EFFECT OF SHEAR WALL ON BEHAVIOUR OF MAT FOUNDATION

SYED ZUBAIR IMAM

DEPARTMENT OF CIVIL ENGINEERING
BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY, DHAKA.

44

EFFECT OF SHEAR WALL ON BEHAVIOUR OF MAT FOUNDATION

A THESIS BY

SYED ZUBAIR IMAM

Submitted in partial fulfilment of the requirements for the degree of

MASTER OF SCIENCE IN CIVIL AND STRUCTURAL ENGINEERING

DEPARTMENT OF CIVIL ENGINEERING

BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY, DHAKA.

JULY, 2003

EFFECT OF SHEAR WALL ON BEHAVIOUR OF MAT FOUNDATION

A THESIS BY

SYED ZUBAIR IMAM

Approved as to the style and content by the Examination committee

Dr. Sohrabuddin Ahmad
Professor
Department of Civil Engineering
BUET, Dhaka.

Chairman
(Supervisor)

Dr. Abdul Muqtadir
Professor
Department of Civil Engineering
BUET, Dhaka.

Member
(Co-supervisor)

Dr. Sk. Sekender Ali
Professor and Head
Department of Civil Engineering
BUET, Dhaka.

Member
(Ex-officio)

Dr. Md. Shafiul Bari
Professor
Department of Civil Engineering
BUET, Dhaka.

Member

Dr. Md. Wahhaj Uddin
Professor
Department of Mechanical Engineering
BUET, Dhaka

Member
(External)

IN THE NAME

OF

Allah(SWT)

CONTENTS

DECLARATION

The Author declares that, except where references are made to other investigators, the work embodied in this thesis is the result of investigation carried out by him under the supervision of Professor Sohrabuddin Ahmad and Professor Abdul Muqtadir of Civil Engineering Department, BUET.

Neither this thesis nor any part thereof has been submitted in candidature for any degree at any other institution.

Author

ACKNOWLEDGEMENT

The author wishes to express his indebtedness to Dr. Sohrabuddin Ahmad, Professor of Civil Engineering, BUET, for his continuous guidance, invaluable suggestions and affectionate encouragement at every stage of this study.

The author expresses his profound gratitude to Dr. Abdul Muqtadir, Professor of Civil Engineering, BUET, for his constant guidance, suggestions and encouragement at all the phases of this work.

The author is grateful to Professor Sk.Sekender Ali, Head of the Department of Civil Engineering, for his constructive and helpful suggestions at various stages of this study.

The author acknowledges the consistent and earnest support by his parents and wife.

The author is also grateful to his other family members, colleagues and well-wishers for their co-operation and companionship extended to him during this research works.

ABSTRACT

Mat foundation is widely used for high-rise buildings where presence of shear wall is very common. But the available analysis and design methods do not properly focus on the effect of shear wall on the behaviour of mat foundation. Shear Wall resists a major portion of the lateral load of high-rise buildings. So, presence of shear wall on mat foundation causes significant change in pattern and intensity of loading on mat foundation. Proper understanding of shear wall effect on mat foundation has not been duly addressed in the past. This gap in knowledge brings some uncertainty in analysis of mat foundation and may result in its over design or unsafe design. For economy in design of mat with shear wall requires comprehensive understanding of the influence of shear wall on mat. This work involved an extensive investigation of shear wall effect on mat foundation using finite element program, ANSYS. Effects of different locations and different numbers of shear walls have been studied.

A parametric study has been made in order to identify the sensitivity of some parameters for the presence of shear wall on mat. Variation in response of different parameters to shear wall loading has been compared with past parametric studies of mat without shear wall.

Non-uniform thickness of mat has received some attention among design engineers for economy. Shear Wall effects on both uniform and non-uniform thickness have, therefore, also been studied. For non-uniform mat analysis, the configuration suggested by Rahman and Morshed has been followed.

Shear wall presence on mat foundation has significant effect on the behaviour of mat in some cases. Presence of shear wall on edge of mat foundation has been found to be very significant. Behaviour of mat foundation with and with out shear wall has been compared. Based on the type and magnitude of variation, design recommendations for mat foundation with shear wall have been suggested.

LIST OF SYMBOLS

A	Plan area of mat
A_s	Steel area
B	Width of the strip
d	Effective depth of mat
D	Mat rigidity
DL	Dead load
E	Modulus of elasticity of materials
E_s	Modulus of elasticity of soil
f_c'	Ultimate concrete strength
f_y	Yield strength of steel
I_F	Moment of inertia of footing
I_B	Moment of inertia of structure per unit length
k	Modulus of subgrade reaction
LL	Live load
L	Length of the strip
L_s	Length of the thicker zone
M	Acting bending moment
M_x, M_y, M_z	Bending moment about x ,y and z axes respectively
S_{xy}, S_{yz}	Shear Stress in xy and yz plane respectively
t	Thickness of mat in mm
t_s	Smaller thickness of non-uniform mat
t_g	Greater thickness of non-uniform mat
v_{pu}	Ultimate punching shear strength
v_{fu}	Ultimate flexural shear strength
w	Load per unit length
WL	Wind load
ν	Poisson's ratio of concrete
ρ	Steel ratio
ρ_{max}	Maximum steel ratio
ρ_{min}	Minimum steel ratio
φ	Strength reduction factor

CHAPTER 1

INTRODUCTION

1.1 GENERAL

A mat foundation is a large concrete footing that transmits the loadings from several columns in a building or the entire building loads to the ground. Mat foundations become economical when the loads are so large that footings would occupy more than fifty percent of the projected area of the building. Mat foundations are commonly used for heavy column loads or for poor soil conditions that results in conventional footings or piles to occupy most of the site. For many multi-storied buildings a single mat foundation is more economical than constructing a multitude of isolated foundation elements. In a foundation on an elastic subgrade, the soil pressure and the deflection vary from point to point. Mat foundations due to their continuous nature provide resistance to independent differential column movements, thus enhancing the structure's performance. Mats can bridge across weak pockets in the non-uniform sub stratums, thus equalizing foundation movements. Mat foundations are predominantly used in regions where the underlying stratum consists of clayey materials with low bearing capacity. This is also used as a load-distributing element placed on piles or directly on high bearing capacity soil or rock. Mat foundation has gained wide popularity among the engineering community of many countries around the world.

Shear wall, at the same time, is a common feature of high-rise buildings. Shear walls are vertical stiffening elements designed to resist lateral forces exerted on a building by wind or earthquakes (Schueller, 1977). Shear walls has got the potentiality of carrying vertical loads effectively. The usefulness of walls in the structural planning of multi-storied buildings has long recognized. When walls are situated in advantageous positions in a building, they can be very efficient in resisting lateral loads. A large portion of the lateral loads, if not the whole amount, and the horizontal shear force resulting from the load, are often assign to shear walls. The engineers invariably use shear wall or lift core to withstand lateral load effectively for medium height buildings. As mat foundation and shear walls are very common feature of tall buildings, the combination of the mat and shear wall for the same structure is often found.

Construction of high-rise building is a hard task on soil with low bearing capacity. As engineers come to the soil eventually, seeking support for their superstructures, they face frequently the unfavourable reality. Heavy column loads may result in large footing areas exceeding half the total foundation area available. In many places, including some parts of Bangladesh, soil has very poor bearing capacity up to 30 m depth (Geological Survey of Bangladesh, 1990) where cast-in-situ pile foundations is not technically and economically sound, even for a six storied building. The most formidable hurdle, the foundation engineers often have to encounter, is the excessive settlement, specially differential settlement. Although pile foundation offers solution to these problems, sharp jump in expense becomes a serious point to ponder for the engineers., not to mention the disturbance to city life and the possibility of damage to underground structures associated with pile foundation construction.

The various advantages of mat foundations are:

(a) use of the raft as a basement floor having considerable commercial values in urban areas,

(b) use of the flexural stiffness to reduce differential settlements due to swelling and shrinking of active soils,

(c) use of the .flexural stiffness to reduce contact pressures in regions of higher soil compressibility,

(d) use of its own rigidity and that of the superstructure to activate bridging effect,

(e) use of the raft in combination with piles to reduce total settlement,

(f) use of flotation effect due to displaced volume of soil.

Mat foundations are designed and constructed in different pattern and varying types. There are several types of mat foundation, namely

i) flat plate,

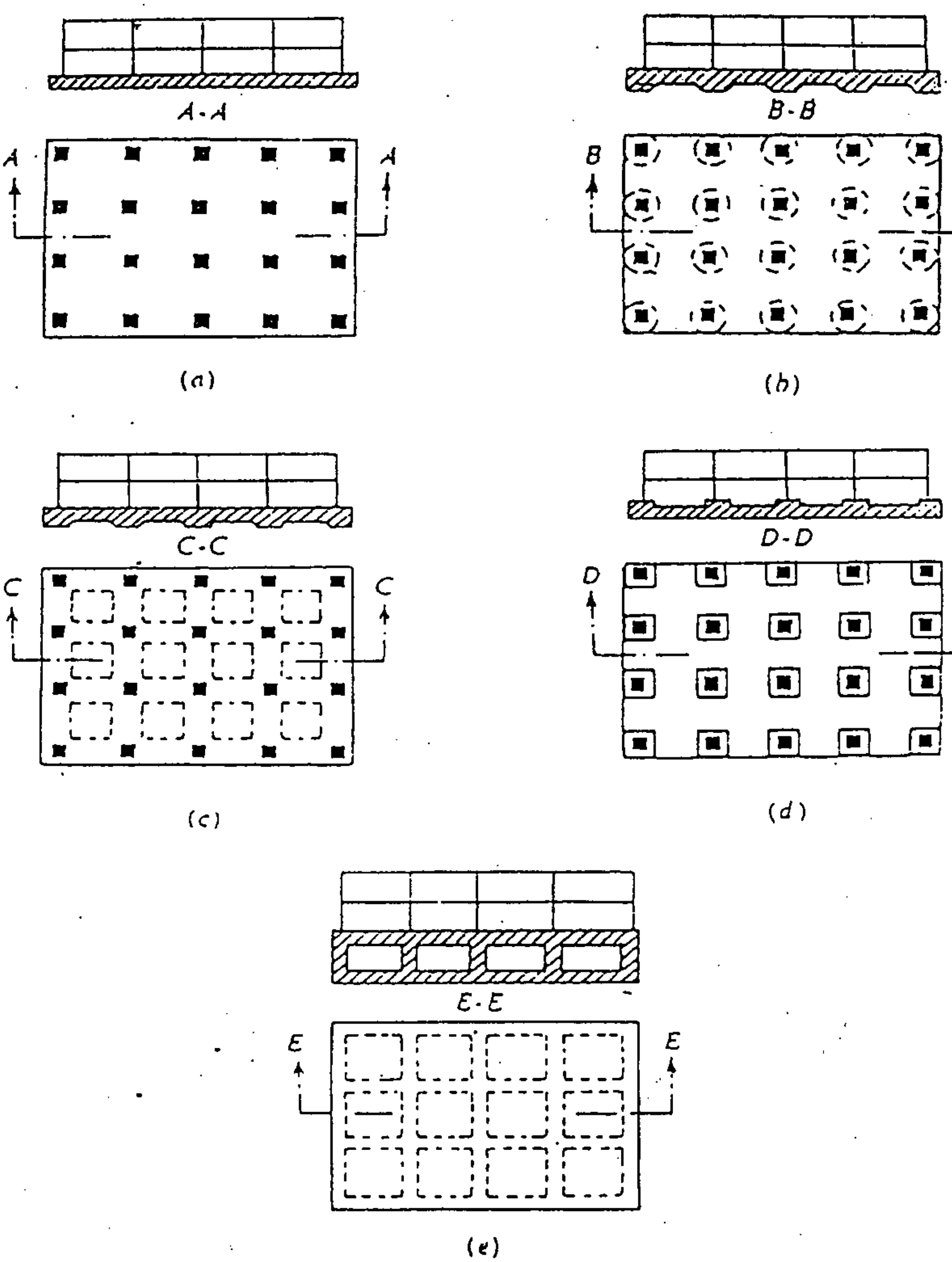

Fig. 1.1 Common types of mat foundation: (a) Flat plate; (b) plate thickened under columns; (c) waffl'e slab; (d) plate with pedestals and (e) basement wall as part of mat.

ii) plate thickened under column,

iii) waffle slab,

iv) plate with pedestal,

v) plates with stiffeners as basement walls,

vi) thin plate with grid floor beams.

Illustrations of several mat foundation configurations, commonly used for buildings, are shown in Fig.1.1.

On the other hand, location and arrangement of shear wall on a structure may vary over a wide range. There does not seem to be any limitation to the geometrical configuration of shear wall systems. Shear wall systems, whether inside or outside a building, may be arranged symmetrically or asymmetrically. Fig.1.2 shows some possible arrangement and shape of shear walls in practice. The most common basic shapes of shear walls are given in the central ring of Fig-1.2.

The most common mat foundation is the flat plate type and the most common shear wall is the planar wall. Flat plate type mat foundation is easy to design and construct but tends to be over designed due to uncertainty in the analysis and the lack of understanding of the interaction of shear wall with mat foundation.

1.2 BACKGROUND OF THE STUDY

The design of mat foundation is a difficult problem in two ways. Firstly, the structure is highly indeterminate that rigorous analysis based on elastic theory is not available. Secondly, the foundation soil is not elastic and the reaction against mat foundation is difficult to predetermine. Reliable analysis and economic design of mat foundation is often a great concern of the designers.

A number of methods are available for the analysis of mat. There are some approximate methods, which are considerably crude and are in use for a long time. Recently, there are some numerical methods available. However, these methods

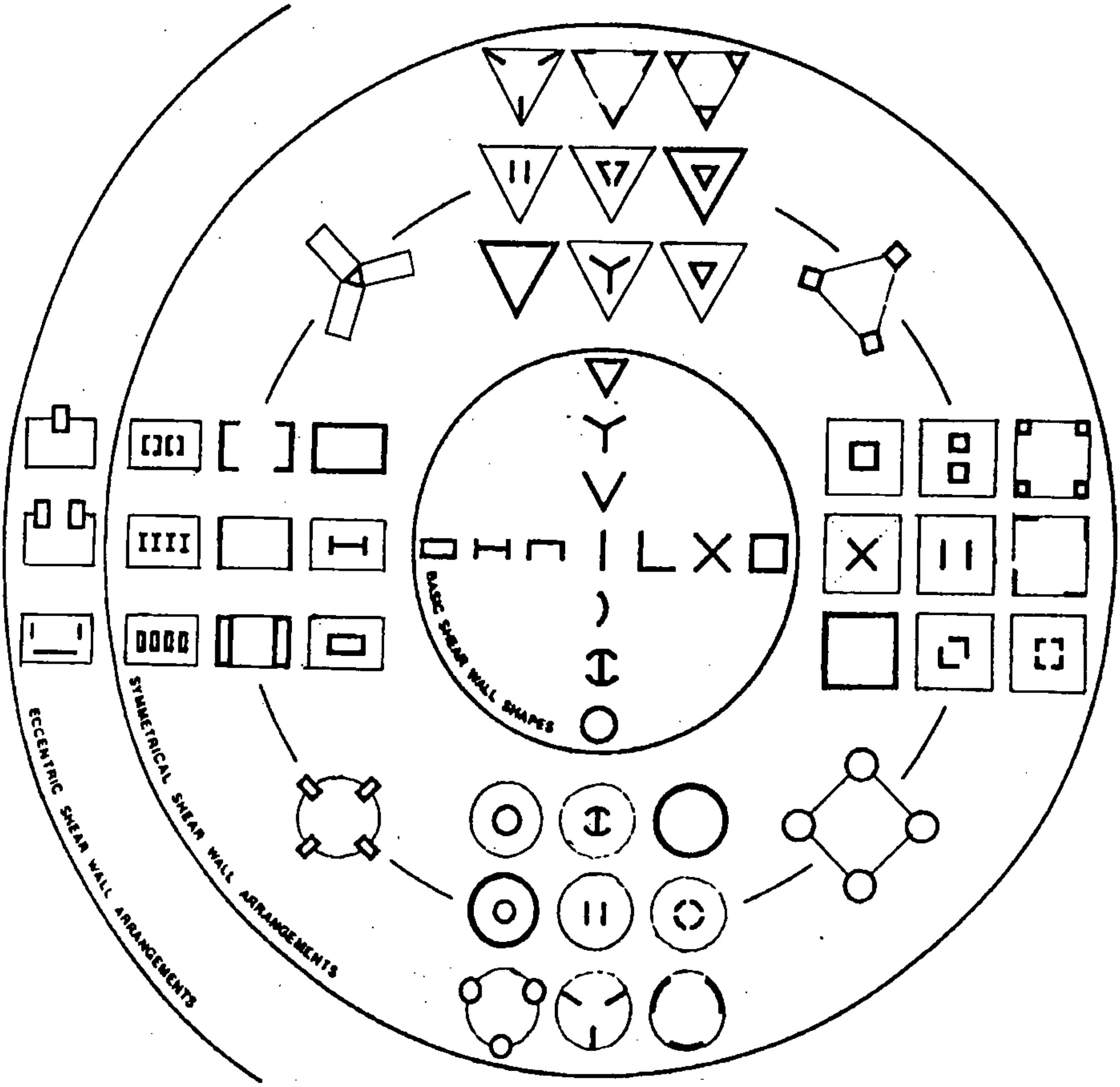

Fig.1.2 Various configuration of shear walls that are used in high rise buildings.

idealize mat unrealistically. The modelling of soil also has got its own limitations (Liou and Lai,1996).

In the most common and simplified method, known as Conventional method, column loads are distributed under the mat; then the mat is divided into strips midway between the column lines and the force system acting on each strip is adjusted to establish equilibrium. Finally, each strip is designed as a combined footing. This is repeated for the other direction. This method is recommended by ACI when adjacent spans and column loads do not vary by more than 20%. One of the most popular methods of mat analysis is the ACI Approximate Flexible method (ACI Committee 336), which is essentially based on the analysis of Schleicher (1926). Shukla (1984) presented design aids for using this method. Later, this method was further modified by Mician (1985).

Baker (1948) proposed a method of mat foundation analysis where the mat is divided into column strips resting on Winkler medium and each strip is analysed separately. Bowles (1974) has proposed Finite Grid method in which the mat is reduced into a grid system consisting of beam-column elements resting on Winkler medium. There is also Finite Difference method (Deryck and Severn 1961, Bowles 1974) where the mat is modelled as large flat plate on elastic medium.

At BUET, Hossain (1993) conducted a comparative study of the available analysing methods of mat foundation and felt the need for a rigorous finite element study of the problem. Later, Molla (1995) tested the performance of Mindlin plate element in finite element analysis of mat foundation and also compared the results with those from other available methods. The study of Molla opened a wide horizon for a rigorous finite element study of the problem with more appropriate and versatile element in search of a more economic design of mat. Sutradhar (1999) compared the analysis of mat foundation by Finite-Element method using Ahmad's thick shell element with those of Finite-Grid method and Finite-Difference method.

Lefas, Georgiannou and Sheppard (1996) presented an iterative procedure for analysis and design of mat foundation based on a soil-structure interaction procedure developed using well-marketed programs *VDISP, OASYS STAAD-III/ISDS* by Research Engineers and *Supercalc* by Computer Associates. VDISP is a geotechnical program for calculating vertical displacements at specified points due to any pattern of loading on an elastic half-space representing the ground. From VDISP the spring constant K_s is entered into the STAAD-III grillage for the raft analysis.

Liou and Lai (1996) presented a simplified structural analysing model for mat foundation with grid floor beams as stiffeners. The model becomes grid floor beams on an elastic foundation with loadings applied at the intersections of floor beams. The yield line theory (Johansen 1962) for bottom slabs is employed to lump the subgrade reaction springs to the location under grid floor beams.

Morshed (1996) and Sutradhar (1999) conducted comparative analysis between finite-element method, using Ahmad's thick shell element, with ACI method and Conventional method. Morshed suggested a mat foundation with variable thickness. His findings paved the way for developing a new design rationale for mat foundation. Sutradhar (1999) suggested a more definite guideline for selecting a mat of variable thickness for analysis with finite element methods. Rahman (2001) also conducted thorough study about the behaviour of mat foundation using finite element software ANSYS. He used plate element to study the behaviour of mat. Based on his work, he suggested a more simplified method to design non-uniform mat foundations.

The foregoing studies have ignored the effect of shear wall on the behaviour of mat foundation and utilize column as the only connecting member to the superstructure. Loads from superstructure are considered to be transmitted to mat by columns only. Shear wall on mat as connecting element with superstructure have not been considered in these studies. But, for high-rise building, the use of shear wall is common in practice. Load transfer patter of shear wall to foundation is different from that of columns. At the same time, for frame-shear wall structures shear wall resists large portion of lateral load. Thus higher load concentration occurs at the base of shear wall. Presence of shear wall increases the intensity of load at some places and changes the loading pattern and intensity of load on mat. So the presence of shear wall may change the overall behaviour of mat. Shear walls are used at different locations and in different numbers. Location and number of shear wall on mat foundation can also influence structural behaviour of mat. Interaction between shear wall and mat foundation is also an important factor in designing the mat foundation.

The available methods of mat analysis do not focus on the influence of shear walls on the behaviour of mat foundation. This gap in knowledge about the behaviour of mat carrying shear wall may result in over design of the mat. An improved understanding the shear wall effect on mat behaviour is also necessary to achieve overall economy of mat design.

1.3 OBJECTIVES OF THE PRESENT STUDY

The present research has the following objectives:

- Investigation of the effect of shear wall on the mat foundation due to different locations of shear walls.
- Performance of sensitivity analysis of the mat-behaviour due to the variation in various parameters (like soil stiffness, mat thickness, column and shear wall spacing) in the presence of shear wall on foundation.
- Identifying interaction between shear wall and mat foundation.
- Study of the behaviour of non-uniform mat foundation with shear wall, and
- Suggest guidelines for the design of rectangular uniform and non-uniform mats with shear walls.

1.4 METHODOLOGY

In order to attain the objectives of the current study a number of mat foundations with different arrangement of shear walls have been analysed. Shear walls were placed at different locations and their number varied from one upward. Loads from superstructure have been placed on mats to investigate the structural behaviour of mat foundation.

For analysing mat foundation and superstructure, a general-purpose finite element program, ANSYS, has been used. Here soil and mat have been idealized as discrete spring elements and 8-node shell elements respectively. Shear wall and frame of superstructure were modelled using four-nodded shell element and three-dimensional Euler's beam elements. Validity of these elements has been checked with known results.

To investigate the sensitivity of mat behaviour to different parameters, a thorough parametric study with variation of each significant parameter has been carried out. Variation of each parameter namely, soil stiffness, mat thickness and others have been performed keeping other parameters constant. These studies have been done by choosing one typical combination of mat and shear wall. Three-dimensional mat-shear wall model has been constructed for studying the direct interaction between mat and shear wall.

Finally, the effect of shear wall loading on different parameters of mat was summarized. Influence of variation of different parameters on mat behaviour due to presence of shear wall was compared with the previous studies for mat with columns. Based on the thorough study a set of recommendations for mat has been presented for the designers for incorporation into presently available methods of analysis and design of a mat foundation.

1.5 ORGANIZATION OF THE THESIS

The main features of the thesis are arranged in six chapters. A comprehensive literature survey on analysis and design of mat foundation, influence of shear wall on mat foundation and related topics has been carried out in Chapter 2. Previous studies on related grounds and subsequent findings have also been included in this chapter. Chapter 3 focuses on different aspects of finite element idealisation of the problem. An extensive parametric study on selected parameters is carried out in Chapter 4. In Chapter 5, a number of mat foundations with different locations and numbers of shear walls are carried out and the results have been summarized. In Chapter 6, based on the present study, analysis and design of uniform and non-uniform mat foundation with shear wall is discussed. Chapter 7 contains the conclusions drawn from this research and the recommendations for future study.

In addition, there are four appendices in this thesis. Appendix A includes description of eight nodded Structural shell Element SHELL93 of ANSYS-Library Function; Appendix B includes description of spring element COMBIN14 of ANSYS library function. Appendix C contains the MACRO used for analysis of mat with ANSYS for prospective researchers. Appendix D contains description of geometry and loading for mat and variation of deflection, bending moment and shearing stress for different location and number of shear walls.

CHAPTER 2

LITERATURE REVIEW

2.1 GENERAL

Effective analysis and efficient design of mat foundation is one of the key concerns for overall economy of many structures. Comprehensive studies on many aspects of mat analysis and design have been so far carried out. Analysis of mat foundation requires study of two aspects, the soil- structure interaction and the structural behaviour within the foundation for loading. The mechanical response of naturally occurring soils can be influenced by a variety of factors. These include shape, size and mechanical properties of the individual soil particles, the configuration of the soil structure, the intergranular stress history and the presence of soil moisture, the degree of saturation and the soil permeability. These factors generally contribute to stress-strain phenomena which display markedly non-linear, irreversible and time dependent characteristics. Thus an attempt to solve a soil-foundation interaction problem taking into account of all such material aspects is clearly an onerous task. Analysis of mat itself is a highly indeterminate problem. So rigorous analysis based on elastic theory is difficult. In order to obtain meaningful and reliable information for practical problems it becomes necessary to idealize the behavior of soil by depicting soil models. At the same time it is necessary to idealized the mat to study the mat response to various soil parameters and to understand the behaviour of mat due to imposed loading. All the loads transmitted to the soil by mat are brought to the mat by either columns or by shear walls. So the structural behavior of mat is dependent on the amount and the pattern of loading it gets from the superstructure.

2.2 BACKGROUND OF THE PROBLEM

The common methods for analysis of mat foundation are

a) Conventional method, b) ACI approximate flexible method, c) Baker's method, d) Finite difference method, and e) Finite grid method.

The above methods are based on the fact that column are the load transmitting members from superstructure to the foundation. The connectivity between columns and mat foundation are through very little areas in comparison to the area of the mat. But when shear walls are introduced in the frame as lateral load resisting element, they transfer the load in a different manner from that of columns. Moreover shear walls resist a larger portion of lateral load. So, intensity of load also changes on mat.

Among the available methods for analyses of mat foundation with columns, Conventional method is the crudest one. Here, mat is treated as a rigid slab with uniform or linearly varying contact pressure, depending on whether the raft supports symmetric and eccentric loads. Actual contact pressure distribution is the result of the foundation-soil interaction, which can be determined by an interaction analysis involving the elastic properties of both the foundation and soil.

All other methods are based on Winkler spring model. ACI method is based on Schleicher's solution of infinite flexible slab on continuous spring support and Baker's method is designed to simulate that solution. Finite grid and Finite difference methods are numerical methods and require extensive computer support though they do not offer any substantial improvement in results over Schleicher's solution.

Shear wall effect on mat behaviour is so far ignored in the previous studies on mat behaviour. But influence of shear wall on mat can be greater concern during design of mat foundation. So it is necessary to study the effect of shear wall on foundation.

2.3 FOUNDATION MODEL

2.3.1 General

Generally, the analysis of bending of beams on elastic foundations is dependent on the assumption that the reaction forces of the foundation are proportional at every point to the deflection of the beam at that point. This assumption was first introduced by Winkler (1867) and formed the basis of Zimmermann's classical work (1930) on the analysis of railroad track. It has been shown by Foppl's classical experiment (1922) and Hetenyi's analytical work (1946) that Winkler's assumption in spite of its simplicity leads to satisfactory results in stress analysis of beams on an elastic foundation.

On the other hand, the hypothesis of isotropic, linearly elastic semi-infinite space can describe, the physical properties of a natural foundation correctly. To bridge the gap between these two extremes, interactions between Winkler's springs were considered by several authors. Hetenyi (1950) treated the problems of beams or plates on an elastic foundation by assuming a continuous beam or a plate embedded in the material of foundation, which is itself without any continuity. Pasternak (1954) assumed that the shear interactions exist between the springs. Vlasov and Leont'ev (1966) also considered the shear interactions in the foundation and formulated their problems by using a variational method. They solved a large number of problems involving beams, plates and shells on two parameter model elastic foundation.

2.3.2 Winkler Model

The idealised model of soil media proposed by Winkler (1867) assumes that deflection w, of the soil medium at any point on the surface is directly proportional to the stress, q applied at that point and independent of stresses applied at other locations. That is

$$q(x,y) = kw(x,y) \tag{2.1}$$

where k is the modulus of subgrade reaction with units of stress per unit length. The equation is usually the response function or the kernel function of Winkler model.

Physically Winkler's idealisation of the soil medium consists of a system of mutually independent spring elements with spring constant k (Fig. 2.1).

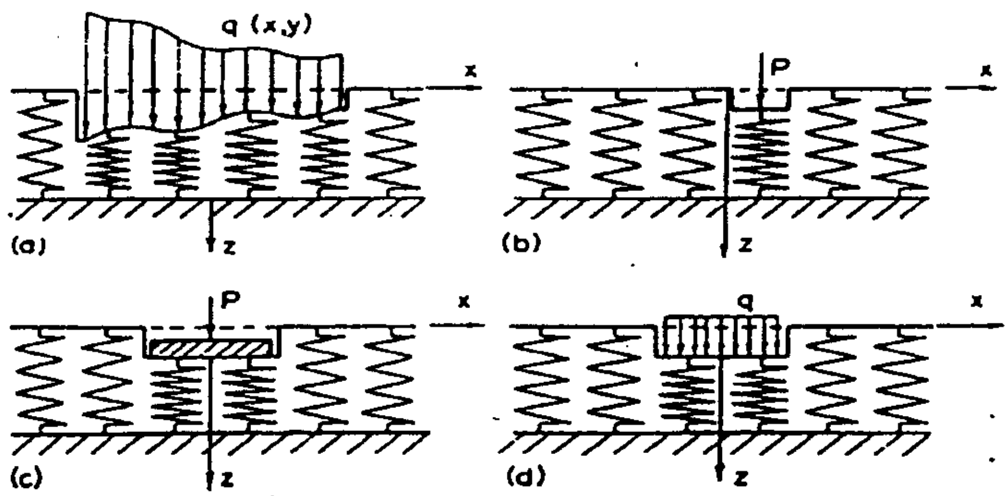

Fig. 2.1 Surface displacements of Winkler model due to (a) a non-uniform load, (b)a concentrated load,(c) a rigid load, (d) a uniform flexible load

One important feature of this soil model is that the displacement occurs immediately under the loaded area and outside this region the displacements are zero. Also for this model the displacements of a loaded region will be constant whether subjected to a rigid load or a uniform flexible load.

2.4 METHODS OF ANALYSIS

2.4.1 Conventional Method of Analysis

In this method, mat is taken as infinitely rigid, giving linear soil pressure distribution. The mat is divided in both directions into strips centred on the column lines and having widths equal to half the spacing of column lines on each side of the column lines. Each strip is loaded by column loads and supported by soil pressure. This method can be used where the mat is very thick and column spacing and loading are fairly uniform. Though quite suitable for hand calculation, this method very inadequate to represent the reality with mat foundation such as shear concentration near the loads.

Applicability And Limitations

According to the ACI Committee 336 (1966), the design of mats may be accomplished using the conventional method if :

a) The average of the two adjacent spans in a continuous strip is less than $1.75/\lambda$ and adjacent column loads and column spacing do not vary by more than 20 percent of the greater value.

b) The relative stiffness factor K_r is found to be greater than 0.5, where

$$K_r = \frac{EI_B}{E_s B^3} \tag{2.2}$$

where

E	= modulus of elasticity of materials used in structure,
I_B	= moment of inertia of structure per unit length,
E_s	= modulus of elasticity of soil and
B	= width of footing.

An approximate value of EI_B can be found by summing flexural rigidity of footing (EI_F), the flexural rigidity of each framed member (EI_b) and the flexural rigidity of any shear walls ($Eah^3/12$) where *a* and *h* are the thickness and height of the walls respectively; EI_B is given by:

$$EI_B = EI_F + \sum EI_b + \sum \frac{Eah^3}{12} \tag{2.3}$$

where

I_F	= Moment of inertia of footing.

2.4.2 ACI Approximate Flexible Method

ACI Committee 336 (1966) suggested this method for the general case of a flexible mat supporting columns at random locations with varying intensities of load. This procedure is essentially based on Schleicher's solution of circular plate on Winkler medium. Shukla (1984) provided charts for easy calculation of moments and shear following this method.

The effect of a concentrated load on a flexible infinite slab resting on continuous spring support has been found to damp out quickly away from the load. It is, therefore, possible to consider a mat as a plate of infinite dimension and determine the effect of a column load in a specific region surrounding the load, called the zone of influence. This zone of influence is generally not large and beyond this zone moments and shears in a mat is insignificant. The total effect of all the column loads at any point can thus be determined by superimposing the effect of all the column loads within whose zones of influence the point lies. If moments and shears are found along the edges then these are later applied in opposite direction at the same location and with a semi-infinite beam analysis their effects inside the mat is calculated and superimposed on the previous solution to have the final moments and shears. The later part of the analysis is called end correction and is a way of getting rid of the errors acquired by treating the mat infinite. Mat deflections, though unrealistic, can be calculated in the same manner.

This method cannot take care of column base moments, does not model boundary conditions realistically and gives unsatisfactory result near the edges.

2.4.3 Baker's Method

The method proposed by Baker (1948) is simple and straight forward in application and gives results which compare well with the Winkler analysis. In this method a specific shape of soil pressure distribution of unknown magnitude is assumed. The soil pressure is applied to the strip of mat, consisting of a single column line and cut separate along the middle lines of adjacent column spacing on both of its sides, and the maximum relative displacement of the beam is expressed as a function of the pressure. The same pressure distribution is applied to the soil and the maximum differential settlement is related to the pressure magnitude, designated as soil equation. Simultaneous solution of these equations gives the pressure and the relative settlement. Values of bending moments can be calculated by adding the moments developed by column loads and the differential settlement.

2.4.4 Finite-Difference Method

Deryck,Severn (1960,1961) and Bowles (1974) have used the finite difference technique to analyse large thin flat slabs on elastic medium. The governing equation is:

$$\frac{\partial^4 w}{\partial x^4} + \frac{2\partial^4 w}{\partial x^2 \partial y^2} + \frac{\partial^4 w}{\partial y^4} = \frac{q}{D} + \frac{p}{D(\partial x \partial y)}$$

where

w = deflection ,

p = subgrade reaction per unit area of mat

D = mat rigidity

$= E_c t^3 / 12(1-\mu^2_c)$

E_c = modulus of elasticity of mat material,

t = thickness of mat,

μ_c = Poisson's ratio of mat material.

For a given mat, one difference equation can be written for each nodal point of intersection of the finite difference grid. By solving these simultaneous equations, the deflection at all the points can be determined. Consequently, soil reactions, bending moments and shear forces can be found.

This solution is applicable to mat when the plan dimensions of mat are reasonably large in comparison to its thickness. Then the error due to higher plate thickness is very small. Though more theoretical in nature, column base moments can be handled by this method. The method is inefficient in terms of time consumption.

2.4.5 Finite-Grid Method

Finite grid method of mat analysis is highly advocated by Bowles (1992) for its computational simplicity. In finite Grid method, the entire mat is transformed in to a suitable grid consisting of beam-column elements, each of which is supported by soil springs at its ends. Nodal displacements are considered to be the basic unknowns. Stiffness matrix and load matrix for each element are built and assembled into global stiffness matrix and global load matrix respectively for the entire mat, resting on Winkler medium. When the global stiffness and load matrices are known, the nodal deflection matrix can readily be obtained from the solution of simultaneous equations and hence the member forces can be calculated.

Though the method is capable of handling column base moments and varying soil properties, the plate characteristics of mat is lost when it is modelled as grid and this makes the finite grid method unrealistic.

2.5 COMPARISON BETWEEN WIDELY USED METHODS

Results obtained by Conventional Method and ACI Approximate Flexible Method are compared with the finite element solution by Morshed (1996) and Sutradhar (1999). Their main findings are tabulated in Table 2.1.

Table 2.1 Comparison Between Various Methods for Mat Foundation with Columns.

Parameter	Location	Conventional Method	ACI Method
Deflection	At Col. Edge	Cannot Calculate	Overestimates
	In between. Column.	Cannot Calculate	Underestimates
Moment	Column Face +ve moment	Fails to predict any moment	Underestimates
	-ve moment between cols.	Overestimates	Overestimates less at edges
Shear	Away from Column.	Compatible	Compatible
	Near Column.	Underestimates too much	Overestimates
Punching Shear	At d/2 from column face	Compatible	Underestimates, Compatible in central cols.
Flexural Shear	At d from column face	Underestimates	Overestimates
Thickness	Whole Mat	Compatible, Governed by Punching Shear	Overestimates, Governed by Flexural Shear
Positive Steel	+ve moment areas	Governed by minimum steel requirements	Governed by minimum steel requirements
Negative steel	-ve moment areas	Overestimates	Largely Overestimates
Economic Evaluation	In terms of concrete & steel	Overestimates	Overestimates

2.6 SENSITIVITY ANALYSIS OF MAT FOUNDATION FOR COLUMN LOADS

Extensive parametric studies have been done by Morshed (1996) and Sutaradhar (1999). The summary of sensitivity analysis of mat foundation is given in Table 2.2.

Table 2.2 Summary of Sensitivity Analysis of Mat without Shear Walls.

Parameter	Displacement	Positive moment	Negative moment	Flexural Shear	Punching shear
Mat thickness Increases	Decreases. More decrease at corner columns than central columns.	Decreases. More decrease in interior columns than exterior columns	Increases. More increase in interior midspan than exterior midspan.	Flexural shear has very little change	Punching shear remains almost constant
Modulus of subgrade reaction (K_s) increases	Displacement decreases proportionately. If K_s is 2 times, displacement is almost half.	Positive moment increases. More increase in exterior columns than interior columns.	Negative moment decreases. More decrease in exterior span than interior span.	Flexural shear has very little change	Punching shear remains almost constant
Ultimate strength of concrete increases	Displacement decreases and the change is small.	Positive moment decreases slightly.	Negative moment increases moderately.	Flexural shear has very little change.	Punching shear remains almost constant.
Width of greater thickness increases	Displacement decreases more in interior columns than exterior columns.	Positive moment increases slightly.	Negative moment decreases moderately.	Flexural shear has very little change.	Punching shear remains almost constant.

2.7 PRESENCE OF SHEAR WALL ON MAT FOUNDATION

Shear walls are vertical stiffening elements designed to resist lateral forces exerted on a building by wind or earthquakes (Schueller, 1977). The usefulness of walls in the structural planning of multi-storied buildings has long been recognised. When walls are situated in advantageous positions in a building, they can be very efficient in resisting lateral loads. A large portion of the lateral loads, if not the whole amount, and the horizontal shear force resulting from the load, are often assign to shear walls. So shear walls transmit a huge amount of load to the foundation. An adequate concentration of load occurs at the line of contact between shear wall and foundation. So, presence of shear walls on mats offers a special pattern of loading on the mat. Location and arrangement of shear wall on a structure can vary within a wide range. There does not seem to be any limitation to the geometrical configuration of shear wall systems. Whether inside or outside a building, Shear wall system may be arranged symmetrically or asymmetrically. The most common basic shapes are given in the central ring of Fig.1.2. Shape and location of the shear walls have significant effects on their structural behaviour under lateral loads. At the same time different arrangement of shear walls also affect the mat differently.

2.8 MAT WITH NON-UNIFORM THICKNESS FOR BETTER ECONOMY

Morshed (1996) and Sutradhar (1999) conducted comparative analysis between finite element method using Ahmad's thick shell element, ACI method and Conventional method. Morshed suggested a non-uniform mat foundation. His findings paved the way for developing a new design rationale for mat foundation. Sutradhar suggested a more definite guideline for selecting a mat of non-uniform thickness and its analysis with finite element methods.

Rahman (2001) also conducted thorough study about the behaviour of mat foundation using finite element software, ANSYS. He used shell element to study the behaviour of mat. Based on his work, he suggested guidelines for selecting mat geometry and distribution coefficients to calculate moments in a straightforward way for designing non-uniform mat foundations.

2.9 RESEMBLANCE BETWEEN MAT WITH NON-UNIFORM THICKNESS AND FLAT SLAB WITH DROP PANELS

Analysis and parametric study have shown that there is a basic similarity between flat slab having drop panels and mat foundation of variable thickness. In flat slab, uniformly distributed load is applied on the slab floor supported on columns. In flat slab, the slab is made somewhat thicker near the column than the rest of the slab, to reduce the shearing stress in the slab within the area of drop. The increase in effective slab thickness provided by the drop also decreases the compressive stresses in the concrete and reduces the amount of steel required over the column heads.

In a mat foundation of non-uniform thickness, a thick slab type mat rests on an elastic subgrade. Column loads are applied to the slab for transmission and distribution to the substratum. A reactive soil pressure is generated at the bottom face of the slab. Mats having greater thickness near the column can actually be considered as an inverted flat slab with drop panels. The reactive soil pressure distribution at the bottom face of mat is not, however, uniform as in the case of flat slab. Comparison of results in this field requires extensive study of mat behaviour.

In flat slab, drop panels are square or rectangular. The ACI Code specifies that the side of a drop panel shall be at least 0.33 times the span in each direction and the smaller thickness out side the drop should be at least 67% of the greater thickness within the drop. This reduction in thickness has been done considering flexural shear.

In beams, simply supported or continuous, at the face of the column, flexural shear is approximately 0.5 wL where w is load/unit length and L is span of the beam. At a distance 0.17L from the column face flexural shear is 0.33wL and bending moment is not significant. Bending moment is maximum at midspan. At a distance of 0.17L, beam thickness is governed by flexural shear and flexural shear is 2/3 of shear at the column face. Considering flexural shear, beam thickness can be reduced to 66% of thickness at the column face. At a distance 0.2L from the column face flexural shear is 0.3wL and beam thickness can be reduced to 60% of the column face thickness.

In a flat slab, each panel is considered as a beam. A drop is extended to 0.165 times the span on each side of the column. Considering flexural shear thickness outside the drop is reduced to 66% of the greater thickness provided that each side of the drop is at least 0.33 times of the span in that direction.

In a mat, to be conservative, width of thickened zone is taken as 0.4 times the span in each direction.. Mat panel can be considered as a total beam. Thickened zone is extended to 0.2 times of the span on each side of the column. At the transition point between greater thickness to smaller thickness, flexural shear is 60% of the flexural shear at column face and bending moment is not significant. So, at a distance of 0.2 times the span, mathematically, thickness can be reduced to 60% of greater thickness.

CHAPTER 3

IDEALISATION OF MAT FOUNDATION AND SHEAR WALL

3.1 GENERAL

Finite element method is the most powerful and versatile of all the available numerical analysis techniques. In this method, the structure to be analysed is modelled as an assemblage of a finite number of discrete interconnected elements and the displacements of the connecting points, called the nodal points, of these elements are taken as the primary unknowns. The applied loads are transformed into equivalent nodal loads and for each element; the relationship between the nodal loads and nodal displacements is established. Then with a suitable assembling of the element load-displacement relationship, sufficient number of load-displacement relations for the whole structure can be found which, upon solution, give the nodal displacements. Once known, these displacements are used to calculate stresses at the nodes or at points within the elements. A well reputed powerful computer program ANSYS has been used for analysis of mat foundation.

3.2 IDEALISATION OF MAT FOUNDATION ON WINKLER MODEL

3.2.1 Structural Idealisation

Mat foundation is a three-dimensional thick plate structure. In case of mat transverse flexural shear and bending moments are the most important internal forces produced in response to the loads it usually encounters e.g. axial column forces and column base moments. Element that can take account of shear deflection is particularly suitable for this purpose. Plate bending elements are acceptable for representing the flexural action of slab.

3.2.2 Idealisation of Soil

Actual contact pressure distribution is the result of the foundation soil interaction. This interaction can be determined only by analysis involving the elastic properties of both the foundation and soil. Soil structure interaction is an important process of predicting overall structural response. Settlement profile and soil contact pressure for raft foundations are dependent on the relative stiffness of raft and supporting soil. Currently, Winkler spring model has been used for representation of the soil behaviour. It consists of representing the soil, which supports a raft by discrete vertical springs.

3.2.3 Selection of Element

Mat foundation, a three-dimensional thick plate structure, is subjected to transverse flexural shears and bending moments. Eight nodded structural shell element SHELL93 in the library of ANSYS is one of the most suitable elements, which matches above-mentioned criteria. It can represent the thickness of the mat by its very own geometry. The element has six degrees of freedom at each node: translations in X, Y, Z directions and rotations about the X, Y, Z axes. Shear deflections are included in this element formulation. Spring element COMBIN14 has been used to represent the soil as the Winkler Spring Model. The longitudinal spring option is a uni-axial tension-compression element with three degrees of freedom at each node.

Soil springs may be uniform or may be zoned to incorporate the coupling effect of soil. Uniformly distributed soil springs are first concentrated at the nodes. This is done element wise and by lumping the total spring stiffness under an element at its nodes. A simplified approach is followed for this purpose. Spring elements are connected at the corner nodes of the element only.

3.2.4 Element Mesh Configuration

The simplest element division scheme is adopted for mat. It makes both data generation and result interpretation straightforward. The mesh used here is a rectangular grid with the option of finer elements near column loads. The mesh is characterized by the number of X and Z directional divisions of the grid and at present, each of these can be increased up to infinite numbers. Details of the mesh are shown in Fig 3.1.

3.2.5 Element and Node Numbering

The program uses frontal solution technique to evaluate nodal displacements. So in order to minimize computer memory requirement, the front must be as narrow as possible. This is accomplished by efficient numbering of elements. Front can be narrowed by numbering the elements serially from one corner of the mat to the other. The node-numbering scheme is such that it makes nodal coordinate generation simple. Nodes are numbered serially from one corner of the mat to the other corner. Details of the node and element numbering scheme are given in Fig. 3.2.

3.3 IDEALISATION OF SUPERSTRUCTURE

3.3.1 Structural Idealisation of Shear Wall

Shear walls that are not connected by beams to other parts of the structure can be modelled by a stack of beam elements located on the centroidal axis of the wall and assigned to have the principal inertia and corresponding shear areas of the wall for analysis. Shear walls connected by beams to other parts of structure can similarly represented by vertical stacks of beam elements located on the centroidal axes of the walls with rigid horizontal beam elements attached at the framing levels to represent the effect of the walls' width. In the case of a beam-connected wall, axial forces will be induced in the wall, so it is necessary to assign to the analogous column an axial area as well as an inertia and a shear area.

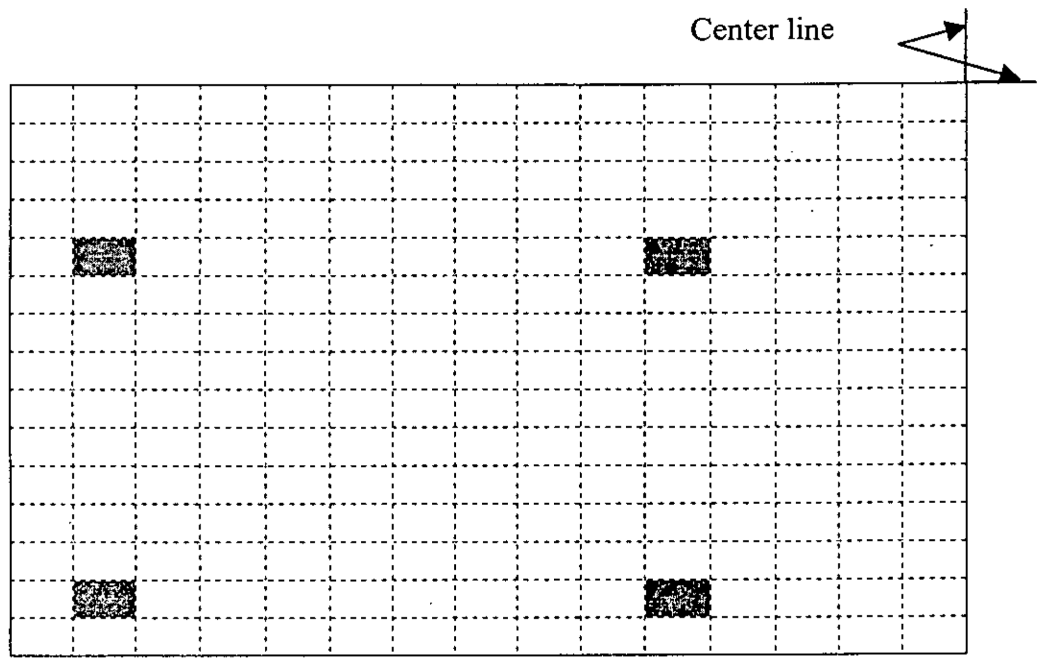

Fig. 3.1 Typical finite element mesh for mat foundation.

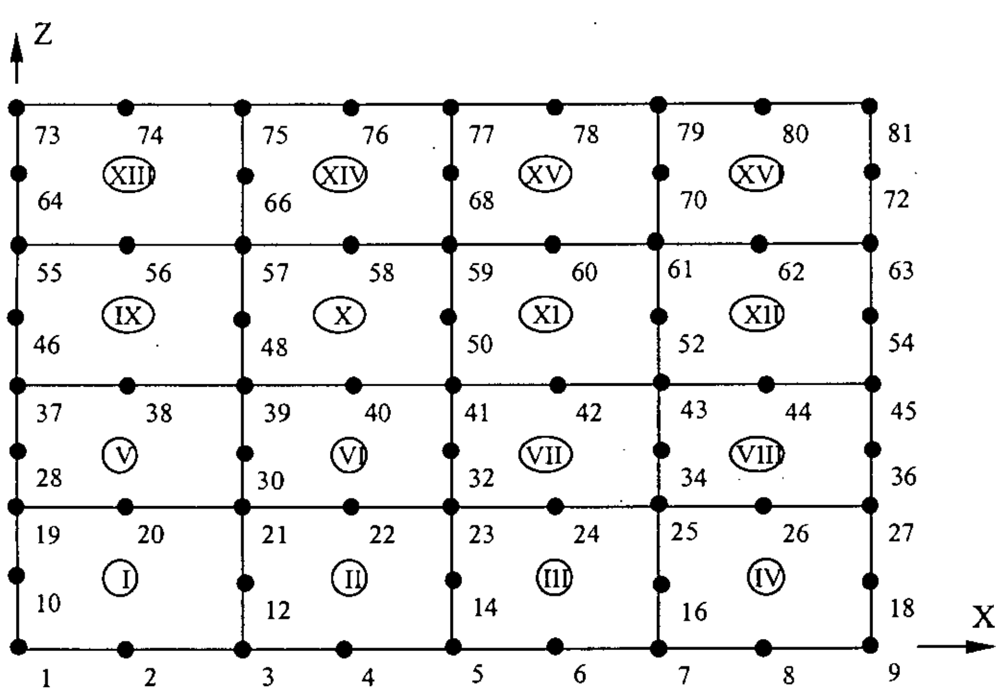

Fig. 3.2 A typical finite element mesh for mat with element and node numbering.

Shear walls that are not slender, or that have openings, cannot be well represented by simple equivalent columns. An assembly of plane-stress membrane elements is a better representation of them. The results for a plane-stress element typically include the horizontal and vertical displacements of the nodes and the vertical and horizontal direct stresses and shear stresses at either the corners or the mid-sides of the element.

