elasto plastic constitutive relations under static loading case. This program is an educational one and has many limitations regarding loading and geometry conditions.

Extensive modifications and newly added subroutines are found necessary to incorporate the initial stress conditions, where the magnitude of insitu stresses in soil embankment layer should be computed at the beginning of the incremental solution, also the embankment layer elements, different properties for different layer, simulation of cement column in embankment soil foundation system

The F.E. program is described, as shown in ***Appendix (A)***. The basic finite steps are performed by primary subroutines, which rely on auxiliary subroutines to carry out secondary operations. An auxiliary subroutine may be required by more than subroutine and the order of calling of the primary subroutine is controlled by a main or master routine.

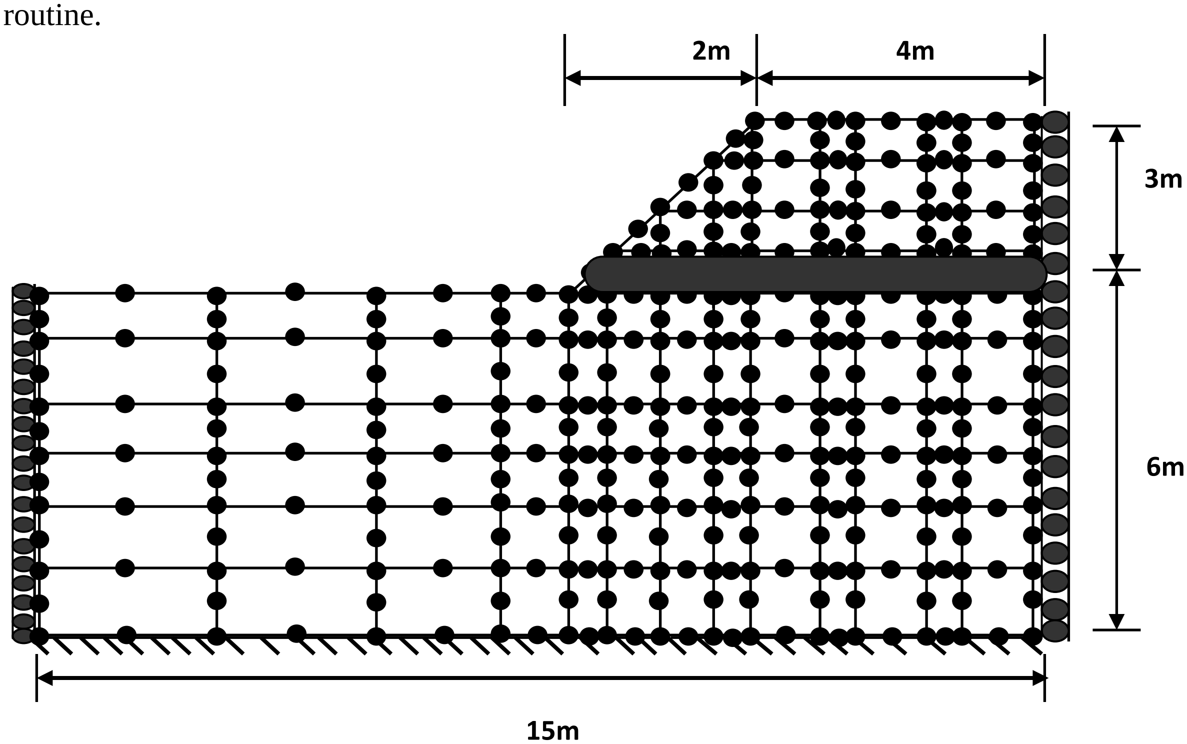

Figure (2): The Finite Element Mesh.

Verification of Computer Program

The results of the finite element program were compared with field data for an embankment section to verify the correct implementation of soil embankment foundation system used in this research. A major instrumented embankment was constructed to 5.5 m elevation above ground level and over soft compressible clay deposit at Leneghan, Newcastle in May 1995 ***(Manivannan, 2005)***.

The Field and finite element results for predicting performance of this embankment are described. The measured vertical displacement profiles obtained from the HPG reading (horizontal reading profile, based on hydrostatic pressure difference) at the foundation level. The embankment profile used for verification of finite element program is shown in Figure (3). Also the input parameters are shown in Table (1) ***(Manivannan, 2005)***. The finite element program results have been verified against the field data as shown in Figure (4). The results obtained from finite element analysis are seemed to have reasonable agreement with the observed performance of Leneghans embankment in terms of vertical displacements. The vertical displacement is measured at the toe of embankment and the maximum deformation was observed at middle of embankment profile.

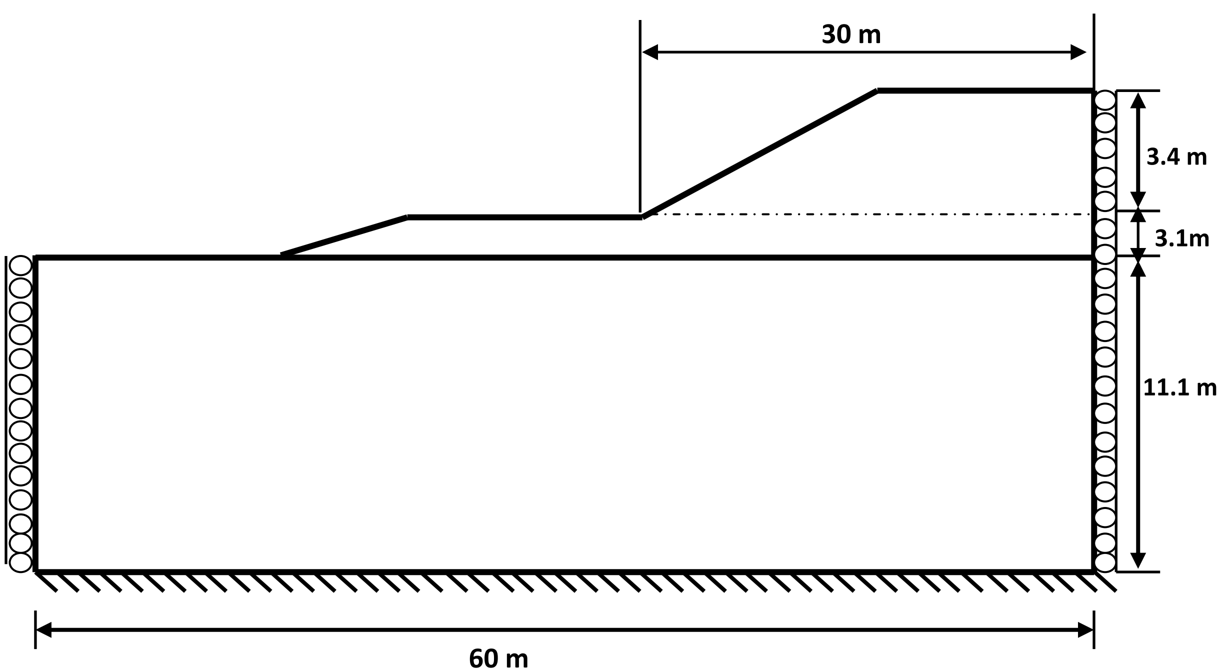

Figure (3): Profile of Cross Section for Test Embankment.

