Analysis of Anchored Earth Wall Supporting Soft Backfill

by

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It is hereby declared that this thesis or any part of it has not been submitted elsewhere for the award of any degree or diploma.

(Md. Jahangir Alam)

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NOTATIONS

B_a = Long term width of anchor;

C = Nondimensional constant for pull out capacity of vertical anchor;

D_m = Depth of embedment;

E = Young's modulus or elastic modulus;

e = Eccentricity of resultant vertical load;

F_γ' = An anchor capacity factor;

f_n = Partial factor for economic ramification of failure;

f_m = Partial factor suggested by BS 8006 (1995) at Table 16;

H = Mechanical height of wall;

h = Depth to the bottom of the anchor from ground surface;

K = Stiffness of reinforcement;

K_o = Coefficient of lateral earth pressure at rest;

K_p = Coefficient of passive earth pressure;

K_a = Coefficient of active earth pressure;

L = Length of reinforcement ;

m = An exponent for pull out capacity of vertical anchor;

n = An exponent for pull out capacity of vertical anchor;

P_{uj} = Ultimate pull-out resistance of anchor at jth layer;

P_{aj} = Bearing resistance of anchor;

P_{sj} = Shaft resistance of reinforcing element/tie bar of anchor developed by friction beyond the potential failure plane;

q = An exponent for pull out capacity of vertical anchor;

q_u = Ultimate pull out capacity of anchor;

q_{ult} = Ultimate bearing capacity of subsoil;

q_r = $R_v/(L - 2e)$, bearing pressure on the bottom of reinforced soil;

R_v = Resultant factored vertical load acting on the bottom of reinforced zone;

R_h = Horizontal factored disturbing force on back of reinforced soil;

S_a = Shape factor for vertical anchor;

T_j = Maximum tensile force;

T_D = Design strength of the reinforcement;

t_a = Long term height of anchor;

y = Location of center of lateral thrust from bottom of reinforced soil;

σ_{vj} = Vertical applied pressure at the j^{th} layer;

ν = Poisson's ratio:

γ = Unit weight of the soil;

ψ = Dilatancy angle;

ϕ = Angle of internal friction;

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The author wishes to convey his profound gratitude to the almighty Allah for allowing him to bring an end of this thesis. The author is indebted to his supervisor Dr. Mohammed Saiful Alam Siddiquee, Associate Professor, Department of Civil Engineering, Bangladesh University of Engineering and Technology (BUET), for his inspiration, encouragement and continued guidance throughout the various stages of this research.

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Abstract

A parametric study using a finite element method of analysis is undertaken to investigate the behavior of a new type of anchored earth wall system supporting simultaneously constructed roadway. Although the elasto-plastic strain hardening softening constitutive models are more appropriate for soil, but for simplicity elasto-perfectly plastic Mohr-Coulomb constitutive model is used in this study. The emphasis of the study is placed on the effect of various components of proposed wall system to the deformation patterns and other associated behavior. The parameters studied are (1) stiffness of reinforcement, (2) elastic modulus of soft backfill, (3) elastic modulus of retained soil, (4) elastic modulus of granular soil in between backfill and retained soil, (5) rigidity of facing (6) anchor size and (7) anchor position.

A 4.5 m high vertically faced anchored earth wall supporting a simultaneously constructed roadway is designed as per BS 8006 (1995). Starting from facing to centerline of roadway, the wall system consists of (i) facing wall, (ii) thin vertical layer of uncompacted coarse sand as filter and drainage, (iv) thick vertical layer of moderately compacted soft backfill, (v) thin vertical layer of compacted granular backfill (vi) anchor plates or blocks and (vii) retained soil of roadway. Anchor sizes are designed according to Rajagopal and Hari (1996) for a surcharge loading of 100 kN/m^2 on the roadway. Horizontal spacing of reinforcement is 1.0 m and length of anchor is also taken as 1.0 m so that it become a plane strain anchor of length 1.0 m and height 0.12 m in the finite element model. Large factor of safety for anchors is used for standard wall configuration to minimize the effect of anchor size during study of other parameters. Lightly steel reinforced concrete wall with a small pad below wall is used as continuous rigid facing to reduce lateral deformation of wall and hence vertical deformation of top surface of roadway.

It is observed that deformation of wall decreases with increasing stiffness of reinforcement and after certain value of stiffness it has no effect on deformation. On the other hand, anchor force increases with increasing stiffness of reinforcement and after certain value of stiffness it has no effect on anchor force. Deformation decreases

with increasing stiffness of backfill and retained soil. Anchor force also decreases with increasing stiffness of backfill but remain constant with variation of stiffness of retained soil. Facing rigidity has significant effect on wall deformations. Deformation decreases with increasing facing rigidity and after certain value of facing rigidity its effect become negligible.

From the study it may be concluded that locally available silty clay soil may be used in the reinforced zone as well as in the retained soil mass of roadway. Moderately compacted fill of which elastic modulus is greater than or equal to 10 MPa is sufficient for reinforced zone, provided that stiffness of reinforcement is greater than 5.0×10^6 N/m and F.S. for anchor size is greater than or equal to 2.0. Moderately compacted fill of which elastic modulus is greater than or equal to 20 MPa is sufficient for retained soil mass of road embankment. Continuous rigid facing must be used for the proposed wall system. To avoid differential settlement of roadway, reinforced soil and retained soil should have same stiffness and strength properties and in no case should stiffness of retained soil be less than that of reinforced soil. Formula given by Rajagopal and Hari (1996) is found to be more acceptable to estimate ultimate pull out capacity of vertical anchor used in anchored earth wall. Greater length of anchorage improves the serviceability of the retained structures in addition to ensuring stability.

Chapter 1

INTRODUCTION

1.1 GENERAL

The basic attributes of soil reinforcement are reduction in cost and speed of construction. Interest in the subject has gained impetus because of the technical and commercial success that has been demonstrated by the practitioners worldwide. The concept of reinforcing soil has also attracted the academic world, as the theoretical aspects involved are numerous. As a result, much research and development work has been undertaken in universities and laboratories, and soil reinforcing is now recognized as a separate subject in its own right in the geotechnical field (Jones, 1996).

Retaining walls may be broadly divided into two categories: one is internally stabilized and the other is externally stabilized. Reinforced soil walls may be categorized as internally stabilized systems whereas conventional earth retaining walls may be grouped into externally stabilized systems. Reinforced soil wall may be with anchor or without anchor (reinforced with polymer geosythetics). Later one is feasible when reinforced soil is well compacted and required length of reinforcement is not so large to hamper the economy of the construction and the structure has sufficient space to accommodate the reinforcement. When reinforced soil without anchor is not feasible considering above factors, anchored soil wall may be a good alternative.

Reinforced soil walls are fundamentally different from conventional soil retaining systems in that they utilise a different mechanism of support and load transfer to soil. Internally stabilized systems involve horizontally laid reinforcements installed within and extending sufficiently beyond the potential failure mass. Within this system, shear transfer to mobilise the tensile capacity of reinforcing elements removes the need for a structural wall. However, facing elements are required to prevent local ravelling, deterioration and/or erosion of soil. Reinforcing elements may be inextensible, e.g. metal strips or tendons, and extensible, e.g. polymeric geosynthetics. These may be enhanced with anchor blocks at their ends. During layer by layer construction of such a wall backfill material may be cohesive, cohesionless or cohesive frictional fill. Whatever it is, backfill must be well compacted. Not only that, for inextensible reinforcement compacted granular backfill must be used to prevent catastrophic failure of wall.

1.2 BACKGROUND OF THE STUDY

To date, in Bangladesh, retaining wall means conventional retaining wall (Gravity type, RCC cantilever type or RCC counterfort type). Conventional retaining walls may be constructed economically only for a height of upto 3 to 3.5m. Reinforced soil wall may be a good alternative beyond this height. Construction of road embankment confined by reinforced soil wall and extension of road width of existing road without acquiring adjacent lands are two good example of application of reinforced soil wall. But construction of reinforced soil wall in countries like Bangladesh would be obstructed due to following reasons: (i) Coarse sand for backfill material is expensive, as it is available only in some selected areas of Bangladesh. Therefore it is necessary to use the local soil in reinforced zone as well as in the retained soil mass for road construction which will lead to a huge cost savings. (ii) Compaction of reinforced soil and retained soil of roadway is also costly, as it requires heavy equipment like compaction rollers. Not only that quality control of such compaction works could not be done due to various unavoidable circumstances. Therefore it was envisaged to use moderately compacted fill. (iii) Having the poor strength properties and low stiffness of such moderately compacted local indigenous soil, geosynthetic (sheet type) reinforced earth wall would require large pull out length which may be costlier or may not be feasible due to space limitation. Therefore, anchored soil wall supporting moderately compacted soft indigenous fill is envisaged.

Based on the results of finite element analyses, Rowe and Ho (1995 and 1996) reported the effects of intermediate reinforcing layers, the effect of interface shear, the effect of panel continuity and location of panel connections, backfill soil stiffness and foundation stiffness on the behavior of reinforced earth wall. They drawn following important conclusions about the stiffness of backfill soil (a) modulus of elasticity of backfill does not have significant effect on the forces required for either external rigid body equilibrium or internal equilibrium of the reinforced soil wall system except for very low values of modulus and (b) a change in backfill modulus only affects the horizontal deformation behind the reinforced soil block and consequently the horizontal deformation at wall face. Rajagopal and Hari (1996) worked on the prediction of anchor capacities in anchored retaining walls based on finite element analysis and laboratory model tests. They proposed simple design method for these walls. Tatsuoka (1992) discussed the role of facing rigidity in the context of observations made in laboratory model tests and field tests, and has shown that facing rigidity is an important parameter to be considered. Numerical findings of Ho and Rowe (1996) also indicate the same.

Getting lessons from above studies proposed study plan is formulated to develop an easy to construct and economic anchored earth wall system supporting soft backfill and newly constructed roadway. Mechanically stabilized backfill structure where the mode of stress transfer from the backfill to the reinforcement is by passive resistance in addition to friction, is not a new concept. Andre Coyne invented one of the earliest versions of this system in 1929. After that, the Transport and Road Research Laboratory in the UK came up with their version of anchored earth in 1981. The application of such system was reported in 1985 (Jones, et al, 1985). In the proposed wall system, what is new is that use of soft backfill mostly and thin layer of granular backfill where the mode of stress transfer from the backfill to the reinforcement is mainly by passive resistance and the reinforcement will be stressed more after subsidence of soft backfill.

1.3 SCOPE OF THE RESEARCH

Outskirts of most of the cities in Bangladesh comprise low-lying areas. But land values of these low-lying areas are high due to continued development of model towns to accommodate large population of city areas. Construction of ring road or bypass road at periphery of city areas will require 4-5 m high road embankment. Vertically faced anchored earth wall supporting newly and simultaneously constructed roadway in these cases will save valuable lands. For a road of 5 m height land saving is 20 m^2 per meter length of road. This land saving reduces the land requirement to half of area required for two lane road embankment of slope 1:2. About the land value it is noteworthy that price of lands adjacent to roadway increases exponentially with time after construction of such roadway. Use of local silty clay soil for roadway and backfill may be an economic solution for the construction of such road embankment. The proposed wall system may also be used to increase the width of existing roads and highway without acquiring adjacent lands. Another application of the system is construction of approach road for grade separation at road intersections. This new anchored wall system can be constructed in remote areas as well as in city areas for grade separation at road intersections.

Behavior of anchored earth wall supporting local soil backfill and newly constructed roadway is not precisely known. The literature now contains numerous examples demonstrating the use of finite element method (FEM) for predicting the performance of specific laboratory model tests or field prototypes. In this study, the results of parametric study by FEM are used as the basis for improving the understanding of the effects of various parameters.

1.4 OBJECTIVES OF THE STUDY

The present study is aimed at the following objectives:

i. To perform a parametric study of the wall considering (a) stiffness of reinforcement, (b) elastic modulus of soft backfill, (c) elastic modulus of retained soil, (d) elastic modulus of granular soil in between backfill and retained soil, (e) rigidity of facing (f) anchor size and (g) anchor position as parameters. Elasto-perfectly plastic constitutive model is used to simulate soils and concretes.

ii. To study the deformation variations of the wall with various parameters and fixing the range of values of parameters for better performance of the wall system.

From the analytical study on the behaviour of proposed wall system, a rational basis may come up for the design of such walls. The most important parameter influencing the behaviour of whole structure may be identified.

1.5 METHODOLOGY

Parametric study of a vertically faced anchored earth wall supporting moderately compacted soft indigenous backfill is done using Finite Element Method. In addition to anchored reinforcement, the proposed wall will have, starting from facing to centerline of roadway, (i) facing wall, (ii) thin vertical layer of compacted coarse sand as filter and drainage, (iv) thick vertical layer of moderately compacted soft backfill, (v) thin vertical layer of compacted granular backfill (vi) anchor plates or blocks and (vii) retained soil of roadway.

A vertical faced 4.5m high anchored earth wall is designed for working loads using the Limit State Design approach (BS8006: 1995, McGown et al, 1998) and this is called standard wall. The wall system is modelled as plane strain problem using finite element software. 2D-plane strain condition is maintained using infinite plane strain anchors.

1.6 ORGANISATION OF THE THESIS

The thesis is arranged into six chapters and one appendix. In Chapter One, background, scope and objectives of the research is described precisely. Chapter Two contains a brief account of literature review. This chapter is divided into three parts consisting of anchored earth wall - design and state of the art, pull-out capacity of horizontally loaded vertical anchors, and constitutive modelling of geomaterials.

Chapter Three contains mainly formulation of parametric study. Numerical model is described and input values of various parameters are tabulated in this chapter. Results are presented in chapter four. Chapter Four also contains the discussion and finding from the study.

Chapter Five contains the conclusions and recommendations for further research. Preliminary construction guidelines, merits and demerits of continuous rigid facing is reported in Appendix A.

Finally Appendix B illustrates the steps followed in developing the finite element model and to solve the problem. The necessary command lines, data file and command file is listed in this appendix of the thesis.

Chapter 2

LITERATURE REVIEW

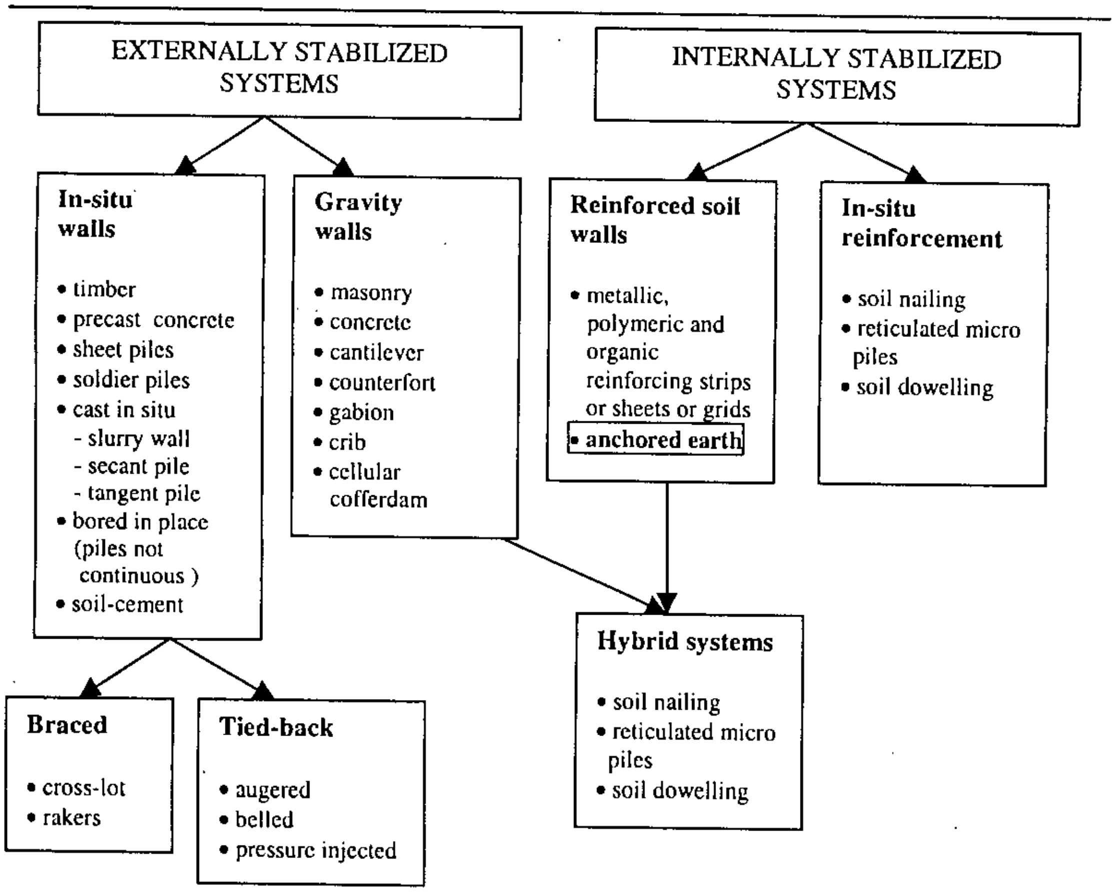
2.1 INTRODUCTION

The literature review given here is basically divided into three parts consisting of (a) anchored earth wall - design and state of the art, (b) pull-out capacity of horizontally loaded vertical anchors, and (c) constitutive modelling of geomaterials.

2.2 CLASSIFICATION OF EARTH RETENTION SYSTEMS

Soil retention systems may be broadly divided into two categories: one is internally stabilized and another is externally stabilized. Reinforced soil walls may be categorized as internally stabilized systems whereas conventional earth retaining

Table 2.1: Classification of earth retention systems



walls may be grouped into externally stabilized systems. Summarized classification scheme for earth retention systems are shown in Table 2.1 (O'Rourke and Jones, 1990).

2.3 ANCHORED EARTH WALL

Anchored Earth Wall, a type of mechanically stabilized backfill structure where the mode of stress transfer from backfill to reinforcement is by passive resistance in addition to friction, is not a new concept. One of the earliest versions of this system was invented by Andre Coyne in 1929. A schematic representation of the invention called Ladder Wall is shown in Fig. 2.1. After that, the Transport and Road Research Laboratory in the UK came up with their version of anchored earth in 1981. The application of such system was reported in 1985 (Jones, et. al, 1985). Now use of anchored earth wall is increasing in many countries of the world. Recently, a 13.0 m high wall is constructed in Malaysia (Lee and Oh, 1997).

2.3.1 Components of Anchored Earth Wall

Anchored earth walls consist of the following components:

(i) reinforced fill

(ii) retained fill

(iii) subsoil

(iv) anchor

(v) reinforcing tendons

(vi) facing

(vii) drainage system

(viii) footing pad

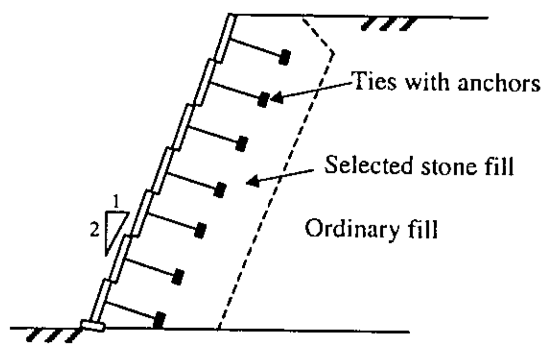


Fig. 2.1: Coyne's Ladder Wall Patented in 1929

A brief account of these three materials is reported in the subsequent paragraphs.

2.3.1.1 Reinforced Fill

For permanent works the reinforced fill or backfill soil used should be frictional or cohesive frictional material and cohesive fill should not be used in vertically faced walls and abutments (BS 8006). Because frictional fills are stable, free draining and relatively non-corrosive to reinforcing elements. Main disadvantage is that it would usually be imported material and therefore, might, be costly. With the cohesive soils the main advantage is availability. The main reasons why fine graded and cohesive soils are generally held to be unsuitable for vertically faced reinforced soil construction are short-term stability and durability.

(a) Short-term stability: the bond between cohesive soil and strip reinforcement is poor and subject to reduction if positive pore water pressures develop.

(b) Some fine-grained cohesive soils are significantly more aggressive than cohesionless soils. It is known that clay materials such as illite accelerate metal corrosion.

It is thought that long-term deformation may occur when plastic soils are reinforced. However, many widespread benefits and applications arise if suitable reinforcements and construction techniques can be adapted to use cohesive fill, particularly in areas where cohesionless fill is in short supply. Cohesive soil will normally require comprehensive drainage and may be difficult to place, especially in wet conditions.

Though use of cohesive fill in anchored earth is rare, permanent geosynthetic-reinforced soil retaining walls and bridge abutments, built using cohesive fill, are used in Japan for railway works. These structures have been shown to be very stable and capable of surviving large seismic forces such as the 1995 Kobe earthquake (Tateyama and Murata, 1994; Tatsuoka et al., 1992, and Tatsuoka et al., 1995). Recently many pioneers in this field used compacted cohesive soil as backfill in their full scale model tests and finite elements models.

Alfaro et. al. (1996) investigated the behavior of reinforced soil wall-embankment system on soft ground through a series of parametric studies using finite element analysis. They used common cohesive backfill soils in their analysis. The effects of compaction reported by Ingold (1979) have good lessons for using uncompacted backfill though uncompacted backfill has other limitations. Based on the results of finite element analyses, Rowe and Ho (1995 and 1996) reported the effects of intermediate reinforcing layers, the effect of interface shear, the effect of panel continuity and location of panel connections, backfill soil stiffness and foundation stiffness. They drawn important conclusions about the stiffness of backfill soil that (a) modulus of elasticity of backfill does not have significant effect on the forces required for either external rigid body equilibrium or internal equilibrium of the reinforced soil wall system except for very low values of modulus and (b) a change in backfill modulus only affects the horizontal deformation behind the reinforced soil block and consequently the horizontal deformation at wall face. Tatsuoka et al (1986) shown that steep side slopes of embankments made of sensitive Kanto loam can be effectively stabilized by using nonwoven geotextile. Ling, H. I. and Tatsuoka, F. (1992) reported the numerical procedure employed to predict the performance of two geosynthetic-reinforced walls, one backfilled with granular soil and the other with cohesive soil.

2.3.1.2 Retained Soil

No specific guidelines are found in literature on the retained soil. In the present study stiffness and strength properties of retained soil is suggested, where the retained soil is road embankment.

2.3.1.3 Subsoil

Subsoil condition is very important for reinforced soil wall. In the case of a reinforced soil structure standing upon a rigid or very stiff foundation, it will tend to rotate about the toe with an active mechanism away from the fill. With a soft foundation the self-weight of the stiff reinforced earth structure and the weight of the retained soil may cause the structure to rotate in a negative sense, which is fundamentally different from to that of stiff foundation. Alfaro et. al.(1996) have studied the behavior of reinforced soil wall-embankment system on soft ground. The practical implication of their numerical finding is that the preference of the designer in attempting to reduce the possible outward movement of reinforced soil wall by intuitively increasing the rigidity of reinforced soil structure could be misleading when such structure is to be constructed on soft ground.

2.3.1.4 Anchor

In the 1980s reinforcement in the form of an anchor was evolved simultaneously in Europe, Japan and the USA. The multi-anchor system was developed by Fukuoka (1980) for the Japanese Ministry of Construction where the anchor is in the form of a rectangular steel plate, Fig. 2.2. A retaining wall system, developed in Austria, is based on an elevated concrete facing and polymeric strips connecting concrete wall blocks and semi-circular anchors in the form of a closed loop, Fig. 2.3 (Brandl and Dalmatiner, 1986). Steel anchors formed from a single piece of rebar were developed by the Transport and Road Research Laboratory in the UK (Murray and Irwin, 1981). This system employs reinforcing steel bent into triangular anchors (Fig. 2.4); pullout resistance is mobilized by friction along the straight portion of the steel element and by passive pressure mobilized at the triangular anchor. The first polymeric anchor was developed in 1992 (Jones and Hassan. 1992). In the USA and the UK, anchored earth concepts have been extended to the use of waste automobile tyres as anchor and/or facing.

2.3.1.5 Reinforcing Tendon

Reinforcing tendon is used to connect the facing with anchor which may termed as tie bar. Stiffness of reinforcing tendon is very important for anchored soil wall. Bending stiffness has not been shown any significant effect on the performance of reinforced soils except in the case of reinforcements used as tension membrane over super soft soil (Jones and Zakaria, 1994).

Longitudinal stiffness has a marked effect on performance as it governs the strain, which occur in the reinforced soil. The effect of placing reinforcement with anchor in resistant zone is to restrict the deformation and a force proportional to the resultant strain is developed in the reinforcement. An equilibrium condition is reached dependent upon the longitudinal stiffness of the reinforcement and the load-displacement characteristics of the soil. The stress-strain characteristics of reinforcement are usually linear, this is not the case with soil. In this case the soil softens once full shear strength has been mobilised.

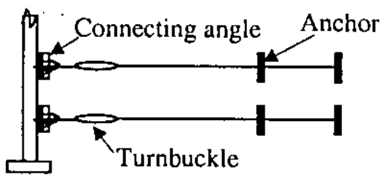


Fig. 2.2: Multi anchor wall

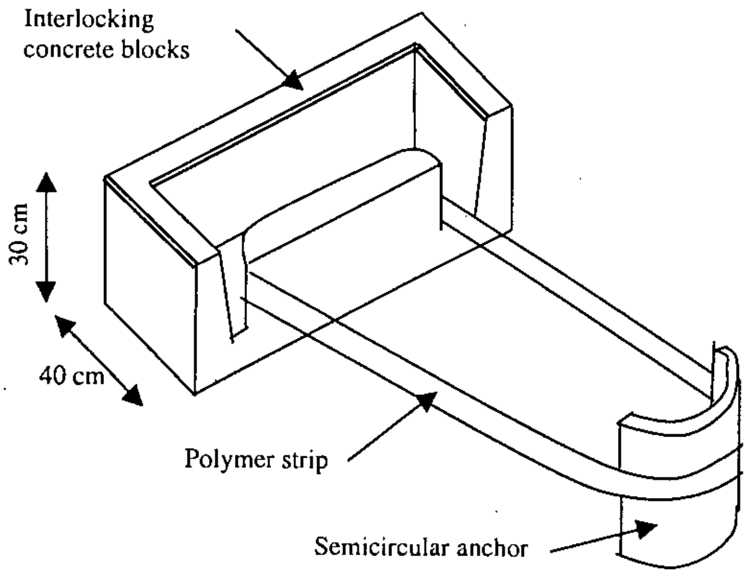


Fig. 2.3: Anchor system with concrete blocks and polymer strips

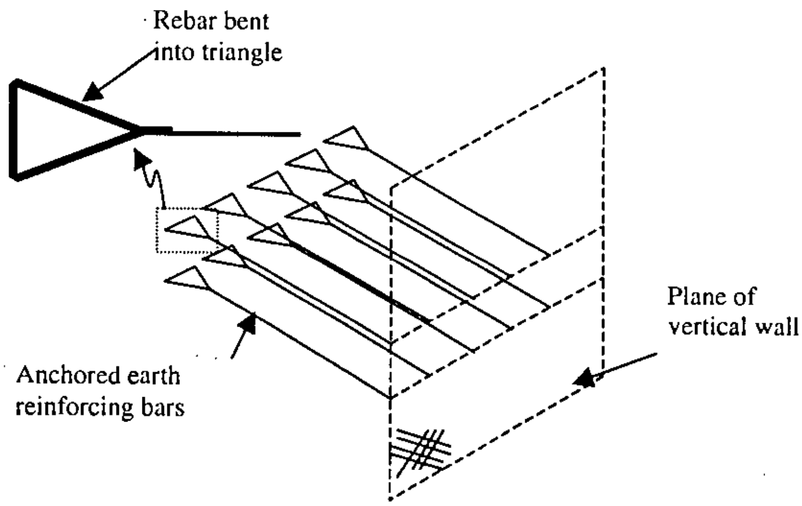


Fig. 2.4: Anchored earth with triangular rebar reinforcement

It is seen that if maximum force in reinforcement can be generated by a strain of less than 3 percent, the maximum strains that develop in the reinforced soil at any point would be less than those required to mobilise the soil strength. In case of in-extensible reinforcement, this condition holds. If reinforcement is extensible the maximum force in reinforcement will not be generated before the soil has passed the point of maximum shear strength. In these cases the maximum force in the reinforcement is controlled by the deformation in the soil. At strains beyond the peak strength of the soil alone, although soil may be losing strength, reinforcement would be taking stress.

Thus the reinforced soil may exhibit a peak load carrying capacity (in case of in-extensible reinforcement) relating to the peak shear strength of soil, or it may exhibit an enhanced strength at strains beyond the point of peak shear strength of the soil. In either case the strength of the reinforced soil is greater than the soil alone, Fig. 2.5.

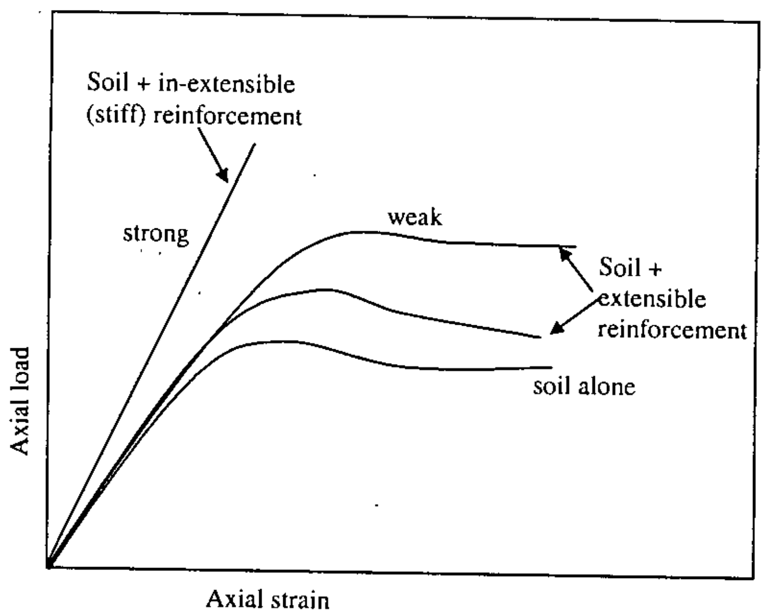


Fig. 2.5: Load - axial strain relationship for soil and reinforced soil (after Andrawes and McGown, 1978)

2.3.1.6 Facing

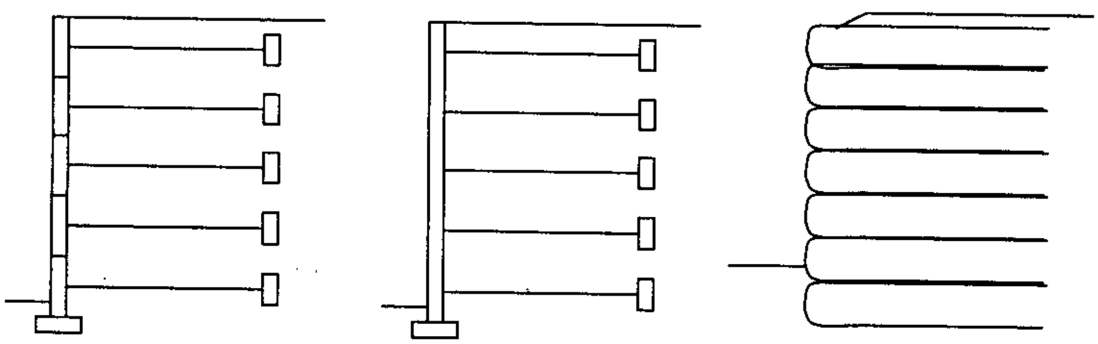
Hard Facings (e.g. concrete, steel sheet etc.) are usually used in anchored earth. Soft facings (e.g. wrap around geotextile or geogrid, gabion, sand filled bag etc.) are used in geosynthetic reinforced soil structures and these are flexible facings also (Fig. 2.6). Facing can be made flexible using modular facing units and can be made rigid using full height concrete panel or continuous walls. Roles of facing rigidity in soil reinforcing and comparison with other facings is well reported by Tatsuoka, F. (1992). Rigid facing increase durability, reduce wall deformation giving better aesthetics and make the construction easier.

2.3.1.7 Drainage System

Proper drainage system must be incorporated in anchored soil to prevent the development of excess pore water pressure and unbalanced hydrostatic pressure at back face of facing.

2.3.1.8 Footing Pad

Small footing pad underneath the facing panels is necessary to avoid localized bearing failure of subsoil. Footing pad also increase the stability of the reinforced soil structure.



(a) Descrete panels (a) Full-height panels (c) Wrap around facing

Fig. 2.6: Common facings used with retaining structures

2.3.2 Mechanisms Involved in Anchored Earth Wall

Investigation of the basic reinforcing mechanism reveal that the retained soil comprises two distinct zones. These are shown in fig. 2.7 as the active zone and the resistant zone. Without reinforcement the active zone is unstable and tends to move outwards and downwards with respect to the resistant zone. If anchor block is installed beyond the active zone with a tie bar across the active and resistant zones it can serve to stabilize the active zone. Due to self-weight of soil and surcharge on the structure, lateral deformation of soil induce lateral thrust on back face of facing, which eventually lead to development of tensile force in reinforcing tendon. Bearing pressure developed in soil resists this pull out force of reinforcing tendon on anchor block. Fig. 2.7 shows a single layer of reinforcement. A practical reinforcement layout would contain multiple layers of reinforcement, however, the single layer shown in Fig. 2.7 is adequate to illustrate the basic mechanisms involved.

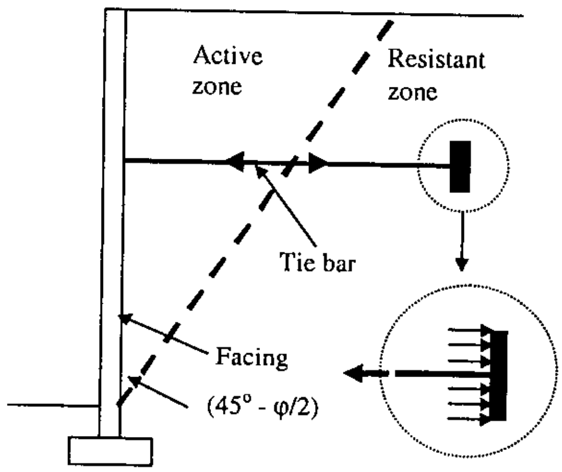


Fig. 2.7: Reinforcing mechanism in anchored earth wall

The precise reinforcing mechanism will be affected by the properties of the reinforcement, which is discussed later. Destabilising forces in active zone is transferred to resistant zone through reinforcement. Most of the resistance comes from anchor blocks and some from soil-reinforcement friction in resistant zone.

2.3.3 Modes of Failure

Potential failure modes for anchored earth wall structures are illustrated in Fig. 2.8 (Bathurst and Simac, 1994). External failure mechanisms consider the stability of an equivalent gravity structure comprising the facing wall, reinforcements (tie bars), anchor blocks and backfill. Not included in the Fig. 2.8 is global instability that involves failure mechanisms passing through or beyond the reinforced soil mass.

Conventional slope stability methods of analysis that have been modified to include the stabilizing influence of horizontal layers of reinforcement can be used for this purpose (e.g. Christopher et. al. 1989).

2.3.4 Factors Affecting the Performance of Anchored Earth Wall

The following factors, listed in Table 2.2, influence the behavior and performance of anchored earth wall (Jones, 1996).

Table 2.2. Factors that influence the behaviour and performance of anchored earth wall

Reinforcement	Reinforcement distribution	Soil	Soil state	Construction
# Stiffness (bending, longitudinal) # Strength # Surface properties	# Spacing # Orientation # Location	# Particle size # Grading # Mineral content # Index properties	# Density (void ratio) # Overburden # State of stress # Degree of saturation	# Geometry of structure # Compaction # Construction system

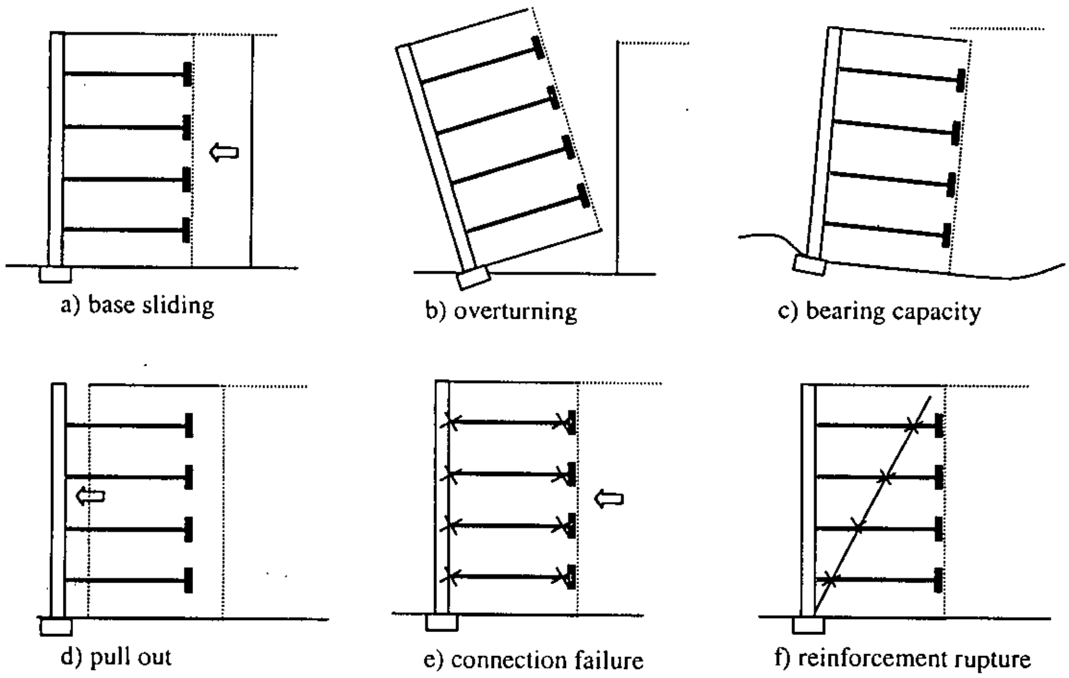


Fig. 2.8: Modes of failure: external (top row); internal (bottom row)

2.3.5 Analysis and Design of Anchored Earth

The cornerstone for the analysis of reinforced soil structures is that the soil strains, soil stresses, reinforcement interaction and gravity, reinforcement boundary forces are all interconnected. The stiffness of the reinforcement has a fundamental influence on the behavior and performance of reinforced soil structures. Axially stiff reinforcement will take up little strain before taking up load. Stress in the reinforcement can accumulate rapidly and may occur at lower strains than those required to mobilize peak soil strength. By contrast, extensible reinforcements require greater deformation before they take up the stresses imposed by the soil. This may lead to higher strains and the peak shear strength of the soil may be approached or exceeded.

In designing anchored earth wall, above mentioned cornerstones of analysis are also valid if backfill soil would be frictional material. In case of indigenous soft backfill, no guidelines of analysis and/or design are found in literature. Therefore failure modes of anchored soil wall may be the starting point and may be used as guide in design.

2.3.5.1 Limit State Principles

Limit state principle is nicely described by McGown et al (1998) and BS 8006 (1995). For each geotechnical design problems, performance criteria during the period of construction and over the design life are set. Whenever a structure at a level equal to any of the performance criteria, it said to have reached a *Limit State*. Limit States are divided into two categories: *Ultimate Limit State (ULS)* and *Serviceavility Limit State (SLS)*.

Ultimate Limit States are concerned with safety, loss of static equilibrium or rupture of either a critical component or the entire structure. That is, they set performance criteria such that no catastrophic damage can occur to a structure.

Serviceability Limit States are conditions, or performance criteria, beyond which the functional or aesthetic utility of a component or of the entire structure is lost. The loss of serviceability may be due to deformation in the ground or deformation in the structure itself. For example, if a retaining wall supporting roadway deforms excessively, the serviceability of roadway is lost. Because due to wall deformation there may be noticeable subsidence of road subgrade which may cause discomfort to the users of that road or put the road out of service until proper maintenance is undertaken.

2.3.5.2 Extensibility of Reinforcements

Depending on extensibility, reinforcements are classified into two categories: inextensible and extensible. It is not very easy to define the extensibility of reinforcement as it depends not only on the properties of reinforcing material but also on applied load and type of structure. As per BS 8006 (1995), extensibility is defined below.

Inextensible reinforcement: where the design load can be sustained at a total axial tensile strain less than or equal to 1% the reinforcement is classified as inextensible.

Extensible reinforcement: where the design load is sustained at a total axial tensile strain exceeding 1% the reinforcement is classified as extensible.

2.3.5.3 Design steps of vertically faced anchored earth wall

According to BS 8006, anchored earth wall can be designed just by following steps.

Step 1: Estimation of initial size of structure

This step includes estimation of length of reinforcement (L) and depth of embedment (D_m) from height of wall. Minimum values are given in Table 2.3.

Step 2: Check for external stability

This step includes check for-

Table 2.3: Dimensions of vertically faced wall and abutments

	Minimum L	Minimum D_m
Walls with normal retaining function	$0.7\,H \geq 3$ m	$H/20 \geq 1.35\text{x}10^{-3}\ q_r$
Bridge abutments	$0.6\,H \geq 7$ m	$H/10 \geq 2.7\text{x}10^{-3}\ q_r$

Here, H = mechanical height of wall

q_r = factored bearing pressure in kN/m^2

(a) Bearing failure:

This criteria can be checked by using Meyerhof distribution as follows:

$q_r < q_{ult}/f_m + \gamma D_m$ for bearing failure (2.3.1)

where,

q_r $= R_v/(L - 2e)$, bearing pressure on the bottom of reinforced soil

R_v is the resultant factored vertical load acting on the bottom of reinforced zone;

L is the length of reinforcement;

e is the eccentricity of resultant vertical load;

q_{ult} is the ultimate bearing capacity of subsoil;

f_m is partial factor suggested by BS 8006 (1995) at Table 16;

(b) Sliding along base: long term and short term stability

$f_s R_h < R_v \tan\varphi'_p/f_{ms} + c'L/f_{ms}$ For long term stability (2.3.2)

$f_s R_h < c_u L/f_{ms}$ For short term stability (2.3.3)

where,

R_h is the horizontal factored disturbing force on back of reinforced soil;

φ'_p is the peak angle of internal friction under effective stress condition;

c' is the cohesion of the soil under effective stress condition;

c_u is the undrained shear strength of soil;

f_{ms} is the partial materials factor (Table 16, BS 8006, 1995)

(c) Overturning failure

$R_v L/2 > R_h y$ (2.3.4)

where,

y is the location of center of lateral thrust from bottom of reinforced soil

(d) Wedge or slip circle stability

This may be assumed that no slip circle would pass through reinforced soil. Numerous literatures are available for slip circle stability.

(e) Settlement

Deformation should be at the end of construction and specified life.

Step 3: Selection of type and arrangement of reinforcement

Step 4: Calculation of tensile forces to be resisted by each layer of anchors

The horizontal force applied on an area (= S_v x S_h) of back face of facing wall for each reinforcing tendon, is the tensile force developed in the reinforcement.

Step 5: Designing the anchor sizes to resist the pull-out forces calculated in step 4

This step requires the knowledge of capacity of vertical anchors, which is discussed in the next article.

Step 6: Check for rupture of reinforcement or tie bar

The capacity of the reinforcing element at each layer should satisfy the following expression:

$$T_D/f_n \geq T_j \qquad (2.3.5)$$

where

T_j is the maximum tensile force

T_D is the design strength of the reinforcement

f_n is the partial factor for economic ramification of failure

Step 7: Check for serviceability

Post construction movement of anchored earth wall result from:

(a) foundation settlement

(b) internal compression of fill

(c) internal creep strain of reinforcement.

Post-construction internal strain should be limited to the values in Table 2.4

Table 2.4: Serviceability limits on post-construction internal strains for vertically faced retaining walls and bridge abutments

	Strain (%)
Walls with normal retaining function	1.0
Bridge abutments	0.5

Step 8: Check of wedge stability for nonstandard load cases

Step 9: Designing connections

2.4 PULL OUT CAPACITY OF VERTICAL ANCHOR

Here discussion is limited to horizontally loaded vertical plate anchors (Fig. 2.9). Numerous research works have been carried on pull out capacity of vertical anchor. Some the examples are Wang and Wu (1982), Das (1975a, 1975b), Akinmusuru (1978), Neely (1973), Rowe (1982a, 1982b), Rajagopal and Hari (1996). BS 8006 (1995) also proposes a simple formula for pull out capacity of vertical anchors. For easy estimation of pull out resistance of anchor some findings of the above researches are mentioned below.

BS 8006: According to BS 8006 (1995) ultimate pull-out resistance of an anchor can be determined from:

$$P_{uj} = P_{aj} + P_{sj} \qquad (2.4.1)$$

and $$P_{aj} = 4\, K_p\, B_a\, t_a\, \sigma_{vj} \qquad (2.4.2)$$

where

P_{uj} is the ultimate pull-out resistance of anchor at jth layer;

P_{aj} is the bearing resistance of anchor;

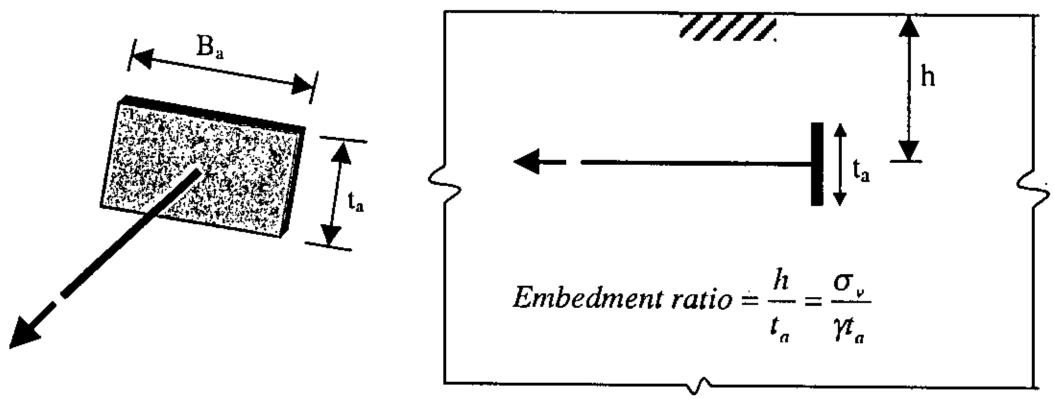


Fig. 2.9: Horizontally loaded vertical plate anchor and definition of embedment ratio (Depth-height ratio)

P_{sj} is the shaft resistance of reinforcing element/tie bar of anchor developed by friction beyond the potential failure plane;

K_p is the coefficient of passive earth pressure;

B_a is the long term width of anchor;

t_a is the long term height of anchor;

σ_{vj} is the vertical applied pressure at the j^{th} layer;

This is the simplest method of estimating pull-out resistance of anchor, though it does not consider the B_a/t_a ratio.

Rajagopal and Hari (1996): They used data generated by laboratory experiments and finite element simulations in developing a simple equation to relate a number of important parameters such as the size and shape of anchors, friction angle of soil, normal pressure acting at the mid-depth of anchors. The equation is given as:

$$\frac{P}{B_a} = S_a C\left[1+\frac{t_a}{B_a}\right]^m \gamma t_a{}^2\left(\frac{\sigma_V}{\gamma t_a}\right)^n K_p^q \qquad (2.4.3)$$

where

K_p is the coefficient of passive earth pressure;

B_a is the long term width of anchor;

t_a is the long term height of anchor;

S_a is the shape factor = 0.8 for circular anchors;

= 1.0 for square and rectangular anchors;

C is a nondimensional constant = 1.42;

n is a exponent = 1.46 for shallow embedment depths for which $\sigma_v/\gamma H$ less than 15;

= 1.03 for higher embedment depths;

m is a exponent = 1.36;

q is a exponent = 1.09;

They also concluded some important facts about behavior of vertical anchor in sand as follows;

(a) The pull-out capacity of anchor increases rapidly at shallow depths and at much slower rates at deep embedments.

(b) The unit capacity of square and circular anchors is more than that of rectangular anchors.

(c) The efficiency of rectangular anchors decreases as the aspect ratio (B_a/t_a) increased.

(d) As the embedment depth increased, the displacement at which peak load occur increases. So it is not practically feasible to utilize the full capacity of such anchors.

Rowe and Davis(1982a): They studied the behavior of vertical and horizontal anchor plates in clay and sand separately and also extended their theory to cohesive frictional material. Here only method of estimating vertical anchor plate in sand is described from. According to their proposal, anchor capacity q_u of an anchor in sand may be expressed in the form

$$q_u = \gamma h F_\gamma' \qquad (2.4.4)$$

where

γ is the unit weight of the soil;

h is the depth to the bottom of the anchor;

F_γ' is an anchor capacity factor;

Anchor capacity factor F_γ' is a function of orientation, embedment ratio, friction angle of soil, dilatancy, initial stress state and anchor roughness. This factor was expressed in terms of a basic anchor capacity factor F_γ and a number of correction factors

$$F_\gamma' = F_\gamma R_\psi R_R R_K \qquad (2.4.5)$$

where

F_γ' is the anchor capacity factor for the basic case of a smooth anchor resting in soil which deforms plastically at constant volume ($\psi = 0$) and $K_o = 1$.

R_ψ, R_R, and R_K are correction factors for the effect of soil dilatancy, anchor roughness and initial stress state, respectively.

Graphs are provided to estimate all these factors.

Akinmusuru (1978): He reported the findings of experimental study carried out on the pull-out capacities of both shallow and deep vertical anchors plates in sand. The parameters were depth of embedment and shape of anchor. The findings were summarized as follows:

(a) The ultimate load of an anchor increased with depth. The rate increase of this load increased to a maximum at depth coefficient (embedment ratio = $\sigma_v/\gamma t_a$) = 6.5 and remained constant at this maximum for all values of $\sigma_v/\gamma t_a > 6.5$.

(b) The failure zone of deep anchors was confined entirely within the soil mass and is of a near circular shape with the anchor height t_a as radius.

(c) For translational movement along the direction of pull only, at any depth, the circular anchors carries the greatest load per unit area, followed by the square and the (h x 2h) rectangular anchors. The infinite anchor under plane strain conditions has the least unit pull-out capacity.