When modelled by membrane elements, shear walls with in-plane connecting beams require special consideration. Membrane elements do not have a degree of freedom to represent an in-plane rotation of their corners; therefore, a beam element connected to a node of a membrane element is effectively connected only by a hinge. A remedy of this deficiency is to add a fictitious, flexurally rigid auxiliary beam to the edge wall element. The adjacent ends of the auxiliary beam and the external beam are both constrained to rotate with the wall-edge node. Consequently, the rotation of the wall, as defined by the relative transverse displacements of the ends of the auxiliary beam, and a moment, are transferred to the external beam. Generally modelled in finite element technique either by plate elements or by plane stress elements. Axial force and in-plane bending are important for shear wall. Plate element SHELL63 of ANSYS library has been used to model shear wall. Shear walls are modelled separately from mat foundation with frame for some studies and they also modelled directly with mat foundation to get the interaction between shear wall and mat foundation.

3.3.2 Modelling of Three-dimensional Frame-Wall Structures

The high-rise rigid frame structure has moment-resisting joints, and its columns and beams are modelled by three-dimensional beam elements. These elements deform axially, in shear and bending in two transverse directions, and in twist. Generally, therefore, they have to be assigned an axial area, two shear areas, two flexural inertias and a torsion constant. Often, however, shear deformations of the columns and beams, and axial deformations of the beams, are assumed negligible. These are usually allowed by omitting the assignment of a shear area and by assigning either a fictitiously large axial area, or constraints between the axial displacements of the member ends. In addition, the torsional stiffness of practically proportioned beams and columns is usually negligible, which is allowed for by omitting the assignment of a torsion constant. The usual results of significance are the translations of the nodes, the shear forces, bending moments and axial forces in the columns, and the shear forces and moments in the beams.

Plane-stress elements alone are not adequate for modelling three-dimensional wall systems because the lack the transverse stiffness necessary at orthogonal wall connections to allow a stiffness matrix analysis of the problem. Plane-stress membrane elements, when used alone, can not provide the out-of-plane rigidity required to maintain the sectional shape of the core. The remedy for these deficiencies is to add at each nodal level a horizontal frame of fictitious, rigid auxiliary beams. If any of the walls are connected in-plane to each other, or to other parts of the structure, by beams, the auxiliary beams adjacent to the wall edge can be made vertically rigid also, to cause the transfer of moment.

Walls can also be modelled successfully by using shell elements. In that case, a fictitious column is to be introduced at the edge of wall, or fictitious, rigid auxiliary beam at wall-beam connection can be used in such a manner that the fictitious beam joins the beam and an internal point in the wall to transfer the moment properly to the wall.

In the present study frame shear wall systems are modelled by three-dimensional beam elements and shell elements to represent beam-column and shear wall respectively. Fictitious, rigid beam elements are used at the level of beam shear wall connections.

3.4 APPLICATION OF LOAD ON MAT FROM SUPERSTRUCTURE

3.4.1 Application of Column Loads

Both column axial loads and column base moments can be applied. Column axial load may be applied as concentrated load or it may be distributed over an area equal to the cross-section of the column by taking an element, termed as column element, applying the load as concentrated force at four corner nodes. Similarly, column base moments may be concentrated or distributed. The later is accomplished by resolving column base moment into nodal loads acting at the nodes of the column element along the sides parallel to the axis of the moment. In this study, column axial load and bending moments are applied to the column element at four corner nodes equally.

3.4.2 Application of Shear wall load on Mat

Application of shear wall loading on mat foundation efficiently is one of the most significant part of the present work. To achieve reliable results, this part was done carefully in the work. For sensitivity analysis and for analysis of mat with different locations of shear wall, superstructure and mat were analysed separately. Frame-shear wall superstructure was modelled separately keeping the superstructure rigid at base and the axial force, shear force and bending moments produced at the base were transferred on the mat reversing their respective direction. To perform this part of work successfully mat and superstructure was modelled keeping the locations of node common for both in the superstructure and in the mat model.

3.5 VERIFICATION OF FINITE ELEMENT MODEL

Results obtained by ANSYS have been verified with closed form solution of a beam on elastic foundation by Hetenyi (1974). The structure is modelled with element SHELL93 and soil is modelled with element COMBIN14 of ANSYS element library.

A beam of unlimited length of unit cross section subjected to a single concentrated force, P, at origin, has the exact solution given by

$$Y = \frac{P\lambda}{2k} e^{-\lambda x} (\cos \lambda x + \sin \lambda x) \tag{3.1}$$

$$M = \frac{P}{4\lambda} e^{-\lambda x} (\cos \lambda x - \sin \lambda x) \tag{3.2}$$

$$\theta = -\frac{P\lambda^2}{k} e^{-\lambda x} \sin \lambda x \quad (3.3)$$

Verification Example:

A beam of unit width and unit depth is modelled with SHELL93 and COMBIN14 element. The model has been analysed with line load P= 440 kN/m across the width at the origin as shown in Fig..3.3.

Modulus of subgrade reaction, k	= 4.7 MN/m^3,
Modulus of concrete, E_c	= 20.7 MPa
Length of the beam, L	= 24.4 m.
Beam of X-section	= .305 m x .305 m

For long beam, λL must be greater than π,

where, $\lambda = \sqrt[4]{k/4E_c I}$

For beam of X-section = 305mm x 305mm

λ = 0.39406

λL = 0.39406 x 24.4

= 9.61 $> \pi$

Hence the beam may be considered as long beam.

Table 3.1 Comparison of results in between exact solution and ANSYS solution.

Distance (m)	Bending Moment (kN-m)		Deflection (mm)		Rotation (Radian)	
	ANSYS	Actual	ANSYS	Actual	ANSYS	Actual
0	0.0000	2.4741	-0.0452	0.1352	0.000251	0.000118
0.6096	0.0259	2.4350	0.1079	0.2164	0.000251	0.000149
1.2192	-0.1371	2.0143	0.2611	0.3159	0.000251	0.000177
1.8288	-0.7573	1.0383	0.4132	0.4303	0.000246	0.000197
2.4384	-2.1004	-0.6924	0.5592	0.5522	0.000229	0.0002
3.048	-4.4212	-3.3891	0.6890	0.6681	0.000189	0.000175
3.6576	-7.9449	-7.2522	0.7848	0.7576	0.000112	0.00011
4.2672	-12.8362	-12.4338	0.8196	0.7910	-0.000016	-0.000011
4.8768	-19.1523	-18.9866	0.7563	0.7288	-0.00021	-0.00021
5.4864	-26.7770	-26.7946	0.5467	0.5213	-0.0005	-0.00049
6.096	-35.3364	-35.4856	0.1329	0.1092	-0.00089	-0.00088
6.7056	-44.0990	-44.3283	-0.5499	-0.5733	-0.00138	-0.00138
7.3152	-51.8622	-52.1179	-1.5683	-1.5925	-0.00199	-0.00198
7.9248	-56.8358	-57.0609	-2.9806	-3.0068	-0.00267	-0.00267
8.5344	-56.5422	-56.6752	-4.8241	-4.8522	-0.00338	-0.00339
9.144	-47.7530	-47.7297	-7.0954	-7.1238	-0.00404	-0.00405
9.7536	-26.4990	-26.2567	-9.7268	-9.7508	-0.00451	-0.00453
10.3632	11.8109	12.3202	-12.5544	-12.5668	-0.00462	-0.00463
10.9728	72.0961	72.8895	-15.2854	-15.2751	-0.00412	-0.00413
11.5824	159.0901	160.1263	-17.4599	-17.4115	-0.0027	-0.0027
12.192	276.5247	277.6747	-18.4233	-18.3094	-1.2E-14	0

Comparison of results between exact solution and ANSYS solution is given in Fig.3.4 - 3.6.

3.6 CRITICAL ASPECTS OF FINITE ELEMENT MODEL

3.6.1 Selection of Finite Element Mesh

Finite element method is a numerical approach, accuracy of solution increases with the number of elements in which the mat is divided. Solutions being converging, a point comes when further refinement in mesh adds nothing significant to the accuracy. Mesh sensitivity study has been made and a final mesh is selected.

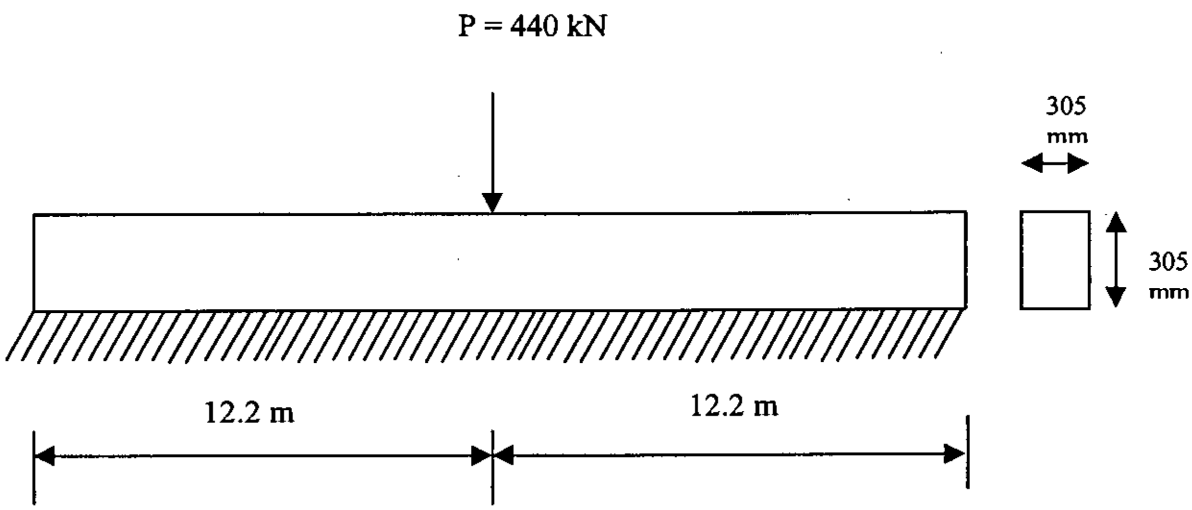

Fig. 3.3 Beam resting on elastic subgrade subjected concentrated load at the center.

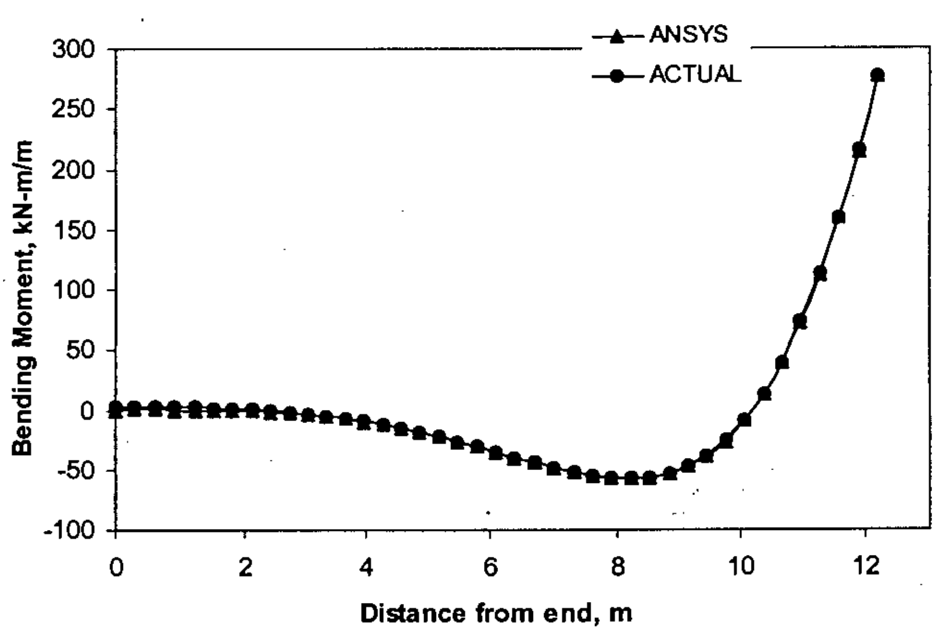

Fig. 3.4 Variation of bending moment against distance along beam line.

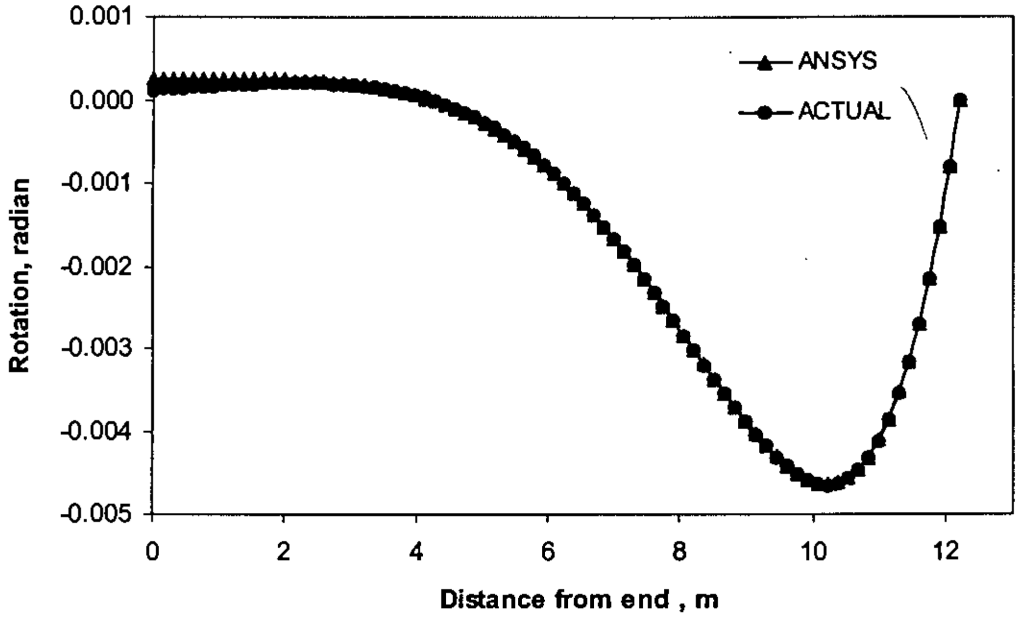

Fig. 3.5 Variation of rotation against distance along beam line.

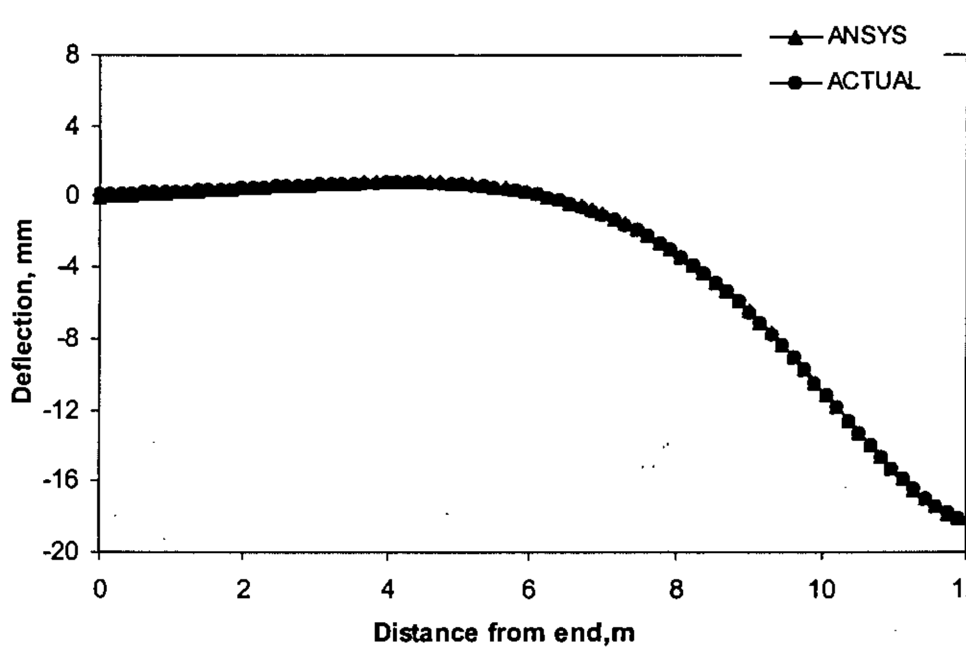

Fig. 3.6 Variation of Deflection against distance along beam line.

3.6.2 Element Aspect Ratio

Shape of the element affects the results. Element aspect ratio must be between 0.5 to 2.0. Study on element aspect ratio has been done. Best results are obtained for element aspect ratio equal to 1.0.

3.3 Effect of Column Rigidity

Columns are monolithically built with mat and they act integrally with it. Height of column highly increases the rigidity of mat at these locations. This effect is realized by increasing the value of modulus of elasticity of the portions of the mat under the columns. To quantify this effect, column deflections, column face moments and shears are plotted against the ratio of the modulus of elasticity of soil under column portions by Sutradhar (1999). It appears that effect of column rigidity dies out with increase of this modulus of elasticity ratio. Examining these, a modulus of elasticity ratio of 8 is found to be justified.

CHAPTER 4

COMPARATIVE STUDY AND SENSITIVITY ANALYSIS

4.1 GENERAL

A parametric study on finite element solution of mat foundation with shear wall for the variation of its different parameters has been made. Comparison between different previous studies on mat foundation with column loading and the present study has been summarized. For this parametric study a sample problem of fifteen-story building with typical planer shear walls has been studied for both vertical loads and lateral loads. From previous studies by Morshed (1996), Sutradhar (1999) and Rahman (2001) variation of subgrade reaction and thickness of mat was found to be dominating parameters in design of mat foundation. So, variation of modulus of subgrade reaction and variation in differential thickness have been taken into consideration for sensitivity analysis.

4.2 SENSITIVITY ANALYSIS OF MAT FOUNDATION

4.2.1 Model Description

A typical fifteen-story building with five bays in long direction and three bays in short direction has been taken for the study. The location of shear walls was chosen as a typical place for the building plan. The plan of the structure is shown in Fig-4.1 with the lines 1 to 10 along which variation in moment, shear and deflection has been studied.

4.2.2 Loading Patterns

Shear wall resists the major portion of lateral loads. So lateral load is intensified on small area of mat due to the presence of shear wall. Consideration of the lateral loading in analysis is an important aspect of parametric study of mat foundation with shear wall. In a study by Rahman (2001) considered only the vertical loading parametric study as for medium height buildings, vertical loading is found to be critical for foundation design. As shear wall presence causes remarkable change in loading pattern on mat for lateral load case, consideration of lateral load is significant is the present study.

For calculating wind load, the Bangladesh National Building Code (BNBC,1993) was followed. The superstructure was considered to be located at Exposure category 'A' where basic wind speed is 210 km/h. Structure importance category was assumed to be Standard occupancy structures. To calculate Design Wind load Projected Area method was used. To distribute lateral load on shear wall and frame was calculated from their relative stiffness. Lateral loads were divided into the frames and walls based on the ratio of their stiffness.

The superstructure is assumed to have a live load of 2.9 kN/m^2, slab dead load of 4.3 kN/m^2, distributed partition wall load of 1.4 kN/m^2 and floor finish 1.2 kN/m^2. An amount of 6.4 kN/m has been considered for 125 mm walls along all beams and column size is 0.6x0.6 m. Story height of the floor is taken as 3.0m and number of stories is 15. Shear wall thickness is taken as 0.3 m.

Calculation of dead load and live load is made in accordance with the USD method of ACI (1983). Proper live load reduction is employed in calculating column loads and shear wall loads. Load cases are used as follows:

Load case I = 1.4DL+ 1.7 LL

Load case II = 0.75*(1.4DL+ 1.7LL+1.7WL)

Where

LL = Live load,

DL = Dead Load,

WL = Wind Load.

Load case I and Load case II have been denoted by LC1 and LC2 later in the chapter. Finite element idealization of the mat and shear wall model has been described earlier in Chapter 3.

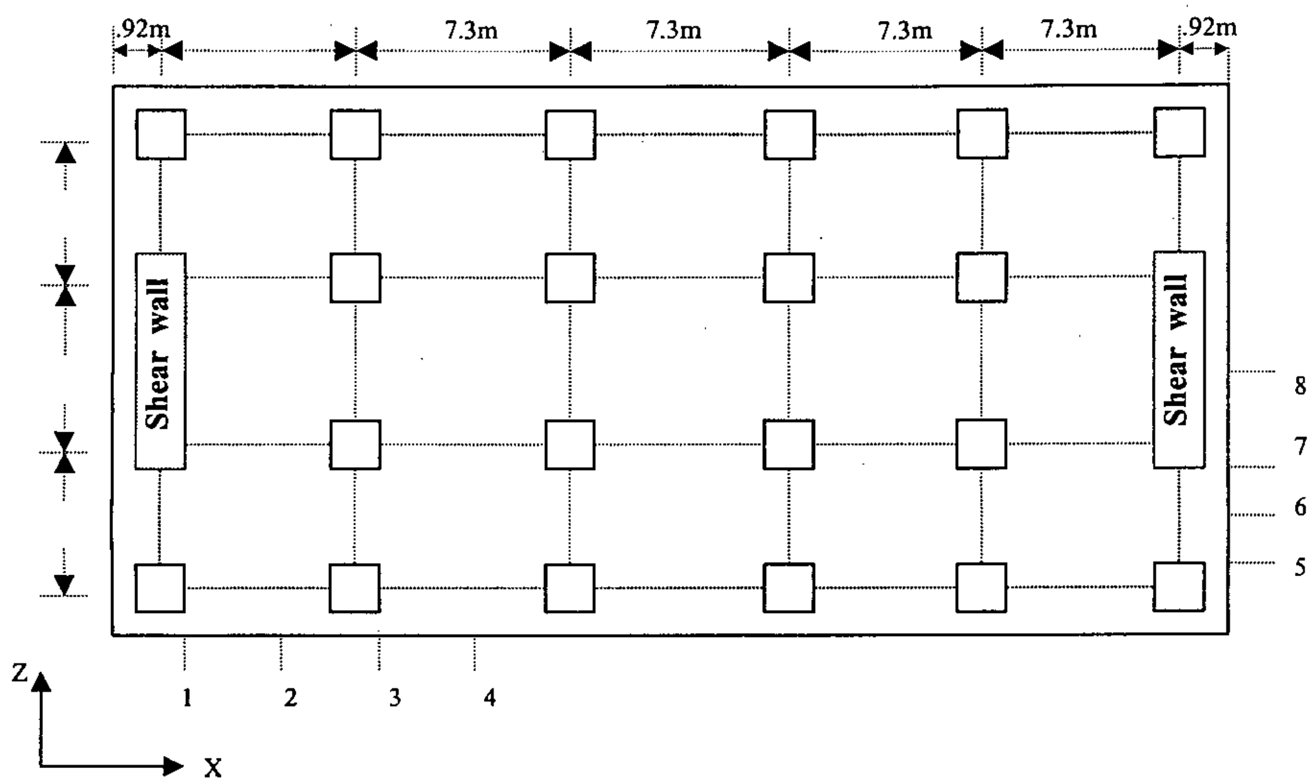

Fig.4.1 Plan area of mat with symmetrically placed Shear walls. Also showing lines along which different parameters have been studied.

4.2.3 Effect of Modulus of Subgrade Reaction

The mat is analysed for constant thickness 1070 mm with variation of modulus of subgrade reaction from 8.0 MN/m^3 to 32.0 MN/m^3. The items those govern the design mat design, have taken for parametric study include displacement, bending moment and shearing stress along lines 1 to 8 (Fig. 4.1). Variation of these items on column faces and mid span for mat are plotted in Fig. 4.2 to Fig.4.7. In the plots K8.0 represents the variation for subgrade reaction 8.0 MN/m^3 and K16.0 for subgrade reaction 16.0 MN/m^3 and so on. Variation corresponds to Load case I and Load case II are represented by LC1 and LC2 respectively.

The following points are observed for variation in subgrade reaction.

- Positive moment below the column increases slightly for increase in subgrade reaction. This change is more pronounced for column line parallel and adjacent to the line of shear wall. (Fig. 4.2 and Fig. 4.3).

- Negative moment of mid panel adjacent to shear wall is more sensitive to change in subgrade reaction than the negative moments at other locations. Negative moment decreases with the increase in subgrade reaction for load case I. (Fig. 4.2 and Fig. 4.3).

- Variation in negative moment is more prominent than that of positive moment for change in the value of subgrade reaction (Fig. 4.2 and Fig. 4.3).

- Change in bending moment (both positive and negative) is high at the face of shear walls. These moment values are much more higher than the column face moments (Fig.4.3)

- The variation of shearing stress is not very significant for any load combination (Fig. 4.4 and Fig 4.5).

- Displacement is most sensitive to variation in subgrade reaction. Vertical displacement of mat decreases rapidly with increase in subgrade reaction. Displacements become almost half when the value of subgrade reaction becomes double. For low subgrade reactions the value of overall deflections are also high. Most remarkable variation in deflection for change in subgrade reaction is found along the line of shear wall. Table 4.3 shows that variation in displacement is significantly high for most of the location of mat foundation. (Fig. 4.6 and Fig.4.7).

- Load case II produces higher differential settlement for lonbw subgrade reactions and the differential settlement for higher subgrade reactions is small. This higher

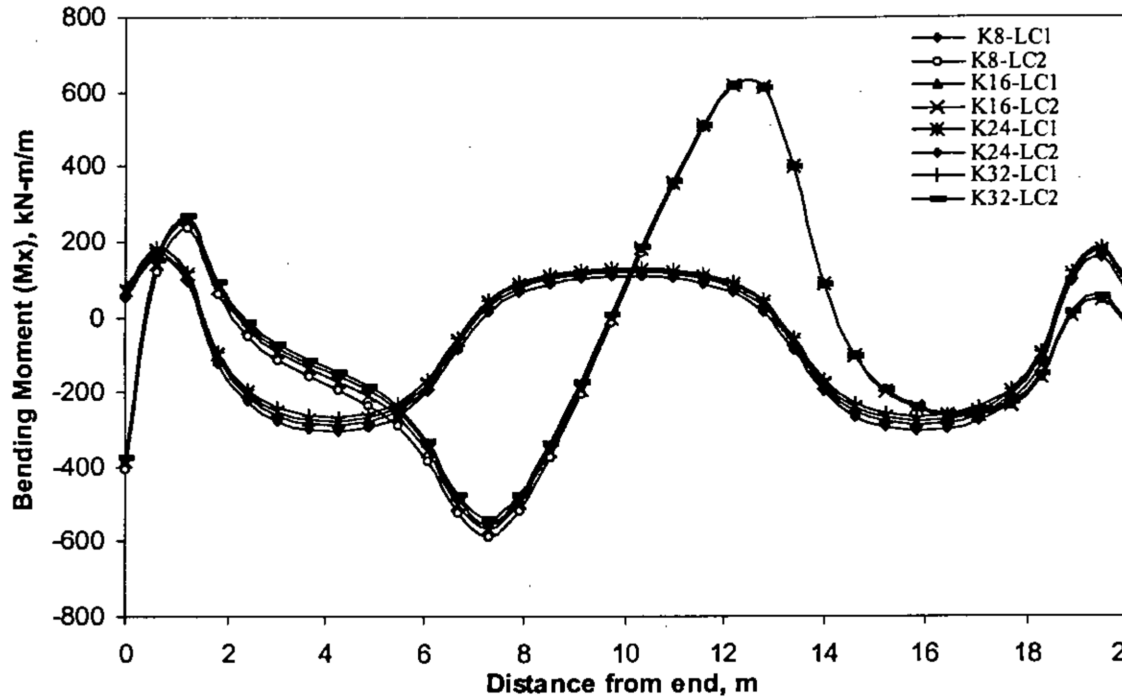

Fig. 4.2a Variation of bending moment M_x along **line 1** with change of subgrade modulus K from 8.0 - 32.0 MN/m^3. (LC1-vertical load case, LC2-lateral and vertical load case).

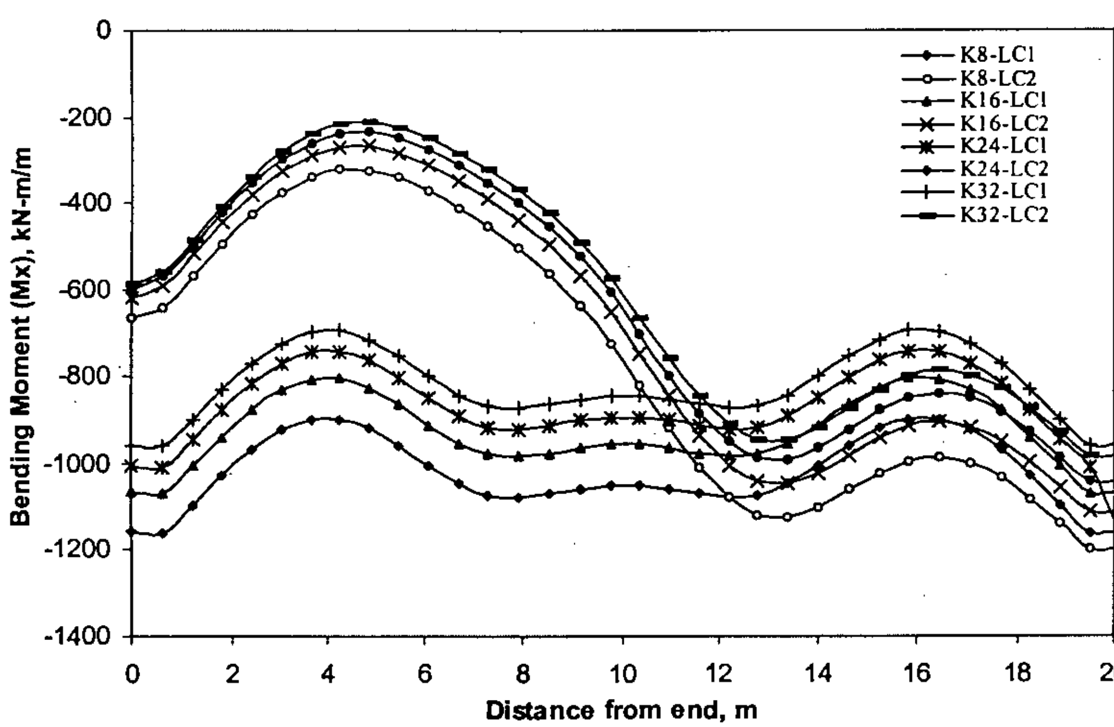

Fig. 4.2b Variation of bending moment M_x along **line 2** with variation of subgrade modulus K.

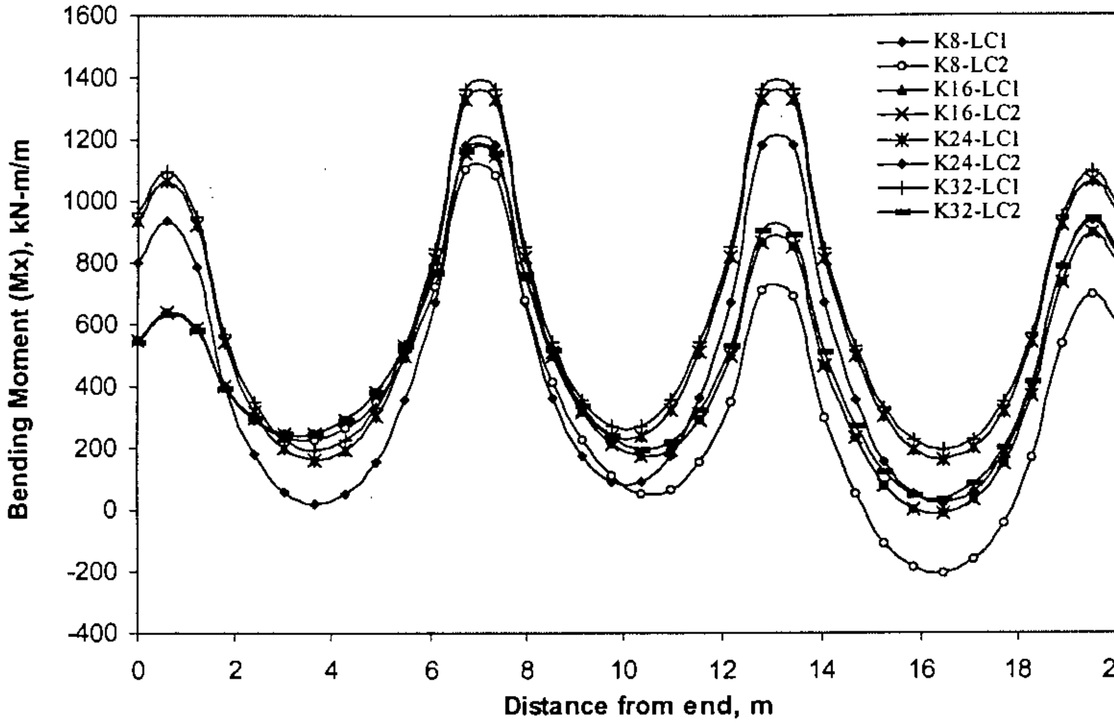

Fig. 4.2c Variation of bending moment M_x along **line 3** with variation of subgrade modulus K.

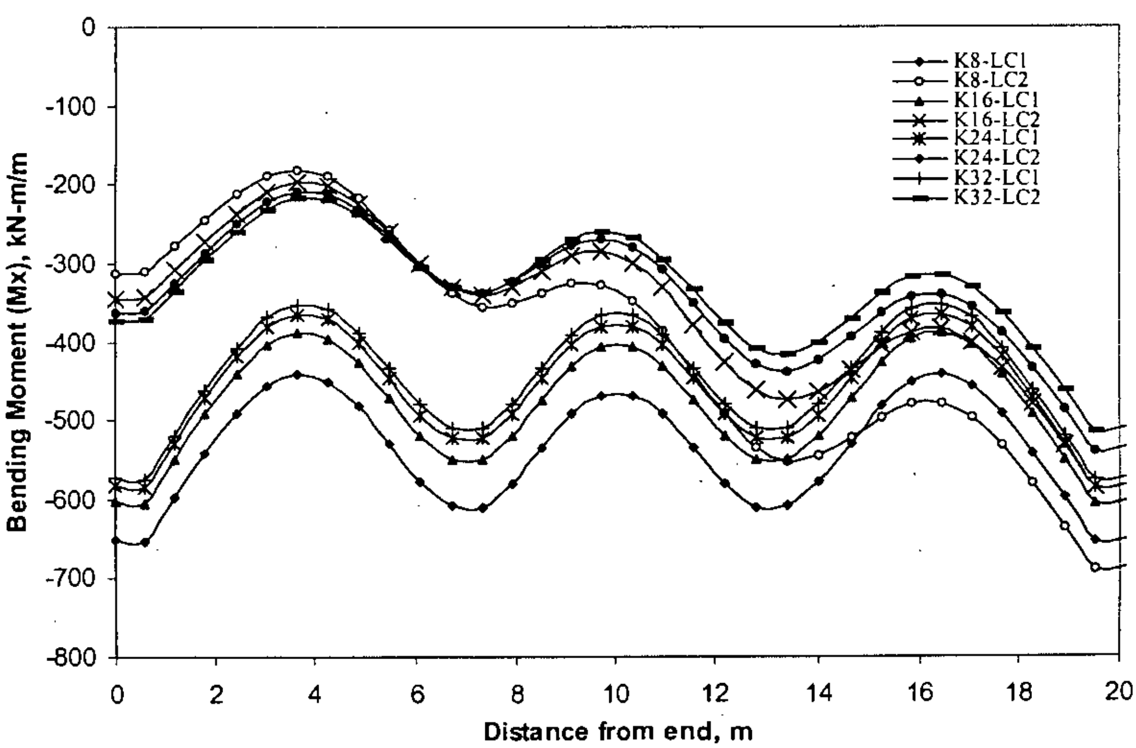

Fig. 4.2d Variation of bending moment M_x along **line 4** with variation of subgrade modulus K.

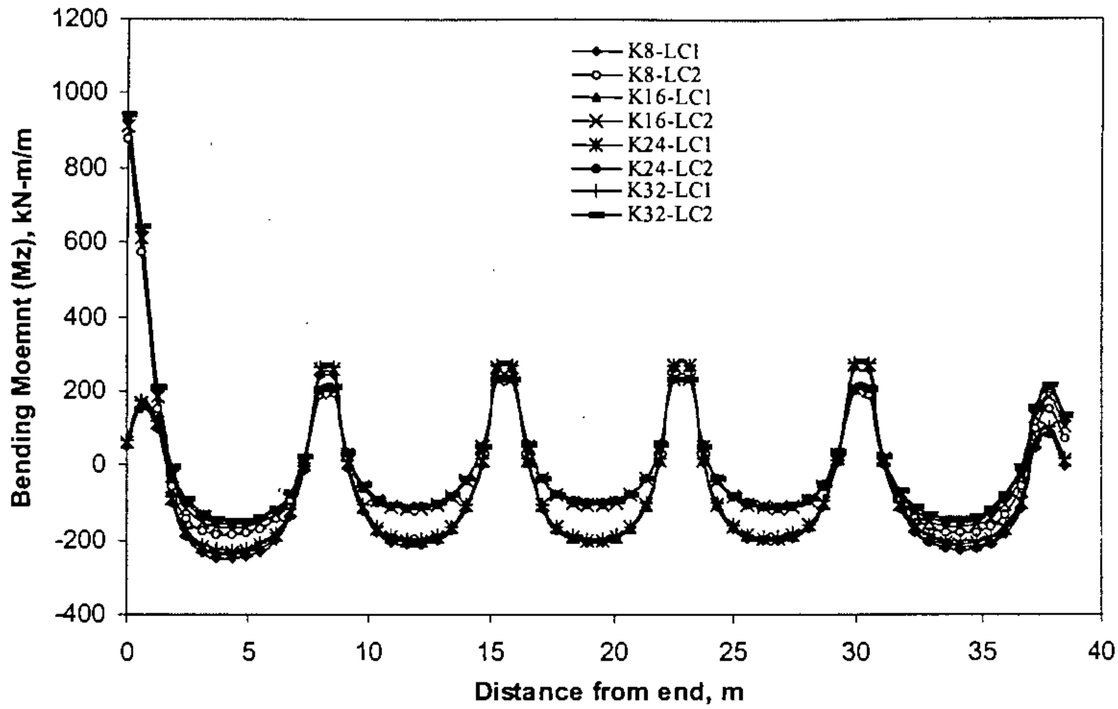

Fig. 4.3a Variation of bending moment M_z along **line 5** with variation of subgrade modulus K.

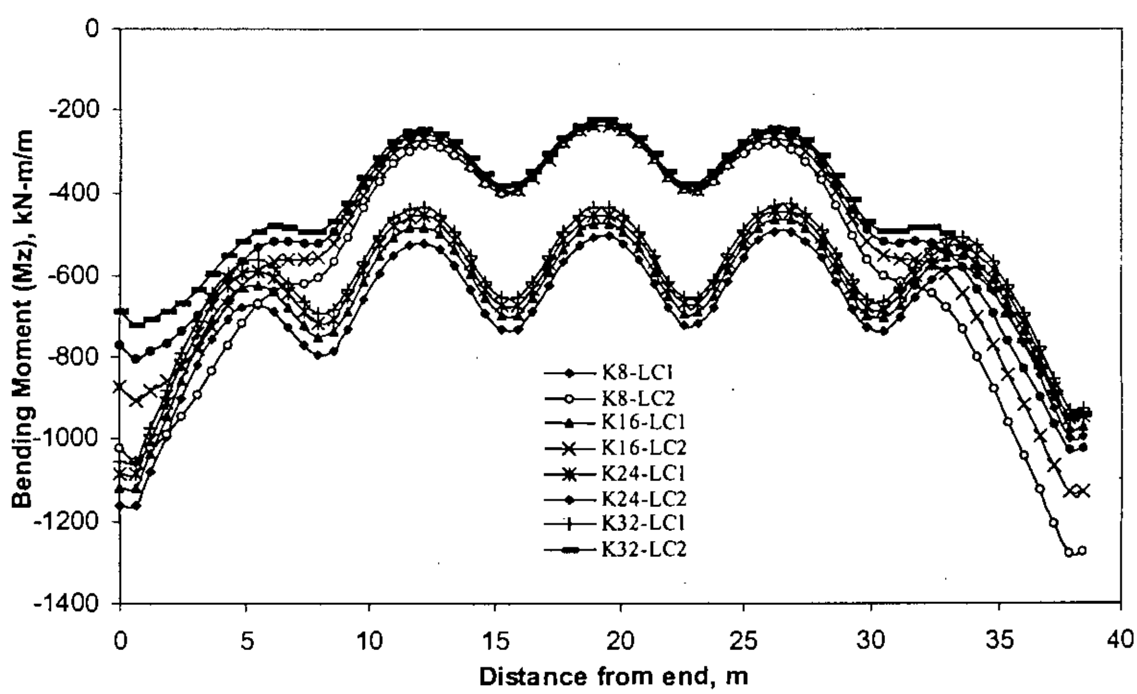

Fig. 4.3b Variation of bending moment M_z along **line 6** with variation of subgrade modulus K.

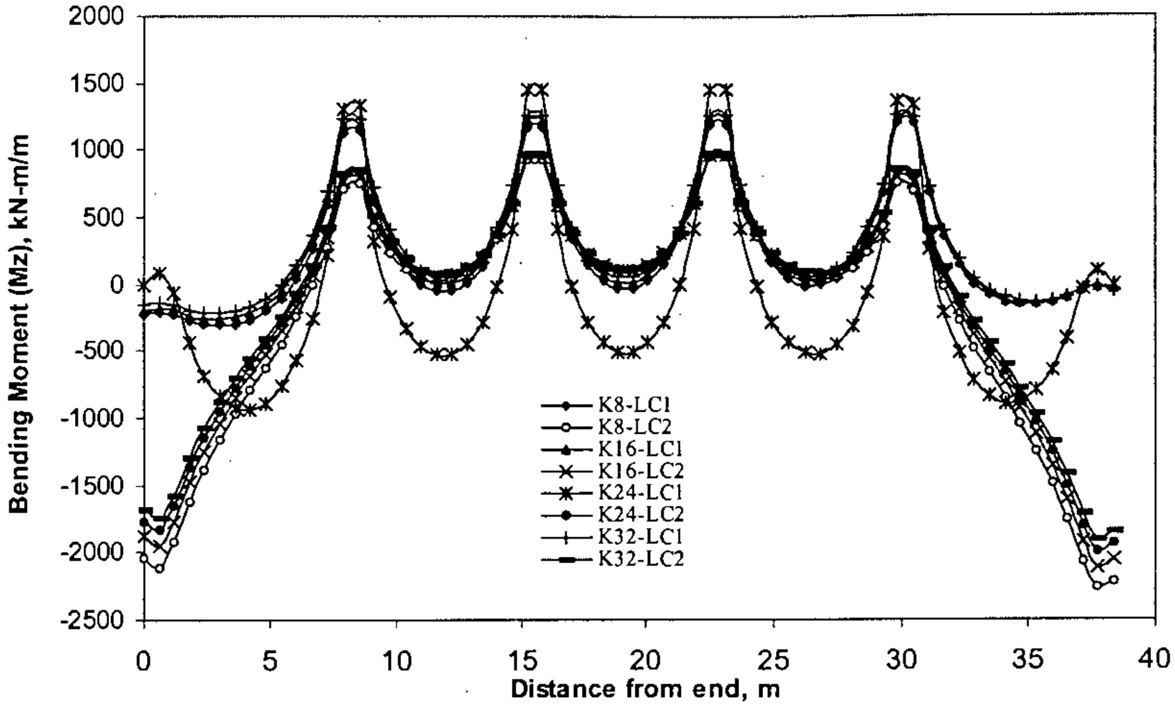

Fig. 4.3c Variation of bending moment Mz along **line 7** with variation of subgrade modulus K.

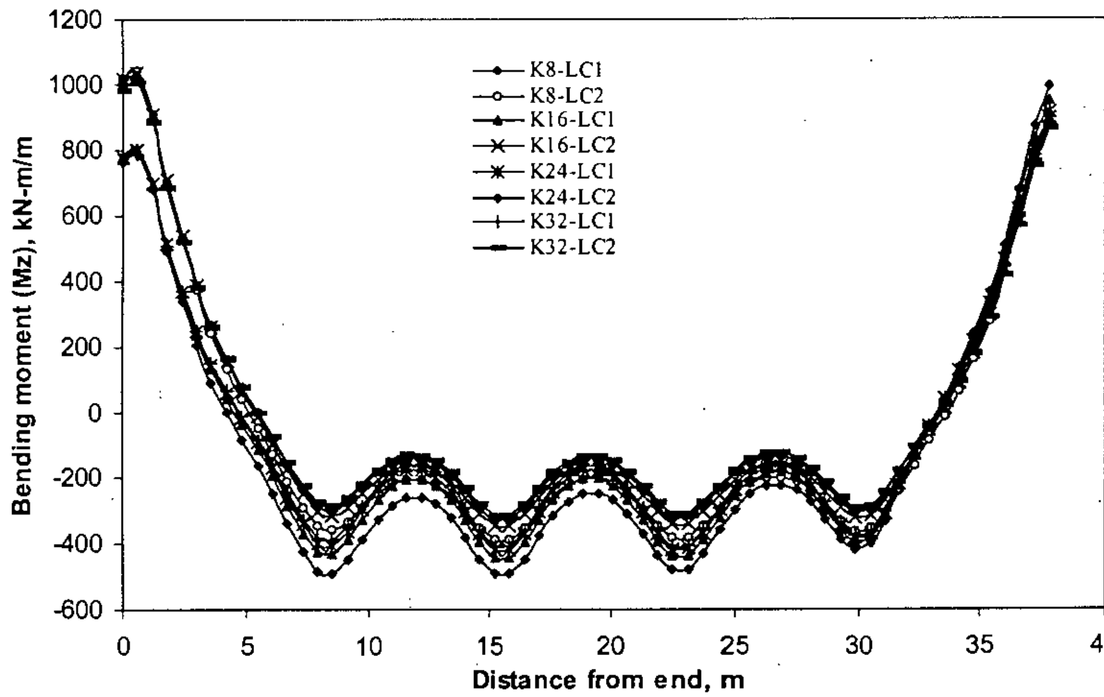

Fig. 4.3d Variation of bending moment M_x along **line 8** with variation of subgrade modulus K.

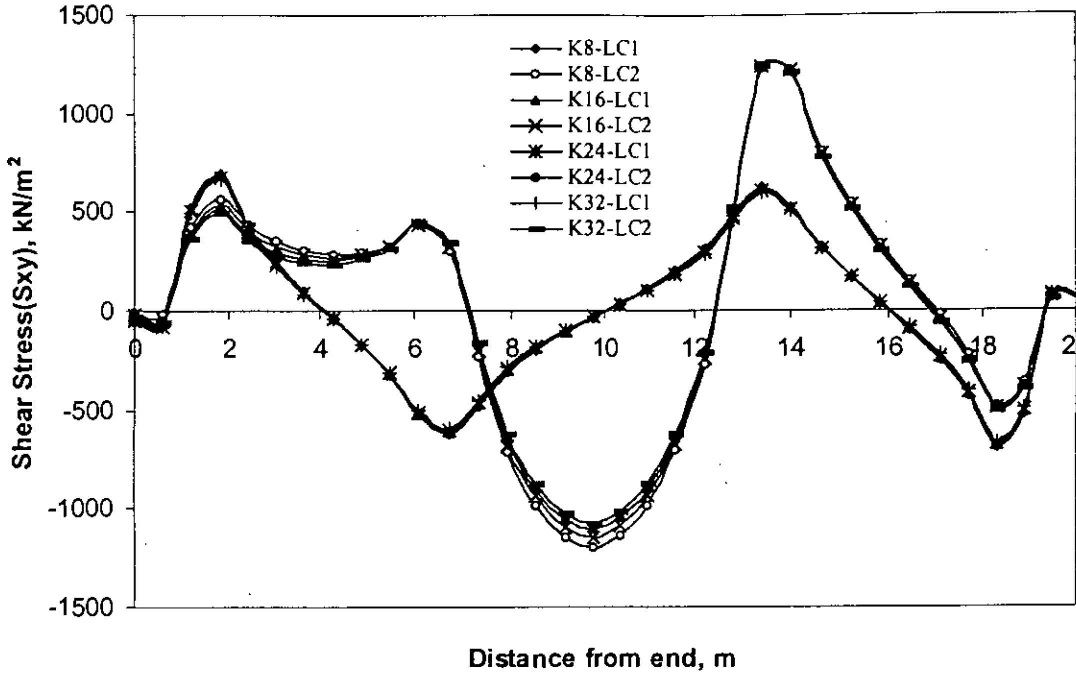

Fig. 4.4a Variation of Shearing stress S_{xy} along **line 1** with variation of subgrade modulus K from 8.0 - 32.0 MN/m^3. (LC1-vetical loads, LC2- lateral and vertical loads).

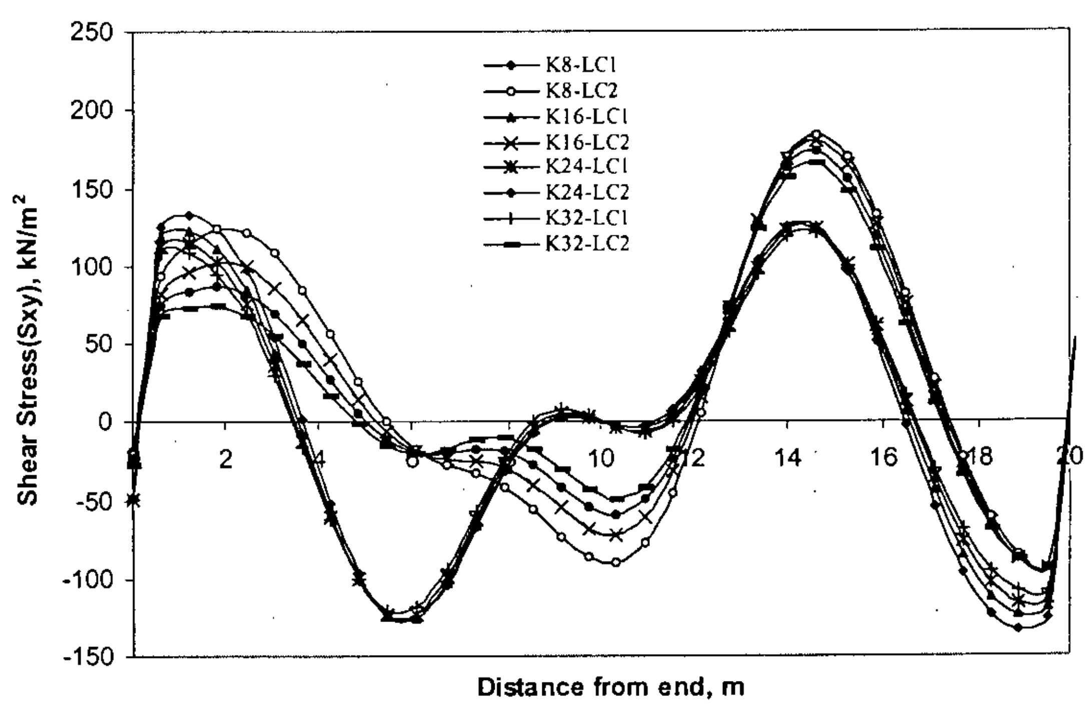

Fig. 4.4b Variation of Shearing stress S_{xy} along **line 2** with variation of subgrade modulus K.