Table (1): Input Parameter for F.E. Program Verification.

Material	Embankment Soil	Foundation Soil (soft soil)
E (kPa)	50	20
Poisons Ratio (v)	.3	.4
Friction Angle (^{o})	28	25
Cohesion (kPa)	5	9.2
Unit weight (kN/m^3)	20	17

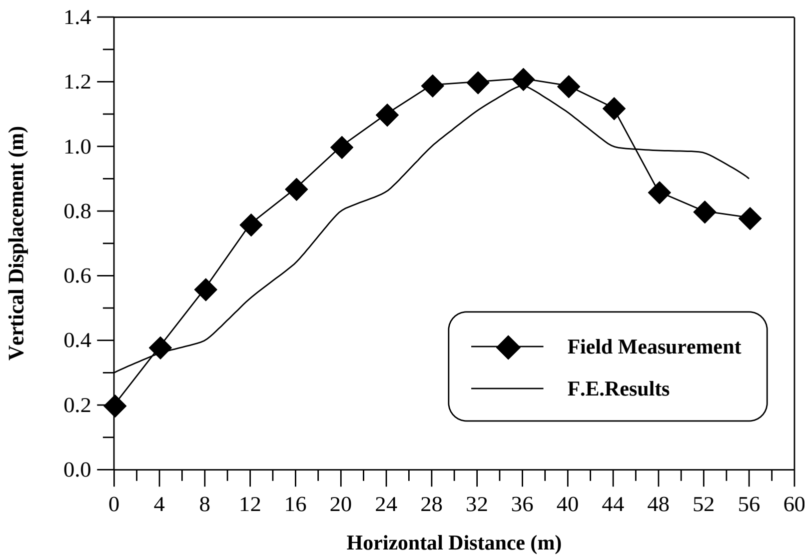

Figure (4): Verification of F.E. Computer Program.

Also verification of computer program for horizontal and vertical stress distribution with depth have been made. Haarajoki test embankment, which its profile section is shown in Figure (5), has been implemented with finite element program and the material parameters are shown in Table (2) **(*Neher and Cudny, 2003)***.

The comparison between field and numerical results are presented in Figure (6) and (7) for vertical and horizontal stress distribution respectively and a good agreement is obtained. But still horizontal stress is overestimated at some location due to the applied isotropic hardening adopted in the finite element program.

Table (2): Input Parameter for F.E. Program Verification *(Neher and Cudny, 2003)*.

Material	**Embankment Soil**	**Foundation Soil**
E (kPa)	50	20
Poisons Ratio (v)	.15	.2
Friction Angle (^{o})	35	25
Cohesion (kPa)	3.0	5.7
Unit weight (kN/m^3)	21	15

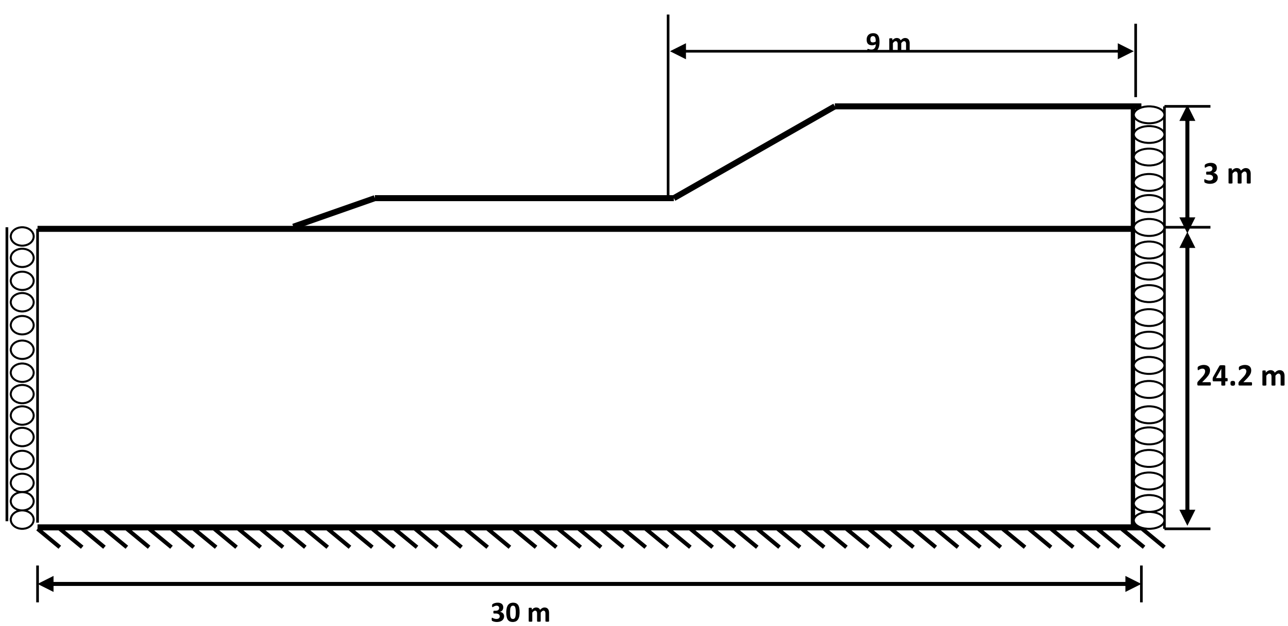

Figure (5): Profile of Cross Section for Haarajoki Test Embankment.