He produced a graph showing variation of non-dimensional anchor load at ultimate failure with embedment ratio. But this graph should not be used to estimate ultimate load for deep anchor as this does not consider the displacement of anchor at failure load.

2.5 CONSTITUTIVE MODELLING IN GEOMATERIALS

The stress-strain relation of soil mass depends on many factors. Therefore, idealization becomes necessary while developing one constitutive model for a given soil mass. So different degrees of idealization depending on different purposes of analysis lead to different soil models. The development of geomechanical modelling began immediately after an era of huge mathematical impulse from the work of

Bernoulli, Euler, Leibnitz, Green, etc. In classical mechanics Newton had put forward the laws of motion and Robert Hooke had formulated the seed of all mechanical model-idea of linear elasticity (Chen and Mizuno, 1990). Here follows a brief description of some constitutive relations.

2.5.1 Isotropic Linear Elastic type

This is mainly for linear elastic analysis, which strictly obeys Hook's law, but also can be applied to nonlinear elasticity by making it segmental linear. This is the most widely used model in the history of classical mechanics. This model can produce a reasonable result with a proper choice of its two parameters, Young's modulus, E and Poisson's ratio, ν.

2.5.2 Nonlinear Elasticity Models

With the success of linear elastic model, a variety of non-linear elastic models evolved in classical mechanics, pioneered by the introduction of hypo-elasticity by Truesdell (1955,1956). This idea was then employed by Tatsuoka (1971) to derive the classical yield condition of Tresca and von Mises from hypo-elasticity.

2.5.3 Plasticity Models

All the nonlinear elastic models described above are lacking the criteria for loading and unloading. To eliminate that problem the following plasticity models were developed.

2.5.3.1 Variable Moduli Model

When deformation theory of plasticity is generalized in the forms of incremental stress-strain relationships, this model evolves. The mathematical description of this model is given by,

$$dp = Kd\varepsilon_{kk},\ ds_{ij} = 2Gde_{ij} \qquad (2.5.1)$$

Where,

dp = Mean hydrostatic stress increment.

$d\varepsilon_{kk}$ = Volumetric strain increment.

ds_{ij} = Deviatoric stress increment.

de_{ij} = deviatoric strain increment.

Shear modulus, G, and Bulk modulus, K, can be different ftinctions according to initial loading, subsequent unloading and reloading. It is used by Nelson and Baladi (1977).

2.5.3.2 *Elasto-Perfect plasticity models*

In elasto-plasticity models, total incremental strain is decomposed into,

$$d\varepsilon_{ij} = d\varepsilon_{ij}^{e} + d\varepsilon_{ij}^{p} \qquad (2.5.2)$$

The elastic strain increment is assumed to be completely described within the framework of incremental Hook's law, when bulk modulus, K, and shear modulus, G can be a relevant function of stress invariants or other state variables. On the other hand, plastic strain increment is derived from flow theory, which needs:

(a) The existence of a yield surface.

(b) The determination of flow rule.

From material strength values, the initial yield surface can be defined as:

$$f(\sigma_{ij}) = f_c \qquad (2.5.3)$$

So, when $f = f_c$ and $df = (\partial f/\partial\sigma_{ij})d\sigma_{ij} = 0$, plastic flow takes place and stress state is on the yield surface. When $f < f_c$ stress point is within the elastic zone (inside the yield surface).

Flow rule establishes the relationship of plastic strain increment $d\varepsilon_{ij}^{p}$ and the present state of stress σ_{ij} for a yielding element subjected to further loading. This is accomplished by having a plastic potential function g. So the plastic strain increment is obtained as;

$$d\varepsilon_{ij}^{p} = d\lambda \frac{\partial g}{\partial \sigma_{ij}} \qquad (2.5.4)$$

Where, $d\lambda$ is a positive scalar of proportionality, which is dependent on the state of stress and load history.

If the potential and yield surface coincide with each other ($f = g$), the flow rule is called the associated type, otherwise it is the non-associated type. Incremental stress-strain relations of perfect plasticity differs depending on assumed yield functions f which are functions of various parameters such as stresses, strains and history of loading. The following are the classical perfectly plastic models with different yield functions, f.

I. Tresca Model

Tresca proposed this in 1864. This yield criterion depends only on the invariants of stresses S_{ij}. If k is the yield stress of material determined from the pure shear test, and σ_1, σ_2 and σ_3 are the three principal stresses, each of them being either of major, intermediate and minor principal stresses, then the yield surface can be written as follows;

$$\left[(\sigma_1-\sigma_2)^2-4k^2\right]\left[(\sigma_2-\sigma_3)^2-4k^2\right]\left[(\sigma_3-\sigma_1)^2-4k^2\right]=0 \qquad (2.5.5)$$

It is a hexagonal prism whose generator is parallel to the hydrostatic axis ($\sigma_1 = \sigma_2 = \sigma_3$) in principal stress space and it is a regular hexagon on the π-plane (Fig. 2.10). Mathematically;

$$f(J_2, J_3) = f_c \qquad (2.5.6)$$

$$J_2 = \frac{1}{2}S_{ij}S_{ij}, \quad S_{ij} = \sigma_{ij} - \frac{1}{3}\sigma_{nn}\delta_{ij}, \quad J_2 = \frac{1}{3}S_{ij}S_{jm}S_{mi}$$

Where, J_2 = Second invariant of deviatoric stress, S_{ij} = Deviatoric Stress and J_2 = Third invariant of deviatoric stress.

II. Von Mises

This model was proposed by Von Mises in 1913, which solely depends on the second invariant of deviatoric stress tensor, J_2 as follows;

$$J_2 = k^2 \qquad (2.5.7)$$

In the principal stress space, it becomes,

$$\frac{1}{6}\left[(\sigma_{11}-\sigma_{22})^2+(\sigma_{22}-\sigma_{33})^2+(\sigma_{33}-\sigma_{11})^2+6\sigma_{12}{}^2+6\sigma_{23}{}^2+6\sigma_{31}{}^2\right]-k^2=0 \qquad (2.5.8)$$

It is a circle on π plane and cylinder in principal stress space (Fig. 2.10).

Extended Tresca surface

In order to include the effect of the hydrostatic pressure on soil strength, the original Tresca can be extended as follows;

$$\frac{f(J_2,J_3)}{I_1+C_1}=C_2 \qquad (2.5.9)$$

This looks like a hexagonal pyramid in the principal stress space as shown in Fig. 2.10. and a regular hexagon on the π-plane.

III. Extended von Mises

Effect of hydrostatic pressure can be included in Von Mises as follows;

$$\frac{\sqrt{J_2}}{I_1+C_3}=C_4 \qquad (2.5.10)$$

This looks like a cone in principal stress space as shown in Fig. 2.10 and it is a circle on the π-plane.

IV. Mohr-Coulomb Model

All the perfect plasticity models described in the above were originally proposed for metals This model derived from Mohr-Coulomb failure criteria, which is the best known failure criterion in Soil Mechanics. Failure criterion is,

$$\tau+\sigma\tan\varphi=C \qquad (2.5.11)$$

Where,

C = Cohesion of soils.

φ = Angle of internal friction.

This is originally a two dimensional mode, in the principal stress space this criterion can be described as;

$$\frac{1}{2}(\sigma_1 - \sigma_3) = -\frac{1}{2}(\sigma_1 + \sigma_3)\sin\varphi + C\cos\varphi \tag{2.5.12}$$

Its representation can be changed to a more convenient form in terms of I_1, J_2 and θ (Lode angle), which is geometrically easy to understand. Then the generalized form of Mohr-Coulomb yield surface is;

$$I_1 + \frac{\sqrt{J_2}}{g(\theta)} - K = 0 \tag{2.4.13}$$

$$g(\theta) = \frac{3 - \sin\varphi}{2\sqrt{3}\cos\theta - 2\sin\theta\sin\varphi}$$

It looks like an irregular hexagonal pyramid in the principal stress space and an irregular hexagon on the π-plane as shown in Fig. 2.11. In a three-dimensional generalization of this model, it exhibits corners or singularities creating difficulties in the calculation of gradients. Further, this surface neglects the influence of intermediate principal stress on the shear strength parameters φ and C. Despite these drawbacks, this can represent the strength characteristics of most of the geotechnical materials quite reasonably. Simplicity and validity of this model is well established for many soils.

V. Drucker-Prager Model

Drucker-Prager (1952) proposed this kind of yield surface, which neglects the influence of J_3 on the shear strength in terms of J_2 of soil, which is equivalent to the extended Von Mises. So this model eliminates the complication of corner singularity associated with Coulomb's surface. This is defined as;

$$f = \alpha J_1 + \sqrt{J_2} - K = 0 \tag{2.5.14}$$

Where, α and K are originally constants. When Coulomb's yield surface is represented by Eq. 2.4.13 the parameters α and K become variable according to different stress conditions. Three-dimensional matching of Drucker-Prager model to

Mohr-Coulomb criterion is illustrated in Fig. 2.11. The values of α and K for three typical stress conditions are listed in Table. 2.5.

2.5.4 Hardening-Softening Plasticity Model

Hardening-softening plasticity models are based on three fundamental assumptions:

(a) The shape of an initial' yield surface.

(b) The evolution of subsequent loading surface (hardening-softening rule).

(c) The formulation of an appropriate flow rule.

(d) The main difference between the elasto-perfect plasticity models and hardening-softening plastic models is the growth or motion of yield surface during plastic flow. For that point a hardening-softening rule is to be established. Hardening-softening process can basically be attained in two parametric ways;

(a) Plastic work (in Work hardening models)

(b) Plastic strain (in Strain hardening models)

There are several different hardening-softening rules. The choice of a particular one depends primarily on its ability to represent the hardening behavior of a particular material. Generally there are three types of hardening;

(a) Isotropic hardening

(b) Kinematic hardening

(c) Mixed hardening

Table 2.5: Constants of Drucker-Prager fitted with different Mohr-Coulomb criteria

Drucker-Prager Constants	Triaxial Compression	Triaxial Extension	Plane strain
α	$\frac{2\sin\varphi}{\sqrt{3}(3-\sin\varphi)}$	$\frac{2\sin\varphi}{\sqrt{3}(3+\sin\varphi)}$	$\frac{\tan\varphi}{\sqrt{9+12\tan^2\varphi}}$
K	$\frac{6C\cos\varphi}{\sqrt{3}(3-\sin\varphi)}$	$\frac{6C\cos\varphi}{\sqrt{3}(3+\sin\varphi)}$	$\frac{3C}{\sqrt{9+12\tan^2\varphi}}$

(a) Isotropic Hardening

The simplest isotropic hardening model assumes that the yield surface expands uniformly from the hydrostatic axis without distortion, depending upon plastic strain/work history. So, the equation of the subsequent yield surface or loading surface can be written as,

$$F(\sigma_{ij}) = \kappa^2(\varepsilon_p) \tag{2.5.15}$$

Where, ε_p = The effective plastic strain. Usually it is the integrated function of plastic strain components. This kind of hardening is good for isotropic material behavior.

(b) Kinematic Hardening Model

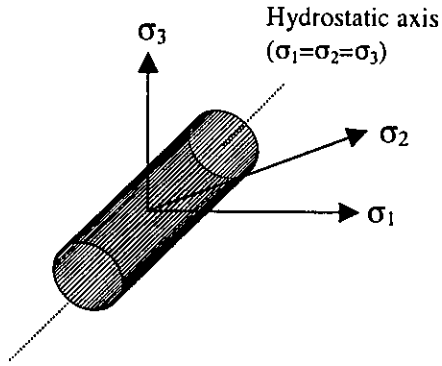
This kind of hardening assumes that loading surface translates as a rigid body in the stress space during plastic deformation. In order to simulate anisotropic behavior this kind of hardening is very effective. Mathematically;

$$f(\sigma_{ij}, \varepsilon_{ij}^P) = F(\sigma_{ij} - \alpha_{ij}) - \kappa^2 = 0 \tag{2.5.16}$$

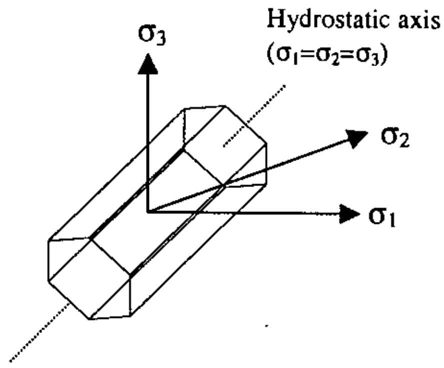
Where, κ is the material strength constant. α_{ij} are the coordinates of the center of the loading surface, which change with plastic flow. Multi-surface model proposed by Mroz (1967) and bounding surface model (Daffalias, 1980) use this kind of hardening.

(c) Mixed Hardening

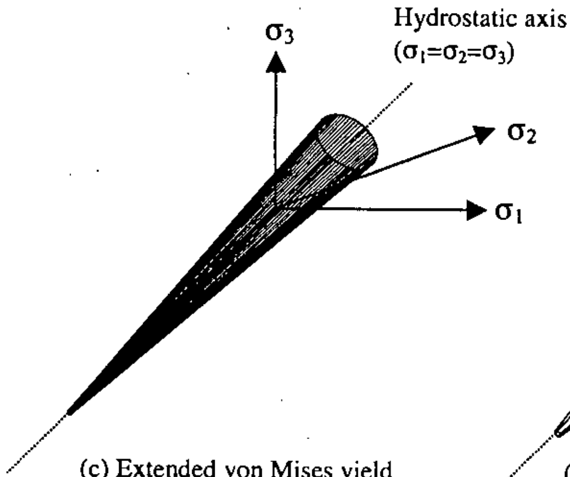
A combination of the previous two models leads to a more realistic mixed hardening model, which can predict different degrees of the Bouschinger effect.



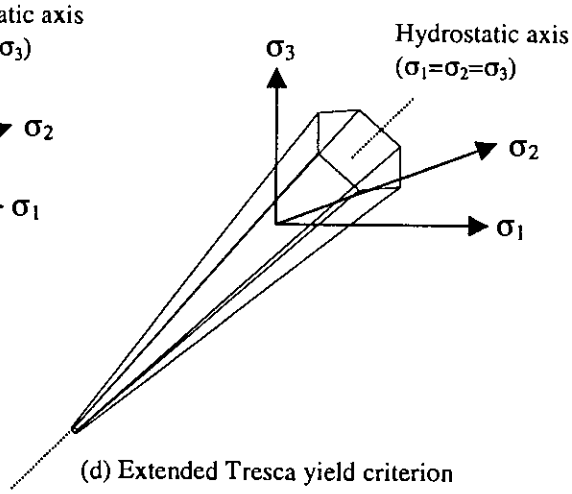
(a) von Mises yield criterion



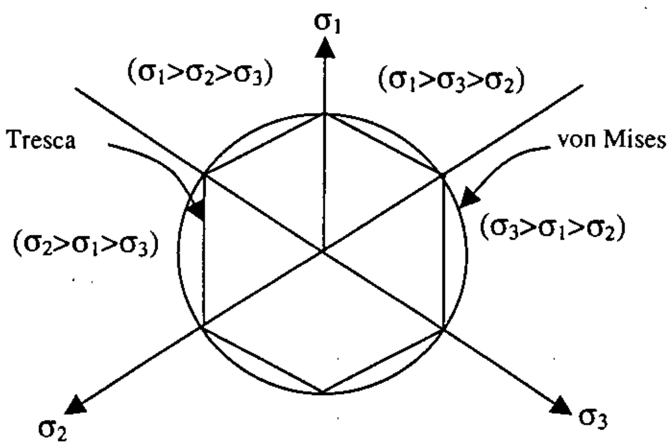
(b) Tresca yield criterion



(c) Extended von Mises yield criterion

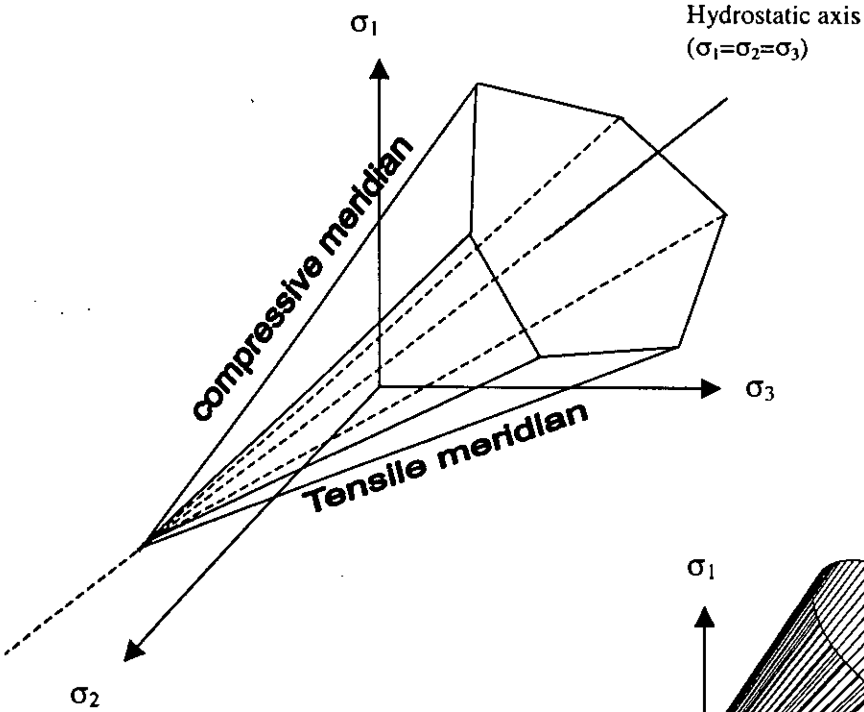


(d) Extended Tresca yield criterion

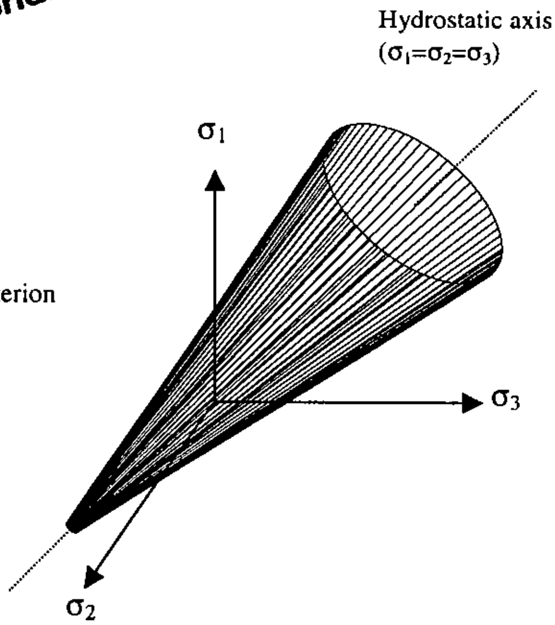


(e) Shape of yield criteria on the π-plane

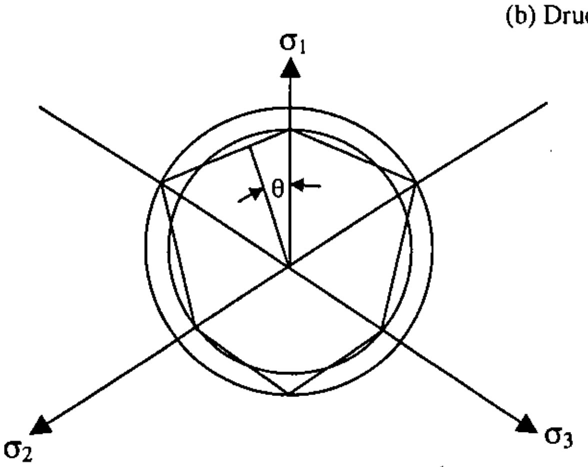
Fig. 2.10: Perfectly plastic yield criteria: (a) von Mises, (b) Extended von Mises, (c) Tresca, (d) Extended Tresca and (e) their presentation on the π-plane.



(a) Mohr-Coulomb yield criterion



(b) Drucker-Prager yield criterion



(c) Shape of yield criteria on the π-plane

Fig. 2.11: Perfectly plastic yield criteria: (a) Mohr-Coulomb, (b) Drucker-Prager, and (c) their presentation on the π-plane.

Chapter 3

PARAMETRIC STUDY

3.1 INTRODUCTION

This chapter describes the formulation of parametric study, selection of element configuration, range of the parameters, and limitations of the study. The linear elastic and elasto-perfectly plastic solution of the standard wall system are compared. The reinforced earth wall system is designed first based on BS 8006 (1995). The standard design values are then varied in order to carry out a comprehensive parametric study. In all the figures standard design values are noted.

3.2 STANDARD WALL GEOMETRY

A 4.5 m high vertically faced anchored earth wall supporting a simultaneously constructed roadway is designed as per BS 8006 (1995). The design procedure of anchored earth wall is briefly described in article 2.2.4.4. Fig. 3.1 shows the geometry of the designed wall system. Anchor sizes are designed according to Rajagopal and Hari (1996) with a factor of safety of about 1, 2 and 6 for a surcharge loading of 100 kN/m^2 on the roadway. Due to surcharge loading, embedment ratio of all anchors ($\sigma_v/\gamma t_a$) were so high that they satisfied the criteria to be deep anchors in all methods. Horizontal spacing of reinforcement is 1.0 m and length of anchor is infinite so that it become a plane strain anchor of length 1.0 m and height 0.12 m (for F.S. = 6) in the finite element model. Though in consideration of ease of construction and efficiency in pull-out resistance, square shaped anchor is the best, to make finite element model of the proposed wall system a plane strain model, plane strain anchors are adopted. Large factor of safety (F.S. = 6) for anchors is used for standard wall configuration to minimize the effect of anchor size during study of other parameters.

RCC wall is used as rigid facing to reduce lateral deformation of wall and hence vertical deformation of top surface of roadway. Material properties used in designing this standard wall is shown in Table 3.1 and Table 3.2. Zoning of materials is shown in Fig. 3.2.

3.3 NUMERICAL MODEL

The finite element mesh (Fig. 3.3) of the proposed wall system is created using finite element software DIANA (1998). In the FEM model, 8 noded quadrilateral plane strain element (CQ16E) is used to represent soil and concrete (anchor blocks and facing wall). No interface element is used considering a perfect bonding between the soil and anchor blocks and back face of facing wall under the working load. Anchor blocks and facing wall were connected by 2 noded spring elements (SP2TR) to represent the reinforcement/tie bars. As a result no contribution of soil-reinforcement friction is considered in the numerical model. The solution remains in conservative side

Elasto-perfectly plastic Mohr-Coulomb constitutive model is used for sand, clay and concrete. Though a Cam-clay model is more suitable for in-situ clay soil than Mohr-Coulomb model, yet it is modeled by Mohr-Coulomb type yield surface for simplicity in calculation. The embedment depth of anchored earth wall is recommended by BS 8006 (1995) to protect the wall from future wash out of soil from in front of wall. But to observe positive effect of embedment depth just after construction of wall system, soil in front of wall is kept in the model.

The out boundaries of finite element mesh should be placed sufficiently far away from the region subjected to the greatest load changes so as not to influence the results. If the boundaries are placed beyond the regions where stress changes are less than 5%, then results would be within sufficient accuracy. For retaining wall, as a general rule, the vertical boundaries should be placed at a distance of at least 4 to 5H from the wall (H = Height of wall). The bottom boundary of the mesh should be at depth of at least 4H or at hard stratum, whichever is nearer. These are shown in Fig. 3.4. In the current study, the base soil is assumed to be sufficiently stiff and proposed wall system has a centerline of roadway, which can be easily considered as an axis of symmetry. Due to stiff base soil bottom boundary is located nearer to bottom of wall (Fig. 3.1).

3.3.1 Characteristics of CQ16E

Plane strain elements are characterized by the fact that their thickness t is equal to unity and that the strain components perpendicular to the element face are zero. They must be positioned in the model XY-plane, i.e., the Z coordinate of the element nodes must be zero. Loading F must act in the plane of the element.

The CQ16E element (Fig. 3.5) is an isoparametric plane strain eight-node quadrilateral element (DIANA User's Manual: Element Library, 1999). It is based on quadratic interpolation and Gauss integration. The polynomial for the displacements can be expressed as

$$u_i(\xi, \eta) = a_0 + a_1\xi + a_2\eta + a_3\xi\eta + a_4\xi^2 + a_5\eta^2 + a_6\xi^2\eta + a_7\xi\eta^2 .$$

Typically, this polynomial yields a strain ε_{xx} which varies linearly in x direction and quadratically in y direction. The strain ε_{yy} varies linearly in y direction and quadratically in x direction. The shear strain ε_{xy} varies quadratically in both directions. Default is a 2 x 2 integration scheme, which yields optimal stress points.

3.4 THE PARAMETERS

To study the effect of variation of various parameters on the behavior of proposed wall system, the following components of the wall system are selected as parameters to study:

(i) Case I: Stiffness of reinforcement; in the numerical model this is the spring constant of spring element SP2TR connecting facing to anchor.

(ii) Case II: Stiffness and strength properties of silty clay fill (clay1 in Fig. 3.2) in between anchors and facing and surrounded by sand;

(iii) Case III: Stiffness and strength properties of silty clay fill (clay2 in Fig. 3.2) of roadway which is retained by proposed wall system;

(iv) Case IV: Stiffness and strength properties of sand (sand2 in Fig. 3.2) in between clay1 and clay2;

(v) Case V: Rigidity of facing; as the I (moment of inertia area) was kept constant and only E was varied.

(vi) Case VI: Anchor size; in the numerical model this is the height of anchor (t_a);

(vii) Case VII: Anchor position;

Variation of these parameters are tabulated in Tables 3.2 - 3.7.

3.4.1 Case I: Stiffness of Reinforcement

This is the spring constant of spring element SP2TR connecting facing to anchor. Stiffness is the combined effect of Modulus of Elasticity (E) of reinforcement, length and cross-sectional area for metallic reinforcement, and thickness for sheet reinforcement. Stiffness is calculated from

$k_s = AE/L$ for metallic reinforcement

$k_s = tE/L$ for sheet reinforcement

The design value of stiffness of reinforcement was $1\text{x}10^7$ N/m. This parameter was varied from $1\text{x}10^6$ to $1\text{x}10^{11}$ N/m. Variation of spring constant in the parametric study is shown in Table 3.2.

3.4.2 Case II: Stiffness and Strength Properties of Clay1

Silty clay fill in between anchors and facing and surrounded by sand is termed as clay1. Case II of the parametric study is divided by two parts; one is considering clay1 as cohesive frictional ($\varphi = 14.5^o$) and another is considering clay1 as purely cohesive ($\varphi = 0^o$). A Young's modulus of 20 MPa, cohesion of 40 kPa and friction angle of 14.5^o were the design values of stiffness and strength properties of clay1. Young's modulus was varied from 5 to 50 MPa and cohesion was varied from 10 to 100 kPa respectively. Angle of internal friction was remained constant. Variation of material properties of clay1 as cohesive frictional soil in the parametric study is shown in Table 3.3. Variation of material properties of clay1 as purely cohesive soil is shown in Table 3.4. To simulate undrained condition of clay1 Poisson's ratio of clay1 is assumed as 0.45. Young's modulus E is estimated from the empirical relation $E = (100 \text{ to } 500)\ S_u$ (Bowles, 1997, pp. 317) for silt and clays. $E = 500\ S_u$ is adopted in this study. To estimate K_o, Jaki's (Jaky, 1944) formula ($1\text{-}\sin\phi$) is used.

3.4.3 Case III: Stiffness and Strength Properties of Clay2

After the sand2, containing anchor blocks, the silty clay fill of roadway, which is retained by the retaining system, is termed as clay2. Case III of the parametric study is also divided by two parts; one is considering clay2 as cohesive frictional ($\varphi = 14.5^o$) and another is considering clay2 as purely cohesive ($\varphi = 0^o$). A Young's modulus of 20 MPa, cohesion of 40 kPa and friction angle of 14.5° were the design values of stiffness and strength properties of clay2. Young's modulus was varied from 5 to 50 MPa and cohesion was varied from 10 to 00 kPa respectively. Angle of internal friction was remained constant. Variation of material properties of clay2 is same as variation of clay1, which is shown in Table 3.3 and Table 3.4.

3.4.4 Case IV: Stiffness and Strength Properties of Sand2

To provide passive resistance to anchor blocks highly frictional sandy soil is placed between clay1 and clay2 and termed as sand2. Variation of material properties of sand2 is tabulated in Table 3.5. At first SPT N_{60} values of 5, 10, 20 and 50 are set for sand2, then elastic modulus E and friction angles are estimated using the corelations given in Bowles (1997. pp. 316 and 163). Dilatancy angles are estimated as one-third of friction angle and K_o is from Jaky's (Jaky, 1944) formula.

3.4.5 Case V: Rigidity of Facing

Rigidity of facing is varied by changing elastic modulus E of facing wall without changing its dimension. In this parametric study it is assumed that facing material has sufficient strength to protect the complete collapse of the whole system. As in case of flexible facing, top 0.5 m has no support. So, extra measure is taken connecting the tip of the wall with anchor in first layer by a spring element SP2TR. The design value of the elastic modulus of lightly steel reinforced concrete facing was 20,000 MPa. This was varied from 1 to 20,000 MPa. Variation of facing rigidity is tabulated in Table 3.6.

3.4.6 Case VI: Anchor Size

Using formula given by Rajagopal and Hari (1996), the anchor sizes are designed for factor of safety of 1, 2 and 6 (Table 3.7). Heights of plane strain anchors are 0.02 m, 0.04 m and 0.12 m respectively. Since Rajagopal and Hari (1996) have performed pull-out test on anchors in an anchored earth wall arrangement, their formula may be suitable for anchors used in anchored earth wall. Comparison of ultimate pull-out capacity of horizontally loaded vertical anchors is made among three methods and shown in Table 3.8.

3.4.7 Case VII: Anchor Position

Effect of anchor position is studied at stiffness of reinforcement equals to 1.0×10^6 N/m to see the improvement of serviceability of roadway. In order to improving serviceability of roadway, anchor position was changed from x = 3.0 m to x = 5.0 m, where x is measured from back face of facing wall. Length of reinforcement becomes 5/3 times of original length for the changed position of anchor, resulting a decrease of stiffness (changed stiffness = 3/5 times the original stiffness) if cross section of reinforcing tendon remains unchanged. To simulate this effect stiffness of reinforcement is reduced to 0.6×10^6 N/m in the numerical model.

3.5 SURCHARGE LOAD ON ROADWAY

On the top surface uniform surcharge load of 100 kN/m^2 is applied. This factored load includes wheel load, self-weight of bituminous carpeting, base and subbase. Concentrated or localized tyre pressure is generally applied on the top of the carpeting of roadway. This localized pressure reaches on soil foundation as uniform pressure on a large area, which is many times of contact area of tyre. Thus the pressure on soil can be assumed as uniform.

3.6 LIMITATIONS OF THE STUDY

The limitations of this study are as follows:

(i) Base soil is assumed to be stiff enough to prevent bearing and tilt failure of the wall system

(ii) Load on the roadway is static and uniform.

(iii) Effect of layer by layer construction of wall is ignored.

(iv) Facing is continuous in Z and Y direction.

(v) Short deformations are found from the study.

(vi) No interface element is used assuming perfect bonding between soil and concrete anchors and facing.

(vii) Plane strain anchor is used.

(viii) Consolidation settlement is not considered.

3.7 MESH REFINEMENT

Effect of mesh density is studied to select the optimum mesh density. Fig. 3.6 shows the variation of displacement at point A and B with number of element in the finite element mesh. It is seen that though variation is negligible, rate of variation decreases with number of element. The finite element mesh with number of element = 301 is used for the parametric study.

3.8 LINEAR ELASTIC VS. ELASTO-PERFECTLY PLASTIC SOLUTION

A linear elastic solution of the standard wall is also carried out to compare the results with those of elasto-perfectly plastic solution. The comparison of deformation and anchor forces are shown in Fig. 3.7 - 3.10. It is observed that difference between two solution is pronounce. In fact, in nonlinear analysis, solution is started from linear elastic solution and redistribution of stresses and displacements are continued until convergence of the solution. As the behavior of soil is mostly nonlinear and reaches the yield surface quickly, linear elastic solution of geotechnical problem is not realistic. Though the elasto-plastic strain hardening softening constitutive models are more appropriate for soil, for simplicity elasto-perfectly plastic Mohr-Coulomb constitutive model is used in this study.

Table 3.1: Material properties of concrete and soils for the designed standard wall

	Unit	Concrete	sand1	sand2	clay1	clay2	clay3
Young's modulus	MPa	20,000	40	40	20	20	50
Poisson's ratio (ν)	-	0.15	0.25	0.25	0.45	0.45	0.40
Cohesion (c)	kPa	400	0	0	40	40	100
Friction angle (ϕ)	Degree	40°	40°	40°	14.5°	14.5°	14.5°
Dilatancy angle (ψ)	Degree	2.3°	13°	13°	0°	0°	0°
K_o (=1-Sinϕ)	-	0.36	0.36	0.36	0.75	0.75	0.75

Table 3.2: Variation of spring constant in Parametric Study: Case I

	1	2	3	4 (design value)	5	6	7
Spring constant (N/m)	$1x10^6$	$2x10^6$	$5x10^6$	$1x10^7$	$1x10^8$	$1x10^9$	$1x10^{11}$

Table 3.3: Variation of material properties of clay1 and clay2 in Parametric Study: Case II and Case III (ϕ = 14.5°) respectively

	Unit	E05	E10	E20 (design value)	E30	E40	E50
Young's modulus	MPa	5	10	20	30	40	50
Poisson's ratio (ν)	-	0.45	0.45	0.45	0.45	0.45	0.45
Cohesion (c)	kPa	10	20	40	60	80	100
Friction angle (ϕ)	Degree	14.5°	14.5°	14.5°	14.5°	14.5°	14.5°
Dilatancy angle (ψ)	Degree	0°	0°	0°	0°	0°	0°
K_o (=1-Sinϕ)	-	0.75	0.75	0.75	0.75	0.75	0.75

Table 3.4: Variation of material properties of clay1 and clay2 in Parametric Study: Case II and Case III (ϕ = 0°) Respectively

	Unit	E20	E30	E50
Young's modulus	MPa	20	30	50
Poisson's ratio (ν)	-	0.45	0.45	0.45
Cohesion (c)	kPa	40	60	100
Friction angle (ϕ)	Degree	0°	0°	0°
Dilatancy angle (ψ)	Degree	0°	0°	0°
K_o (=1-Sinϕ)	-	0.75	0.75	0.75

Table 3.5: Variation of material properties of sand2 in Parametric Study: Case IV

	Unit	E20 $N_{60} = 5$	E40(design value) $N_{60} = 20$	E60 $N_{60} = 50$
Young's modulus	MPa	20	40	60
Poisson's ratio (ν)	-	0.25	0.25	0.25
Cohesion (c)	kPa	0	0	0
Friction angle (ϕ)	Degree	30°	40°	50°
Dilatancy angle (ψ)	Degree	10°	13°	17°
K_o (=1-Sinϕ)	-	0.50	0.36	0.23

Table 3.6: Variation of facing rigidity (EI) in Parametric Study: Case V ($I = 6.67 \times 10^{-4}$ m^4)

	1	2	3	4	5	6 (design value)
E (MPa)	1	2	10	100	1000	20000
EI (kN-m^2)	0.67×10^3	1.33×10^3	6.67×10^3	6.67×10^4	6.67×10^5	1.33×10^7

Table 3.7: Variation of anchor size (1.0 m x t_a) in Parametric Study: Case VI

	1	2	3
t_a	0.02 m	0.04 m	0.12 m
Factor of Safety	1	2	6

Table 3.8: Comparison of ultimate pull-out capacity of anchors at different levels of the proposed wall system calculated using 3 methods for 3 anchor sizes.

			Anchor size = 0.02 m^2			Anchor size = 0.04 m^2			Anchor size = 0.12 m^2		
	Method	Rankin's Theory (K_a=0.22)	BS 8006 (1995)	Rajagopal and Hari (1996)	Rowe and Davis (1982a)	BS 8006 (1995)	Rajagopal and Hari (1996)	Rowe and Davis (1982a)	BS 8006 (1995)	Rajagopal and Hari (1996)	Rowe and Davis (1982a)
depth (m)	$\square_v$ (kPa)	P_{req} (kN)	P_u (kN)	P_u (kN)	P_u (kN)	P_u (kN)	P_u (kN)	P_u (kN)	P_u (kN)	P_u (kN)	P_u (kN)
0.5	108	24	40	**20**	28	79	**40**	55	238	**128**	166
1.5	124	27	46	**23**	32	91	**46**	64	274	**147**	191
2.5	140	31	52	**26**	36	103	**52**	72	309	**167**	216
3.5	156	34	57	**29**	40	115	**58**	80	344	**187**	240
4.5	172	38	63	**32**	44	127	**64**	88	380	**206**	265

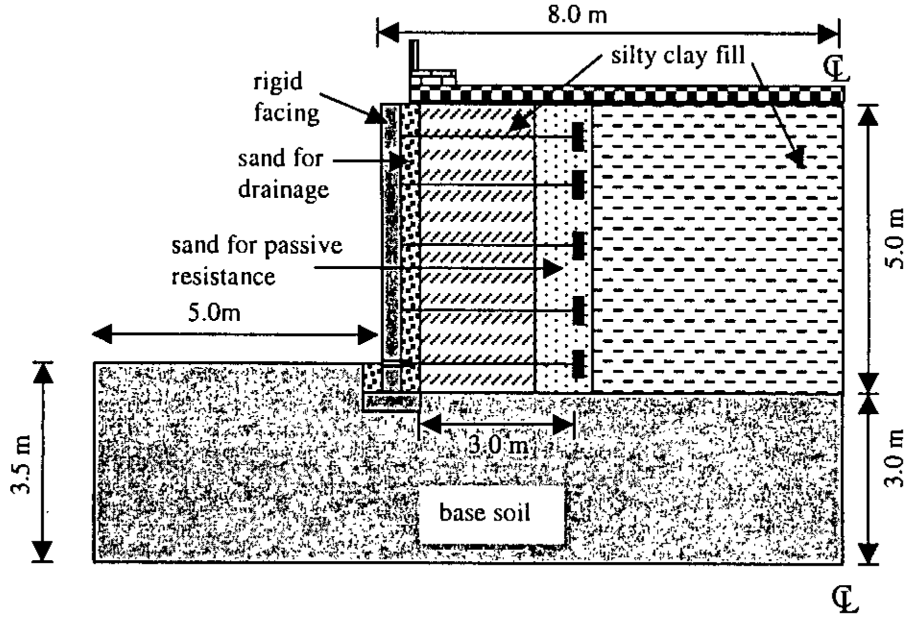


Fig. 3.1: Geometry of anchored earth wall supporting a roadway.

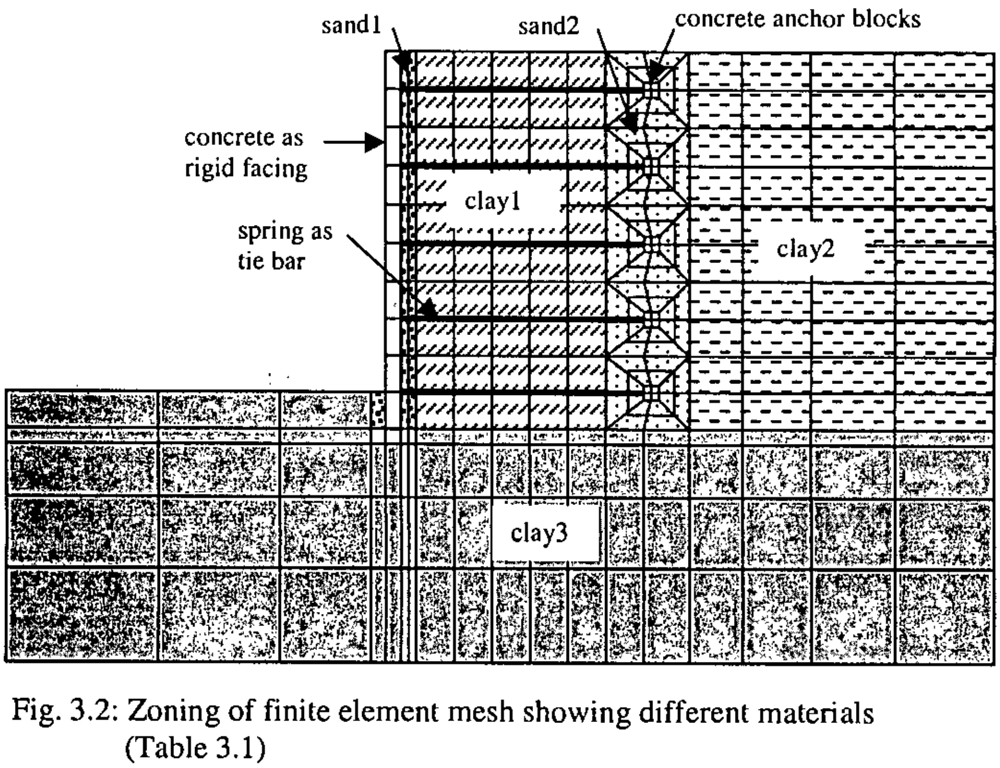


Fig. 3.2: Zoning of finite element mesh showing different materials (Table 3.1)

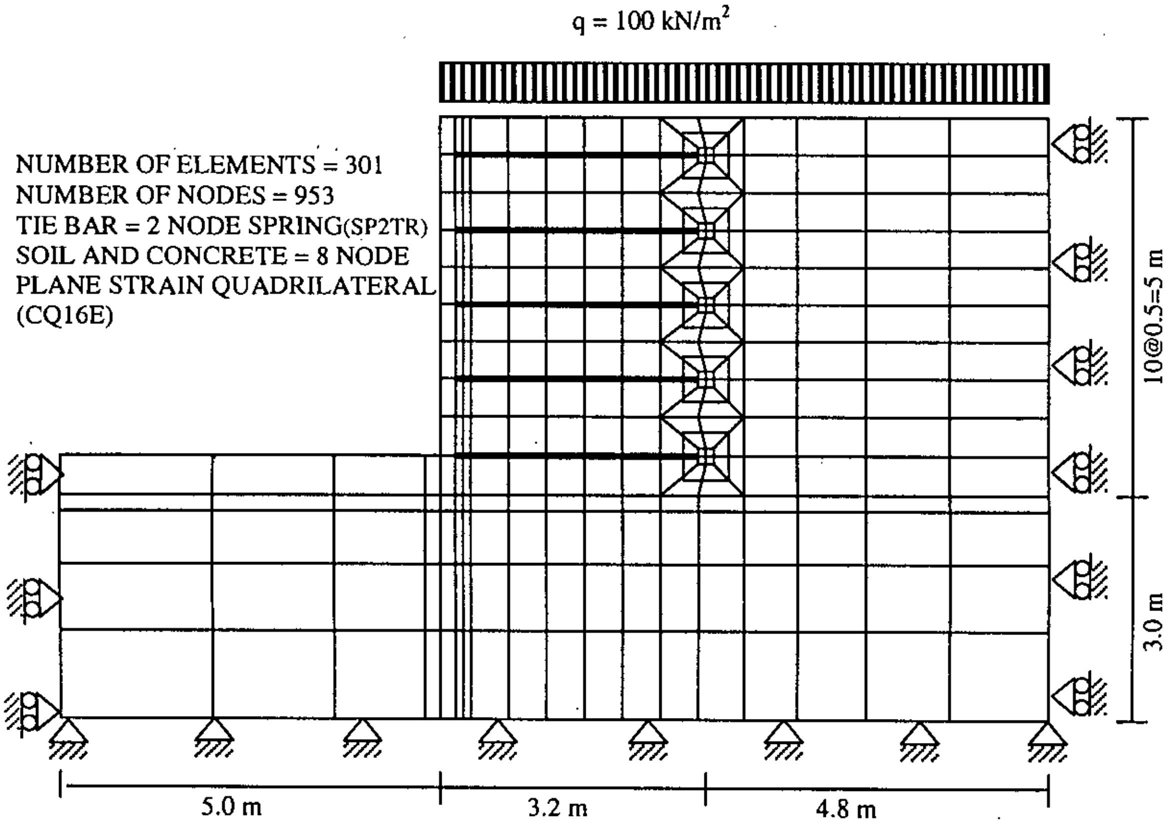


Fig. 3.3: Finite element mesh and boundary condition of proposed anchored earth wall

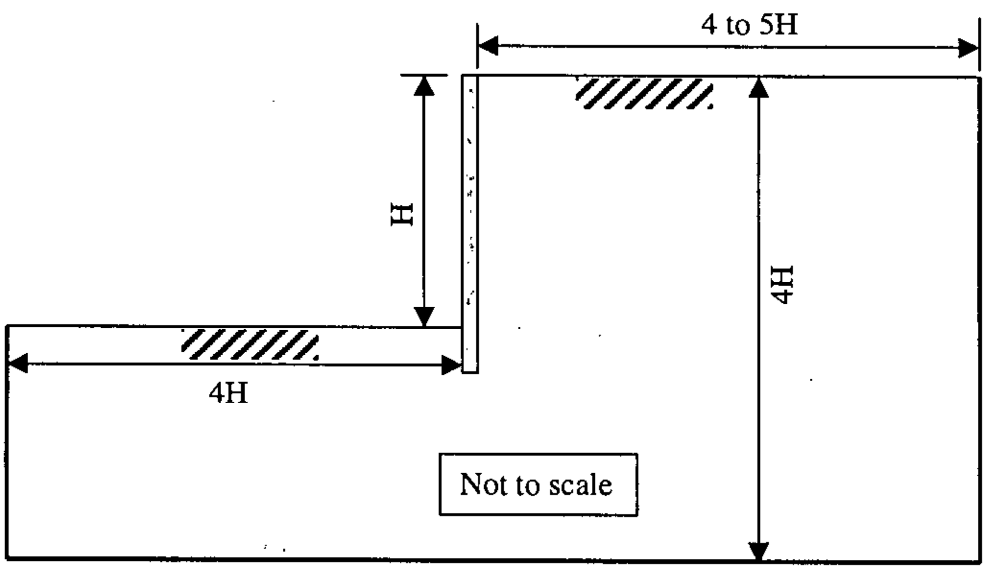


Fig. 3.4: Boundary locations of a numerical model of retaining wall

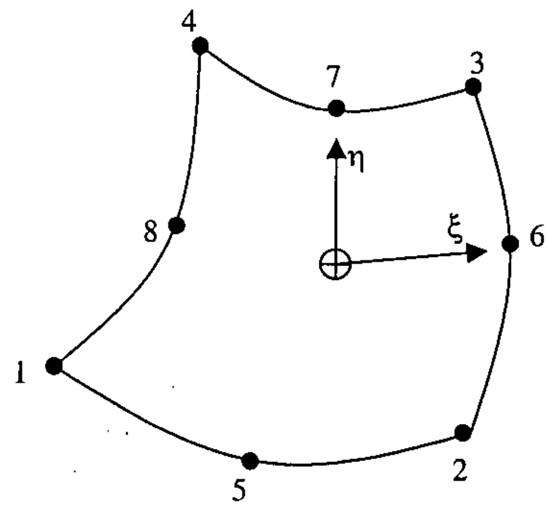


Fig. 3.5: Characteristics of isoparametric element CQ16E

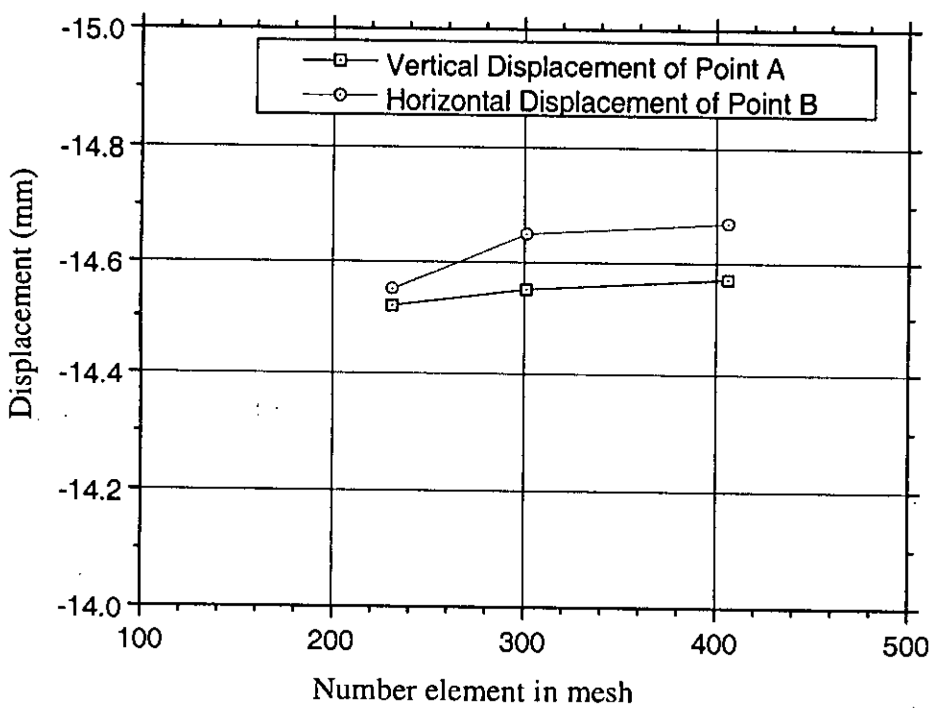


Fig. 3.6: Displacement variation with number of element in mesh

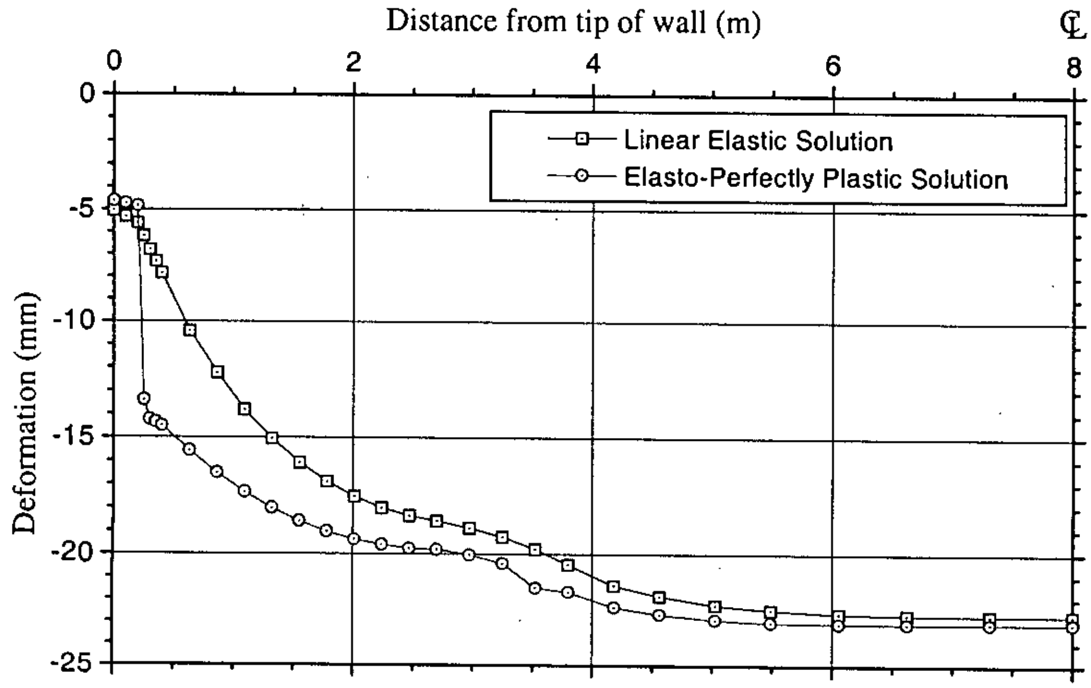


Fig. 3.7: Comparison between linear elastic and elasto-perpectly plastic solution of standard wall: deformed shape of top surface of roadway after 100 kPa uniform static loading on roadway)