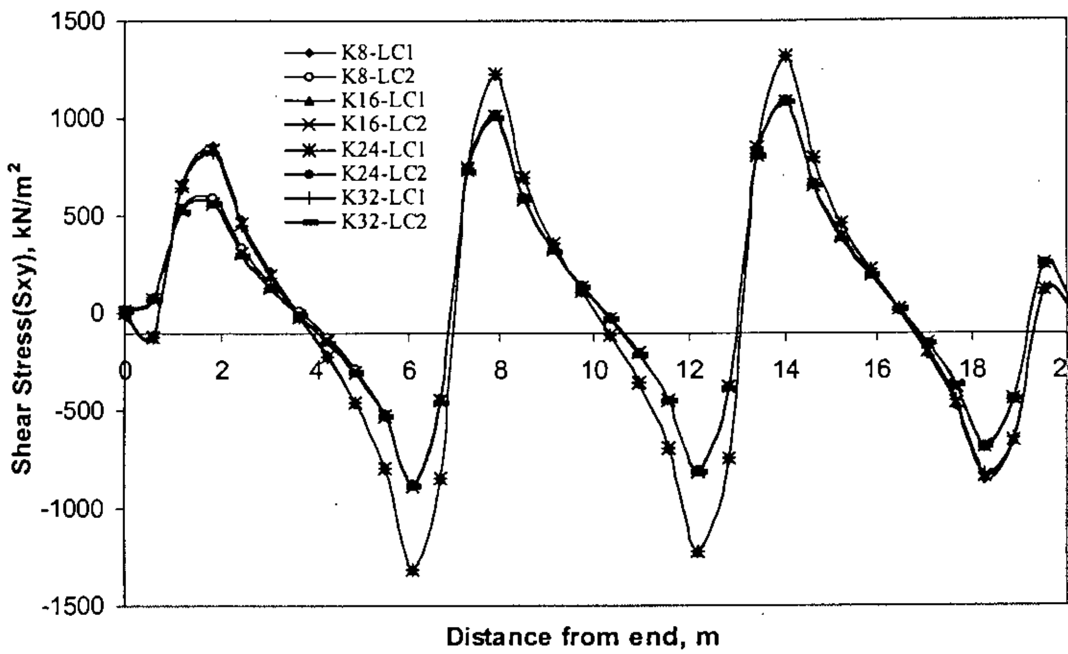

Fig. 4.4c Variation of Shearing stress S_{xy} along **line 3** with variation of subgrade modulus K

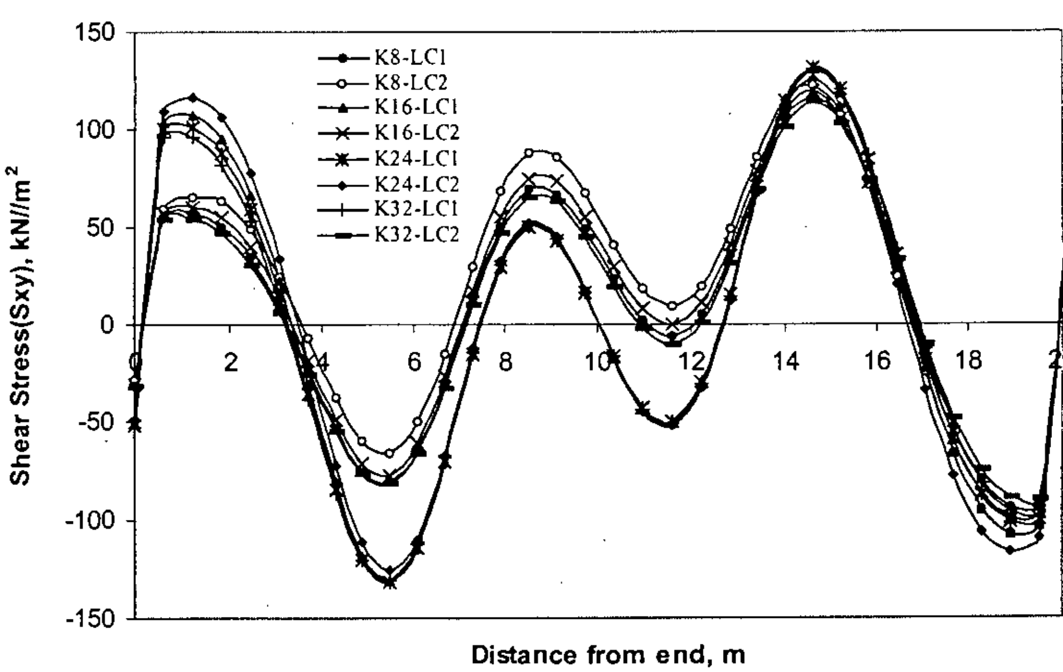

Fig. 4.4d Variation of Shearing stress S_{xy} along **line 4** with variation of subgrade modulus K

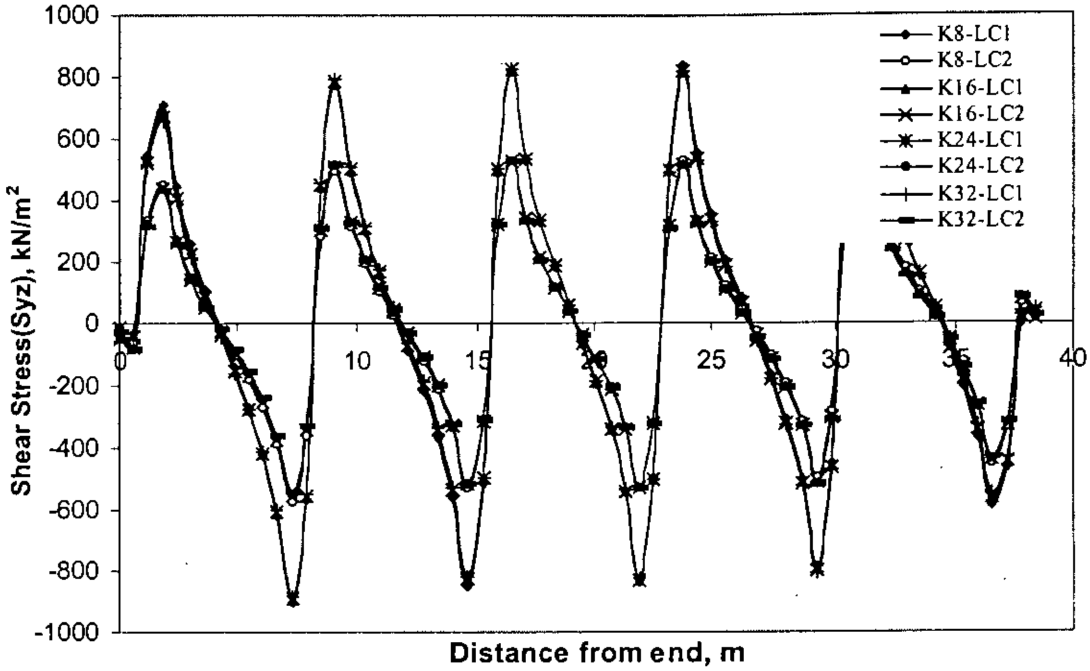

Fig. 4.5a Variation of Shearing stress S_{xy} along **line 5** with variation of subgrade modulus K.

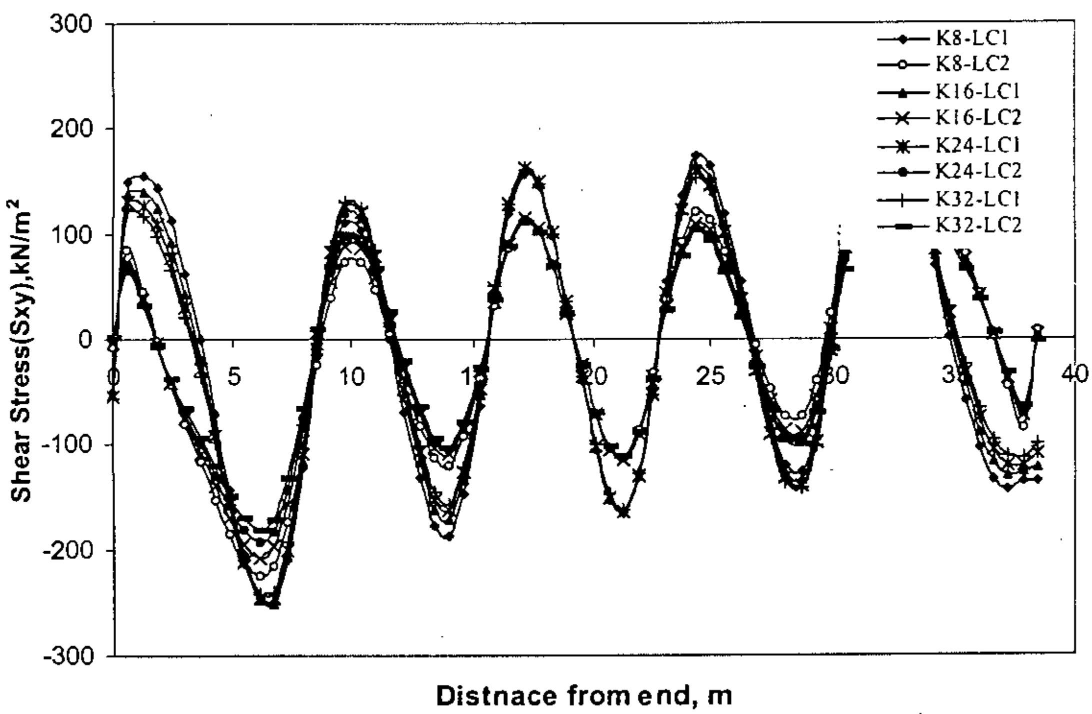

Fig. 4.5b Variation of Shearing stress S_{xy} along **line 6** with variation of subgrade modulus K.

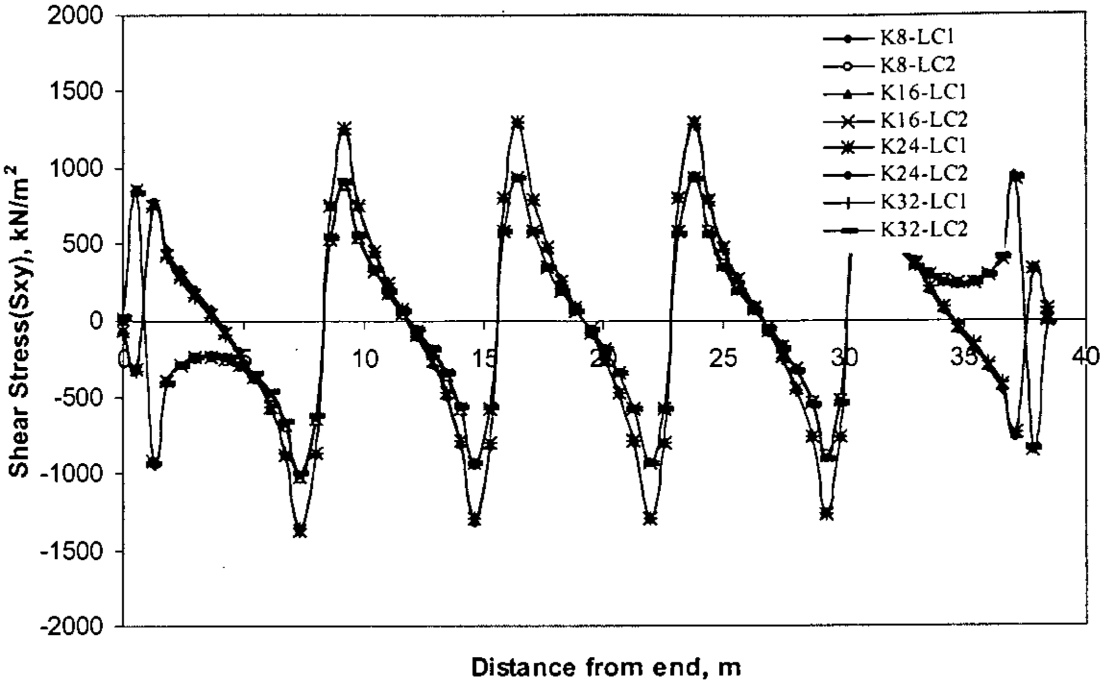

Fig. 4.5c Variation of Shearing stress S_{xy} along **line 7** with variation of subgrade modulus K

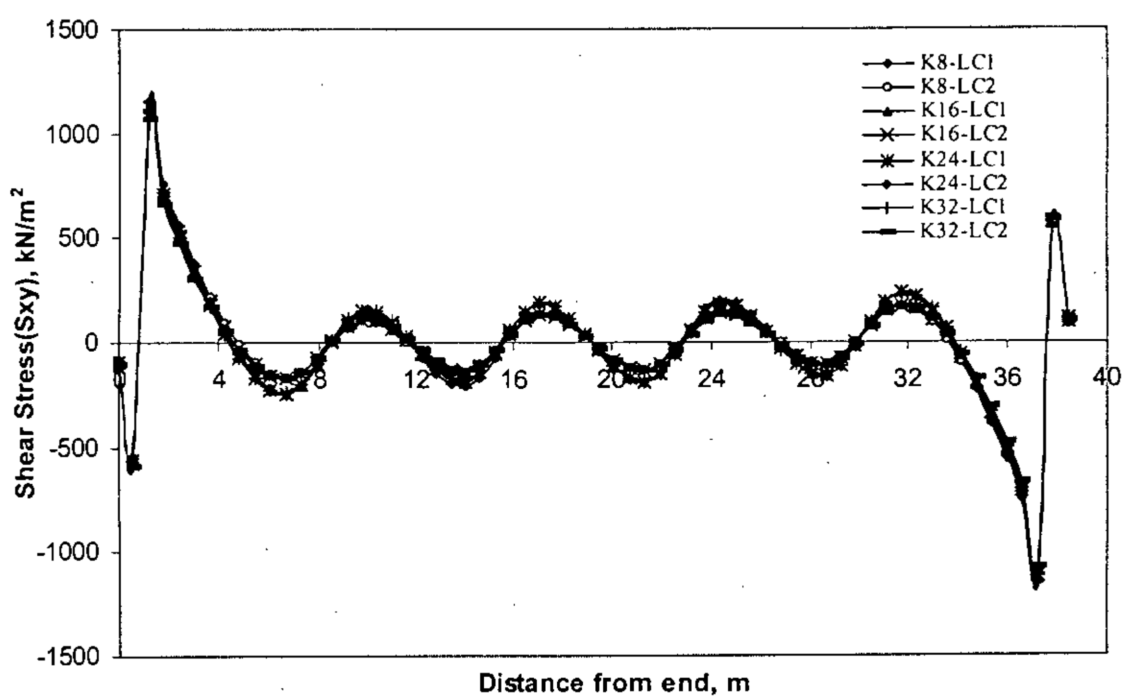

Fig. 4.5d Variation of Shearing stress S_{xy} along **line 8** with variation of subgrade modulus K

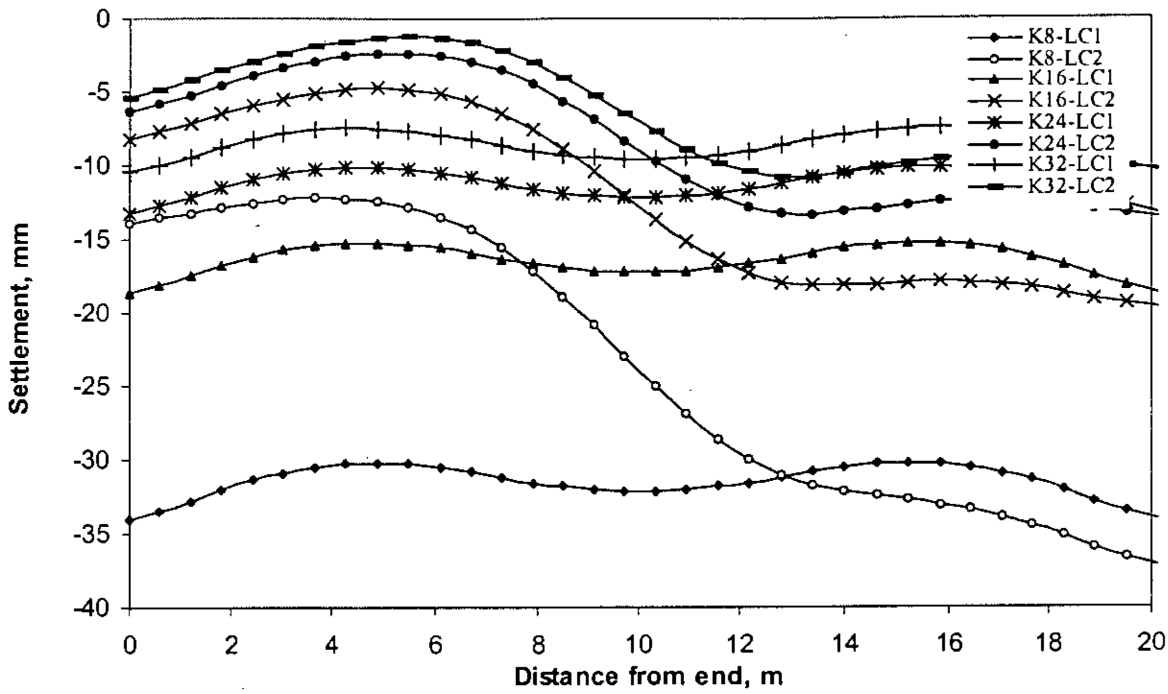

Fig. 4.6a Variation of Settlement alone **line 1** with variation of subgrade modulus K from 8.0 - 32.0MN/m^3. (LC1-vetical loads, LC2-lateral and vertical loads).

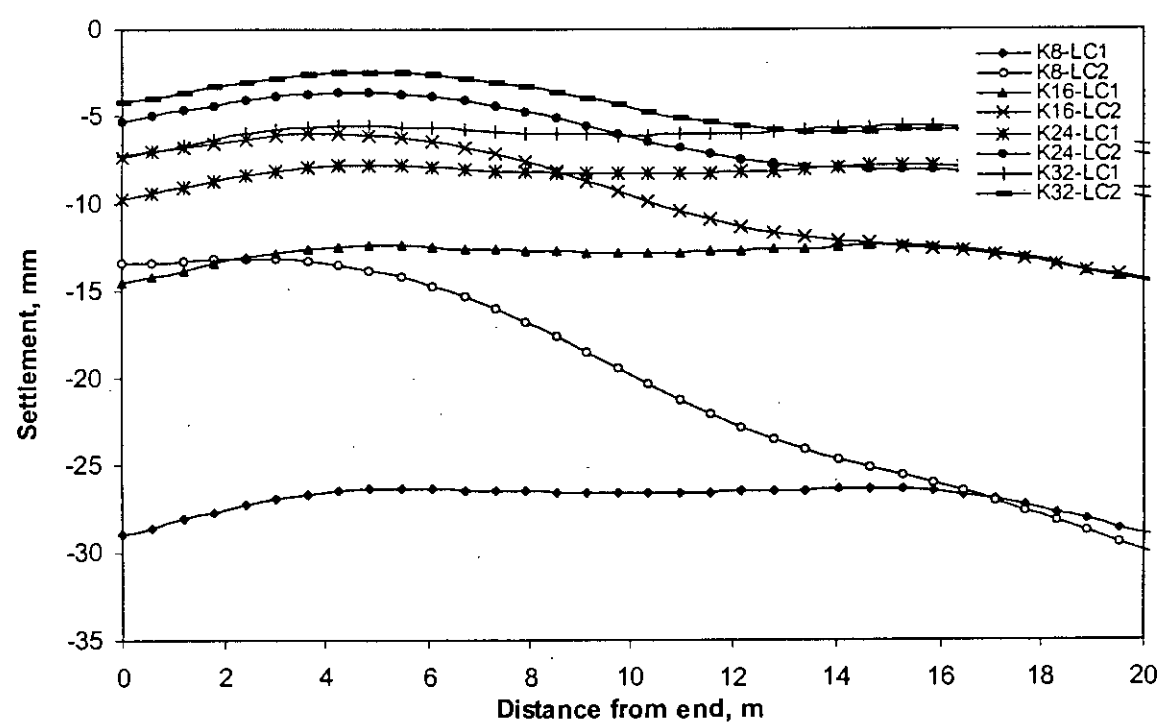

Fig. 4.6b Variation of Settlement along **line 2** with variation of subgrade modulus K.

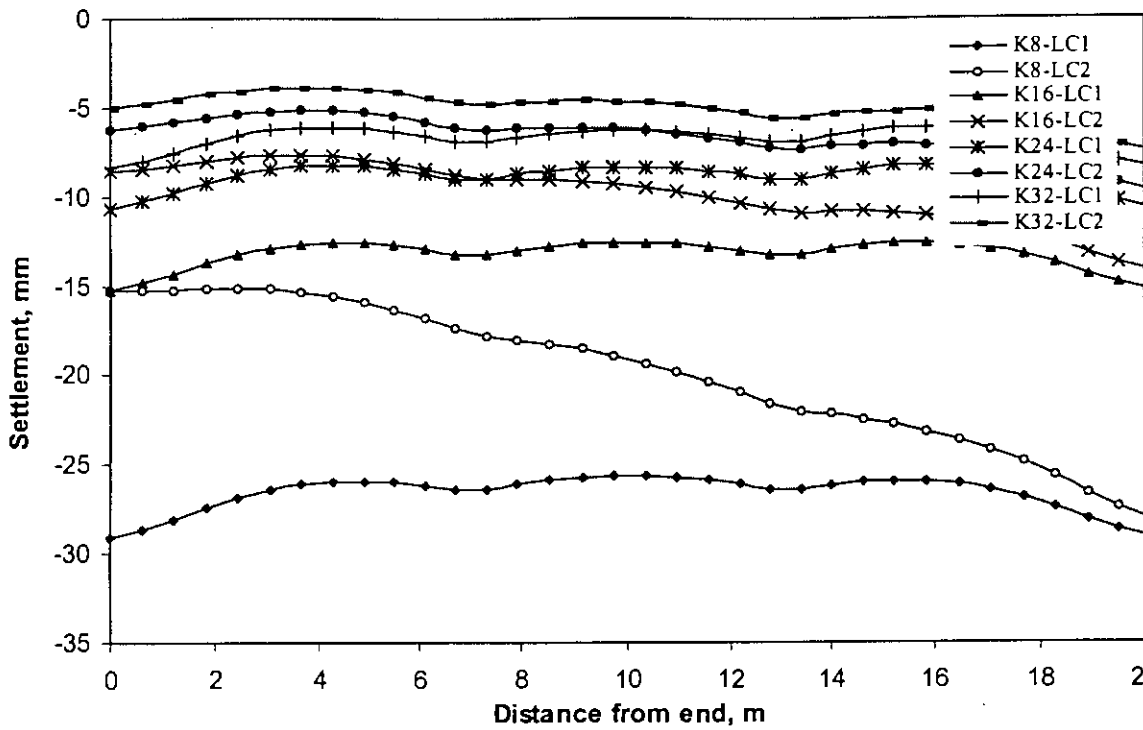

Fig. 4.6c Variation of Settlement along **line 3** with variation of subgrade modulus K.

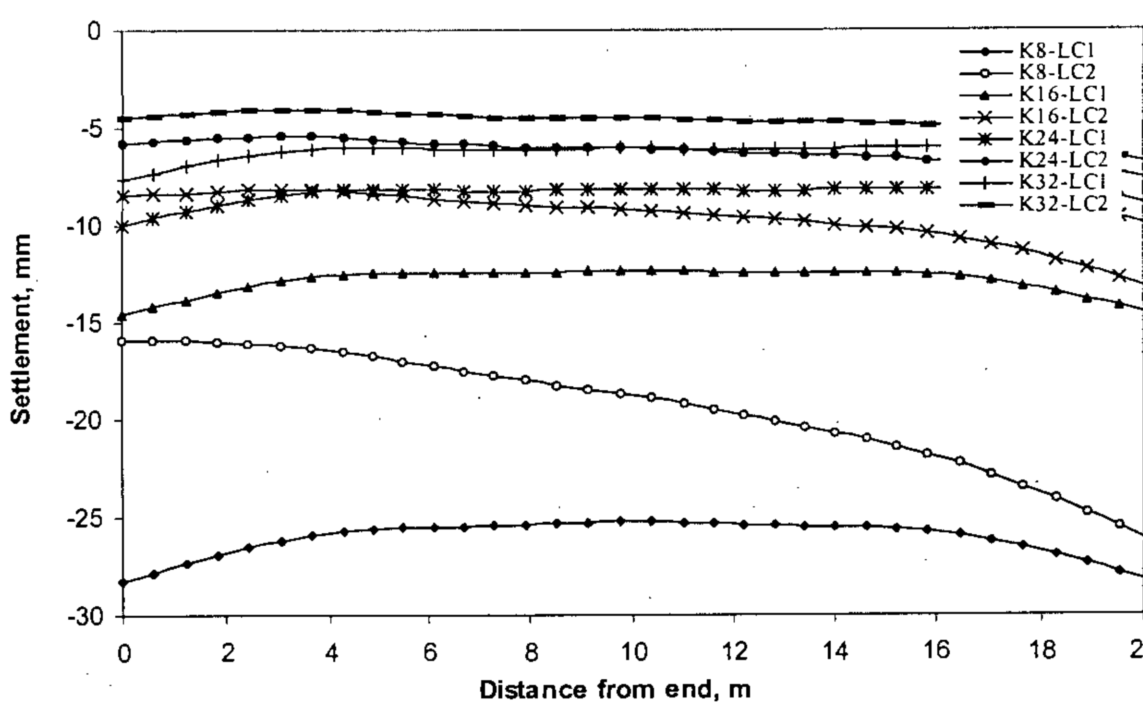

Fig. 4.6d Variation of Settlement along **line 4** with variation of subgrade modulus K

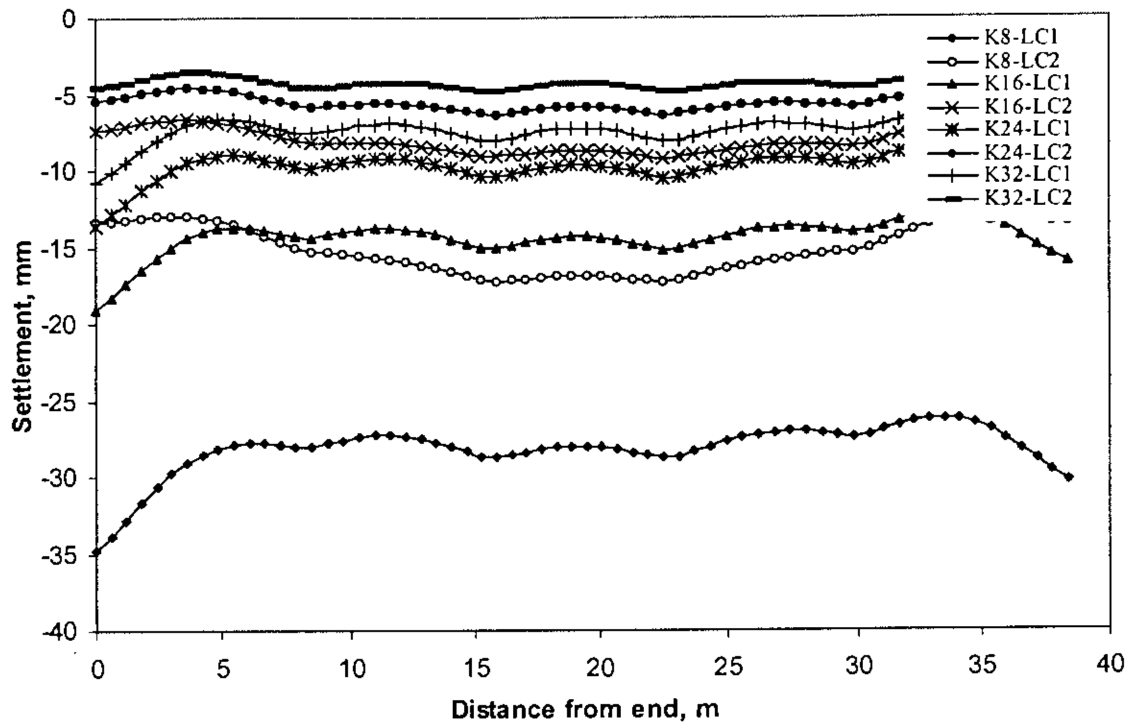

Fig. 4.7a Variation of Settlement along **line 5** with variation of subgrade modulus K.

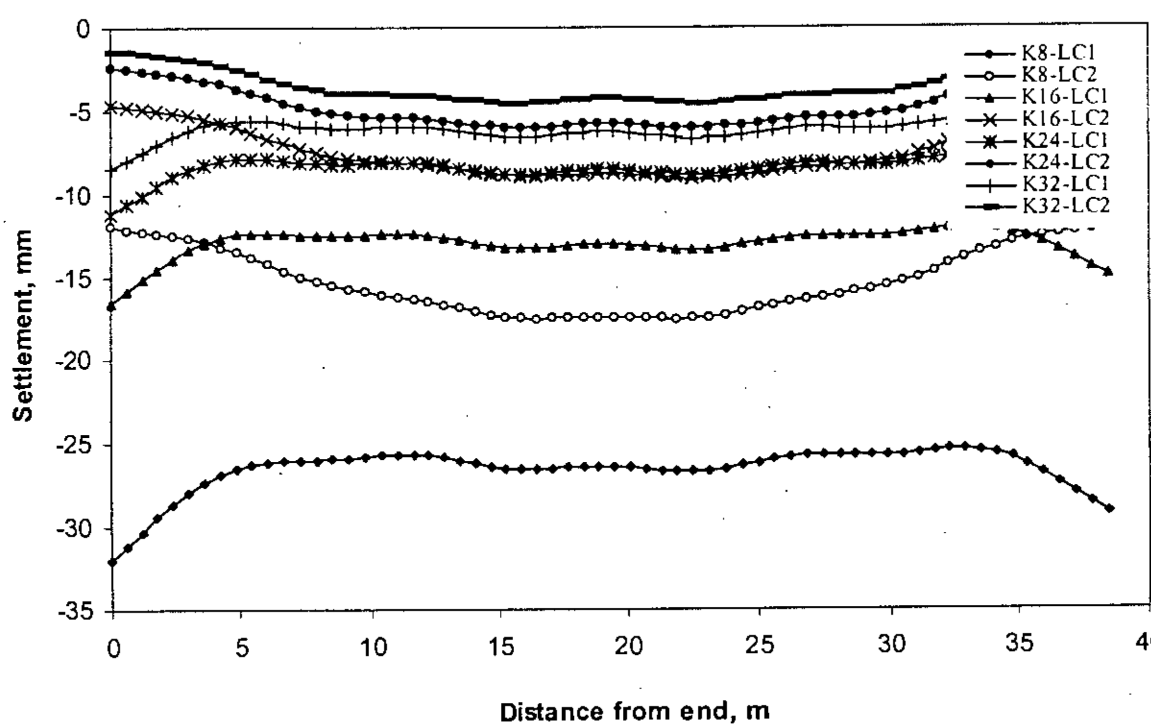

Fig. 4.7b Variation of Settlement along **line 6** with variation of subgrade modulus K.

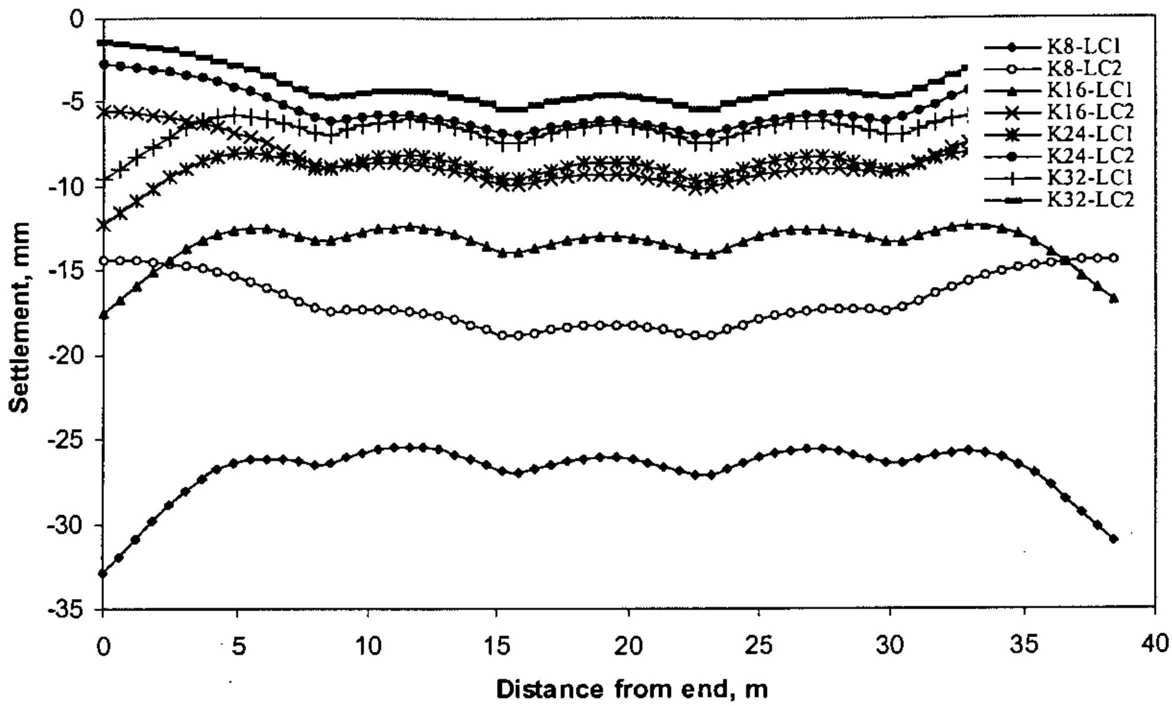

Fig. 4.7c Variation of Settlement along **line 7** with variation of subgrade modulus K

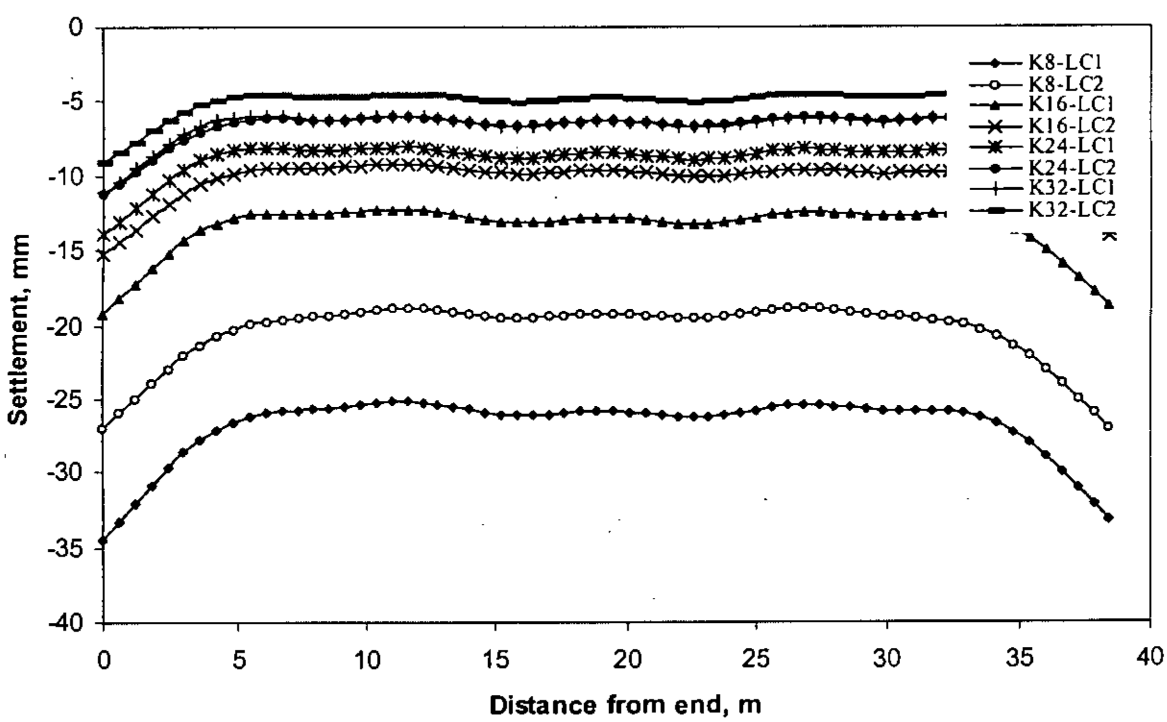

Fig. 4.7d Variation of Settlement along **line 8** with variation of subgrade modulus K

differntial settlements are found along the line of shear wall (Fig.4.2c). Differential settlement reduces for the points far from shear walls.

Table 4.1 Variation of Displacement, Moment and Shearing Stress when Modulus of Subgrade Reaction is Increased from 8.0 MN/m^3 to 32.0 MN/m^3 along the Short Direction of Mat Foundation. (Upper values in the boxes are for vertical load case and the lower values for lateral plus vertical load case.)

Location		Displacement (mm)		Bending Moment (kN-m/m)		Shearing stress (kN/m^2)	
		K 8.0 MN/m^3	K 32.0 MN/m^3	K 8.0 MN/m^3	K 32.0 MN/m^3	K 8.0 MN/m^3	K 32.0 MN/m^3
Line 1	Face of exterior column	-32.80 -13.24	-9.44 -4.24	92.5 237.3	121.9 269.5	550.5 337.9	513.2 318.4
	Mid span of first panel	-30.29 -12.25	-7.49 -1.57	-303.6 -194.8	-266.8 -146.3	155.6 44.5	117.6 31.6
	Face of interior column	-30.88 -14.39	-8.29 -1.61	-86.2 -525.2	-54.2 -474.0	775.3 -915.0	733.9 -929.4
Line 2	Exterior column line	-28.12 -13.29	-6.66 -3.61	-1095.8 -568.5	-897.6 -484.7	-143.8 -104.2	-158.6 -86.0
	Mid span of first panel	-26.47 -13.53	-5.59 -2.52	-897.7 -323.6	-694.7 -217.3	-142.5 -184.8	-157.2 -148.2
	Interior column line	-26.42 -15.33	-5.81 -2.82	-1047.8 -412.1	-842.6 -284.1	-204.8 -311.0	-224.2 -277.3
Line 3	Face of exterior column	-28.04 -15.27	-7.54 -4.57	788.2 588.5	950.1 583.6	440.5 286.7	457.7 309.8
	Mid span of first panel	-25.95 -15.57	-6.08 -3.88	49.3 265.0	224.9 289.6	-16.5 -25.2	1.85 8.51
	Face of interior column	-26.45 -17.42	-6.90 -4.72	1183.6 1100.2	1360.7 1159.2	743.1 510.0	757.8 542.0

Table 4.1 Variation of Displacement, Moment and Shearing Stress when Modulus of Subgrade Reaction is Increased from 8.0 MN/m³ to 32.0 MN/m³ along the Short Direction of Mat Foundation. **(Continued)**

Location		Displacement (mm)		Bending Moment (kN-m/m)		Shearing stress (kN/m²)	
		K 8.0 MN/m³	K 32.0 MN/m³	K 8.0 MN/m³	K 32.0 MN/m³	K 8.0 MN/m³	K 32.0 MN/m³
Line 4	Exterior column line	-27.37 -15.97	-6.98 -4.26	-599.4 -278.2	-519.8 -335.1	-93.4 -44.2	-64.7 -29.5
	Mid span of first panel	-25.73 -16.51	-6.01 -4.08	-451.4 -190.0	-359.3 -218.6	-69.3 -40.8	-40.6 -20.6
	Interior column line	-25.47 -17.52	-6.11 -4.41	-609.1 -338.6	-509.6 -331.4	-117.2 -83.2	-88.1 -59.3
Line 5	Face of exterior column	-28.74 -17.23	-8.07 -4.83	1066.5 656.9	1029.3 558.1	488.4 320.9	501.6 323.1
	Mid span of first panel	-26.57 -17.48	-6.61 -4.50	310.4 265.6	293.4 190.8	36.3 31.6	50.9 36.8
	Face of interior column	-26.98 -18.90	-7.40 -5.38	1454.1 1124.5	1439.6 1069.7	793.7 573.3	807.0 580.0
Line 6	Exterior column line	-28.02 -16.90	-7.23 -4.29	-478.6 -277.0	-531.0 -366.2	-65.1 -38.0	-60.7 -37.0
	Mid span of first panel	-26.36 -17.39	-6.26 -4.24	-337.3 -204.0	-372.5 -273.7	-40.1 -25.3	-35.5 24.7
	Interior column line	-26.09 -18.25	-6.36 -4.61	-494.2 -335.2	-520.8 -384.9	-87.4 -61.7	-82.1 -60.7

Table 4.2 Variation of Displacement, Moment and Shearing Stress when Modulus of Subgrade Reaction is Increased from 8.0 MN/m^3 to 32.0 MN/m^3 along the Long Direction of Mat Foundation (Upper values in the boxes are for vertical load case and the lower values for lateral plus vertical load case.)

Location		Displacement (mm)		Bending Moment (kN-m/m)		Shearing stress (kN/m^2)	
		K 8.0 MN/m^3	K 32.0 MN/m^3	K 8.0 MN/m^3	K 32.0 MN/m^3	K 8.0 MN/m^3	K 32.0 MN/m^3
Line 7	Face of exterior column	-32.80 -13.24	-9.44 -4.24	98.9 151.4	116.6 211.2	552.3 420.9	496.9 359.0
	Mid span of first panel	-28.12 -13.28	-6.66 -3.61	-246.7 -182.6	-221.6 -147.8	133.2 113.6	108.2 73.4
	Face of interior column	-28.09 -15.02	-7.50 -4.51	240.9 189.6	261.1 205.6	668.6 547.4	643.1 522.3
Line 8	Exterior column line	-30.29 -12.25	-7.49 -1.57	-1082.3 -1024.6	-974.6 -706.7	-34.5 284.7	-42.4 235.9
	Mid span of first panel	-26.47 13.53	-5.59 -2.52	-679.9 -715.4	-569.7 -517.5	-51.4 56.0	-62.6 17.2
	Interior column line	-26.00 -15.30	-6.02 -3.75	-795.2 -604.4	-693.4 -495.2	-216.1 120.2	-227.6 -146.5
Line 9	Face of shear wall	-30.88 -14.39	-8.29 -1.61	-226.0 -1921.7	-148.2 -1573.1	-621.7 297.8	-595.6 344.3
	Mid span of first panel	-26.42 -15.33	-5.81 2.81	-205.3 -621.5	-101.7 -400.3	-104.0 -27.7	-94.3 -17.4
	Face of interior column	-26.51 -17.23	-6.85 -4.59	1123.5 701.6	1224.4 824.5	-848.8 -445.0	-845.4 -453.8
Line 10	Face of shear wall	-32.11 -24.99	-9.55 -7.74	676.3 909.9	685.8 882.2	36.0 -1137.6	31.5 -1021.1
	Mid span of first panel	-26.60 -20.31	-6.09 -4.72	-85.0 39.6	-9.9 79.2	-2.1 -90.2	-37.7 -48.9
	Interior column line	-25.74 -19.44	-6.23 -4.70	-482.6 -344.2	-383.3 -275.4	-112.1 -32.0	-111.3 -33.2

Table 4.3 Maximum Variation of Displacement, Moment and Shearing Stress at the Selected Locations Expressed in Percentage when Modulus of Subgrade Reaction is Increased from 8.0 MN/m^3 to 32.0 MN/m^3.

Variation along the location	Displacement	Bending Moment	Shearing stress
Line 1	-89%	+37%	-29%
Line 2	-81%	-31%	+10% / -20%
Line 3	-75%	+156%	+8% / -66%
Line 4	-76%	+20% / -19%	-49%
Line 5	-75%	-28%	+51%
Line 6	-76%	+34%	-11%
Line 7	-76%	+40% / -19%	-35%
Line 8	-87%	-31%	+23% / -69%
Line 9	-88%	+9% / -51%	+16% / -37%
Line 10	-76%	+100% / -88%	-46%

Subgrade reaction has a significant effect on the displacement of mat foundation with shear wall. Table 4.1 and Table 4.2 indicate that the displacements for low subgrade reaction are quite high. But increase in subgrade reaction causes rapid reduction in displacement. Table 4.3 shows the percentile variation in bending moment, shear stress and displacement for change in subgrade reation from 8 MN/m^3 to 32 MN/m^3. It is evident that the variation in displacement is most consistent with the change in subgrade reaction for mat with shear wall Negative and positive change along same line is found for bending moment and shear stress. The negative and positive variation are tabulated in the Table 4.3. The percentile variation in shear stress are showing significant figures in Table 4.3, but the actual values in Table 4.1 and Table 4.2 shows that due to their initial small values, the percentile change is looking significant.

4.2.2 Effect of Non-uniform Mat Thickness

A study by Morshed (1996) shows that mat thickness is quite sensitive to different parameters of mat. Negative moments has been found to be very sensitive to mat thickness. As the minimum thickness below column and shear walls are governed by punching shear, option remains to reduce thickness at midspan between column lines. Mat of non-uniform thickness consists of thickened part in the zone of higher shear and positive moment near the columns and shear walls and smaller thickness in the zone of low shear and negative moment away from the columns and shear walls. The higher thickness in the column and shear wall zones are termed as **mat thickness** (t) which is calculated for punching shear. The smaller thickness is termed as reduced thickness (t_r). The reduced thickness(t_r) is varied for different values in the range of 40% to 70% of the mat thickness. The width of thickened part is taken equal to the width of column and the length of transition (neck section) where mat thickness and reduced thickness meets as shown in Fig.4.8 also taken equal to column dimension. The non-uniform configuration is chosen based on the non-uniform configuration suggested for mat with columns by Rahman (2001) and Morshed (1996). In the problem taken for comparative study, mat thickness is calculated to be 1070 mm from punching shear and reduced thickness is taken as 450 mm, 610 mm and 760 mm. For all cases modulus of subgrade reaction, K_s have been taken 16.0 MN/m^3.

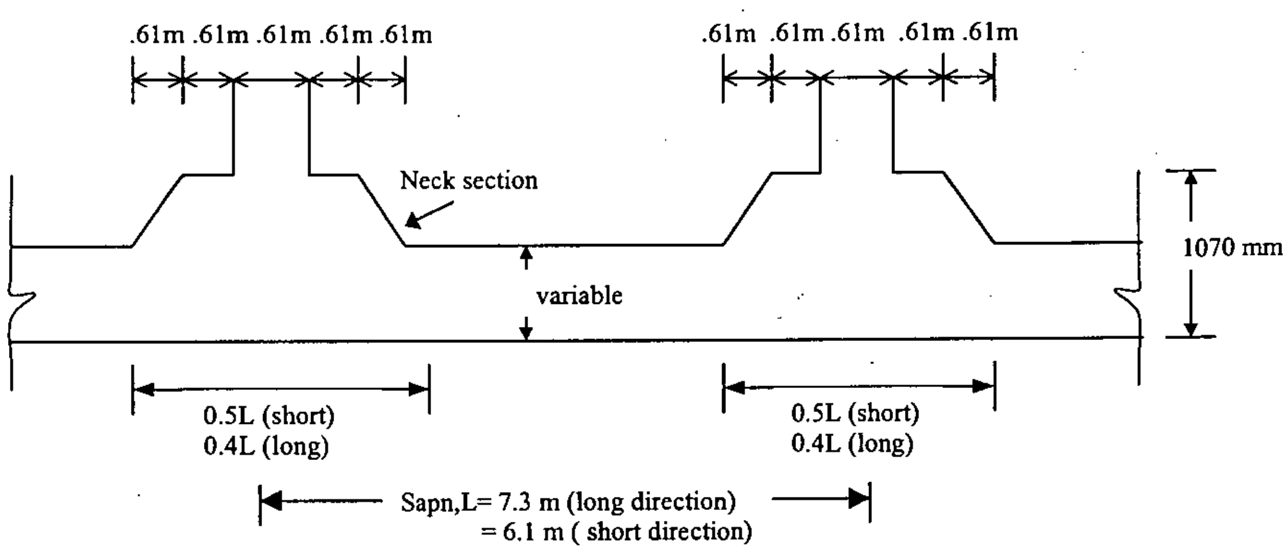

Fig. 4.8 Non-uniform configuration of mat foundation.

Selected items for parametric study are taken as displacement, bending moment and shearing stress along lines 1 to 8. Variation of these items on column faces and midspans for mat with variable thickness with reduced thickness 450 mm and 760 mm for modulus of subgrade reaction 16 MN/m^3 are tabulated in Table 4.4 and Table 4.5. Upper values in the chart are results for Load case1 and lower values are for Load case 2. The variations of parameters for different reduced thickness are also plotted in Fig. 4.9 to Fig. 4.14.

The following points are observed for the variation in smaller thickness.

- Positive moment for mat with shear wall decreases along different column lines parallel to shear wall line and increases between columns for increase in reduced thickness of mat (Fig. 4.9a and Fig. 4.9c).

- Negative moment increases with increase in reduced thickness (Fig. 4.9b and Fig. 4.9d). As thickness in the mid panel reduces, the negative moment at the zone also reduces. The vertical load case (LC-1) dominates the variation.

- Shearing stress increases with increase in reduced thickness at the face of shear wall and column and decreases in region away from columns. The variation is not significant at column face. Shearing stress is decreased in the region away from column face due to increase in effective area by increased smaller thickness(Fig.4.11 and Fig.4.12).

- Displacements decreases significantly below shear wall with increase in reduced thickness. Differential settlement is more pronounced for lower value of reduced thickness. With increase in reduced thickness the amount of differential settlement decreases. Differential settlements are higher for Load case II. Differential displacements are prominent places adjacent to shear wall. Deflection occurs at the highest amount below the shear wall. Deflection diagram is more uniform for mat with constant thickness. (Fig. 4.13 and Fig.4.14).