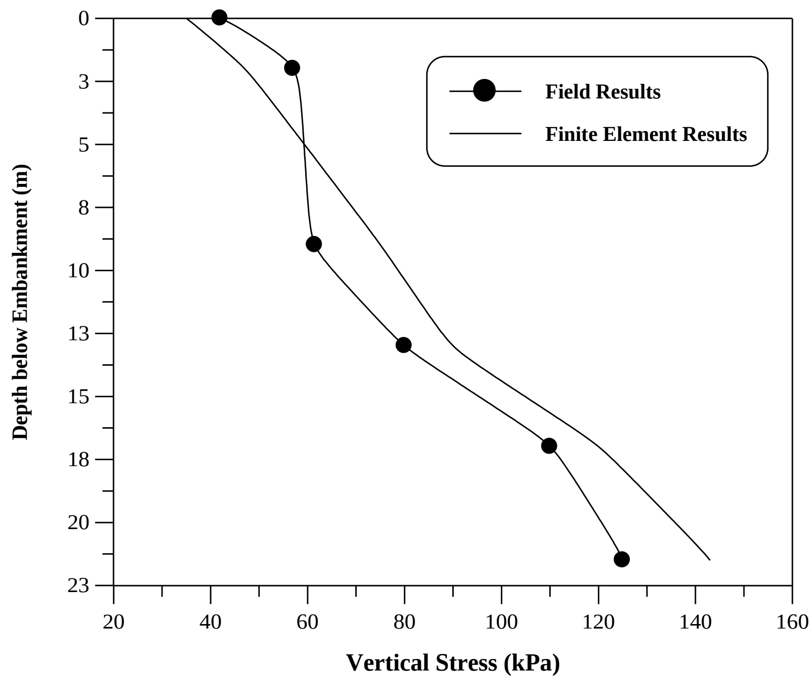

Figure (6): Vertical Stress Distribution below Embankment.

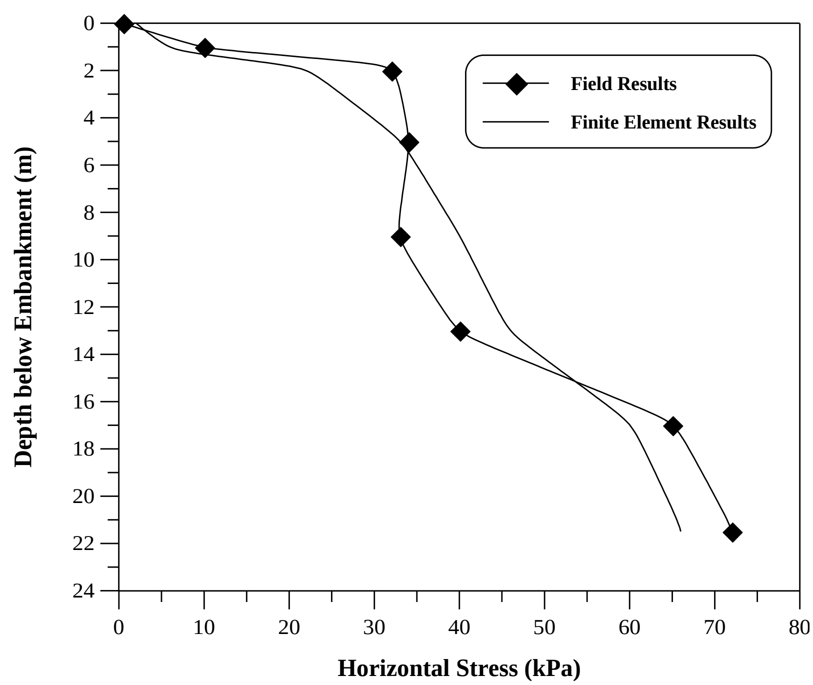

Figure (7): Horizontal Stress Distribution below Embankment.

RESULTS AND DISCUSSIONS

Before the Finite element analysis, the effect of element number on finite element analysis results was checked by comparing the finite element results for two cases with different element number. As shown in Table (3), a check case had four times the foundation elements, four times embankment elements. The F.E.M analysis predicted almost the same maximum surface deformation and maximum foundation stress for both cases.

Table (3): Effect of Element Numbers on Accuracy of Results.

Case	Element Number		Surface Deformation(m)	Foundation Stress (kPa)
	Foundation Element	Embankment Element		
Base case	48	32	0.02044	192.523
Check case	192	128	.02035	191.997

After complete the verification of F.E. program for both model simulation and the accuracy of element numbers, the behaviour of CMC with embankment foundation system has been investigated. The profile section of embankment with CMC is shown in Figure (8) for 1.4 C/C column spacing, and a parametric study was conducted. The input parameter used in the finite element analysis is listed in Table (4) below with traffic load surcharge 20 kPa .