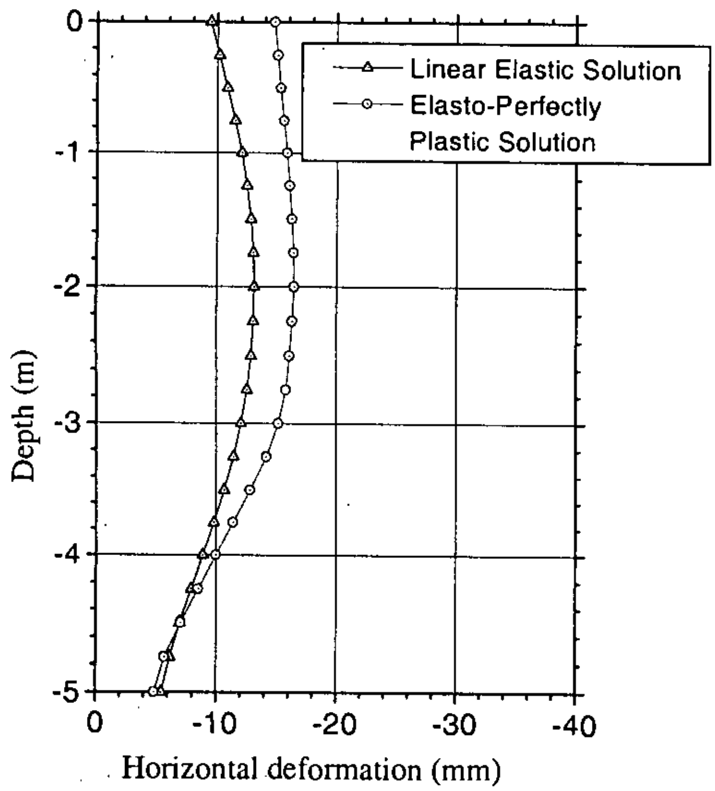


Fig. 3.8: Comparison between linear elastic and elasto-perpectly plastic solution of standard wall: Deformed shape of facing wall after 100 kPa uniform static loading on roadway

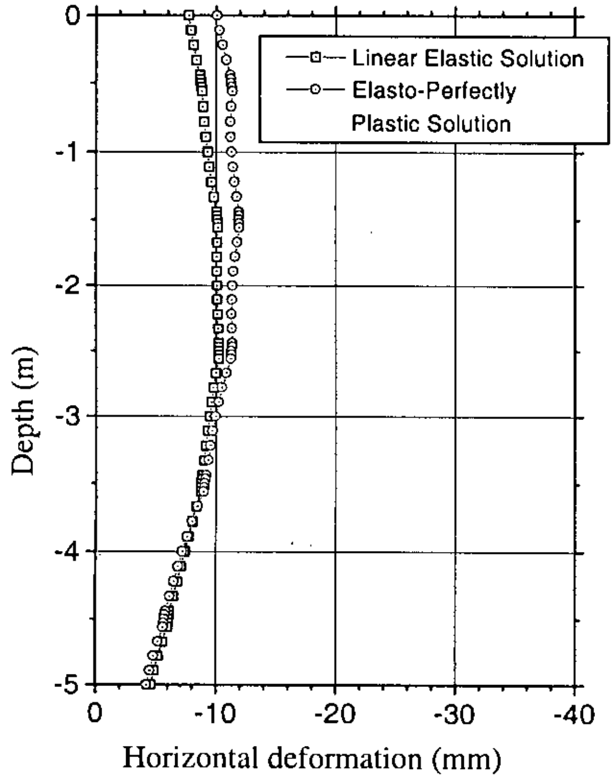


Fig. 3.9: Comparison between linear elastic and elasto-perpectly plastic solution of standard wall: Deformed shape of anchor front wall after 100 kPa uniform static loading on roadway

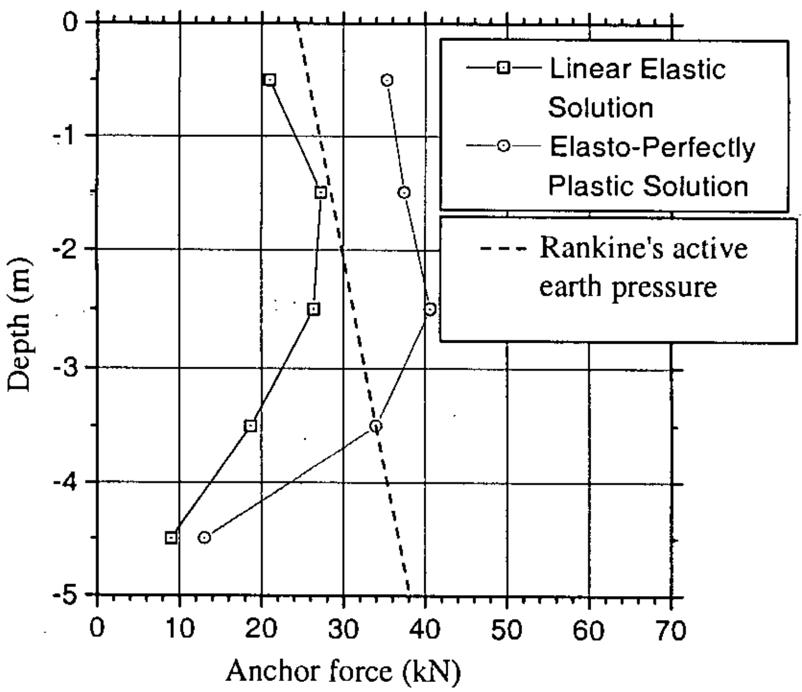


Fig. 3.10: Comparison between linear elastic and elasto-perfecly plastic solution of standard wall: Variation of anchor force with depth

Chapter 4

RESULTS AND DISCUSSION

4.1 INTRODUCTION

The outcomes of the parametric study are presented in this chapter. This chapter also discusses the results critically. Range of parameters is set to study the optimum performance of the proposed wall system. Effects of stiffness of reinforcement, properties of backfill soil, properties of retained soil, facing rigidity anchor size and anchor position on the behavior of anchored earth wall are discussed separately in subsequent articles. For convenience of presentation of results Fig. 4.1 shows the finite element mesh showing the position of reinforcements and points A, B and C in the mesh.

4.2 EFFECT OF STIFFNESS OF REINFORCEMENT

Fig. 4.2 shows the deformation of top surface of roadway with respect to distance from tip of wall at different stiffness of reinforcement. Fig. 4.3 shows the lateral displacement of the wall face with respect to depth. Fig. 4.4 shows the lateral displacement of the anchor front with respect to depth. Fig. 4.5 is the graphical plot of anchor force with depth. In Fig. 4.6, vertical displacements of point A, horizontal displacements of point B and C (Fig. 4.1) is plotted against stiffness of tie bar in logarithmic scale to show the rate of variation clearly. In Fig. 4.7, anchor force at level 3 is also plotted against stiffness of tie bar in logarithmic scale.

Stiffness of reinforcement or tie bar is a very important parameter among the parameters to be considered in designing anchored earth wall. It is observed from Fig. 4.2 that stiffness of tie bar has less effect on deformation of top surface of retained soil and has more effect on deformation of top surface of backfill soil. The stiffness of reinforcement should be equal to or greater than 5.0×10^6 N/m. In case of metallic reinforcement, its yield strength governs the design. As a result stiffness of reinforcement become greater than the requirement. But if geogrid or any other type of reinforcement is used for the proposed wall system, it must be ensured that stiffness is greater than 5.0×10^6 N/m. Same conclusions may be drawn from Fig. 4.3 and 4.4. Lateral deformation of wall may be kept within 0.5% of height of wall if stiffness of reinforcement is greater than or equal to 5.0×10^6 N/m. The combined effect of embedment depth and small pad under continuous rigid facing is clearly observed in Fig. 4.3. Lateral displacement of bottom of wall is only about 5 mm and this value is independent of stiffness of reinforcement.

Due to self weight of soil, the anchor force should increase linearly with depth. Due to surcharge loading anchor force should decrease with depth. So combined effect of self weight of soil and surcharge load anchor force is almost constant (Fig. 4.5) with depth upto 3m. Beyond this depth anchor force decreases due to combined effect of embedment depth and small pad under facing.

Vertical deformation of top surface and lateral deformation of wall decreases exponentially (Fig. 4.6) with increasing stiffness of reinforcement and become constant beyond stiffness 1×10^8 N/m. Lateral displacement of points B and C are equal beyond stiffness 1×10^8 N/m indicating that beyond this stiffness total wall system works as a rigid body and the rigid body movement of about 10 mm is due to lateral deformation of retained soil only. Anchor force increases with increasing stiffness of tie bar and beyond the stiffness of 1.0×10^8 N/m the curve becomes horizontal (Fig. 4.7). Because no relative movement of facing and anchor blocks occur at higher stiffness. For better performance of designed wall, lower limit of stiffness of reinforcement is 5.0×10^6 N/m. That implies that in the proposed wall system extensible reinforcement (Axial strain > 1.0%) could not used.

From the anchor forces of level 1 to 3, coefficient of lateral earth pressure (K) is calculated and plotted against logarithm of stiffness of tie bar in Fig. 4.8. It is observed that when $K = K_a$ at stiffness of reinforcement 1×10^6 N/m, the wall deformations are so large that exceed the serviceability limits. Therefore, for this type of retaining wall, required anchor forces or tensile forces in reinforcements should be estimated from K_o condition of backfill soil.

4.3 EFFECT OF STIFFNESS OF BACKFILL SOIL (CLAY1)

Case II of the parametric study is divided by two parts; one is considering clay1 as cohesive frictional ($\varphi = 14.5^{o}$) and another is considering clay1 as purely cohesive ($\varphi = 0^{o}$). Settlement of top surface of roadway against distance from tip of wall is plotted in Fig. 4.9 at different elastic modulus of clay1 ($\phi = 14.5^{o}$). Fig. 4.10 is the plot of lateral deformation of facing against depth of wall and Fig. 4.11 is the plot of lateral deformation of anchor front against depth of wall. From these three figures it is observed that elastic modulus of clay1 ($\phi = 14.5^{o}$) should be greater than or equal to 10 MPa and cohesion should be greater than 20 kPa. Fig. 4.12 shows the anchor force variation with depth. Anchor forces are almost constant with depth upto 3m and decreases beyond this, because of embedment depth. In Fig. 4.13, vertical displacements of a point on top surface at a distance of 1.55m from tip of wall, horizontal displacements of point B and C (Fig. 4.1) is plotted against elastic modulus of clay1 to show the rate of variation. In Fig. 4.14, anchor force at level 3 is also plotted against elastic modulus of clay1.

Maximum displacement of top surface, lateral displacement of wall facing and lateral displacement of anchor front decreases rapidly (Fig. 4.13) with increasing stiffness of backfill soil and rate of decrease become constant beyond stiffness 30 MPa. For better performance of designed wall, lower limit of stiffness of clay1 is 10 MPa. Clay1 with stiffness 10 MPa has cohesion c = 20 kPa which is in the range of soft consistency. It is also clear that design value of elastic modulus and cohesion of clay1 is the optimum value considering deformations and anchor forces.

From the anchor forces of level 1 to 3, coefficient of lateral earth pressure (K) is calculated and plotted against elastic modulus of clay1 in Fig. 4.15. It is seen that anchor forces decreases with increasing stiffness of clay1. This means that well compacted backfill soil reduces the requirement of reinforcement and hence the size of anchors.

Settlement of top surface of roadway against distance from tip of wall is plotted in Fig. 4.16 at different elastic modulus of clay1 ($\phi = 0^{o}$). Fig. 4.17 is the plot of lateral deformation of facing against depth of wall and Fig. 4.18 is the plot of lateral deformation of anchor front against depth of wall at different elastic modulus of clay1 ($\phi = 0^{o}$). Anchor force variation with depth is plotted in Fig. 4.19.

Effect of changing ϕ of clay1 on the deformations and anchor forces are shown in Fig. 4.20 – 4.23. It is seen that basically there is no effect of ϕ on deformations of wall beyond the stiffness of clay1 = 20 MPa. Because beyond this stiffness, shear strength properties (Table 3.2) are high enough to keep stress point within initial yield surface.

4.4 EFFECT OF STIFFNESS OF RETAINED SOIL (CLAY2)

Case III of the parametric study is also divided by two parts; one is considering clay2 as cohesive frictional ($\varphi = 14.5^{o}$) and another is considering clay2 as purely cohesive ($\varphi = 0^{o}$). Settlement of top surface of roadway against distance from tip of wall is plotted in Fig. 4.24 at different elastic modulus of clay2 ($\phi = 14.5^{o}$). Fig. 4.25 is the plot of lateral deformation of facing against depth of wall and Fig. 4.26 is the plot of lateral deformation of anchor front against depth of wall. From these three figures it is observed that elastic modulus of clay2 ($\phi = 14.5^{o}$) should be greater than or equal to 20 MPa and cohesion should be greater than 40 kPa. Fig. 4.27 shows the anchor force variation with depth. Anchor forces are almost constant with depth upto 3m and decreases beyond this, because of embedment depth. In Fig. 4.28, vertical displacements of a point on top surface at center of roadway, horizontal displacements of point B and C (Fig. 4.1) is plotted against elastic modulus of clay2 to show the rate of variation. In Fig. 4.29, anchor force at level 3 is also plotted against elastic modulus of clay2.

Maximum displacement of top surface, lateral displacement of wall facing and lateral displacement of anchor front decreases rapidly (Fig. 4.28) with increasing stiffness of retained soil and rate of decrease become constant beyond stiffness 30 MPa. For better performance of designed wall, lower limit of stiffness of clay2 is 20 MPa. It is also clear that design value of elastic modulus and cohesion of clay2 is the lower limit considering deformations.

From the anchor forces of level 1 to 3, coefficient of lateral earth pressure (K) is calculated as 0.65. It is seen that anchor force remains constant with increasing stiffness of clay2. This indicates that relative movement of anchor and facing wall produces the pull-out tensile forces in reinforcements. Stiffness of retained soil affect the rigid body movement of total retaining system. Displacement difference of point B and C seen in Fig. 4.28 is constant with variation of stiffness of clay2, this also proves the rigid body movement of total retaining system due deformation of retained soil.

Settlement of top surface of roadway against distance from tip of wall is plotted in Fig. 4.30 at different elastic modulus of clay2 ($\phi = 0^o$). Fig. 4.31 is the plot of lateral deformation of facing against depth of wall and Fig. 4.32 is the plot of lateral deformation of anchor front against depth of wall at different elastic modulus of clay2 ($\phi = 0^o$). Anchor force variation with depth is plotted in Fig. 4.33.

Effect of changing ϕ of clay2 on the deformations and anchor forces are shown in Fig. 4.34 – 4.39. It is seen that effect of ϕ on deformations of wall is decreasing with increasing stiffness of clay2 and basically there is no effect at higher stiffness. At $\phi = 0^o$ deformations are more than those at $\phi = 14.5^o$. This is because at $\phi = 0^o$ the yield surface is nearer than yield surface at $\phi = 14.5^o$ producing more plastic strain at $\phi = 0^o$.

4.5 EFFECT OF STIFFNESS OF SAND2

In between backfill soil clayl and retained soil clay2, sand2 is placed to provide passive resistance to anchor blocks. Settlement of top surface of roadway against distance from tip of wall is plotted in Fig. 4.38 at different elastic modulus of sand2. Fig. 4.39 is the plot of lateral deformation of facing against depth of wall and Fig. 4.40 is the plot of lateral deformation of anchor front against depth of wall. From these three figures it is observed that elastic modulus of sand2 should be greater than or equal to 20 MPa and friction angle should be greater than 30°. Under the applied surcharge pressure of 100 kPa, at elastic modulus of 10 MPa and friction angle of 25°, plastic deformation of sand2 occurred (Fig. 4.40). Fig. 4.41 shows the anchor force variation with depth. Anchor forces are almost constant with depth upto 3m and decreases beyond this, because of embedment depth. In Fig. 4.42, vertical displacements of a point on top surface at center of roadway, horizontal displacements of point B and C (Fig. 4.1) is plotted against elastic modulus of sand2 to show the rate of variation. In Fig. 4.43, anchor force at level 3 is also plotted against elastic modulus of sand2. Due large plastic deformation of sand2, tensile force could not developed in tie bar and hence anchor force developed less compared to those developed at elastic modulus of 20 MPa.

Maximum displacement of top surface, lateral displacement of wall facing and lateral displacement of anchor front decreases (Fig. 4.42) with increasing stiffness of sand2. For better performance of designed wall, lower limit of stiffness of sand2 is 20 MPa with a corresponding friction angle should be greater than 30^o.

4.6 EFFECT OF FACING RIGIDITY

In the designed standard wall system, facing was lightly steel reinforced concrete plate of thickness 0.2m. The elastic modulus of this facing wall was varied during Case V of the parametric study. The thickness of facing wall was not varied. Settlement of top surface of roadway against distance from tip of wall is plotted in Fig. 4.44 at different elastic modulus of facing wall. Fig. 4.45 is the plot of lateral deformation of facing against depth of wall and Fig. 4.46 is the plot of lateral deformation of anchor front against depth of wall. From these three figures it is observed that rigidity of facing should be greater than or equal to 6.67×10^4 kN-m^2. Fig. 4.47 shows the anchor force variation with depth. In Fig. 4.48, vertical displacements of a point A, horizontal displacements of point B and C (Fig. 4.1) is plotted against elastic modulus of sand2 to show the rate of variation. In Fig. 4.49, anchor force at level 3 is also plotted against elastic modulus of facing.

Facing rigidity is very important for anchored earth wall. In case of polymer reinforced earth, facing is required mainly to prevent raveling of local soils. But in case of the proposed wall system, facing rigidity is necessary to maintain the integrity of the system. From Fig. 4.45 it is observed that overall bending rigidity is lost when facing rigidity is less than 6.67×10^4 kN-m^2 (corresponding E_{face}= 100 MPa). Top surface of roadway also become out of service when facing rigidity is less than 6.67×10^4 kN-m^2 (corresponding E_{face}= 100 MPa).

At lower rigidity of facing deformations are so large that upper portions of clay1 and sand2 fall within active zone. As a result anchor forces are less (Fig. 4.47) and anchor deformations are more (Fig. 4.46). Therefore it may be concluded that anchor positions should be at a distance of more than height of wall (H) from facing of wall, considering backfill soil as purely cohesive.

Maximum displacement of top surface, lateral displacement of wall facing and lateral displacement of anchor front decreases rapidly (Fig. 4.48) with increasing facing rigidity with a decreasing rate. If the strength properties of facing material is high enough so that it would not rupture, minimum facing rigidity requirement is 6.67×10^4 kN-m^2 corresponding to E = 100 MPa.

4.7 EFFECT OF ANCHOR SIZE

Settlement of top surface of roadway against distance from tip of wall is plotted in Fig. 4.50 at different sizes of anchors. Fig. 4.51 is the plot of lateral deformation of facing against depth of wall and Fig. 4.52 is the plot of lateral deformation of anchor front against depth of wall. Fig. 4.53 shows the anchor force variation with depth. In Fig. 4.54, vertical displacements of point A, horizontal displacements of point B and C (Fig. 4.1) is plotted against size of anchor to show the rate of variation. In Fig. 4.55, anchor force at level 3 is also plotted against size of anchor.

The anchors are designed using a formula given by Rajagopal and Hari (1996). Deformation of anchor front at t_a = 0.02 m (FS = 1) in Fig. 4.52 proves local shear failure of anchors at ultimate pull-out load (Table 3.8). If anchors are designed for a F.S. equals to 2 or greater, anchor size has very negligible effect on wall deformations.

4.8 EFFECT OF ANCHOR POSITION

Anchor position is important for stability of wall system, though external stability is studied in the present study. In case of geosynthetic reinforced soil, anchorage length is the related terms of anchor position in anchored soil. Effect of anchor position is studied after observing the excessive deformations of top surface of roadway (Fig. 4.2), lateral deformation of facing (Fig. 4.3) and lateral deformation of anchor front at stiffness of reinforcement equals to $1.0x10^6$ N/m. Due to excessive deformations, serviceability of roadway may be lost. In order to improving serviceability of roadway, anchor position was changed from x = 3.0 m to x = 5.0 m, where x is measured from back face of facing wall. Length of reinforcement becomes 5/3 times of original length for the changed position of reinforcement, resulting a decrease of stiffness (changed stiffness = 3/5 times the original stiffness) if cross section of reinforcing tendon remains unchanged. To simulate this effect stiffness of reinforcement is changed to $0.6x10^6$ N/m from $1.0x10^6$ N/m.

Settlement of top surface of roadway against distance from tip of wall is plotted in Fig. 4.56 for the two anchor positions. Fig. 4.57 is the plot of lateral deformation of facing against depth of wall and Fig. 4.58 is the plot of lateral deformation of anchor front against depth of wall. Fig. 4.59 shows the anchor force variation with depth. Improvement of serviceability is clearly observed from these figures. If the stiffness of reinforcement were kept unchanged, improvement of serviceability may be more.

4.9 EFFECT OF STIFFNESS REDUCTION OF CLAY1 AND CLAY2

Comparative effect of stiffness reduction of clay1 and clay2 on vertical deformation of top surface of roadway, horizontal deformation of facing and anchor front is shown in Fig. 4.60 - 4.62. Anchor force variations with depth is shown in Fig. 4.63. Unequal stiffness of clay1 and clay2 cause non-uniform deformation of top surface (Fig. 4.60). Lateral deformation of facing is more significant due to stiffness reduction of clay1 than that of clay2. Movement of anchors relative to surrounding soil occurs due to stiffness reduction of clay1 while this is negligible in case of stiffness reduction of clay2. In case of stiffness reduction of clay2, rigid body movement of retaining system occurs. As a result, no additional pull-out forces of anchors are developed (Fig. 4.63).

4.10 EFFECT OF EMBEDMENT DEPTH

Positive effect of embedment depth is observed in the parametric study, which is discussed before. It provides the fixity to the rigid facing and reduces the lateral displacement of the wall system.

4.11 FINDINGS

Proposed earth wall system was formulated initially from the following concepts:

(i) Coarse sand for backfill material is expensive, as it is available only in some selected areas of Bangladesh. On the other hand anchored earth retaining wall required compacted coarse sand. So it was a dream that if selected fill would be replaced by local silty clay soil which is available everywhere in Bangladesh with free of cost in most of cases, it will lead to a huge cost savings.

(ii) Compaction of reinforced soil and retained soil of roadway is also costly, as it requires heavy equipment like compaction rollers. Not only that quality control of such compaction works could not be done in countries like Bangladesh due to various unavoidable situations. Therefore it was envisaged that if compaction is performed using only hand operated small compaction equipment, the construction of retaining system and roadway may be carried out easily by local labors and the proposed wall system in the present study should perform well. Thus compaction cost may be also reduced.

(iii) Having the poor strength properties and low stiffness of such moderately compacted local indigenous soil, geosynthetic (sheet type) reinforced earth wall would require large reinforcement length which may be costlier than proposed system.

After examining the results of the present parametric study, it may be concluded that for a retaining wall height of upto 6m the proposed anchored earth wall system may be used to retain a roadway. It may also be used to support reclamation area.

Behavior of such a retaining system was not known to us. More or less, the behavior is known to us, after this parametric study. Stiffness of reinforcing tendon is a very important parameter among the parameters to be considered in designing anchored earth wall. Serviceability of anchored earth wall may be severely hampered if stiffness of reinforcement is below certain limit. From this parametric study it is not possible to forecast nondimensionalized lower limit of stiffness of reinforcing tendon. The lower limits suggested in this study is only for this specific case, which is of course cover the most of the cases might be in Bangladesh.

To avoid differential settlement of roadway, reinforced soil and retained soil should have same stiffness and strength properties and in no case should stiffness of retained soil be less than that of reinforced soil. Anchor force or tensile force in tie bar and lateral deformation of facing mostly depends on the stiffness of reinforced soil not on the retained soil.

Continuous rigid facing is suggested for the anchored earth wall. Potential problems associated with the use of continuous rigid facing are (a) the connection between reinforcing member and facing may be damaged due to relative settlement between them, (b) only small tensile strains may be mobilized in reinforcing members as soil layers are compacted and a continuous rigid facing is firmly propped and (c) large earth pressure may be activated on the back face of the facing due to compaction of backfill as a continuous rigid facing is firmly propped. This is a field of research to find a suitable construction method using continuous rigid facing.

In designing proposed anchored earth wall, factor of safety should be greater than two (F.S. > 2) for designing anchor sizes. Formula given by Rajagopal and Hari (1996) is found to be valid to estimate ultimate pull out capacity of vertical anchor used in anchored earth wall.

Anchor position is also important factor both for ultimate states and serviceability limit states. Though sometime space constraint dictates the anchor positions or reinforcement length, anchorage length is determined from the stability consideration mainly. Greater length of anchorage also improves the serviceability of the retained structures.

Finally it may concluded that anchored earth wall system supporting the simultaneously constructed roadway may be constructed by adopting the proposed system, where fill materials may be locally available silty clay soils with moderate compaction by hand operated compactions equipment.

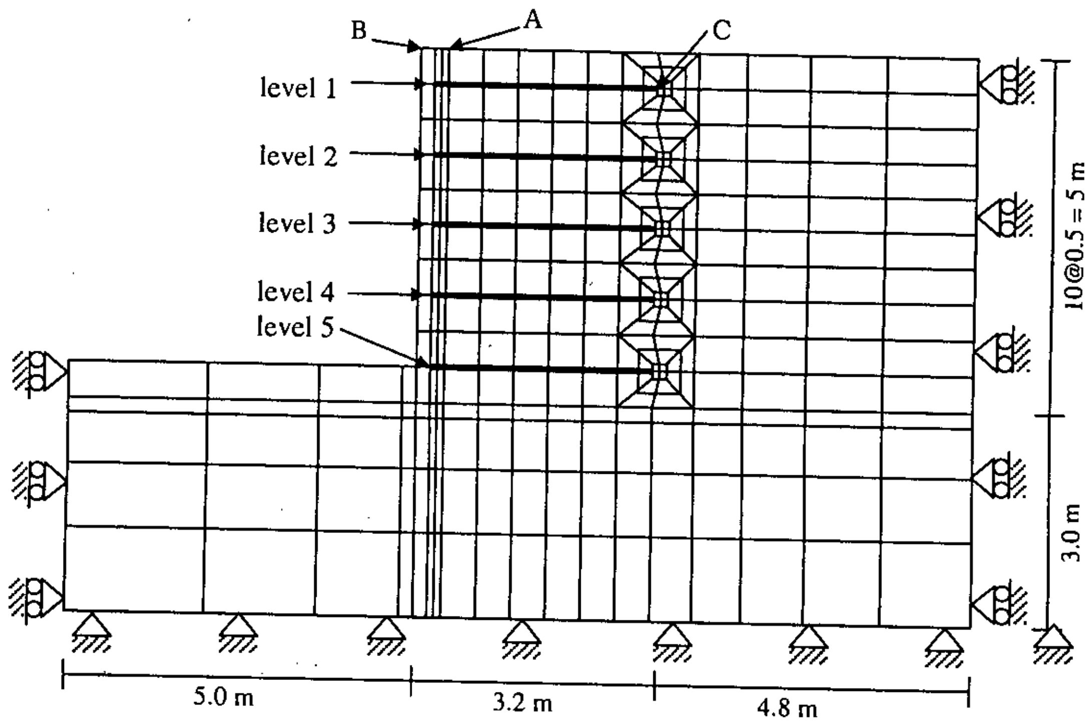


Fig. 4.1: Finite element mesh showing the position of reinforcements and points A, B and C.

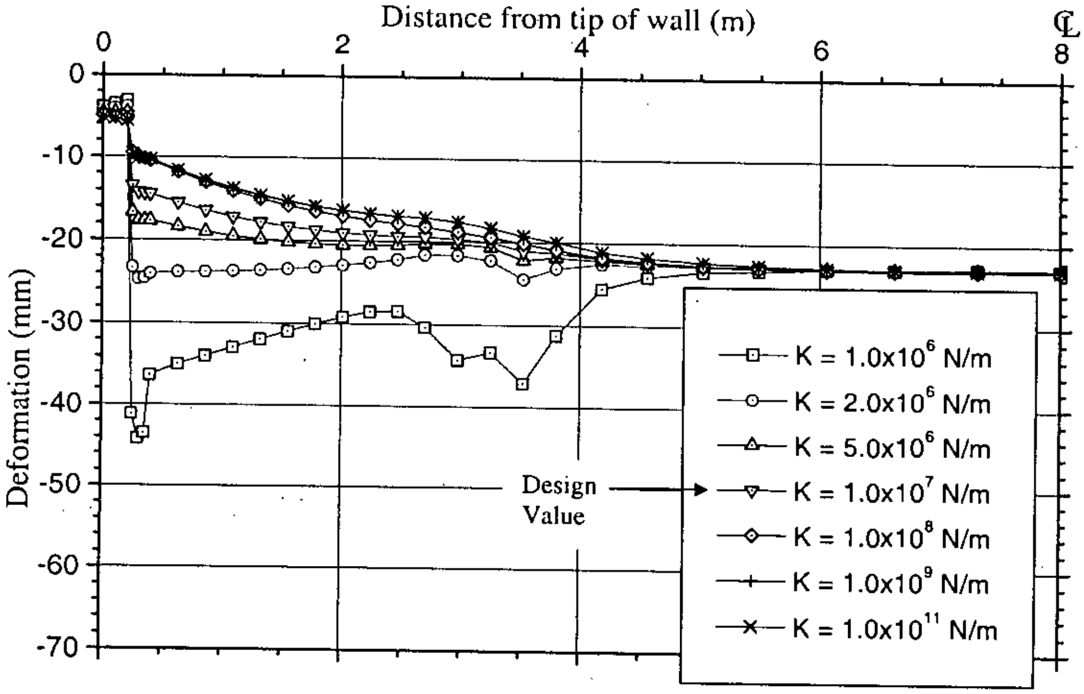


Fig. 4.2: Deformed shape of top surface of roadway after 100 kPa uniform static loading on roadway (Parameter: stiffness of tie bar)

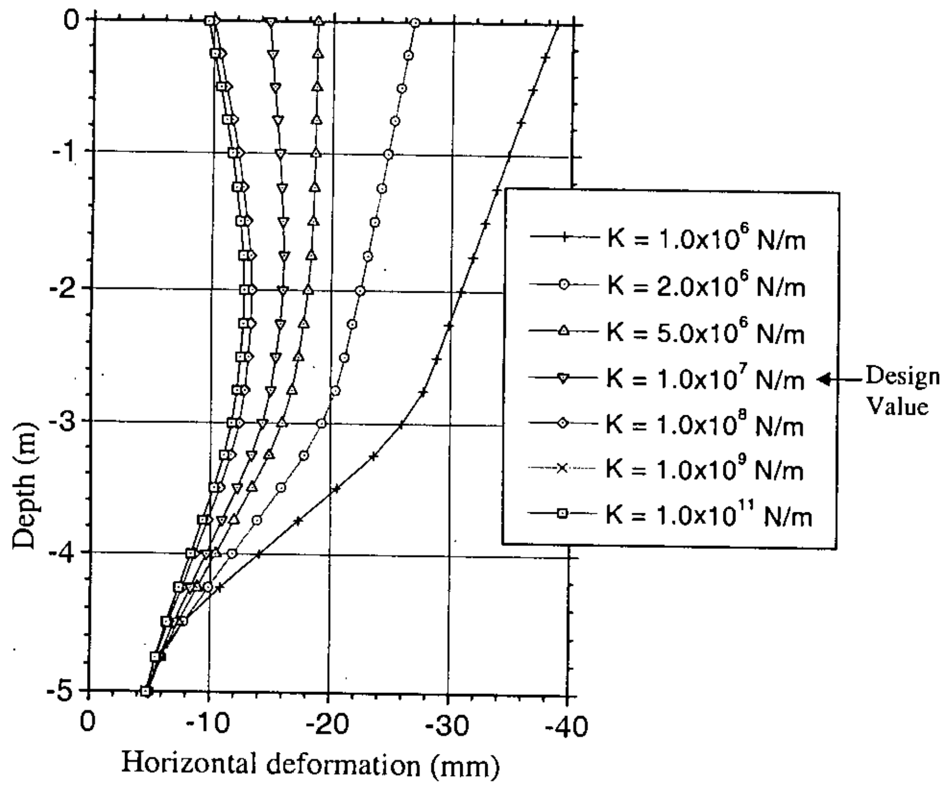


Fig. 4.3: Deformed shape of facing wall after 100 kPa uniform static loading on roadway (Parameter: stiffness of tie bar)

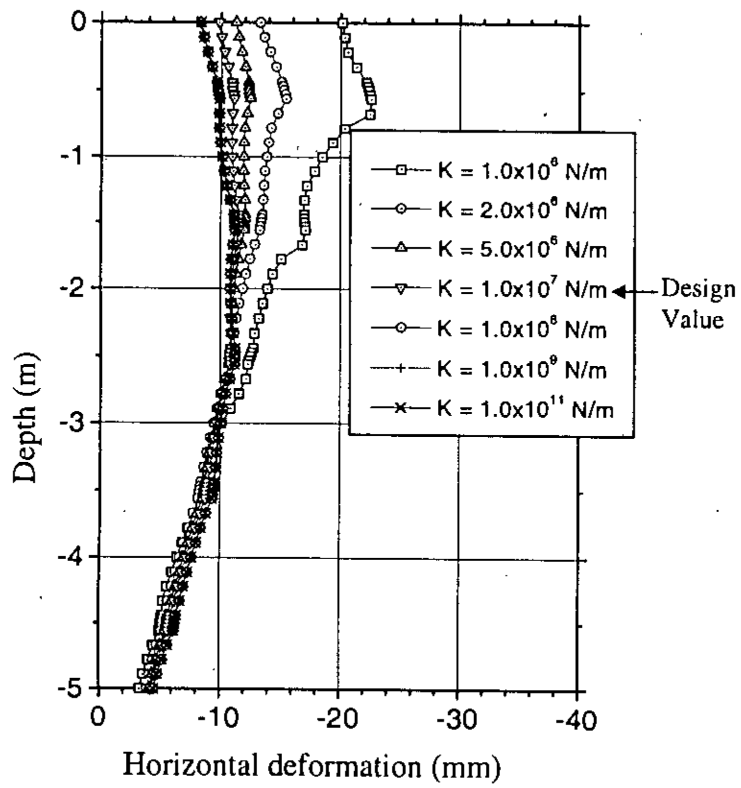


Fig. 4.4: Deformed shape of anchor front of wall after 100 kPa uniform static loading on roadway (Parameter: stiffness of tie bar)

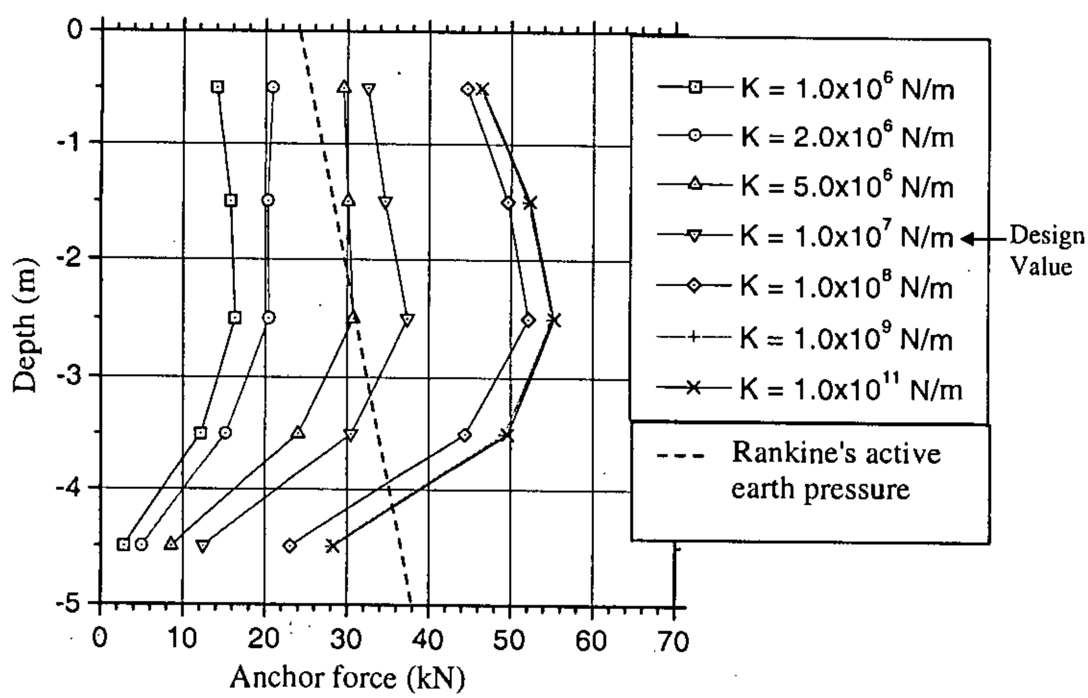


Fig. 4.5: Variation of Anchor Force with depth (Parameter: stiffness of tie bar)

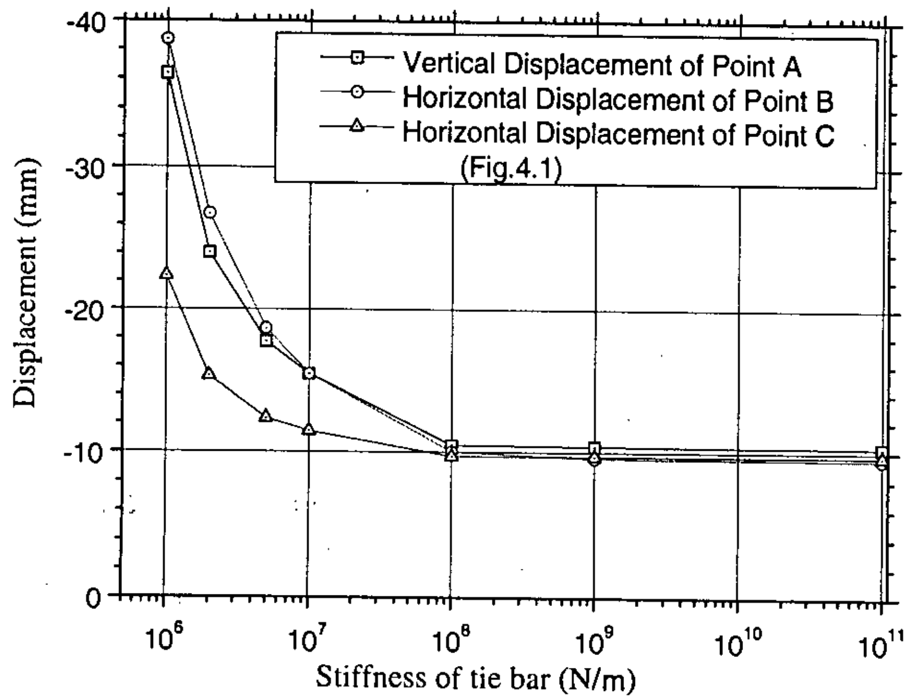


Fig. 4.6: Displacement variation with stiffness of tie bar

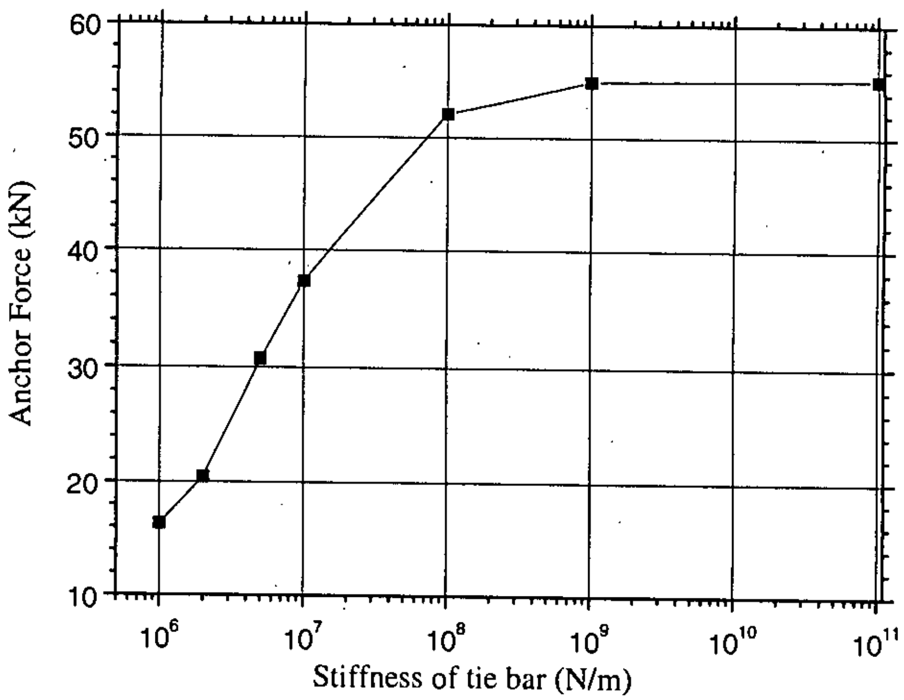


Fig. 4.7: Variation of anchor force at level 3 with stiffness of tie bar

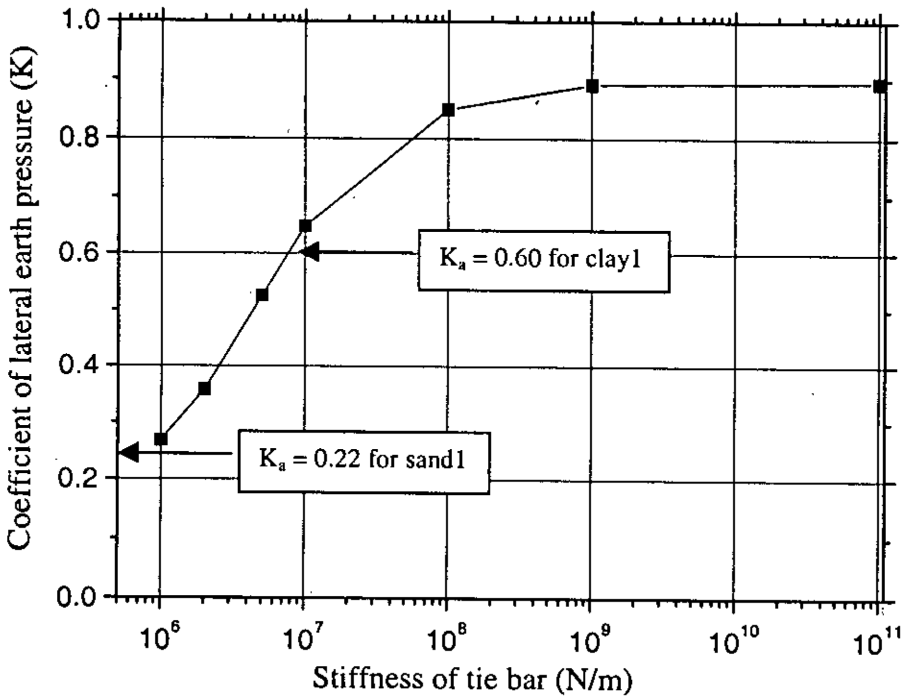


Fig. 4.8: Variation of coefficient of lateral earth pressure with stiffness of tie bar

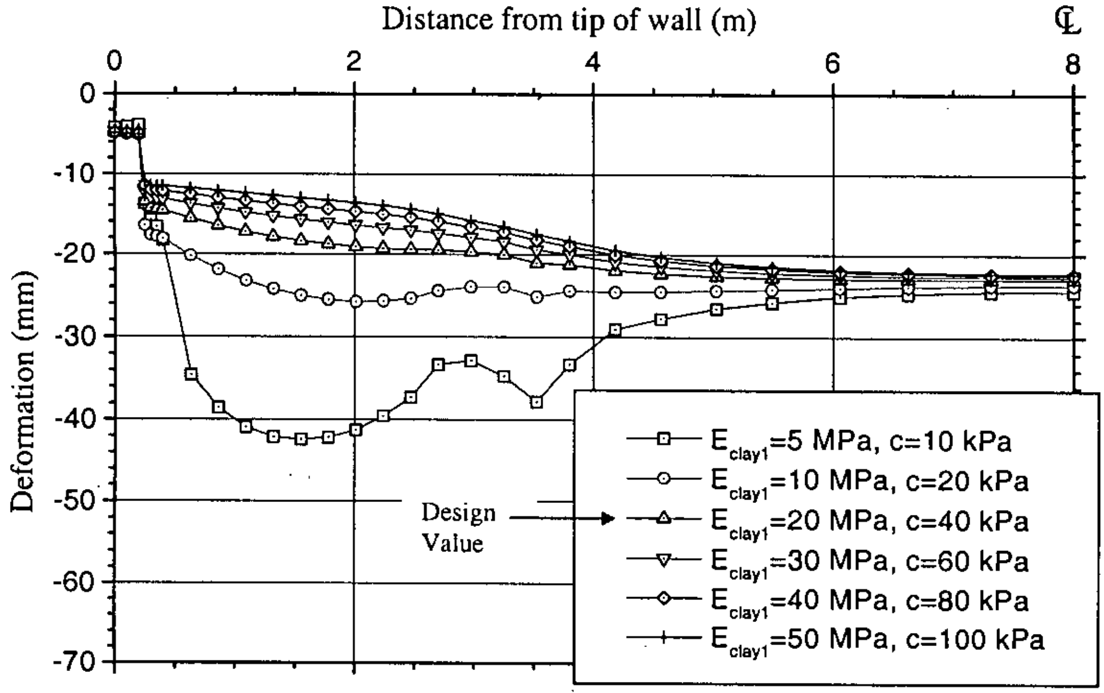


Fig. 4.9: Deformed shape of top surface of roadway after 100 kPa uniform static loading on roadway (Parameter: stiffness of clay1 (ϕ = 14.5°))

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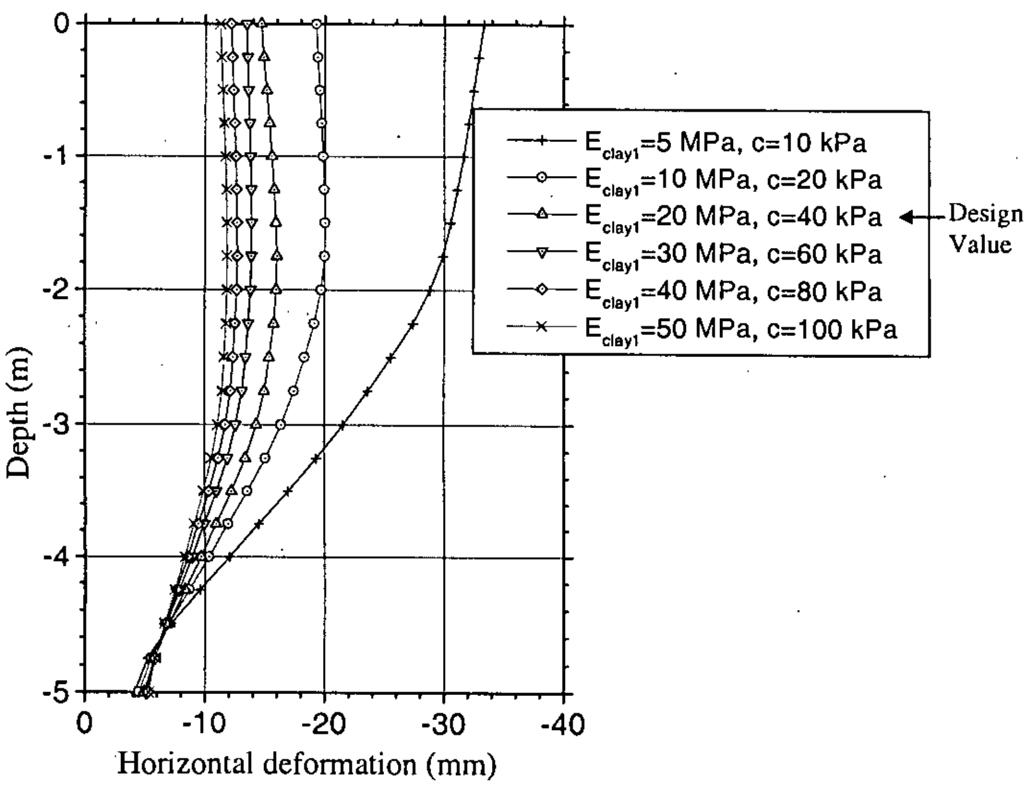

Fig. 4.10: Deformed shape of facing wall after 100 kPa uniform static loading on roadway (Parameter: stiffness of clay1 (ϕ = 14.5°))