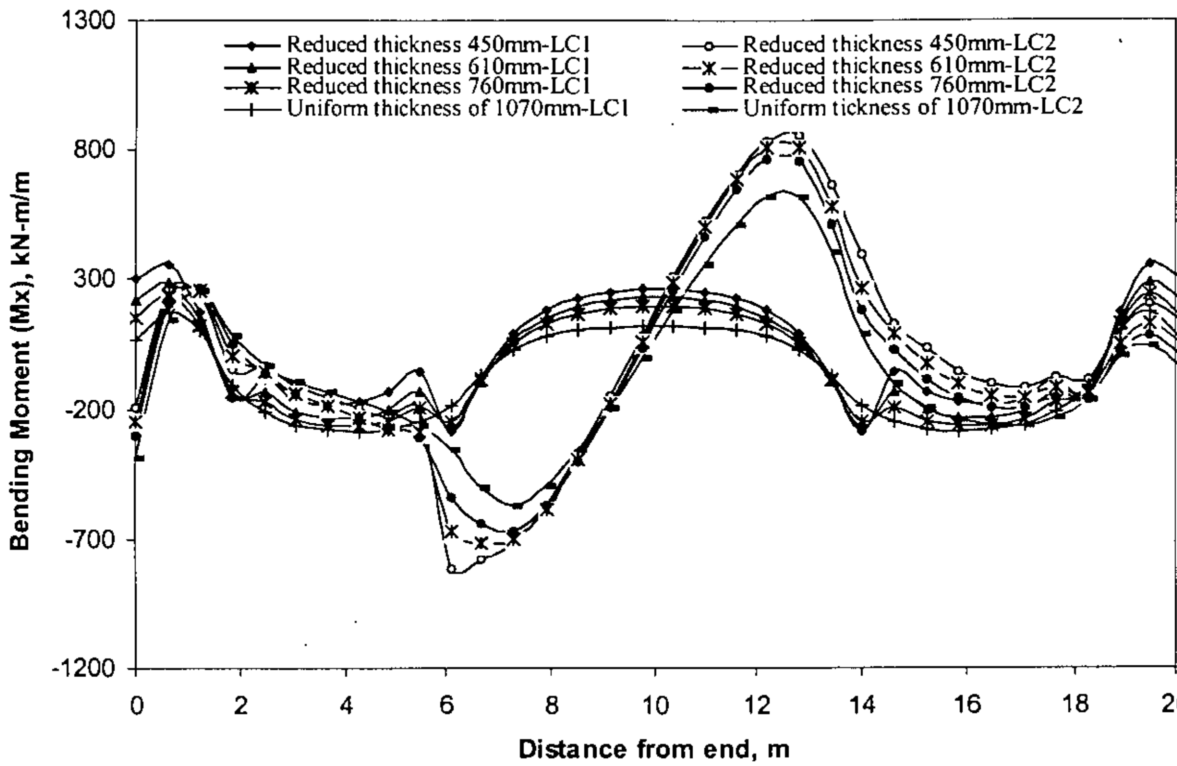

Fig. 4.9a Variation of bending moment M_x along **line 1** with variation of thickness in mid span(LC1-vertical loads, LC2-lateral and vertical loads).

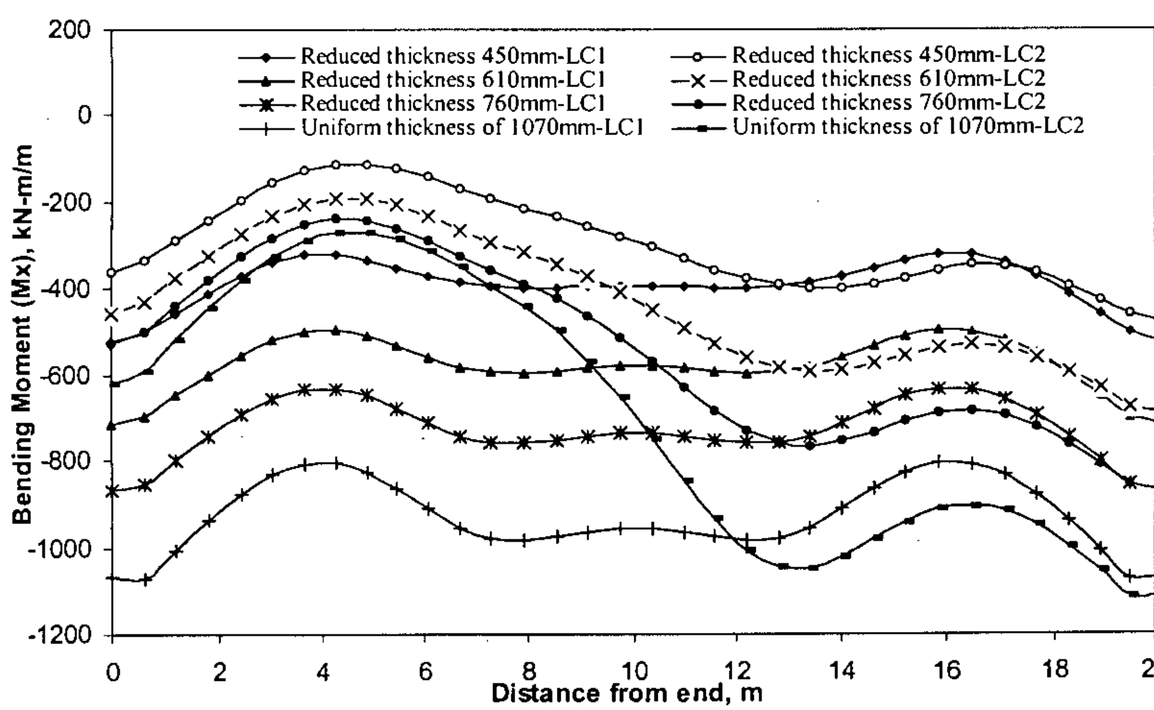

Fig. 4.9b Variation of bending moment M_x along **line 2** with variation of thickness in midspan.

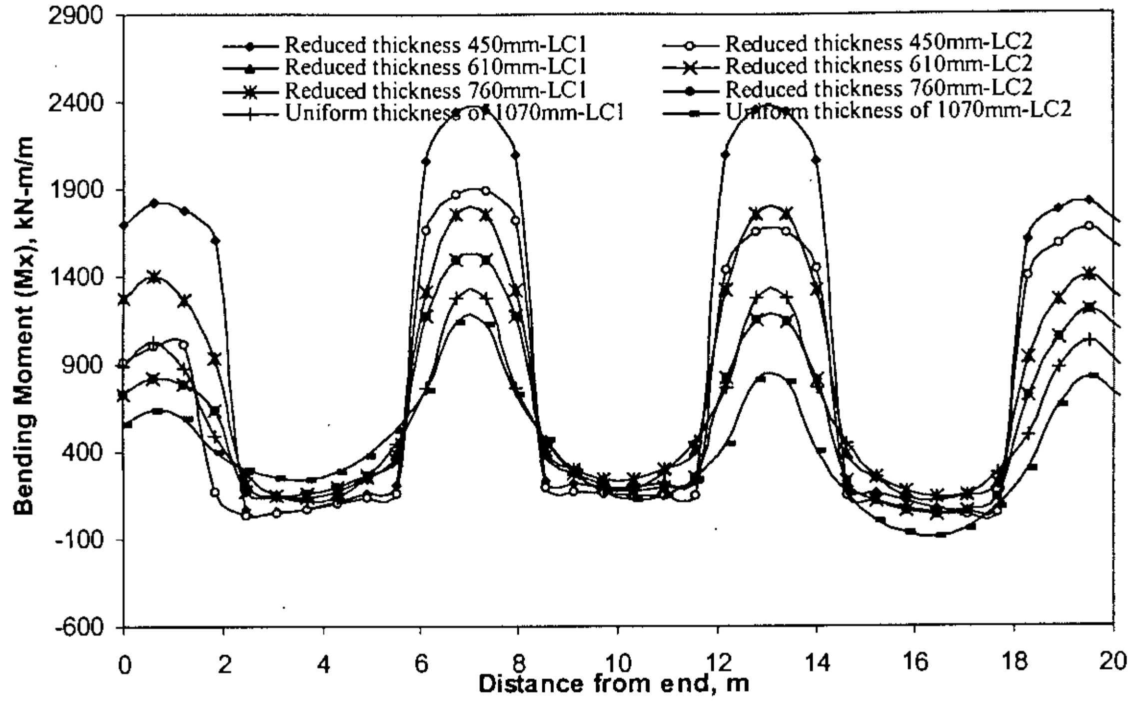

Fig. 4.9c Variation of bending moment M_x along **line 3** with variation of thickness in midspan.

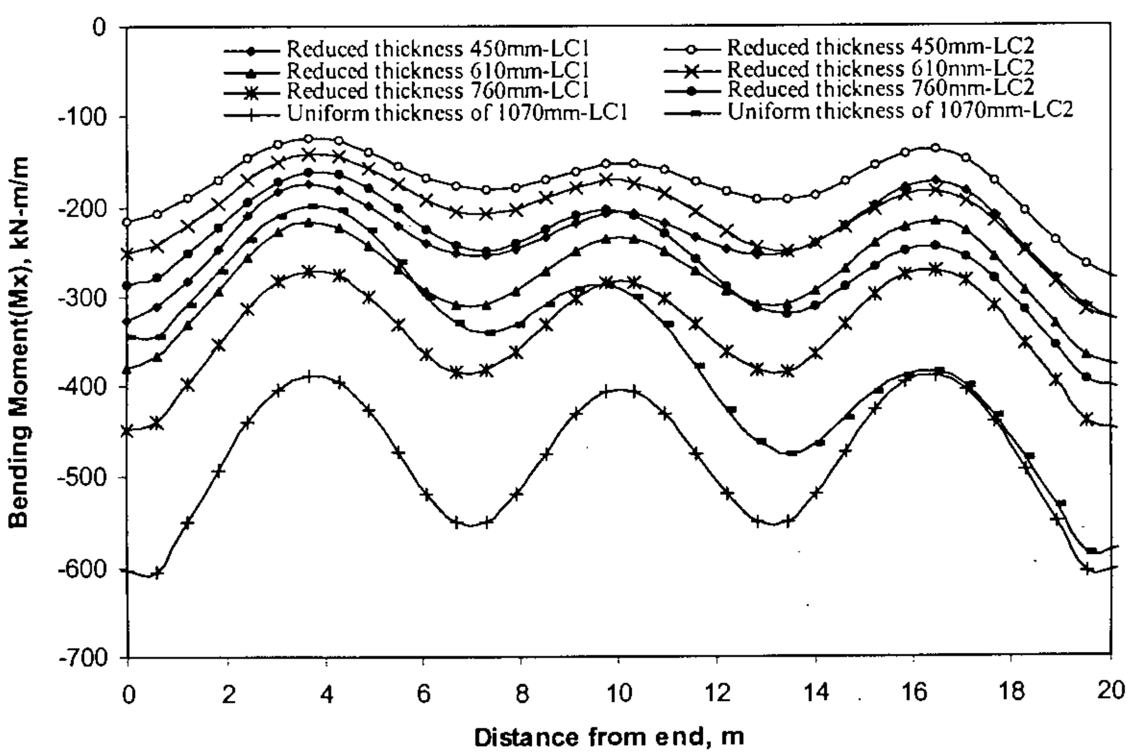

Fig. 4.9d Variation of bending moment M_x along **line 4** with variation of thickness in midspan.

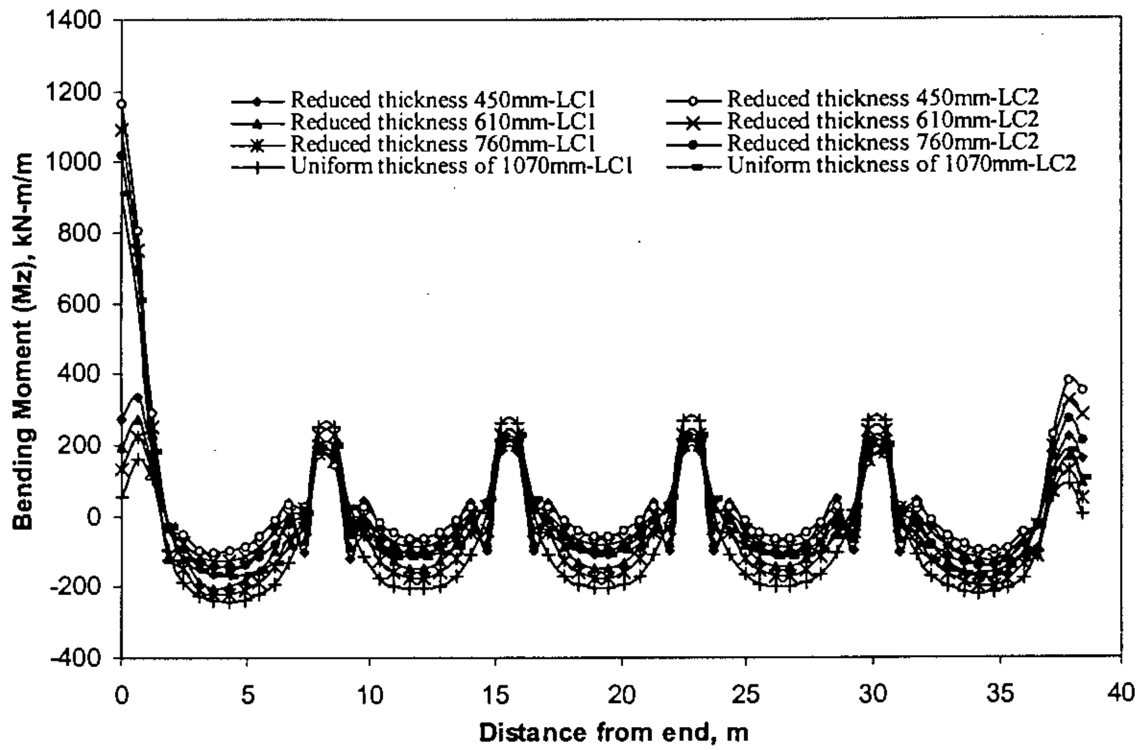

Fig. 4.10a Variation of bending moment M_x along **line 5** with variation of thickness in midspan.

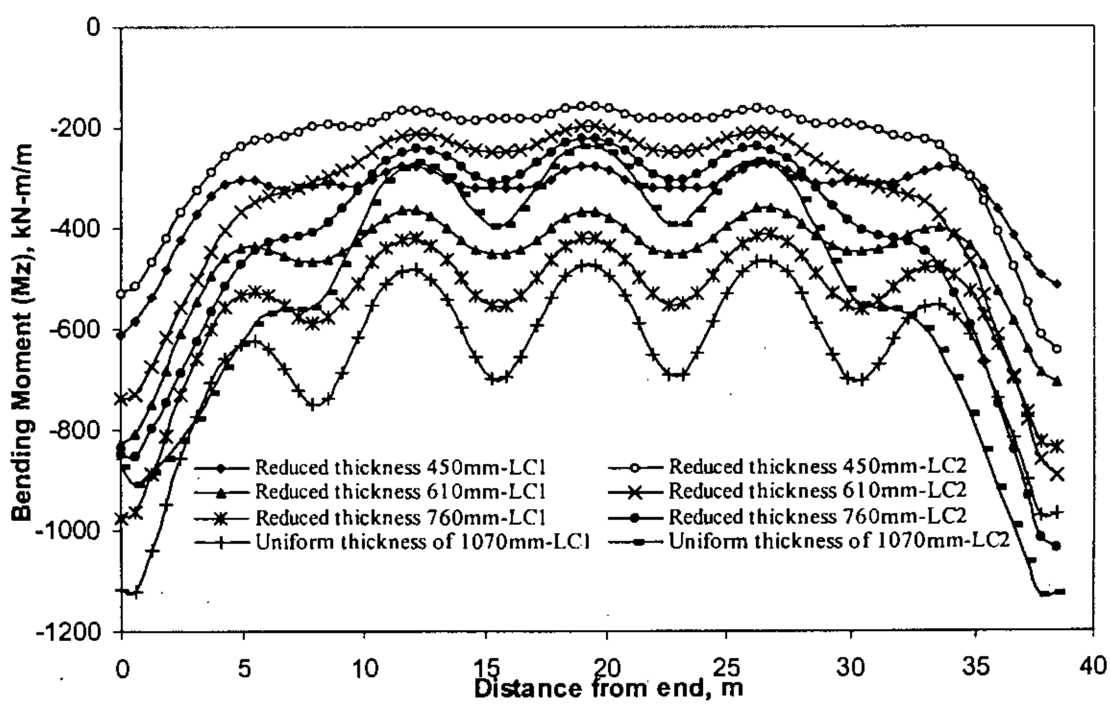

Fig. 4.10b Variation of bending moment M_x along **line 6** with variation of thickness in midspan.

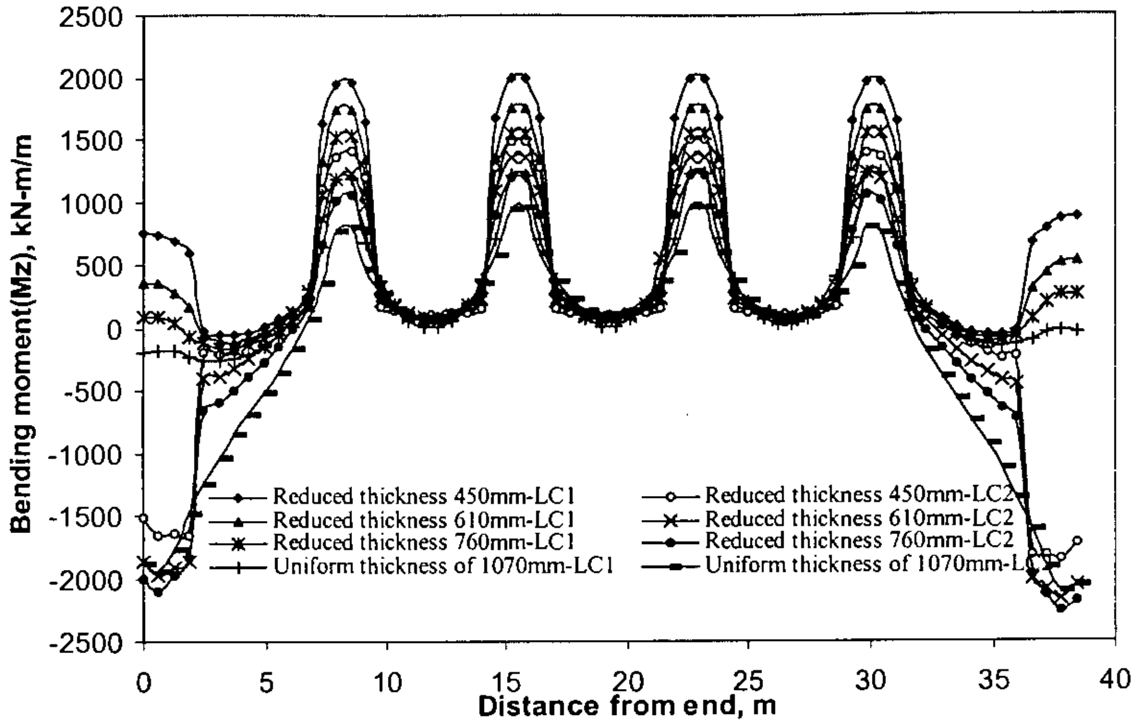

Fig. 4.10c Variation of bending moment M_x along **line 7** with variation of thickness in midspan.

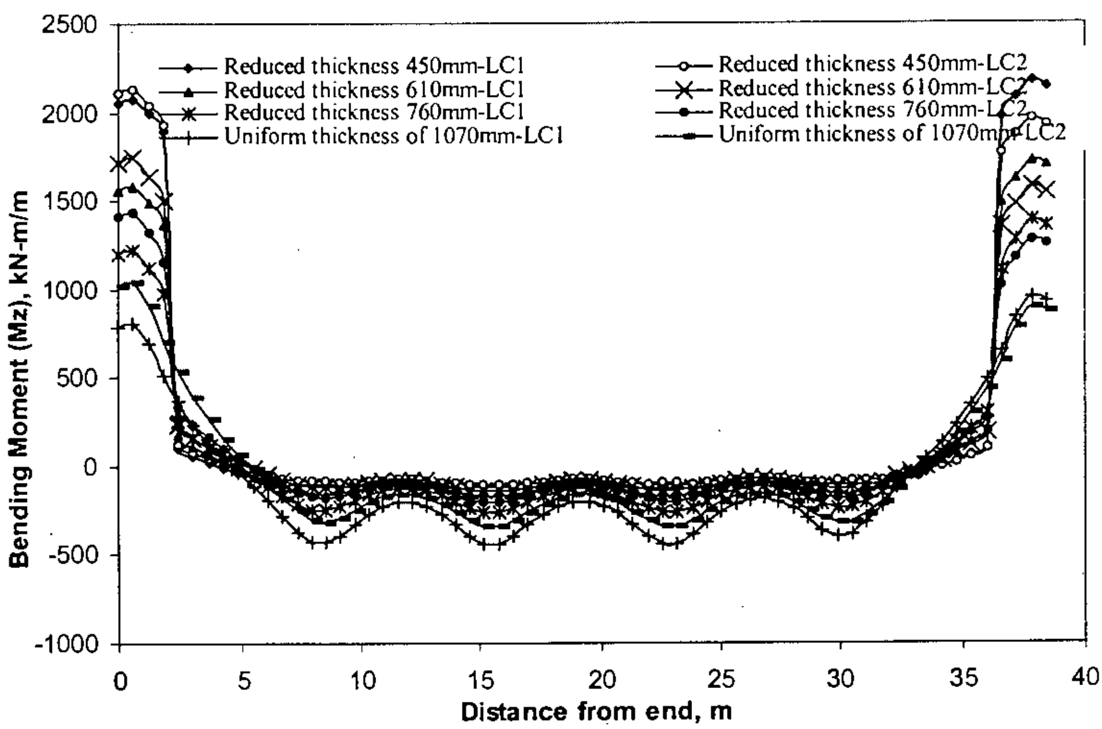

Fig. 4.10d Variation of bending moment M_x along **line 8** with variation of thickness in midspan.

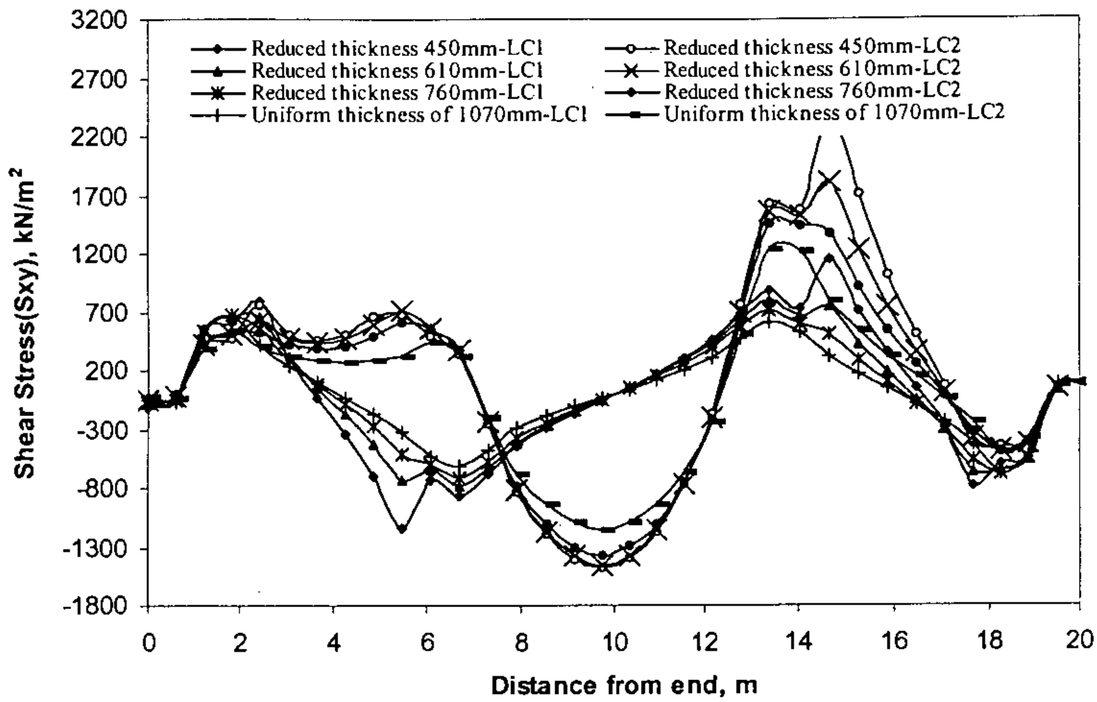

Fig. 4.11a Variation of Shearing stress S_{xy} along **line 1** with variation of thickness in mid panel of non-uniform mat. (LC1-vetical loads, LC2-lateral and vertical loads).

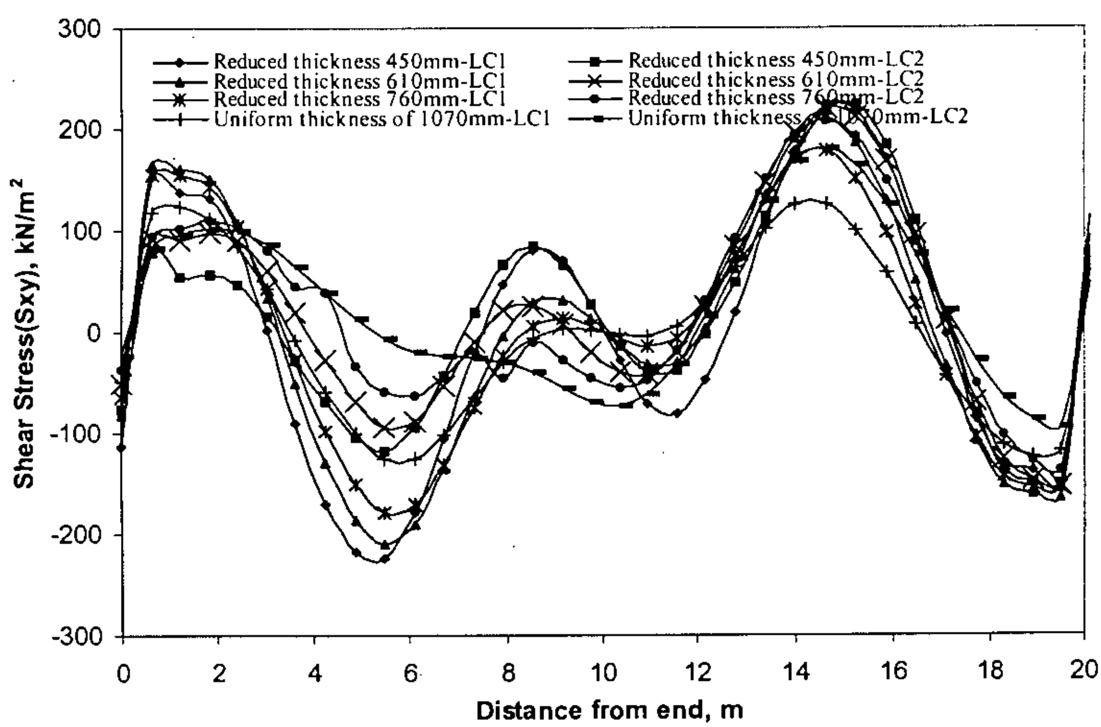

Fig. 4.11b Variation of Shearing stress S_{xy} along **line 2** with variation of thickness in mid panel of non-uniform mat.

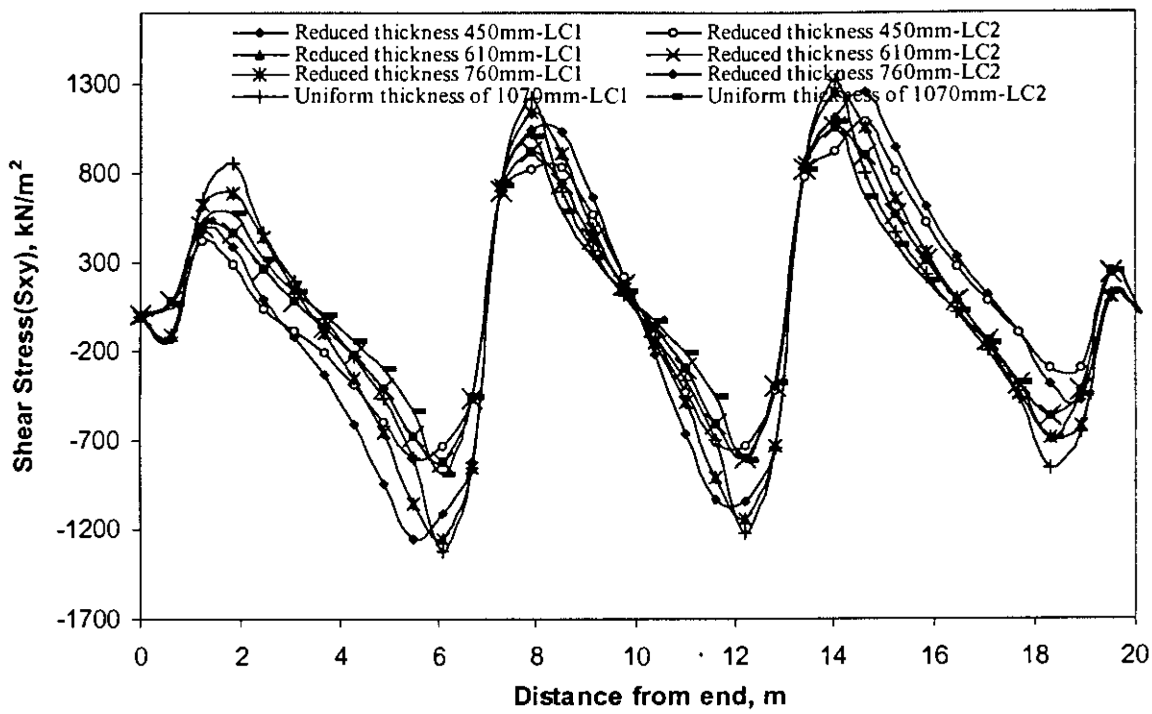

Fig. 4.11c Variation of Shearing stress S_{xy} along **line 3** with variation of thickness in mid panel of non-uniform mat.

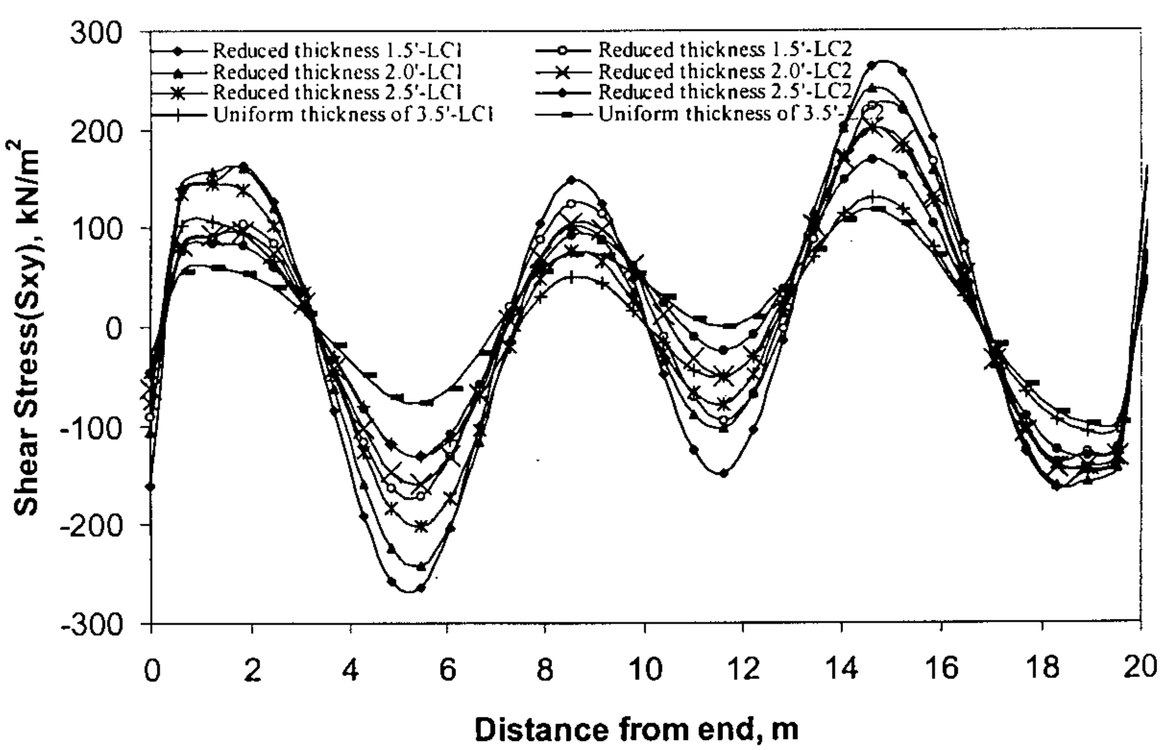

Fig. 4.11d Variation of Shearing stress S_{xy} along **line 4** with variation of thickness in mid panel of non-uniform mat.

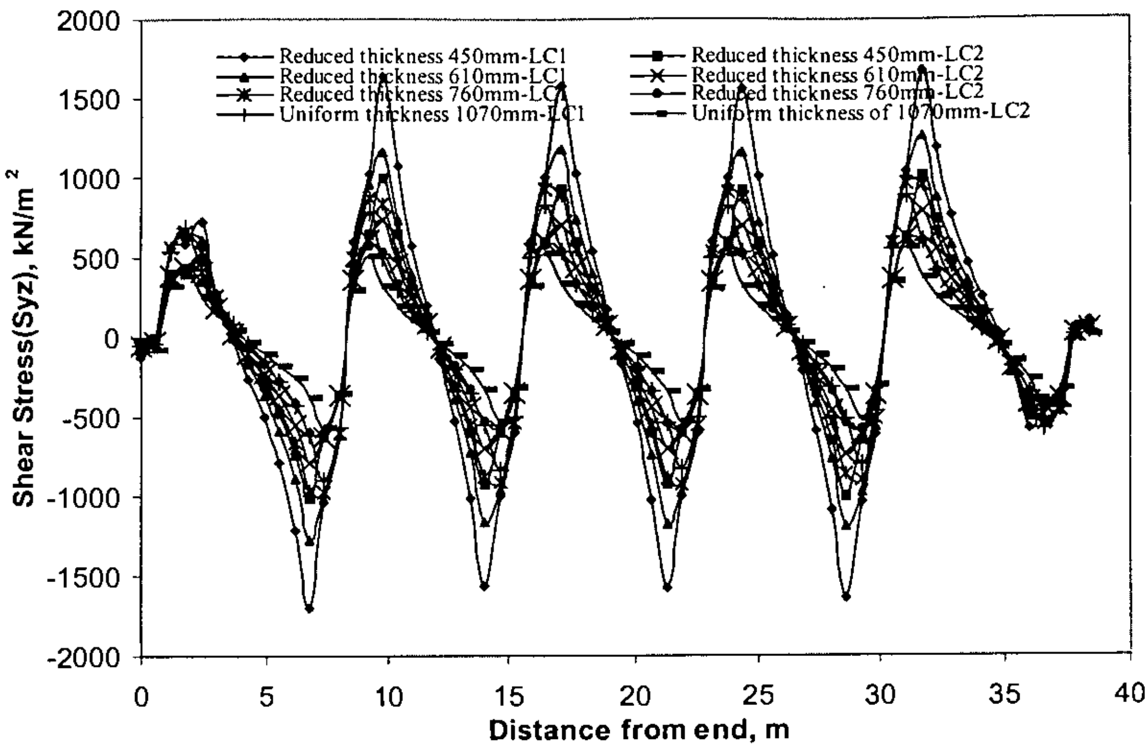

Fig. 4.12a Variation of Shearing stress S_{xy} along **line 5** with variation of thickness in mid panel of non-uniform mat.

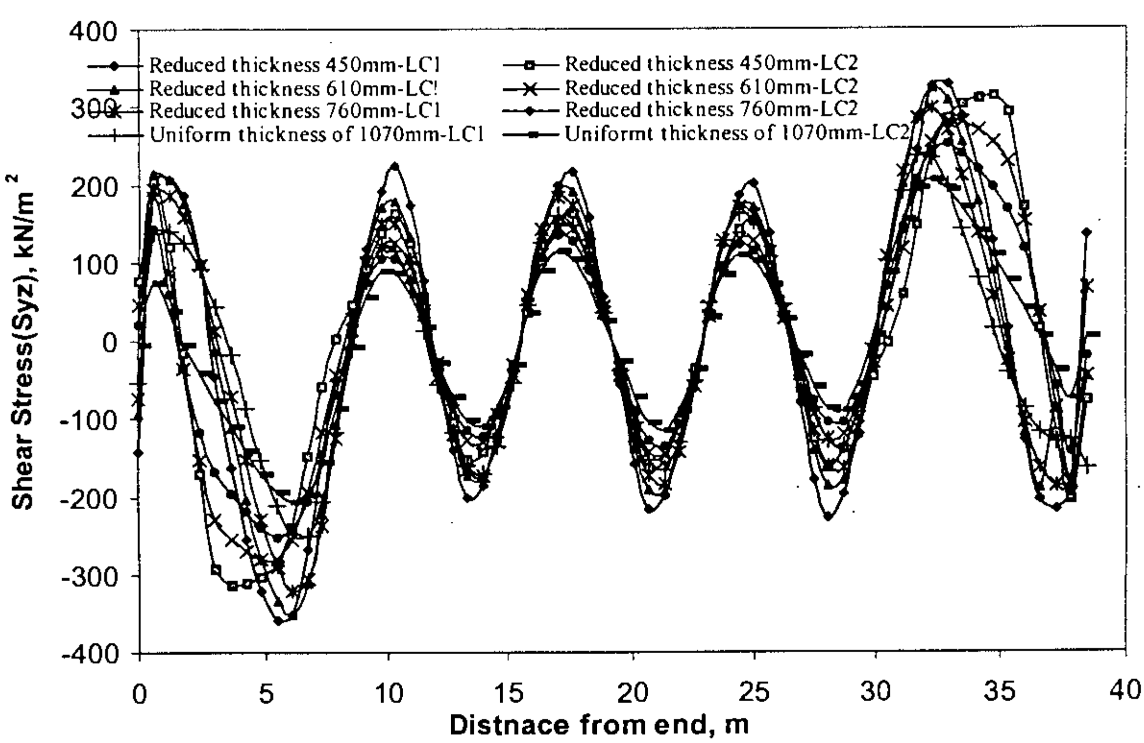

Fig. 4.12b Variation of Shearing stress S_{xy} along **line 6** with variation of thickness in mid panel of non-uniform mat.

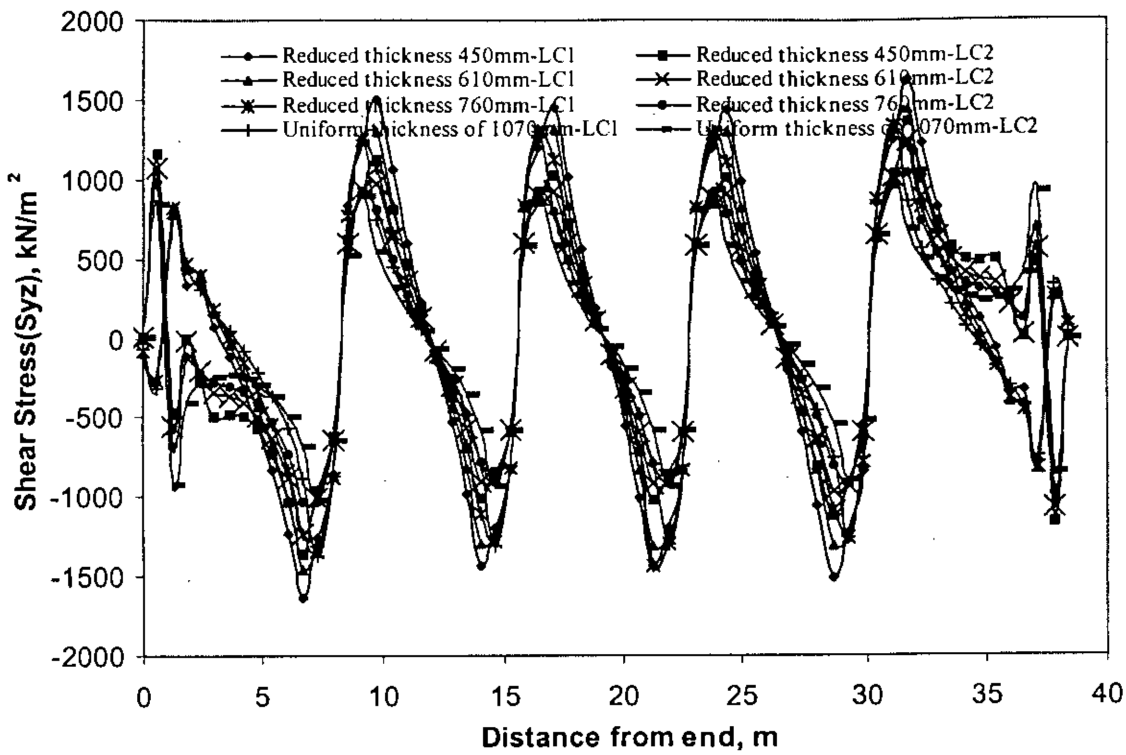

Fig. 4.12c Variation of Shearing stress S_{xy} along **line 7** with variation of thickness in mid panel of non-uniform mat.

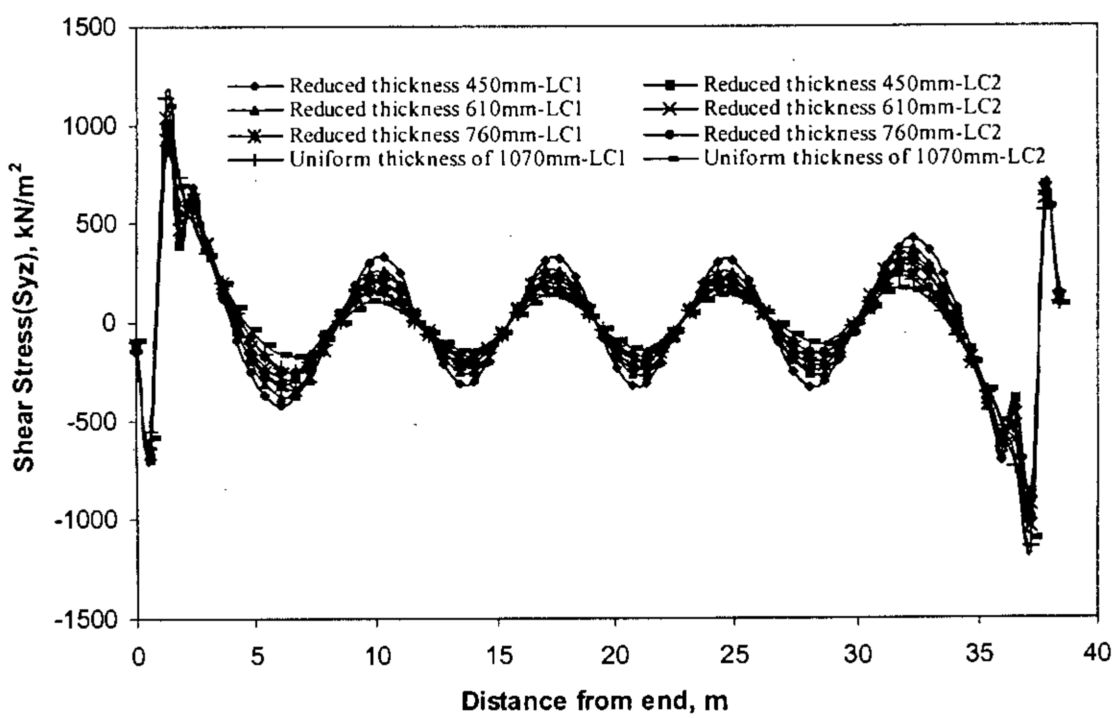

Fig. 4.12d Variation of Shearing stress S_{xy} along **line 8** with variation of thickness in mid panel of non-uniform mat.

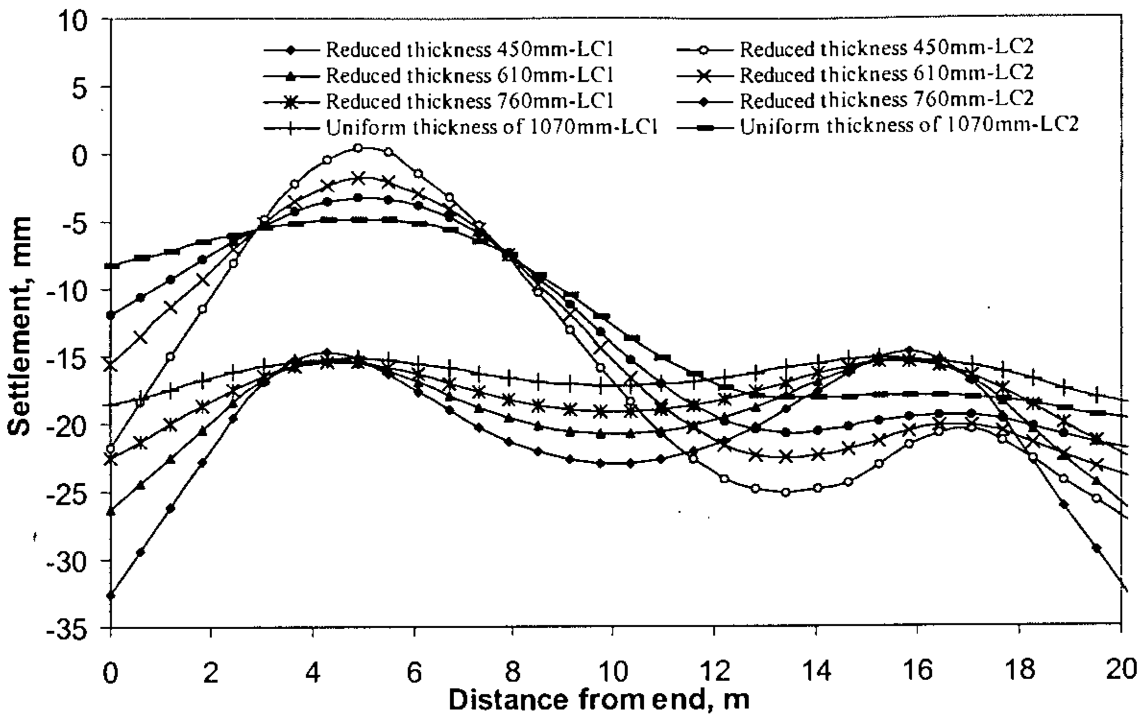

Fig. 4.13a Variation of Settlement alone **line 1** with variation of thickness in mid span of non-uniform mat. (LC1-vetical loads, LC2-lateral and vertical loads).

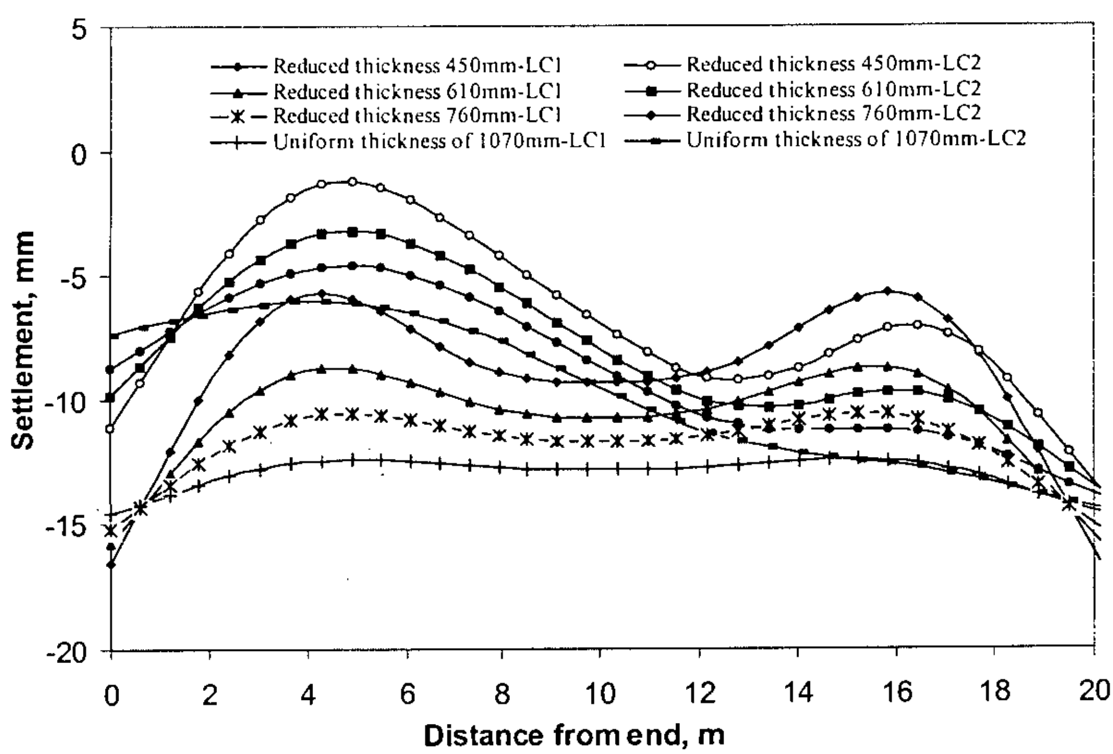

Fig. 4.13 b Variation of Settlement along **line 2** with variation of thickness in mid span of non-uniform mat.

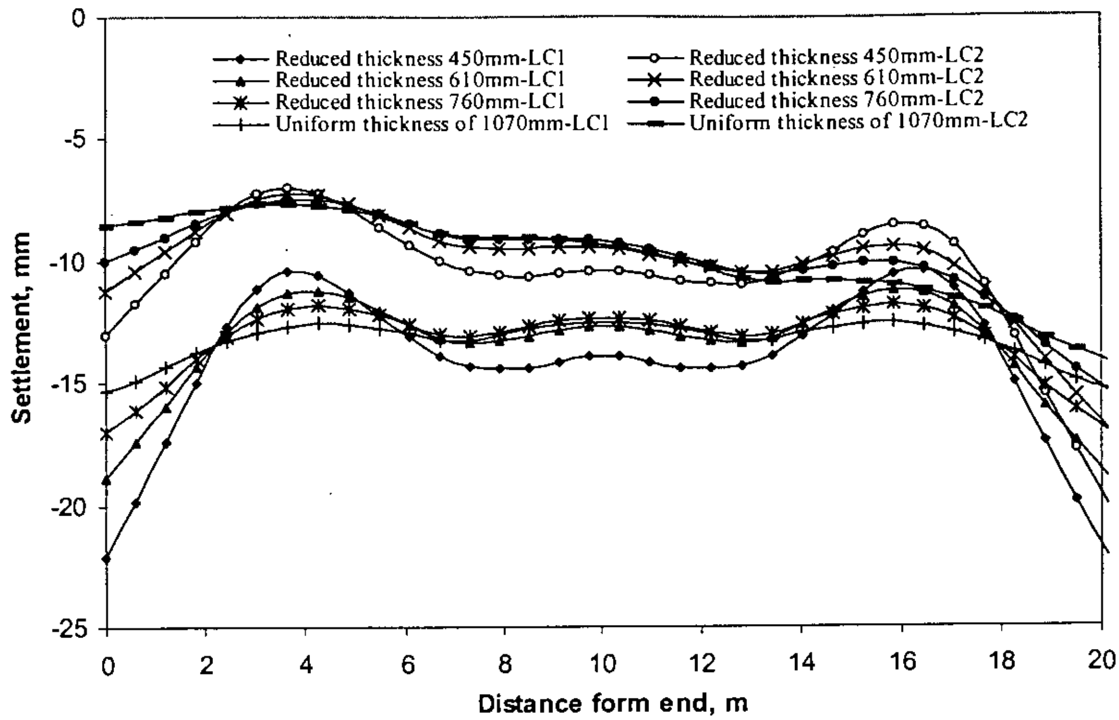

Fig. 4.13c Variation of Settlement along **line 3** with variation of thickness in mid span of non-uniform mat.