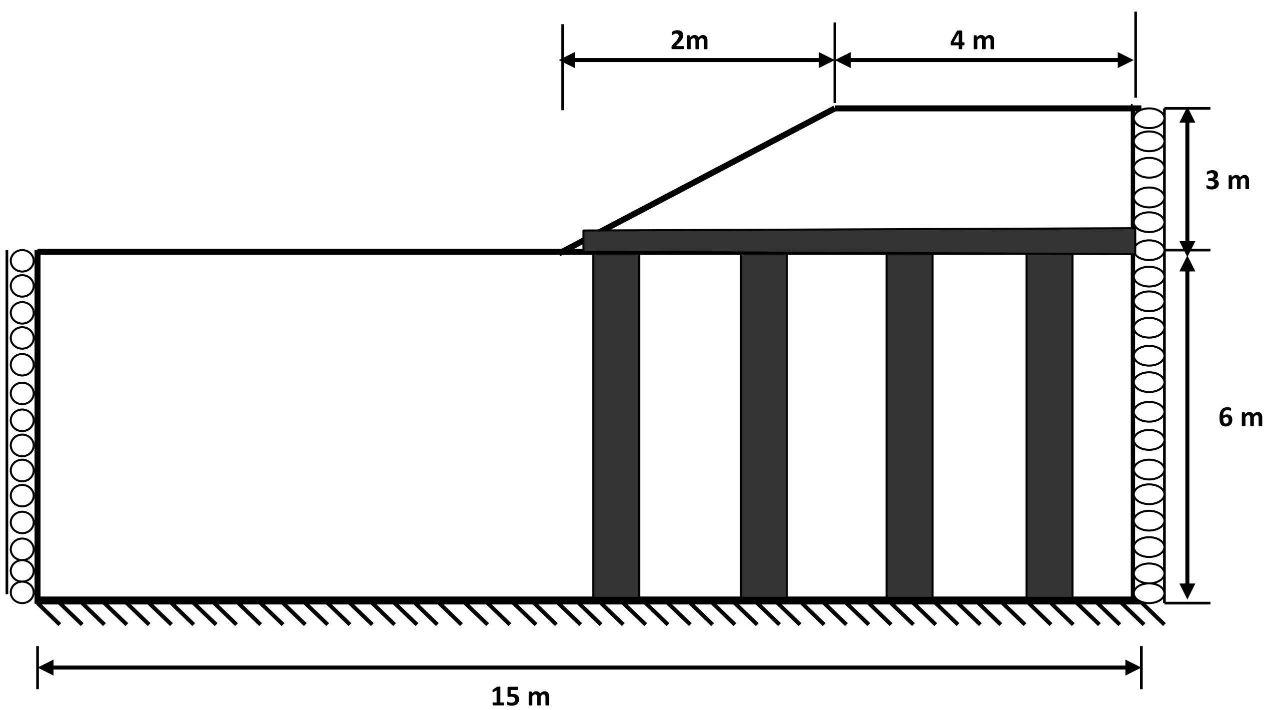

Figure (8): Profile of Cross Section for Studied Embankment.

Table (4): Input Parameter for F.E. Analysis.

Material	Embankment Soil	CMC	Transition Layer (Stiff Layer)
E	50 (kPa)	11000 MPa	80
Poisons Ratio (v)	.4	-	.3
Friction Angle (^{o})	5-30	-	30
Cohesion (kpa)	5	-	20
Diameter (m)	-	0.2 – 1.0	

To consider the effect of soil strength, angle of friction are considered in parametric study. Figures (9) and (10) show the effect of soil properties on surface deformation at the toe of embankment in terms of angle of internal friction and undrained shear strength. It can be concluded that the effect of CMC could be negligible when the soil strength increased in terms of its angle of internal friction. With low values of internal friction angle, the CMC reduce the potential of surface deformation about 12%.

Also Figure (11) show the effect of column diameter on surface deformation. The finite element results indicates that the values of surface deformation decreased with column diameter until it reach constant values at (0.5m) where below this values the reduction in deformation could be negligible or have insignificant effect.

Figure (12) show the variation of surface deformation at the bottom of embankment with radial distance. The maximum deformation as shown in figure is in the middle of the embankment foundation, and the deformation at the embankment foundation reduce by about (17%) when take into consideration the CMC in soil embankment foundation.

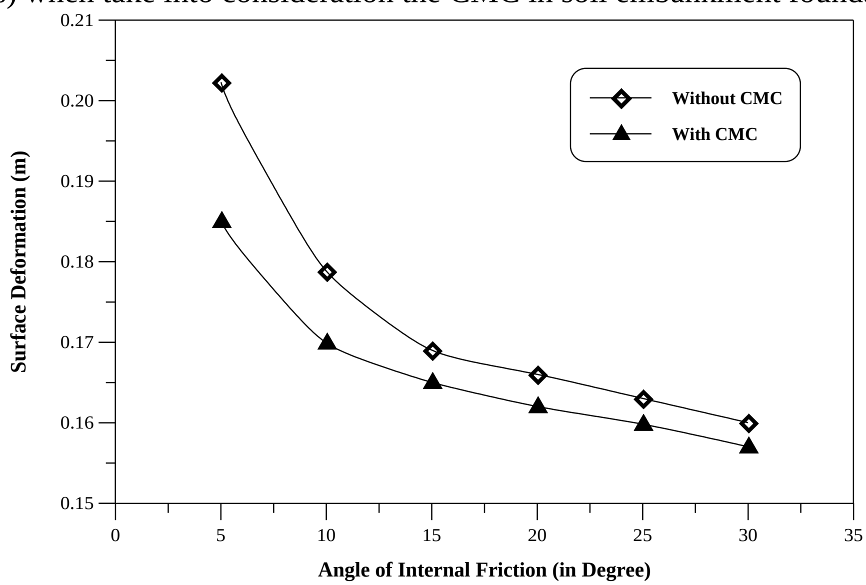

Figure (9): Variation of Surface Deformation with Angle of Internal Friction.

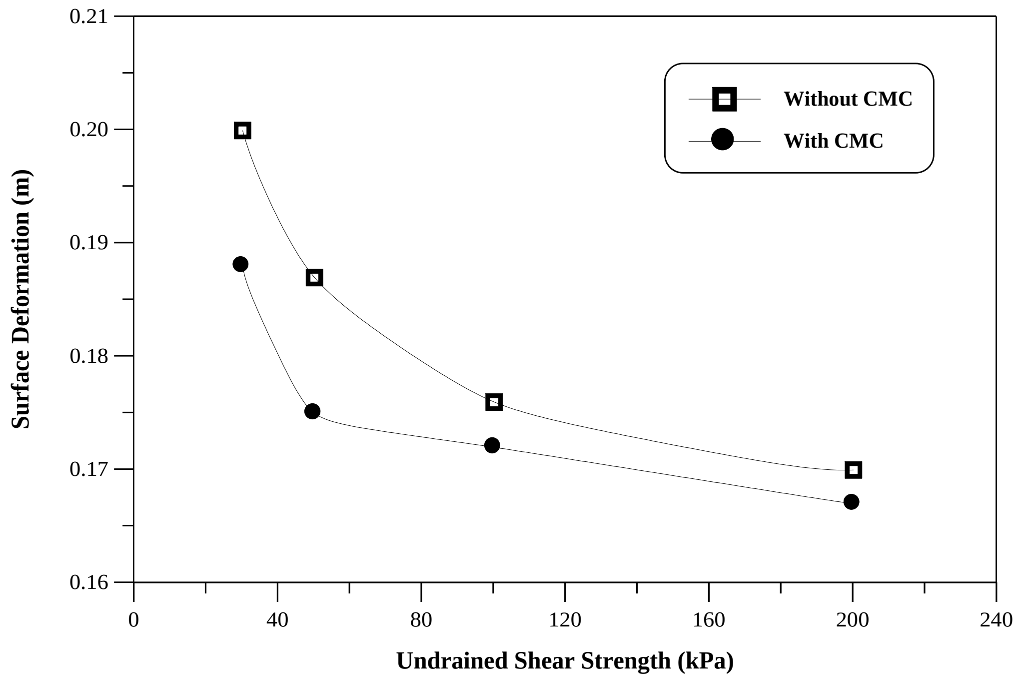

Figure (10): Relation of Undrined Shear Strength with Surface Deformation.