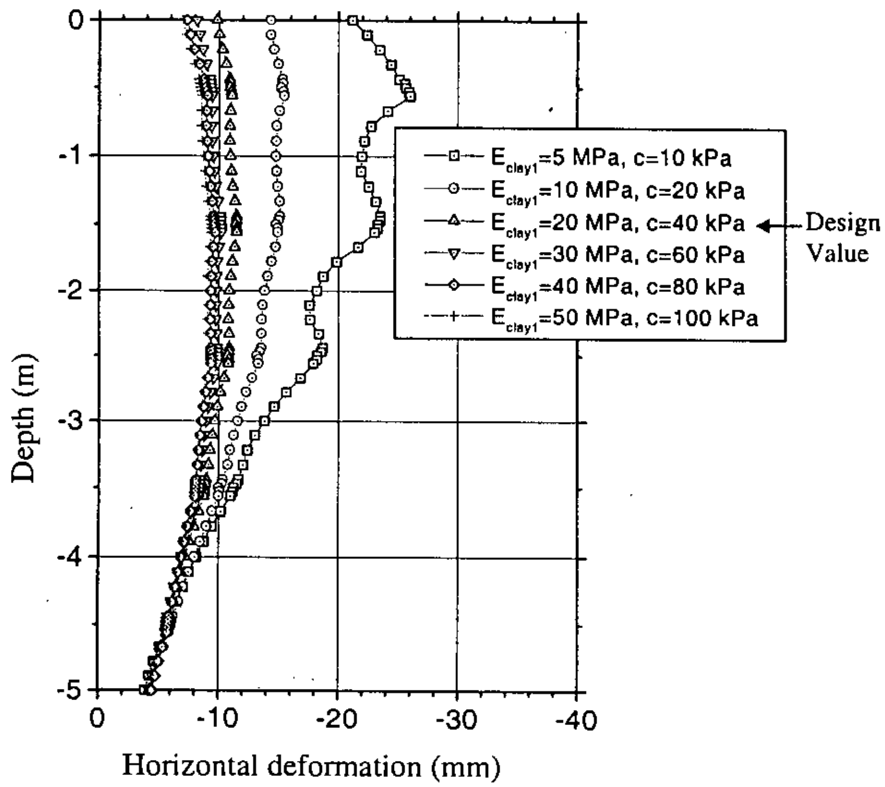

Fig. 4.11: Deformed shape of anchor front of wall after 100 kPa uniform static loading on roadway (Parameter: stiffness of clay1 ($\phi = 14.5^{o}$))

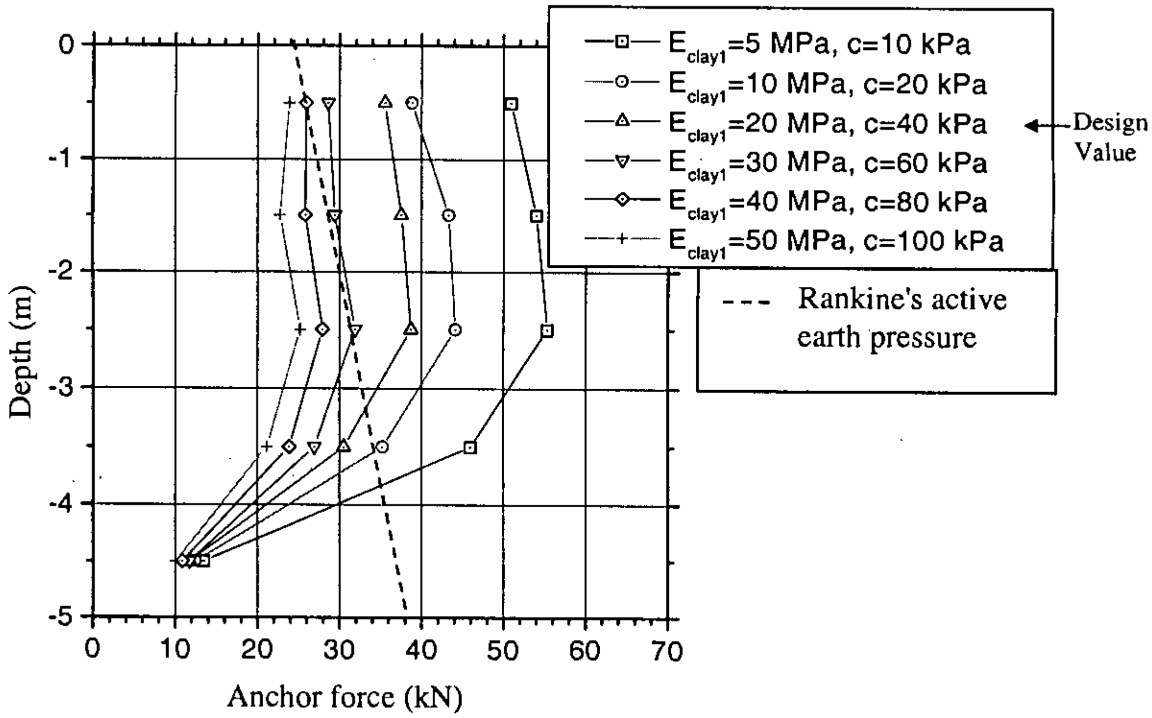

Fig. 4.12: Variation of anchor force with depth (Parameter: stiffness of clay1 ($\phi = 14.5^{o}$))

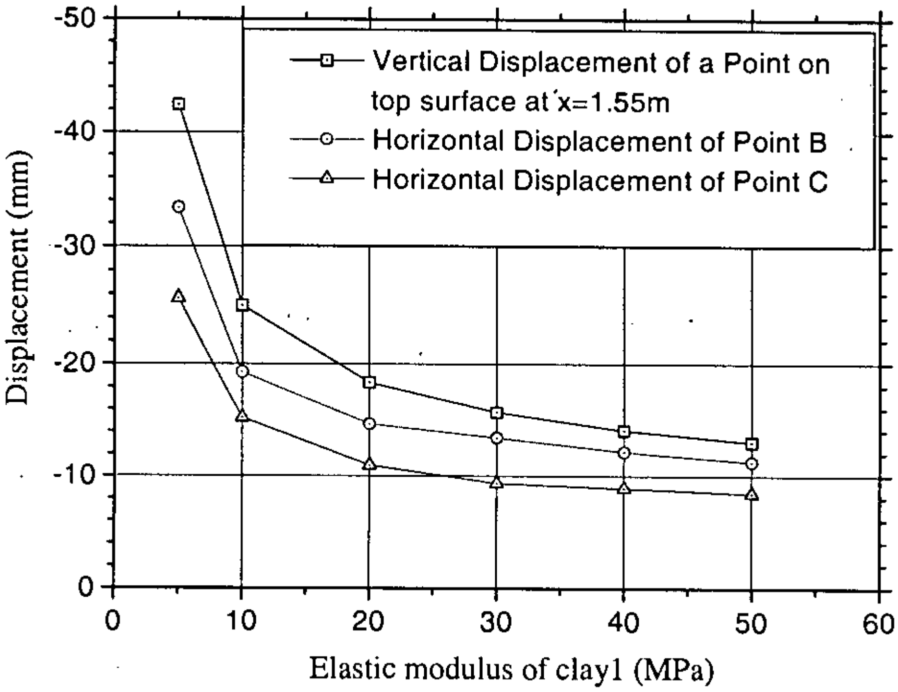

Fig. 4.13: Displacement variation with elastic modulus of clay1

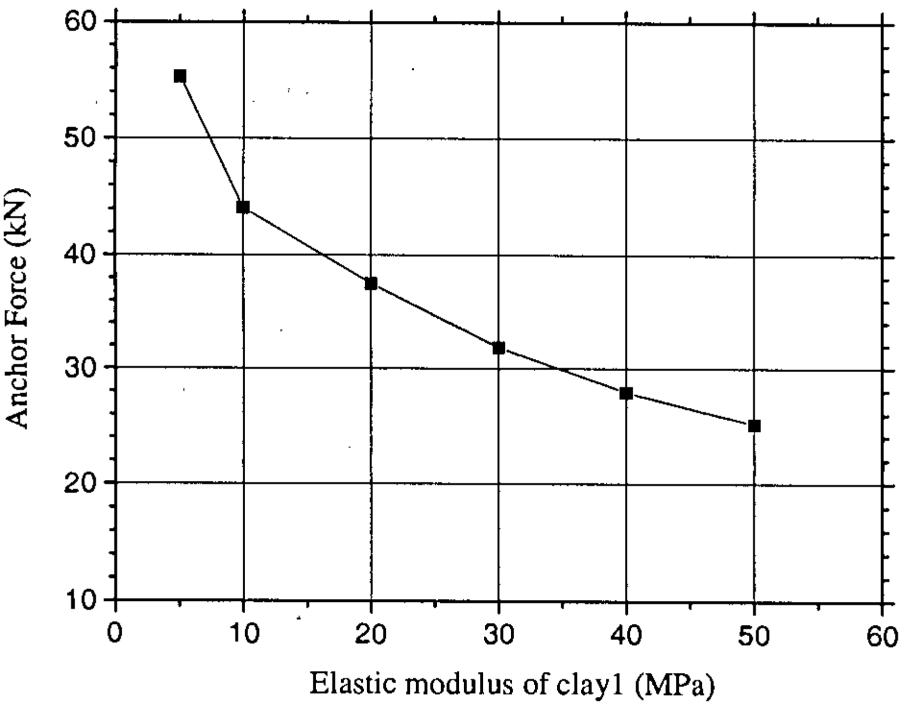

Fig. 4.14: Variation of anchor force at level 3 elastic modulus of clay1

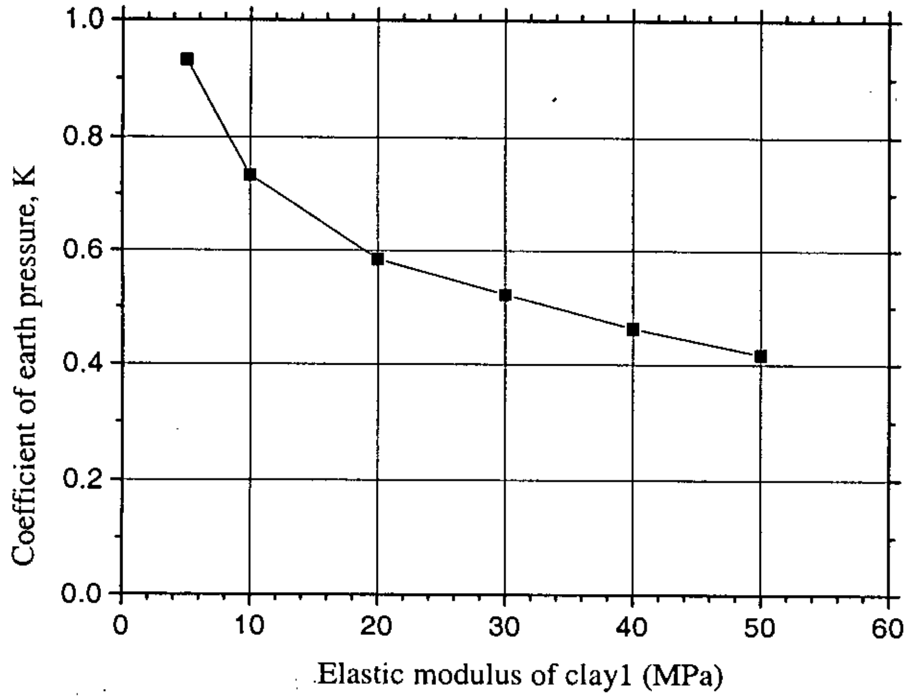

Fig. 4.15: Variation of coefficient of earth pressure, K with elastic modulus of clay1

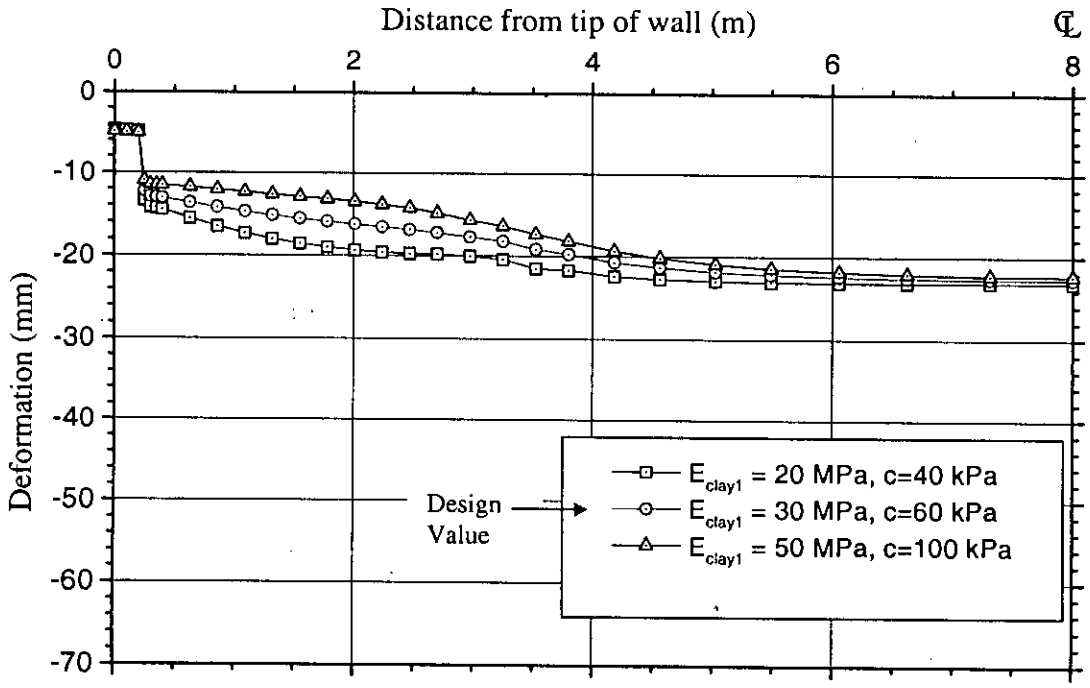

Fig. 4.16: Deformed shape of top surface of roadway after 100 kPa uniform static loading on roadway (Parameter: stiffness of clay1 ($\phi = 0^{o}$))

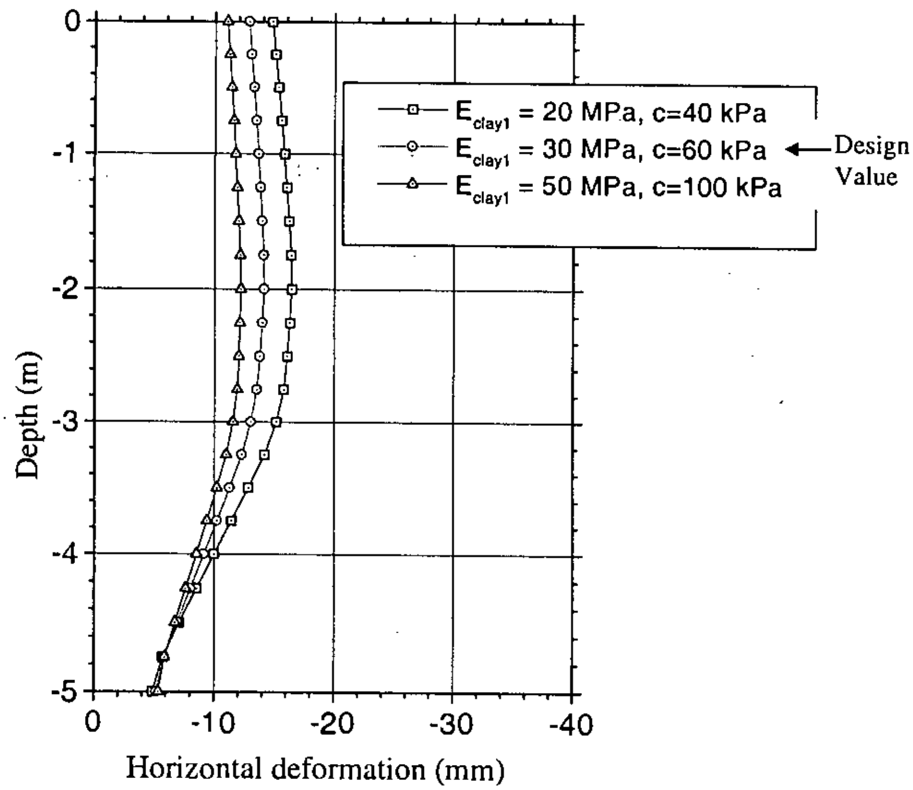

Fig. 4.17: Deformed shape of facing wall after 100 kPa uniform static loading on roadway (Parameter: stiffness of clay1 ($\phi = 0^{o}$))

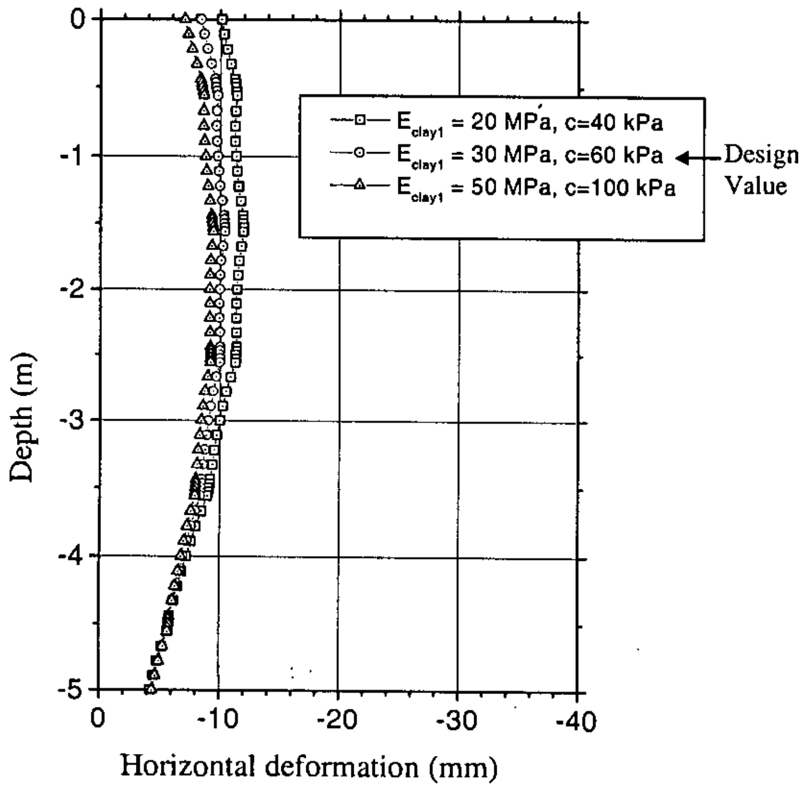

Fig. 4.18: Deformed shape of anchor front of wall after 100 kPa uniform static loading on roadway (Parameter: stiffness of clay1 ($\phi = 0^{o}$))

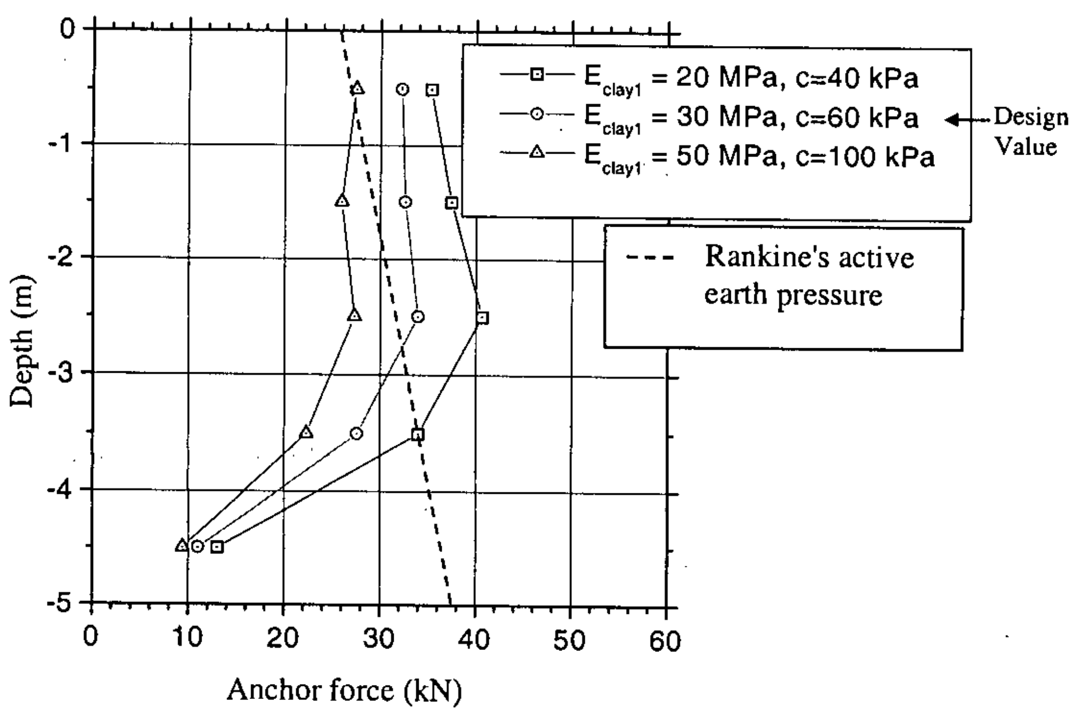

Fig. 4.19: Variation of anchor force with depth (Parameter: stiffness of clay1 ($\phi = 0^{o}$))

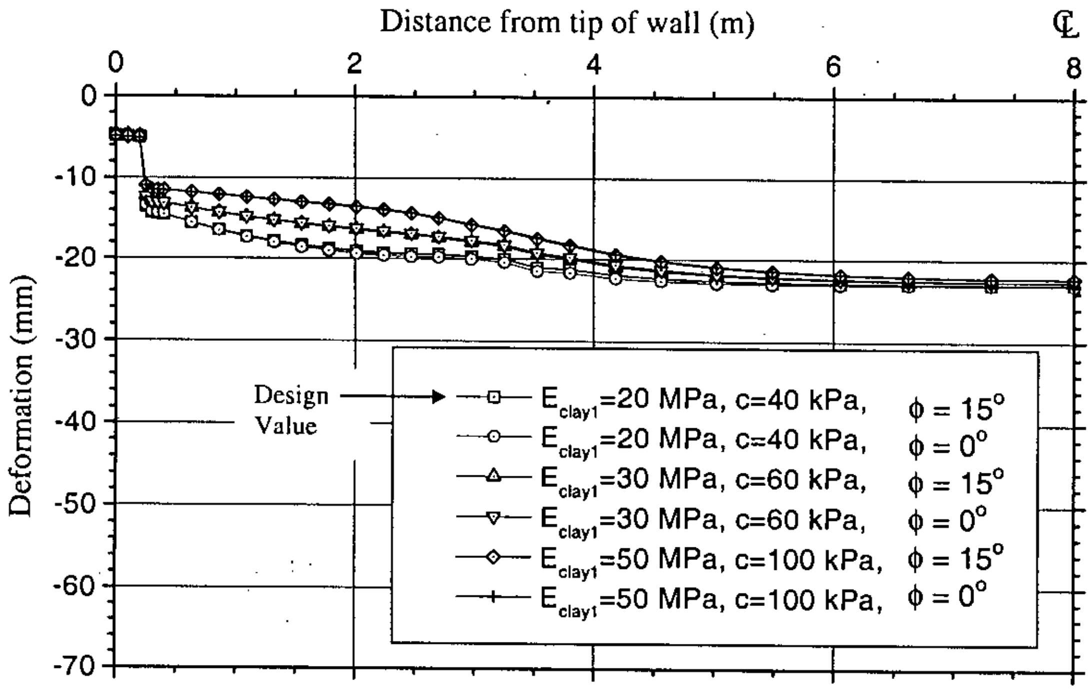

Fig. 4.20: Deformed shape of top surface of roadway after 100 kPa uniform static loading on roadway (Parameter: stiffness of clay1 ($\phi = 0^o$, 14.5^o))

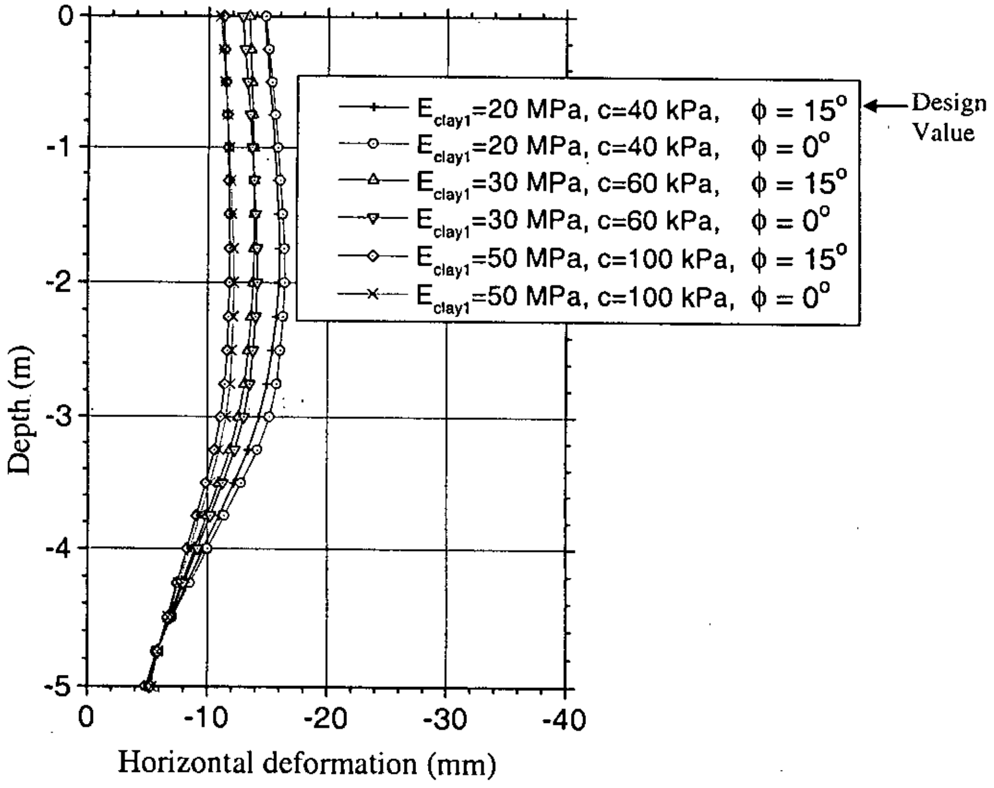

Fig. 4.21: Deformed shape of facing wall after 100 kPa uniform static loading on roadway (Parameter: stiffness of clay1 ($\phi = 0^o$, 14.5^o))

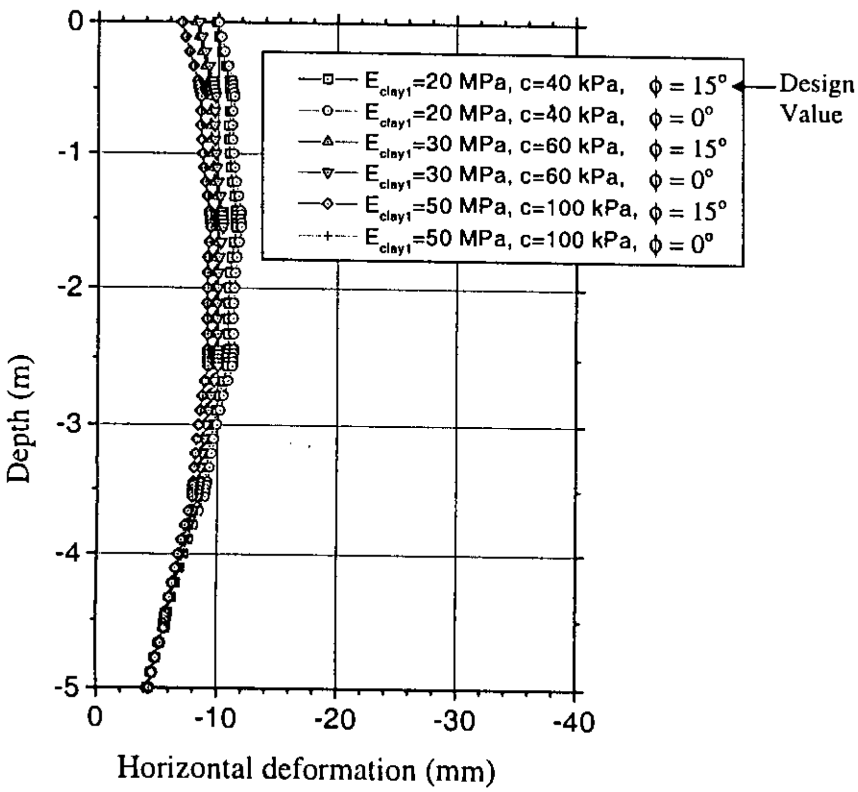

Fig. 4.22: Deformed shape of anchor front of wall after 100 kPa uniform static loading on roadway (Parameter: stiffness of clay1 (ϕ= 0°, 14.5°))

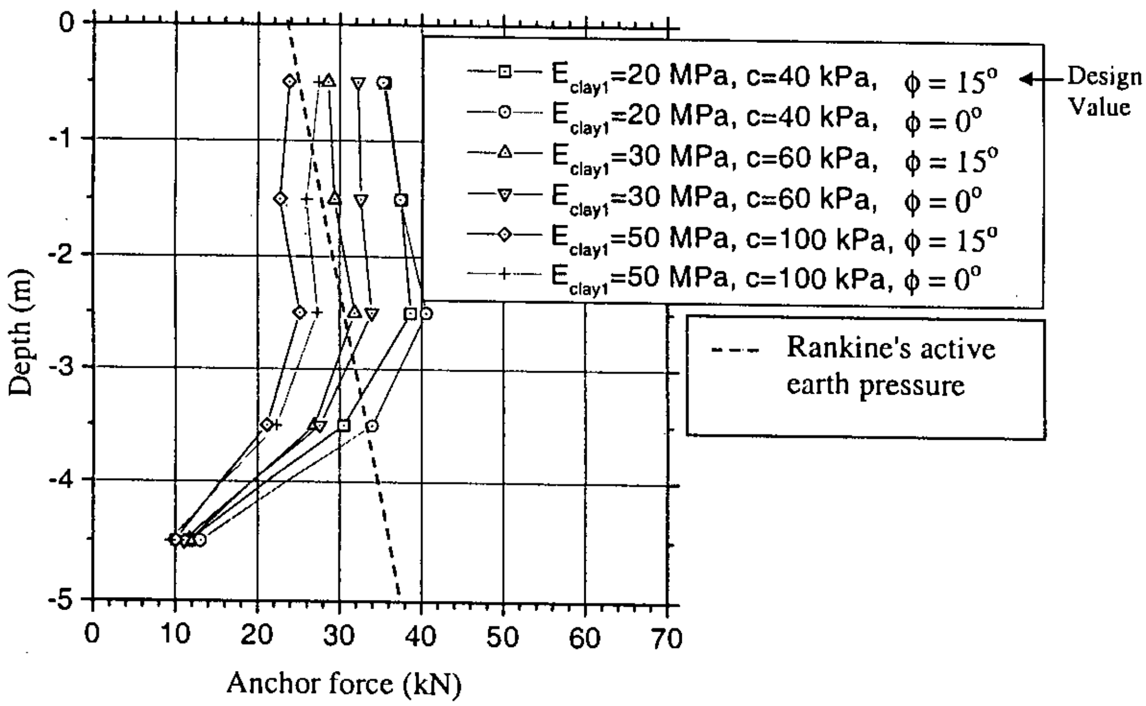

Fig. 4.23: Variation of anchor force with depth (Parameter: stiffness of clay1 ($\phi = 0°$, 14.5°))

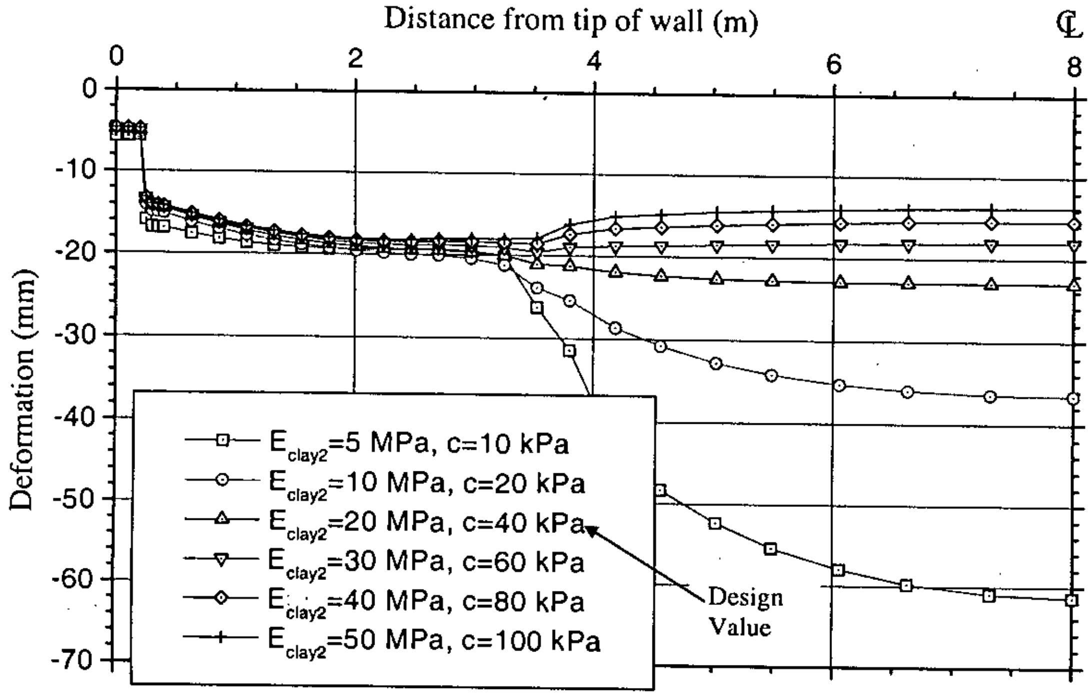

Fig. 4.24: Deformed shape of top surface of roadway after 100 kPa uniform static loading on roadway (Parameter: stiffness of clay2 (ϕ = 14.5°))

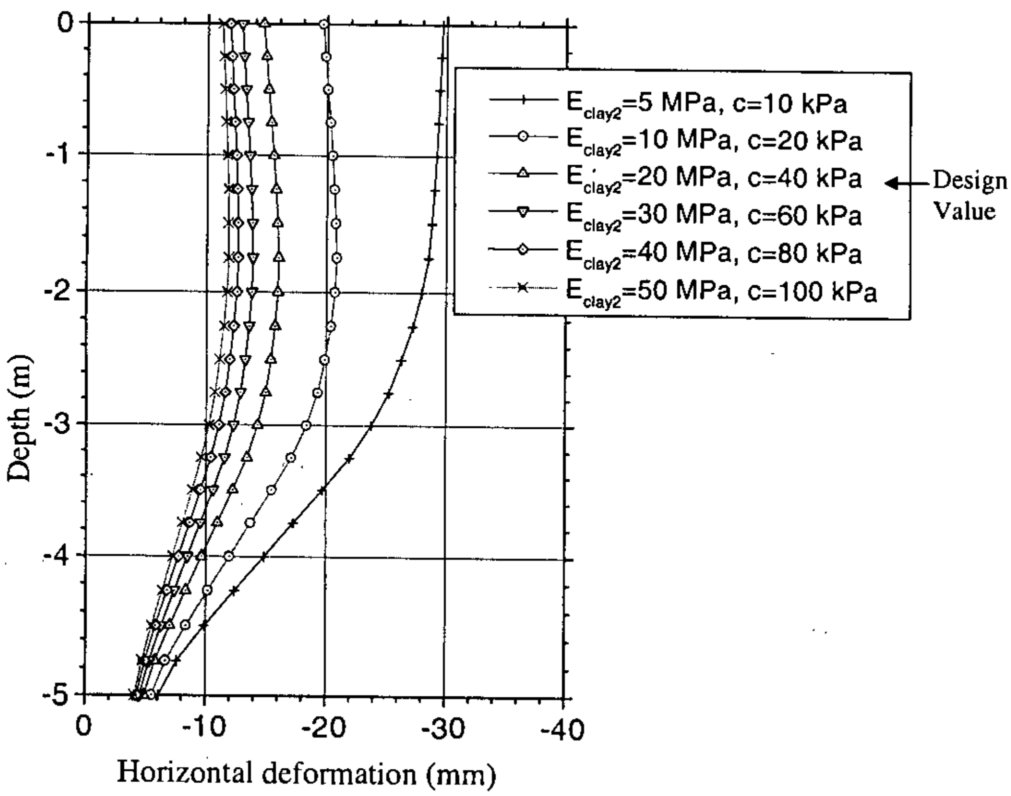

Fig. 4.25: Deformed shape of facing wall after 100 kPa uniform static loading on roadway (Parameter: stiffness of clay2 (ϕ = 14.5°))

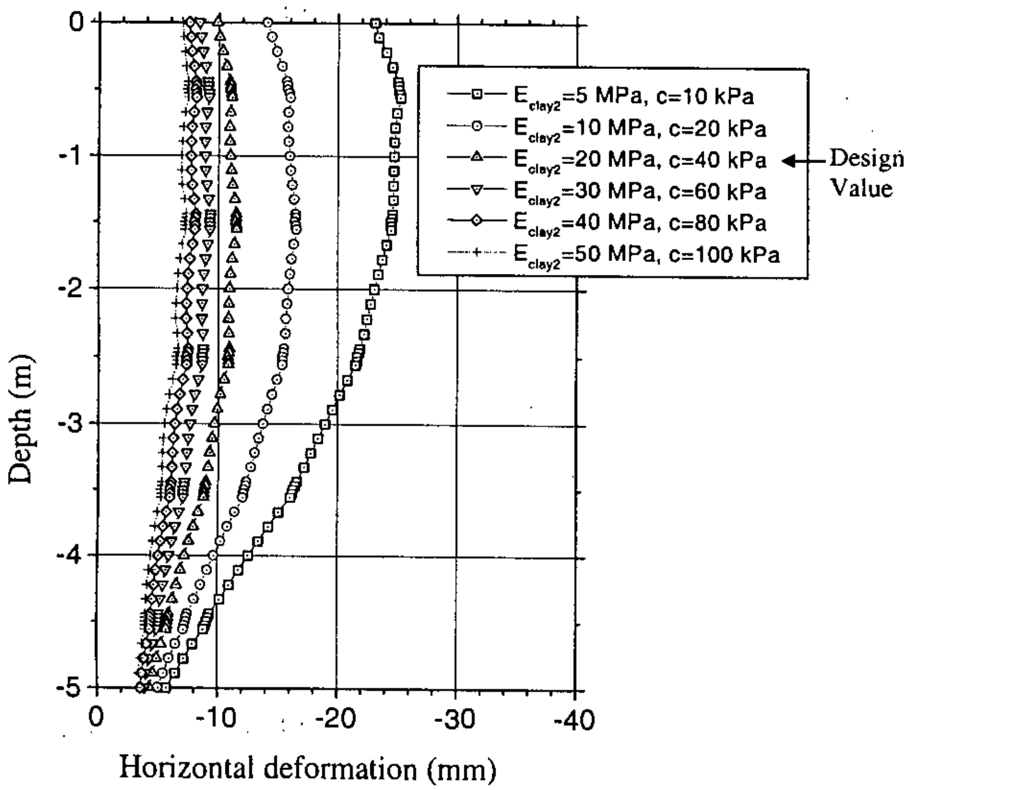

Fig. 4.26: Deformed shape of anchor front of wall after 100 kPa uniform static loading on roadway (Parameter: stiffness of clay2 ($\phi = 14.5^{\circ}$))

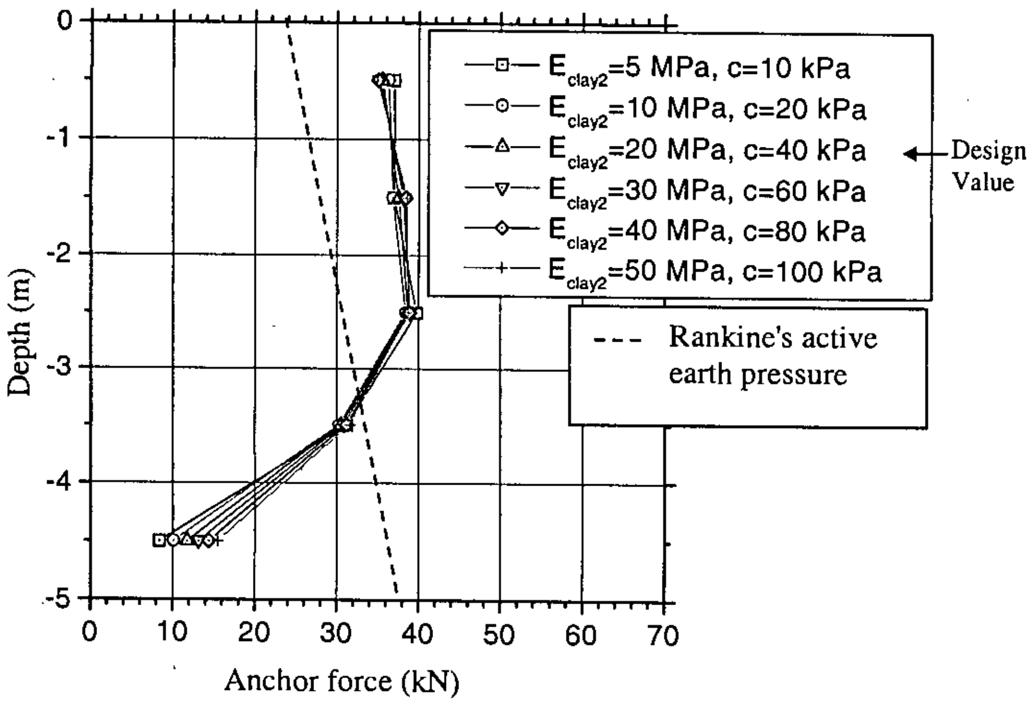

Fig. 4.27: Variation of anchor force with depth (Parameter: stiffness of clay2 ($\phi = 14.5^{\circ}$))

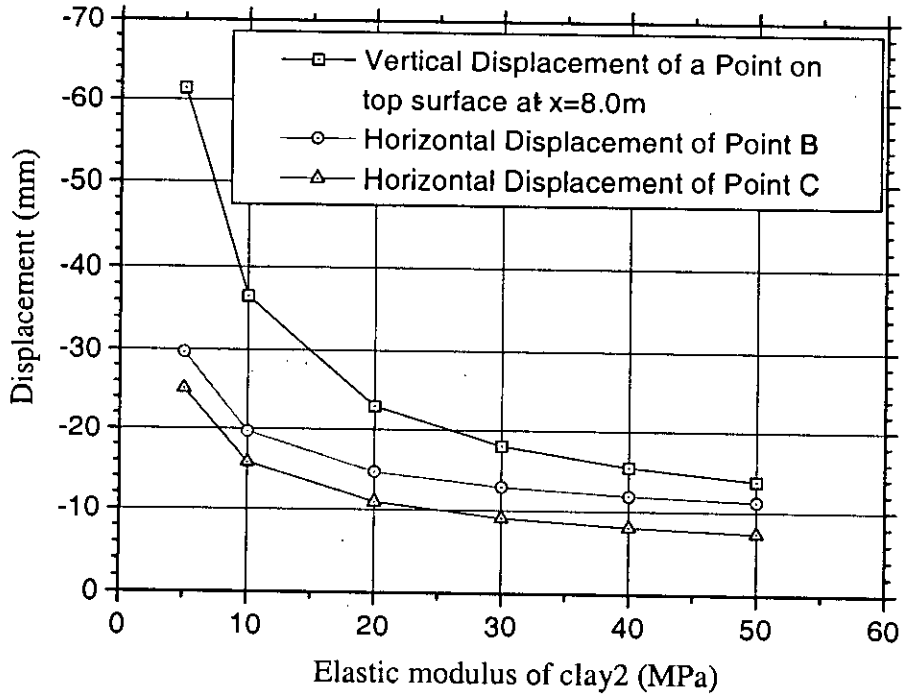

Fig. 4.28: Displacement variation with elastic modulus of clay2

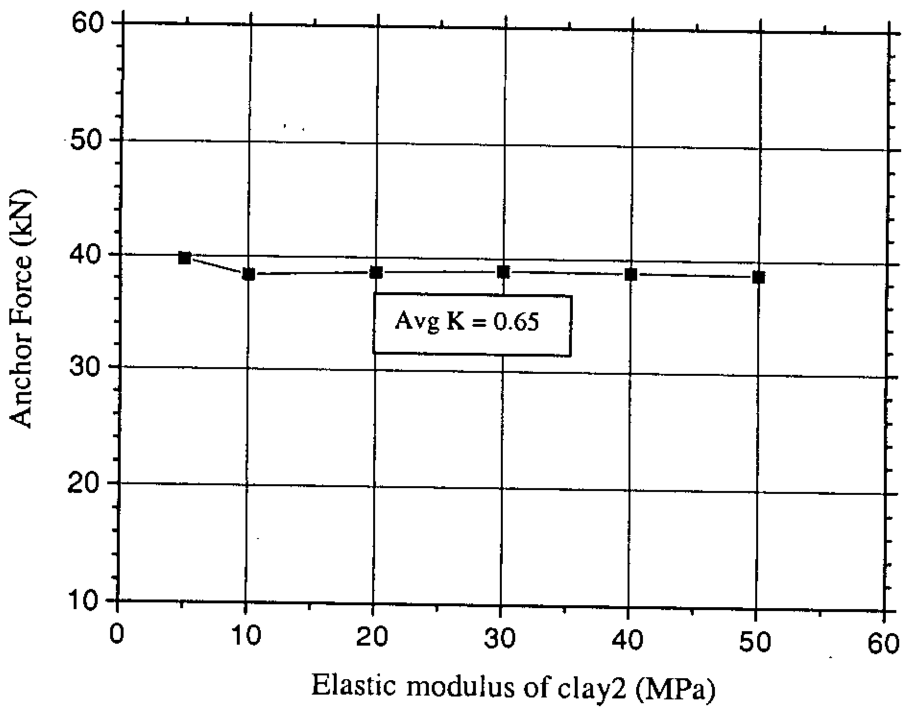

Fig. 4.29: Variation of anchor force at level 3 elastic modulus of clay2

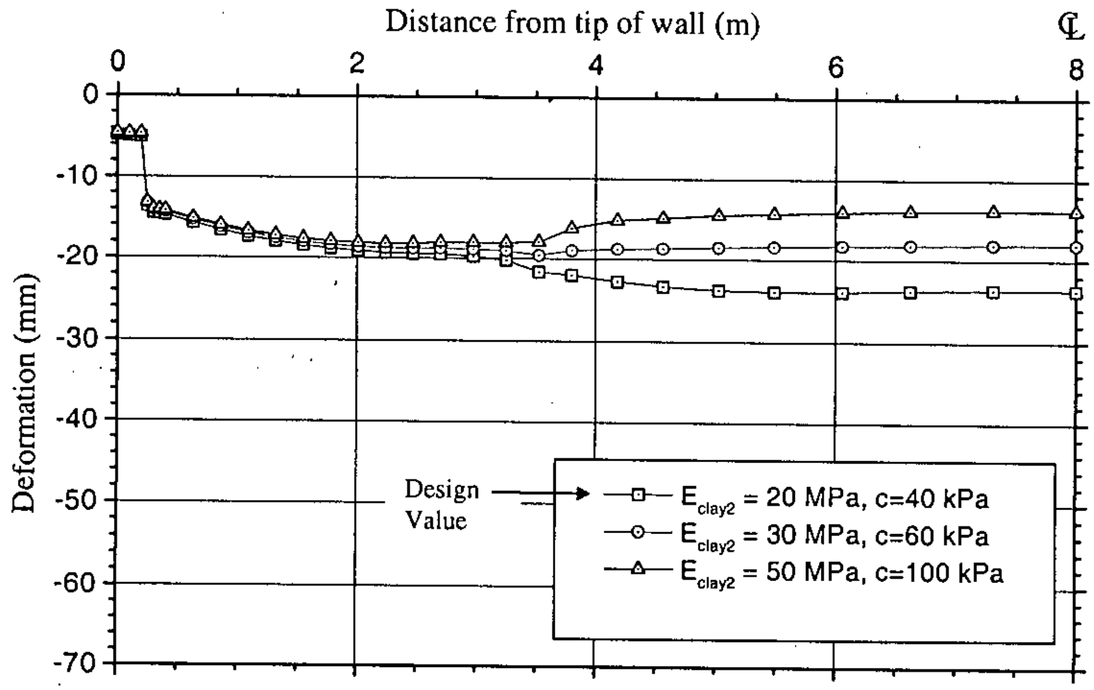

Fig. 4.30: Deformed shape of top surface of roadway after 100 kPa uniform static loading on roadway (Parameter: stiffness of clay2 ($\phi = 0^{o}$))

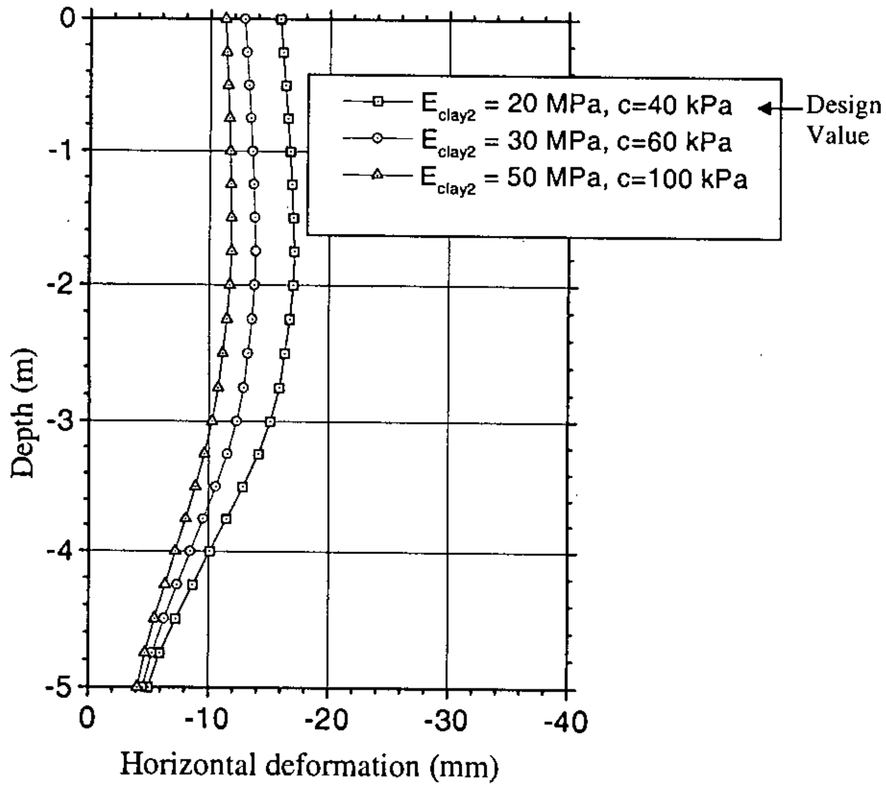

Fig. 4.31: Deformed shape of facing wall after 100 kPa uniform static loading on roadway (Parameter: stiffness of clay2 ($\phi = 0^{o}$))