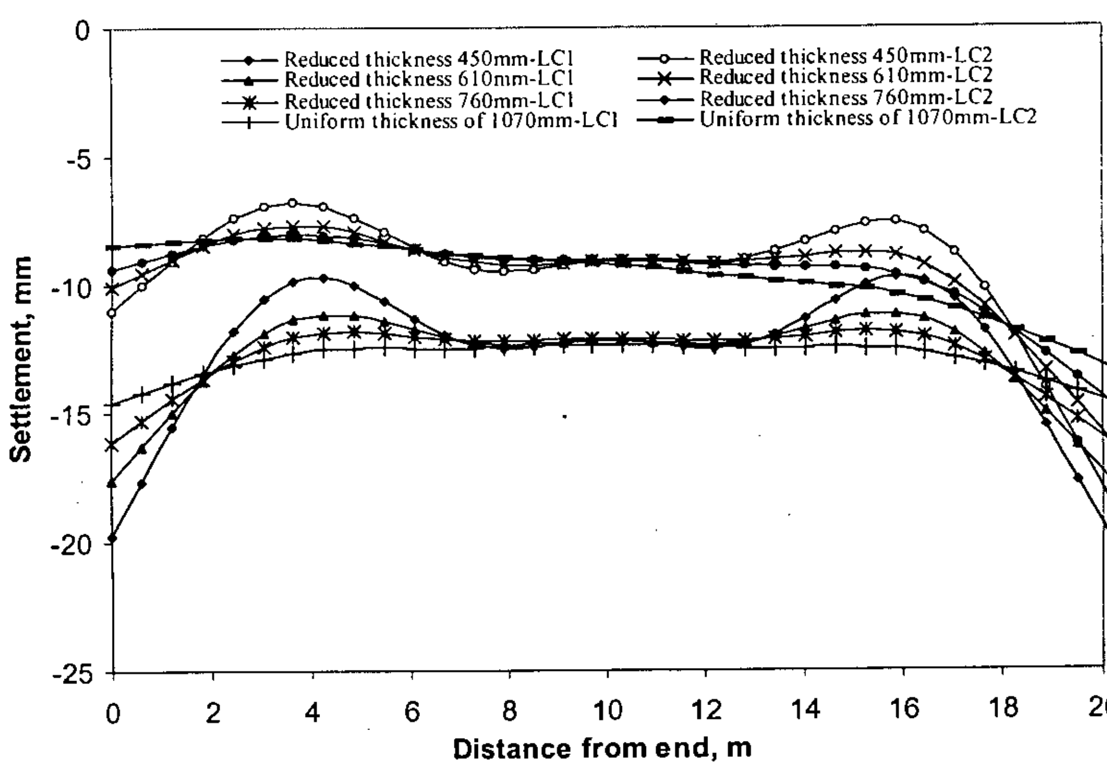

Fig. 4.13d Variation of Settlement along **line 4** with variation of thickness in mid span of non-uniform mat.

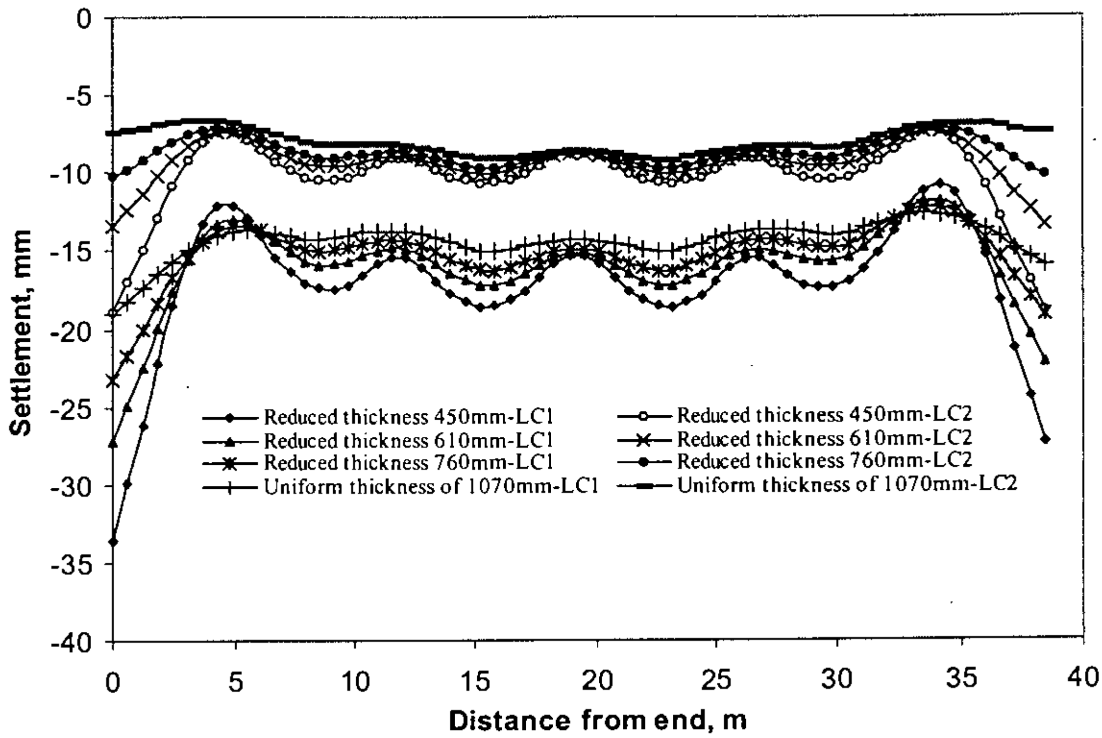

Fig. 4.14a Variation of Settlement along **line 5** with variation of thickness in mid span of non-uniform mat.

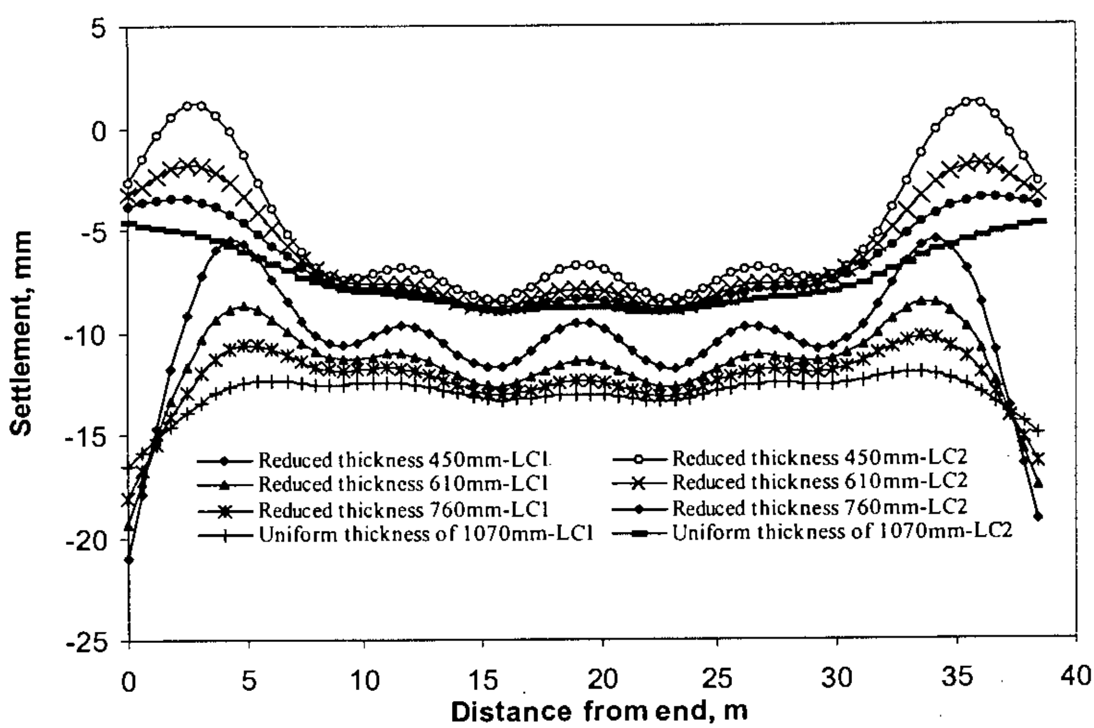

Fig. 4.14b Variation of Settlement along **line 6** with variation of smaller thickness in mid span of non-uniform mat.

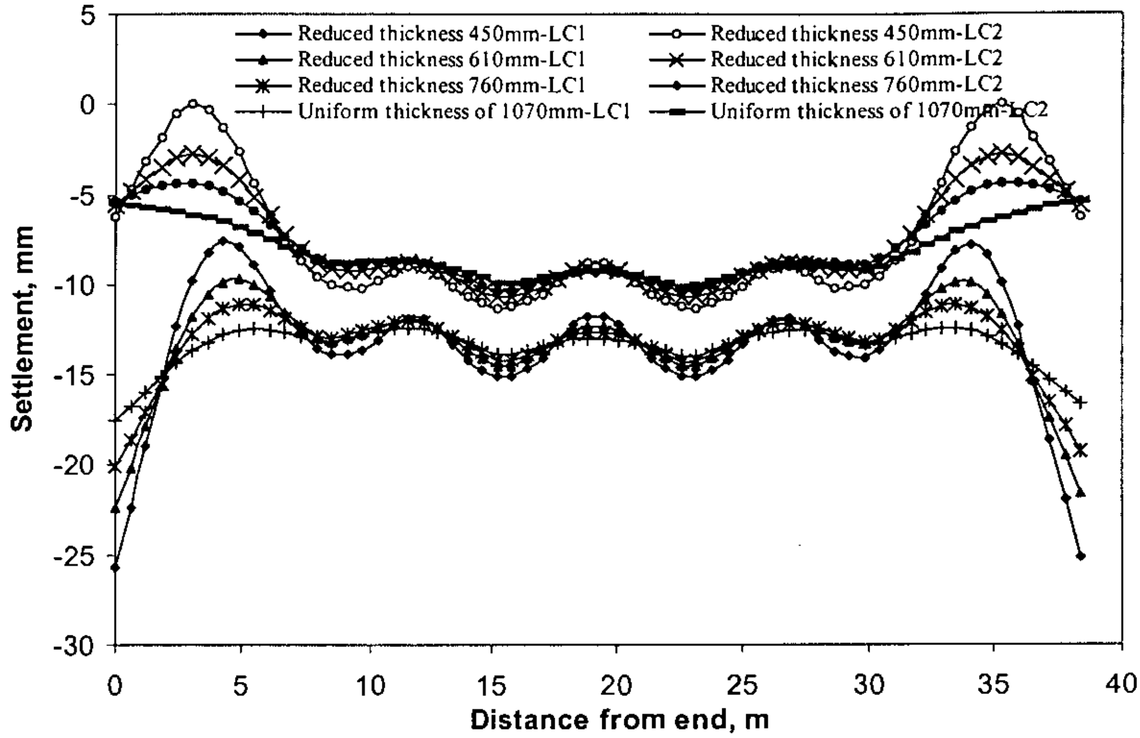

Fig. 4.14c Variation of Settlement along **line 7** with variation of thickness in mid span of non-uniform mat.

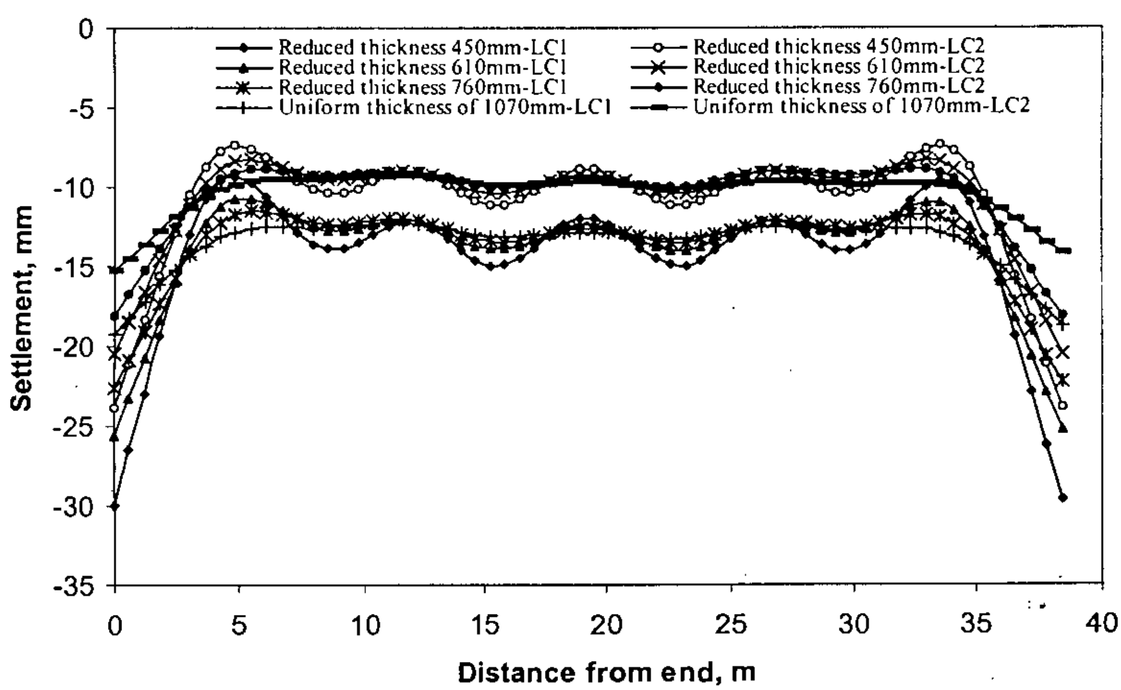

Fig. 4.14d Variation of Settlement along **line 8** with variation of thickness in mid span of non-uniform mat.

Table 4.4. Variation of Displacement, Moment and Shearing Stress against Variation of Reduced Thickness along Short Direction (K_s = 16.0 MN/m^3). (Upper values in the boxes are for vertical load case and the lower values for lateral plus vertical load case.)

Location		Reduced thickness 42% of mat thickness			Reduced thickness 71% of mat thickness		
		Displacement (mm)	Bending Moment (kN-m/m)	Shearing stress (kN/m^2)	Displacement (mm)	Bending Moment (kN-m/m)	Shearing stress (kN/m^2)
Line 1	Exterior column face	-26.14 -14.95	171.0 244.6	554.0 417.6	-20.06 -9.22	122.9 265.5	546.2 412.0
	Mid of first panel	-14.73 -0.37	-171.7 -196.2	-350.0 500.3	-15.45 -3.56	-266.8 -230.4	-95.3 405.7
	Face shear wall	-18.99 -3.20	-83.2 -782.0	-870.3 332.3	-17.04 -4.73	-89.9 -641.8	-715.9 377.9
Line 2	Exterior column line	-12.10 -7.42	-459.3 -288.0	136.9 54.9	-13.45 -7.24	-800.9 -439.7	154.4 102.5
	Mid of first panel	-5.70 -1.33	-321.6 -113.7	-169.8 69.3	-10.61 -4.65	-632.6 -238.0	-97.5 38.3
	Interior column line	-7.87 -2.65	-384.6 -166.2	-105.1 -43.8	-11.08 -5.36	-741.9 -325.02	-131.0 -44.4
Line 3	Exterior column face	-17.43 -10.50	1773.0 1018.0	475.8 414.0	-15.11 -9.04	1261.8 783.4	616.7 500.5
	Mid of first panel	-10.55 -7.21	115.25 99.3	-603.4 -384.6	-11.81 -7.50	168.5 199.04	-350.5 -221.3
	Face of interior column	-13.91 -10.01	2342.1 1869.7	-819.3 -449.5	-13.05 -8.91	1752.7 1495.1	-462.8 -848.4

Table 4.5. Variation of Displacement, Moment and Shearing Stress against Variation of Reduced Thickness along Long Direction (K_s = 16.0 MN/m^3). (Upper values in the boxes are for vertical load case and the lower values for lateral plus vertical load case.)

Location		Reduced thickness 42% of mat thickness			Reduced thickness 71% of mat thickness		
		Displacement (mm)	Bending Moment (kN-m/m)	Shearing stress (kN/m^2)	Displacement (mm)	Bending Moment (kN-m/m)	Shearing stress (kN/m^2)
Line 7	Exterior column face	-26.14 -14.95	171.0 244.6	554.0 417.6	-20.06 -9.22	122.9 265.5	546.2 412.0
	Mid of first panel	-14.73 -0.37	-171.7 -196.2	-350.0 500.3	-15.45 -3.56	-266.8 -230.4	-95.3 405.7
	Face of interior column	-18.99 -3.20	-83.2 -782.0	-870.3 332.3	-17.04 -4.73	-89.9 -641.8	-715.9 377.9
Line 8	Exterior column line	-12.10 -7.42	-459.3 -288.0	136.9 54.9	-13.45 -7.24	-800.9 -439.7	154.4 102.5
	Mid of first panel	-5.70 -1.33	-321.6 -113.7	-169.8 69.3	-10.61 -4.65	-632.6 -238.0	-97.5 38.3
	Interior column line	-7.87 -2.65	-384.6 -166.2	-105.1 -43.8	-11.08 -5.36	-741.9 -325.02	-131.0 -44.4
Line 9	Face shear wall	-17.43 -10.50	1773.0 1018.0	475.8 414.0	-15.11 -9.04	1261.8 783.4	616.7 500.5
	Mid of first panel	-10.55 -7.21	115.25 99.3	-603.4 -384.6	-11.81 -7.50	168.5 199.04	-350.5 -221.3
	Face of interior column	-13.91 -10.01	2342.1 1869.7	-819.3 -449.5	-13.05 -8.91	1752.7 1495.1	-462.8 -848.4

Past studies (Sutradhar 1999, Rahman 2001) shows that the design of mat foundation is mostly governed by the minimum reinforcement criteria for resisting the bending moment. Reduced thickness, t_r for mat with non-uniform thickness at midspan is governed by negative moment. As thickness in midspan decreases negative moment also decreases, at the same time capacity of the section decreases. Table 4.6 shows the variation of bending moment and moment capacity for unit width of the smaller section for the above example along line 2 and 6. Maximum and minimum moment capacity of a section has been calculated with maximum and minimum steel ratio for unit width of the section as singly reinforced beam. It appears (Fig.4.19) that negative moment increases with the increase in reduced thickness (t_r) for non-uniform mat Minimum moment capacity with minimum reinforcement also increases with the increase of reduced thickness. Any thickness in negative moment zone larger than 80% of mat thickness (t) can withstand the negative moment in the zone with minimum reinforcement. So in the mid span zone the thickness of mat can be reduce upto 20% of mat thickness with using minimum reinforcement for the area.

Punching and flexural shear both are important parameters in designing the mat foundation. For non-uniform mat the mat-thickness near shear wall and column is calculated from punching shear. So beam shear (flexural) is significant for reduced thickness zone of non-uniform mat. For presence of shear wall it is evident that shear stress concentration occurs at the face of shear wall. This concentration is more pronounce for the lateral-vertical load combination (LC-2). Flexural shear force varies from maximum at the column face and minimum at midspan. From Fig.4.11a to Fig.4.12d it is evident that for flexural shear, most critical section is neck section, that is, at the contact point in between mat thickness and reduced thickness. In region of reduced thickness of mat with non-uniform thickness, flexural shear force is maximum at the neck section. As mat is a plate type structure local increase in flexural shear cannot cause failure. It fails only when ultimate flexural shearing capacity is less than the flexural shear force across the width. Fig. 4.15 and Fig.17 shows the ultimate stress capacity in flexure of the neck sections along with the variation of shearing stress due to change in thickness. Neck sections are chosen as, one is adjacent to the shear wall line and the other one is an interior section.

As the reduced thickness increases, flexural shearing stress decreases, but total flexural force remains constant. This decrease in flexural shearing stress is due to increase in effective area due to increase in thickness. As the reduced thickness increases capacity for flexural shear increases. Table 4.7 shows the capacity of the neck section along with the flexural shear force at that section due to variation of reduced thickness. Flexural shear force and flexural capacity of the neck section for different neck thickness has shown in Fig. 4.16 and Fig. 4.18.

From this study, it has been observed that for thickness 55% of the mat-thickness flexural shear capacity and flexural force are equal. Thickness 55% of mat thickness is sufficient to take flexural shearing force across the width provided that column strip width at least 0.4 times of the span in that direction.

Table 4.6 Negative Moment in Midspan along Line 2 and Line 6 with Moment Capacity for Unit Width of Different Reduced Thickness.

	Thickness at Midspan			
	450 mm	**610 mm**	**760 mm**	**1070 mm**
Maximum Negative moment (along line 2) (kN-m/m)	321.6	495.9	632.6	805.1
Maximum Negative moment (along line 6) (kN-m/m)	302.9	439.3	531.2	631.8
Minimum moment capacity * (kN-m/m)	141.4	280.2	485.1	1062.6
Maximum moment capacity * (kN-m/m)	932.7	1847.7	3199.4	7007.8

*for f_c'= 27.6 MPa, f_y= 414 MPa

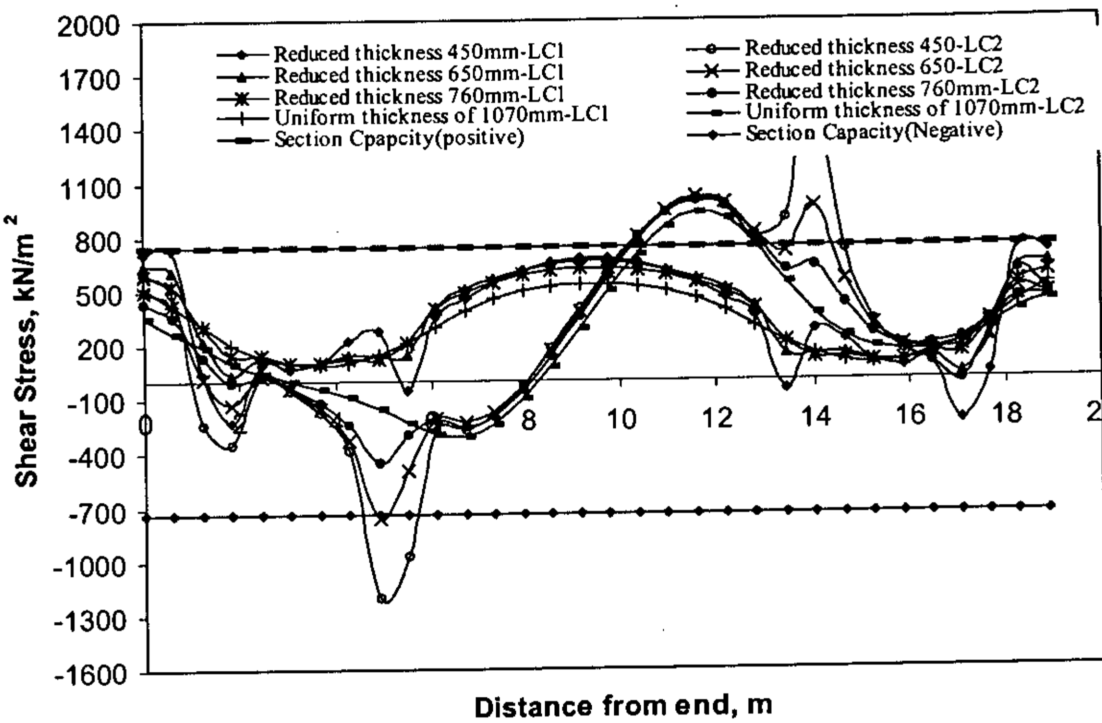

Fig.4.15. Variation of shear stress and flexural shear capacity across the width at the neck section adjacent to shear wall.

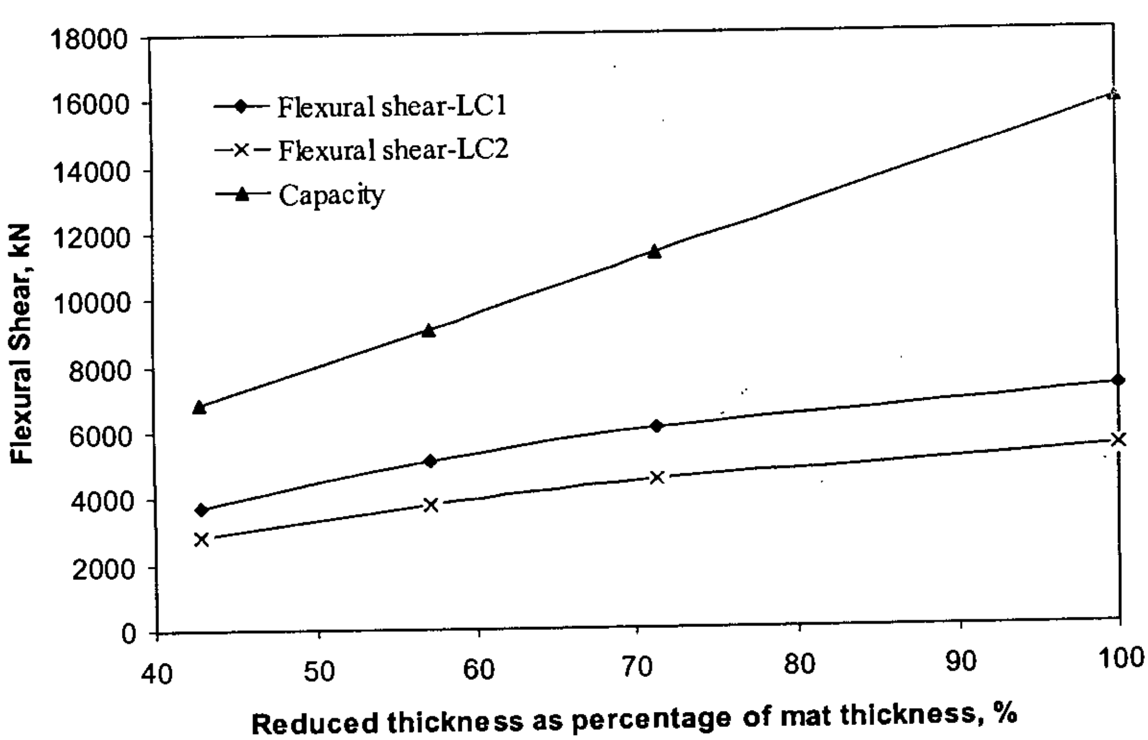

Fig.4.16. Variation of total flexural shear force and ultimate flexural shear capacity at the neck section adjacent to shear wall with change in midspan thickness.

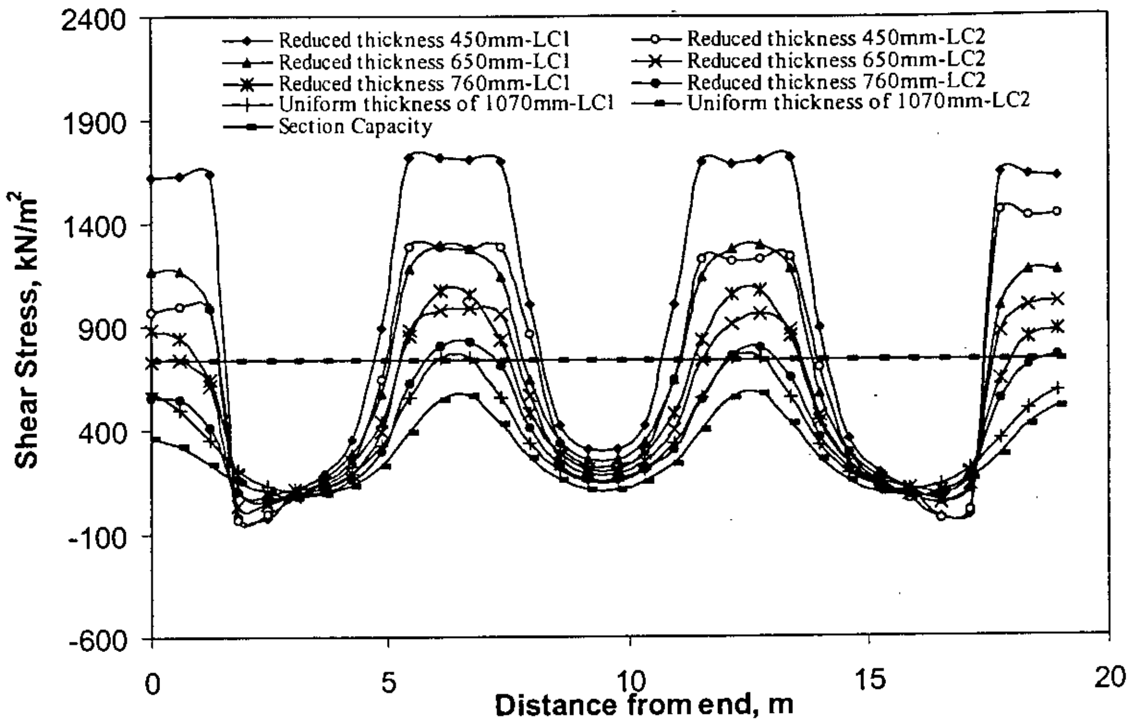

Fig.4.17. Variation of shear stress and flexural shear capacity across the width at an interior neck section.

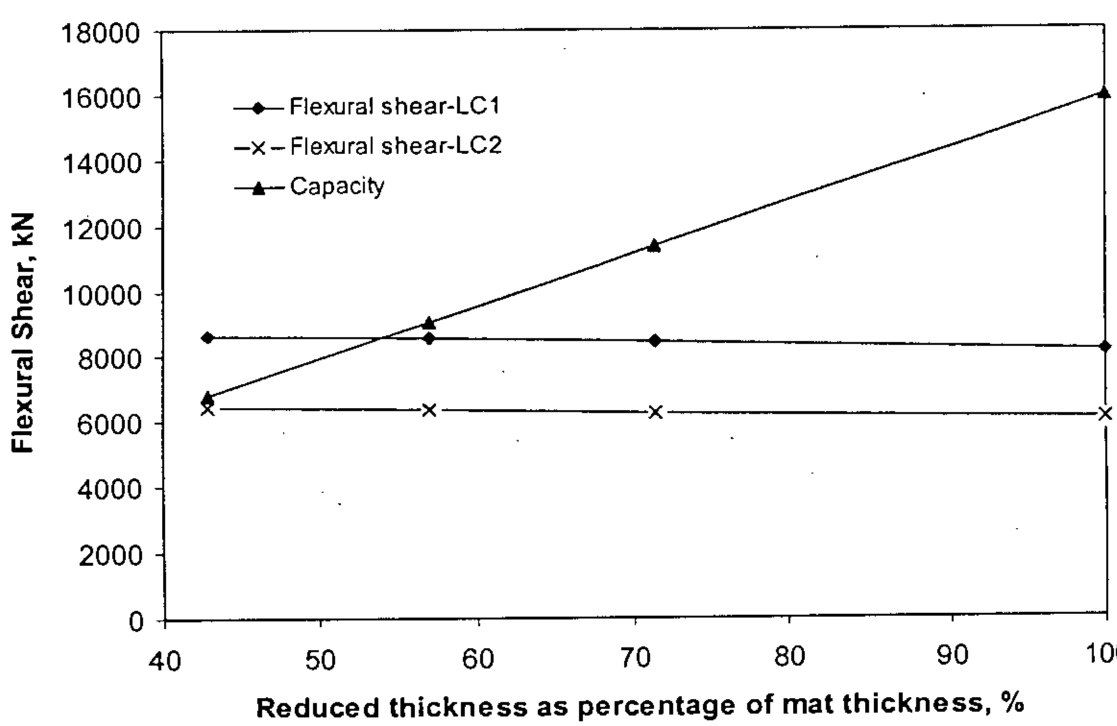

Fig.4.18. Variation of total flexural shear force and ultimate flexural shear capacity at an interior neck section with change in midspan thickness.

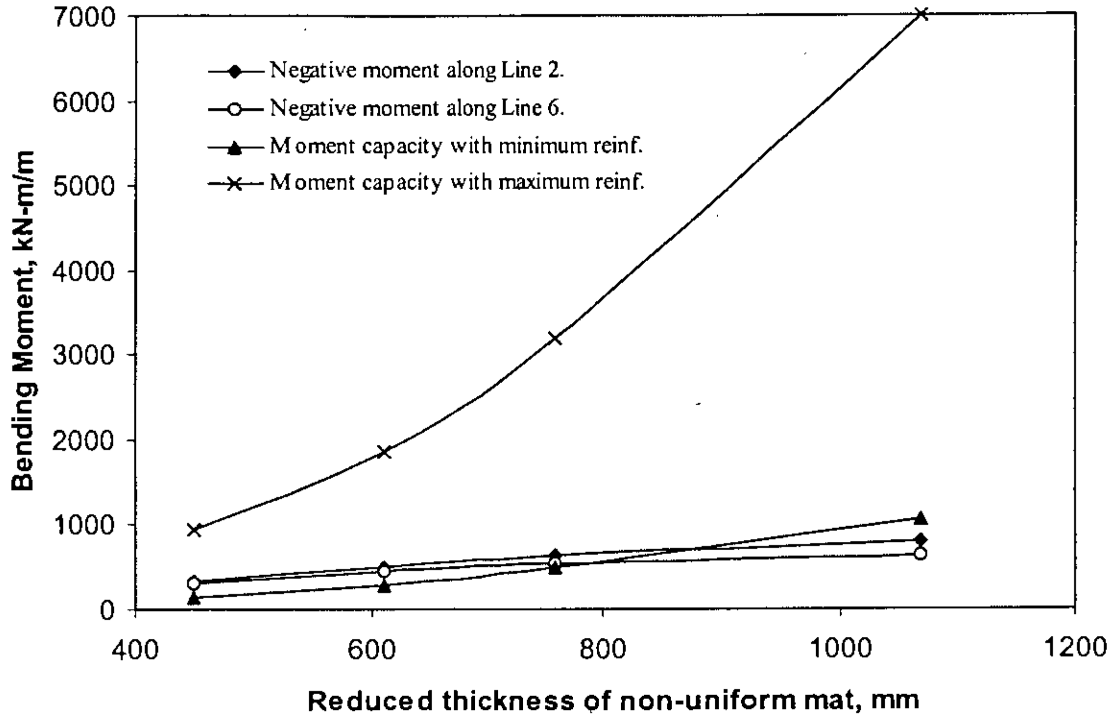

Fig.4.19. Variation of bending moment and moment capacity along **line 2** and **line 6** with change in midspan thickness.

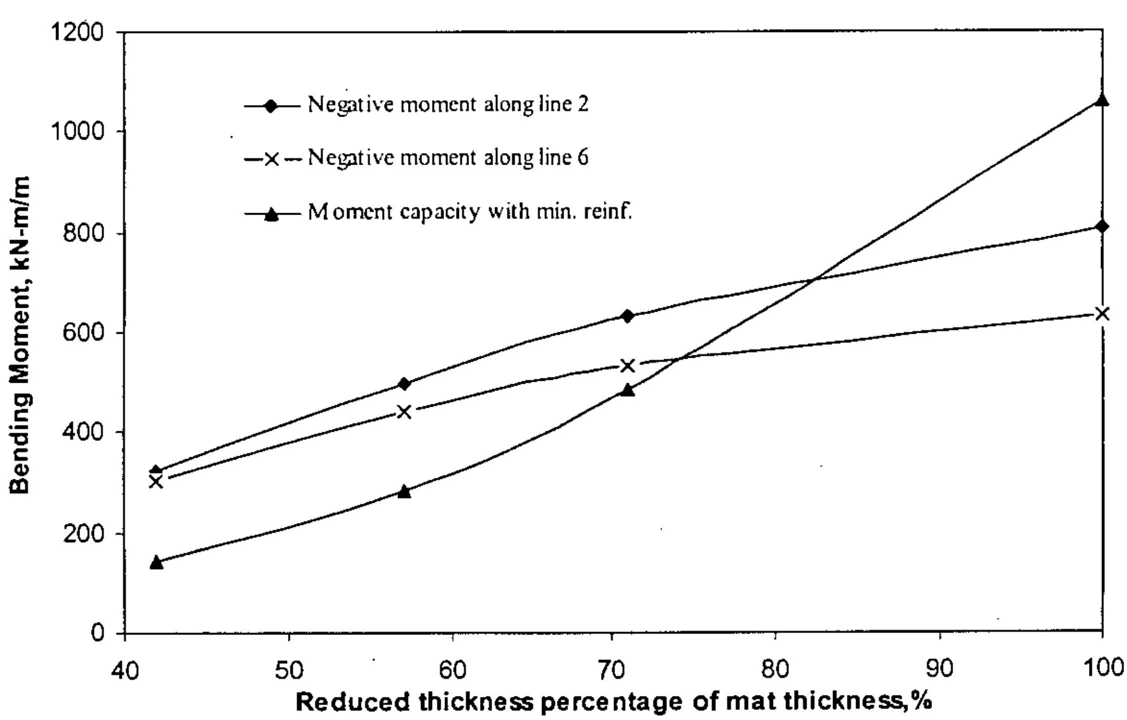

Fig.4.20. Variation of bending moment and moment capacity along **line 2** and **line 6** with change in midspen thickness expressed in percentage of mat thickness.

Table 4.7 Capacity and Flexural Shear Force of the Neck Section with Change in Reduced Thickness.

Reduced thickness, mm	Reduced thickness as % of mat thickness	Flexural shear force kN		Flexural Shear Capacity* kN
		Load Case-1	Load Case-2	
450	42%	8607	6418	6819
610	57%	8600	6411	9090
760	71%	8434	6287	11364
1070	100%	8178	6102	15909

*for $f_c' = 27.6$ Mpa

4.3 SUMMARY OF THE PARAMETRIC ANALYSIS OF MAT FOUNDATION WITH SHEAR WALL

The summary of parametric analysis of two significant parameters for design of mat foundation is shown in Table 4.8.

Table 4.8 Summary of parametric study of mat foundation.

Parameter	Displacement	Positive moment	Negative moment	Shearing Stress
Increase in Modulus of Subgrade Reaction	Displacement decreases rapidly. Differential settlement is high near shear walls. Variation is less for points away from shear walls.	Positive moment increases slightly.	Negative moment decreases significantly. Lateral load combination becomes pronounced due to presence of shear wall for negative moment.	Shearing stress changes little.
Increase in Reduced thickness	Displacements decrease below the column and shear wall and increases at midspan. Change below shear wall is most significant. Differential settlement reduces.	Positive moment decreases along shear wall and column line and increases along line between columns.	Negative moment increases. This variation is more for spans adjacent to shear walls.	Change in shear stress is pronounced at neck section. Shear stress variation is significant near at the mid span near wall.

4.3 SIGNIFICANT DIFFERENCE IN PARAMETRIC ANALYSIS FOR THE PRESENCE OF SHEAR WALL

- Previous studies (Rahman 2001, Sutradhar 1999 and Morshed 1995) suggests that from moment consideration, thickness at the negative moment zone of mat with columns can be reduced up to 40% of the mat thickness. But presence of shear wall allows much less reduction in thickness to resist moment with minimum reinforcement at negative moment zone.

- Negative moment at midspan close to shear wall is governed by lateral load combination.

- Significant differential settlement is found adjacent places to the shear walls. Differential settlement is prominent for lateral load case (LC-2) as presence of shear wall resists major portion of lateral force. Settlement below the shear wall is much higher than the deflection under columns.

- Presence of shear wall causes a higher rate of change in negative moment in the mid span close to shear wall line.

- Variation in subgrade reaction does not affect the positive moment along the line parallel to the longitudinal axis of shear wall significantly.

- From the flexural shear consideration the thickness required in mid sections of mat with shear wall are the same as mat without shear wall. Previous studies show (Rahman 2001, Sutradhar 1999) that thickness 55% of mat thickness is sufficient to resist the flexural shear force. This is due to the fact that flexural shear for buildings with 12 to15 stories is governed by vertical load case. So presence of shear wall does not influence the flexural shear criteria significantly.

CHAPTER 5

STRUCTURAL BEHAVIOUR OF MAT FOUNDATION WITH SHEAR WALL

5.1 GENERAL

Mat is a three-dimensional thick plate structure that acts integrally with the building frame and supported by soil stratum. Proper understanding of mat response to imposed loading on it is most important part for efficient design of mat foundation. Mat foundations are commonly designed with uniform thickness all over the mat for loadings from columns. The methods available for design of mat foundations are discussed in previous chapters. As the available methods of mat analysis do not focus on the influence of shear walls on the behaviour of mat foundation, design engineers may feel uncertain about the shear wall-mat interaction. This gap in knowledge about the behaviour of mat with shear wall results in over design or under design of the mat. Location and number of shear walls can influence the behaviour of mat foundation significantly. An improved understanding of the shear wall effect on mat behaviour is necessary to achieve overall economy of mat design. Study of Rahman (2001) reveals that about 25% economy can be achieved with non-uniform mat foundation over mat having constant thickness. This aspect is also looked into, specially with the presence of shear wall.

In the present study, mat foundation with thickened plate under columns and shear walls, termed *non-uniform mat,* hereafter, is analysed along with mat with constant thickness. In the previous chapter it was found that minimum reinforcement can not resist bending moments if the thickness of mat is reduced too much in the zone of negative moment zones. The parameters related to mat with uniform and non-uniform thickness for different location and number of shear walls are critically reviewed.

A sample problem of fifteen-story building has been studied for both vertical and lateral loads for different locations and numbers of shear walls on mat. Various parameters relevant to mat are selected for study.

5.2 ANALYSIS OF MAT FOUNDATION WITH SHEAR WALL

A typical fifteen-story building with five bays in long direction and three bays in short direction has been taken for the study. The shear walls were placed at different places in the plan. The different locations of shear walls are shown in Fig-5.1 to Fig.5.6 with the lines 1 to 18 along which variation in moment, shear and defection has been studied. First the building with only columns as connecting member is analysed, then five different models with different number and different location of shear walls are analysed. In the first model a single shear wall is placed at one end of the mat. The second model is with two shear walls at both the end lines along short direction of mat foundation. In the third and fourth model two shear walls are used symmetrically in two column lines. The last model is with a single shear wall at an interior column line. For the cases of symmetrically placed shear walls the variation of different parameters in half of the foundation is presented. These models are analysed both with uniform thickness and non-uniform thickness. The mat thickness was calculated for punching and it was found to be nearly 1050 mm. For non-uniform mat, the mat thickness below and near column and shear walls was taken as 1070 mm and the reduced thickness in mid panel zones was taken as 610 mm. In the case of uniform mat 1070 mm thickness was used for entire foundation.

Shear wall resists the major portion of lateral loads. So consideration of the lateral loading is an important factor for study of mat behaviour with shear wall. For calculating wind load the Bangladesh National Building Code (BNBC,1993) was followed. The superstructure was considered to be located at Exposure category 'A' where basic wind speed is 210 km/h. Structure importance category was assumed to be Standard occupancy structures. To calculate Design Wind load, Projected Area method was used. Lateral loads were divided into the frames and walls based on the ratio of their stiffnesses.

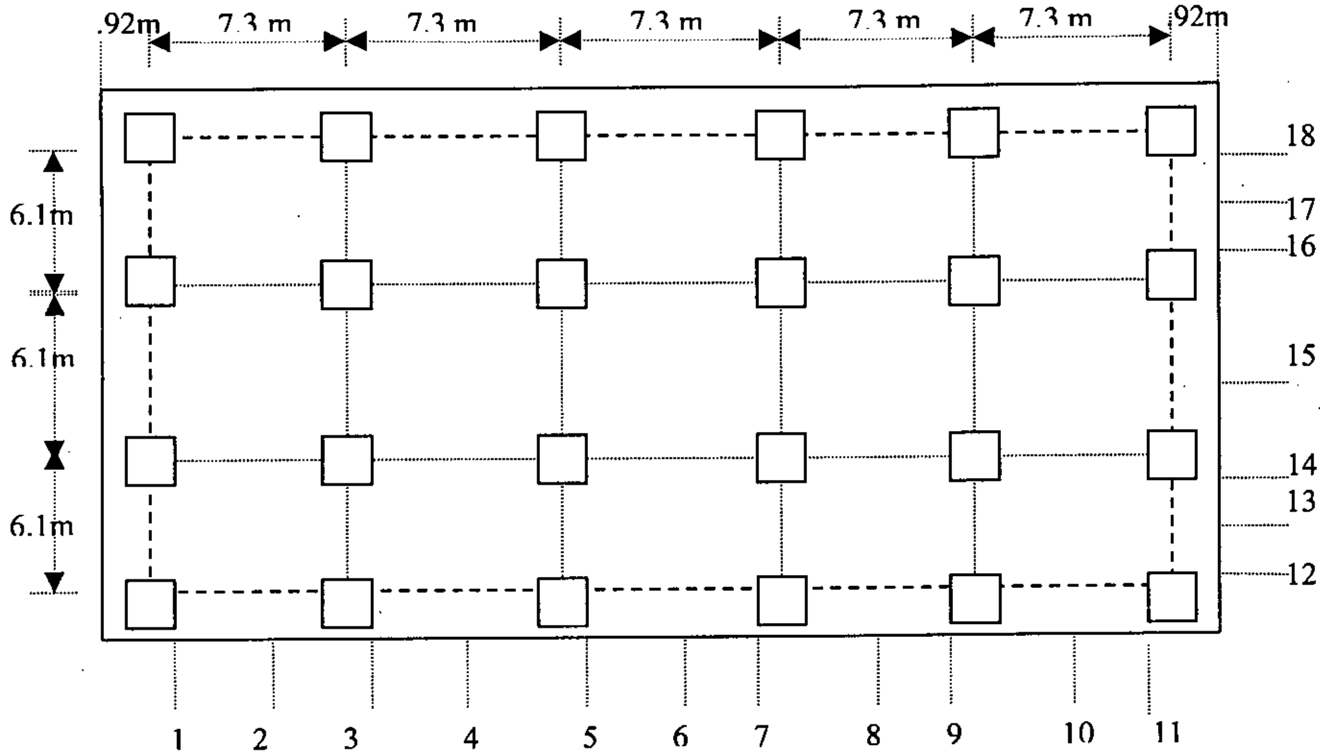

Fig.5.1 Plan of a fifteen story building of frame structure

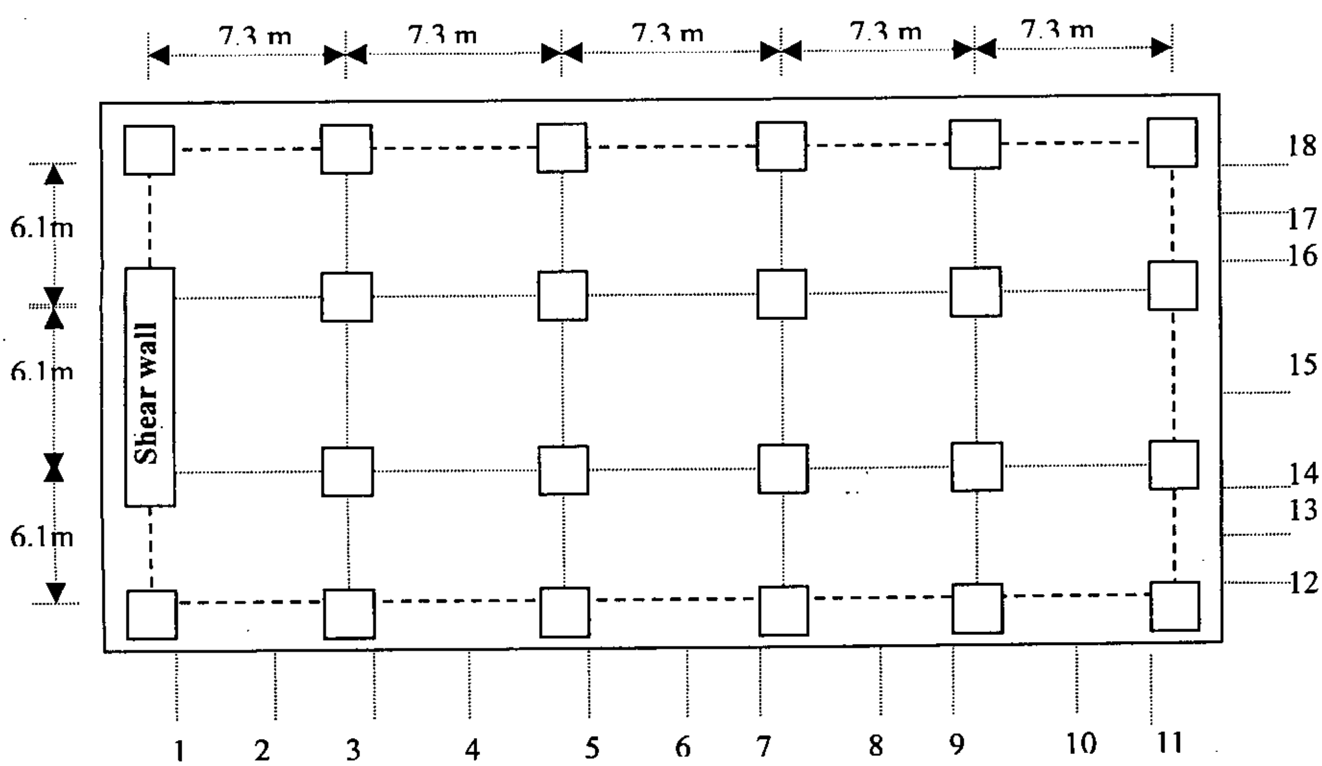

Fig.5.2 Plan of the fifteen story building with frame and wall **(MODEL-A)**

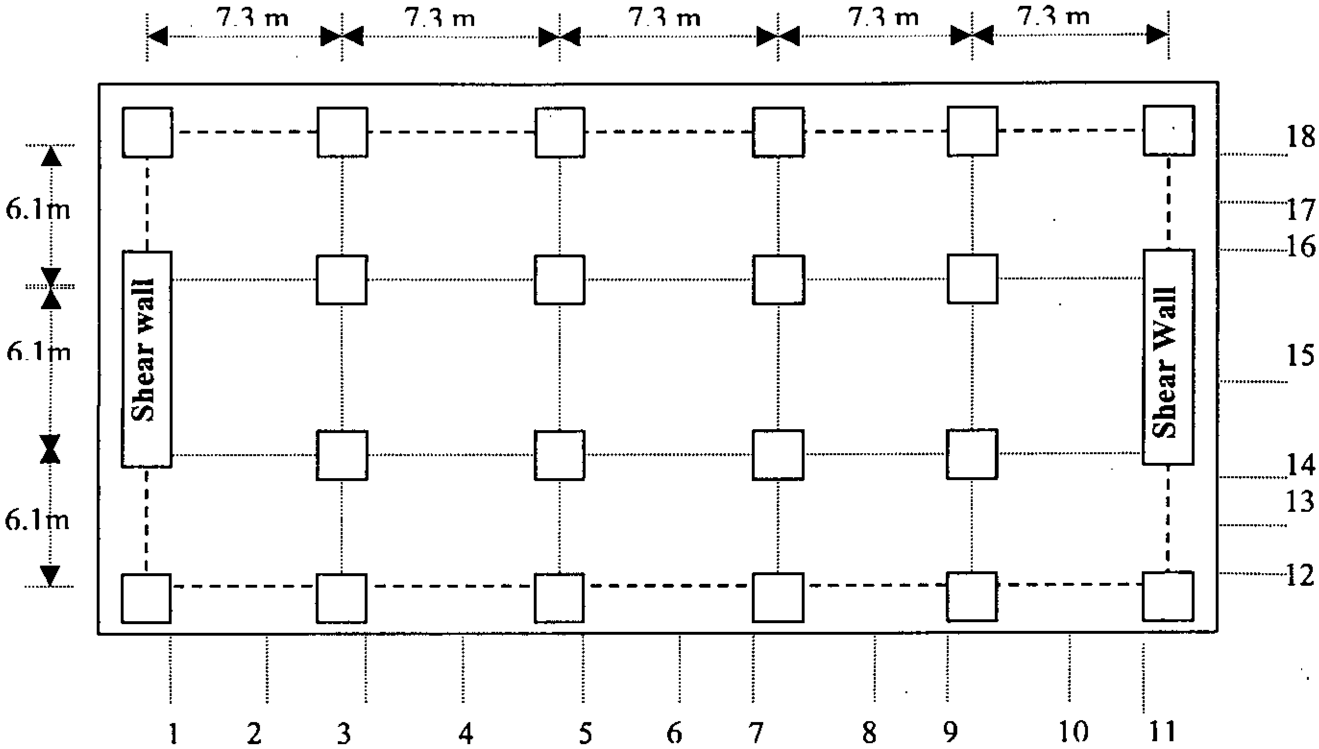

Fig.5.3 Plan of the fifteen story building with frame and shear walls **(MODEL-B)**