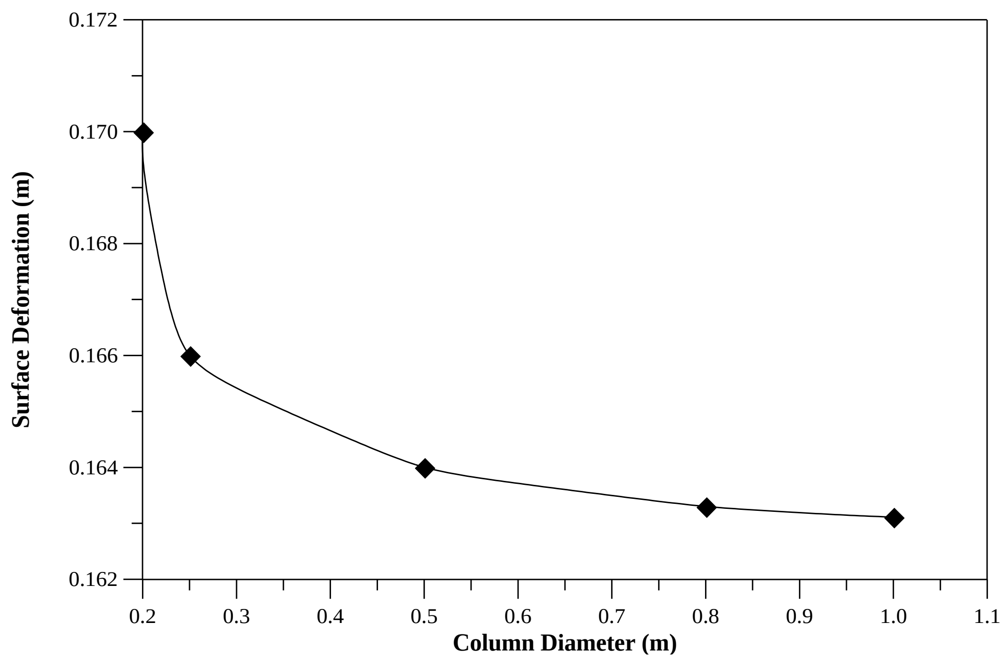

Figure (11): Effect of Column Diameter on Surface Deformation.

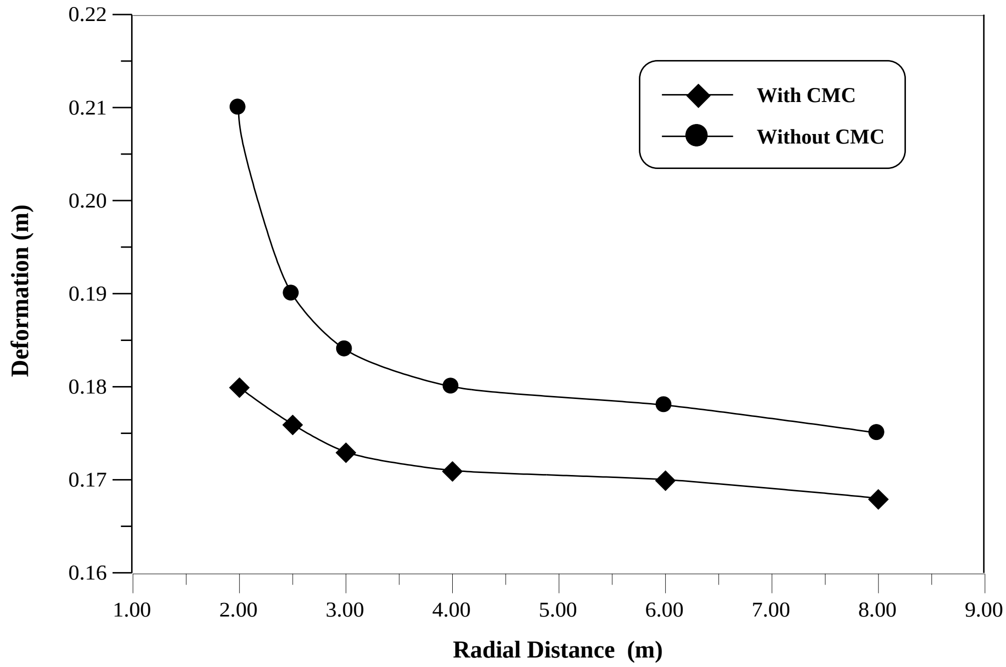

Figure (12): Variation of Bottom Deformation with Radial Distance.

STRESS DISTRIBUTION BENEATH EMBANKMENT

The stress distribution was evaluated using elasto-plastic analysis with the finite element program. And the obtained results were plotted using surfer program to obtain contour lines of horizontal and vertical stress distribution as shown in Figure (13) and (14) respectively. It can be observed from these figure that the horizontal stress increase with depth below embankment.

Figures (15) and (16) represent the 3D surface for horizontal and vertical distribution respectively. According to the stress distribution pattern shown in Figures below for vertical stress, a stiff layer between the embankment and CMC should be applied to ensure that the great part of the generated stress transfer to the head of control modulus column CMC and to study its effect, a transition layer between embankment and soil foundation is applied as shown in Figure (8) with properties of stiff soil as shown in Table (4). Figure (17) and (18) show the horizontal and vertical stress distribution with depth below embankment respectively. Also the 3D-surface for horizontal and vertical stress distribution are shown in Figure (19) and (20) respectively.