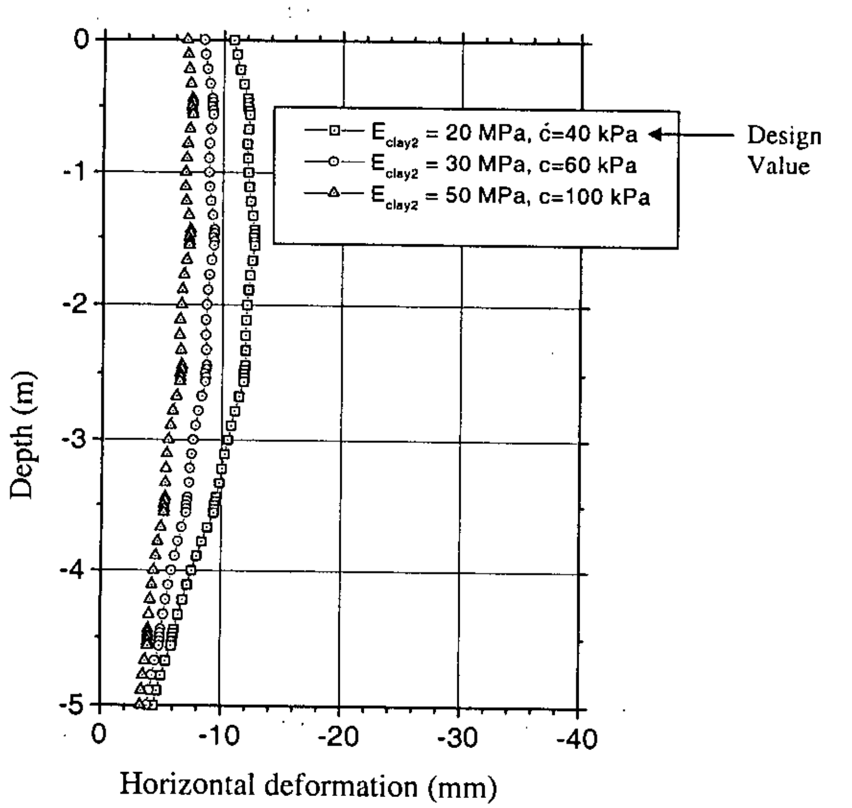

Fig. 4.32: Deformed shape of anchor front of wall after 100 kPa uniform static loading on roadway (Parameter: stiffness of clay2 (ϕ= 0°))

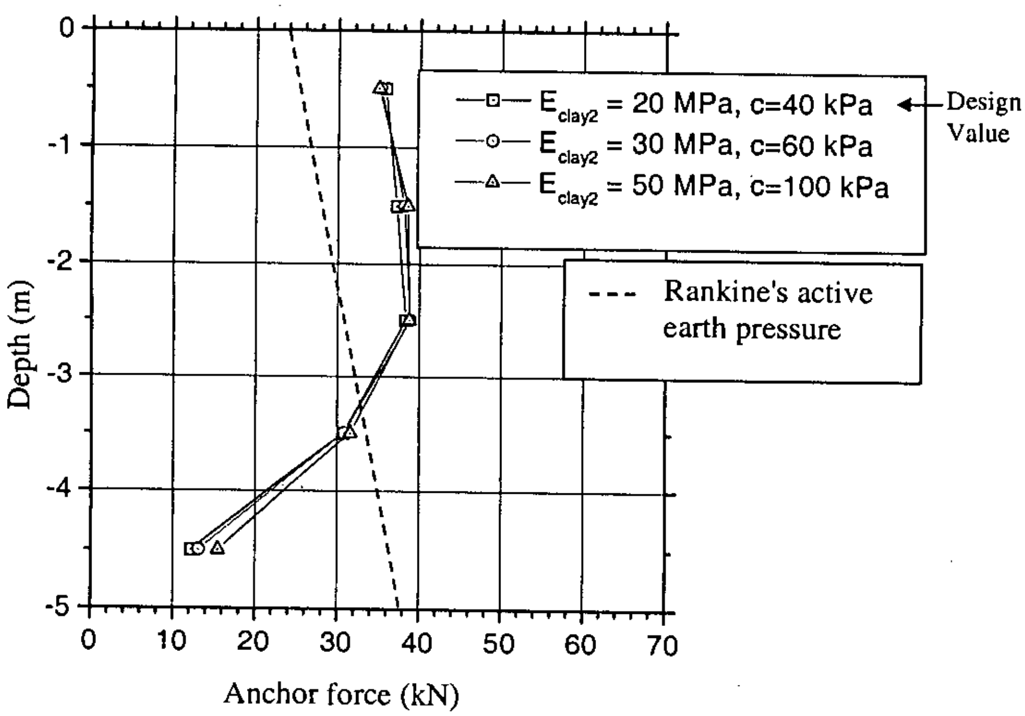

Fig. 4.33: Variation of anchor force with depth (Parameter: Stiffness of clay2 (ϕ = 0°))

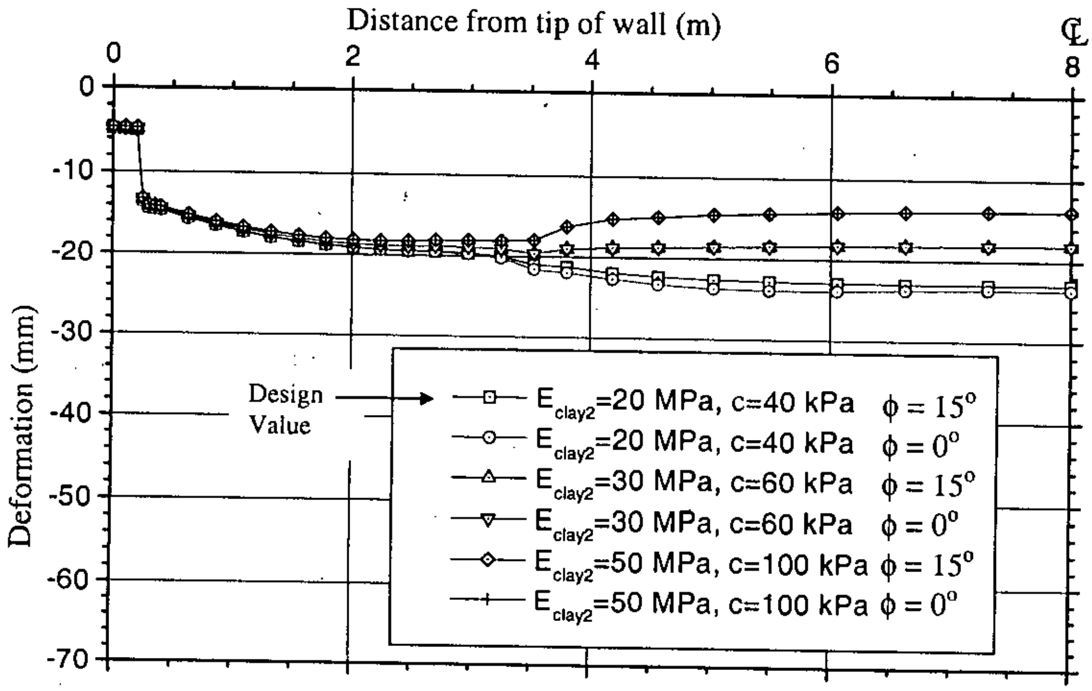

Fig. 4.34: Deformed shape of top surface of roadway after 100 kPa uniform static loading on roadway (Parameter: stiffness of clay2 ($\phi = 0^o, 15^o$))

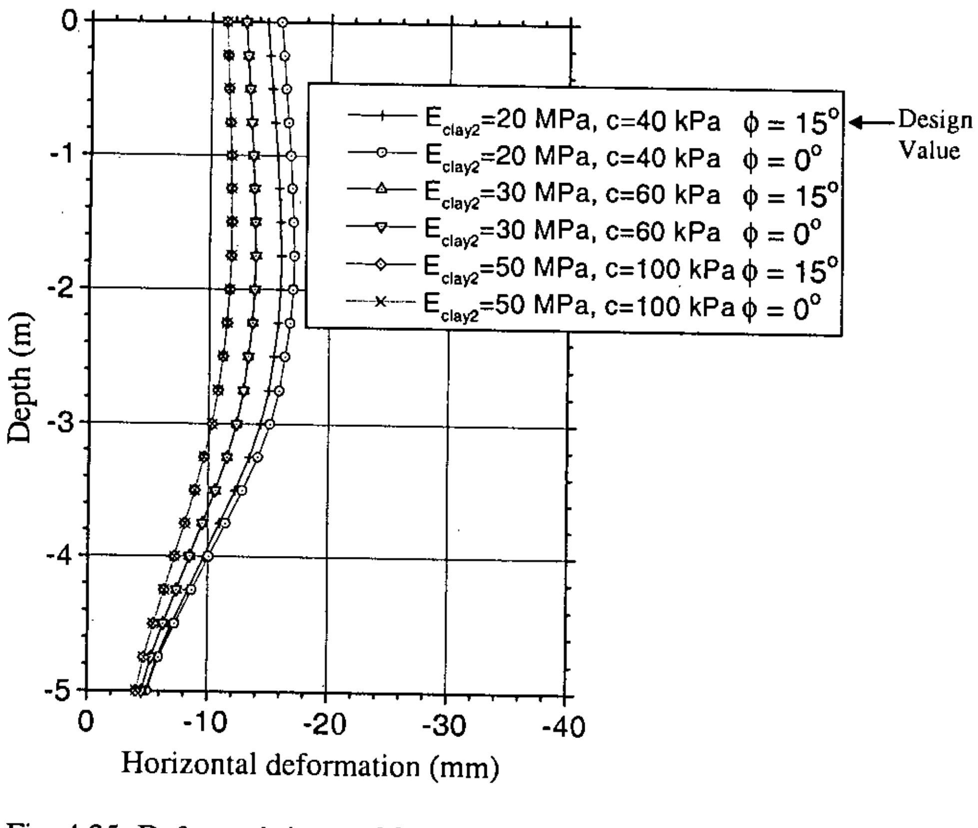

Fig. 4.35: Deformed shape of facing wall after 100 kPa uniform static loading on roadway (Parameter: stiffness of clay2 ($\phi = 0^o, 15^o$))

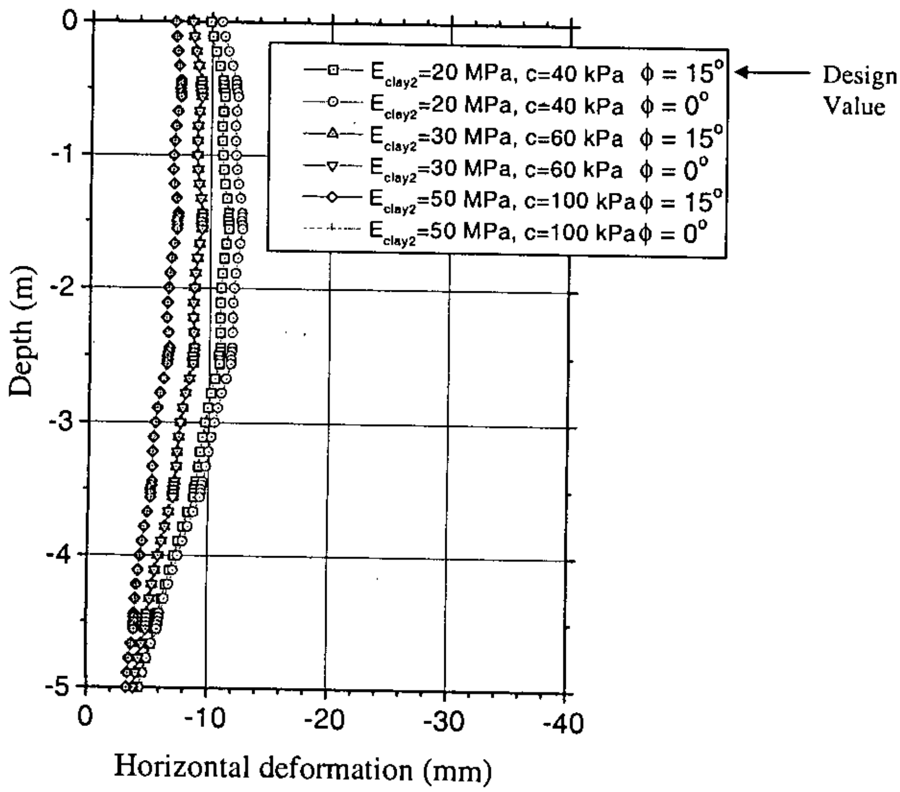

Fig. 4.36: Deformed shape of anchor front of wall after 100 kPa uniform static loading on roadway (Parameter: stiffness of clay2 ($\phi = 0°, 15°$))

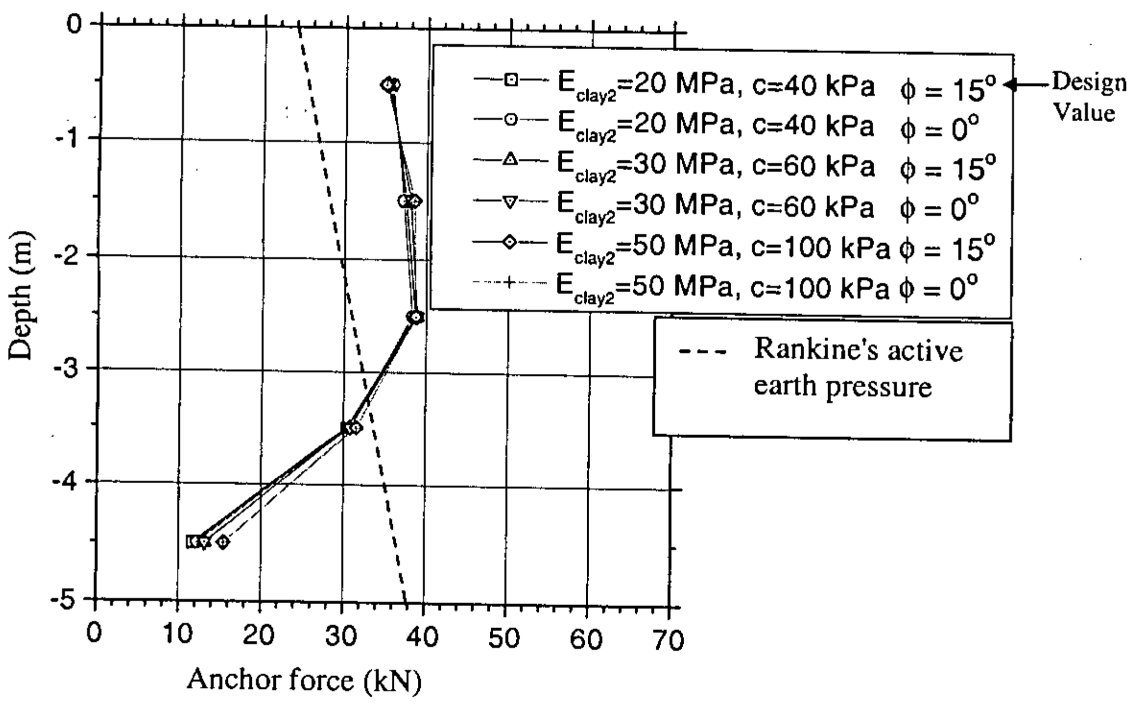

Fig. 4.37: Variation of anchor force with depth (Parameter: stiffness of clay2 ($\phi = 0°, 15°$))

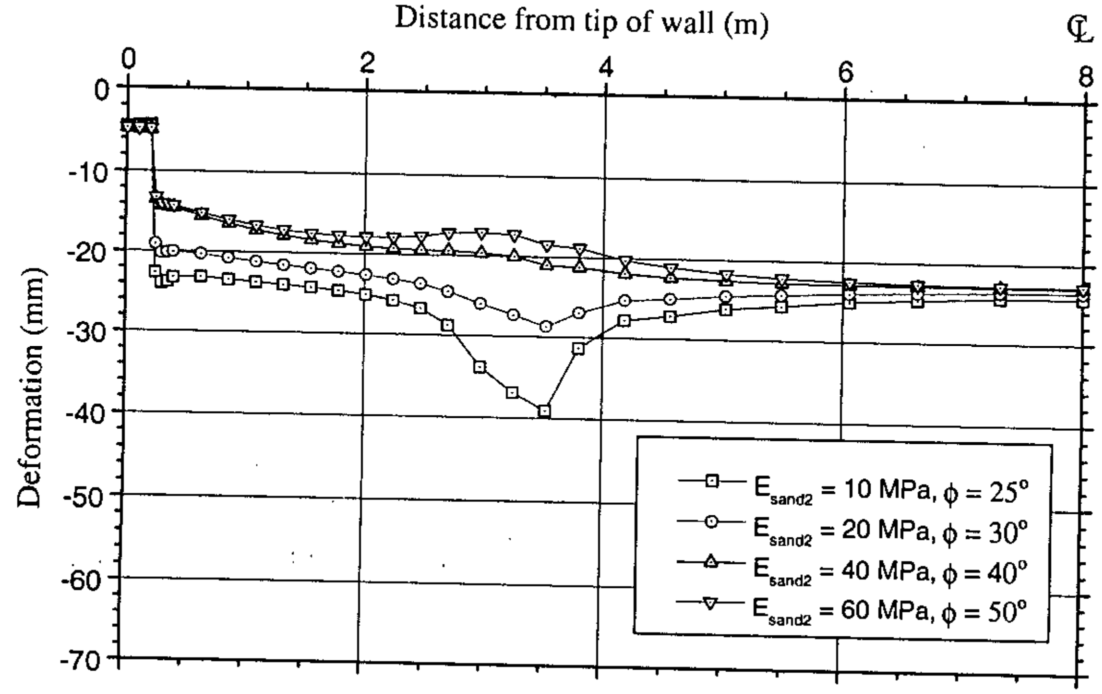

Fig. 4.38: Deformed shape of top surface of roadway after 100 kPa uniform static loading on roadway (Parameter: stiffness of sand2)

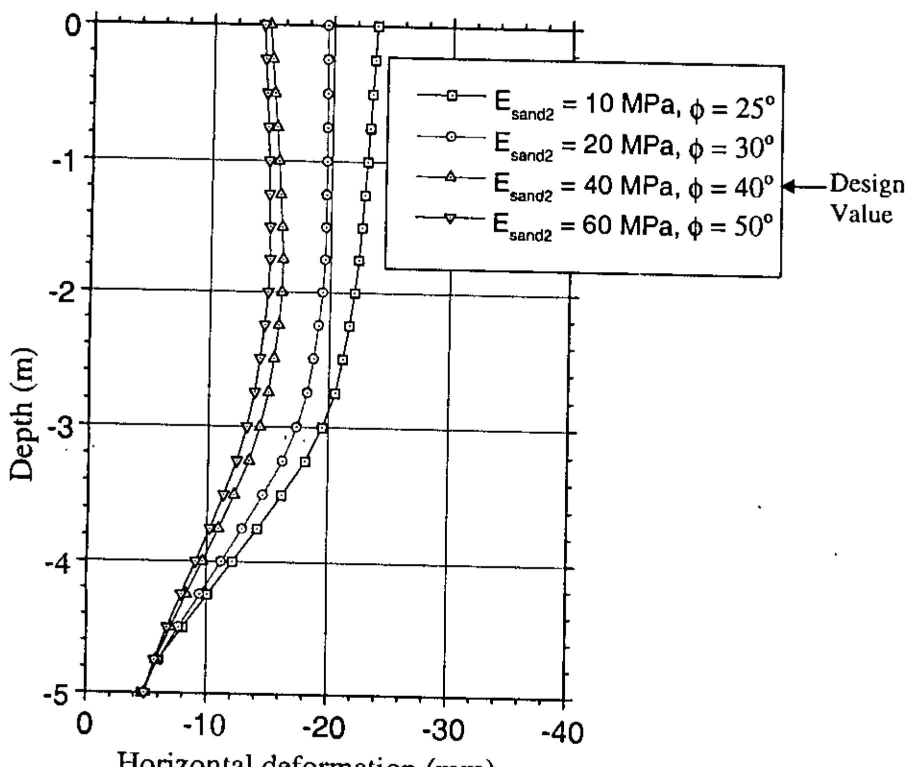

Fig. 4.39: Deformed shape of facing wall after 100 kPa uniform static loading on roadway (Parameter: stiffness of sand2)

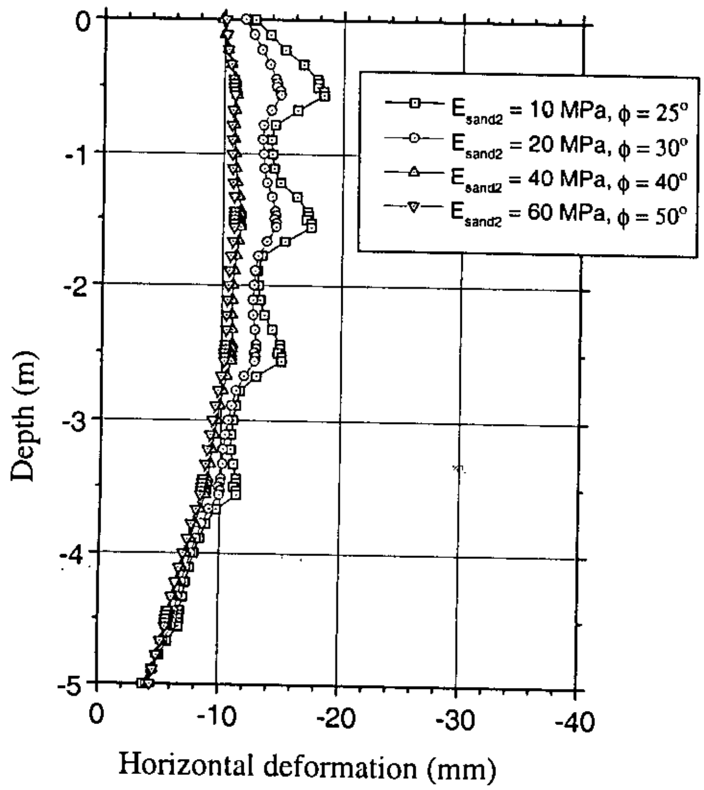

Fig. 4.40: Deformed shape of anchor front wall after 100 kPa uniform static loading on roadway (Parameter: stiffness of sand2)

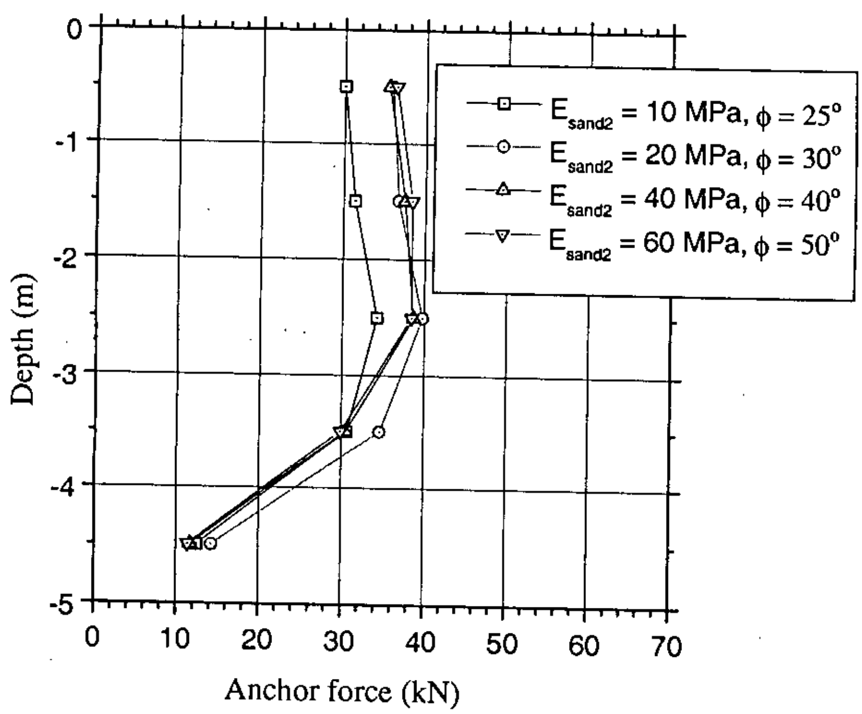

Fig. 4.41: Variation of anchor force with depth (Parameter: stiffness of sand2)

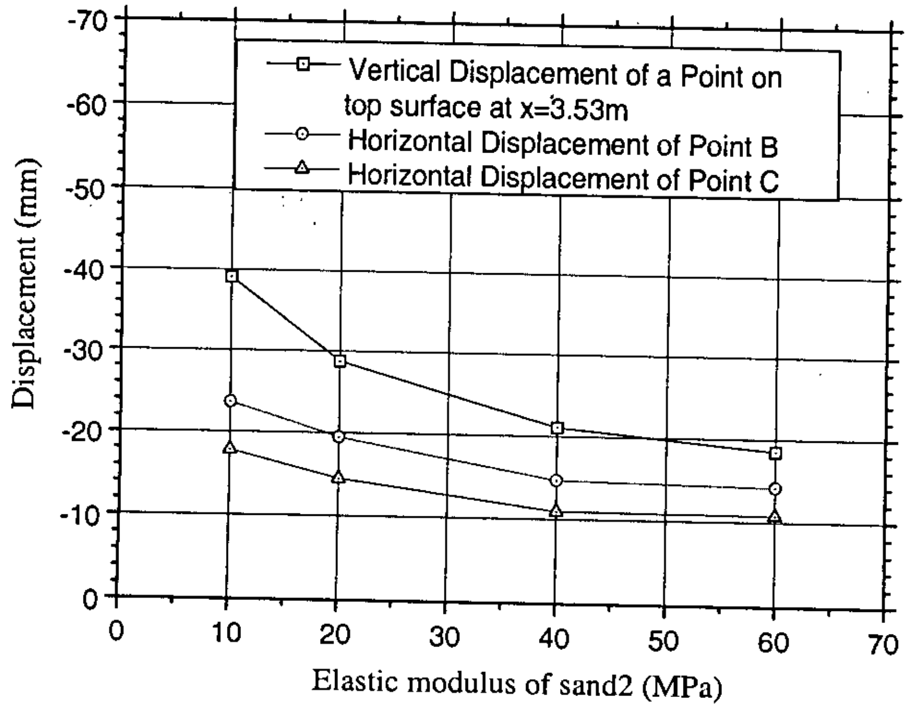

Fig. 4.42: Displacement variation with elastic modulus of sand2

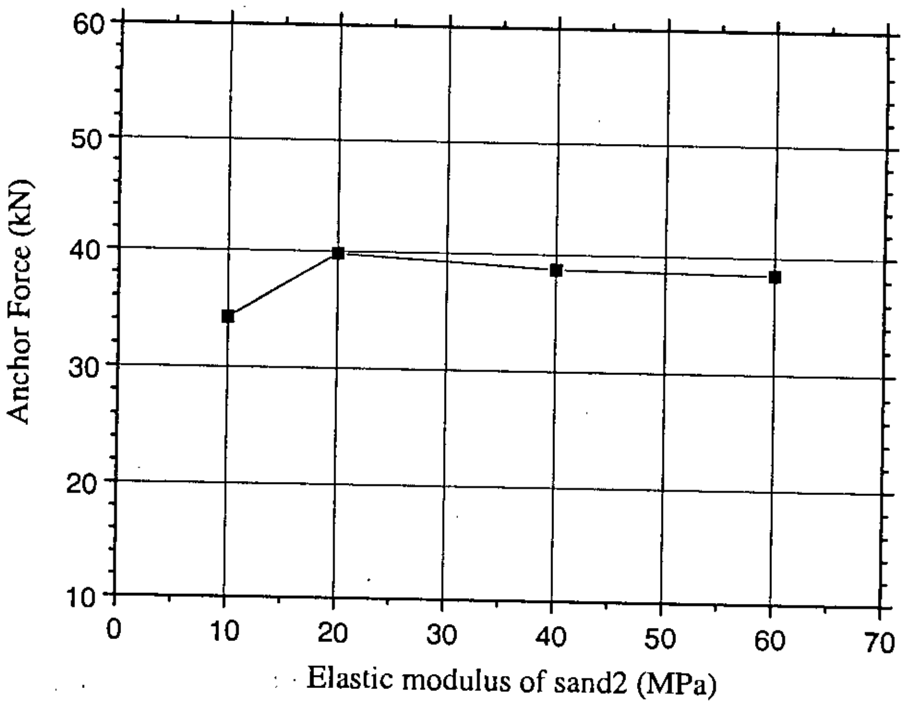

Fig. 4.43: Variation of anchor force at level 3 with elastic modulus of sand2

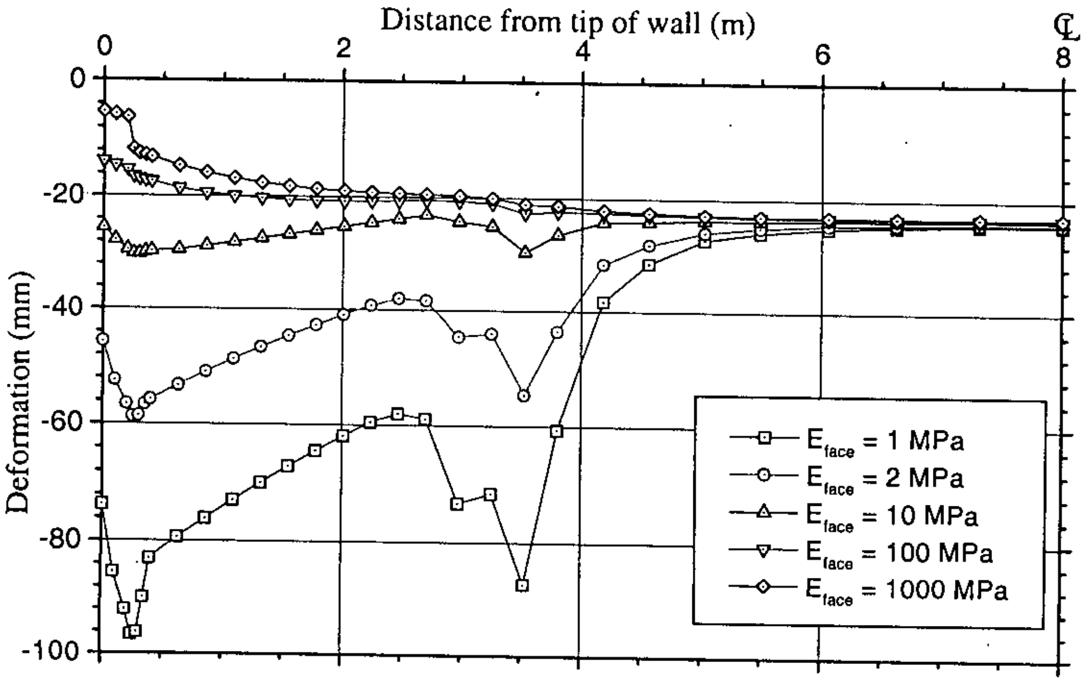

Fig. 4.44: Deformed shape of top surface of roadway after 100 kPa uniform static loading on roadway (Parameter: rigidity of facing)

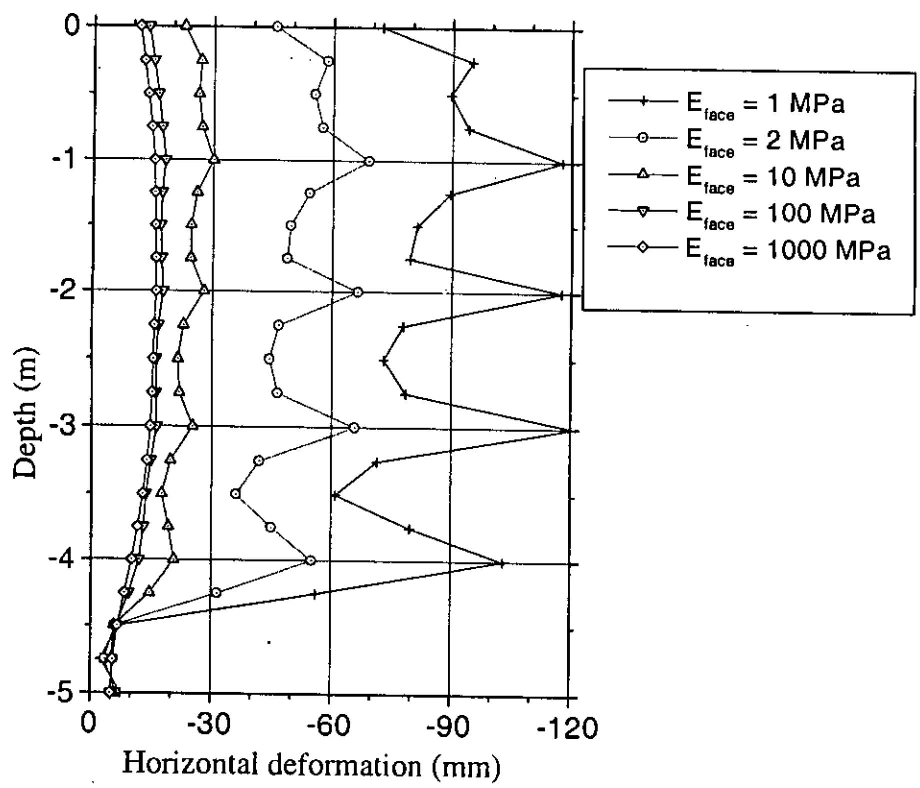

Fig. 4.45: Deformed shape of facing wall after 100 kPa uniform static loading on roadway (Parameter: rigidity of facing)

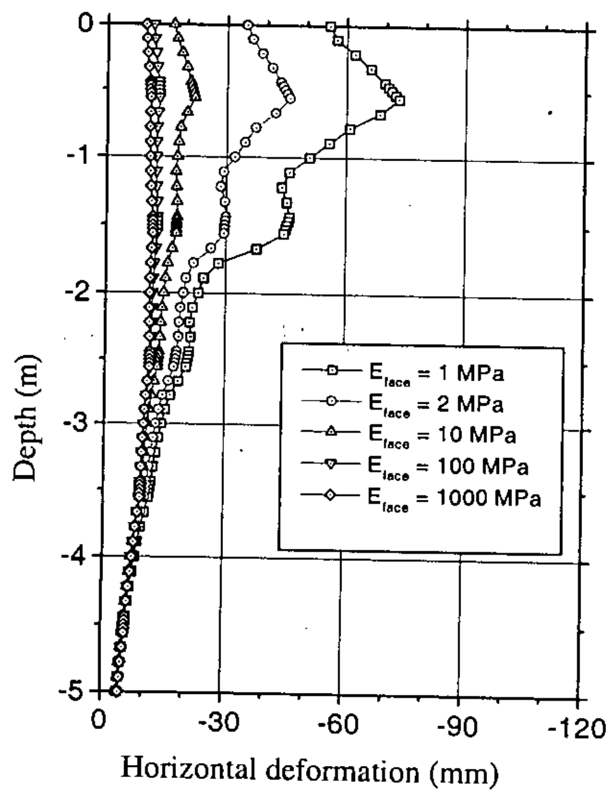

Fig. 4.46: Deformed shape of anchor front of wall after 100 kPa uniform static loading on roadway (Parameter: rigidity of facing)

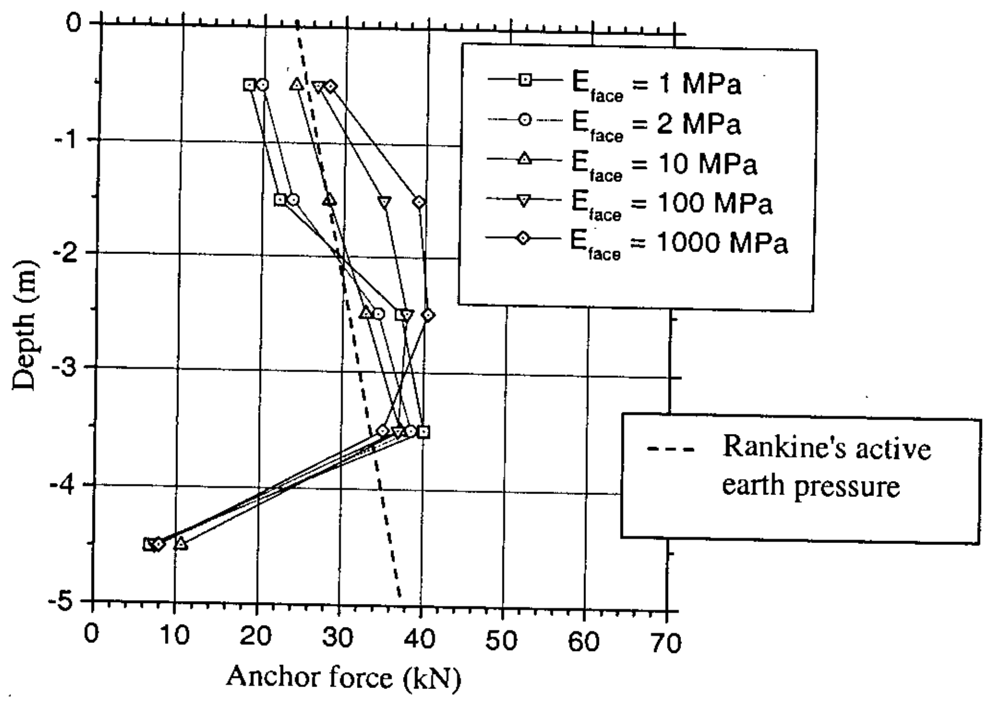

Fig. 4.47: Variation of anchor force with depth (Parameter: rigidity of facing)

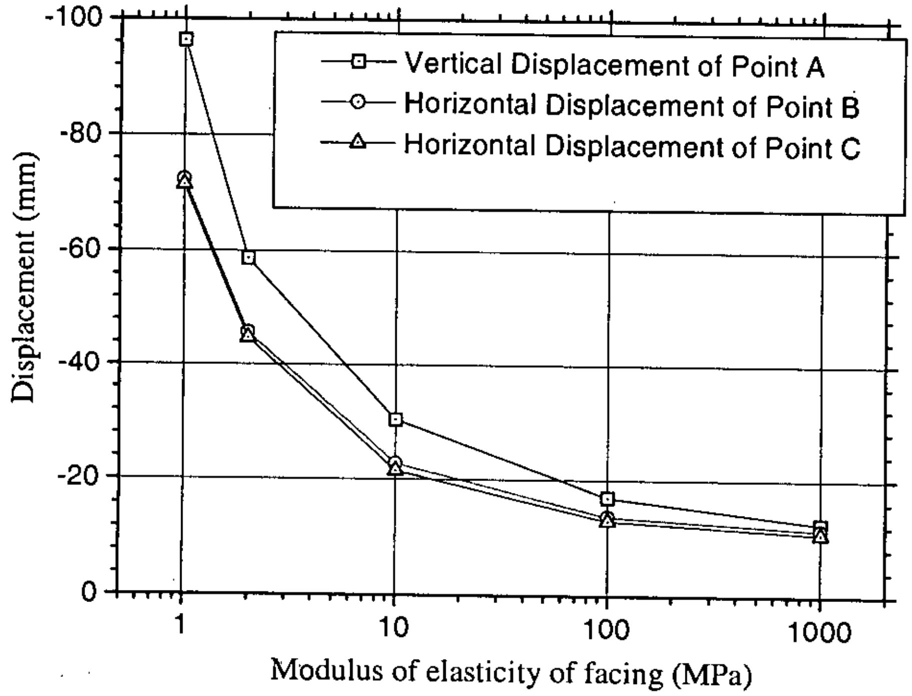

Fig. 4.48: Variation of displacement at points A, B and C with rigidity of facing

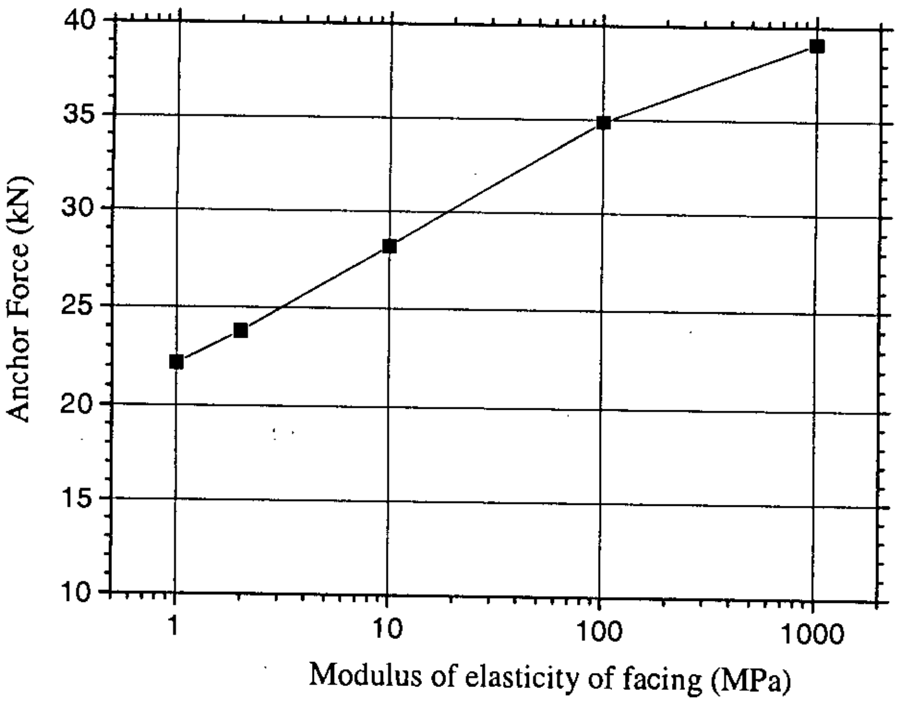

Fig. 4.49: Variation of anchor force at level 3 with rigidity of facing

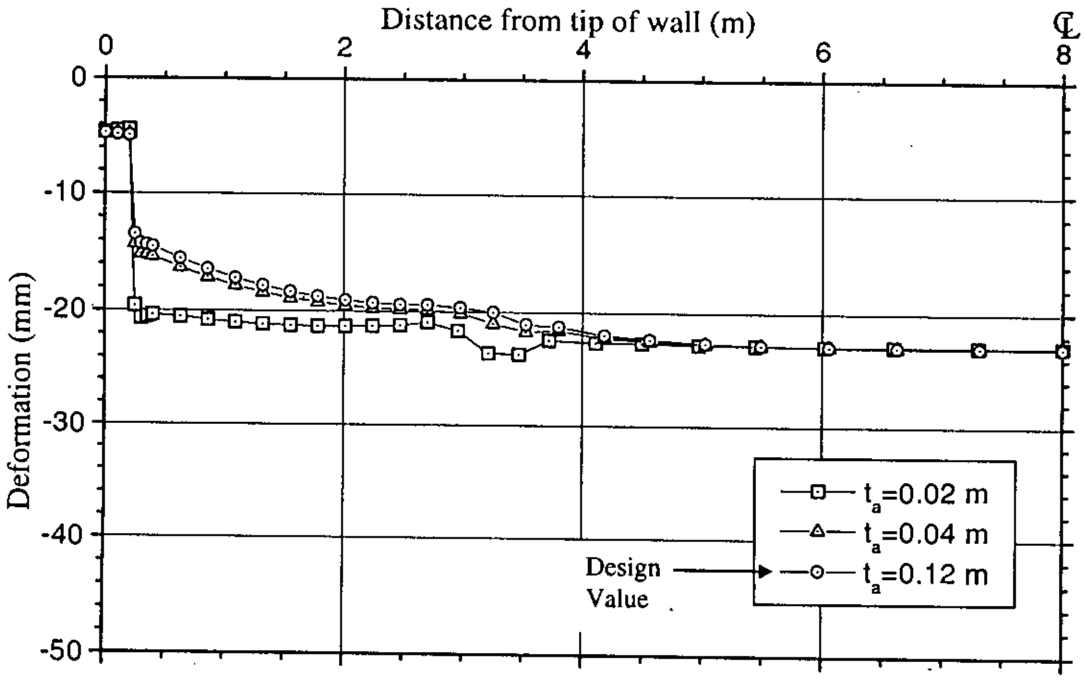

Fig. 4.50: Deformed shape of top surface of roadway after 100 kPa uniform static loading on roadway (Parameter: size of anchor block)

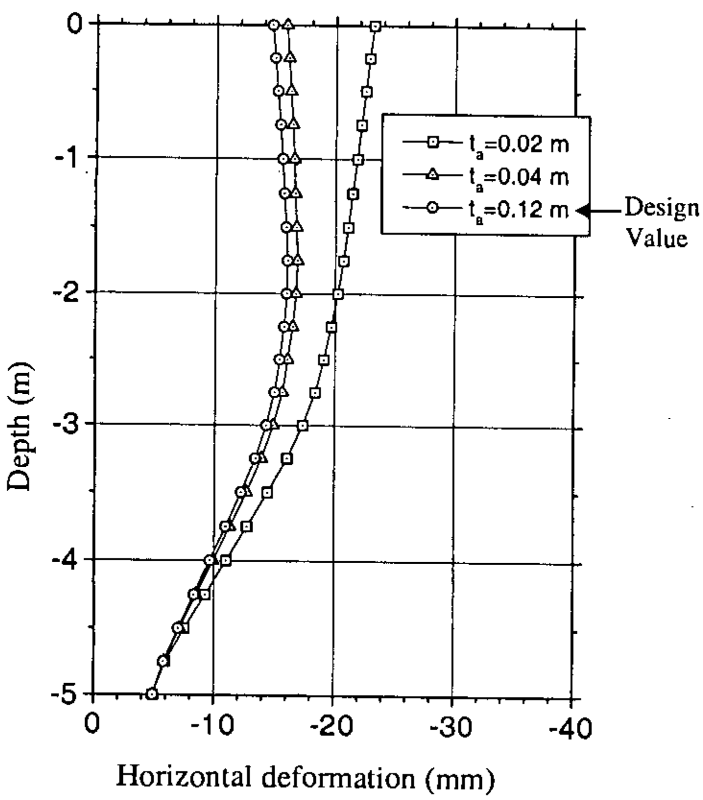

Fig. 4.51: Deformed shape of facing wall after 100 kPa uniform static loading on roadway (Parameter: size of anchor block)

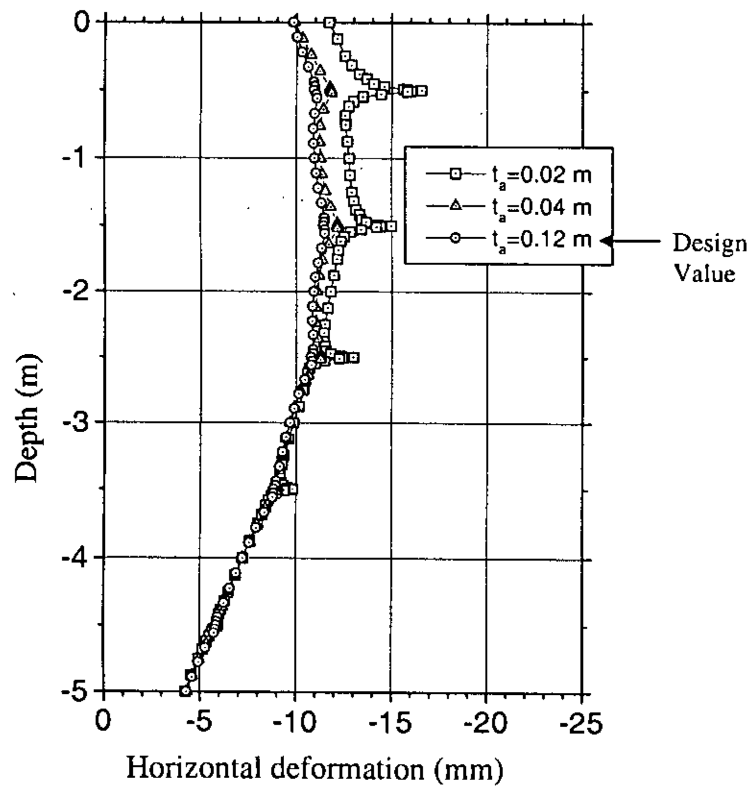

Fig. 4.52: Deformed shape of anchor front of wall after 100 kPa uniform static loading on roadway (Parameter: size of anchor block)

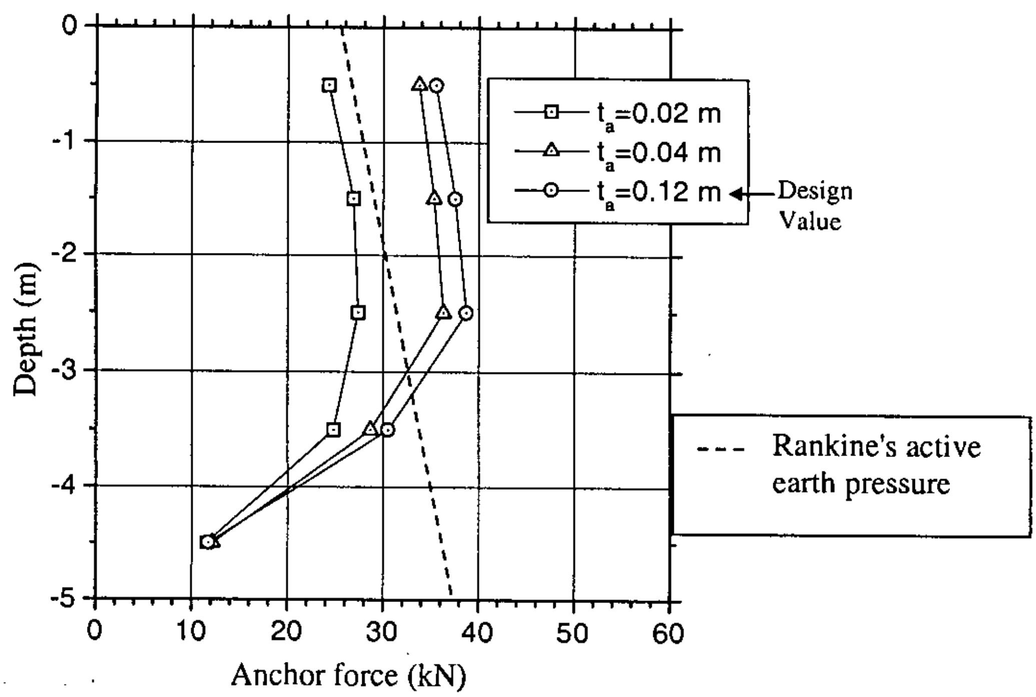

Fig. 4.53: Variation of anchor force with depth (Parameter: size of anchor block)