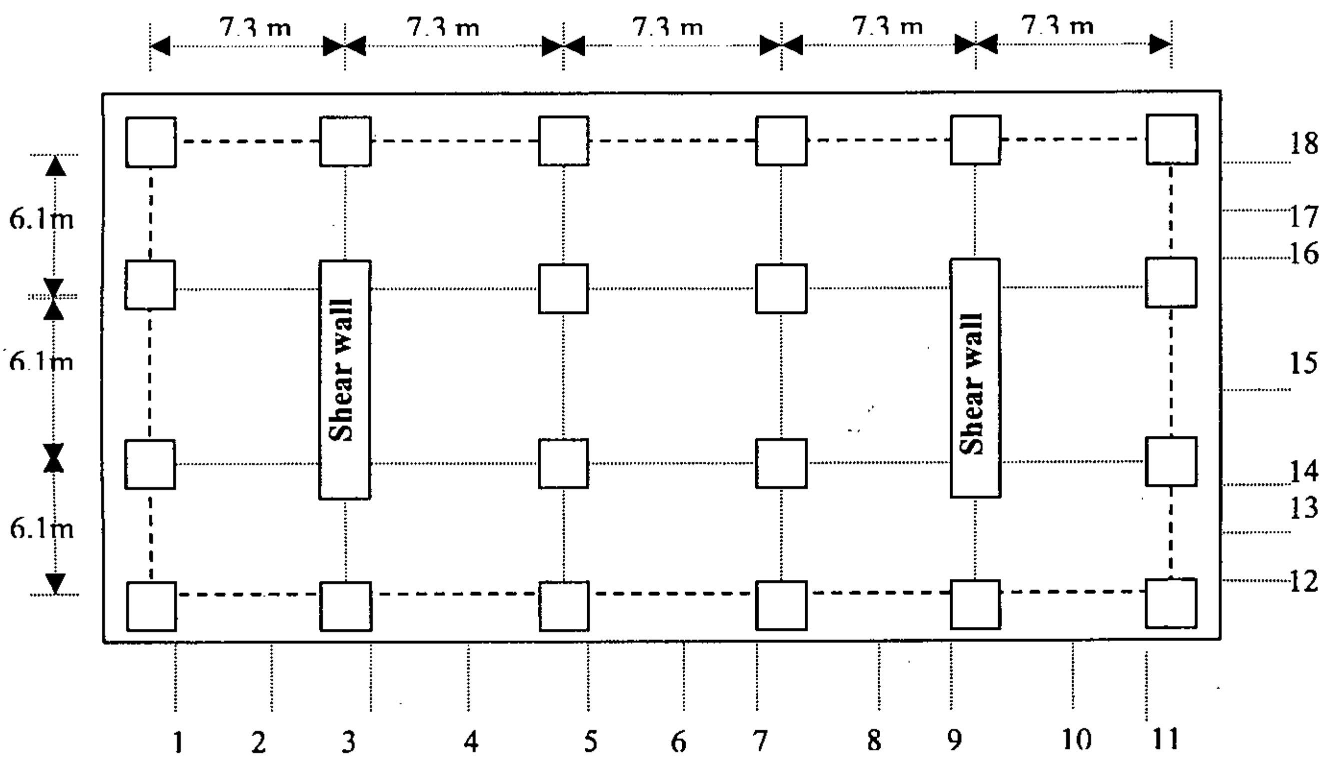

Fig.5.4 Plan of the fifteen story building with frame and shear walls **(MODEL-C)**

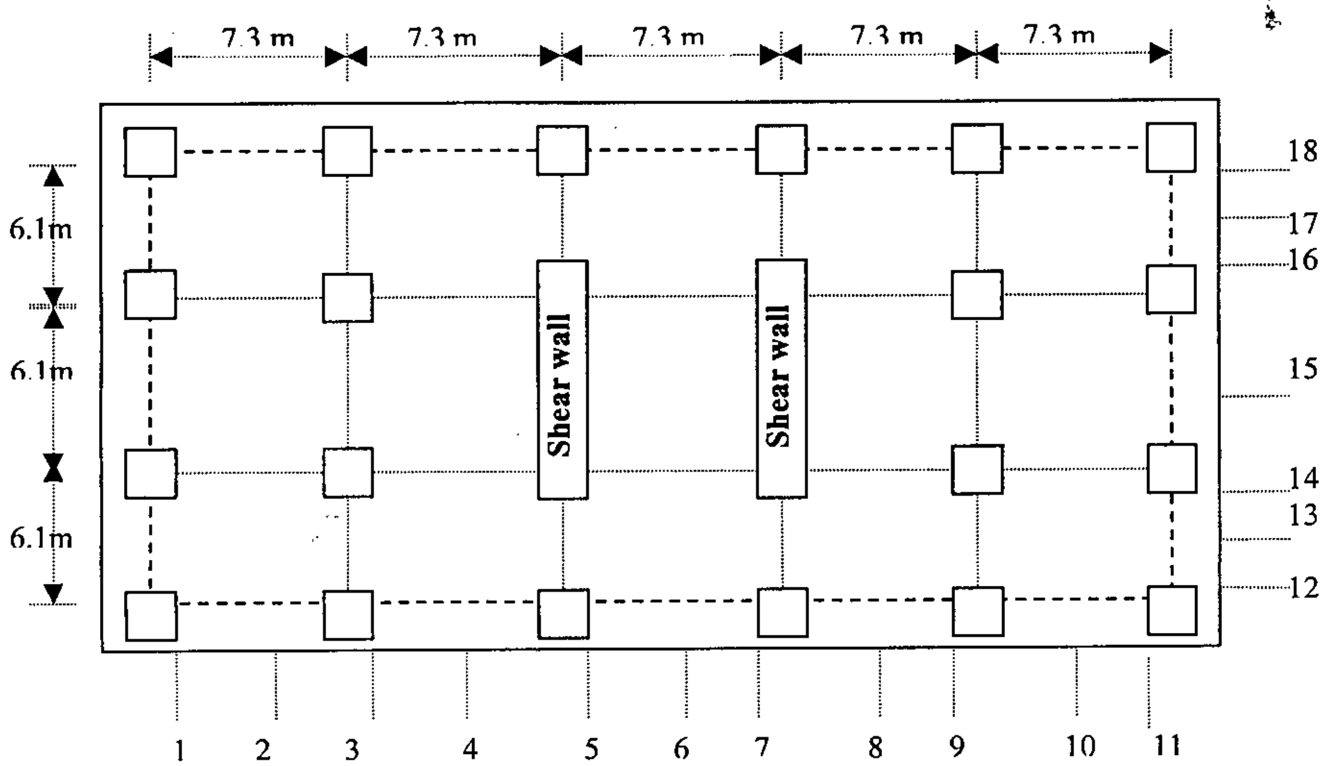

Fig.5.5 Plan of the fifteen story building with frame and shear walls **(MODEL-D)**

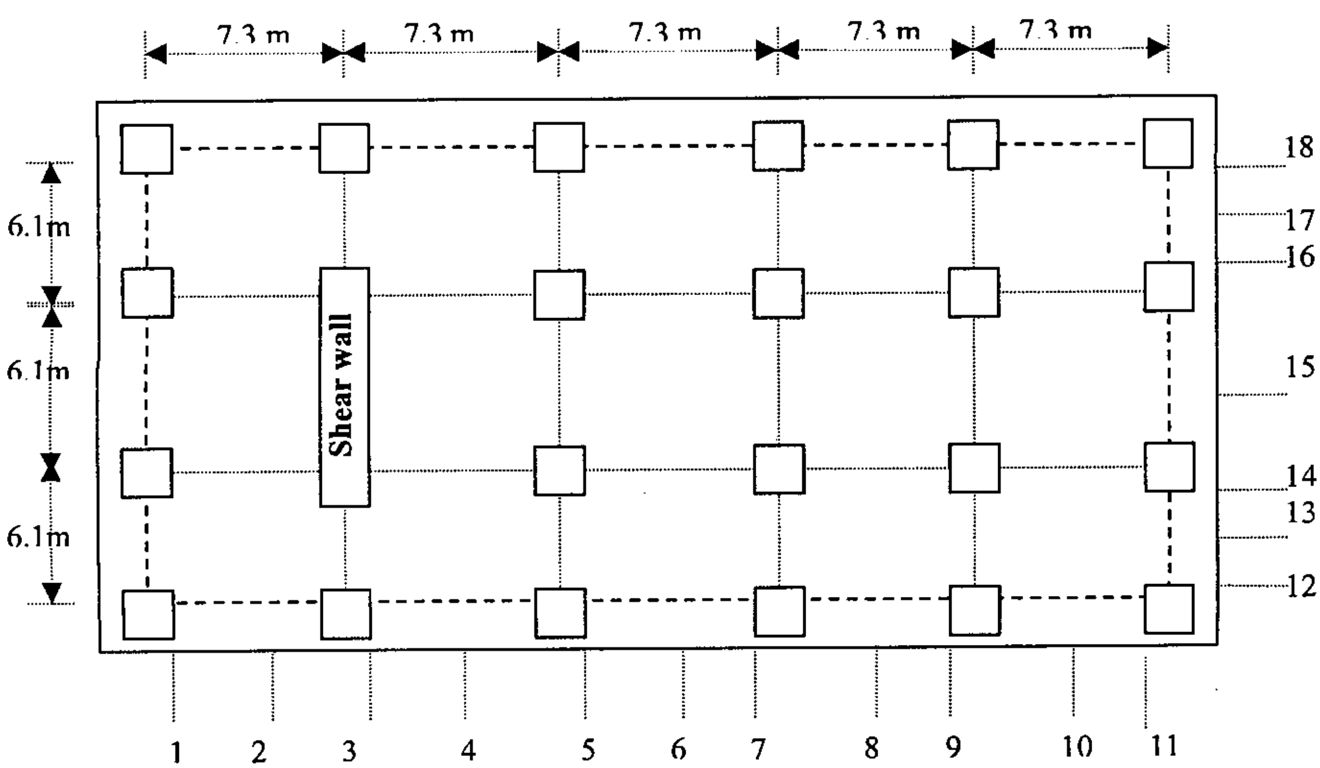

Fig.5.6 Plan of the fifteen story building with frame and shear wall **(MODEL-E)**

The superstructure is assumed to have a live load of 2.9 kN/m^2, slab dead load of 4.3 kN/m^2, distributed partition wall load of 1.4 kN/m^2 and floor-finish 1.2 kN/m^2. An amount of 6.4 kN/m has been considered for 125 mm walls along all beams and column size is 0.6x0.6 m. Story height of the floor is taken as 3.0m. Shear wall thickness is taken as 0.3 m.

Calculation of dead load and live load is made in accordance with the USD method of ACI (1983). Proper live load reduction is employed in calculating column loads and shear wall loads. Load cases are used as follows:

Load case I (LC-1) = 1.7LL+ 1.4 DL

Load case II (LC-2) = 0.75*(1.7LL+ 1.4 DL+1.7WL)

Where

LL = Live load,

DL = Dead Load,

WL = Wind Load.

Finite element idealization of the mat and shear wall model has been described in Chapter 3.

5.3 VARIATION IN BENDING MOMENT FOR THE PRESENCE OF SHEAR WALL

Mat foundation commonly faces positive bending moment below the column and negative moment at the midspan in between the columns for column loading on it. Generally maximum negative moments in midspan and column face positive moments along the column lines are used for flexural design. From the variation of bending moment along different lines for different location of shear walls are shown in the Fig.5.7 to Fig.5.21. Similar variations in other lines are given in Appendix-D. Variations are plotted along line parallel to the faces of column and shear wall and in mid span. For the case of symmetrically placed shear walls variations are shown for half of the structure and for non-symmetric shear wall locations bending moment are plotted along all column lines and mid spans. Variation of the bending moment for mat without shear walls are also plotted with that of mat with shear walls in all the cases.

Previous studies by Rahman (2001), Sutradhar (1999) and Morshed (1996) showed that a regular variation in bending moment is observed along the column line and along mid span in between the column lines. So, for this nearly uniform variation in bending moment, they suggested that each panel of mat could be divided into column strip and middle strip. And negative moment governs the reinforcement design of middle strip and positive moment controls the reinforcement design of column strip.

The presented variation in bending for different locations of shear wall shows that the change in moment for presence of shear wall are not as regular as revealed by previous studies for the case of mat foundation without shear walls. Line along which considerable change in moment has been found are given in Fig.5.7 to Fig.5.21.The following observation was made from the current study.

- It is evident that negative moment along mid span increases considerably for the presence of shear wall. For any location of shear wall, the negative moment in the adjacent mid panel to shear wall faces significant variation. The variation of negative bending moment along the adjacent panel and panel next to the adjacent panel are given in Fig.5.7 to Fig.5.16. For any location of shear wall the variation in negative moment along mid span of exterior panels suffer considerable change.

- In long direction (direction perpendicular to the length of shear wall) variation in bending moment is regular and controlled by the gravity load case for the mat foundation without shear walls (Rahman 2001, Sutradhar 1999). But presence of shear wall makes considerable change in the long direction bending moment. The change in bending moment remains significant, up to the length of span of adjacent panel as shown in Fig.5.17 to Fig.5.21.

- Variation in negative moment in mid of panel is more pronounced for the case of non-uniform thickness. Increase is negative bending moment is high for the case of non-uniform thickness. The increased values of negative moments are much higher than the moment capacity of the section with minimum reinforcement.

- Bending moment variation is more significant for shear wall presence at ends of foundation. Any other location of shear walls in mat has less influence on mat bending moment. Intermediate location of shear wall results in less variation for negative bending moment than that for shear walls at edges. Table 5.1 shows the variation of mid panel moments adjacent to shear wall.

- Positive moment increases along the line of shear wall for lateral load combination (LC2). Significant change in positive moment occurs in the column line (along short direction) next to the shear wall line. Variation in positive moments along the direction of shear walls are not very significant. Along the direction perpendicular to shear walls significant change in positive bending moment occurs.

- For any location of shear wall the change of the negative moment in exterior panel is always significant.

- Change in long direction bending moment is less for shear wall location in mid part of mat (as model-C and D). Fig.5.17 to Fig.5.21 shows the variation for different locations of shear wall.

- Positive moment of mat with shear wall along the column lines in the direction of shear wall follow the same trend as in the case of mat without any shear wall.

- Variation in positive moment along column lines in short direction other than the shear wall line is not much significant.

- Positive moment along the column line next to shear wall line faces some increase in value.

- Significant variation in positive moment occurs below the shear wall. Both uniform and non-uniform mat face considerable amount of positive moment increase below the shear wall. Table 5.4 shows that the values of positive moment at the face of shear wall are very significant. These increased moments are more pronounced for the case of non-uniform mat.

Table 5.1 Variation in Maximum Midspan Negative Moment for **Uniform** Thickness Mat.

	Bending Moment at Mid Span of Panel Adjacent to Shear Wall, kN-m/m		**Bending Moment at Mid Span of Panel Second from Shear wall, kN-m/m**		**Moment Capacity* with Minimum Reinf., kN-m/m**
	Load Case-1	Load Case-2	Load Case-1	Load Case-2	
Model-A	-1066.8	-1172.9	-604.8	-665.9	1062.6
Model-B	-1069.2	-1111.5	-602.7	-581.8	1062.6
Model-C	-866.7	-825.9	-589.3	-583.6	1062.6
Model-D	-829.8	-868.9	-646.6	-453.4	1062.6
Model-E	-866.8	-817.9	-576.2	-575.9	1062.6

* $f'_c = 27.6$ MPa , $f_y = 414$ MPa

Table 5.2 Variation in Maximum Midspan Negative Moment for **Non-uniform** Thickness Mat.

	Moment at Mid Span of Panel Adjacent to Shear Wall, kN-m/m		**Moment at Mid Span of Panel Second from Shear wall, kN-m/m**		**Moment Capacity with Minimum Reinf.*, kN-m/m**	**Moment Capacity with Maximum Reinf.*, kN-m/m**	**Moment Capacity of smaller thickness-with Min^m Reinf.*of Greater Thickness, kN-m/m**
	Load Case-1	**Load Case-2**	**Load Case-1**	**Load Case-2**			
Model A	-714.3	-722.4	-376.6	-390.1	280.2	1847.7	530.2
Model B	-716.3	-689.2	-378.3	-327.4	280.2	1847.7	530.2
Model C	-562.6	-555.1	-449.5	-404.9	280.2	1847.7	530.2
Model D	-403.8	-350.3	-547.4	-557.9	280.2	1847.7	530.2
Model E	-562.6	-553.8	-440.7	-431.8	280.2	1847.7	530.2

*f'_c = 27.6 MPa , f_y = 414 MPa

Table 5.3 Percent Variation in Maximum Negative Moment with respect to Negative Moment for Mat without Shear Wall.

	Negative Moment Variation, %			
	Mid Span Adjacent to Shear Wall		**Mid Span Second from Shear wall**	
	Uniform thickness	**Non-uniform thickness**	**Uniform thickness**	**Non-uniform thickness**
Model-A	30.3	32.7	11.4	4.2
Model-B	30.6	26.2	9.8	2.0
Model-C	6.1	8.3	2.4	3.2
Model-D	12.3	7.6	1.6	1.1
Model-E	6.1	4.6	0.2	2.1

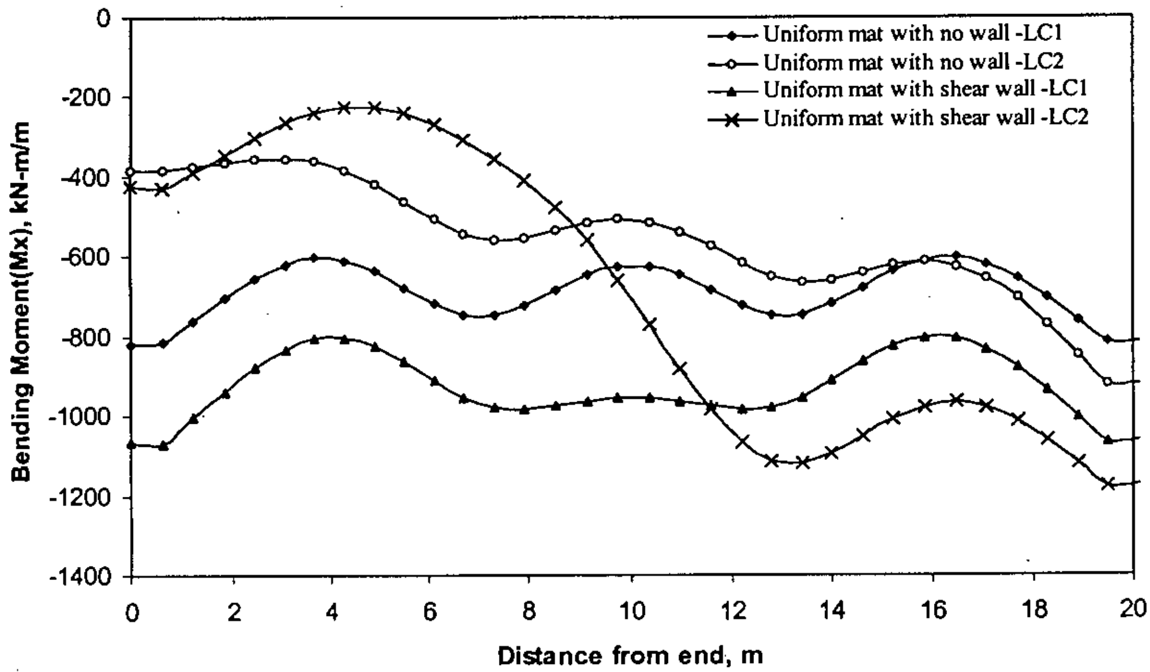

Fig.5.7a Variation in negative moment along mid panel adjacent to shear wall for uniform mat of model-A (along line-2)

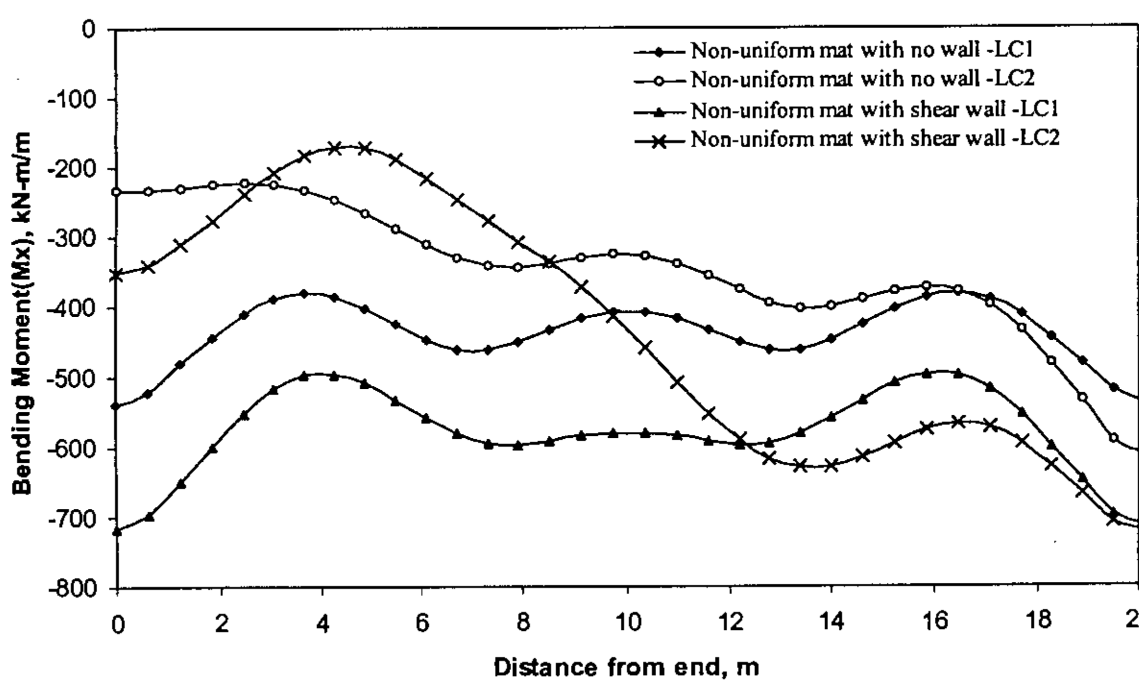

Fig.5.7b Variation in negative moment along mid panel adjacent to shear wall for non-uniform mat of model-A (along line-2).

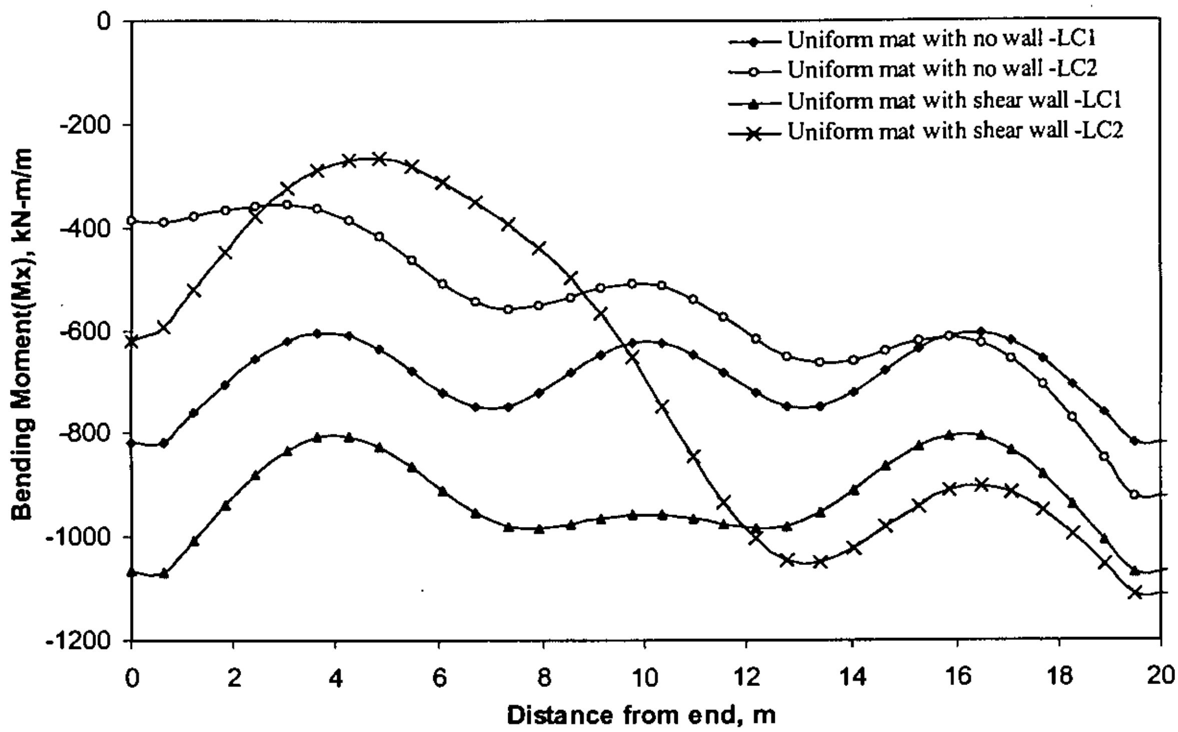

Fig.5.8a Variation in negative moment along mid panel adjacent to shear wall for uniform mat of model-B (along line-2).

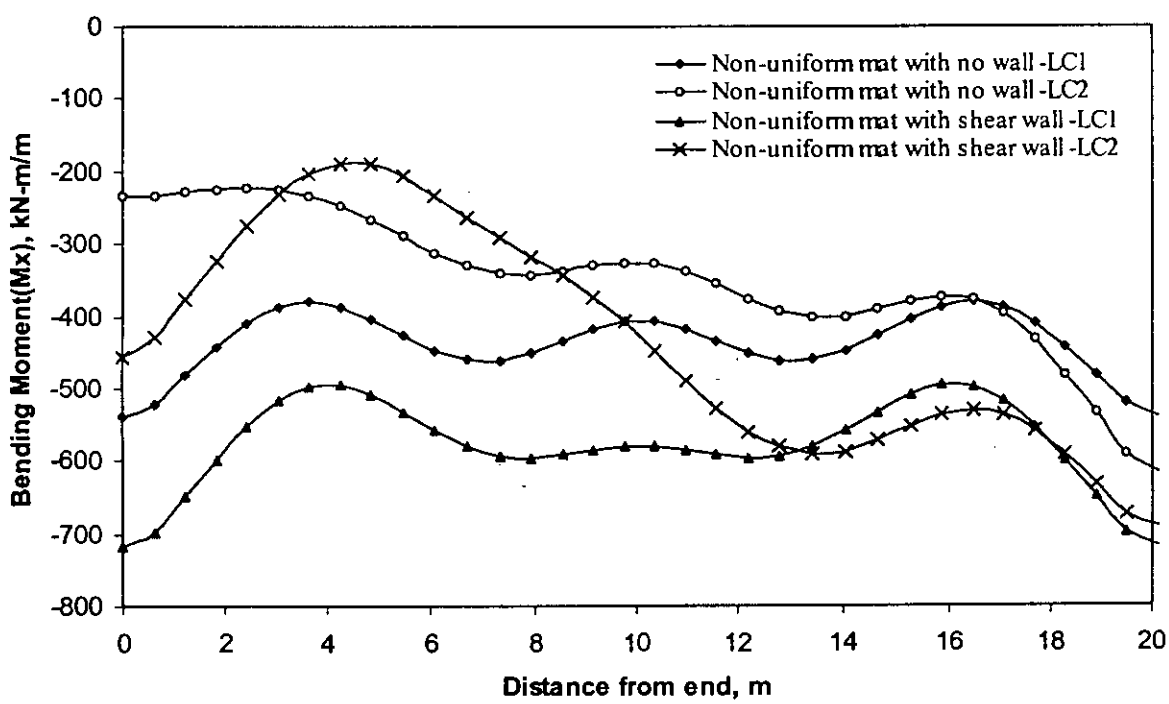

Fig.5.8b Variation in negative moment along mid panel adjacent to shear wall for non-uniform mat of model-B(along line-2)

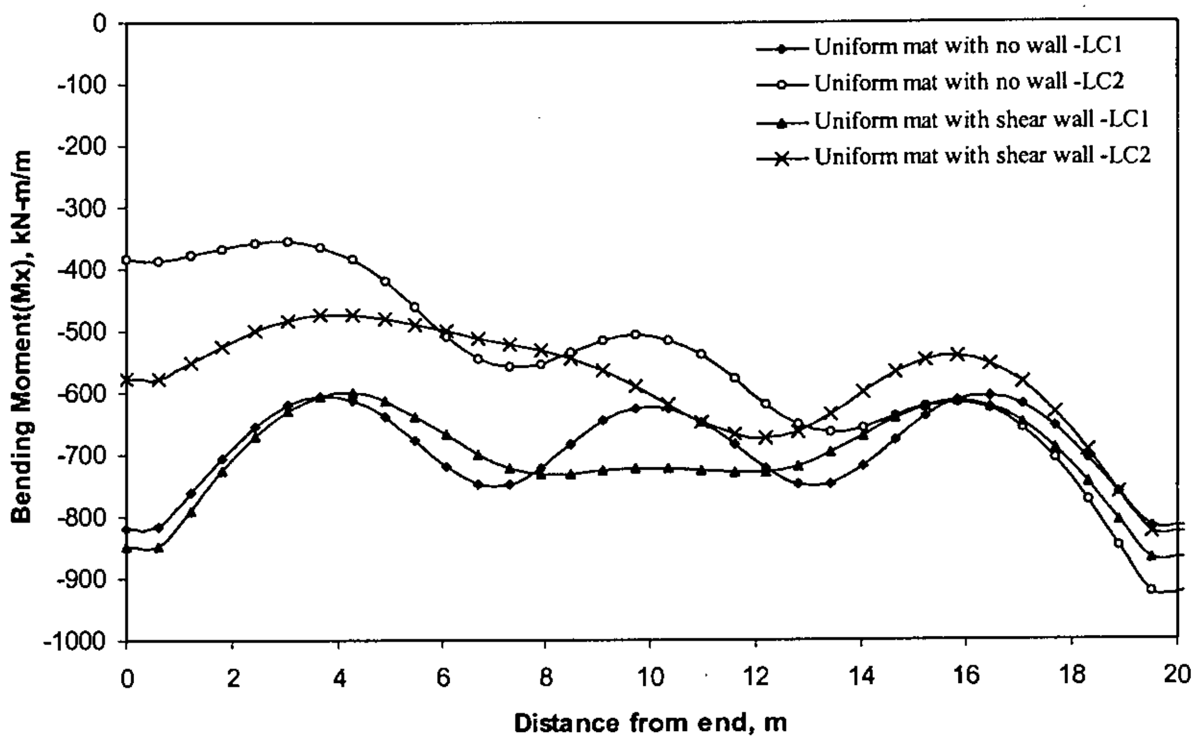

Fig.5.9a Variation in negative moment along mid panel adjacent to shear wall for uniform mat of model-C (along line-2)

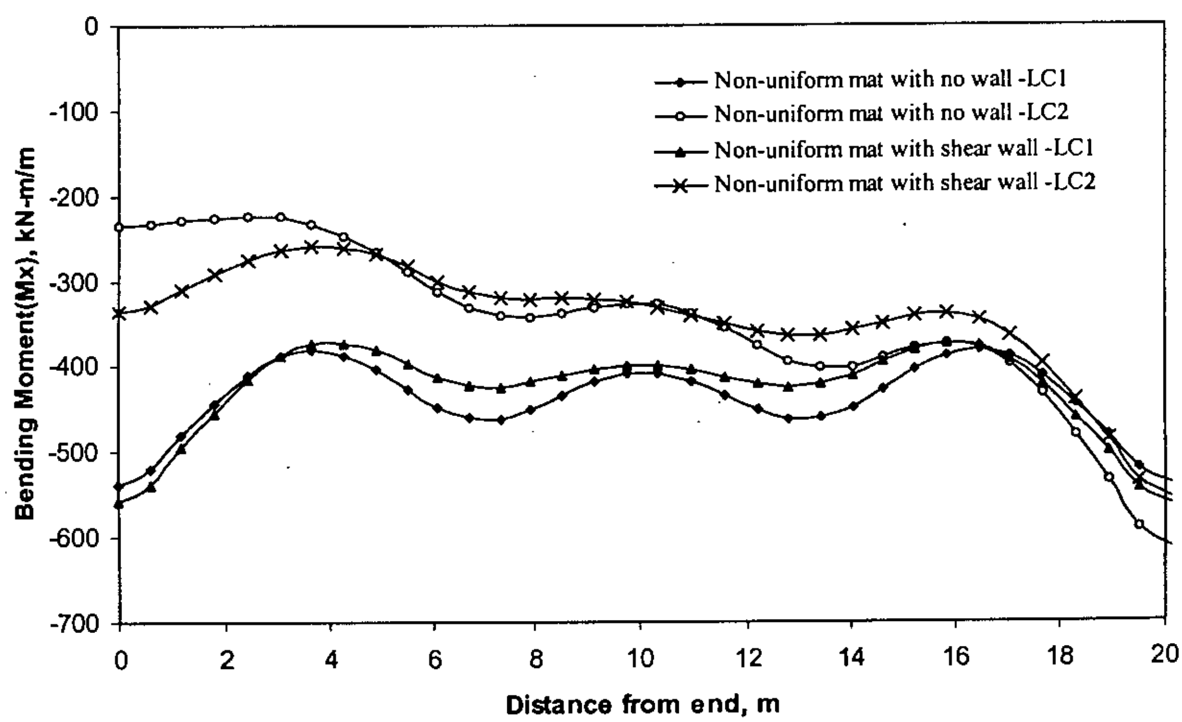

Fig.5.9b Variation in negative moment along mid panel adjacent to shear wall for non-uniform mat of model-C (along line-2)

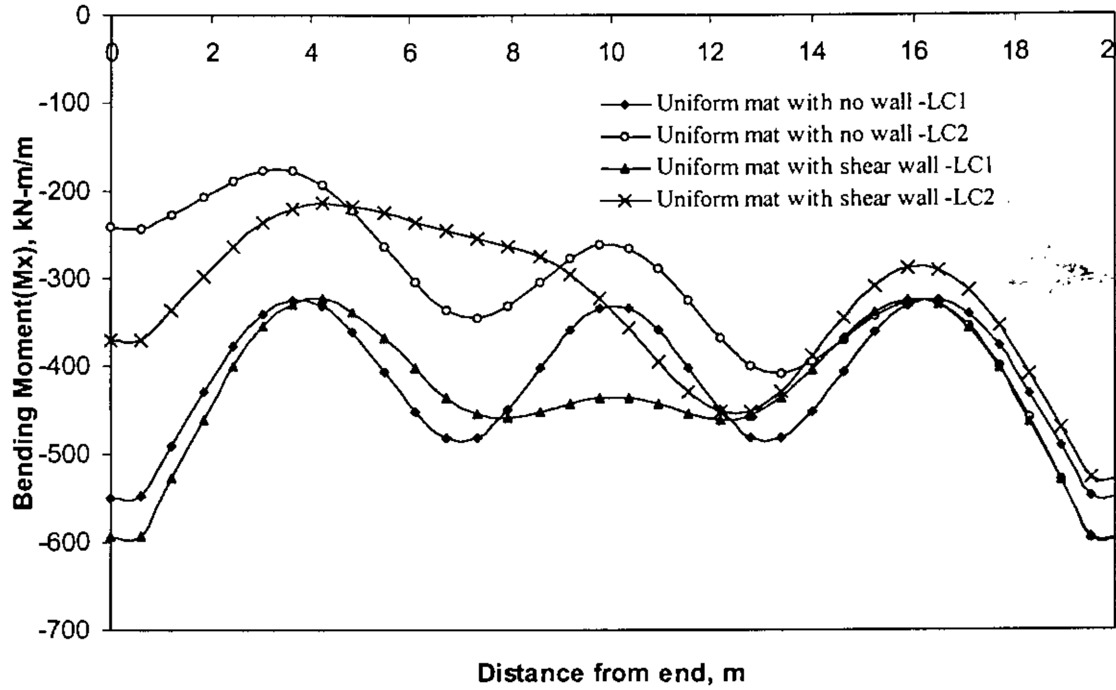

Fig.5.10a Variation in negative moment along mid panel adjacent to shear wall for uniform mat of model-D (along line-4)

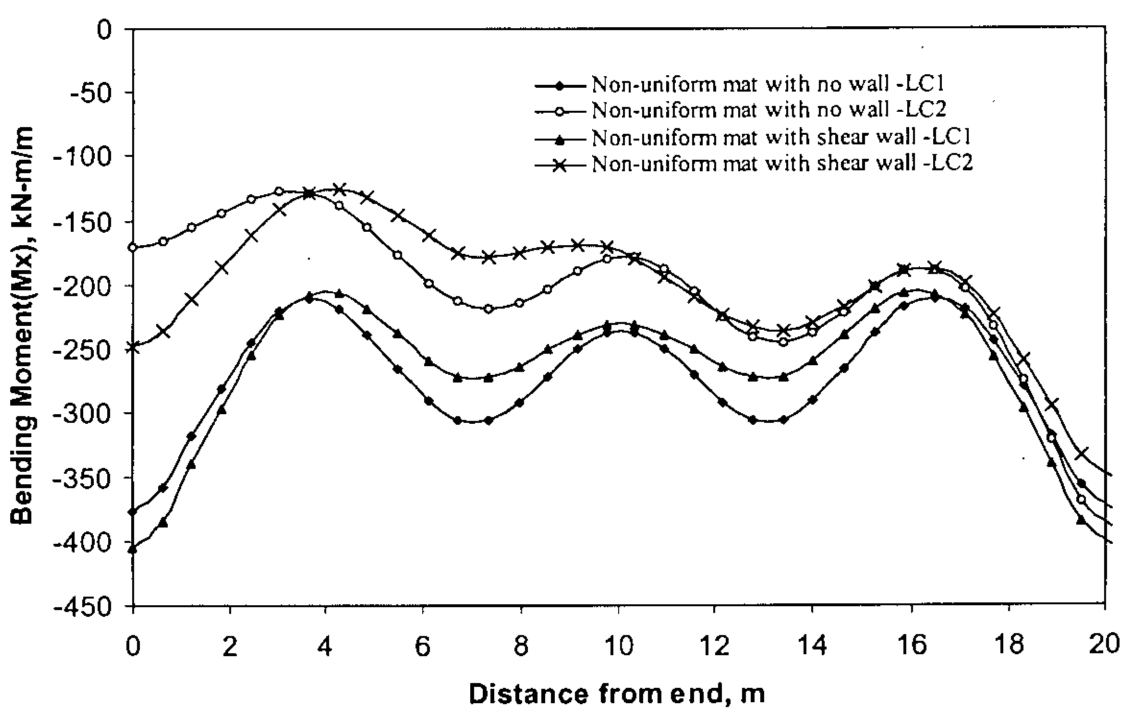

Fig.5.10b Variation in negative moment along mid panel adjacent to shear wall for non-uniform mat of model-D (along line-4)

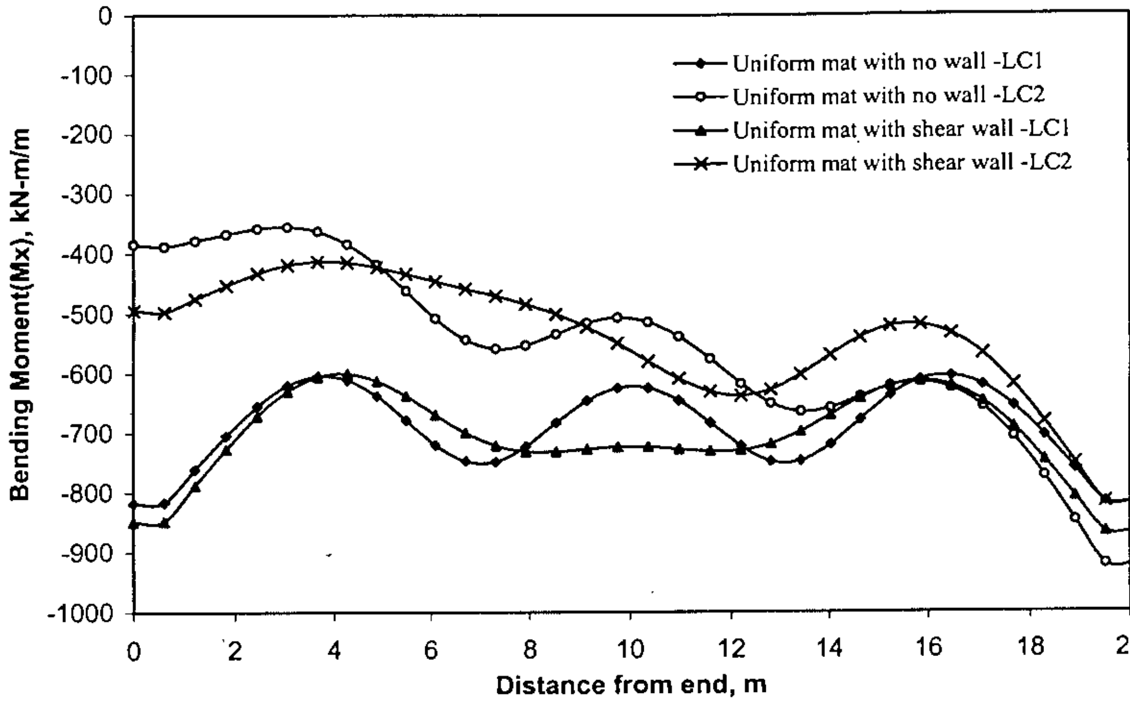

Fig.5.11a Variation in negative moment along mid panel adjacent to shear wall for uniform mat of model-E (along line-2)

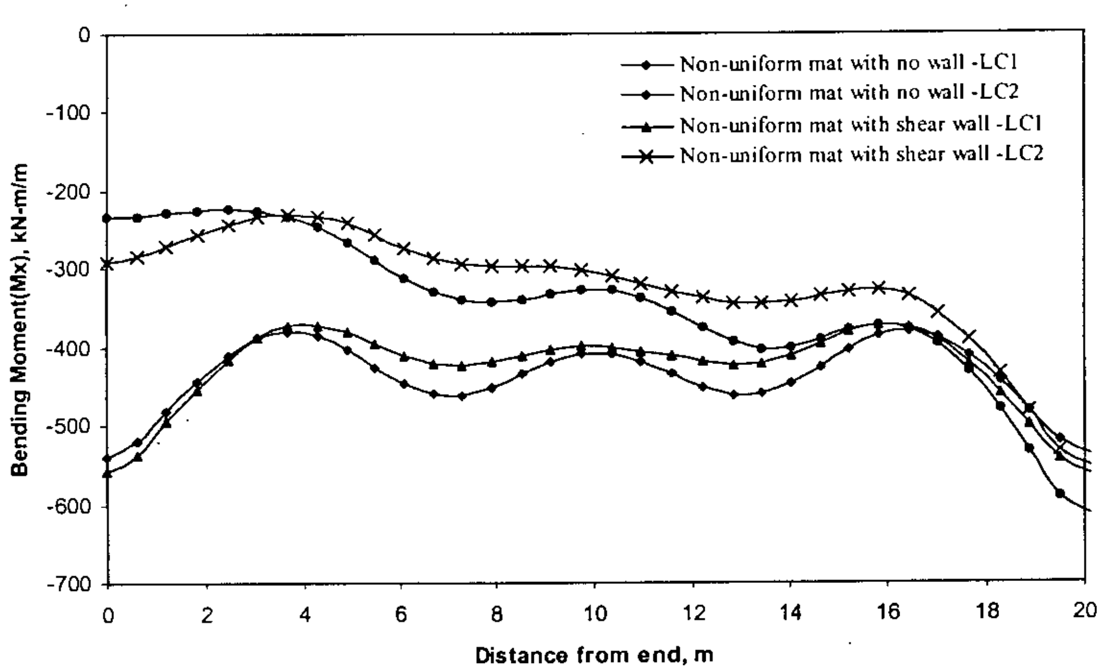

Fig.5.11b Variation in negative moment along mid panel adjacent to shear wall for non-uniform mat of model-E (along line-2).

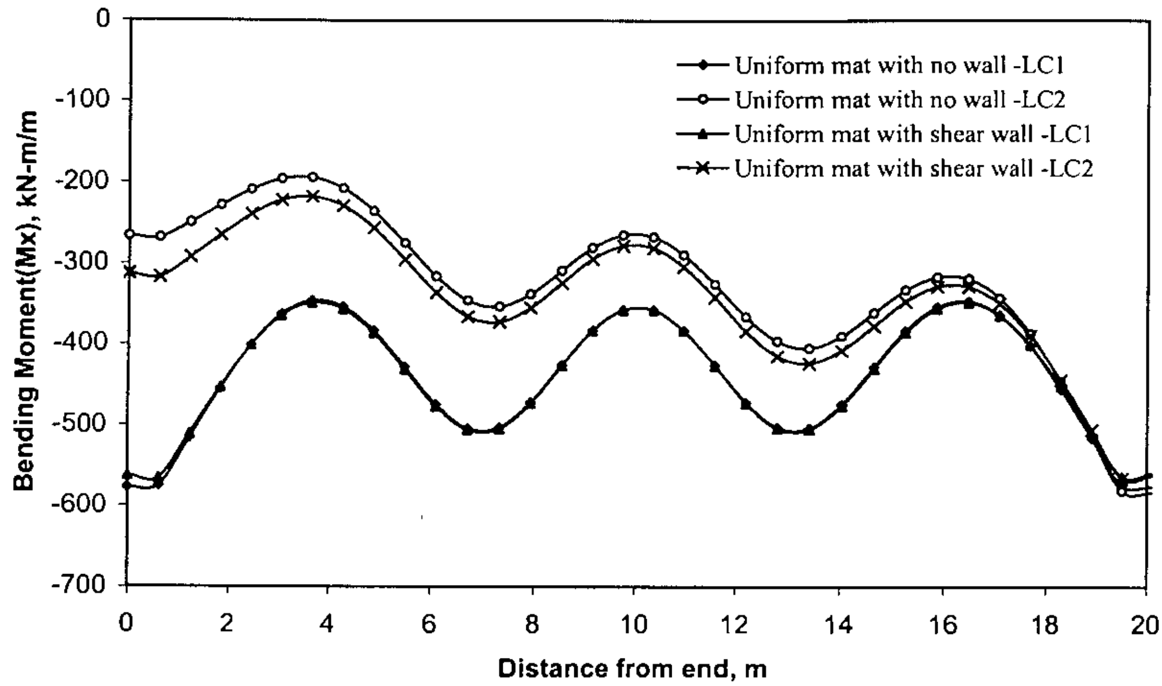

Fig.5.12a Variation in negative moment along mid of the panel situated one panel away from shear wall for uniform mat of model-A (along Line-4).

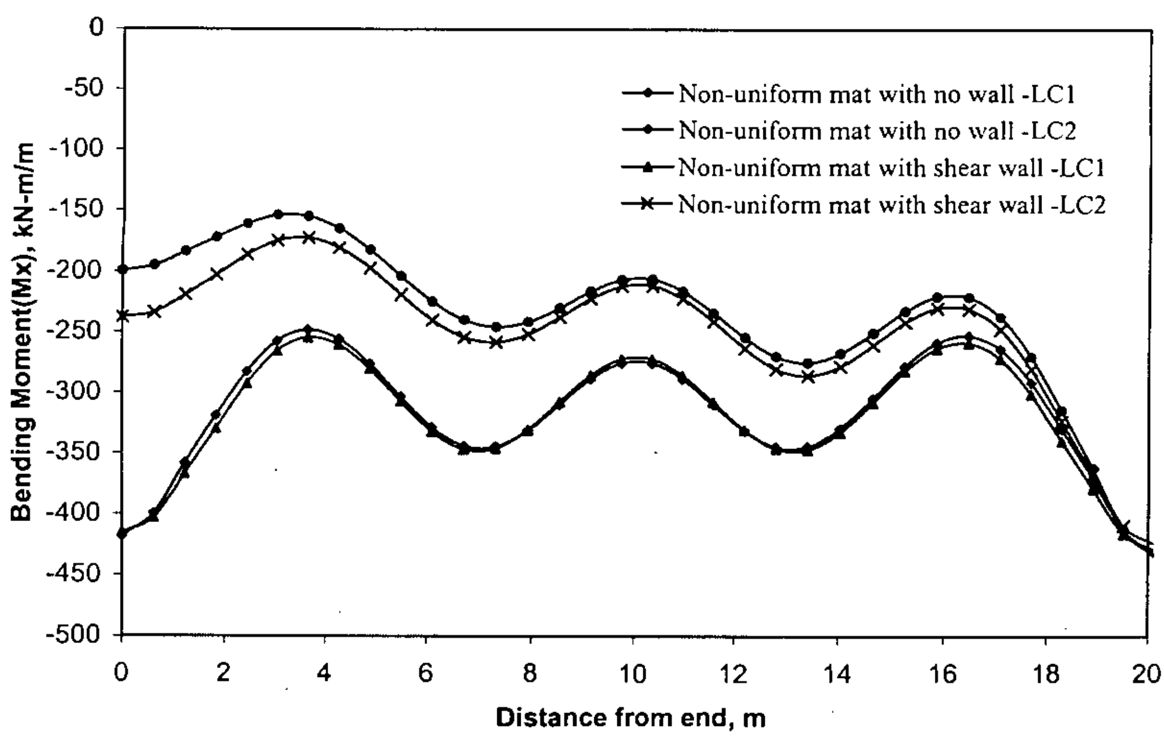

Fig.5.12b Variation in negative moment along mid of the panel situated one panel away from shear wall for non-uniform mat of model-A (along Line-4).