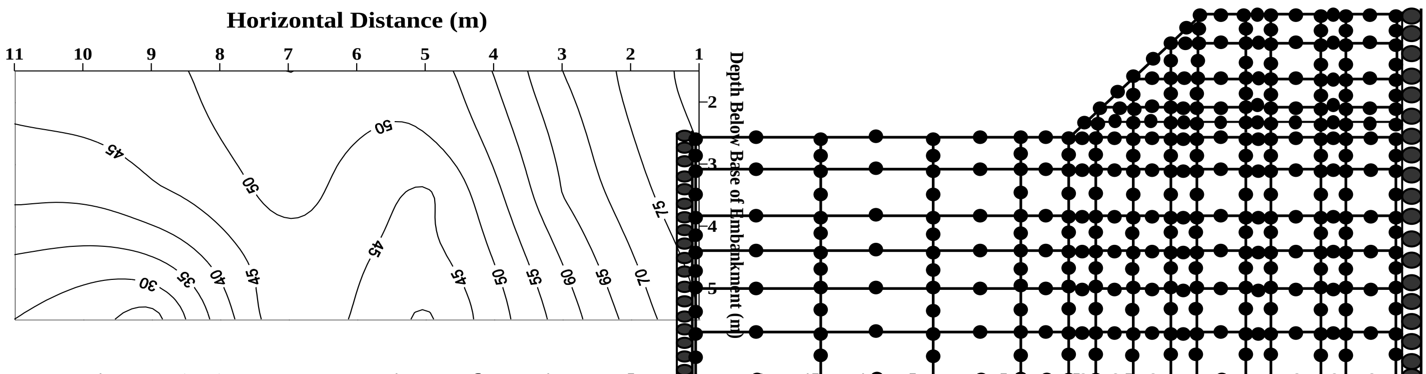

Figure (13): Contour Lines of Horizontal Stress Distribution beneath Embankment.

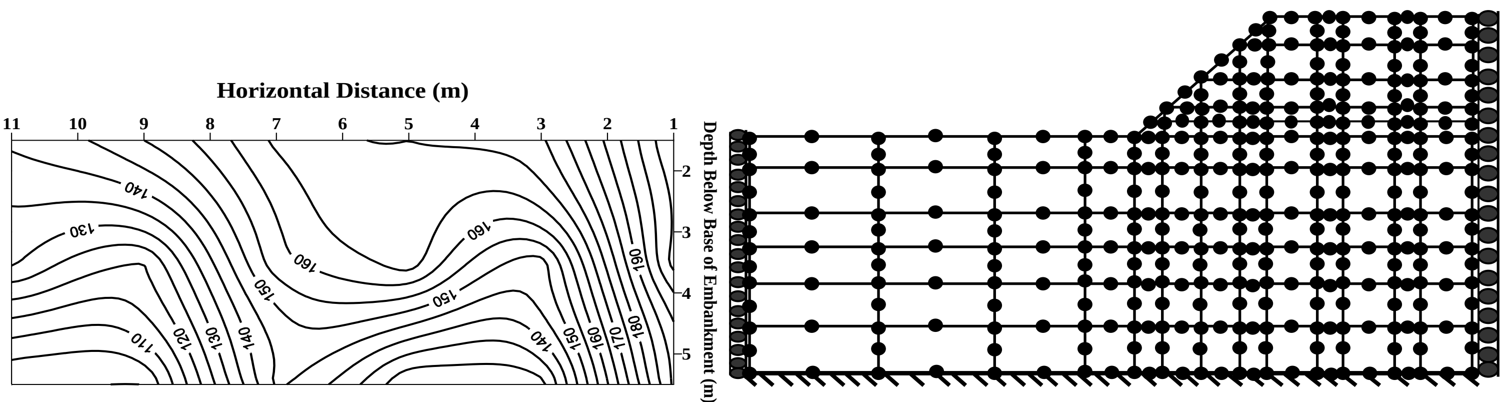

Figure (14): Contour Lines of Vertical Stress Distribution beneath Embankment without transition Layer.

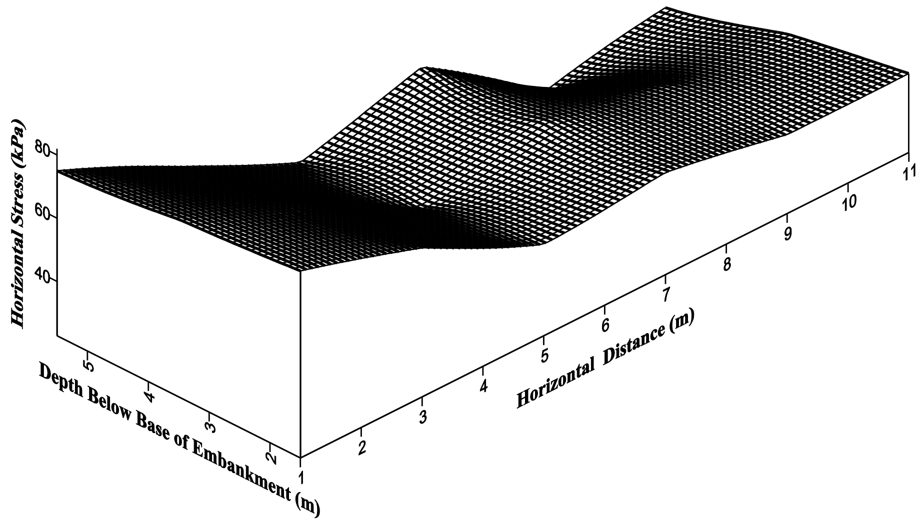

Figure (15): 3D surface of Horizontal Stress Distribution beneath Embankment.

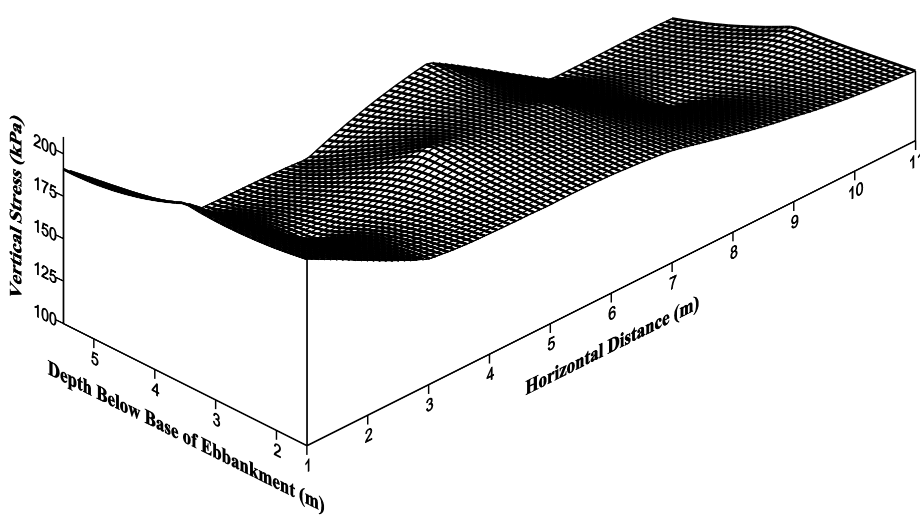

Figure (16): 3D surface of Vertical Stress Distribution beneath Embankment.