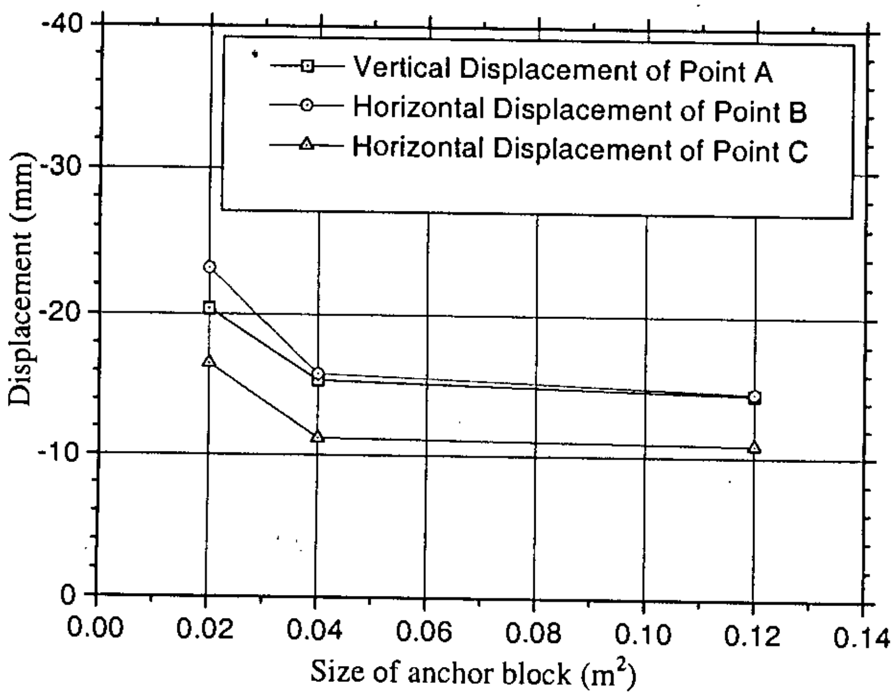

Fig. 4.54: Variation of displacement at points A, B and C with size of anchor block

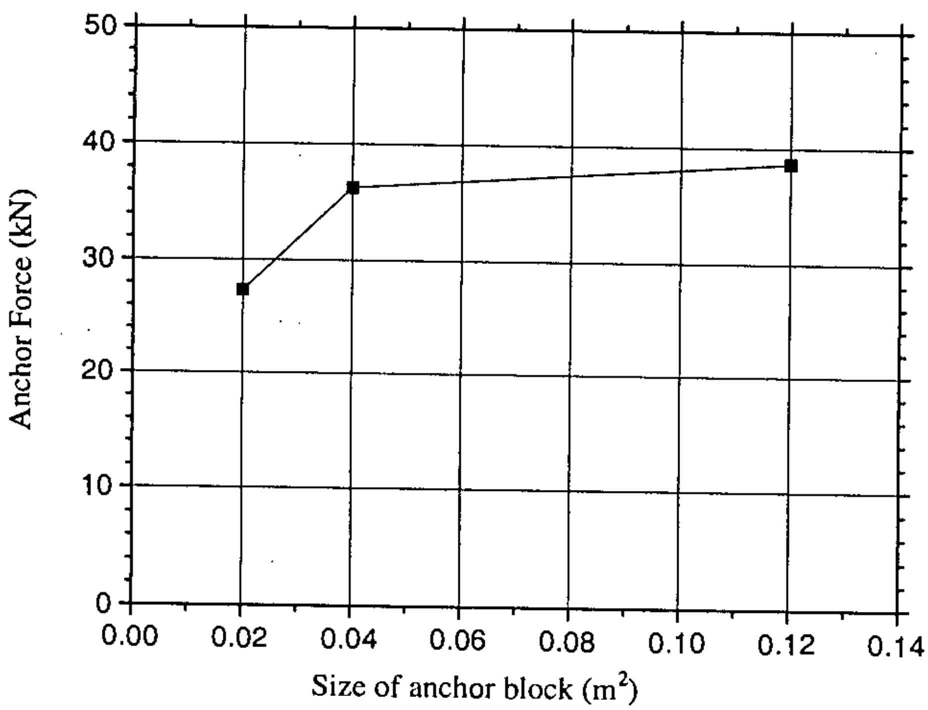

Fig. 4.55: Variation of anchor force at level 3 with Size of anchor block

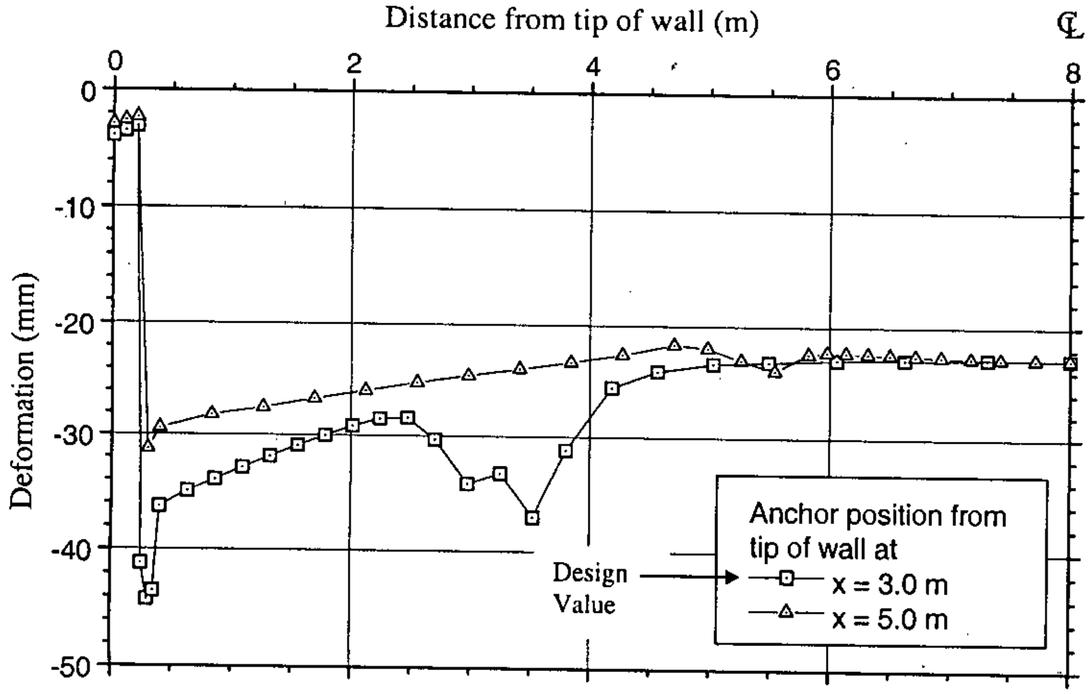

Fig. 4.56: Deformed shape of top surface of roadway after 100 kPa uniform static loading on roadway (Parameter: anchor position)

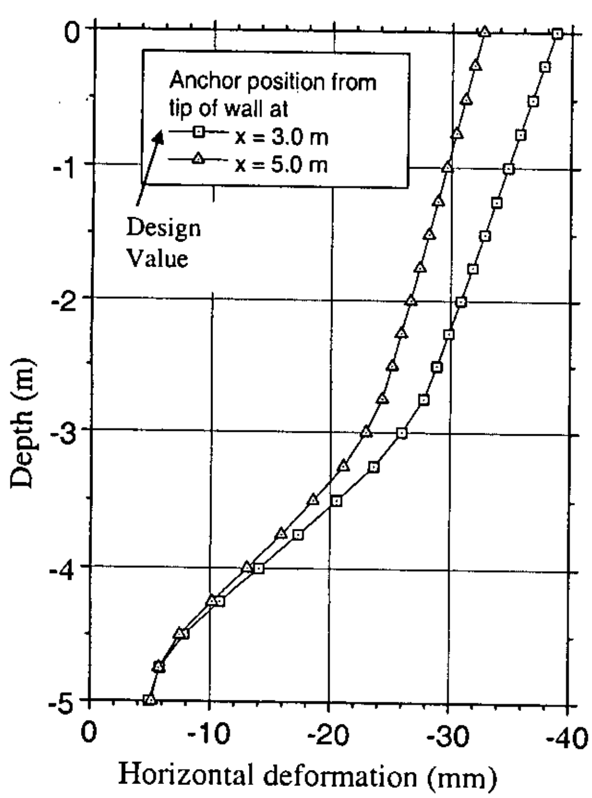

Fig. 4.57: Deformed shape of facing wall after 100 kPa uniform static loading on roadway (Parameter: anchor position)

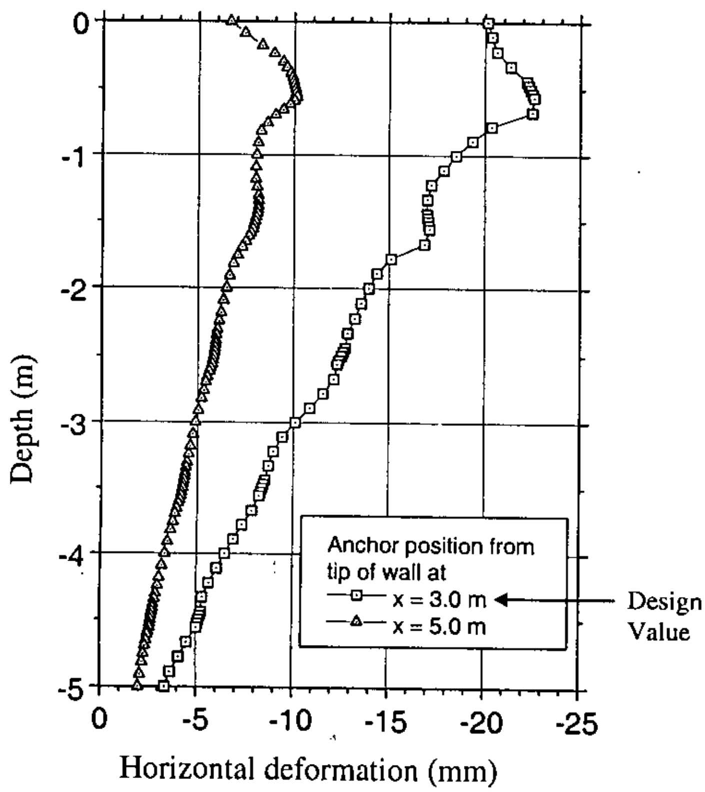

Fig. 4.58: Deformed shape of anchor front of wall after 100 kPa uniform static loading on roadway (Parameter: anchor position)

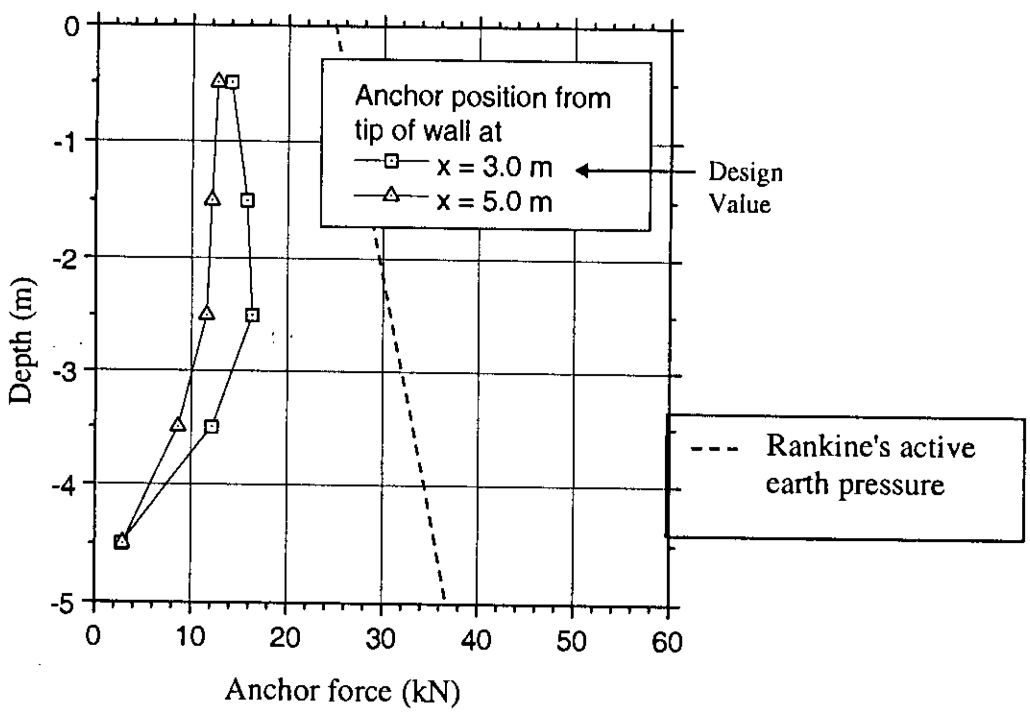

Fig. 4.59: Variation of anchor force with depth (Parameter: anchor position)

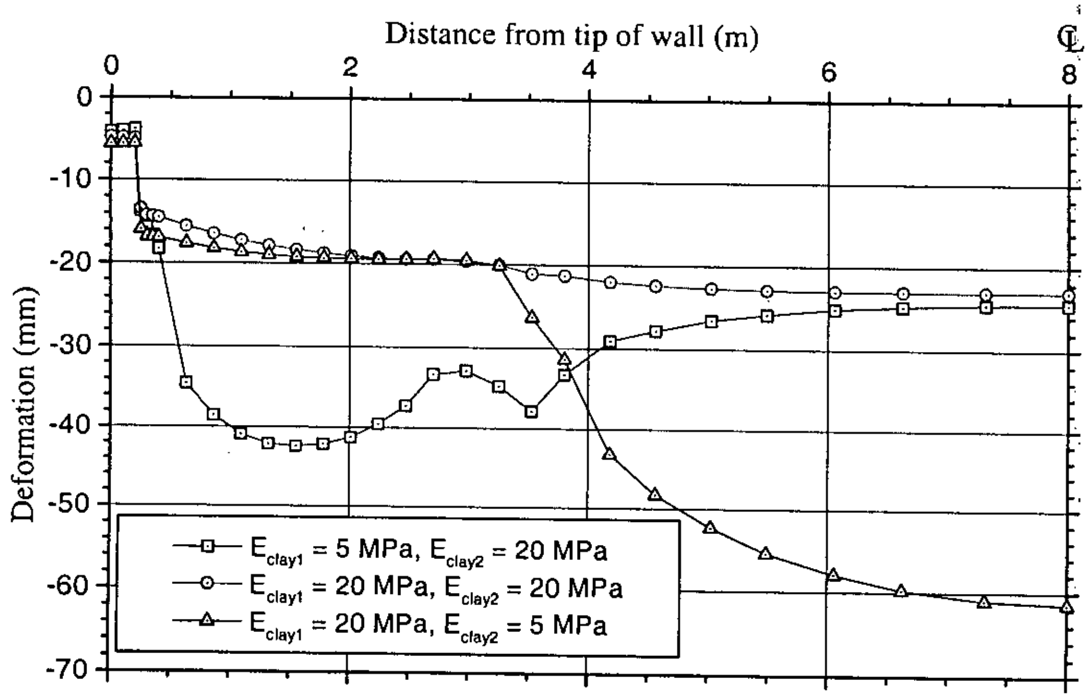

Fig. 4.60: Effect of stiffness reduction of clay1 and clay2: Deformed shape of top surface of roadway after 100 kPa uniform static loading on roadway

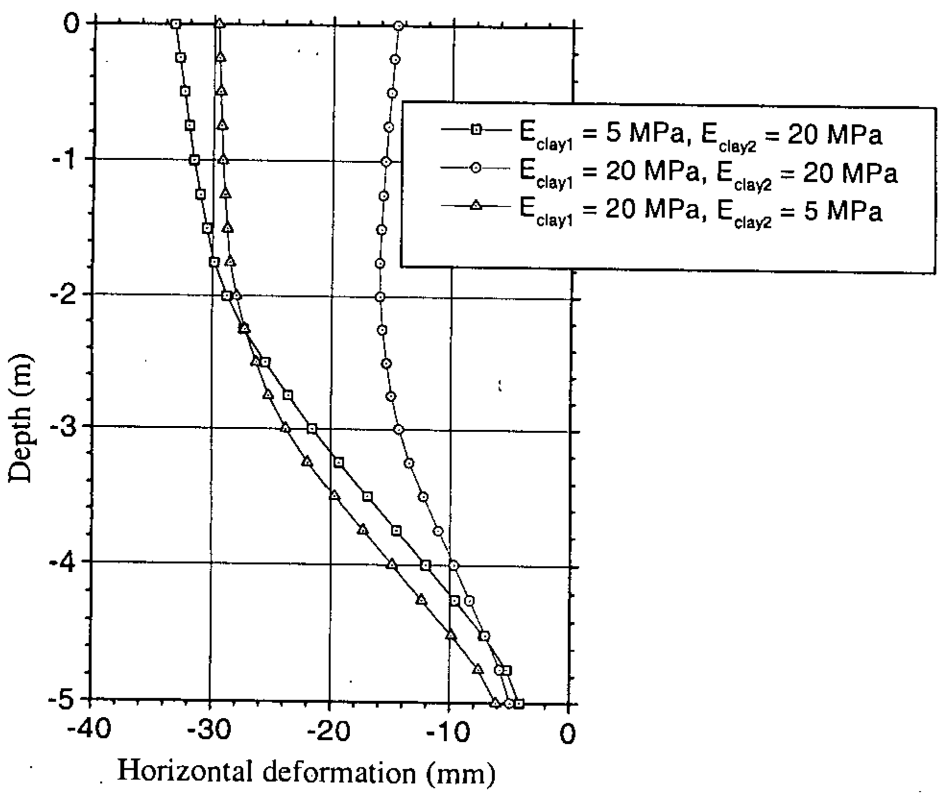

Fig. 4.61: Effect of stiffness reduction of clay1 and clay2: Deformed shape of facing wall after 100 kPa uniform static loading on roadway

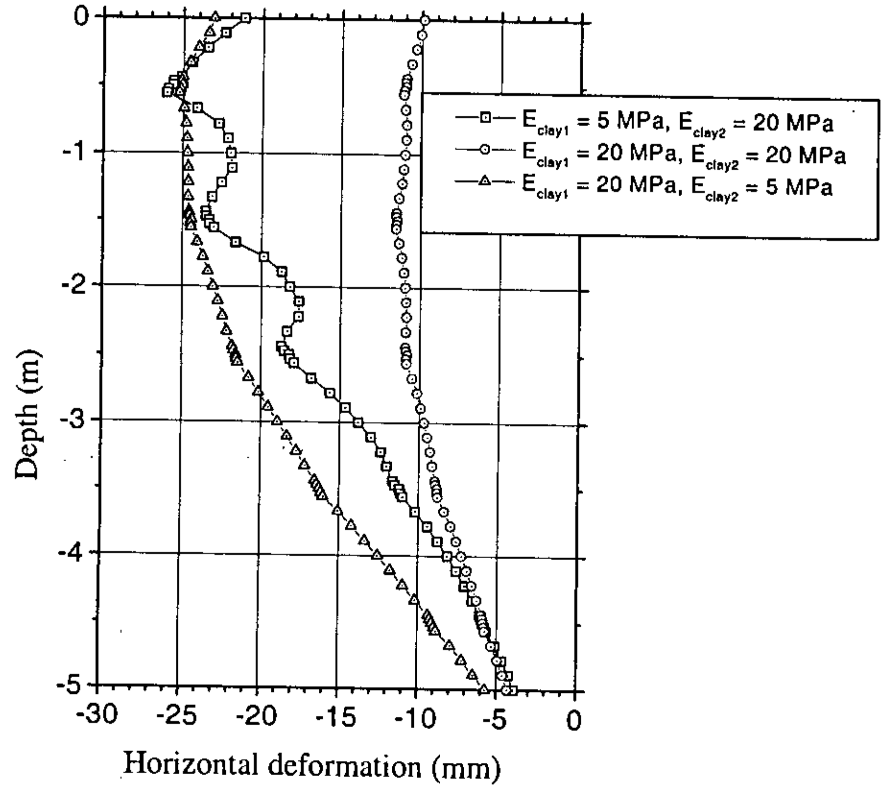

Fig. 4.62: Effect of stiffness reduction of clay1 and clay2: Deformed shape of anchor front of wall after 100 kPa uniform static loading on roadway

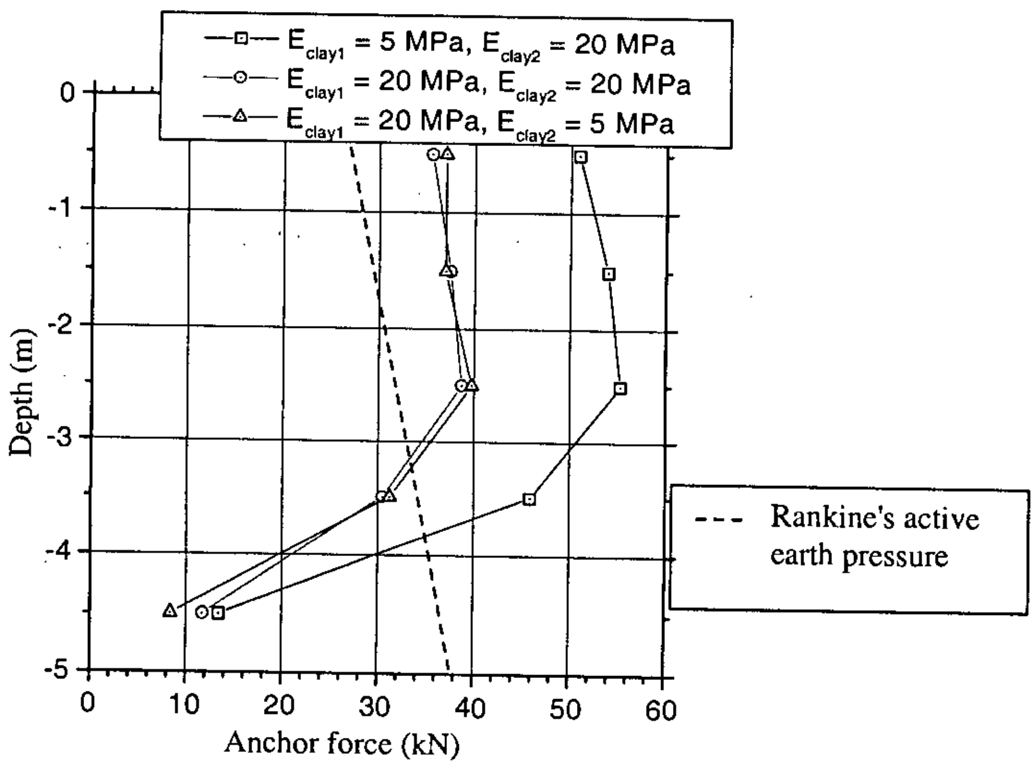

Fig. 4.63: Effect of stiffness reduction of clay1 and clay2: Variation of anchor force with depth

Chapter 5

CONCLUSIONS

1.1 INTRODUCTION

This study is undertaken to investigate the behavior of a new type of anchored earth wall system supporting simultaneously constructed roadway, through a parametric study using a finite element method of analysis. The emphasis of the parametric study is placed on the effect of various components of proposed wall system to the deformation patterns and other associated behavior. Main purpose is to use the local soil in reinforced zone as well as in the retained soil mass for road construction of fill height 4 - 6 m. Findings are summarized in this chapter.

1.2 CONCLUSIONS

The following conclusions may be drawn with respect to the cases studied in the parametric study:

(i) Deformation of wall decreases with increasing stiffness of reinforcement and after certain value of stiffness it has no effect on deformation.

(ii) Anchor force increases with increasing stiffness of reinforcement and after certain value of stiffness it has no effect on anchor force.

(iii) Deformation decreases with increasing stiffness of backfill and retained soil. Anchor force also decreases with increasing stiffness of backfill but remain constant with variation of stiffness of retained soil.

(iv) Facing rigidity has significant effect on wall deformations. Deformation decreases with increasing facing rigidity and after certain value of facing rigidity its effect become negligible.

(v) Moderately compacted fill of which elastic modulus is greater than or equal to 10 MPa is sufficient for reinforced zone, provided that stiffness of reinforcement is greater than 5.0×10^6 N/m and F.S. for anchor size is greater than or equal to 2.0.

(vi) Moderately compacted fill of which elastic modulus is greater than or equal to 20 MPa is sufficient for retained soil mass of road embankment.

(vii) Continuous rigid facing must be used for the proposed wall system.

(viii) To avoid differential settlement of roadway, reinforced soil and retained soil should have same stiffness and strength properties and in no case should stiffness of retained soil be less than that of reinforced soil.

(ix) Formula given by Rajagopal and Hari (1996) is found to be valid to estimate ultimate pull out capacity of vertical anchor used in anchored earth wall.

(x) Greater length of anchorage improves the serviceability of the retained structures in addition to ensuring stability.

(xi) Finally, locally available silty clay soil may be used in the reinforced zone as well as in the retained soil mass of roadway.

1.3 RECOMMENDATIONS FOR FUTURE STUDY

From the lessons of the present study, the recommendations for future study may be summarised as follows:

a) The parametric study carried out in this thesis may be refined by

   i) Removing the embedment depth of wall system from the numerical model.

   ii) Using the Cam Clay constitutive model for clay soils in the numerical model.

   iii) Using interface elements at all the interfaces in the numerical model. This is very important to make the finite element model more realistic.

   iv) Relocating the bottom boundary to a depth of 4H (H = height of wall) from the top surface of roadway. and

   v) Using BEAM element for facing wall.

Therefore another parametric study plan may be formulated by doing above refinement to the numerical model.

b) A 3-D numerical model of the retaining system of 1.0 m width may be created where square or rectangular anchor plates may be used instead of plane strain anchors.

c) If the wall system could be analysed for different H (height of wall), nondimensionalized results may be produced. This may lead to generalised formula for lower limits of various parameters, for better performance of the wall system.

d) To characterise the moderately compacted silty clay fill, a study plan may be initiated where elastic modulus and other parameters necessary for various constitutive numerical model of may be determined in the laboratory as well as in the field.

e) A comparative economic study may be performed to compare costs between the proposed wall system and other alternatives (e.g. road embankment with side slopes, RCC cantilever retaining wall, anchored earth wall with current practice, geosynthetic reinforced soil wall etc.).

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Appendices

Appendix A

CONSTRUCTION GUIDELINES

A.1 INTRODUCTION

This chapter deals with the guidelines to be followed in the construction of the proposed wall system. Fact is that a realistic construction guideline of the proposed wall system demands another thorough study about the detailing of each component of the wall. If possible, a full-scale model of the wall should be constructed and tested. The lessons from the full-scale model test will make the construction guideline very rich.

A.2 ADVANTAGES OF CONTINUOUS RIGID FACING

Having local, overall vertical, overall shear and overall bending rigidity, continuous rigid facing has the following advantages in construction of anchored earth retaining walls:

i. Increases the stability of wall

ii. Reduces the lateral deformation of wall and hence reduces the settlement of backfill soil.

iii. Provide confinement to backfill which lead to high degree of compaction backfill near face of wall.

iv. Local failure of facing is completely removed compared to facing comprising modular units.

v. It is also possible to create a decorated pattern on the wall face of continuous rigid facig.

Having these merits, still it has some limitations.

A.3 LIMITATIONS OF CONTINUOUS RIGID FACING

Potential problems associated with the use of continuous rigid facing are summarized by Tatsuaka et. al. (1992) as follows:

i. The connection between reinforcing member and facing may be damaged due to relative settlement between them.

ii. Only small tensile strains may be mobilized in reinforcing members as soil layers are compacted as the continuous rigid facing is firmly propped.

iii. Large earth pressure may be activated on the back face of the facing due to compaction of backfill as the continuous rigid facing is firmly propped.

To alleviate above problems of using rigid facing, a stage construction method for GRS (Geosysthetic Reinforced Soil) retaining wall was adopted. First a wall is constructed with the aid of gabions, wrapping around them with a geotextile sheet. After major part of the compression of the backfill and the supporting ground has occured, a continuous rigid facing is placed by either of the following methods; (a) A lightly steel reinforced cast in situ concrete slab is constructed directly over the wrapped around wall so that the slab does not seperate from the wall face. (b) A lightly steel reinforced precast concrete plate unit is erected, leaving a space between its back face and slope face. Some other remedial measures were proposed by Tatsuoka et. al. (1992) to use the continuous rigid facing without stage construction method. In case of anchored earth retaining wall with metallic reinforcement a preliminary construction guideline is proposed here in the next article.

A.4 PRELIMINARY CONSTRUCTION GUIDELINE

Proposed wall system in the present study has some new features compared to existing mechanically stabilized earth walls. Firstly, backfill is locally available silty clay and moderately compacted by hand driven light machines. Secondly, the use of a continuous rigid facing which is cast in situ or precast lightly reinforced concrete, erected prior to construction. Thirdly, the wall system supports a simultaneously constructed roadway using locally available silty clay soil which is also moderately compacted by hand driven light machines. Considering all these new features, this preliminary construction guideline is prepared and explained in following figures (Fig. 5.1 - 5.5).

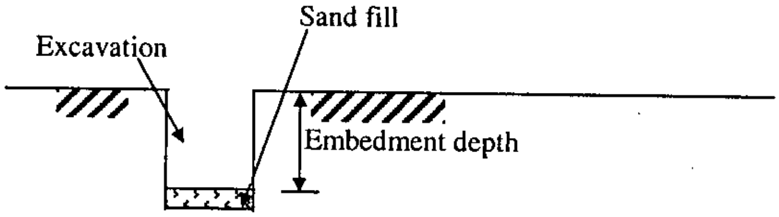

Fig. 5.1: Step 1; Excavation and sand fill beneath the pad

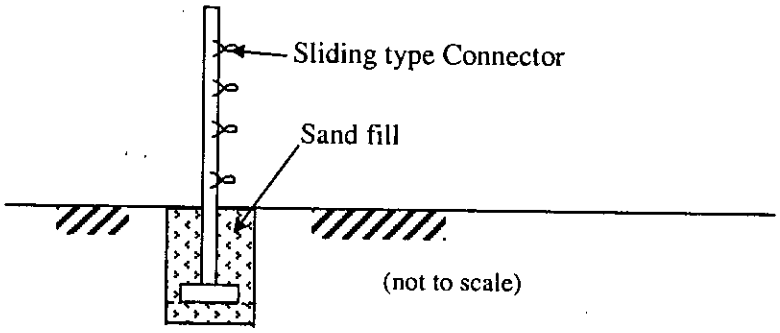

Fig. 5.2: Step 2; Erection of concrete facing wall with small pad

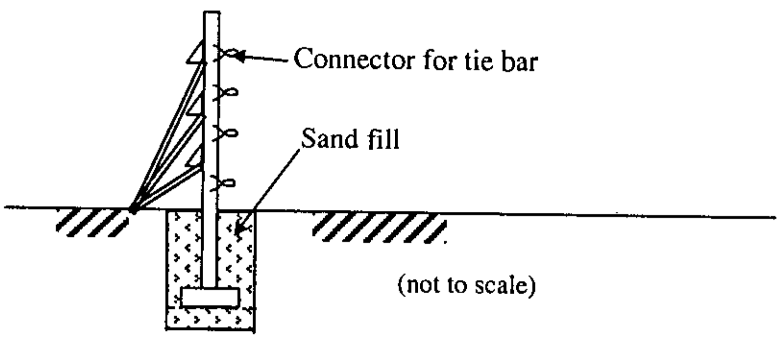

Fig. 5.3: Step 3; Installation of props before commencement of construction of roadway.

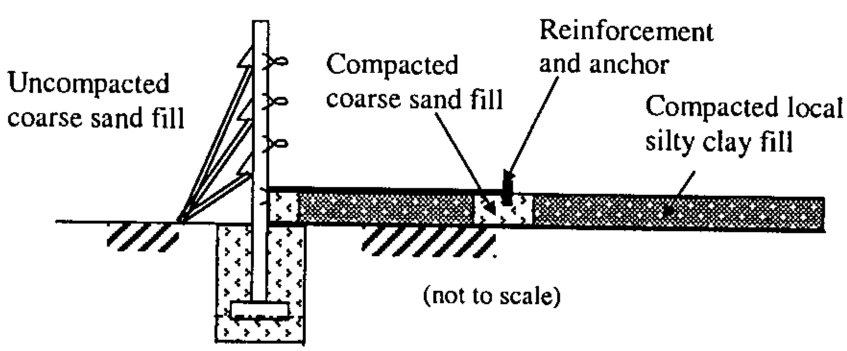

Fig. 5.4: Step 4; Layer by layer filling of backfill and roadway, compaction and placement of anchor and reinforcement

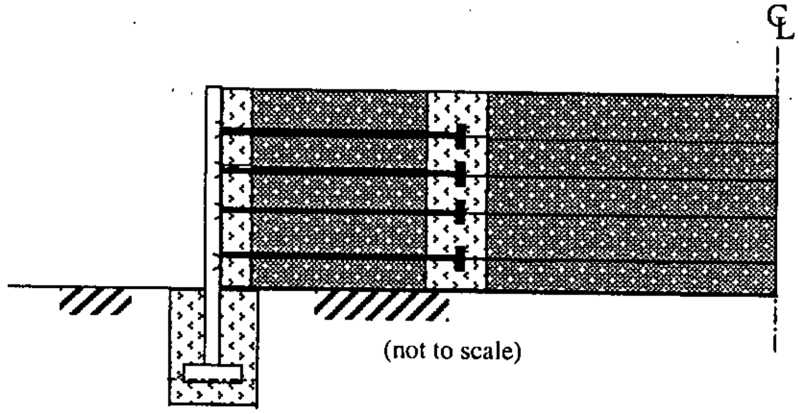

Fig. 5.5: Step 5; Removal of props after completion of construction

Appendix B

GENERATION OF NUMERICAL MODEL

B.1 INTRODUCTION

This illustrates the steps followed to generate the numerical model using DIANA, finite element software.

B.2 GENERATION OF GEOMETRY

Using FemGV Graphical User Interface, geometry of the problem is generated. This preprocessing includes generation of geometry points, lines, surfaces and sets, defining boundary constraints and application of load. During this preprocessing command lines needed are listed in L.1 sequentially.

B.3 MESH GENERATION

After generation of model geometry command lines in L.2 were applied to generate the finite element mesh.

B.4 WRITING THE DATA FILE

Graphical numerical model generated in above steps is converted to data file, which is required to solve the numerical model. In this step a data file was generated using command lines in L.3.

B.5 EDITING THE DATA FILE

The data file was edited to include SPRING elements (SP2TR), to make corrections in material property data ('MATERIALS') and finally to make corrections in load data ('LOADS'). After editing of data file, it looks like L.4 for standard geometry and material properties (Fig. 3.3, Table. 3.1 and 3.2). Corrections and additions are shown in bold letters.

B.6 WRITING THE COMMAND FILE

For solution of the numerical model (data file: **wal3.dat**) a command file was written. This command file dictates the type of problem (linear, nonlinear, etc.) solution method, load steps, and output parameters and formats etc. The command file (wal3.com) used in the current study is given in L.5.

B.7 RUNNING THE PROGRAM

At first, DIANA analysis window is opened from the start menu (**start → program → DIANA → diana_w**), then the data file and command file is located in the analysis window. A base name is required so that output files would be generated with this name and different extensions. If no filos file exists, a blank text file with file name <diana.ff> is created and located in the DIANA analysis window. Finally, clicking on the **Run** button, program is run.

L.1 Listing of Command Lines for Preprocessing:

```
FEMGEN wal3
PROPERTY FE-PROG DIANA
UTILITY SETUP UNDO ON
PROPERTY FE-PROG DIANA

CONSTRUCT PARAMETER X01     0.0
CONSTRUCT PARAMETER X02     0.2
CONSTRUCT PARAMETER X03     0.4
CONSTRUCT PARAMETER X04     2.7
CONSTRUCT PARAMETER X05     3.2
CONSTRUCT PARAMETER X06     3.4
CONSTRUCT PARAMETER X07     3.8
CONSTRUCT PARAMETER X08     8.0
CONSTRUCT PARAMETER X09    -0.2
CONSTRUCT PARAMETER X10    -5.0

CONSTRUCT PARAMETER Y01      0.0
CONSTRUCT PARAMETER Y02     -0.5
CONSTRUCT PARAMETER Y03     -1.0
CONSTRUCT PARAMETER Y04     -1.5
CONSTRUCT PARAMETER Y05     -2.0
CONSTRUCT PARAMETER Y06     -2.5
CONSTRUCT PARAMETER Y07     -3.0
CONSTRUCT PARAMETER Y08     -3.5
CONSTRUCT PARAMETER Y09     -4.0
CONSTRUCT PARAMETER Y10     -4.5
CONSTRUCT PARAMETER Y11     -5.0
CONSTRUCT PARAMETER Y12     -5.2
CONSTRUCT PARAMETER Y13     -8.0

CONSTRUCT PARAMETER BLOC01     -0.44
CONSTRUCT PARAMETER BLOC02     -0.56
CONSTRUCT PARAMETER BLOC03     -1.44
CONSTRUCT PARAMETER BLOC04     -1.56
CONSTRUCT PARAMETER BLOC05     -2.44
CONSTRUCT PARAMETER BLOC06     -2.56
CONSTRUCT PARAMETER BLOC07     -3.44
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CONSTRUCT PARAMETER BLOC08 -3.56
CONSTRUCT PARAMETER BLOC09 -4.44
CONSTRUCT PARAMETER BLOC10 -4.56

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GEOMETRY POINT COORD P2 X02 Y01
GEOMETRY POINT COORD P3 X03 Y01
GEOMETRY POINT COORD P4 X04 Y01
GEOMETRY POINT COORD P5 X05 Y01
GEOMETRY POINT COORD P6 X06 Y01
GEOMETRY POINT COORD P7 X07 Y01
GEOMETRY POINT COORD P8 X08 Y01
GEOMETRY POINT COORD P11 X01 Y02
GEOMETRY POINT COORD P12 X02 Y02
GEOMETRY POINT COORD P13 X03 Y02
GEOMETRY POINT COORD P14 X04 Y02
GEOMETRY POINT COORD P15 X05 Y02
GEOMETRY POINT COORD P16 X06 Y02
GEOMETRY POINT COORD P17 X07 Y02
GEOMETRY POINT COORD P18 X08 Y02
GEOMETRY POINT COORD P21 X01 Y03
GEOMETRY POINT COORD P22 X02 Y03
GEOMETRY POINT COORD P23 X03 Y03
GEOMETRY POINT COORD P24 X04 Y03
GEOMETRY POINT COORD P25 X05 Y03
GEOMETRY POINT COORD P26 X06 Y03
GEOMETRY POINT COORD P27 X07 Y03
GEOMETRY POINT COORD P28 X08 Y03
GEOMETRY POINT COORD P31 X01 Y04
GEOMETRY POINT COORD P32 X02 Y04
GEOMETRY POINT COORD P33 X03 Y04
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GEOMETRY SURFACE 4SIDES S10 L91 L392 L101 L391
GEOMETRY SURFACE 4SIDES S11 L101 L402 L111 L401
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GEOMETRY SURFACE 4SIDES S59 L281 L517 L94 L384
GEOMETRY SURFACE 4SIDES S60 L94 L519 L291 L394
GEOMETRY SURFACE 4SIDES S61 L203 L307 L16 L502
GEOMETRY SURFACE 4SIDES S62 L16 L317 L213 L504
GEOMETRY SURFACE 4SIDES S63 L223 L327 L36 L506
GEOMETRY SURFACE 4SIDES S64 L36 L337 L233 L508
GEOMETRY SURFACE 4SIDES S65 L243 L347 L56 L510
GEOMETRY SURFACE 4SIDES S66 L56 L357 L253 L512
GEOMETRY SURFACE 4SIDES S67 L263 L367 L76 L514
GEOMETRY SURFACE 4SIDES S68 L76 L377 L273 L516
GEOMETRY SURFACE 4SIDES S69 L283 L387 L96 L518
GEOMETRY SURFACE 4SIDES S70 L96 L397 L293 L520
GEOMETRY SURFACE 4SIDES S71 L204 L203 L202 L201
GEOMETRY SURFACE 4SIDES S72 L212 L213 L224 L211
GEOMETRY SURFACE 4SIDES S73 L224 L223 L222 L221
GEOMETRY SURFACE 4SIDES S74 L232 L233 L244 L231
GEOMETRY SURFACE 4SIDES S75 L244 L243 L242 L241
GEOMETRY SURFACE 4SIDES S76 L252 L253 L264 L251
GEOMETRY SURFACE 4SIDES S77 L264 L263 L262 L261
GEOMETRY SURFACE 4SIDES S78 L272 L273 L284 L271
GEOMETRY SURFACE 4SIDES S79 L284 L283 L282 L281
GEOMETRY SURFACE 4SIDES S80 L292 L293 L294 L291
GEOMETRY SURFACE 4SIDES S101 L3 L304 L13 L303
GEOMETRY SURFACE 4SIDES S102 L13 L314 L23 L313
GEOMETRY SURFACE 4SIDES S103 L23 L324 L33 L323
GEOMETRY SURFACE 4SIDES S104 L33 L334 L43 L333
GEOMETRY SURFACE 4SIDES S105 L43 L344 L53 L343
GEOMETRY SURFACE 4SIDES S106 L53 L354 L63 L353
GEOMETRY SURFACE 4SIDES S107 L63 L364 L73 L363
GEOMETRY SURFACE 4SIDES S108 L73 L374 L83 L373
GEOMETRY SURFACE 4SIDES S109 L83 L384 L93 L383
GEOMETRY SURFACE 4SIDES S110 L93 L394 L103 L393
GEOMETRY SURFACE 4SIDES S111 L7 L308 L17 L307
GEOMETRY SURFACE 4SIDES S112 L17 L318 L27 L317

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GEOMETRY SURFACE 4SIDES S113 L27 L328 L37 L327
GEOMETRY SURFACE 4SIDES S114 L37 L338 L47 L337
GEOMETRY SURFACE 4SIDES S115 L47 L348 L57 L347
GEOMETRY SURFACE 4SIDES S116 L57 L358 L67 L357
GEOMETRY SURFACE 4SIDES S117 L67 L368 L77 L367
GEOMETRY SURFACE 4SIDES S118 L77 L378 L87 L377
GEOMETRY SURFACE 4SIDES S119 L87 L388 L97 L387
GEOMETRY SURFACE 4SIDES S120 L97 L398 L107 L397
GEOMETRY SURFACE 4SIDES S121 L111 L412 L121 L411
GEOMETRY SURFACE 4SIDES S122 L112 L413 L122 L412
GEOMETRY SURFACE 4SIDES S123 L113 L414 L123 L413
GEOMETRY SURFACE 4SIDES S124 L295 L417 L296 L414
GEOMETRY SURFACE 4SIDES S125 L294 L407 L295 L404
GEOMETRY SURFACE 4SIDES S126 L117 L418 L127 L417
GEOMETRY SURFACE 4SIDES S127 L103 L404 L113 L403
GEOMETRY SURFACE 4SIDES S128 L107 L408 L117 L407
GEOMETRY SURFACE 4SIDES S129 L118 L411 L128 L419
GEOMETRY SURFACE 4SIDES S130 L119 L419 L129 L420
GEOMETRY SURFACE 4SIDES S131 L109 L409 L119 L410
GEOMETRY SURFACE 4SIDES S132 L99 L399 L109 L400

CONSTRUCT SET OPEN COL1
CONSTRUCT SET APPEND LINES L1 L11 L21 L31 L41
CONSTRUCT SET APPEND LINES L51 L61 L71 L81 L91
CONSTRUCT SET APPEND LINES L101 L111 L121
CONSTRUCT SET CLOSE COL1
CONSTRUCT SET OPEN COL2
CONSTRUCT SET APPEND LINES L2 L12 L22 L32 L42
CONSTRUCT SET APPEND LINES L52 L62 L72 L82 L92
CONSTRUCT SET APPEND LINES L102 L112 L122
CONSTRUCT SET CLOSE COL2
CONSTRUCT SET OPEN COL3
CONSTRUCT SET APPEND LINES L3 L13 L23 L33 L43
CONSTRUCT SET APPEND LINES L53 L63 L73 L83 L93
CONSTRUCT SET APPEND LINES L103 L113 L123
CONSTRUCT SET CLOSE COL3
CONSTRUCT SET OPEN COL4
CONSTRUCT SET APPEND LINES L14 L34
CONSTRUCT SET APPEND LINES L54 L74 L94
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CONSTRUCT SET CLOSE COL4
CONSTRUCT SET OPEN INCL
CONSTRUCT SET APPEND LINES L201 L211 L221 L231 L241
CONSTRUCT SET APPEND LINES L251 L261 L271 L281 L291
CONSTRUCT SET CLOSE INCL
CONSTRUCT SET OPEN COL5
CONSTRUCT SET APPEND LINES L204 L15 L224 L35 L244
CONSTRUCT SET APPEND LINES L55 L264 L75 L284 L95
CONSTRUCT SET APPEND LINES L294 L295 L296
CONSTRUCT SET APPEND LINES L202 L212 L222 L232 L242
CONSTRUCT SET APPEND LINES L252 L262 L272 L282 L292
CONSTRUCT SET CLOSE COL5
CONSTRUCT SET OPEN COL6
CONSTRUCT SET APPEND LINES L16 L36
CONSTRUCT SET APPEND LINES L56 L76 L96
CONSTRUCT SET CLOSE COL6
CONSTRUCT SET OPEN INCR
CONSTRUCT SET APPEND LINES L203 L213 L223 L233 L243
CONSTRUCT SET APPEND LINES L253 L263 L273 L283 L293
CONSTRUCT SET CLOSE INCR
CONSTRUCT SET OPEN COL7
CONSTRUCT SET APPEND LINES L7 L17 L27 L37 L47
CONSTRUCT SET APPEND LINES L57 L67 L77 L87 L97
CONSTRUCT SET APPEND LINES L107 L117 L127
CONSTRUCT SET CLOSE COL7
CONSTRUCT SET OPEN COL8
CONSTRUCT SET APPEND LINES L98
CONSTRUCT SET APPEND LINES L108 L118 L128
CONSTRUCT SET CLOSE COL8
CONSTRUCT SET OPEN COL9
CONSTRUCT SET APPEND LINES L99
CONSTRUCT SET APPEND LINES L109 L119 L129
CONSTRUCT SET CLOSE COL9
CONSTRUCT SET OPEN ALLROW
CONSTRUCT SET OPEN ROW1
CONSTRUCT SET APPEND LINES L301 L302 L303
CONSTRUCT SET APPEND LINES L304 L307 L308
CONSTRUCT SET CLOSE ROW1
CONSTRUCT SET OPEN RO2T10
```

```
CONSTRUCT SET APPEND LINES L311 L312 L313 L314 L317 L318
CONSTRUCT SET APPEND LINES L321 L322 L323 L324 L327 L328
CONSTRUCT SET APPEND LINES L331 L332 L333 L334 L337 L338
CONSTRUCT SET APPEND LINES L341 L342 L343 L344 L347 L348
CONSTRUCT SET APPEND LINES L351 L352 L353 L354 L357 L358
CONSTRUCT SET APPEND LINES L361 L362 L363 L364 L367 L368
CONSTRUCT SET APPEND LINES L371 L372 L373 L374 L377 L378
CONSTRUCT SET APPEND LINES L381 L382 L383 L384 L387 L388
CONSTRUCT SET APPEND LINES L391 L392 L393 L394 L397
CONSTRUCT SET APPEND LINES L398 L399 L400
CONSTRUCT SET CLOSE RO2T10
CONSTRUCT SET OPEN ROW11
CONSTRUCT SET APPEND LINES L401 L402 L403 L404 L405
CONSTRUCT SET APPEND LINES L406 L407 L408 L409 L410
CONSTRUCT SET CLOSE ROW11
CONSTRUCT SET OPEN ROW12
CONSTRUCT SET APPEND LINES L411 L412 L413 L414 L415
CONSTRUCT SET APPEND LINES L416 L417 L418 L419 L420
CONSTRUCT SET CLOSE ROW12
CONSTRUCT SET CLOSE ALLROW
CONSTRUCT SET OPEN ANCROW
CONSTRUCT SET APPEND LINES L501 L502 L503 L504 L505
CONSTRUCT SET APPEND LINES L506 L507 L508 L509 L510
CONSTRUCT SET APPEND LINES L511 L512 L513 L514 L515
CONSTRUCT SET APPEND LINES L516 L517 L518 L519 L520
CONSTRUCT SET CLOSE ANCROW
CONSTRUCT SET OPEN SNDROW
CONSTRUCT SET APPEND LINES L305 L306 L315 L316
CONSTRUCT SET APPEND LINES L325 L326 L335 L336
CONSTRUCT SET APPEND LINES L345 L346 L355 L356
CONSTRUCT SET APPEND LINES L365 L366 L375 L376
CONSTRUCT SET APPEND LINES L385 L386 L395 L396
CONSTRUCT SET CLOSE SNDROW

CONSTRUCT SET OPEN POINTL
CONSTRUCT SET APPEND POINTS P12 P32 P52 P72 P92
CONSTRUCT SET CLOSE POINTL
CONSTRUCT SET OPEN POINTR
CONSTRUCT SET APPEND POINTS P15 P35 P55 P75 P95
```