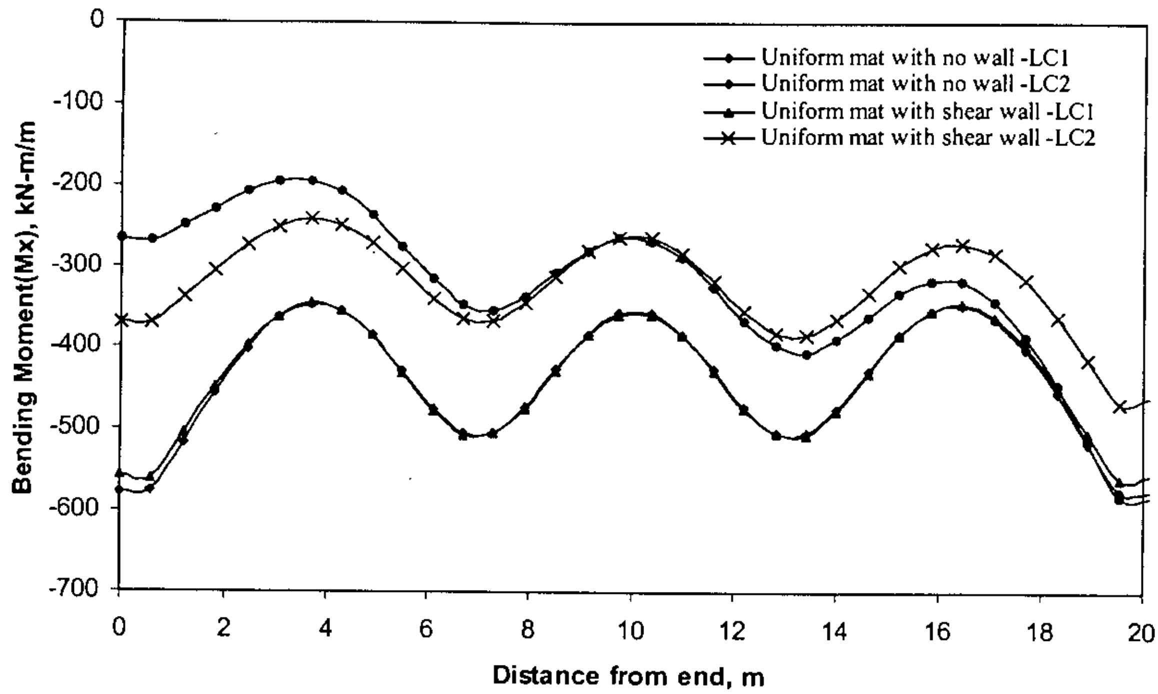

Fig.5.13a Variation in negative moment along mid of the panel situated one panel away from shear wall for uniform mat of model-B (along Line-4).

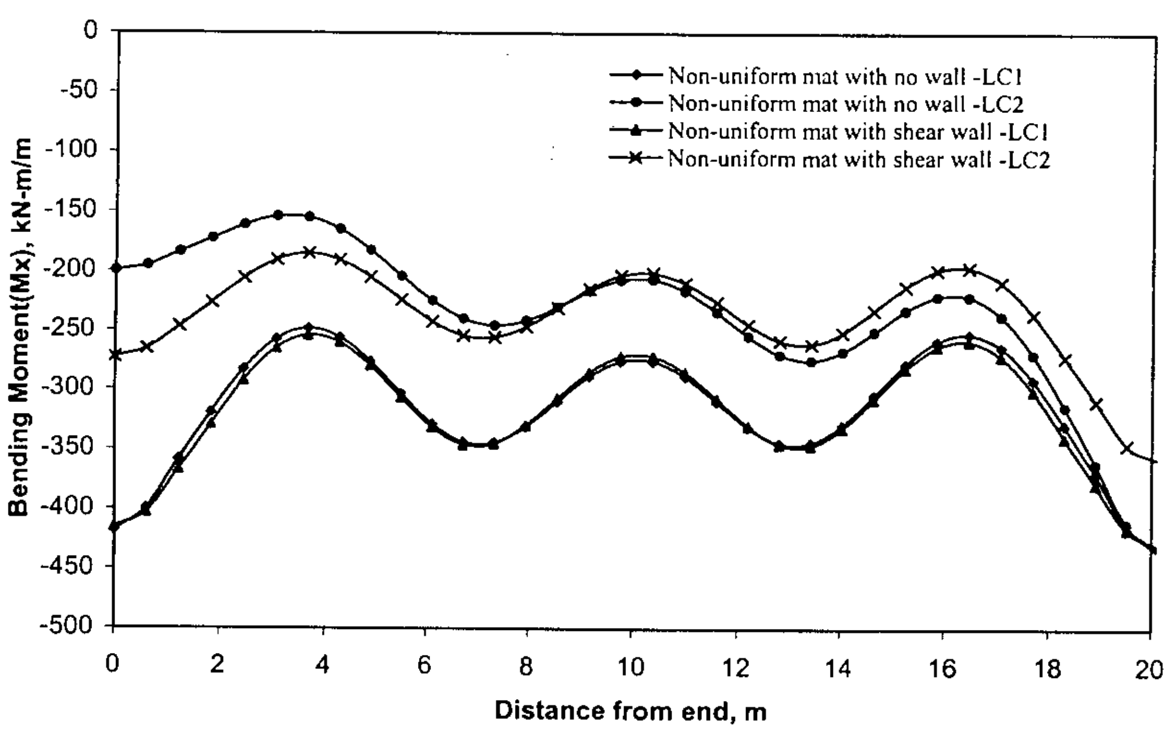

Fig.5.13b Variation in negative moment along mid of the panel situated one panel away from shear wall for non-uniform mat of model-B (along Line-4).

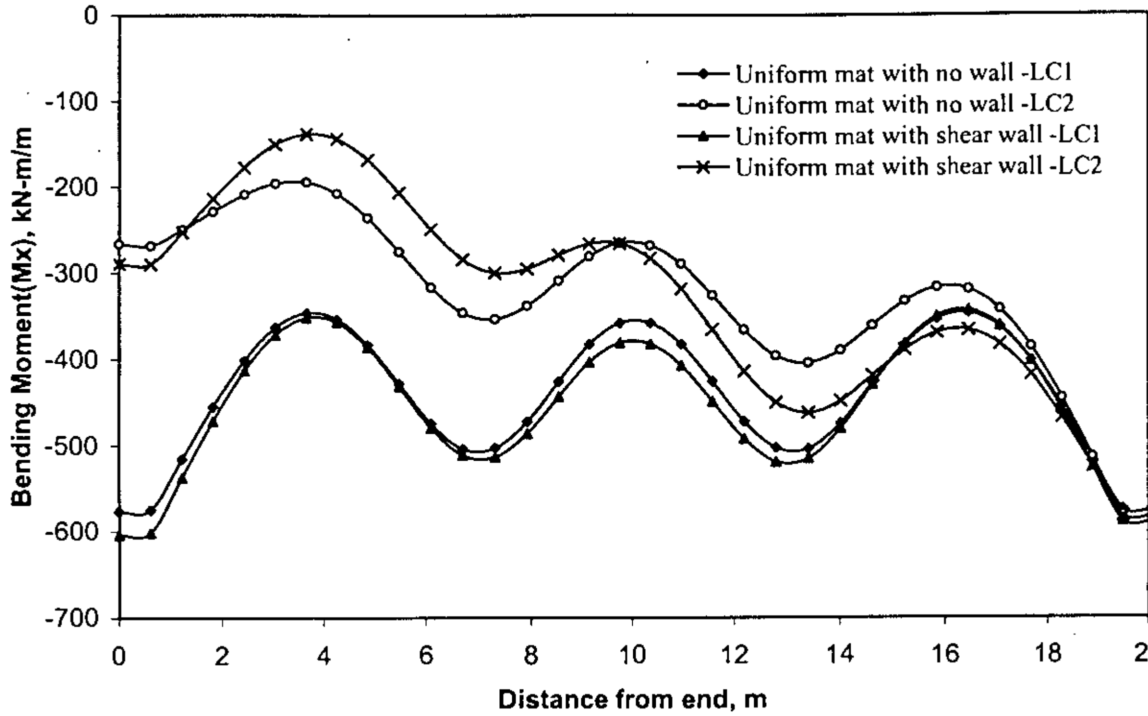

Fig.5.14a Variation in negative moment along mid of the panel situated one panel away from shear wall for uniform mat of model-C (along Line-6).

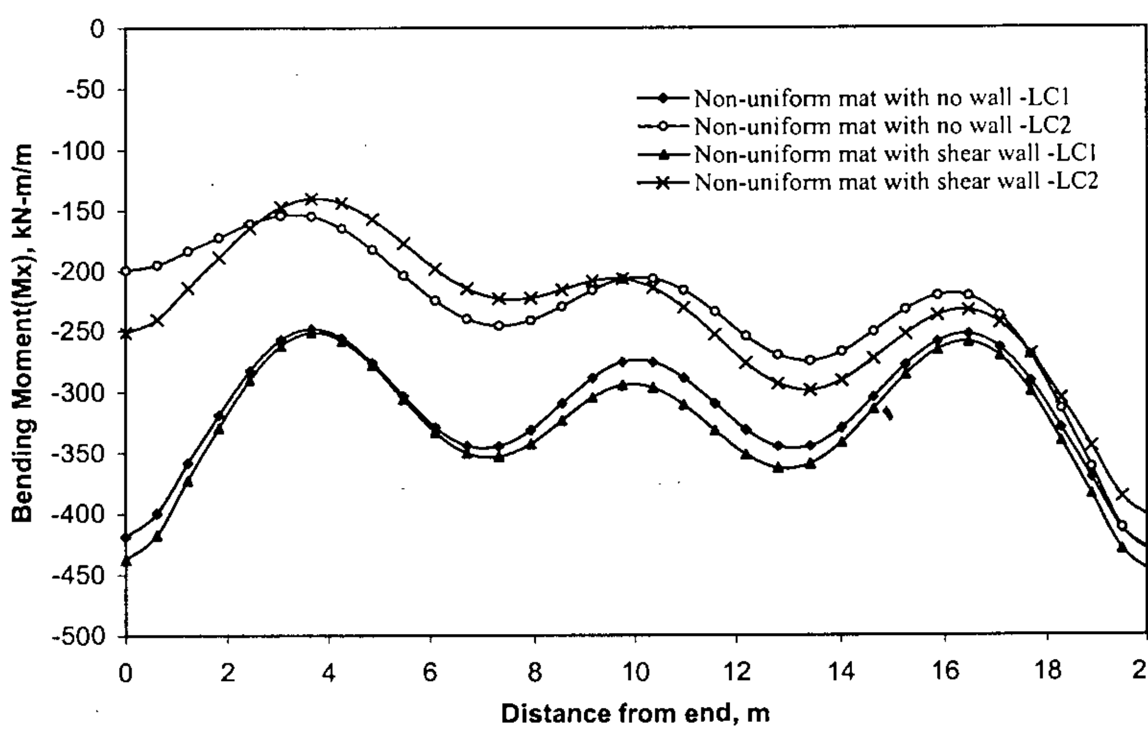

Fig.5.14b Variation in negative moment along mid of the panel situated one panel away from shear wall for non-uniform mat of model-C(along Line-6).

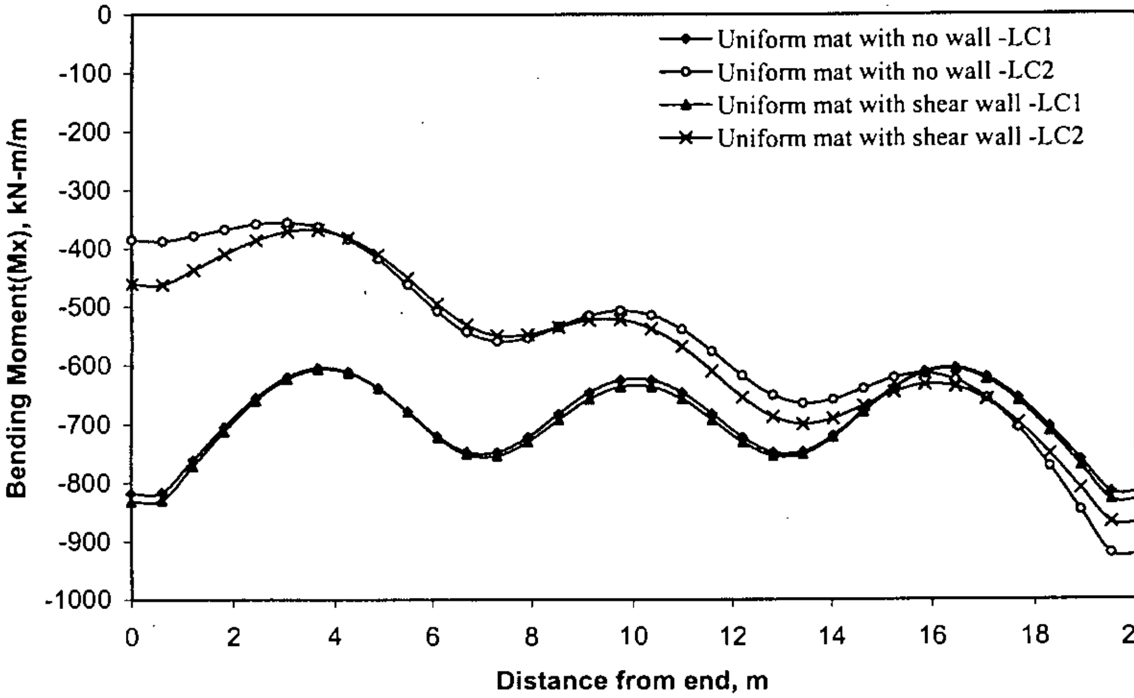

Fig.5.15a Variation in negative moment along mid of the panel situated one panel away from shear wall for uniform mat of model-D (along Line-2).

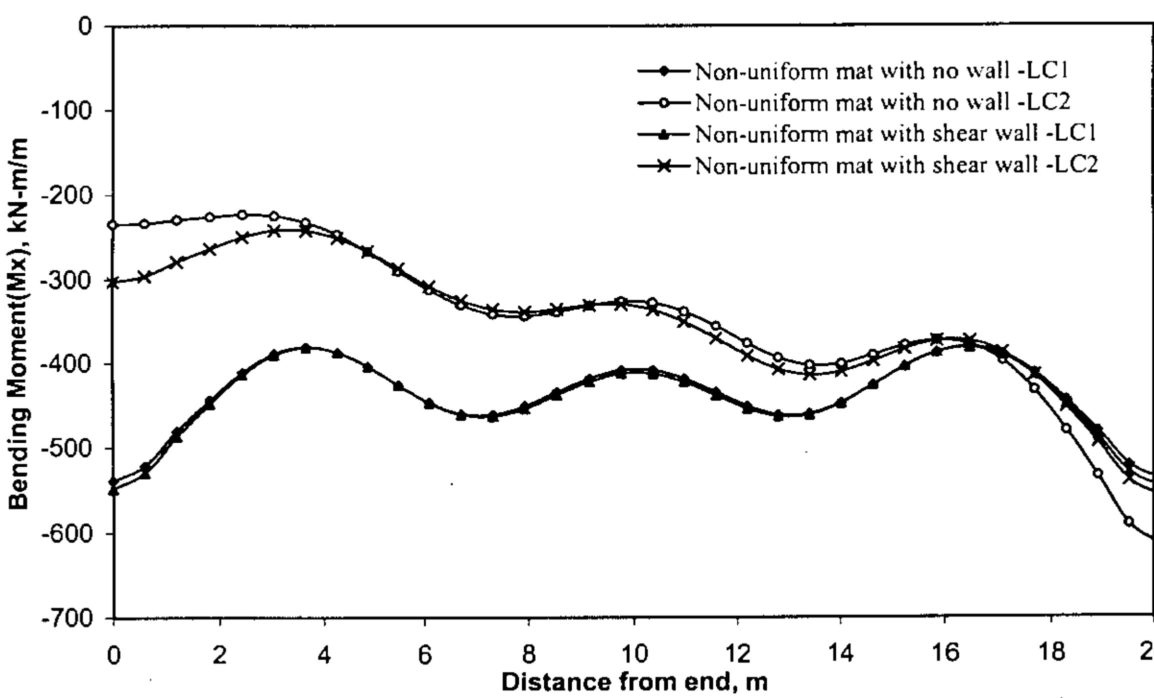

Fig.5.15b Variation in negative moment along mid of the panel situated one panel away from shear wall for non-uniform mat of model-D (along Line-2).

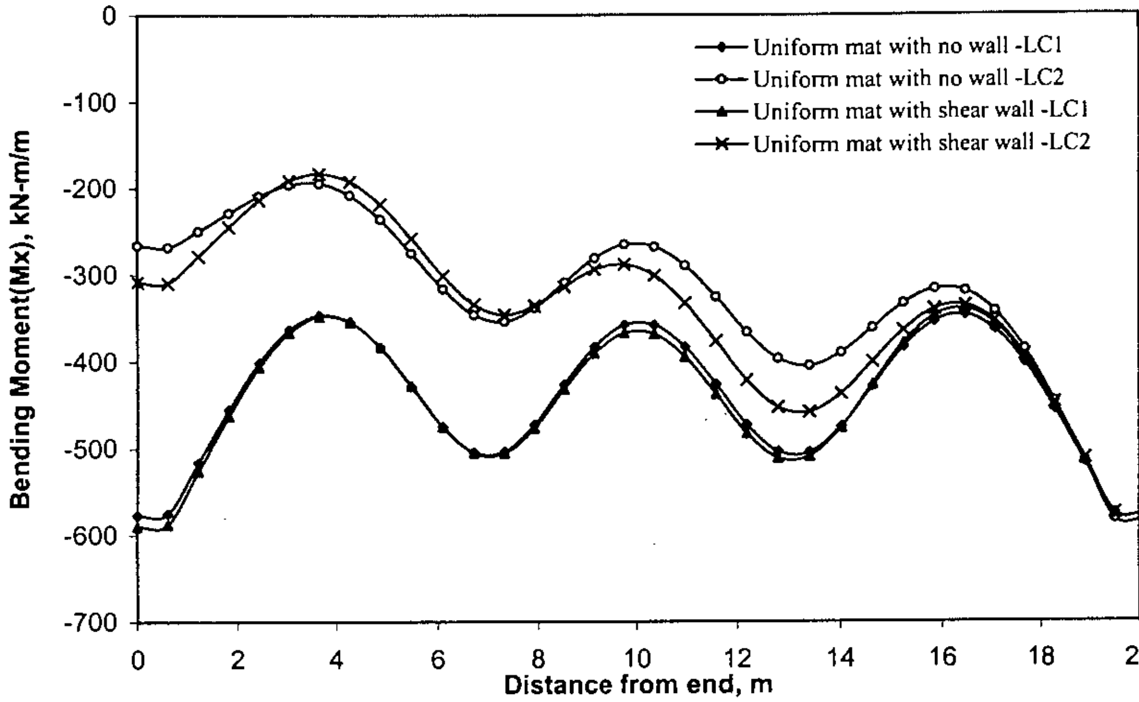

Fig.5.16a Variation in negative moment along mid of the panel situated one panel away from shear wall for uniform mat of model-E.(along Line-6).

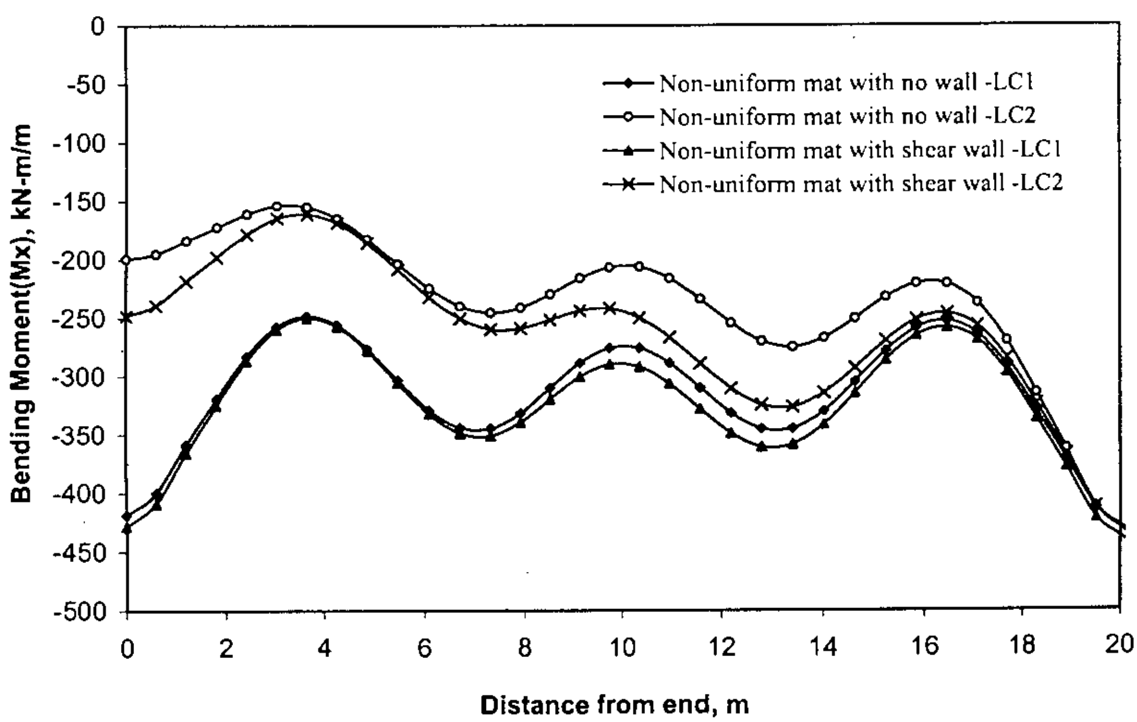

Fig.5.16b Variation in negative moment along mid of the panel situated one panel away from shear wall for non-uniform mat of model-E (along Line-6).

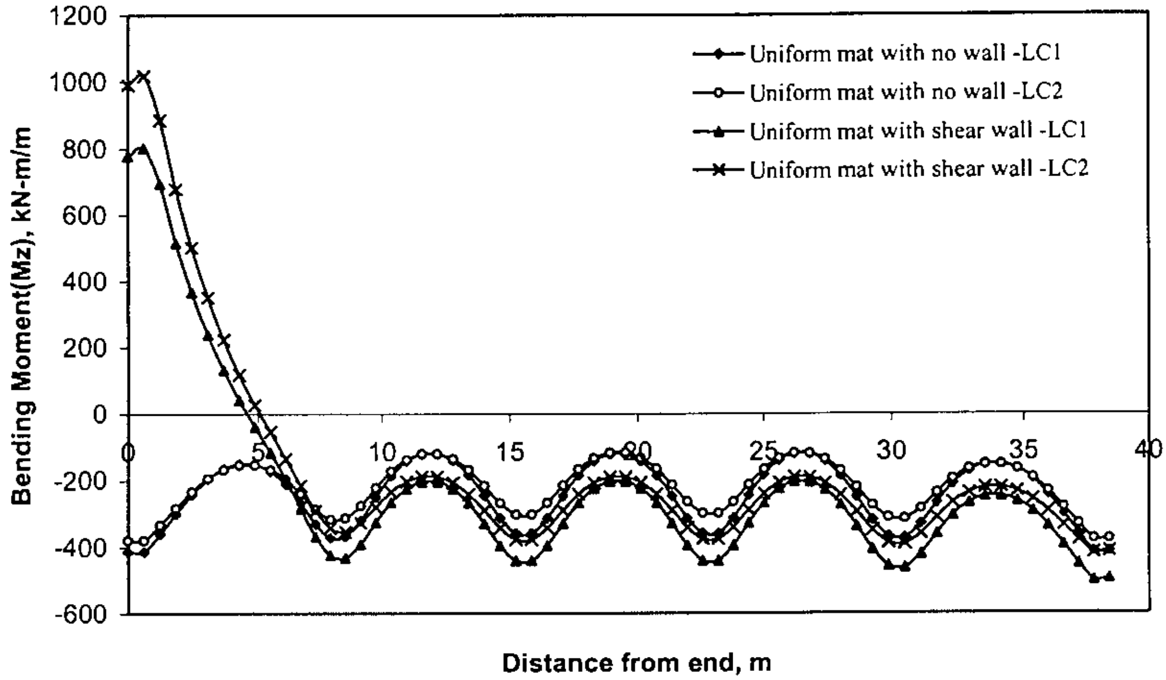

Fig.5.17a Variation in moment along line transverse to shear wall for uniform mat of model-A (along Line-15).

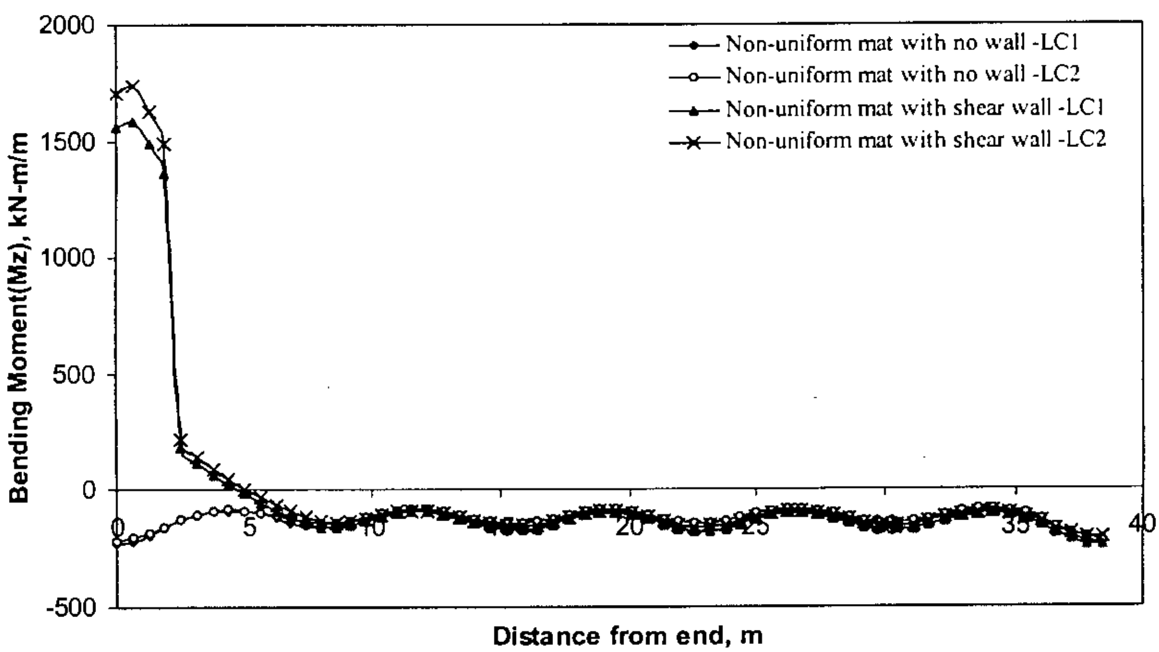

Fig.5.17b Variation in moment along line transverse to shear wall for non-uniform mat of model-A (along Line-15).

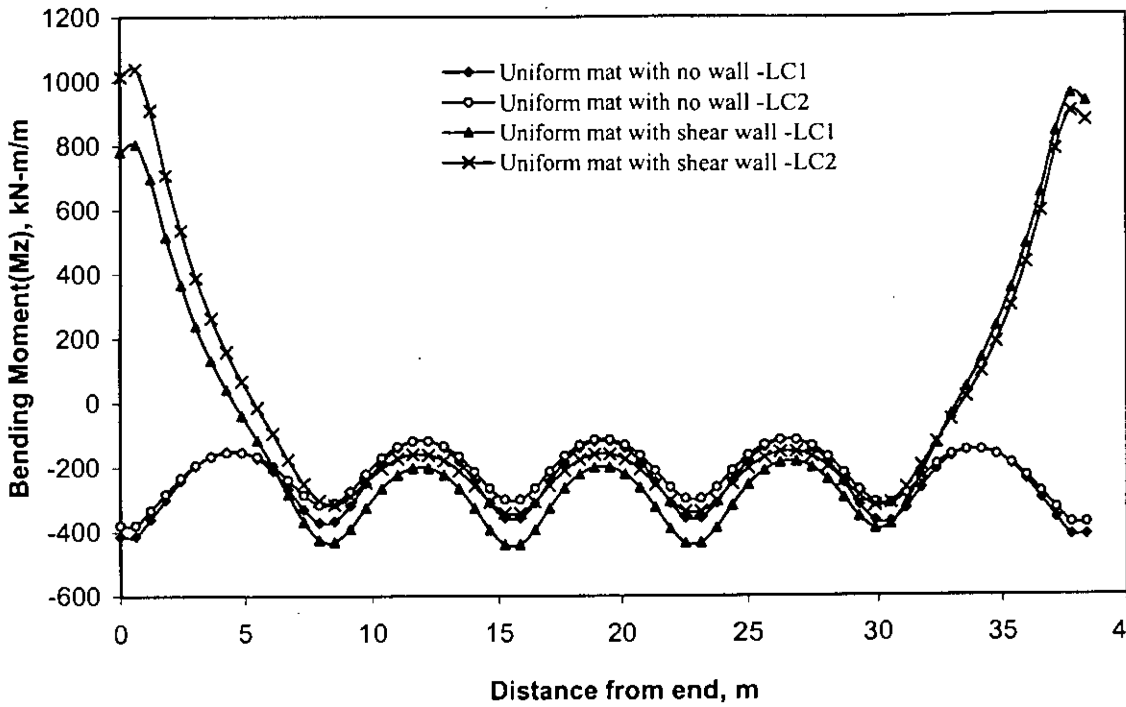

Fig.5.18a Variation in moment along line transverse to shear wall for uniform mat of model-B (along Line-15).

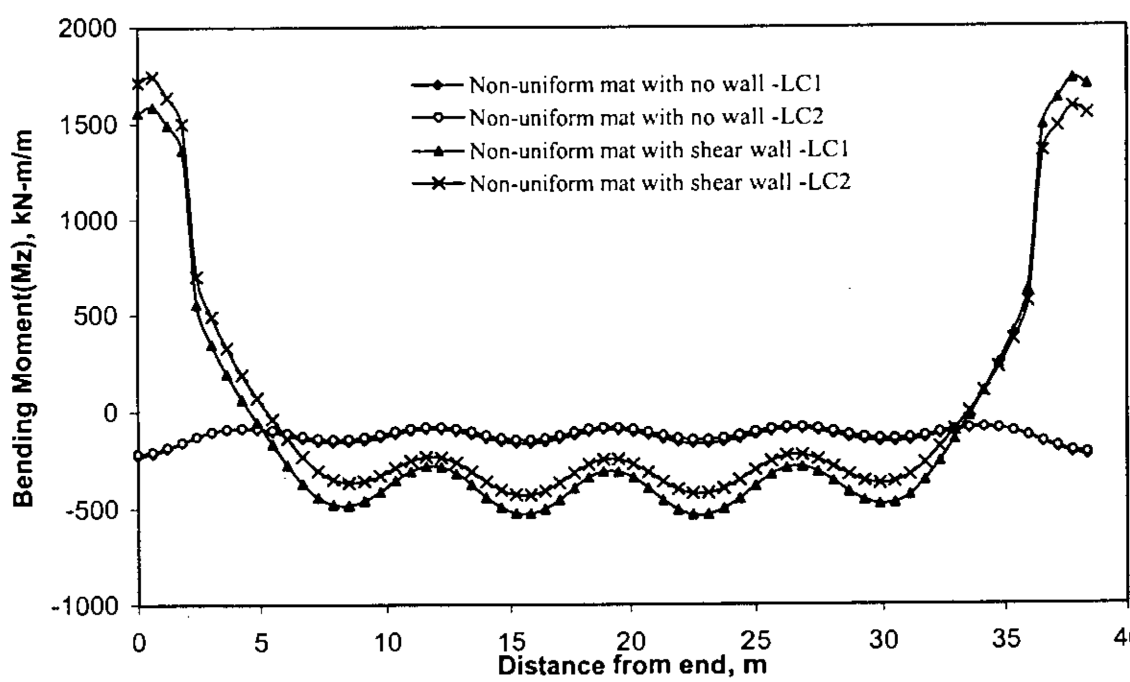

Fig.5.18b Variation in moment along line transverse to shear wall for non-uniform mat of model-B (along Line-15).

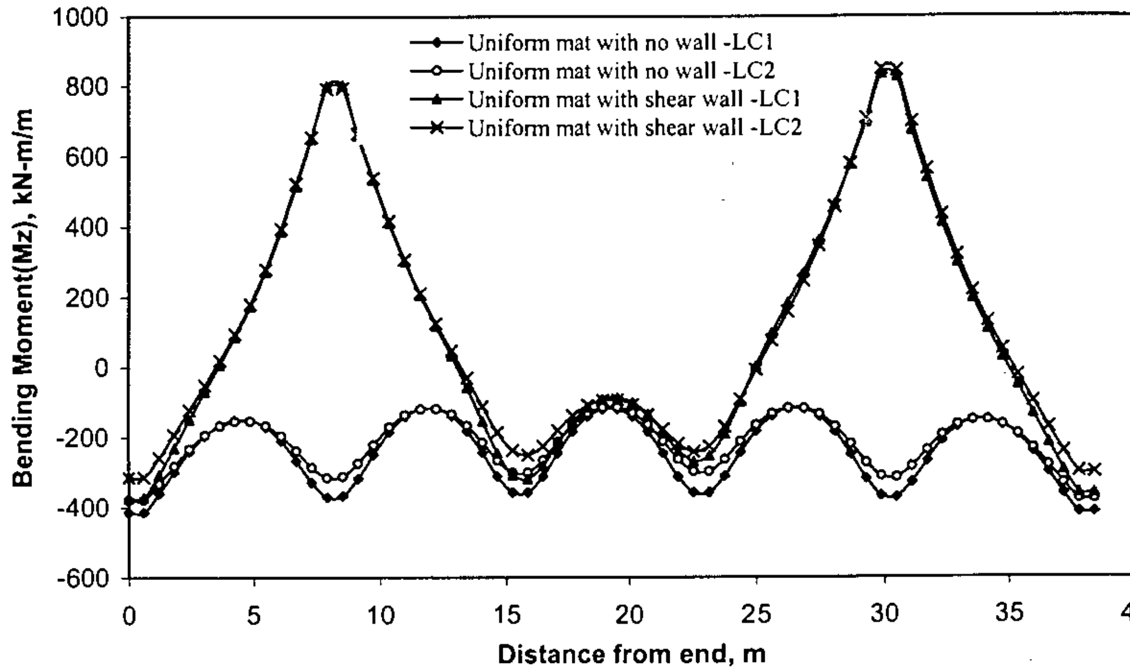

Fig.5.19a Variation in moment along line transverse to shear wall for uniform mat of model-C (along Line-15).

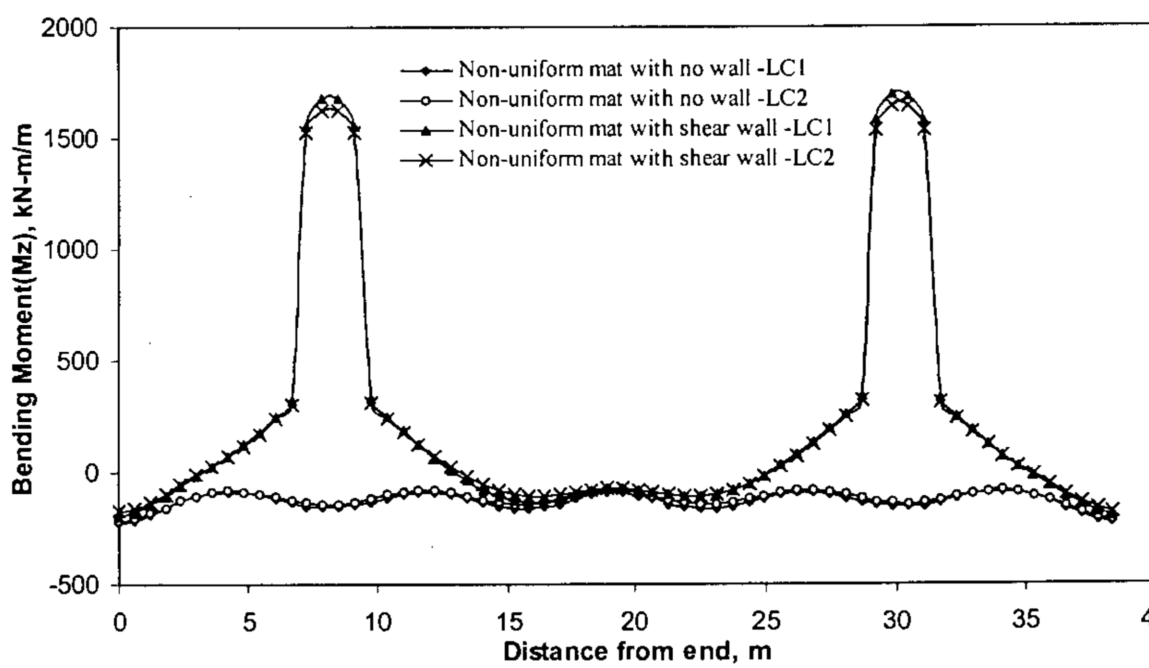

Fig.5.19b Variation in moment along line transverse to shear wall for non-uniform mat of model-C (along Line-15).

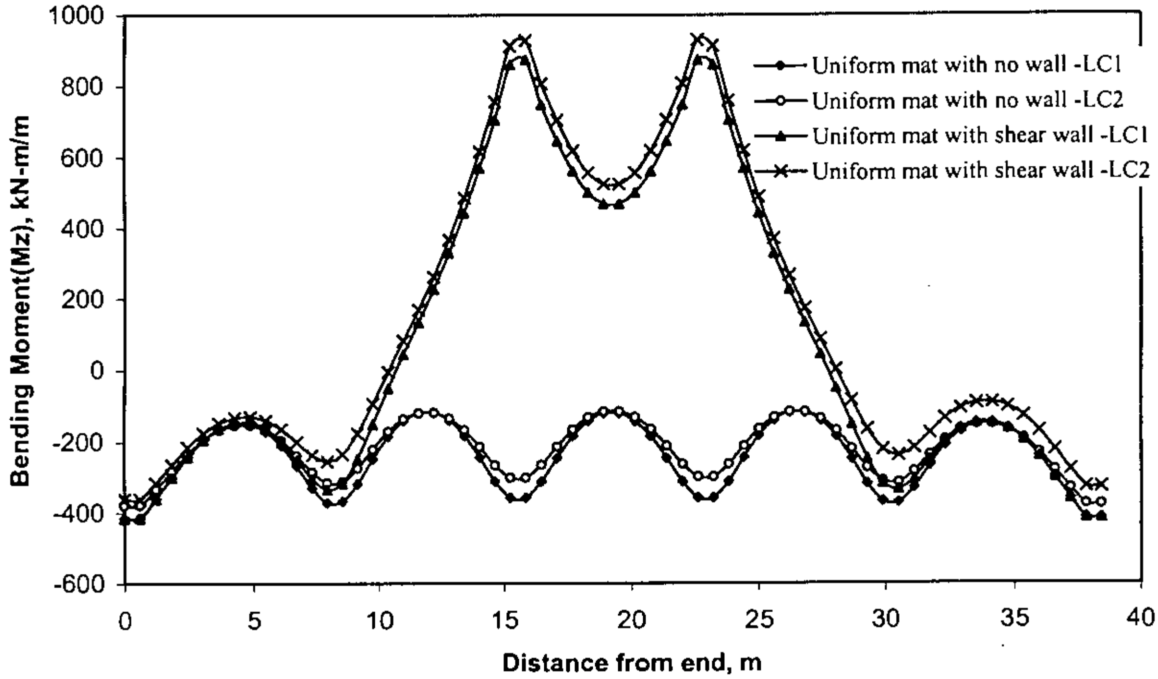

Fig.5.20a Variation in moment along line transverse to shear wall for uniform mat of model-D (along Line-15).

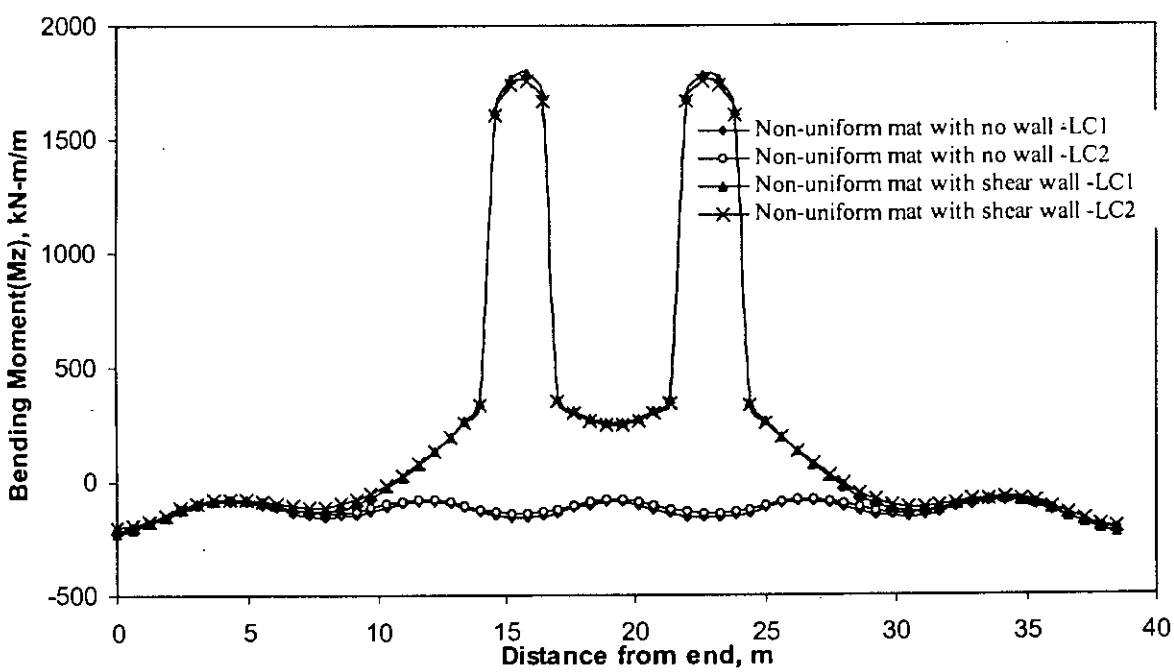

Fig.5.20b Variation in moment along line transverse to shear wall for non-uniform mat of model-D (along Line-15).

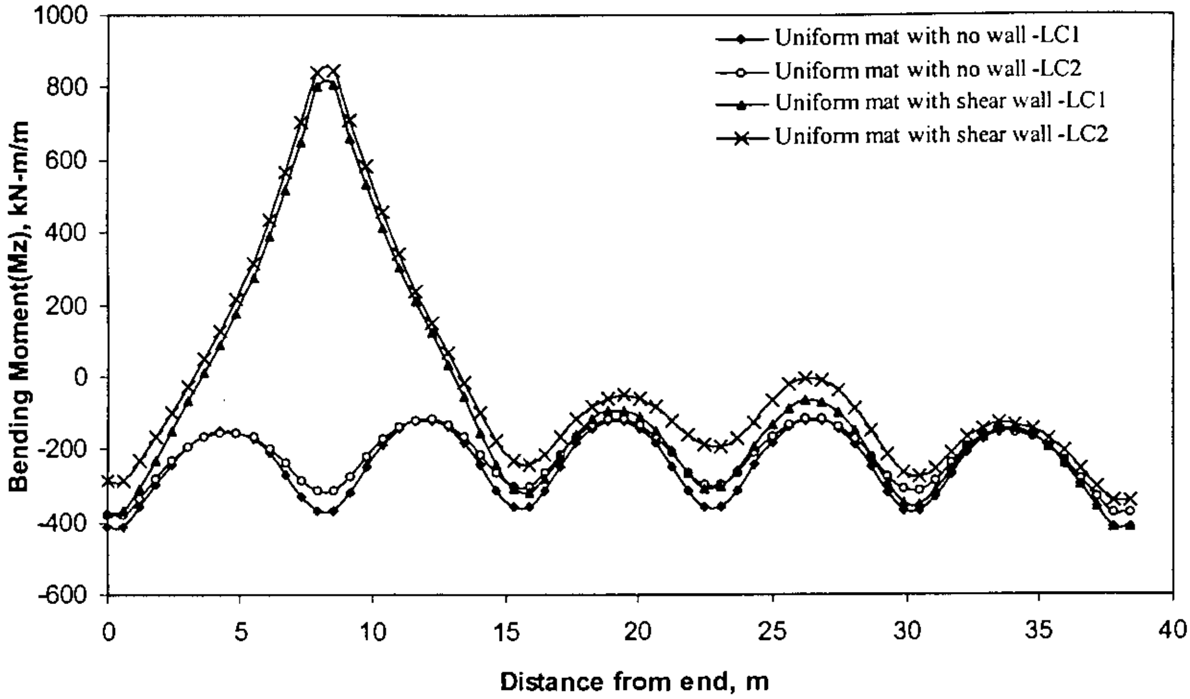

Fig.5.21a Variation in moment along line transverse to shear wall for uniform mat of model-E (along Line-15).

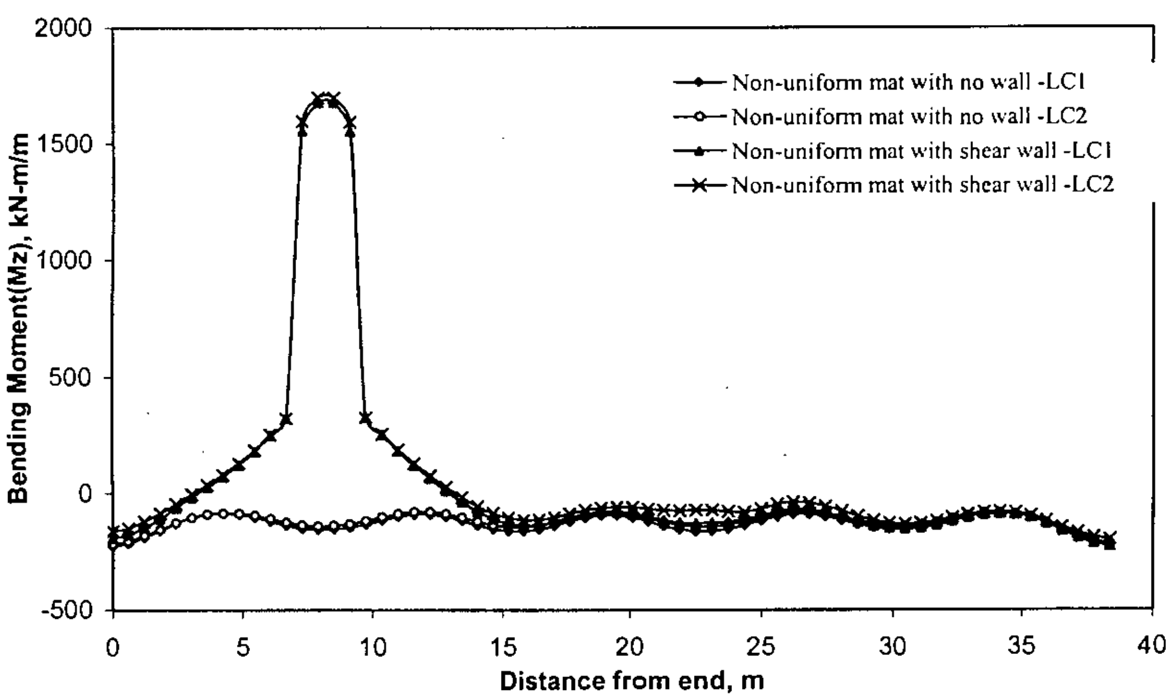

Fig.5.21b Variation in moment along line transverse to shear wall for non-uniform mat of model-E (along Line-15).

Table 5.4 Maximum Positive Moment for Mat at the Face of Shear Wall.

	Maximum Positive Moment at Face of Shear Wall, kN-m/m		Moment Capacity* At the Section with Minimum Reinf., kN-m/m
	Uniform Thickness	Non-uniform Thickness	
Model-A	1863.6	2817.2	1062.6
Model-B	1634.5	2505.1	1062.6
Model-C	1050.4	1856.0	1062.6
Model-D	1184.8	1987.4	1062.6
Model-E	1291.0	1789.4	1062.6

*f'_c = 27.6 MPa , f_y = 414 MPa

Table 5.5 Variation in Positive Moment along Column Line parallel and next to Shear Wall Line.

		Positive Moment at Face of Column, kN-m/m			
		Uniform mat		Non-uniform mat	
		Load case-1	Load case-2	Load case-1	Load case-2
Model A	Exterior column	1021.1	779.1	1626.2	1028.0
	1st Interior column	1279.2	1214.0	2059.6	1790.5
Model B	Exterior column	876.6	594.6	1520.3	902.7
	1st Interior column	1279.7	1138.5	2057.8	1703.9
Model C	Exterior column	1034.3	663.4	1482.2	895.1
	1st Interior column	1461.9	1193.4	2034.9	1633.7
Model D	Exterior column	1005.9	627.4	1564.7	950.2
	1st Interior column	1435.1	1137.3	2144.7	1715.0
Model E	Exterior column	1039.4	665.3	1484.5	918.9
	1st Interior column	1464.0	1200.9	2034.7	1662.8

5.4 VARIATION IN SHEAR STRESS FOR THE PRESENCE OF SHEAR WALL

One of the most important design criteria for mat foundation is the shear force. Since mat is a plate structure, shear reinforcements is avoided from practical considerations. Instead, mat is made sufficiently thick to withstand shear. Presence of heavy column loads concentrated on very small areas makes considerations of punching shear, in addition to flexural shear, essential. Previous study by Morshed (1996) revealed that punching shear does not change much with variation of different parameters. The greater thickness of the mat used for analysis was chosen based on punching. So flexural shear for the mat needs to be studied.

Mat is a slab type structure, local failure due to flexural shear cannot occur. For a failure due to flexural shear, it must occur along a line across the width. So total shear force produced along the face of shear wall for entire width in different location of shear wall is shown with the shear force capacity in Table 5.9.

Variation of shear stress are given in Fig.5.22 to Fig.5.36. Variation along the other lines shown in Appendix-D.

- Variation in shear stress along the line between column lines is well within the shear stress capacity of the mat for any location and number of shear wall. This change in mid panel shear stress is not pronounced for either uniform or non-uniform thickness mat. Table 5.6 shows the variation at the mid panel adjacent to shear wall line. Values in the table shows that the shear stress in mid panel is much lower that shear stress capacity of the section for all the case.

- Significant variation in shear stress occurs along the column face and at the face of shear walls.

- Variation in shear stress is much higher for the load case-2 than the shear stress produced by load case-1. So lateral load produces a significant change in shear stress.

- Shear Stresses at the face of shear wall are higher than the shear stress capacity of the section at some points. But table 5.9 shows that total shear force of the entire width along the face of wall is higher than the produced shear force from the superimposed loading.

Table 5.6 Variation in Shear Stress for **Uniform** Thickness Mat along Short Direction.