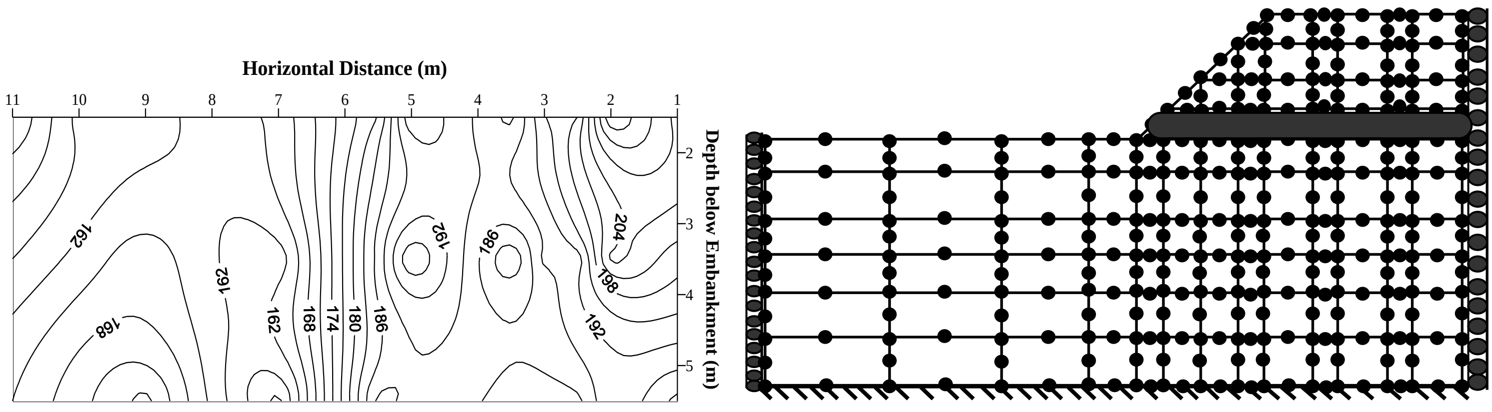

Figure (17): Contour Lines of Horizontal Stress Distribution beneath Embankment with Stiff Layer.

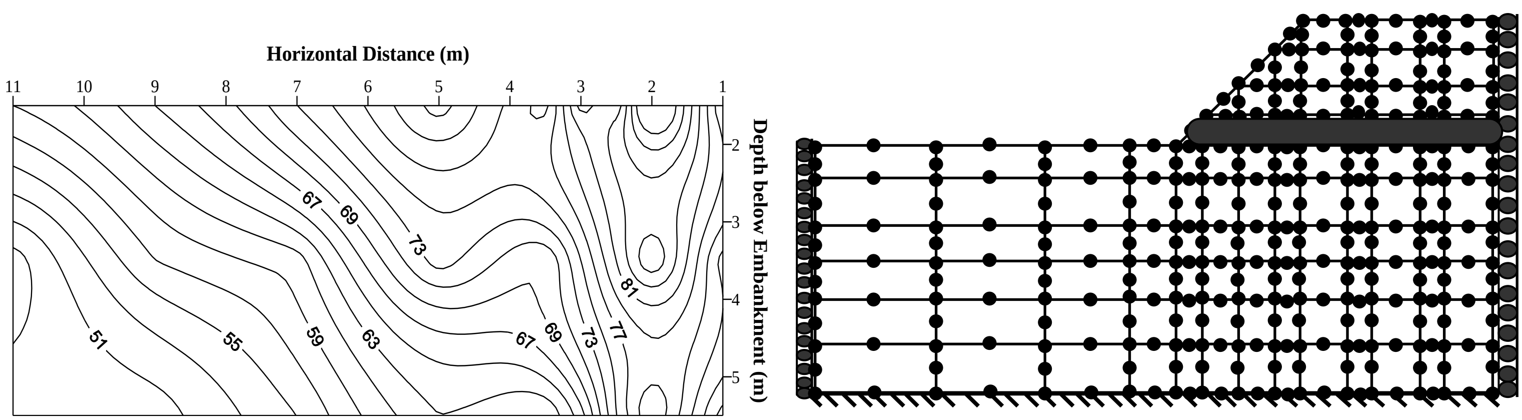

Figure (18): Contour Lines of Vertical Stress Distribution beneath Embankment with Stiff Layer.

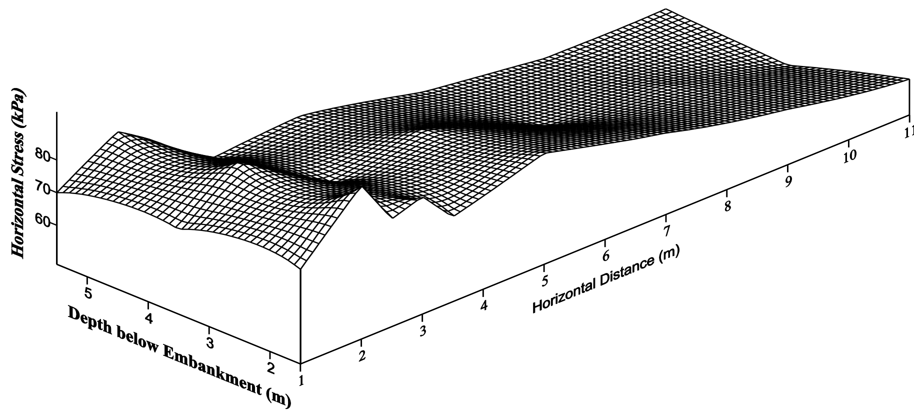

Figure (19): 3D surface of Horizontal Stress Distribution beneath Embankment.