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CONSTRUCT SET CLOSE POINTR
CONSTRUCT SET OPEN LEFTB
CONSTRUCT SET APPEND LINES L400 L410 L420
CONSTRUCT SET CLOSE LEFTB
CONSTRUCT SET OPEN RIGHTB
CONSTRUCT SET APPEND LINES L308 L318 L328 L338 L348
CONSTRUCT SET APPEND LINES L358 L368 L378 L388 L398
CONSTRUCT SET APPEND LINES L408 L418
CONSTRUCT SET CLOSE RIGHTB
CONSTRUCT SET OPEN BOTOMB
CONSTRUCT SET APPEND LINES L121 L122 L123
CONSTRUCT SET APPEND LINES L296 L127 L128 L129
CONSTRUCT SET CLOSE BOTOMB
CONSTRUCT SET OPEN FACE
CONSTRUCT SET APPEND LINES L301 L311 L321 L331 L341
CONSTRUCT SET APPEND LINES L351 L361 L371 L381 L391
CONSTRUCT SET CLOSE FACE
CONSTRUCT SET OPEN ANCFRT
CONSTRUCT SET APPEND LINES L305 L315 L325 L335 L345
CONSTRUCT SET APPEND LINES L355 L365 L375 L385 L395
CONSTRUCT SET APPEND LINES L501 L503 L505 L507 L509
CONSTRUCT SET APPEND LINES L511 L513 L515 L517 L519
CONSTRUCT SET CLOSE ANCFRT
CONSTRUCT SET OPEN TOPLIN
CONSTRUCT SET OPEN TOPLFT
CONSTRUCT SET APPEND LINES L1 L2 L3 L204
CONSTRUCT SET CLOSE TOPLFT
CONSTRUCT SET OPEN TOPRHT
CONSTRUCT SET APPEND LINES L7
CONSTRUCT SET CLOSE TOPRHT
CONSTRUCT SET CLOSE TOPLIN
CONSTRUCT SET OPEN FACING
CONSTRUCT SET APPEND SURFACES S1 S2 S3 S4 S5
CONSTRUCT SET APPEND SURFACES S6 S7 S8 S9 S10
CONSTRUCT SET APPEND SURFACES S11 S12 S13
CONSTRUCT SET CLOSE FACING

CONSTRUCT SET OPEN ANCHOR
CONSTRUCT SET APPEND SURFACES S21 S22 S23 S24 S25
```

```
CONSTRUCT SET APPEND SURFACES S26 S27 S28 S29 S30
CONSTRUCT SET CLOSE ANCHOR
CONSTRUCT SET OPEN SAND1
CONSTRUCT SET APPEND SURFACES S31 S32 S33 S34 S35
CONSTRUCT SET APPEND SURFACES S36 S37 S38 S39 S40
CONSTRUCT SET APPEND SURFACES S41
CONSTRUCT SET CLOSE SAND1


CONSTRUCT SET OPEN SAND2
CONSTRUCT SET APPEND SURFACES S51 S52 S53 S54 S55
CONSTRUCT SET APPEND SURFACES S56 S57 S58 S59 S60
CONSTRUCT SET APPEND SURFACES S61 S62 S63 S64 S65
CONSTRUCT SET APPEND SURFACES S66 S67 S68 S69 S70
CONSTRUCT SET APPEND SURFACES S71 S72 S73 S74 S75
CONSTRUCT SET APPEND SURFACES S76 S77 S78 S79 S80
CONSTRUCT SET CLOSE SAND2
CONSTRUCT SET OPEN CLAY1
CONSTRUCT SET APPEND SURFACES S101 S102 S103 S104 S105
CONSTRUCT SET APPEND SURFACES S106 S107 S108 S109 S110
CONSTRUCT SET CLOSE CLAY1
CONSTRUCT SET OPEN CLAY2
CONSTRUCT SET APPEND SURFACES S111 S112 S113 S114 S115
CONSTRUCT SET APPEND SURFACES S116 S117 S118 S119 S120
CONSTRUCT SET CLOSE CLAY2
CONSTRUCT SET OPEN CLAY3
CONSTRUCT SET APPEND SURFACES S121 S122 S123 S124 S125
CONSTRUCT SET APPEND SURFACES S126 S127 S128 S129 S130
CONSTRUCT SET APPEND SURFACES S131 S132
CONSTRUCT SET CLOSE CLAY3
CONSTRUCT SET OPEN FILL
CONSTRUCT SET APPEND FACING ANCHOR SAND1
CONSTRUCT SET APPEND SAND2 CLAY1 CLAY2
CONSTRUCT SET CLOSE FILL

PROPERTY BOUNDARY CONSTRAINT CO1 BOTOMB X Y
PROPERTY BOUNDARY CONSTRAINT CO2 LEFTB X
PROPERTY BOUNDARY CONSTRAINT CO3 RIGHTB X
PROPERTY LOADS GRAVITY LO1 ALL -9.8 Y
```

```
PROPERTY LOADS PRESSURE LO2 TOPLIN -100000.0 Y
!**********************************************************************
PROPERTY MATERIAL ISOTRO CONCRT 2E+010 0.15 2400 0 0 0 0
PROPERTY MATERIAL ISOTRO SAND1M 2E+007 0.2 1200 0 0 0 0
PROPERTY MATERIAL ISOTRO SAND2M 2E+007 0.2 1600 0 0 0 0
PROPERTY MATERIAL ISOTRO CLAY1M 3E+006 0.35 1500 0 0 0 0
PROPERTY MATERIAL ISOTRO CLAY2M 3E+007 0.2 1650 0 0 0 0
PROPERTY MATERIAL ISOTRO CLAY3M 5E+006 0.3 15 0 0 0 0 0

PROPERTY ATTACH FACING MATERIAL CONCRT
PROPERTY ATTACH ANCHOR MATERIAL CONCRT
PROPERTY ATTACH SAND1 MATERIAL SAND1M
PROPERTY ATTACH SAND2 MATERIAL SAND2M
PROPERTY ATTACH CLAY1 MATERIAL CLAY1M
PROPERTY ATTACH CLAY2 MATERIAL CLAY2M
PROPERTY ATTACH CLAY3 MATERIAL CLAY3M
--------------------------------------------------------------------
```

L.2 Listing of Command Lines for Mesh Generation:

```
MESHING DIVISION LINE COL1   2
MESHING DIVISION LINE COL2   4
MESHING DIVISION LINE COL3   10
MESHING DIVISION LINE COL4   4
MESHING DIVISION LINE COL5   4
MESHING DIVISION LINE COL6   4
MESHING DIVISION LINE COL7   208
MESHING DIVISION LINE COL8   2
MESHING DIVISION LINE COL9   206

MESHING DIVISION LINE INCL   4
MESHING DIVISION LINE INCR   4

MESHING DIVISION LINE ROW1   2
MESHING DIVISION LINE RO2T10 2
MESHING DIVISION LINE ROW11  2
MESHING DIVISION LINE ROW12  206

MESHING DIVISION LINE ANCROW 2
MESHING DIVISION LINE SNDROW 2

MESHING TYPES ALL CQ16E

MESHING GENERATE
```

L.3 Listing Command Lines for Writing Data File:

```
UTILITY WRITE DIANA

! CONFIRM WRITE TO NEW FILE =>

YES
```

L.4 Listing Data File (Wal.dat):

KEYWORDS: PRE:FEMGEN

FEMGEN MODEL : WAL3
MODEL DESCRIPTION : MODEL 3 FINAL
'COORDINATES'

1	0.000000E+00	0.000000E+00	0.000000E+00
2	2.000000E-01	0.000000E+00	0.000000E+00
3	0.000000E+00	-5.000000E-01	0.000000E+00
4	2.000000E-01	-5.000000E-01	0.000000E+00
5	1.000000E-01	0.000000E+00	0.000000E+00
6	0.000000E+00	-2.500000E-01	0.000000E+00
7	2.000000E-01	-2.500000E-01	0.000000E+00
8	1.000000E-01	-5.000000E-01	0.000000E+00
9	0.000000E+00	-1.000000E+00	0.000000E+00
10	2.000000E-01	-1.000000E+00	0.000000E+00
11	0.000000E+00	-7.500000E-01	0.000000E+00
12	2.000000E-01	-7.500000E-01	0.000000E+00
13	1.000000E-01	-1.000000E+00	0.000000E+00
14	0.000000E+00	-1.500000E+00	0.000000E+00
15	2.000000E-01	-1.500000E+00	0.000000E+00
16	0.000000E+00	-1.250000E+00	0.000000E+00
17	2.000000E-01	-1.250000E+00	0.000000E+00
18	1.000000E-01	-1.500000E+00	0.000000E+00
19	0.000000E+00	-2.000000E+00	0.000000E+00
20	2.000000E-01	-2.000000E+00	0.000000E+00
21	0.000000E+00	-1.750000E+00	0.000000E+00
22	2.000000E-01	-1.750000E+00	0.000000E+00
23	1.000000E-01	-2.000000E+00	0.000000E+00
24	0.000000E+00	-2.500000E+00	0.000000E+00
25	2.000000E-01	-2.500000E+00	0.000000E+00
26	0.000000E+00	-2.250000E+00	0.000000E+00
27	2.000000E-01	-2.250000E+00	0.000000E+00
28	1.000000E-01	-2.500000E+00	0.000000E+00
29	0.000000E+00	-3.000000E+00	0.000000E+00
30	2.000000E-01	-3.000000E+00	0.000000E+00
31	0.000000E+00	-2.750000E+00	0.000000E+00
32	2.000000E-01	-2.750000E+00	0.000000E+00

33	1.000000E-01	-3.000000E+00	0.000000E+00
34	0.000000E+00	-3.500000E+00	0.000000E+00
35	2.000000E-01	-3.500000E+00	0.000000E+00
36	0.000000E+00	-3.250000E+00	0.000000E+00
37	2.000000E-01	-3.250000E+00	0.000000E+00
38	1.000000E-01	-3.500000E+00	0.000000E+00
39	0.000000E+00	-4.000000E+00	0.000000E+00
40	2.000000E-01	-4.000000E+00	0.000000E+00
41	0.000000E+00	-3.750000E+00	0.000000E+00
42	2.000000E-01	-3.750000E+00	0.000000E+00
43	1.000000E-01	-4.000000E+00	0.000000E+00
44	0.000000E+00	-4.500000E+00	0.000000E+00
45	2.000000E-01	-4.500000E+00	0.000000E+00
46	0.000000E+00	-4.250000E+00	0.000000E+00
47	2.000000E-01	-4.250000E+00	0.000000E+00
48	1.000000E-01	-4.500000E+00	0.000000E+00
49	0.000000E+00	-5.000000E+00	0.000000E+00
50	2.000000E-01	-5.000000E+00	0.000000E+00
51	0.000000E+00	-4.750000E+00	0.000000E+00
52	2.000000E-01	-4.750000E+00	0.000000E+00
53	1.000000E-01	-5.000000E+00	0.000000E+00
54	0.000000E+00	-5.200000E+00	0.000000E+00
55	2.000000E-01	-5.200000E+00	0.000000E+00
56	0.000000E+00	-5.100000E+00	0.000000E+00
57	2.000000E-01	-5.100000E+00	0.000000E+00
58	1.000000E-01	-5.200000E+00	0.000000E+00
59	-2.000000E-01	-5.000000E+00	0.000000E+00
60	-2.000000E-01	-5.200000E+00	0.000000E+00
61	-1.000000E-01	-5.000000E+00	0.000000E+00
62	-2.000000E-01	-5.100000E+00	0.000000E+00
63	-1.000000E-01	-5.200000E+00	0.000000E+00
64	3.000000E-01	-5.000000E+00	0.000000E+00
65	4.000000E-01	-5.000000E+00	0.000000E+00
66	3.000000E-01	-5.200000E+00	0.000000E+00
67	4.000000E-01	-5.200000E+00	0.000000E+00
68	2.500000E-01	-5.000000E+00	0.000000E+00
69	3.500000E-01	-5.000000E+00	0.000000E+00
70	3.000000E-01	-5.100000E+00	0.000000E+00
71	4.000000E-01	-5.100000E+00	0.000000E+00

72	2.500000E-01	-5.200000E+00	0.000000E+00
73	3.500000E-01	-5.200000E+00	0.000000E+00
74	3.200000E+00	-4.400000E-01	0.000000E+00
75	3.300000E+00	-4.400000E-01	0.000000E+00
76	3.400000E+00	-4.400000E-01	0.000000E+00
77	3.200000E+00	-5.000000E-01	0.000000E+00
78	3.300000E+00	-5.000000E-01	0.000000E+00
79	3.400000E+00	-5.000000E-01	0.000000E+00
80	3.250000E+00	-4.400000E-01	0.000000E+00
81	3.350000E+00	-4.400000E-01	0.000000E+00
82	3.200000E+00	-4.700000E-01	0.000000E+00
83	3.300000E+00	-4.700000E-01	0.000000E+00
84	3.400000E+00	-4.700000E-01	0.000000E+00
85	3.250000E+00	-5.000000E-01	0.000000E+00
86	3.350000E+00	-5.000000E-01	0.000000E+00
87	3.200000E+00	-5.600000E-01	0.000000E+00
88	3.300000E+00	-5.600000E-01	0.000000E+00
89	3.400000E+00	-5.600000E-01	0.000000E+00
90	3.200000E+00	-5.300000E-01	0.000000E+00
91	3.300000E+00	-5.300000E-01	0.000000E+00
92	3.400000E+00	-5.300000E-01	0.000000E+00
93	3.250000E+00	-5.600000E-01	0.000000E+00
94	3.350000E+00	-5.600000E-01	0.000000E+00
95	3.200000E+00	-1.440000E+00	0.000000E+00
96	3.300000E+00	-1.440000E+00	0.000000E+00
97	3.400000E+00	-1.440000E+00	0.000000E+00
98	3.200000E+00	-1.500000E+00	0.000000E+00
99	3.300000E+00	-1.500000E+00	0.000000E+00
100	3.400000E+00	-1.500000E+00	0.000000E+00
101	3.250000E+00	-1.440000E+00	0.000000E+00
102	3.350000E+00	-1.440000E+00	0.000000E+00
103	3.200000E+00	-1.470000E+00	0.000000E+00
104	3.300000E+00	-1.470000E+00	0.000000E+00
105	3.400000E+00	-1.470000E+00	0.000000E+00
106	3.250000E+00	-1.500000E+00	0.000000E+00
107	3.350000E+00	-1.500000E+00	0.000000E+00
108	3.200000E+00	-1.560000E+00	0.000000E+00
109	3.300000E+00	-1.560000E+00	0.000000E+00
110	3.400000E+00	-1.560000E+00	0.000000E+00

111	3.200000E+00	-1.530000E+00	0.000000E+00
112	3.300000E+00	-1.530000E+00	0.000000E+00
113	3.400000E+00	-1.530000E+00	0.000000E+00
114	3.250000E+00	-1.560000E+00	0.000000E+00
115	3.350000E+00	-1.560000E+00	0.000000E+00
116	3.200000E+00	-2.440000E+00	0.000000E+00
117	3.300000E+00	-2.440000E+00	0.000000E+00
118	3.400000E+00	-2.440000E+00	0.000000E+00
119	3.200000E+00	-2.500000E+00	0.000000E+00
120	3.300000E+00	-2.500000E+00	0.000000E+00
121	3.400000E+00	-2.500000E+00	0.000000E+00
122	3.250000E+00	-2.440000E+00	0.000000E+00
123	3.350000E+00	-2.440000E+00	0.000000E+00
124	3.200000E+00	-2.470000E+00	0.000000E+00
125	3.300000E+00	-2.470000E+00	0.000000E+00
126	3.400000E+00	-2.470000E+00	0.000000E+00
127	3.250000E+00	-2.500000E+00	0.000000E+00
128	3.350000E+00	-2.500000E+00	0.000000E+00
129	3.200000E+00	-2.560000E+00	0.000000E+00
130	3.300000E+00	-2.560000E+00	0.000000E+00
131	3.400000E+00	-2.560000E+00	0.000000E+00
132	3.200000E+00	-2.530000E+00	0.000000E+00
133	3.300000E+00	-2.530000E+00	0.000000E+00
134	3.400000E+00	-2.530000E+00	0.000000E+00
135	3.250000E+00	-2.560000E+00	0.000000E+00
136	3.350000E+00	-2.560000E+00	0.000000E+00
137	3.200000E+00	-3.440000E+00	0.000000E+00
138	3.300000E+00	-3.440000E+00	0.000000E+00
139	3.400000E+00	-3.440000E+00	0.000000E+00
140	3.200000E+00	-3.500000E+00	0.000000E+00
141	3.300000E+00	-3.500000E+00	0.000000E+00
142	3.400000E+00	-3.500000E+00	0.000000E+00
143	3.250000E+00	-3.440000E+00	0.000000E+00
144	3.350000E+00	-3.440000E+00	0.000000E+00
145	3.200000E+00	-3.470000E+00	0.000000E+00
146	3.300000E+00	-3.470000E+00	0.000000E+00
147	3.400000E+00	-3.470000E+00	0.000000E+00
148	3.250000E+00	-3.500000E+00	0.000000E+00
149	3.350000E+00	-3.500000E+00	0.000000E+00

150	3.200000E+00	-3.560000E+00	0.000000E+00
151	3.300000E+00	-3.560000E+00	0.000000E+00
152	3.400000E+00	-3.560000E+00	0.000000E+00
153	3.200000E+00	-3.530000E+00	0.000000E+00
154	3.300000E+00	-3.530000E+00	0.000000E+00
155	3.400000E+00	-3.530000E+00	0.000000E+00
156	3.250000E+00	-3.560000E+00	0.000000E+00
157	3.350000E+00	-3.560000E+00	0.000000E+00
158	3.200000E+00	-4.440000E+00	0.000000E+00
159	3.300000E+00	-4.440000E+00	0.000000E+00
160	3.400000E+00	-4.440000E+00	0.000000E+00
161	3.200000E+00	-4.500000E+00	0.000000E+00
162	3.300000E+00	-4.500000E+00	0.000000E+00
163	3.400000E+00	-4.500000E+00	0.000000E+00
164	3.250000E+00	-4.440000E+00	0.000000E+00
165	3.350000E+00	-4.440000E+00	0.000000E+00
166	3.200000E+00	-4.470000E+00	0.000000E+00
167	3.300000E+00	-4.470000E+00	0.000000E+00
168	3.400000E+00	-4.470000E+00	0.000000E+00
169	3.250000E+00	-4.500000E+00	0.000000E+00
170	3.350000E+00	-4.500000E+00	0.000000E+00
171	3.200000E+00	-4.560000E+00	0.000000E+00
172	3.300000E+00	-4.560000E+00	0.000000E+00
173	3.400000E+00	-4.560000E+00	0.000000E+00
174	3.200000E+00	-4.530000E+00	0.000000E+00
175	3.300000E+00	-4.530000E+00	0.000000E+00
176	3.400000E+00	-4.530000E+00	0.000000E+00
177	3.250000E+00	-4.560000E+00	0.000000E+00
178	3.350000E+00	-4.560000E+00	0.000000E+00
179	3.000000E-01	0.000000E+00	0.000000E+00
180	4.000000E-01	0.000000E+00	0.000000E+00
181	3.000000E-01	-5.000000E-01	0.000000E+00
182	4.000000E-01	-5.000000E-01	0.000000E+00
183	2.500000E-01	0.000000E+00	0.000000E+00
184	3.500000E-01	0.000000E+00	0.000000E+00
185	3.000000E-01	-2.500000E-01	0.000000E+00
186	4.000000E-01	-2.500000E-01	0.000000E+00
187	2.500000E-01	-5.000000E-01	0.000000E+00
188	3.500000E-01	-5.000000E-01	0.000000E+00

189	3.000000E-01	-1.000000E+00	0.000000E+00
190	4.000000E-01	-1.000000E+00	0.000000E+00
191	3.000000E-01	-7.500000E-01	0.000000E+00
192	4.000000E-01	-7.500000E-01	0.000000E+00
193	2.500000E-01	-1.000000E+00	0.000000E+00
194	3.500000E-01	-1.000000E+00	0.000000E+00
195	3.000000E-01	-1.500000E+00	0.000000E+00
196	4.000000E-01	-1.500000E+00	0.000000E+00
197	3.000000E-01	-1.250000E+00	0.000000E+00
198	4.000000E-01	-1.250000E+00	0.000000E+00
199	2.500000E-01	-1.500000E+00	0.000000E+00
200	3.500000E-01	-1.500000E+00	0.000000E+00
201	3.000000E-01	-2.000000E+00	0.000000E+00
202	4.000000E-01	-2.000000E+00	0.000000E+00
203	3.000000E-01	-1.750000E+00	0.000000E+00
204	4.000000E-01	-1.750000E+00	0.000000E+00
205	2.500000E-01	-2.000000E+00	0.000000E+00
206	3.500000E-01	-2.000000E+00	0.000000E+00
207	3.000000E-01	-2.500000E+00	0.000000E+00
208	4.000000E-01	-2.500000E+00	0.000000E+00
209	3.000000E-01	-2.250000E+00	0.000000E+00
210	4.000000E-01	-2.250000E+00	0.000000E+00
211	2.500000E-01	-2.500000E+00	0.000000E+00
212	3.500000E-01	-2.500000E+00	0.000000E+00
213	3.000000E-01	-3.000000E+00	0.000000E+00
214	4.000000E-01	-3.000000E+00	0.000000E+00
215	3.000000E-01	-2.750000E+00	0.000000E+00
216	4.000000E-01	-2.750000E+00	0.000000E+00
217	2.500000E-01	-3.000000E+00	0.000000E+00
218	3.500000E-01	-3.000000E+00	0.000000E+00
219	3.000000E-01	-3.500000E+00	0.000000E+00
220	4.000000E-01	-3.500000E+00	0.000000E+00
221	3.000000E-01	-3.250000E+00	0.000000E+00
222	4.000000E-01	-3.250000E+00	0.000000E+00
223	2.500000E-01	-3.500000E+00	0.000000E+00
224	3.500000E-01	-3.500000E+00	0.000000E+00
225	3.000000E-01	-4.000000E+00	0.000000E+00
226	4.000000E-01	-4.000000E+00	0.000000E+00
227	3.000000E-01	-3.750000E+00	0.000000E+00

228	4.000000E-01	-3.750000E+00	0.000000E+00
229	2.500000E-01	-4.000000E+00	0.000000E+00
230	3.500000E-01	-4.000000E+00	0.000000E+00
231	3.000000E-01	-4.500000E+00	0.000000E+00
232	4.000000E-01	-4.500000E+00	0.000000E+00
233	3.000000E-01	-4.250000E+00	0.000000E+00
234	4.000000E-01	-4.250000E+00	0.000000E+00
235	2.500000E-01	-4.500000E+00	0.000000E+00
236	3.500000E-01	-4.500000E+00	0.000000E+00
237	3.000000E-01	-4.750000E+00	0.000000E+00
238	4.000000E-01	-4.750000E+00	0.000000E+00
239	-2.000000E-01	-4.500000E+00	0.000000E+00
240	-1.000000E-01	-4.500000E+00	0.000000E+00
241	-2.000000E-01	-4.750000E+00	0.000000E+00
242	2.700000E+00	0.000000E+00	0.000000E+00
243	2.950000E+00	-2.200000E-01	0.000000E+00
244	2.700000E+00	-5.000000E-01	0.000000E+00
245	2.950000E+00	-5.000000E-01	0.000000E+00
246	2.825000E+00	-1.100000E-01	0.000000E+00
247	3.075000E+00	-3.300000E-01	0.000000E+00
248	2.700000E+00	-2.500000E-01	0.000000E+00
249	2.950000E+00	-3.600000E-01	0.000000E+00
250	2.825000E+00	-5.000000E-01	0.000000E+00
251	3.075000E+00	-5.000000E-01	0.000000E+00
252	2.700000E+00	-1.000000E+00	0.000000E+00
253	2.950000E+00	-7.800000E-01	0.000000E+00
254	2.700000E+00	-7.500000E-01	0.000000E+00
255	2.950000E+00	-6.400000E-01	0.000000E+00
256	2.825000E+00	-8.900000E-01	0.000000E+00
257	3.075000E+00	-6.700000E-01	0.000000E+00
258	2.950000E+00	-1.220000E+00	0.000000E+00
259	2.700000E+00	-1.500000E+00	0.000000E+00
260	2.950000E+00	-1.500000E+00	0.000000E+00
261	2.825000E+00	-1.110000E+00	0.000000E+00
262	3.075000E+00	-1.330000E+00	0.000000E+00
263	2.700000E+00	-1.250000E+00	0.000000E+00
264	2.950000E+00	-1.360000E+00	0.000000E+00
265	2.825000E+00	-1.500000E+00	0.000000E+00
266	3.075000E+00	-1.500000E+00	0.000000E+00

267	2.700000E+00	-2.000000E+00	0.000000E+00
268	2.950000E+00	-1.780000E+00	0.000000E+00
269	2.700000E+00	-1.750000E+00	0.000000E+00
270	2.950000E+00	-1.640000E+00	0.000000E+00
271	2.825000E+00	-1.890000E+00	0.000000E+00
272	3.075000E+00	-1.670000E+00	0.000000E+00
273	2.950000E+00	-2.220000E+00	0.000000E+00
274	2.700000E+00	-2.500000E+00	0.000000E+00
275	2.950000E+00	-2.500000E+00	0.000000E+00
276	2.825000E+00	-2.110000E+00	0.000000E+00
277	3.075000E+00	-2.330000E+00	0.000000E+00
278	2.700000E+00	-2.250000E+00	0.000000E+00
279	2.950000E+00	-2.360000E+00	0.000000E+00
280	2.825000E+00	-2.500000E+00	0.000000E+00
281	3.075000E+00	-2.500000E+00	0.000000E+00
282	2.700000E+00	-3.000000E+00	0.000000E+00
283	2.950000E+00	-2.780000E+00	0.000000E+00
284	2.700000E+00	-2.750000E+00	0.000000E+00
285	2.950000E+00	-2.640000E+00	0.000000E+00
286	2.825000E+00	-2.890000E+00	0.000000E+00
287	3.075000E+00	-2.670000E+00	0.000000E+00
288	2.950000E+00	-3.220000E+00	0.000000E+00
289	2.700000E+00	-3.500000E+00	0.000000E+00
290	2.950000E+00	-3.500000E+00	0.000000E+00
291	2.825000E+00	-3.110000E+00	0.000000E+00
292	3.075000E+00	-3.330000E+00	0.000000E+00
293	2.700000E+00	-3.250000E+00	0.000000E+00
294	2.950000E+00	-3.360000E+00	0.000000E+00
295	2.825000E+00	-3.500000E+00	0.000000E+00
296	3.075000E+00	-3.500000E+00	0.000000E+00
297	2.700000E+00	-4.000000E+00	0.000000E+00
298	2.950000E+00	-3.780000E+00	0.000000E+00
299	2.700000E+00	-3.750000E+00	0.000000E+00
300	2.950000E+00	-3.640000E+00	0.000000E+00
301	2.825000E+00	-3.890000E+00	0.000000E+00
302	3.075000E+00	-3.670000E+00	0.000000E+00
303	2.950000E+00	-4.220000E+00	0.000000E+00
304	2.700000E+00	-4.500000E+00	0.000000E+00
305	2.950000E+00	-4.500000E+00	0.000000E+00

306	2.825000E+00	-4.110000E+00	0.000000E+00
307	3.075000E+00	-4.330000E+00	0.000000E+00
308	2.700000E+00	-4.250000E+00	0.000000E+00
309	2.950000E+00	-4.360000E+00	0.000000E+00
310	2.825000E+00	-4.500000E+00	0.000000E+00
311	3.075000E+00	-4.500000E+00	0.000000E+00
312	2.700000E+00	-5.000000E+00	0.000000E+00
313	2.950000E+00	-4.780000E+00	0.000000E+00
314	2.700000E+00	-4.750000E+00	0.000000E+00
315	2.950000E+00	-4.640000E+00	0.000000E+00
316	2.825000E+00	-4.890000E+00	0.000000E+00
317	3.075000E+00	-4.670000E+00	0.000000E+00
318	3.600000E+00	-2.200000E-01	0.000000E+00
319	3.800000E+00	0.000000E+00	0.000000E+00
320	3.600000E+00	-5.000000E-01	0.000000E+00
321	3.800000E+00	-5.000000E-01	0.000000E+00
322	3.500000E+00	-3.300000E-01	0.000000E+00
323	3.700000E+00	-1.100000E-01	0.000000E+00
324	3.600000E+00	-3.600000E-01	0.000000E+00
325	3.800000E+00	-2.500000E-01	0.000000E+00
326	3.500000E+00	-5.000000E-01	0.000000E+00
327	3.700000E+00	-5.000000E-01	0.000000E+00
328	3.600000E+00	-7.800000E-01	0.000000E+00
329	3.800000E+00	-1.000000E+00	0.000000E+00
330	3.600000E+00	-6.400000E-01	0.000000E+00
331	3.800000E+00	-7.500000E-01	0.000000E+00
332	3.500000E+00	-6.700000E-01	0.000000E+00
333	3.700000E+00	-8.900000E-01	0.000000E+00
334	3.600000E+00	-1.220000E+00	0.000000E+00
335	3.600000E+00	-1.500000E+00	0.000000E+00
336	3.800000E+00	-1.500000E+00	0.000000E+00
337	3.500000E+00	-1.330000E+00	0.000000E+00
338	3.700000E+00	-1.110000E+00	0.000000E+00
339	3.600000E+00	-1.360000E+00	0.000000E+00
340	3.800000E+00	-1.250000E+00	0.000000E+00
341	3.500000E+00	-1.500000E+00	0.000000E+00
342	3.700000E+00	-1.500000E+00	0.000000E+00
343	3.600000E+00	-1.780000E+00	0.000000E+00
344	3.800000E+00	-2.000000E+00	0.000000E+00

345	3.600000E+00	-1.640000E+00	0.000000E+00
346	3.800000E+00	-1.750000E+00	0.000000E+00
347	3.500000E+00	-1.670000E+00	0.000000E+00
348	3.700000E+00	-1.890000E+00	0.000000E+00
349	3.600000E+00	-2.220000E+00	0.000000E+00
350	3.600000E+00	-2.500000E+00	0.000000E+00
351	3.800000E+00	-2.500000E+00	0.000000E+00
352	3.500000E+00	-2.330000E+00	0.000000E+00
353	3.700000E+00	-2.110000E+00	0.000000E+00
354	3.600000E+00	-2.360000E+00	0.000000E+00
355	3.800000E+00	-2.250000E+00	0.000000E+00
356	3.500000E+00	-2.500000E+00	0.000000E+00
357	3.700000E+00	-2.500000E+00	0.000000E+00
358	3.600000E+00	-2.780000E+00	0.000000E+00
359	3.800000E+00	-3.000000E+00	0.000000E+00
360	3.600000E+00	-2.640000E+00	0.000000E+00
361	3.800000E+00	-2.750000E+00	0.000000E+00
362	3.500000E+00	-2.670000E+00	0.000000E+00
363	3.700000E+00	-2.890000E+00	0.000000E+00
364	3.600000E+00	-3.220000E+00	0.000000E+00
365	3.600000E+00	-3.500000E+00	0.000000E+00
366	3.800000E+00	-3.500000E+00	0.000000E+00
367	3.500000E+00	-3.330000E+00	0.000000E+00
368	3.700000E+00	-3.110000E+00	0.000000E+00
369	3.600000E+00	-3.360000E+00	0.000000E+00
370	3.800000E+00	-3.250000E+00	0.000000E+00
371	3.500000E+00	-3.500000E+00	0.000000E+00
372	3.700000E+00	-3.500000E+00	0.000000E+00
373	3.600000E+00	-3.780000E+00	0.000000E+00
374	3.800000E+00	-4.000000E+00	0.000000E+00
375	3.600000E+00	-3.640000E+00	0.000000E+00
376	3.800000E+00	-3.750000E+00	0.000000E+00
377	3.500000E+00	-3.670000E+00	0.000000E+00
378	3.700000E+00	-3.890000E+00	0.000000E+00
379	3.600000E+00	-4.220000E+00	0.000000E+00
380	3.600000E+00	-4.500000E+00	0.000000E+00
381	3.800000E+00	-4.500000E+00	0.000000E+00
382	3.500000E+00	-4.330000E+00	0.000000E+00
383	3.700000E+00	-4.110000E+00	0.000000E+00

384	3.600000E+00	-4.360000E+00	0.000000E+00
385	3.800000E+00	-4.250000E+00	0.000000E+00
386	3.500000E+00	-4.500000E+00	0.000000E+00
387	3.700000E+00	-4.500000E+00	0.000000E+00
388	3.600000E+00	-4.780000E+00	0.000000E+00
389	3.800000E+00	-5.000000E+00	0.000000E+00
390	3.600000E+00	-4.640000E+00	0.000000E+00
391	3.800000E+00	-4.750000E+00	0.000000E+00
392	3.500000E+00	-4.670000E+00	0.000000E+00
393	3.700000E+00	-4.890000E+00	0.000000E+00
394	3.250000E+00	0.000000E+00	0.000000E+00
395	3.275000E+00	-2.200000E-01	0.000000E+00
396	2.975000E+00	0.000000E+00	0.000000E+00
397	3.525000E+00	0.000000E+00	0.000000E+00
398	3.262500E+00	-1.100000E-01	0.000000E+00
399	3.112500E+00	-2.200000E-01	0.000000E+00
400	3.437500E+00	-2.200000E-01	0.000000E+00
401	3.287500E+00	-3.300000E-01	0.000000E+00
402	3.275000E+00	-7.800000E-01	0.000000E+00
403	3.250000E+00	-1.000000E+00	0.000000E+00
404	3.287500E+00	-6.700000E-01	0.000000E+00
405	3.112500E+00	-7.800000E-01	0.000000E+00
406	3.437500E+00	-7.800000E-01	0.000000E+00
407	3.262500E+00	-8.900000E-01	0.000000E+00
408	2.975000E+00	-1.000000E+00	0.000000E+00
409	3.525000E+00	-1.000000E+00	0.000000E+00
410	3.275000E+00	-1.220000E+00	0.000000E+00
411	3.262500E+00	-1.110000E+00	0.000000E+00
412	3.112500E+00	-1.220000E+00	0.000000E+00
413	3.437500E+00	-1.220000E+00	0.000000E+00
414	3.287500E+00	-1.330000E+00	0.000000E+00
415	3.275000E+00	-1.780000E+00	0.000000E+00
416	3.250000E+00	-2.000000E+00	0.000000E+00
417	3.287500E+00	-1.670000E+00	0.000000E+00
418	3.112500E+00	-1.780000E+00	0.000000E+00
419	3.437500E+00	-1.780000E+00	0.000000E+00
420	3.262500E+00	-1.890000E+00	0.000000E+00
421	2.975000E+00	-2.000000E+00	0.000000E+00
422	3.525000E+00	-2.000000E+00	0.000000E+00

423	3.275000E+00	-2.220000E+00	0.000000E+00
424	3.262500E+00	-2.110000E+00	0.000000E+00
425	3.112500E+00	-2.220000E+00	0.000000E+00
426	3.437500E+00	-2.220000E+00	0.000000E+00
427	3.287500E+00	-2.330000E+00	0.000000E+00
428	3.275000E+00	-2.780000E+00	0.000000E+00
429	3.250000E+00	-3.000000E+00	0.000000E+00
430	3.287500E+00	-2.670000E+00	0.000000E+00
431	3.112500E+00	-2.780000E+00	0.000000E+00
432	3.437500E+00	-2.780000E+00	0.000000E+00
433	3.262500E+00	-2.890000E+00	0.000000E+00
434	2.975000E+00	-3.000000E+00	0.000000E+00
435	3.525000E+00	-3.000000E+00	0.000000E+00
436	3.275000E+00	-3.220000E+00	0.000000E+00
437	3.262500E+00	-3.110000E+00	0.000000E+00
438	3.112500E+00	-3.220000E+00	0.000000E+00
439	3.437500E+00	-3.220000E+00	0.000000E+00
440	3.287500E+00	-3.330000E+00	0.000000E+00
441	3.275000E+00	-3.780000E+00	0.000000E+00
442	3.250000E+00	-4.000000E+00	0.000000E+00
443	3.287500E+00	-3.670000E+00	0.000000E+00
444	3.112500E+00	-3.780000E+00	0.000000E+00
445	3.437500E+00	-3.780000E+00	0.000000E+00
446	3.262500E+00	-3.890000E+00	0.000000E+00
447	2.975000E+00	-4.000000E+00	0.000000E+00
448	3.525000E+00	-4.000000E+00	0.000000E+00
449	3.275000E+00	-4.220000E+00	0.000000E+00
450	3.262500E+00	-4.110000E+00	0.000000E+00
451	3.112500E+00	-4.220000E+00	0.000000E+00
452	3.437500E+00	-4.220000E+00	0.000000E+00
453	3.287500E+00	-4.330000E+00	0.000000E+00
454	3.275000E+00	-4.780000E+00	0.000000E+00
455	3.250000E+00	-5.000000E+00	0.000000E+00
456	3.287500E+00	-4.670000E+00	0.000000E+00
457	3.112500E+00	-4.780000E+00	0.000000E+00
458	3.437500E+00	-4.780000E+00	0.000000E+00
459	3.262500E+00	-4.890000E+00	0.000000E+00
460	2.975000E+00	-5.000000E+00	0.000000E+00
461	3.525000E+00	-5.000000E+00	0.000000E+00

462	8.600000E-01	0.000000E+00	0.000000E+00
463	1.320000E+00	0.000000E+00	0.000000E+00
464	1.780000E+00	0.000000E+00	0.000000E+00
465	2.240000E+00	0.000000E+00	0.000000E+00
466	8.600000E-01	-5.000000E-01	0.000000E+00
467	1.320000E+00	-5.000000E-01	0.000000E+00
468	1.780000E+00	-5.000000E-01	0.000000E+00
469	2.240000E+00	-5.000000E-01	0.000000E+00
470	6.300000E-01	0.000000E+00	0.000000E+00
471	1.090000E+00	0.000000E+00	0.000000E+00
472	1.550000E+00	0.000000E+00	0.000000E+00
473	2.010000E+00	0.000000E+00	0.000000E+00
474	2.470000E+00	0.000000E+00	0.000000E+00
475	8.600000E-01	-2.500000E-01	0.000000E+00
476	1.320000E+00	-2.500000E-01	0.000000E+00
477	1.780000E+00	-2.500000E-01	0.000000E+00
478	2.240000E+00	-2.500000E-01	0.000000E+00
479	6.300000E-01	-5.000000E-01	0.000000E+00
480	1.090000E+00	-5.000000E-01	0.000000E+00
481	1.550000E+00	-5.000000E-01	0.000000E+00
482	2.010000E+00	-5.000000E-01	0.000000E+00
483	2.470000E+00	-5.000000E-01	0.000000E+00
484	8.600000E-01	-1.000000E+00	0.000000E+00
485	1.320000E+00	-1.000000E+00	0.000000E+00
486	1.780000E+00	-1.000000E+00	0.000000E+00
487	2.240000E+00	-1.000000E+00	0.000000E+00
488	8.600000E-01	-7.500000E-01	0.000000E+00
489	1.320000E+00	-7.500000E-01	0.000000E+00
490	1.780000E+00	-7.500000E-01	0.000000E+00
491	2.240000E+00	-7.500000E-01	0.000000E+00
492	6.300000E-01	-1.000000E+00	0.000000E+00
493	1.090000E+00	-1.000000E+00	0.000000E+00
494	1.550000E+00	-1.000000E+00	0.000000E+00
495	2.010000E+00	-1.000000E+00	0.000000E+00
496	2.470000E+00	-1.000000E+00	0.000000E+00
497	8.600000E-01	-1.500000E+00	0.000000E+00
498	1.320000E+00	-1.500000E+00	0.000000E+00
499	1.780000E+00	-1.500000E+00	0.000000E+00
500	2.240000E+00	-1.500000E+00	0.000000E+00

501	8.600000E-01	-1.250000E+00	0.000000E+00
502	1.320000E+00	-1.250000E+00	0.000000E+00
503	1.780000E+00	-1.250000E+00	0.000000E+00
504	2.240000E+00	-1.250000E+00	0.000000E+00
505	6.300000E-01	-1.500000E+00	0.000000E+00
506	1.090000E+00	-1.500000E+00	0.000000E+00
507	1.550000E+00	-1.500000E+00	0.000000E+00
508	2.010000E+00	-1.500000E+00	0.000000E+00
509	2.470000E+00	-1.500000E+00	0.000000E+00
510	8.600000E-01	-2.000000E+00	0.000000E+00
511	1.320000E+00	-2.000000E+00	0.000000E+00
512	1.780000E+00	-2.000000E+00	0.000000E+00
513	2.240000E+00	-2.000000E+00	0.000000E+00
514	8.600000E-01	-1.750000E+00	0.000000E+00
515	1.320000E+00	-1.750000E+00	0.000000E+00
516	1.780000E+00	-1.750000E+00	0.000000E+00
517	2.240000E+00	-1.750000E+00	0.000000E+00
518	6.300000E-01	-2.000000E+00	0.000000E+00
519	1.090000E+00	-2.000000E+00	0.000000E+00
520	1.550000E+00	-2.000000E+00	0.000000E+00
521	2.010000E+00	-2.000000E+00	0.000000E+00
522	2.470000E+00	-2.000000E+00	0.000000E+00
523	8.600000E-01	-2.500000E+00	0.000000E+00
524	1.320000E+00	-2.500000E+00	0.000000E+00
525	1.780000E+00	-2.500000E+00	0.000000E+00
526	2.240000E+00	-2.500000E+00	0.000000E+00
527	8.600000E-01	-2.250000E+00	0.000000E+00
528	1.320000E+00	-2.250000E+00	0.000000E+00
529	1.780000E+00	-2.250000E+00	0.000000E+00
530	2.240000E+00	-2.250000E+00	0.000000E+00
531	6.300000E-01	-2.500000E+00	0.000000E+00
532	1.090000E+00	-2.500000E+00	0.000000E+00
533	1.550000E+00	-2.500000E+00	0.000000E+00
534	2.010000E+00	-2.500000E+00	0.000000E+00
535	2.470000E+00	-2.500000E+00	0.000000E+00
536	8.600000E-01	-3.000000E+00	0.000000E+00
537	1.320000E+00	-3.000000E+00	0.000000E+00
538	1.780000E+00	-3.000000E+00	0.000000E+00
539	2.240000E+00	-3.000000E+00	0.000000E+00

540	8.600000E-01	-2.750000E+00	0.000000E+00
541	1.320000E+00	-2.750000E+00	0.000000E+00
542	1.780000E+00	-2.750000E+00	0.000000E+00
543	2.240000E+00	-2.750000E+00	0.000000E+00
544	6.300000E-01	-3.000000E+00	0.000000E+00
545	1.090000E+00	-3.000000E+00	0.000000E+00
546	1.550000E+00	-3.000000E+00	0.000000E+00
547	2.010000E+00	-3.000000E+00	0.000000E+00
548	2.470000E+00	-3.000000E+00	0.000000E+00
549	8.600000E-01	-3.500000E+00	0.000000E+00
550	1.320000E+00	-3.500000E+00	0.000000E+00
551	1.780000E+00	-3.500000E+00	0.000000E+00
552	2.240000E+00	-3.500000E+00	0.000000E+00
553	8.600000E-01	-3.250000E+00	0.000000E+00
554	1.320000E+00	-3.250000E+00	0.000000E+00
555	1.780000E+00	-3.250000E+00	0.000000E+00
556	2.240000E+00	-3.250000E+00	0.000000E+00
557	6.300000E-01	-3.500000E+00	0.000000E+00
558	1.090000E+00	-3.500000E+00	0.000000E+00
559	1.550000E+00	-3.500000E+00	0.000000E+00
560	2.010000E+00	-3.500000E+00	0.000000E+00
561	2.470000E+00	-3.500000E+00	0.000000E+00
562	8.600000E-01	-4.000000E+00	0.000000E+00
563	1.320000E+00	-4.000000E+00	0.000000E+00
564	1.780000E+00	-4.000000E+00	0.000000E+00
565	2.240000E+00	-4.000000E+00	0.000000E+00
566	8.600000E-01	-3.750000E+00	0.000000E+00
567	1.320000E+00	-3.750000E+00	0.000000E+00
568	1.780000E+00	-3.750000E+00	0.000000E+00
569	2.240000E+00	-3.750000E+00	0.000000E+00
570	6.300000E-01	-4.000000E+00	0.000000E+00
571	1.090000E+00	-4.000000E+00	0.000000E+00
572	1.550000E+00	-4.000000E+00	0.000000E+00
573	2.010000E+00	-4.000000E+00	0.000000E+00
574	2.470000E+00	-4.000000E+00	0.000000E+00
575	8.600000E-01	-4.500000E+00	0.000000E+00
576	1.320000E+00	-4.500000E+00	0.000000E+00
577	1.780000E+00	-4.500000E+00	0.000000E+00
578	2.240000E+00	-4.500000E+00	0.000000E+00

579	8.600000E-01	-4.250000E+00	0.000000E+00
580	1.320000E+00	-4.250000E+00	0.000000E+00
581	1.780000E+00	-4.250000E+00	0.000000E+00
582	2.240000E+00	-4.250000E+00	0.000000E+00
583	6.300000E-01	-4.500000E+00	0.000000E+00
584	1.090000E+00	-4.500000E+00	0.000000E+00
585	1.550000E+00	-4.500000E+00	0.000000E+00
586	2.010000E+00	-4.500000E+00	0.000000E+00
587	2.470000E+00	-4.500000E+00	0.000000E+00
588	8.600000E-01	-5.000000E+00	0.000000E+00
589	1.320000E+00	-5.000000E+00	0.000000E+00
590	1.780000E+00	-5.000000E+00	0.000000E+00
591	2.240000E+00	-5.000000E+00	0.000000E+00
592	8.600000E-01	-4.750000E+00	0.000000E+00
593	1.320000E+00	-4.750000E+00	0.000000E+00
594	1.780000E+00	-4.750000E+00	0.000000E+00
595	2.240000E+00	-4.750000E+00	0.000000E+00
596	6.300000E-01	-5.000000E+00	0.000000E+00
597	1.090000E+00	-5.000000E+00	0.000000E+00
598	1.550000E+00	-5.000000E+00	0.000000E+00
599	2.010000E+00	-5.000000E+00	0.000000E+00
600	2.470000E+00	-5.000000E+00	0.000000E+00
601	4.561358E+00	0.000000E+00	0.000000E+00
602	5.489465E+00	0.000000E+00	0.000000E+00
603	6.620839E+00	0.000000E+00	0.000000E+00
604	8.000000E+00	0.000000E+00	0.000000E+00
605	4.561358E+00	-5.000000E-01	0.000000E+00
606	5.489465E+00	-5.000000E-01	0.000000E+00
607	6.620839E+00	-5.000000E-01	0.000000E+00
608	8.000000E+00	-5.000000E-01	0.000000E+00
609	4.180679E+00	0.000000E+00	0.000000E+00
610	5.025412E+00	0.000000E+00	0.000000E+00
611	6.055152E+00	0.000000E+00	0.000000E+00
612	7.310420E+00	0.000000E+00	0.000000E+00
613	4.561358E+00	-2.500000E-01	0.000000E+00
614	5.489465E+00	-2.500000E-01	0.000000E+00
615	6.620839E+00	-2.500000E-01	0.000000E+00
616	8.000000E+00	-2.500000E-01	0.000000E+00
617	4.180679E+00	-5.000000E-01	0.000000E+00

618	5.025412E+00	-5.000000E-01	0.000000E+00
619	6.055152E+00	-5.000000E-01	0.000000E+00
620	7.310420E+00	-5.000000E-01	0.000000E+00
621	4.561358E+00	-1.000000E+00	0.000000E+00
622	5.489465E+00	-1.000000E+00	0.000000E+00
623	6.620839E+00	-1.000000E+00	0.000000E+00
624	8.000000E+00	-1.000000E+00	0.000000E+00
625	4.561358E+00	-7.500000E-01	0.000000E+00
626	5.489465E+00	-7.500000E-01	0.000000E+00
627	6.620839E+00	-7.500000E-01	0.000000E+00
628	8.000000E+00	-7.500000E-01	0.000000E+00
629	4.180679E+00	-1.000000E+00	0.000000E+00
630	5.025412E+00	-1.000000E+00	0.000000E+00
631	6.055152E+00	-1.000000E+00	0.000000E+00
632	7.310420E+00	-1.000000E+00	0.000000E+00
633	4.561358E+00	-1.500000E+00	0.000000E+00
634	5.489465E+00	-1.500000E+00	0.000000E+00
635	6.620839E+00	-1.500000E+00	0.000000E+00
636	8.000000E+00	-1.500000E+00	0.000000E+00
637	4.561358E+00	-1.250000E+00	0.000000E+00
638	5.489465E+00	-1.250000E+00	0.000000E+00
639	6.620839E+00	-1.250000E+00	0.000000E+00
640	8.000000E+00	-1.250000E+00	0.000000E+00
641	4.180679E+00	-1.500000E+00	0.000000E+00
642	5.025412E+00	-1.500000E+00	0.000000E+00
643	6.055152E+00	-1.500000E+00	0.000000E+00
644	7.310420E+00	-1.500000E+00	0.000000E+00
645	4.561358E+00	-2.000000E+00	0.000000E+00
646	5.489465E+00	-2.000000E+00	0.000000E+00
647	6.620839E+00	-2.000000E+00	0.000000E+00
648	8.000000E+00	-2.000000E+00	0.000000E+00
649	4.561358E+00	-1.750000E+00	0.000000E+00
650	5.489465E+00	-1.750000E+00	0.000000E+00
651	6.620839E+00	-1.750000E+00	0.000000E+00
652	8.000000E+00	-1.750000E+00	0.000000E+00
653	4.180679E+00	-2.000000E+00	0.000000E+00
654	5.025412E+00	-2.000000E+00	0.000000E+00
655	6.055152E+00	-2.000000E+00	0.000000E+00
656	7.310420E+00	-2.000000E+00	0.000000E+00

657	4.561358E+00	-2.500000E+00	0.000000E+00
658	5.489465E+00	-2.500000E+00	0.000000E+00
659	6.620839E+00	-2.500000E+00	0.000000E+00
660	8.000000E+00	-2.500000E+00	0.000000E+00
661	4.561358E+00	-2.250000E+00	0.000000E+00
662	5.489465E+00	-2.250000E+00	0.000000E+00
663	6.620839E+00	-2.250000E+00	0.000000E+00
664	8.000000E+00	-2.250000E+00	0.000000E+00
665	4.180679E+00	-2.500000E+00	0.000000E+00
666	5.025412E+00	-2.500000E+00	0.000000E+00
667	6.055152E+00	-2.500000E+00	0.000000E+00
668	7.310420E+00	-2.500000E+00	0.000000E+00
669	4.561358E+00	-3.000000E+00	0.000000E+00
670	5.489465E+00	-3.000000E+00	0.000000E+00
671	6.620839E+00	-3.000000E+00	0.000000E+00
672	8.000000E+00	-3.000000E+00	0.000000E+00
673	4.561358E+00	-2.750000E+00	0.000000E+00
674	5.489465E+00	-2.750000E+00	0.000000E+00
675	6.620839E+00	-2.750000E+00	0.000000E+00
676	8.000000E+00	-2.750000E+00	0.000000E+00
677	4.180679E+00	-3.000000E+00	0.000000E+00
678	5.025412E+00	-3.000000E+00	0.000000E+00
679	6.055152E+00	-3.000000E+00	0.000000E+00
680	7.310420E+00	-3.000000E+00	0.000000E+00
681	4.561358E+00	-3.500000E+00	0.000000E+00
682	5.489465E+00	-3.500000E+00	0.000000E+00
683	6.620839E+00	-3.500000E+00	0.000000E+00
684	8.000000E+00	-3.500000E+00	0.000000E+00
685	4.561358E+00	-3.250000E+00	0.000000E+00
686	5.489465E+00	-3.250000E+00	0.000000E+00
687	6.620839E+00	-3.250000E+00	0.000000E+00
688	8.000000E+00	-3.250000E+00	0.000000E+00
689	4.180679E+00	-3.500000E+00	0.000000E+00
690	5.025412E+00	-3.500000E+00	0.000000E+00
691	6.055152E+00	-3.500000E+00	0.000000E+00
692	7.310420E+00	-3.500000E+00	0.000000E+00
693	4.561358E+00	-4.000000E+00	0.000000E+00
694	5.489465E+00	-4.000000E+00	0.000000E+00
695	6.620839E+00	-4.000000E+00	0.000000E+00

696	8.000000E+00	-4.000000E+00	0.000000E+00
697	4.561358E+00	-3.750000E+00	0.000000E+00
698	5.489465E+00	-3.750000E+00	0.000000E+00
699	6.620839E+00	-3.750000E+00	0.000000E+00
700	8.000000E+00	-3.750000E+00	0.000000E+00
701	4.180679E+00	-4.000000E+00	0.000000E+00
702	5.025412E+00	-4.000000E+00	0.000000E+00
703	6.055152E+00	-4.000000E+00	0.000000E+00
704	7.310420E+00	-4.000000E+00	0.000000E+00
705	4.561358E+00	-4.500000E+00	0.000000E+00
706	5.489465E+00	-4.500000E+00	0.000000E+00
707	6.620839E+00	-4.500000E+00	0.000000E+00
708	8.000000E+00	-4.500000E+00	0.000000E+00
709	4.561358E+00	-4.250000E+00	0.000000E+00
710	5.489465E+00	-4.250000E+00	0.000000E+00
711	6.620839E+00	-4.250000E+00	0.000000E+00
712	8.000000E+00	-4.250000E+00	0.000000E+00
713	4.180679E+00	-4.500000E+00	0.000000E+00
714	5.025412E+00	-4.500000E+00	0.000000E+00
715	6.055152E+00	-4.500000E+00	0.000000E+00
716	7.310420E+00	-4.500000E+00	0.000000E+00
717	4.561358E+00	-5.000000E+00	0.000000E+00
718	5.489465E+00	-5.000000E+00	0.000000E+00
719	6.620839E+00	-5.000000E+00	0.000000E+00
720	8.000000E+00	-5.000000E+00	0.000000E+00
721	4.561358E+00	-4.750000E+00	0.000000E+00
722	5.489465E+00	-4.750000E+00	0.000000E+00
723	6.620839E+00	-4.750000E+00	0.000000E+00
724	8.000000E+00	-4.750000E+00	0.000000E+00
725	4.180679E+00	-5.000000E+00	0.000000E+00
726	5.025412E+00	-5.000000E+00	0.000000E+00
727	6.055152E+00	-5.000000E+00	0.000000E+00
728	7.310420E+00	-5.000000E+00	0.000000E+00
729	0.000000E+00	-5.889552E+00	0.000000E+00
730	2.000000E-01	-5.889552E+00	0.000000E+00
731	0.000000E+00	-6.799421E+00	0.000000E+00
732	2.000000E-01	-6.799421E+00	0.000000E+00
733	0.000000E+00	-8.000000E+00	0.000000E+00
734	2.000000E-01	-8.000000E+00	0.000000E+00

735	0.000000E+00	-5.544775E+00	0.000000E+00
736	2.000000E-01	-5.544775E+00	0.000000E+00
737	1.000000E-01	-5.889552E+00	0.000000E+00
738	0.000000E+00	-6.344486E+00	0.000000E+00
739	2.000000E-01	-6.344486E+00	0.000000E+00
740	1.000000E-01	-6.799421E+00	0.000000E+00
741	0.000000E+00	-7.399710E+00	0.000000E+00
742	2.000000E-01	-7.399710E+00	0.000000E+00
743	1.000000E-01	-8.000000E+00	0.000000E+00
744	3.000000E-01	-5.889552E+00	0.000000E+00
745	4.000000E-01	-5.889552E+00	0.000000E+00
746	3.000000E-01	-6.799421E+00	0.000000E+00
747	4.000000E-01	-6.799421E+00	0.000000E+00
748	3.000000E-01	-8.000000E+00	0.000000E+00
749	4.000000E-01	-8.000000E+00	0.000000E+00
750	3.000000E-01	-5.544776E+00	0.000000E+00
751	4.000000E-01	-5.544775E+00	0.000000E+00
752	2.500000E-01	-5.889552E+00	0.000000E+00
753	3.500000E-01	-5.889552E+00	0.000000E+00
754	3.000000E-01	-6.344486E+00	0.000000E+00
755	4.000000E-01	-6.344486E+00	0.000000E+00
756	2.500000E-01	-6.799421E+00	0.000000E+00
757	3.500000E-01	-6.799421E+00	0.000000E+00
758	3.000000E-01	-7.399710E+00	0.000000E+00
759	4.000000E-01	-7.399710E+00	0.000000E+00
760	2.500000E-01	-8.000000E+00	0.000000E+00
761	3.500000E-01	-8.000000E+00	0.000000E+00
762	8.600000E-01	-5.200000E+00	0.000000E+00
763	1.320000E+00	-5.200000E+00	0.000000E+00
764	1.780000E+00	-5.200000E+00	0.000000E+00
765	2.240000E+00	-5.200000E+00	0.000000E+00
766	2.700000E+00	-5.200000E+00	0.000000E+00
767	8.600000E-01	-5.889552E+00	0.000000E+00
768	1.320000E+00	-5.889552E+00	0.000000E+00
769	1.780000E+00	-5.889552E+00	0.000000E+00
770	2.240000E+00	-5.889552E+00	0.000000E+00
771	2.700000E+00	-5.889552E+00	0.000000E+00
772	8.600000E-01	-6.799421E+00	0.000000E+00
773	1.320000E+00	-6.799421E+00	0.000000E+00

774	1.780000E+00	-6.799421E+00	0.000000E+00
775	2.240000E+00	-6.799421E+00	0.000000E+00
776	2.700000E+00	-6.799421E+00	0.000000E+00
777	8.600000E-01	-8.000000E+00	0.000000E+00
778	1.320000E+00	-8.000000E+00	0.000000E+00
779	1.780000E+00	-8.000000E+00	0.000000E+00
780	2.240000E+00	-8.000000E+00	0.000000E+00
781	2.700000E+00	-8.000000E+00	0.000000E+00
782	6.300000E-01	-5.200000E+00	0.000000E+00
783	1.090000E+00	-5.200000E+00	0.000000E+00
784	1.550000E+00	-5.200000E+00	0.000000E+00
785	2.010000E+00	-5.200000E+00	0.000000E+00
786	2.470000E+00	-5.200000E+00	0.000000E+00
787	8.600000E-01	-5.544776E+00	0.000000E+00
788	1.320000E+00	-5.544776E+00	0.000000E+00
789	1.780000E+00	-5.544776E+00	0.000000E+00
790	2.240000E+00	-5.544775E+00	0.000000E+00
791	2.700000E+00	-5.544775E+00	0.000000E+00
792	6.300001E-01	-5.889552E+00	0.000000E+00
793	1.090000E+00	-5.889552E+00	0.000000E+00
794	1.550000E+00	-5.889552E+00	0.000000E+00
795	2.010000E+00	-5.889552E+00	0.000000E+00
796	2.470000E+00	-5.889552E+00	0.000000E+00
797	8.600000E-01	-6.344486E+00	0.000000E+00
798	1.320000E+00	-6.344486E+00	0.000000E+00
799	1.780000E+00	-6.344486E+00	0.000000E+00
800	2.240000E+00	-6.344486E+00	0.000000E+00
801	2.700000E+00	-6.344486E+00	0.000000E+00
802	6.300001E-01	-6.799421E+00	0.000000E+00
803	1.090000E+00	-6.799421E+00	0.000000E+00
804	1.550000E+00	-6.799421E+00	0.000000E+00
805	2.010000E+00	-6.799421E+00	0.000000E+00
806	2.470000E+00	-6.799421E+00	0.000000E+00
807	8.600001E-01	-7.399710E+00	0.000000E+00
808	1.320000E+00	-7.399710E+00	0.000000E+00
809	1.780000E+00	-7.399710E+00	0.000000E+00
810	2.240000E+00	-7.399710E+00	0.000000E+00
811	2.700000E+00	-7.399710E+00	0.000000E+00
812	6.300000E-01	-8.000000E+00	0.000000E+00

813	1.090000E+00	-8.000000E+00	0.000000E+00
814	1.550000E+00	-8.000000E+00	0.000000E+00
815	2.010000E+00	-8.000000E+00	0.000000E+00
816	2.470000E+00	-8.000000E+00	0.000000E+00
817	3.250000E+00	-5.200000E+00	0.000000E+00
818	3.800000E+00	-5.200000E+00	0.000000E+00
819	3.250000E+00	-5.889552E+00	0.000000E+00
820	3.800000E+00	-5.889552E+00	0.000000E+00
821	3.250000E+00	-6.799421E+00	0.000000E+00
822	3.800000E+00	-6.799421E+00	0.000000E+00
823	3.250000E+00	-8.000000E+00	0.000000E+00
824	3.800000E+00	-8.000000E+00	0.000000E+00
825	2.975000E+00	-5.200000E+00	0.000000E+00
826	3.525000E+00	-5.200000E+00	0.000000E+00
827	3.250000E+00	-5.544776E+00	0.000000E+00
828	3.800000E+00	-5.544775E+00	0.000000E+00
829	2.975000E+00	-5.889552E+00	0.000000E+00
830	3.525000E+00	-5.889552E+00	0.000000E+00
831	3.250000E+00	-6.344486E+00	0.000000E+00
832	3.800000E+00	-6.344486E+00	0.000000E+00
833	2.975000E+00	-6.799421E+00	0.000000E+00
834	3.525000E+00	-6.799421E+00	0.000000E+00
835	3.250000E+00	-7.399710E+00	0.000000E+00
836	3.800000E+00	-7.399710E+00	0.000000E+00
837	2.975000E+00	-8.000000E+00	0.000000E+00
838	3.525000E+00	-8.000000E+00	0.000000E+00
839	2.700000E+00	-5.100000E+00	0.000000E+00
840	3.250000E+00	-5.100000E+00	0.000000E+00
841	3.800000E+00	-5.100000E+00	0.000000E+00
842	4.561358E+00	-5.200000E+00	0.000000E+00
843	5.489465E+00	-5.200000E+00	0.000000E+00
844	6.620839E+00	-5.200000E+00	0.000000E+00
845	8.000000E+00	-5.200000E+00	0.000000E+00
846	4.561358E+00	-5.889552E+00	0.000000E+00
847	5.489465E+00	-5.889552E+00	0.000000E+00
848	6.620839E+00	-5.889552E+00	0.000000E+00
849	8.000000E+00	-5.889552E+00	0.000000E+00
850	4.561359E+00	-6.799421E+00	0.000000E+00
851	5.489465E+00	-6.799421E+00	0.000000E+00

852	6.620839E+00	-6.799421E+00	0.000000E+00
853	8.000000E+00	-6.799421E+00	0.000000E+00
854	4.561358E+00	-8.000000E+00	0.000000E+00
855	5.489465E+00	-8.000000E+00	0.000000E+00
856	6.620839E+00	-8.000000E+00	0.000000E+00
857	8.000000E+00	-8.000000E+00	0.000000E+00
858	4.180679E+00	-5.200000E+00	0.000000E+00
859	5.025412E+00	-5.200000E+00	0.000000E+00
860	6.055152E+00	-5.200000E+00	0.000000E+00
861	7.310420E+00	-5.200000E+00	0.000000E+00
862	4.561358E+00	-5.544776E+00	0.000000E+00
863	5.489465E+00	-5.544776E+00	0.000000E+00
864	6.620839E+00	-5.544776E+00	0.000000E+00
865	8.000000E+00	-5.544775E+00	0.000000E+00
866	4.180679E+00	-5.889552E+00	0.000000E+00
867	5.025412E+00	-5.889552E+00	0.000000E+00
868	6.055152E+00	-5.889552E+00	0.000000E+00
869	7.310420E+00	-5.889552E+00	0.000000E+00
870	4.561358E+00	-6.344486E+00	0.000000E+00
871	5.489465E+00	-6.344486E+00	0.000000E+00
872	6.620839E+00	-6.344486E+00	0.000000E+00
873	8.000000E+00	-6.344486E+00	0.000000E+00
874	4.180679E+00	-6.799421E+00	0.000000E+00
875	5.025412E+00	-6.799421E+00	0.000000E+00
876	6.055152E+00	-6.799421E+00	0.000000E+00
877	7.310420E+00	-6.799421E+00	0.000000E+00
878	4.561359E+00	-7.399710E+00	0.000000E+00
879	5.489465E+00	-7.399710E+00	0.000000E+00
880	6.620839E+00	-7.399710E+00	0.000000E+00
881	8.000000E+00	-7.399710E+00	0.000000E+00
882	4.180679E+00	-8.000000E+00	0.000000E+00
883	5.025412E+00	-8.000000E+00	0.000000E+00
884	6.055152E+00	-8.000000E+00	0.000000E+00
885	7.310420E+00	-8.000000E+00	0.000000E+00
886	8.600000E-01	-5.100000E+00	0.000000E+00
887	1.320000E+00	-5.100000E+00	0.000000E+00
888	1.780000E+00	-5.100000E+00	0.000000E+00
889	2.240000E+00	-5.100000E+00	0.000000E+00
890	4.561358E+00	-5.100000E+00	0.000000E+00

891	5.489465E+00	-5.100000E+00	0.000000E+00
892	6.620839E+00	-5.100000E+00	0.000000E+00
893	8.000000E+00	-5.100000E+00	0.000000E+00
894	-2.000000E-01	-5.889552E+00	0.000000E+00
895	-2.000000E-01	-6.799421E+00	0.000000E+00
896	-2.000000E-01	-8.000000E+00	0.000000E+00
897	-2.000000E-01	-5.544775E+00	0.000000E+00
898	-1.000000E-01	-5.889552E+00	0.000000E+00
899	-2.000000E-01	-6.344486E+00	0.000000E+00
900	-1.000000E-01	-6.799421E+00	0.000000E+00
901	-2.000000E-01	-7.399710E+00	0.000000E+00
902	-1.000000E-01	-8.000000E+00	0.000000E+00
903	-5.000000E+00	-5.200000E+00	0.000000E+00
904	-2.941864E+00	-5.200000E+00	0.000000E+00
905	-1.382089E+00	-5.200000E+00	0.000000E+00
906	-5.000000E+00	-5.889552E+00	0.000000E+00
907	-2.941864E+00	-5.889552E+00	0.000000E+00
908	-1.382088E+00	-5.889552E+00	0.000000E+00
909	-5.000000E+00	-6.799421E+00	0.000000E+00
910	-2.941864E+00	-6.799421E+00	0.000000E+00
911	-1.382089E+00	-6.799421E+00	0.000000E+00
912	-5.000000E+00	-8.000000E+00	0.000000E+00
913	-2.941864E+00	-8.000000E+00	0.000000E+00
914	-1.382089E+00	-8.000000E+00	0.000000E+00
915	-3.970932E+00	-5.200000E+00	0.000000E+00
916	-2.161977E+00	-5.200000E+00	0.000000E+00
917	-7.910444E-01	-5.200000E+00	0.000000E+00
918	-5.000000E+00	-5.544775E+00	0.000000E+00
919	-2.941864E+00	-5.544776E+00	0.000000E+00
920	-1.382088E+00	-5.544775E+00	0.000000E+00
921	-3.970932E+00	-5.889552E+00	0.000000E+00
922	-2.161976E+00	-5.889552E+00	0.000000E+00
923	-7.910443E-01	-5.889552E+00	0.000000E+00
924	-5.000000E+00	-6.344486E+00	0.000000E+00
925	-2.941864E+00	-6.344486E+00	0.000000E+00
926	-1.382089E+00	-6.344486E+00	0.000000E+00
927	-3.970932E+00	-6.799421E+00	0.000000E+00
928	-2.161976E+00	-6.799421E+00	0.000000E+00
929	-7.910444E-01	-6.799421E+00	0.000000E+00

930	-5.000000E+00	-7.399710E+00	0.000000E+00
931	-2.941864E+00	-7.399710E+00	0.000000E+00
932	-1.382089E+00	-7.399710E+00	0.000000E+00
933	-3.970932E+00	-8.000000E+00	0.000000E+00
934	-2.161977E+00	-8.000000E+00	0.000000E+00
935	-7.910444E-01	-8.000000E+00	0.000000E+00
936	-5.000000E+00	-5.000000E+00	0.000000E+00
937	-2.941864E+00	-5.000000E+00	0.000000E+00
938	-1.382089E+00	-5.000000E+00	0.000000E+00
939	-3.970932E+00	-5.000000E+00	0.000000E+00
940	-2.161977E+00	-5.000000E+00	0.000000E+00
941	-7.910444E-01	-5.000000E+00	0.000000E+00
942	-5.000000E+00	-5.100000E+00	0.000000E+00
943	-2.941864E+00	-5.100000E+00	0.000000E+00
944	-1.382089E+00	-5.100000E+00	0.000000E+00
945	-5.000000E+00	-4.500000E+00	0.000000E+00
946	-2.941864E+00	-4.500000E+00	0.000000E+00
947	-1.382089E+00	-4.500000E+00	0.000000E+00
948	-3.970932E+00	-4.500000E+00	0.000000E+00
949	-2.161977E+00	-4.500000E+00	0.000000E+00
950	-7.910444E-01	-4.500000E+00	0.000000E+00
951	-5.000000E+00	-4.750000E+00	0.000000E+00
952	-2.941864E+00	-4.750000E+00	0.000000E+00
953	-1.382089E+00	-4.750000E+00	0.000000E+00

'ELEMENTS'

CONNECTIVITY

1 CQ16E 1 5 2 7 4 8 3 6
2 CQ16E 3 8 4 12 10 13 9 11
3 CQ16E 9 13 10 17 15 18 14 16
4 CQ16E 14 18 15 22 20 23 19 21
5 CQ16E 19 23 20 27 25 28 24 26
6 CQ16E 24 28 25 32 30 33 29 31
7 CQ16E 29 33 30 37 35 38 34 36
8 CQ16E 34 38 35 42 40 43 39 41
9 CQ16E 39 43 40 47 45 48 44 46
10 CQ16E 44 48 45 52 50 53 49 51
11 CQ16E 49 53 50 57 55 58 54 56
12 CQ16E 59 61 49 56 54 63 60 62
13 CQ16E 50 68 64 70 66 72 55 57

14 CQ16E 64 69 65 71 67 73 66 70
15 CQ16E 74 80 75 83 78 85 77 82
16 CQ16E 75 81 76 84 79 86 78 83
17 CQ16E 77 85 78 91 88 93 87 90
18 CQ16E 78 86 79 92 89 94 88 91
19 CQ16E 95 101 96 104 99 106 98 103
20 CQ16E 96 102 97 105 100 107 99 104
21 CQ16E 98 106 99 112 109 114 108 111
22 CQ16E 99 107 100 113 110 115 109 112
23 CQ16E 116 122 117 125 120 127 119 124
24 CQ16E 117 123 118 126 121 128 120 125
25 CQ16E 119 127 120 133 130 135 129 132
26 CQ16E 120 128 121 134 131 136 130 133
27 CQ16E 137 143 138 146 141 148 140 145
28 CQ16E 138 144 139 147 142 149 141 146
29 CQ16E 140 148 141 154 151 156 150 153
30 CQ16E 141 149 142 155 152 157 151 154
31 CQ16E 158 164 159 167 162 169 161 166
32 CQ16E 159 165 160 168 163 170 162 167
33 CQ16E 161 169 162 175 172 177 171 174
34 CQ16E 162 170 163 176 173 178 172 175
35 CQ16E 2 183 179 185 181 187 4 7
36 CQ16E 179 184 180 186 182 188 181 185
37 CQ16E 4 187 181 191 189 193 10 12
38 CQ16E 181 188 182 192 190 194 189 191
39 CQ16E 10 193 189 197 195 199 15 17
40 CQ16E 189 194 190 198 196 200 195 197
41 CQ16E 15 199 195 203 201 205 20 22
42 CQ16E 195 200 196 204 202 206 201 203
43 CQ16E 20 205 201 209 207 211 25 27
44 CQ16E 201 206 202 210 208 212 207 209
45 CQ16E 25 211 207 215 213 217 30 32
46 CQ16E 207 212 208 216 214 218 213 215
47 CQ16E 30 217 213 221 219 223 35 37
48 CQ16E 213 218 214 222 220 224 219 221
49 CQ16E 35 223 219 227 225 229 40 42
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52 CQ16E 225 230 226 234 232 236 231 233

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54 CQ16E 231 236 232 238 65 69 64 237
55 CQ16E 239 240 44 51 49 61 59 241
56 CQ16E 242 246 243 249 245 250 244 248
57 CQ16E 243 247 74 82 77 251 245 249
58 CQ16E 244 250 245 255 253 256 252 254
59 CQ16E 245 251 77 90 87 257 253 255
60 CQ16E 252 261 258 264 260 265 259 263
61 CQ16E 258 262 95 103 98 266 260 264
62 CQ16E 259 265 260 270 268 271 267 269
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65 CQ16E 273 277 116 124 119 281 275 279
66 CQ16E 274 280 275 285 283 286 282 284
67 CQ16E 275 281 119 132 129 287 283 285
68 CQ16E 282 291 288 294 290 295 289 293
69 CQ16E 288 292 137 145 140 296 290 294
70 CQ16E 289 295 290 300 298 301 297 299
71 CQ16E 290 296 140 153 150 302 298 300
72 CQ16E 297 306 303 309 305 310 304 308
73 CQ16E 303 307 158 166 161 311 305 309
74 CQ16E 304 310 305 315 313 316 312 314
75 CQ16E 305 311 161 174 171 317 313 315
76 CQ16E 76 322 318 324 320 326 79 84
77 CQ16E 318 323 319 325 321 327 320 324
78 CQ16E 79 326 320 330 328 332 89 92
79 CQ16E 320 327 321 331 329 333 328 330
80 CQ16E 97 337 334 339 335 341 100 105
81 CQ16E 334 338 329 340 336 342 335 339
82 CQ16E 100 341 335 345 343 347 110 113
83 CQ16E 335 342 336 346 344 348 343 345
84 CQ16E 118 352 349 354 350 356 121 126
85 CQ16E 349 353 344 355 351 357 350 354
86 CQ16E 121 356 350 360 358 362 131 134
87 CQ16E 350 357 351 361 359 363 358 360
88 CQ16E 139 367 364 369 365 371 142 147
89 CQ16E 364 368 359 370 366 372 365 369
90 CQ16E 142 371 365 375 373 377 152 155
91 CQ16E 365 372 366 376 374 378 373 375

92 CQ16E 160 382 379 384 380 386 163 168
93 CQ16E 379 383 374 385 381 387 380 384
94 CQ16E 163 386 380 390 388 392 173 176
95 CQ16E 380 387 381 391 389 393 388 390
96 CQ16E 242 396 394 398 395 399 243 246
97 CQ16E 394 397 319 323 318 400 395 398
98 CQ16E 243 399 395 401 75 80 74 247
99 CQ16E 395 400 318 322 76 81 75 401
100 CQ16E 87 93 88 404 402 405 253 257
101 CQ16E 88 94 89 332 328 406 402 404
102 CQ16E 253 405 402 407 403 408 252 256
103 CQ16E 402 406 328 333 329 409 403 407
104 CQ16E 252 408 403 411 410 412 258 261
105 CQ16E 403 409 329 338 334 413 410 411
106 CQ16E 258 412 410 414 96 101 95 262
107 CQ16E 410 413 334 337 97 102 96 414
108 CQ16E 108 114 109 417 415 418 268 272
109 CQ16E 109 115 110 347 343 419 415 417
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111 CQ16E 415 419 343 348 344 422 416 420
112 CQ16E 267 421 416 424 423 425 273 276
113 CQ16E 416 422 344 353 349 426 423 424
114 CQ16E 273 425 423 427 117 122 116 277
115 CQ16E 423 426 349 352 118 123 117 427
116 CQ16E 129 135 130 430 428 431 283 287
117 CQ16E 130 136 131 362 358 432 428 430
118 CQ16E 283 431 428 433 429 434 282 286
119 CQ16E 428 432 358 363 359 435 429 433
120 CQ16E 282 434 429 437 436 438 288 291
121 CQ16E 429 435 359 368 364 439 436 437
122 CQ16E 288 438 436 440 138 143 137 292
123 CQ16E 436 439 364 367 139 144 138 440
124 CQ16E 150 156 151 443 441 444 298 302
125 CQ16E 151 157 152 377 373 445 441 443
126 CQ16E 298 444 441 446 442 447 297 301
127 CQ16E 441 445 373 378 374 448 442 446
128 CQ16E 297 447 442 450 449 451 303 306
129 CQ16E 442 448 374 383 379 452 449 450
130 CQ16E 303 451 449 453 159 164 158 307

131	CQ16E	449	452	379	382	160	165	159	453
132	CQ16E	171	177	172	456	454	457	313	317
133	CQ16E	172	178	173	392	388	458	454	456
134	CQ16E	313	457	454	459	455	460	312	316
135	CQ16E	454	458	388	393	389	461	455	459
136	CQ16E	180	470	462	475	466	479	182	186
137	CQ16E	462	471	463	476	467	480	466	475
138	CQ16E	463	472	464	477	468	481	467	476
139	CQ16E	464	473	465	478	469	482	468	477
140	CQ16E	465	474	242	248	244	483	469	478
141	CQ16E	182	479	466	488	484	492	190	192
142	CQ16E	466	480	467	489	485	493	484	488
143	CQ16E	467	481	468	490	486	494	485	489
144	CQ16E	468	482	469	491	487	495	486	490
145	CQ16E	469	483	244	254	252	496	487	491
146	CQ16E	190	492	484	501	497	505	196	198
147	CQ16E	484	493	485	502	498	506	497	501
148	CQ16E	485	494	486	503	499	507	498	502
149	CQ16E	486	495	487	504	500	508	499	503
150	CQ16E	487	496	252	263	259	509	500	504
151	CQ16E	196	505	497	514	510	518	202	204
152	CQ16E	497	506	498	515	511	519	510	514
153	CQ16E	498	507	499	516	512	520	511	515
154	CQ16E	499	508	500	517	513	521	512	516
155	CQ16E	500	509	259	269	267	522	513	517
156	CQ16E	202	518	510	527	523	531	208	210
157	CQ16E	510	519	511	528	524	532	523	527
158	CQ16E	511	520	512	529	525	533	524	528
159	CQ16E	512	521	513	530	526	534	525	529
160	CQ16E	513	522	267	278	274	535	526	530
161	CQ16E	208	531	523	540	536	544	214	216
162	CQ16E	523	532	524	541	537	545	536	540
163	CQ16E	524	533	525	542	538	546	537	541
164	CQ16E	525	534	526	543	539	547	538	542
165	CQ16E	526	535	274	284	282	548	539	543
166	CQ16E	214	544	536	553	549	557	220	222
167	CQ16E	536	545	537	554	550	558	549	553
168	CQ16E	537	546	538	555	551	559	550	554
169	CQ16E	538	547	539	556	552	560	551	555

170	CQ16E	539 548 282 293 289 561 552 556
171	CQ16E	220 557 549 566 562 570 226 228
172	CQ16E	549 558 550 567 563 571 562 566
173	CQ16E	550 559 551 568 564 572 563 567
174	CQ16E	551 560 552 569 565 573 564 568
175	CQ16E	552 561 289 299 297 574 565 569
176	CQ16E	226 570 562 579 575 583 232 234
177	CQ16E	562 571 563 580 576 584 575 579
178	CQ16E	563 572 564 581 577 585 576 580
179	CQ16E	564 573 565 582 578 586 577 581
180	CQ16E	565 574 297 308 304 587 578 582
181	CQ16E	232 583 575 592 588 596 65 238
182	CQ16E	575 584 576 593 589 597 588 592
183	CQ16E	576 585 577 594 590 598 589 593
184	CQ16E	577 586 578 595 591 599 590 594
185	CQ16E	578 587 304 314 312 600 591 595
186	CQ16E	319 609 601 613 605 617 321 325
187	CQ16E	601 610 602 614 606 618 605 613
188	CQ16E	602 611 603 615 607 619 606 614
189	CQ16E	603 612 604 616 608 620 607 615
190	CQ16E	321 617 605 625 621 629 329 331
191	CQ16E	605 618 606 626 622 630 621 625
192	CQ16E	606 619 607 627 623 631 622 626
193	CQ16E	607 620 608 628 624 632 623 627
194	CQ16E	329 629 621 637 633 641 336 340
195	CQ16E	621 630 622 638 634 642 633 637
196	CQ16E	622 631 623 639 635 643 634 638
197	CQ16E	623 632 624 640 636 644 635 639
198	CQ16E	336 641 633 649 645 653 344 346
199	CQ16E	633 642 634 650 646 654 645 649
200	CQ16E	634 643 635 651 647 655 646 650
201	CQ16E	635 644 636 652 648 656 647 651
202	CQ16E	344 653 645 661 657 665 351 355
203	CQ16E	645 654 646 662 658 666 657 661
204	CQ16E	646 655 647 663 659 667 658 662
205	CQ16E	647 656 648 664 660 668 659 663
206	CQ16E	351 665 657 673 669 677 359 361
207	CQ16E	657 666 658 674 670 678 669 673
208	CQ16E	658 667 659 675 671 679 670 674

209 CQ16E 659 668 660 676 672 680 671 675
210 CQ16E 359 677 669 685 681 689 366 370
211 CQ16E 669 678 670 686 682 690 681 685
212 CQ16E 670 679 671 687 683 691 682 686
213 CQ16E 671 680 672 688 684 692 683 687
214 CQ16E 366 689 681 697 693 701 374 376
215 CQ16E 681 690 682 698 694 702 693 697
216 CQ16E 682 691 683 699 695 703 694 698
217 CQ16E 683 692 684 700 696 704 695 699
218 CQ16E 374 701 693 709 705 713 381 385
219 CQ16E 693 702 694 710 706 714 705 709
220 CQ16E 694 703 695 711 707 715 706 710
221 CQ16E 695 704 696 712 708 716 707 711
222 CQ16E 381 713 705 721 717 725 389 391
223 CQ16E 705 714 706 722 718 726 717 721
224 CQ16E 706 715 707 723 719 727 718 722
225 CQ16E 707 716 708 724 720 728 719 723
226 CQ16E 54 58 55 736 730 737 729 735
227 CQ16E 729 737 730 739 732 740 731 738
228 CQ16E 731 740 732 742 734 743 733 741
229 CQ16E 55 72 66 750 744 752 730 736
230 CQ16E 66 73 67 751 745 753 744 750
231 CQ16E 730 752 744 754 746 756 732 739
232 CQ16E 744 753 745 755 747 757 746 754
233 CQ16E 732 756 746 758 748 760 734 742
234 CQ16E 746 757 747 759 749 761 748 758
235 CQ16E 67 782 762 787 767 792 745 751
236 CQ16E 762 783 763 788 768 793 767 787
237 CQ16E 763 784 764 789 769 794 768 788
238 CQ16E 764 785 765 790 770 795 769 789
239 CQ16E 765 786 766 791 771 796 770 790
240 CQ16E 745 792 767 797 772 802 747 755
241 CQ16E 767 793 768 798 773 803 772 797
242 CQ16E 768 794 769 799 774 804 773 798
243 CQ16E 769 795 770 800 775 805 774 799
244 CQ16E 770 796 771 801 776 806 775 800
245 CQ16E 747 802 772 807 777 812 749 759
246 CQ16E 772 803 773 808 778 813 777 807
247 CQ16E 773 804 774 809 779 814 778 808

248 CQ16E 774 805 775 810 780 815 779 809
249 CQ16E 775 806 776 811 781 816 780 810
250 CQ16E 766 825 817 827 819 829 771 791
251 CQ16E 817 826 818 828 820 830 819 827
252 CQ16E 771 829 819 831 821 833 776 801
253 CQ16E 819 830 820 832 822 834 821 831
254 CQ16E 776 833 821 835 823 837 781 811
255 CQ16E 821 834 822 836 824 838 823 835
256 CQ16E 312 460 455 840 817 825 766 839
257 CQ16E 455 461 389 841 818 826 817 840
258 CQ16E 818 858 842 862 846 866 820 828
259 CQ16E 842 859 843 863 847 867 846 862
260 CQ16E 843 860 844 864 848 868 847 863
261 CQ16E 844 861 845 865 849 869 848 864
262 CQ16E 820 866 846 870 850 874 822 832
263 CQ16E 846 867 847 871 851 875 850 870
264 CQ16E 847 868 848 872 852 876 851 871
265 CQ16E 848 869 849 873 853 877 852 872
266 CQ16E 822 874 850 878 854 882 824 836
267 CQ16E 850 875 851 879 855 883 854 878
268 CQ16E 851 876 852 880 856 884 855 879
269 CQ16E 852 877 853 881 857 885 856 880
270 CQ16E 65 596 588 886 762 782 67 71
271 CQ16E 588 597 589 887 763 783 762 886
272 CQ16E 589 598 590 888 764 784 763 887
273 CQ16E 590 599 591 889 765 785 764 888
274 CQ16E 591 600 312 839 766 786 765 889
275 CQ16E 389 725 717 890 842 858 818 841
276 CQ16E 717 726 718 891 843 859 842 890
277 CQ16E 718 727 719 892 844 860 843 891
278 CQ16E 719 728 720 893 845 861 844 892
279 CQ16E 60 63 54 735 729 898 894 897
280 CQ16E 894 898 729 738 731 900 895 899
281 CQ16E 895 900 731 741 733 902 896 901
282 CQ16E 903 915 904 919 907 921 906 918
283 CQ16E 904 916 905 920 908 922 907 919
284 CQ16E 905 917 60 897 894 923 908 920
285 CQ16E 906 921 907 925 910 927 909 924
286 CQ16E 907 922 908 926 911 928 910 925