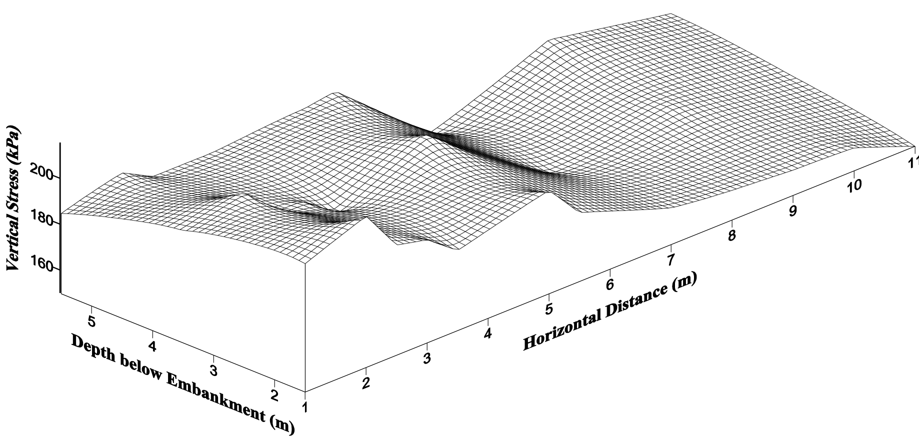

Figure (20): 3D surface of Vertical Stress Distribution beneath Embankment.

CONCLUSIONS

The deformation of embankment supported on controlled column modulus improved foundation soil and can be analyzed using numerical methods. The following conclusions remarks are obtained:

1. The elasto-plastic finite element model used to simulate the embankment soil foundation system including different layer properties and CMC have been verified against field data and seemed to have reasonable agreement with the observed performance of Leneghans embankment in terms of vertical displacements.

2. The effect of CMC could be negligible when the soil strength increased in terms of its angle of internal friction. And with low values of internal friction angle, the CMC reduce the potential of surface deformation about 12%.

3. The values of surface deformation decreased with column diameter until it reach constant values at (0.5m) where below this values the reduction in deformation could be negligible or have insignificant effect. And the maximum deformation was observed at the middle of embankment, also the deformation at the embankment foundation reduce by about (17%) when take into consideration the CMC in soil embankment foundation.

4. The stress distribution pattern for vertical and horizontal stress increases with depth below embankment, and according to the stress distribution pattern a stiff layer between the embankment and CMC should be applied to ensure that the great part of the generated stress transfer to the head of control modulus column CMC.

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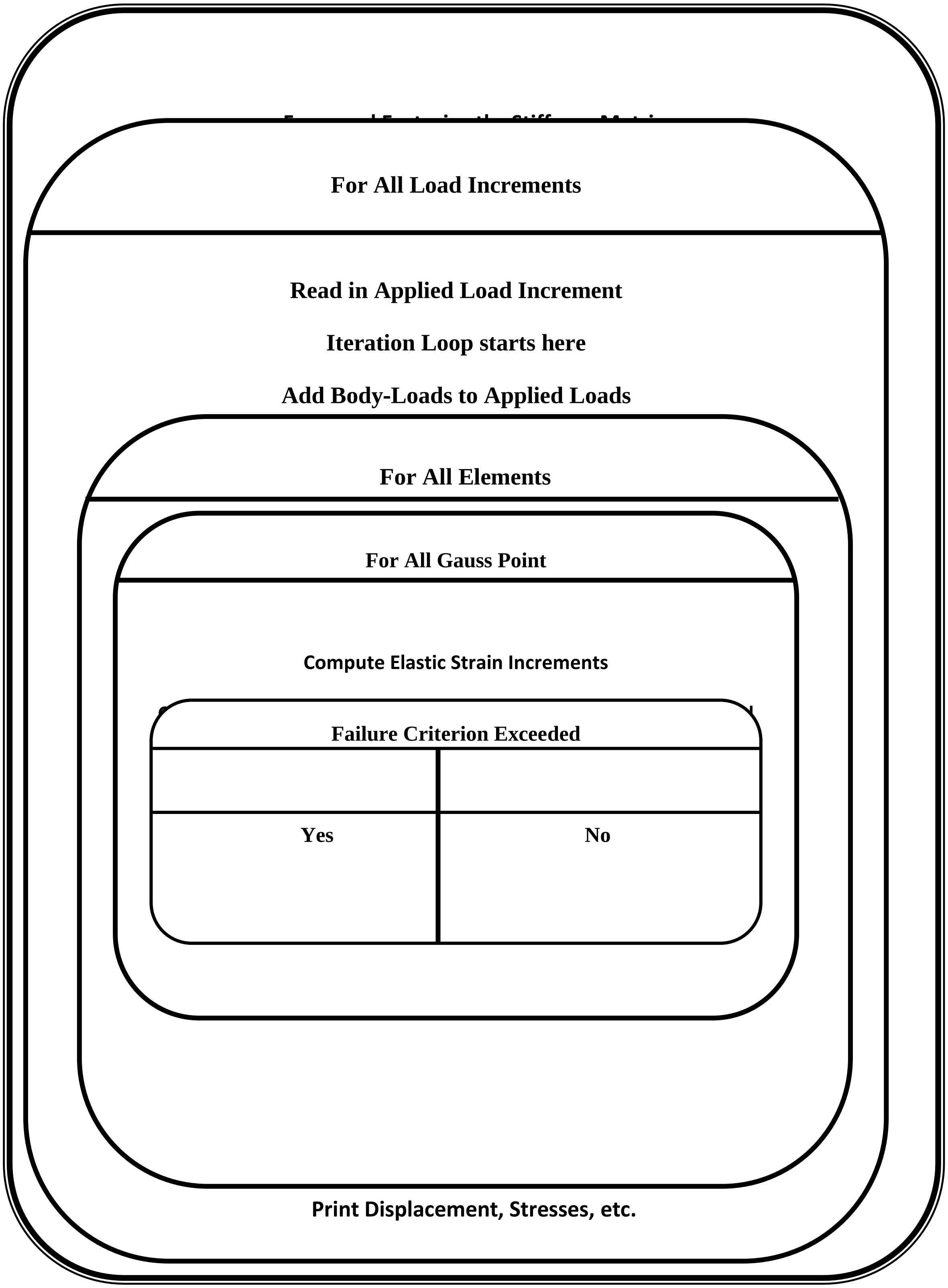
Appendix A


For All Load Increments
Read in Applied Load Increment
Iteration Loop starts here
Add Body-Loads to Applied Loads
For All Elements
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Compute Elastic Strain Increments
Failure Criterion Exceeded
Yes
No
Print Displacement, Stresses, etc.