```
287 CQ16E  908 923 894 899 895 929 911 926
288 CQ16E  909 927 910 931 913 933 912 930
289 CQ16E  910 928 911 932 914 934 913 931
290 CQ16E  911 929 895 901 896 935 914 932
291 CQ16E  936 939 937 943 904 915 903 942
292 CQ16E  937 940 938 944 905 916 904 943
293 CQ16E  938 941 59 62 60 917 905 944
294 CQ16E  945 948 946 952 937 939 936 951
295 CQ16E  946 949 947 953 938 940 937 952
296 CQ16E  947 950 239 241 59 941 938 953

297 SP2TR  4 77
298 SP2TR  15 98
299 SP2TR  25 119
300 SP2TR  35 140
301 SP2TR  45 161

MATERIALS
/ 1-34 /  1
/ 35-55 /  2
/ 56-135 /  3
/ 136-185 /  4
/ 186-225 /  5
/ 226-296 /  6
/ 297-301 /  7

GEOMETRY
/ 297-301 /  1

'MATERIALS'
: facing + anchor blocks
  1 YOUNG     2.000000E+10
    POISON    1.500000E-01
    DENSIT    1.200000E+03
    DENSFL    1.000000E+03
    porosi    0.1
    yield  mohrco
:           c        Sin phi  Sin psi
    yldval    0.4E+06   0.64     0.04
```

```
    K0       0.36
: sand1 for drainage
  2 YOUNG     4.000000E+07
    POISON    2.500000E-01
    DENSIT    1.600000E+03
    DENSFL    1.000000E+03
    porosi    0.3
    yield  mohrco
:           c       Sin phi  Sin psi
    yldval    0.0      0.64     0.23
    K0       0.36
: sand2 for passive resistance
  3 YOUNG     4.000000E+07
    POISON    2.500000E-01
    DENSIT    1.600000E+03
    DENSFL    1.000000E+03
    porosi    0.3
    yield  mohrco
:           c       Sin phi  Sin psi
    yldval    0.0      0.64     0.23
    K0       0.36
: clay1 as soft fill
  4 YOUNG     2.000000E+07
    POISON    4.500000E-01
    DENSIT    1.550000E+03
    DENSFL    1.000000E+03
    porosi    0.32
    yield  mohrco
:           c       Sin phi  Sin psi
    yldval    40.0E+03 0.25     0.00
    K0       0.75
: clay2 as compacted fill
  5 YOUNG     2.000000E+07
    POISON    4.500000E-01
    DENSIT    1.550000E+03
    DENSFL    1.000000E+03
    porosi    0.40
```

```
    yield  mohrco
:          c       Sin phi  Sin psi
    yldval   40.0E+03  0.25    0.00
    K0       0.75
: clay3 as base
   6 YOUNG      5.000000E+07
     POISON     4.000000E-01
     DENSIT     1.600000E+00
     DENSFL     1.000000E+03
     porosi     0.30
     yield  mohrco
:          c       Sin phi  Sin psi
    yldval   100.0E+03  0.25    0.00
    K0       0.75
: spring as tie bars
   7 SPRING     1.000000E+07

'GEOMETRY'
   1 AXIS      1.000000E+00   0.000000E+00   0.000000E+00

'GROUPS'
 NODES
 1  COL1    / 1-5 8-10 13-15 18-20 23-25 28-30 33-35 38-40 43-45
              48-50 53-55 58 733-734 743 /
 2  COL2    / 2 4 10 15 20 25 30 35 40 45 50 55 64-69 72-73
              179-184 187-190 193-196 199-202 205-208 211-214
              217-220 223-226 229-232 235-236 734 748-749 760-761 /
 3  COL3    / 65 67 180 182 190 196 202 208 214 220 226 232
              242 244 252 259 267 274 282 289 297 304 312 462-474
              479-487 492-500 505-513 518-526 531-539 544-552
              557-565 570-578 583-591 596-600 749 762-766 777-786
              812-816 /
 4  COL4    / 77 98 119 140 161 244-245 250-251 259-260 265-266
              274-275 280-281 289-290 295-296 304-305 310-311 /
 5  INCL    / 74 87 95 108 116 129 137 150 158 171 242-243 246-247
              252-253 256-258 261-262 267-268 271-273 276-277
              282-283 286-288 291-292 297-298 301-303 306-307
              312-313 316-317 /
 6  COL5    / 74-81 85-89 93-102 106-110 114-123 127-131 135-144
```

148-152 156-165 169-173 177-178 242 252 267 282
297 312 319 329 344 359 374 389 394 396-397 403
408-409 416 421-422 429 434-435 442 447-448 455
460-461 766 781 817-818 823-826 837-838 /

7 COL6 / 79 100 121 142 163 320-321 326-327 335-336 341-342
350-351 356-357 365-366 371-372 380-381 386-387 /

8 INCR / 76 89 97 110 118 131 139 152 160 173 318-319 322-323
328-329 332-334 337-338 343-344 347-349 352-353
358-359 362-364 367-368 373-374 377-379 382-383
388-389 392-393 /

9 COL7 / 319 321 329 336 344 351 359 366 374 381 389 601-612
617-624 629-636 641-648 653-660 665-672 677-684
689-696 701-708 713-720 725-728 818 824 842-845
854-861 882-885 /

10 COL8 / 44 49 54 59-61 63 239-240 733 896 902 /

11 COL9 / 59-60 239 896 903-905 912-917 933-941 945-950 /

12 ALLROW / 1-4 6-7 9-12 14-17 19-22 24-27 29-32 34-37 39-42
44-47 49-52 54-57 59-60 62 65 67 71 180 182 186
190 192 196 198 202 204 208 210 214 216 220 222
226 228 232 234 238-239 241-242 244 248 252 254
259 263 267 269 274 278 282 284 289 293 297 299
304 308 312 314 319 321 325 329 331 336 340 344
346 351 355 359 361 366 370 374 376 381 385 389
391 604 608 616 624 628 636 640 648 652 660 664
672 676 684 688 696 700 708 712 720 724 729-736
738-739 741-742 745 747 749 751 755 759 766 771
776 781 791 801 811 818 820 822 824 828 832 836
839 841 845 849 853 857 865 873 881 893-897 899
901 903 906 909 912 918 924 930 936 942 945 951 /

13 ROW1 / 1-4 6-7 180 182 186 242 244 248 319 321 325 604
608 616 /

14 RO2T10 / 3-4 9-12 14-17 19-22 24-27 29-32 34-37 39-42
44-47 49-52 59 65 182 190 192 196 198 202 204
208 210 214 216 220 222 226 228 232 234 238-239
241 244 252 254 259 263 267 269 274 278 282 284
289 293 297 299 304 308 312 314 321 329 331 336
340 344 346 351 355 359 361 366 370 374 376 381
385 389 391 608 624 628 636 640 648 652 660 664
672 676 684 688 696 700 708 712 720 724 936 945

951 /

15 ROW11 / 49-50 54-57 59-60 62 65 67 71 312 389 720 766
818 839 841 845 893 903 936 942 /

16 ROW12 / 54-55 60 67 729-736 738-739 741-742 745 747 749
751 755 759 766 771 776 781 791 801 811 818 820
822 824 828 832 836 845 849 853 857 865 873 881
894-897 899 901 903 906 909 912 918 924 930 /

17 ANCROW / 74 76-77 79 82 84 87 89-90 92 95 97-98 100 103
105 108 110-111 113 116 118-119 121 124 126 129
131-132 134 137 139-140 142 145 147 150 152-153
155 158 160-161 163 166 168 171 173-174 176 /

18 SNDROW / 74 76 87 89 95 97 108 110 116 118 129 131 137
139 150 152 158 160 171 173 /

19 POINTL / 4 15 25 35 45 /

20 POINTR / 77 98 119 140 161 /

21 LEFTB / 903 906 909 912 918 924 930 936 942 945 951 /

22 RIGHTB / 604 608 616 624 628 636 640 648 652 660 664 672
676 684 688 696 700 708 712 720 724 845 849 853
857 865 873 881 893 /

23 BOTOMB / 733-734 743 748-749 760-761 777-781 812-816 823-824
837-838 854-857 882-885 896 902 912-914 933-935 /

24 FACE / 1 3 6 9 11 14 16 19 21 24 26 29 31 34 36 39 41
44 46 49 51 /

25 ANCFRT / 74 77 82 87 90 95 98 103 108 111 116 119 124
129 132 137 140 145 150 153 158 161 166 171 174 /

26 TOPLIN / 1-2 5 179-180 183-184 242 319 394 396-397 462-465
470-474 601-604 609-612 /

27 TOPLFT / 1-2 5 179-180 183-184 242 319 394 396-397 462-465
470-474 /

28 TOPRHT / 319 601-604 609-612 /

ELEMEN

29 FACING / 1-14 /

NODES

30 FACING_N / 1-73 /

ELEMEN

31 ANCHOR / 15-34 /

NODES

32 ANCHOR_N / 74-178 /

ELEMEN

```
33  SAND1     / 35-55 /
NODES
34  SAND1_N   / 2 4 7 10 12 15 17 20 22 25 27 30 32 35 37 40
              42 44-45 47 49-52 59 61 64-65 68-69 179-241 /
ELEMEN
35  SAND2     / 56-135 /
NODES
36  SAND2_N   / 74-77 79-82 84 87-90 92-98 100-103 105 108-111
              113-119 121-124 126 129-132 134-140 142-145 147
              150-153 155-161 163-166 168 171-174 176-178 242-461 /
ELEMEN
37  CLAY1     / 136-185 /
NODES
38  CLAY1_N   / 65 180 182 186 190 192 196 198 202 204 208 210
              214 216 220 222 226 228 232 234 238 242 244 248
              252 254 259 263 267 269 274 278 282 284 289 293
              297 299 304 308 312 314 462-600 /
ELEMEN
39  CLAY2     / 186-225 /
NODES
40  CLAY2_N   / 319 321 325 329 331 336 340 344 346 351 355 359
              361 366 370 374 376 381 385 389 391 601-728 /
ELEMEN
41  CLAY3     / 226-296 /
NODES
42  CLAY3_N   / 54-55 58-60 62-63 65-67 71-73 239 241 312 389
              455 460-461 588-591 596-600 717-720 725-953 /
ELEMEN
43  FILL     / 1-225 /
NODES
44  FILL_N   / 1-728 /
'SUPPORTS'
/ 604 608 616 624 628 636 640 648 652 660 664 672 676 684 688 696
  700 708 712 720 724 733-734 743 748-749 760-761 777-781 812-816
  823-824 837-838 845 849 853-857 865 873 881-885 893 896 902-903
  906 909 912-914 918 924 930 933-936 942 945 951 /  TR   1
/ 733-734 743 748-749 760-761 777-781 812-816 823-824 837-838 854-857
  882-885 896 902 912-914 933-935 /  TR   2
```

```
'LOADS'
CASE 1
WEIGHT
 2   -9.80000
CASE 2
ELEMEN
/ 1 /
   EDGE   ETA1
   FORCE    -1.000000E+05
   DIRELM    NORMAL
/ 35-36 /
   EDGE   ETA1
   FORCE    -1.000000E+05
   DIRELM    NORMAL
/ 136-140 /
   EDGE   ETA1
   FORCE    -1.000000E+05
   DIRELM    NORMAL
/ 96-97 /
   EDGE   ETA1
   FORCE    -1.000000E+05
   DIRELM    NORMAL
/ 186-189 /
   EDGE   ETA1
   FORCE    -1.000000E+05
   DIRELM    NORMAL
'DIRECTIONS'
  1  1.000000E+00  0.000000E+00  0.000000E+00
  2  0.000000E+00  1.000000E+00  0.000000E+00
  3  0.000000E+00  0.000000E+00  1.000000E+00
'END'
```

L.5 Listing of Command File (wal3.com):

```
*FILOS
 INITIA MA = 100000000
*INPUT
*LINSTA
*NONLIN
 INITIALIZE
  ANALYS PHYSIC
 END INITIA
 LOADING
  LOAD(1): (1) 1.0 /
  LOAD(2): (2) 1.0 /
 END LOADING
: 1
 SELECT
  STEP LAST /
 END SELECT
: VIEW FILLE FILE FOR VARIOUS PLOTS
OUTPUT FEMVIEW NONLIN BINARY
 DISPLA TOTAL GLOBAL
 STRESS TOTAL GLOBAL
 STRAIN TOTAL GLOBAL
END OUTPUT
: 2
 SELECT
  STEP LAST /
 END SELECT

OUTPUT GRAPHI NONLIN
 DISPLA
END OUTPUT
: 3 TABULAR OUTPUT OF VERTICAL DISPLACEMENT OF TOPLINE
SELECT
 NODES 1-2 5 179-180 183-184 242 319 394 396-397 462-465
       470-474 601-604 609-612 /
 STEP 50 100-500(100) 550-1000(50) /
END SELECT
OUTPUT TABULA NONLIN
```

```
 DISPLA TOTAL Y
END OUTPUT

: 4 TABULAR OUTPUT OF HORIZONTAL DISPLACEMENT OF A POINT IN FACE
SELECT
 NODES 25 /
 STEP 50 100-500(100) 550-1000(50) /
END SELECT
OUTPUT TABULA NONLIN
 DISPLA TOTAL X
END OUTPUT

: 5 TABULAR OUTPUT OF HORIZONTAL DISPLACEMENT OF FACE OF WALL
SELECT
 NODES 1 3 6 9 11 14 16 19 21 24 26 29 31 34 36 39 41
     44 46 49 51 /
 STEP 50 100-500(100) 550-1000(50) /
END SELECT
OUTPUT TABULA NONLIN
 DISPLA TOTAL X
END OUTPUT

: 6 TABULAR OUTPUT OF HORIZONTAL DISPLACEMENT OF FACE OF ANCHORS
SELECT
 NODES 75 78 83 88 91 96 99 104 109 112 117 120 125 130 133 138
     141 146 151 154 159 162 167 172 175 394 395 398 401-404
     407 410 411 414-417 420 423 424 427-430 433 436 437 440-443
     446 449 450 453-456 459 /
 STEP 50 100-500(100) 550-1000(50) /
END SELECT
OUTPUT TABULA NONLIN
 DISPLA TOTAL X
END OUTPUT

: 7 TABULAR OUTPUT OF FORCES IN REINFORCEMENTS
SELECT
 ELEMEN 297-301 /
 END ELEMEN
 STEP 50 100-500(100) 550-1000(50) /
```

```
END SELECT
OUTPUT TABULA NONLIN
 STRESS TOTAL FORCE
END OUTPUT

: 8 TABULAR OUTPUT OF STRESS STRAIN OF ELEMENT
SELECT
 ELEMEN 147 /
 END ELEMEN
 STEP 50 100-500(100) 550-1000(50) /
END SELECT
OUTPUT TABULA NONLIN
 STRESS TOTAL GLOBAL
 STRAIN TOTAL GLOBAL
END OUTPUT

 EXECUT LOAD(1) STEPS
  SIZE 0.005(100) 0.002(100) 0.001(300) /
  PERFOR CONSTA MI=100
  NORM FORCE CONTIN CO=1.0E-03
  STOP TOTAL 1.0
 END EXECUT
 EXECUT LOAD(2) STEPS
  SIZE 0.005(100) 0.002(100) 0.001(300) /
  PERFOR CONSTA MI=100
  NORM FORCE CONTIN CO=1.0E-03
  STOP TOTAL 1.0
 END EXECUT

*END
```