	Shear Stress at Face of Shear Wall, kN/m²		**Maximum Shear Stress at Mid Span of Panel Adjacent Shear wall, kN/m²**		**Flexural Shear Stress Capacity*, kN/m²**
	Load Case-1	Load Case-2	Load Case-1	Load Case-2	
Model-A	421.8	1133.9	125.6	196.9	741.2
Model-B	421.3	1009.6	124.9	180.0	741.2
Model-C	551.9	675.8	139.3	159.6	741.2
Model-D	565.7	1037.9	207.7	240.8	741.2
Model-E	552.1	696.2	139.2	173.2	741.2

*f'_c= 27.6 MPa

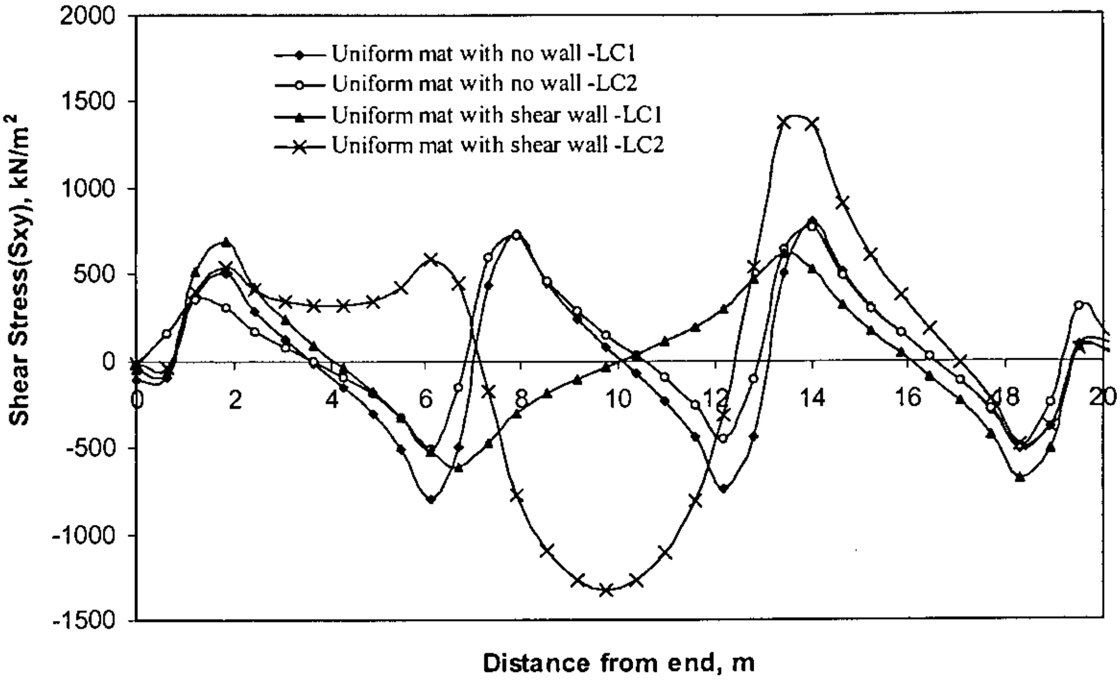

Fig.5.22a Variation in Shear Stress along the face of shear wall for uniform mat of model-A (along line-1)

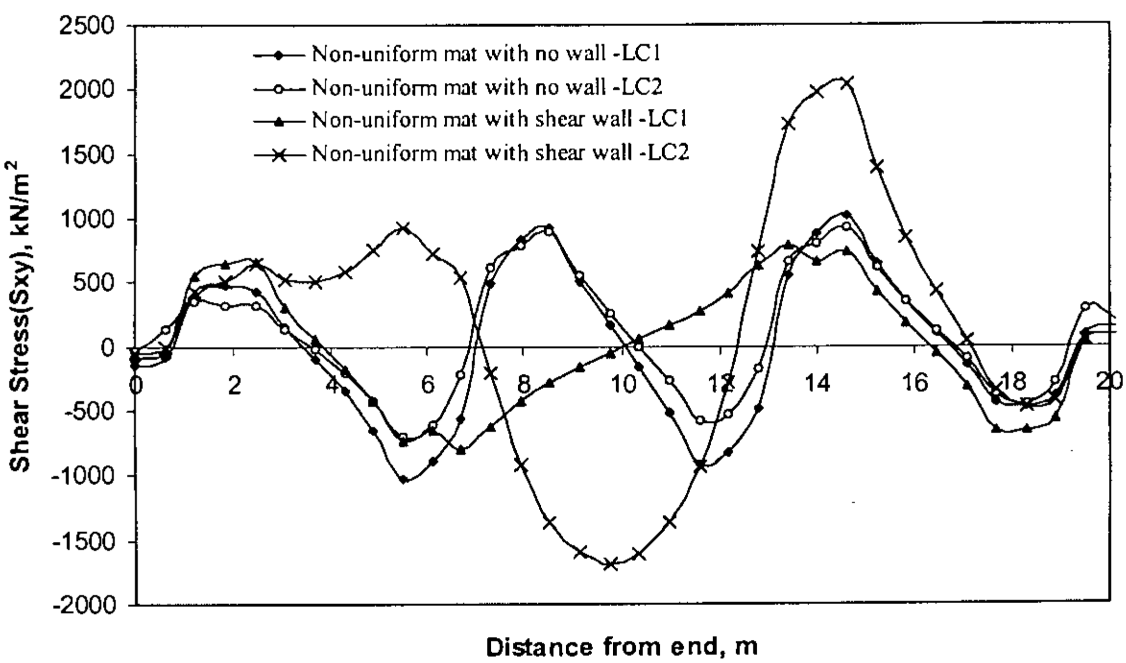

Fig.5.22b Variation in Shear Stress along the face of shear wall for non-uniform mat of model-A (along line-1).

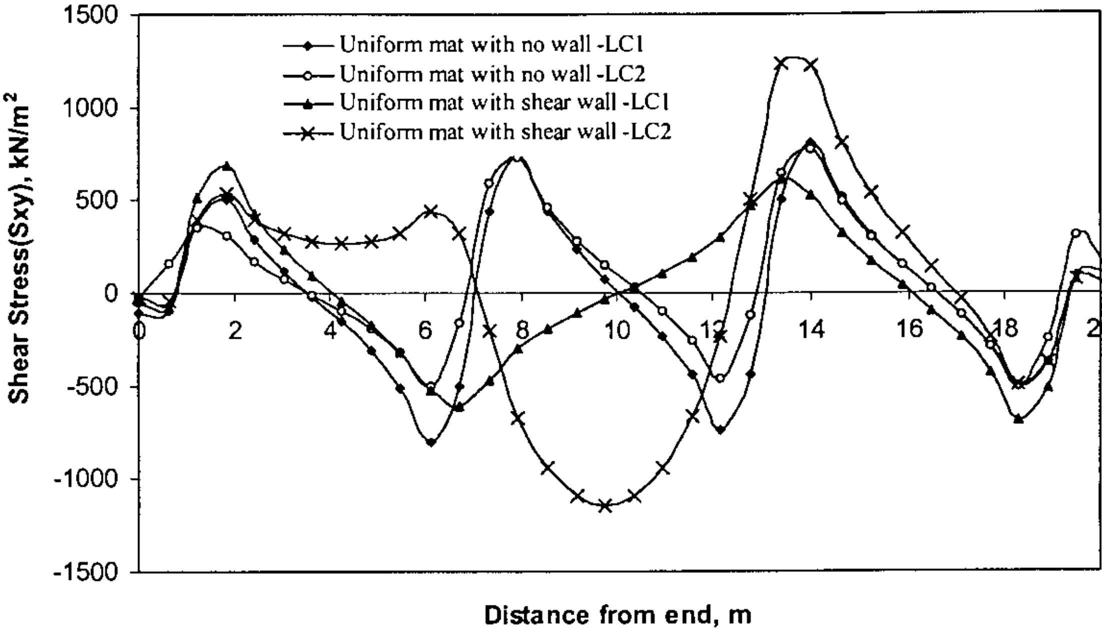

Fig.5.23a Variation in Shear Stress along the face of shear wall for uniform mat of model-B (along line-1).

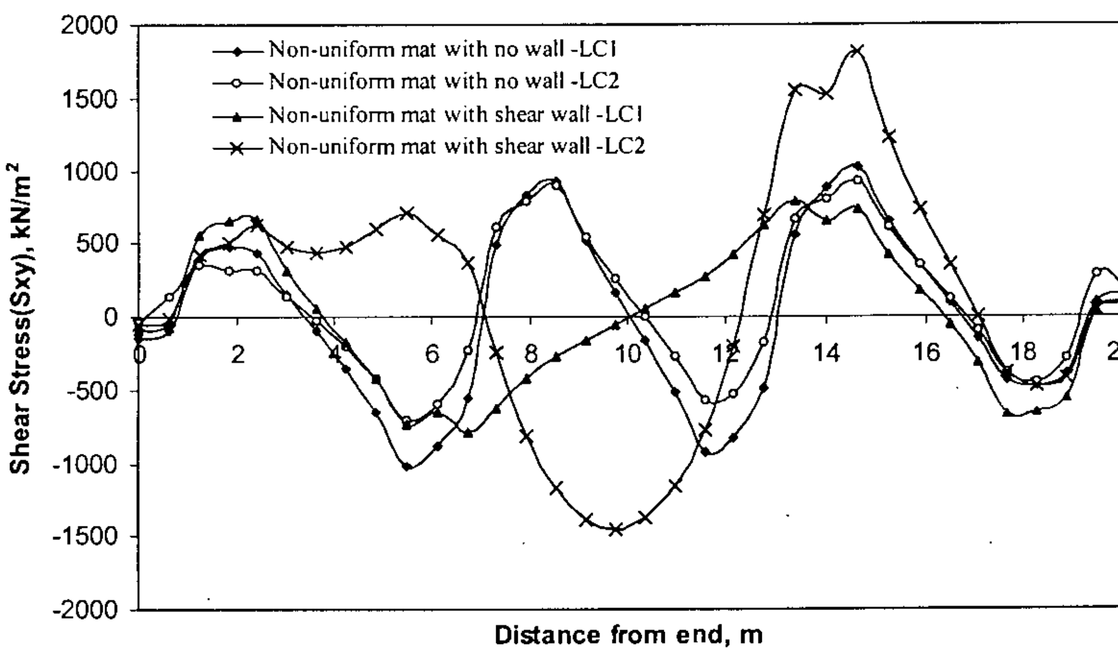

Fig.5.23b Variation in Shear Stress along the face of shear wall for non-uniform mat of model-B (along line-1)

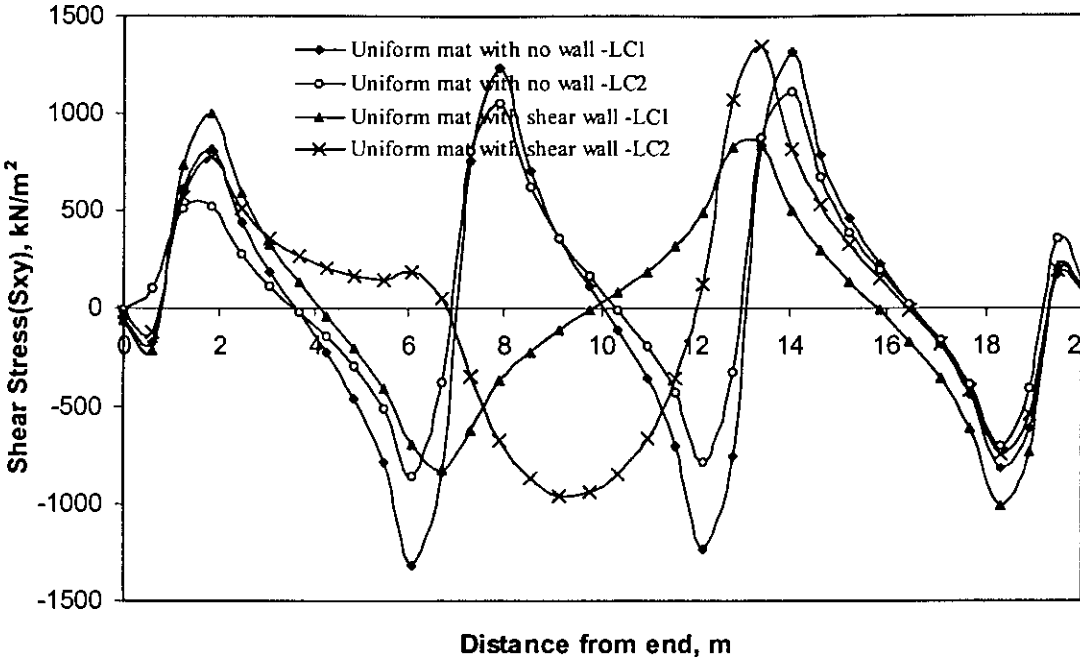

Fig.5.24a Variation in Shear Stress along the face of shear wall for uniform mat of model-C (along line-3)

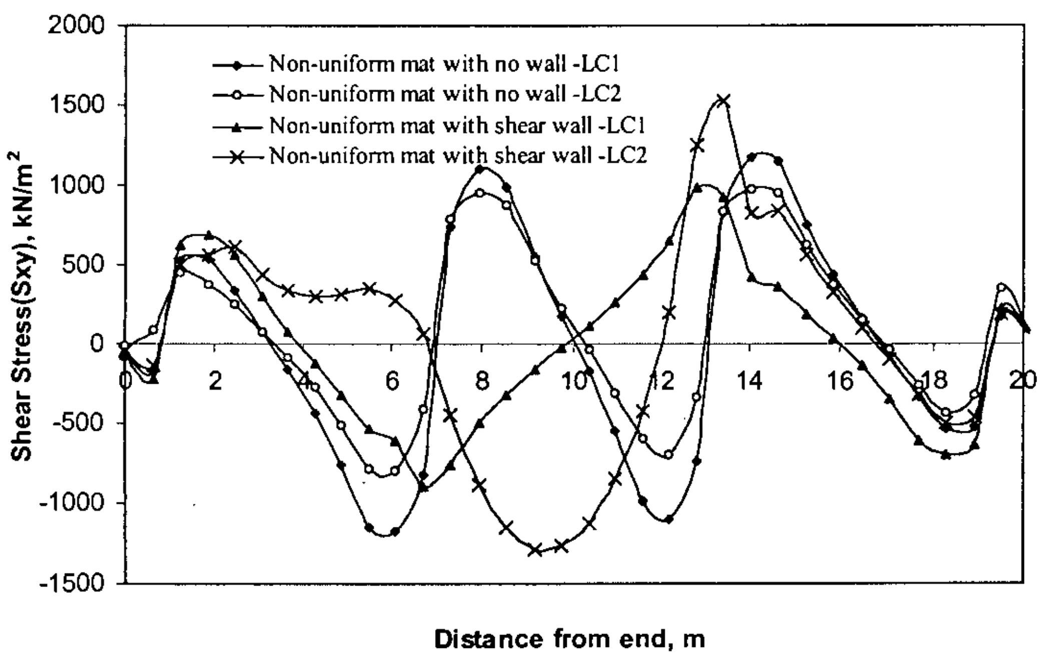

Fig.5.24b Variation in Shear Stress along the face of shear wall for non-uniform mat of model-C (along line-3)

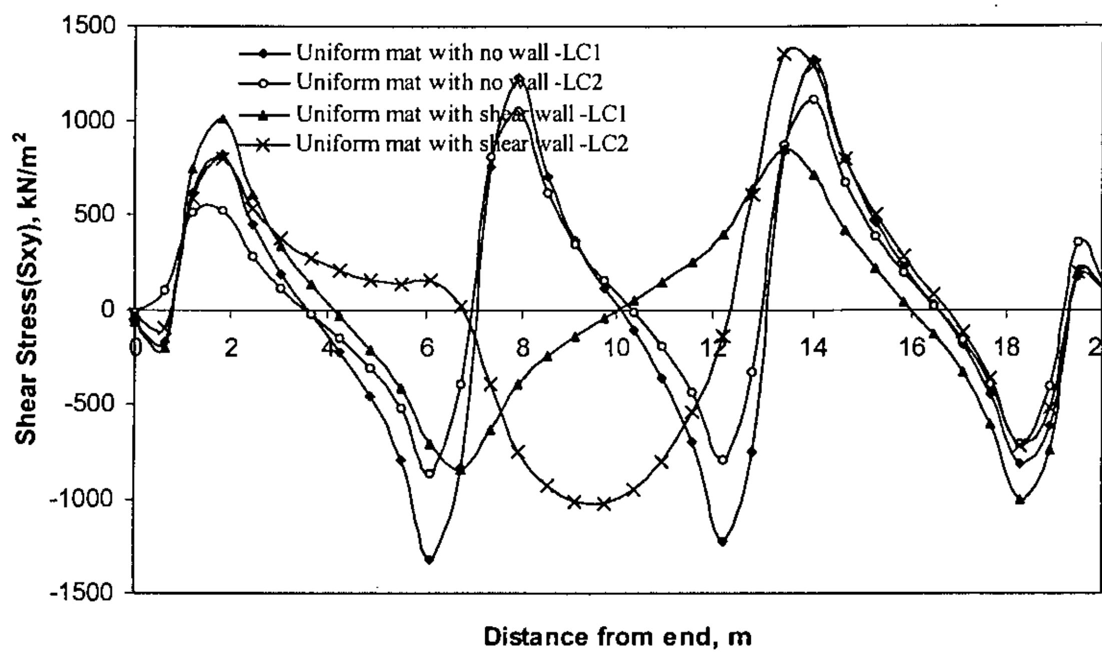

Fig.5.25a Variation in Shear Stress along the face of shear wall for uniform mat of model-D(along line-5)

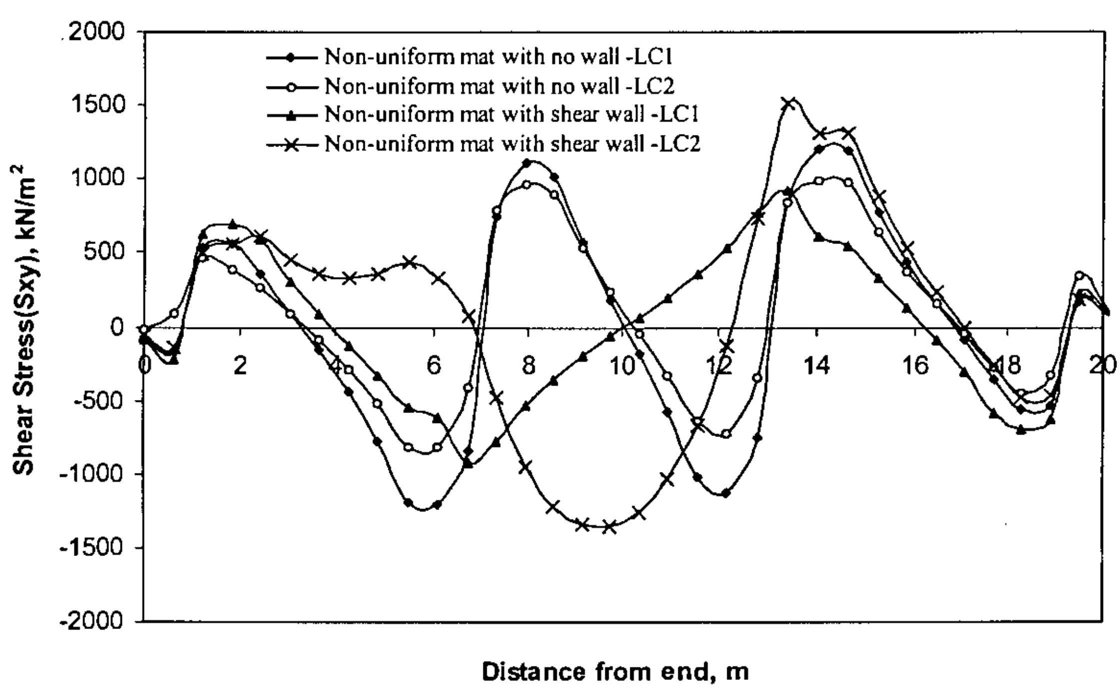

Fig.5.25b Variation in Shear Stress along the face of shear wall for non-uniform mat of model-D (along line-5)

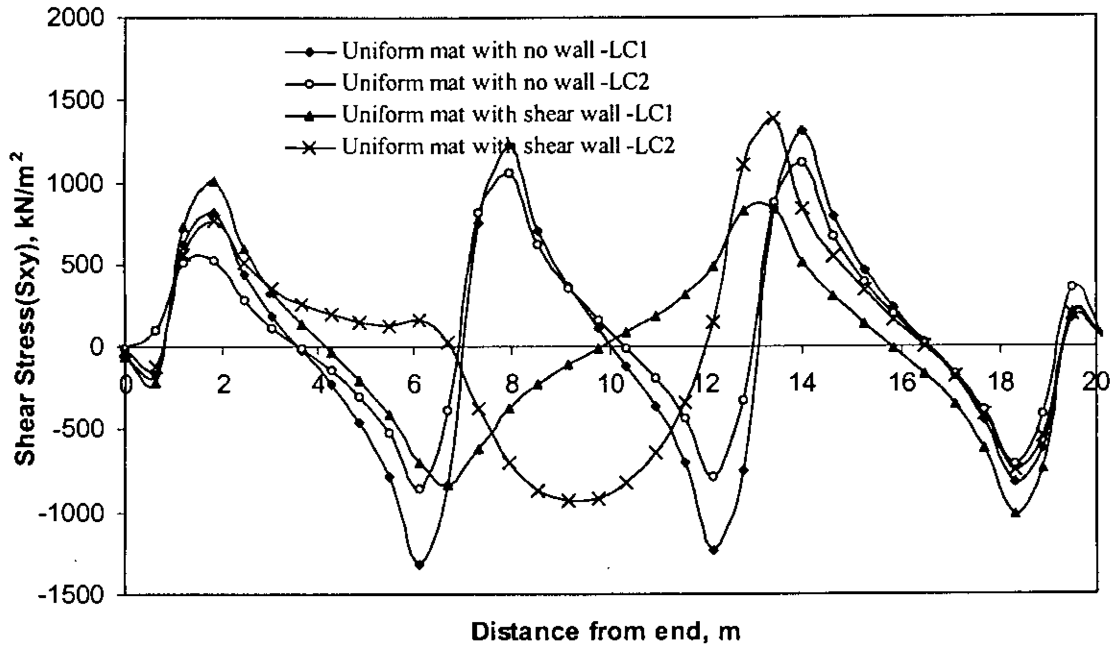

Fig.5.26a Variation in Shear Stress along the face of shear wall for uniform mat of model-E (along line-3)

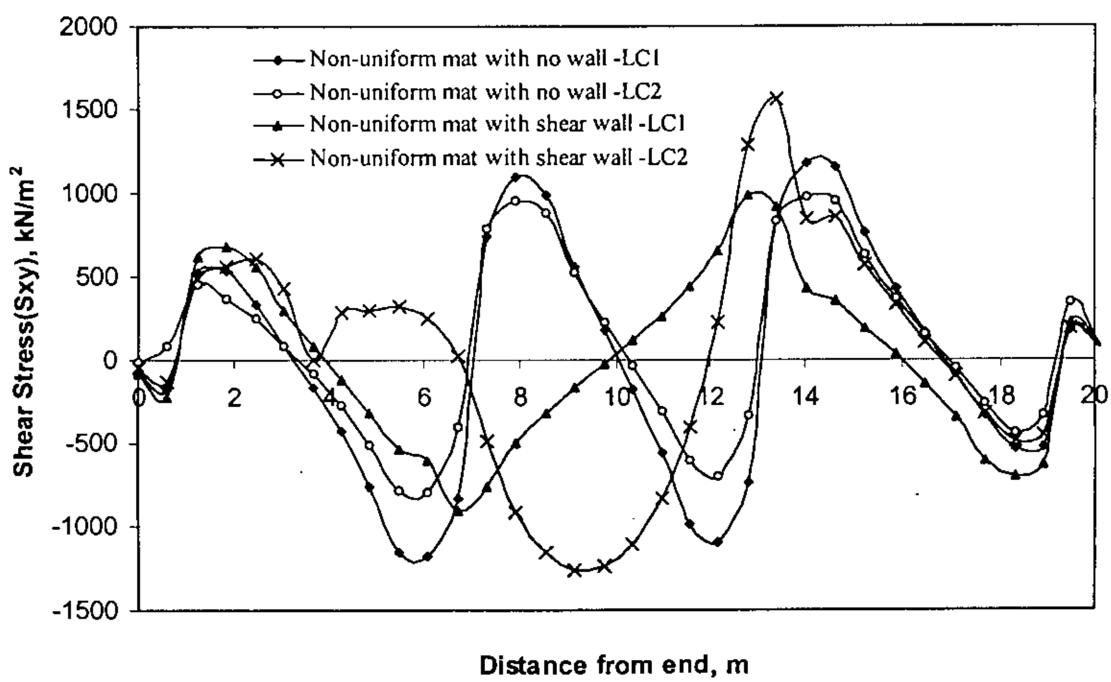

Fig.5.26b Variation in Shear Stress along the face of shear wall for non-uniform mat of model-E (along line-3).

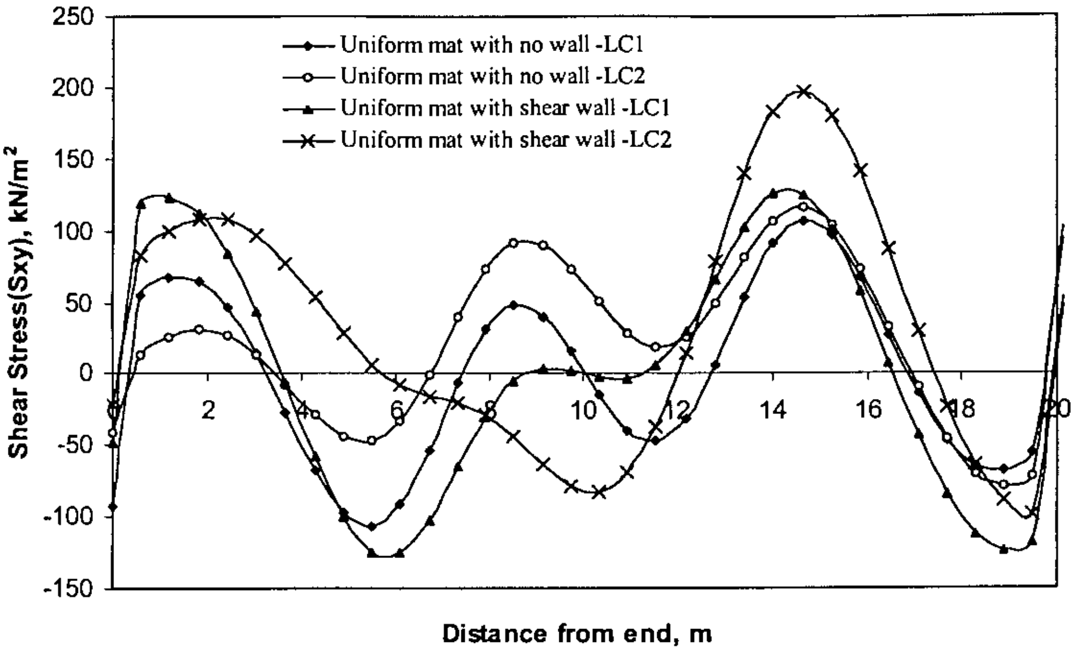

Fig.5.27a Variation in Shear Stress along mid of panel adjacent to shear wall for uniform mat of model-A(along Line-2).

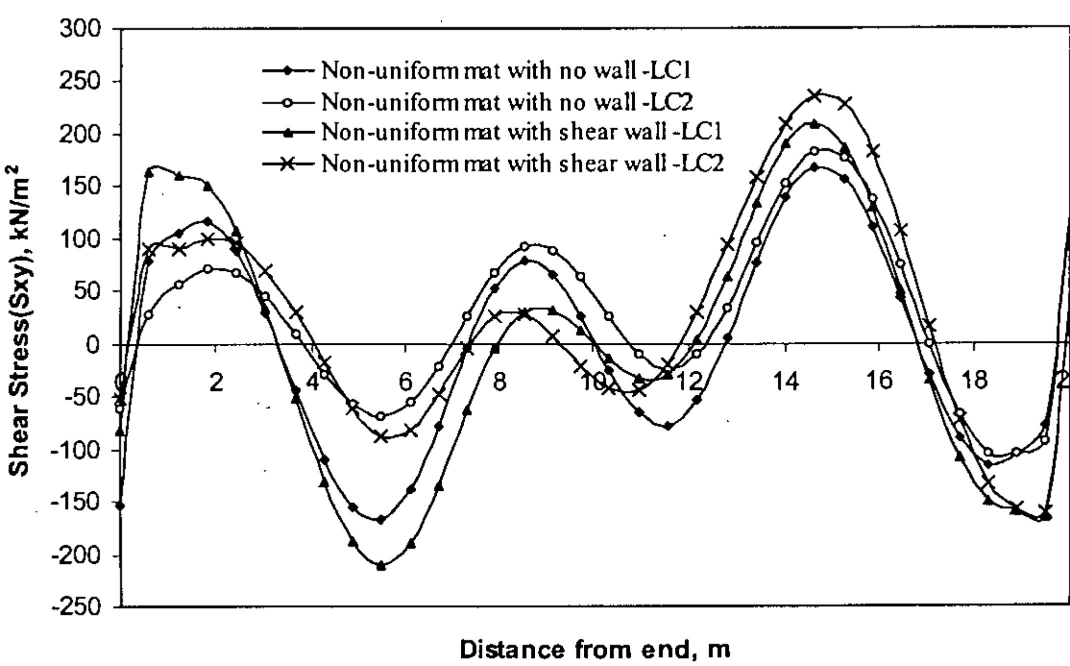

Fig.5.27b Variation in Shear Stress along mid of panel adjacent to shear wall for non-uniform mat of model-A (along Line-2).

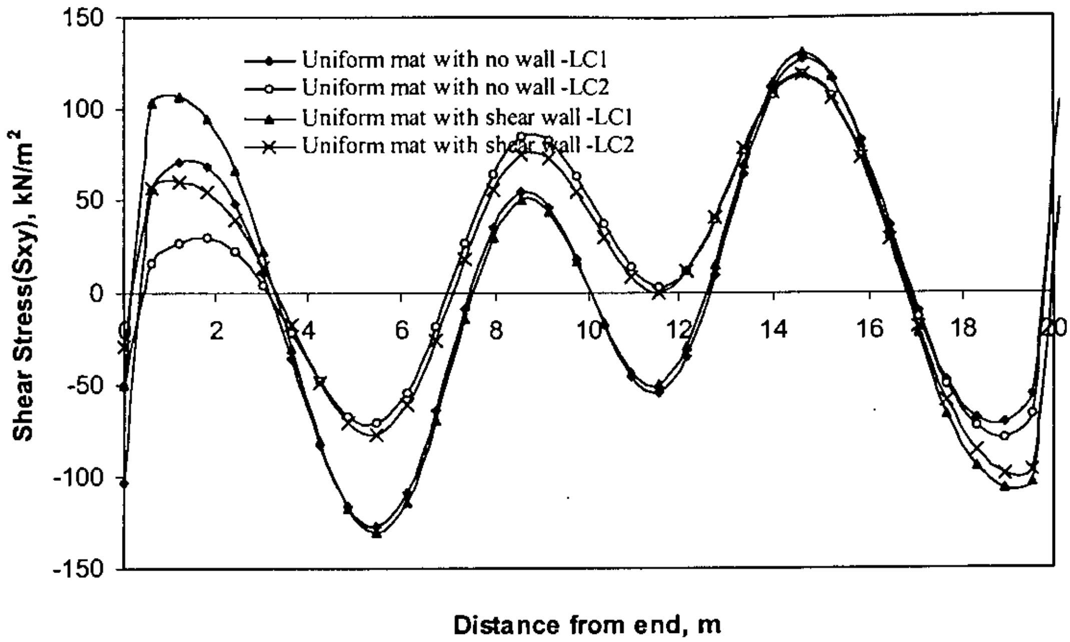

Fig.5.28a Variation in Shear Stress along mid of panel adjacent to shear wall for uniform mat of model-B (along Line-2).

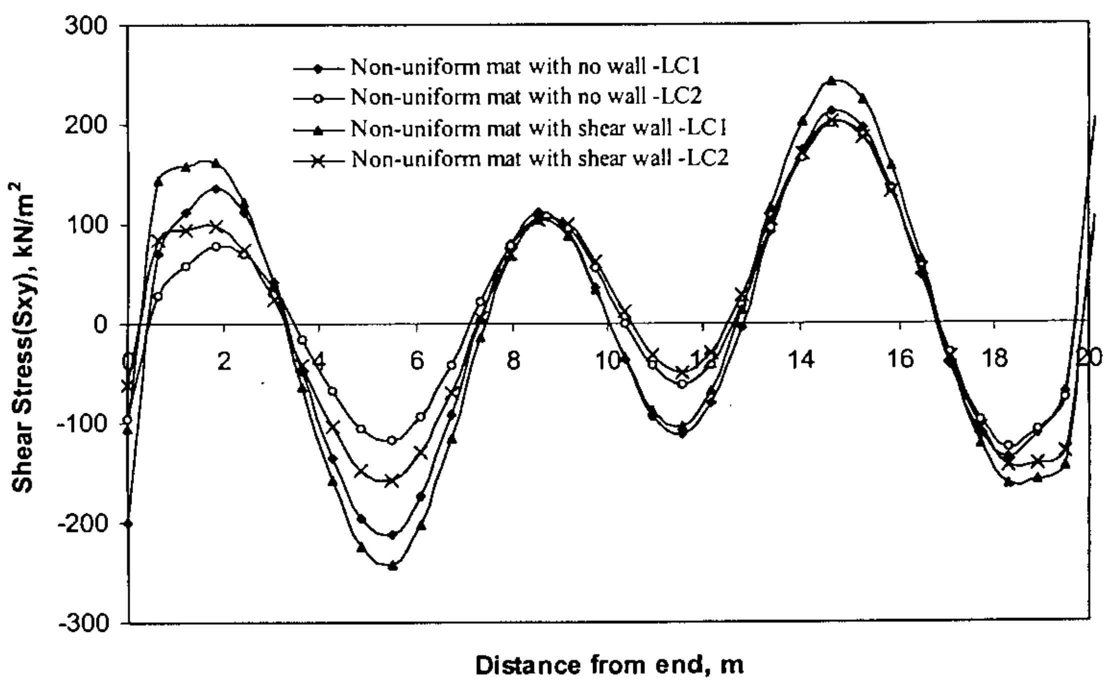

Fig.5.28b Variation in Shear Stress along mid of panel adjacent to shear wall for non-uniform mat of model-B (along Line-2).

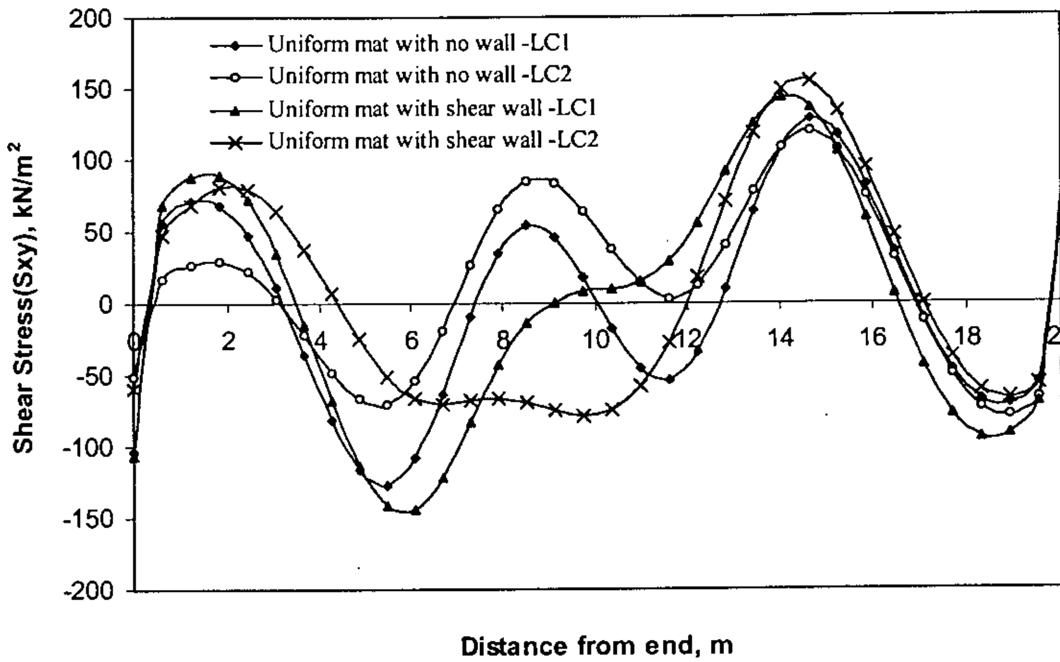

Fig.5.29a Variation in Shear Stress along mid of panel adjacent to shear wall for uniform mat of model-C (along Line-2).

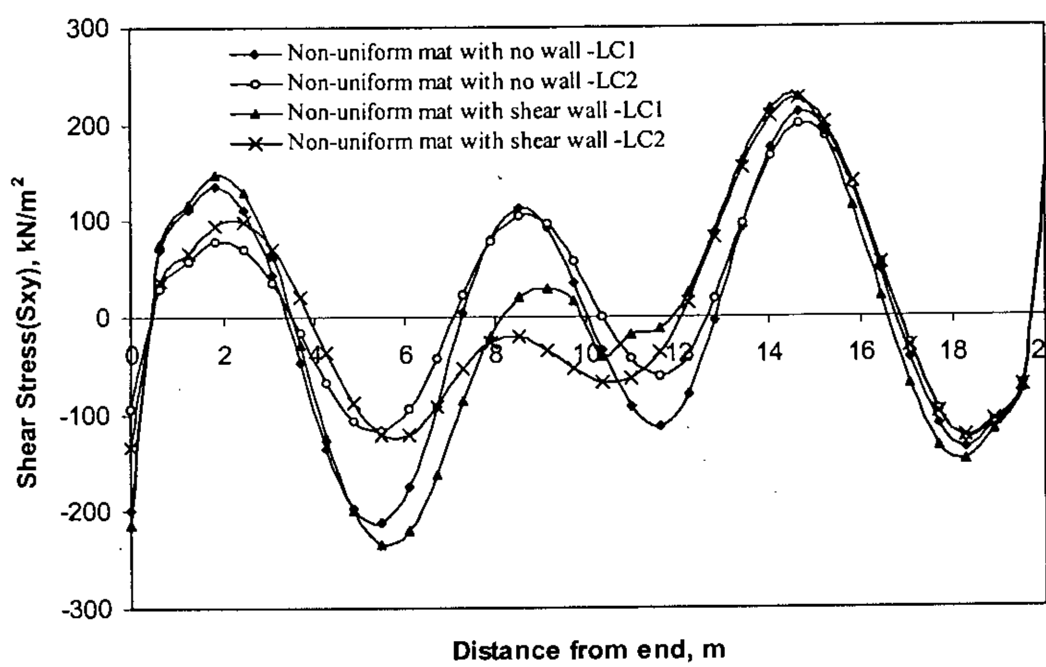

Fig.5.29b Variation in Shear Stress along mid of panel adjacent to shear wall for non-uniform mat of model-C(along Line-2).

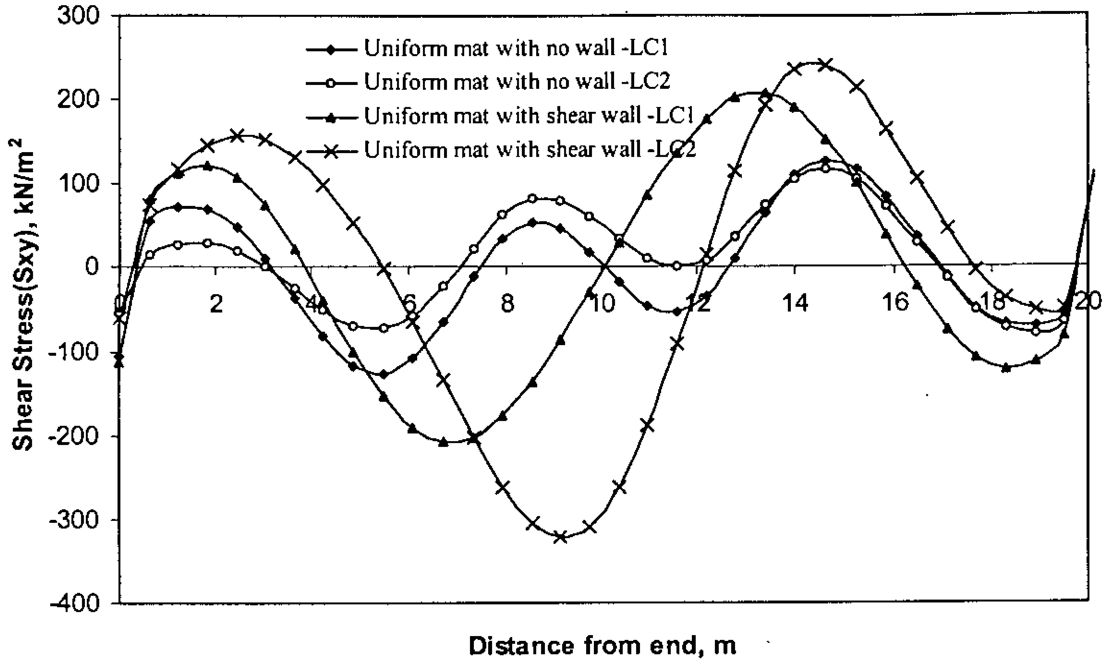

Fig.5.30a Variation in Shear Stress along mid of panel adjacent to shear wall for uniform mat of model-D (along Line-4).

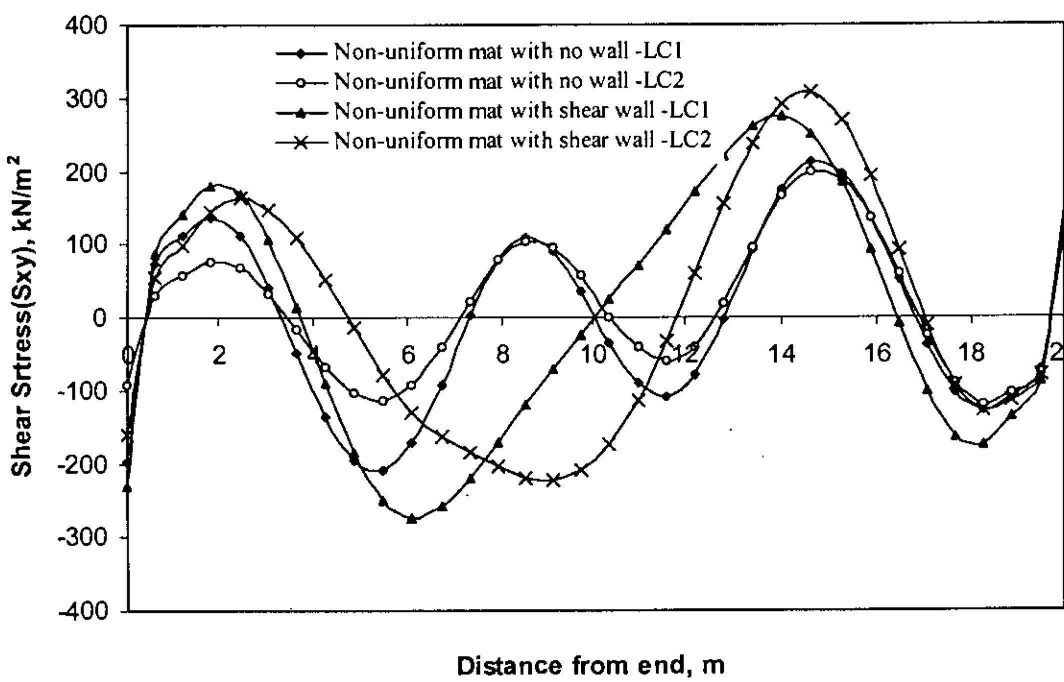

Fig.5.30b Variation in Shear Stress along mid of panel adjacent to shear wall for non-uniform mat of model-D (along Line-4).

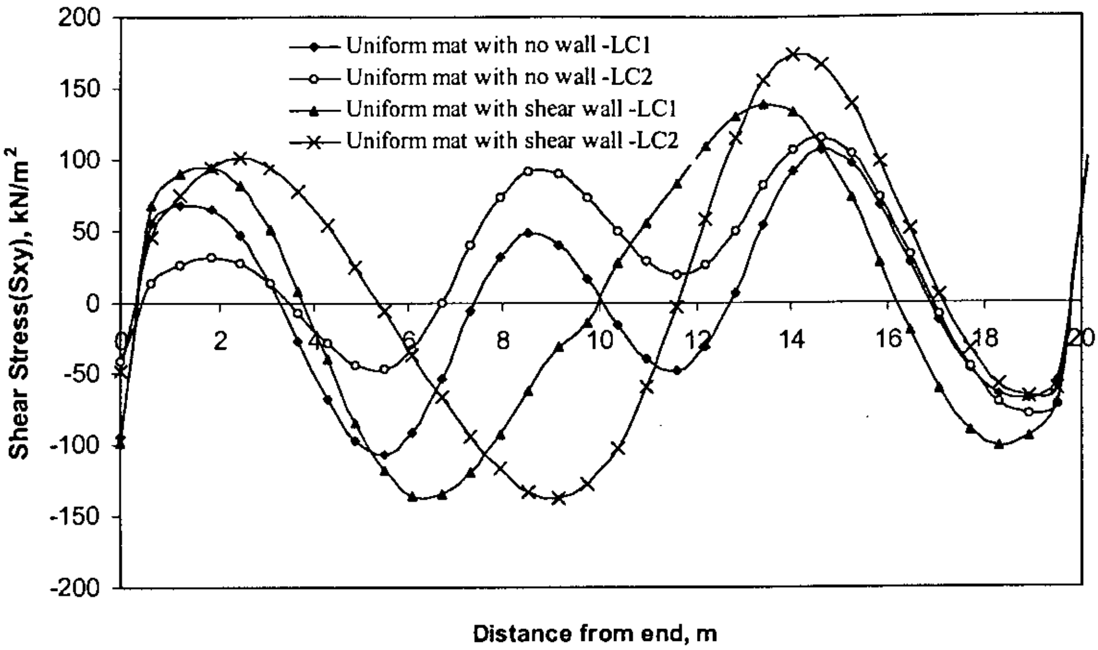

Fig.5.31a Variation in Shear Stress along mid of panel adjacent to shear wall for uniform mat of model-E (along Line-2).

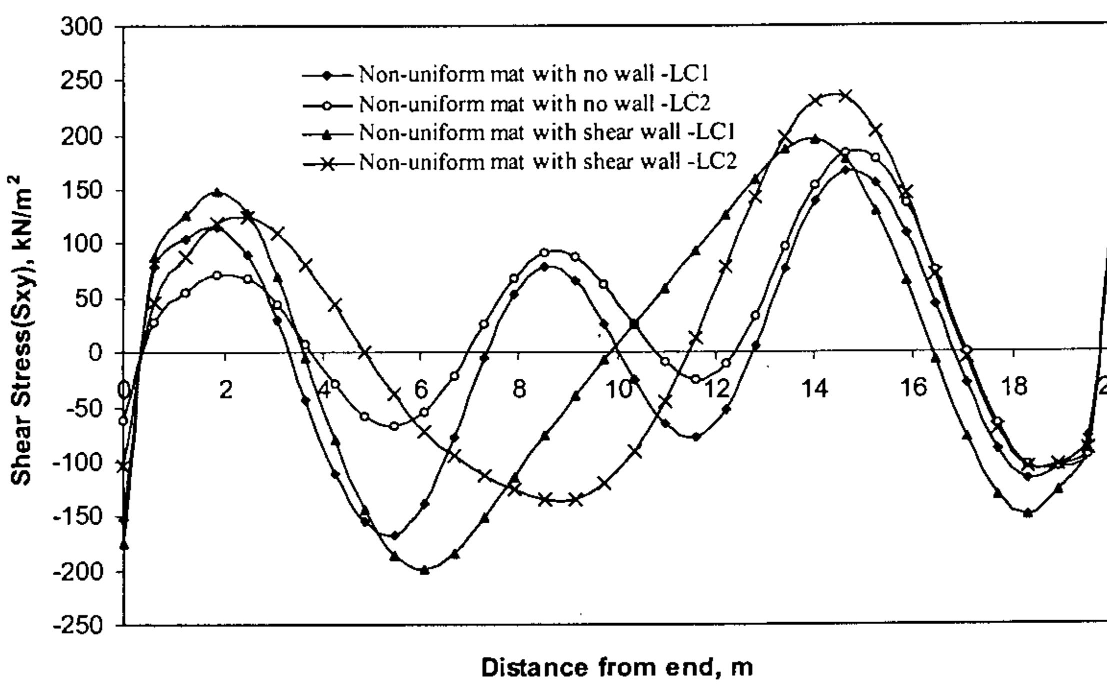

Fig.5.31b Variation in Shear Stress along mid of panel adjacent to shear wall for non-uniform mat of model-E (along Line-2).

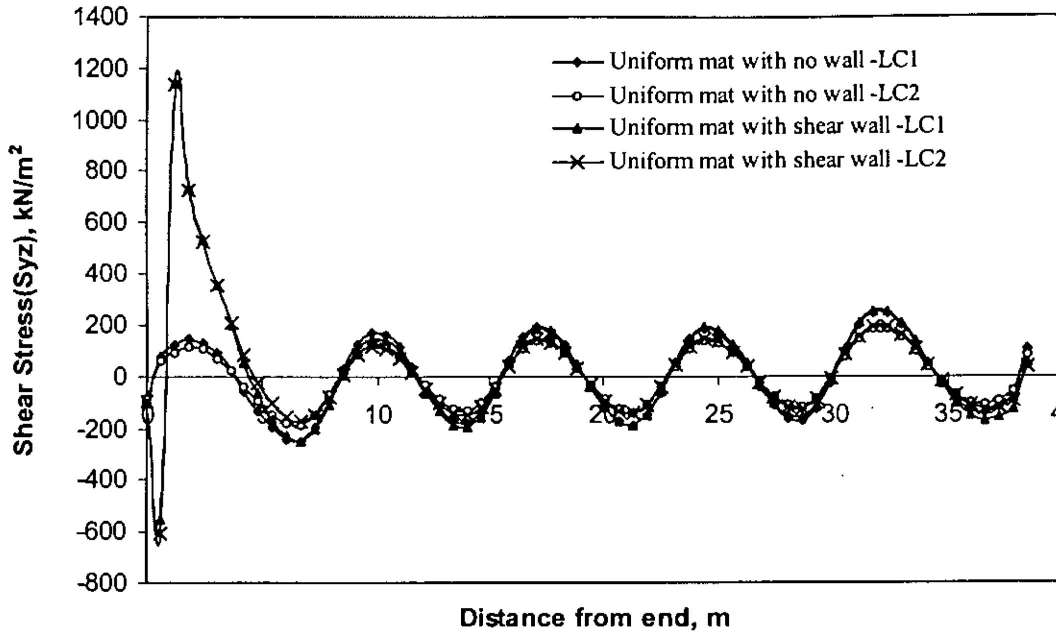

Fig.5.32a Variation in Shear Stress along line transverse to shear wall for uniform mat of model-A (along Line-15).

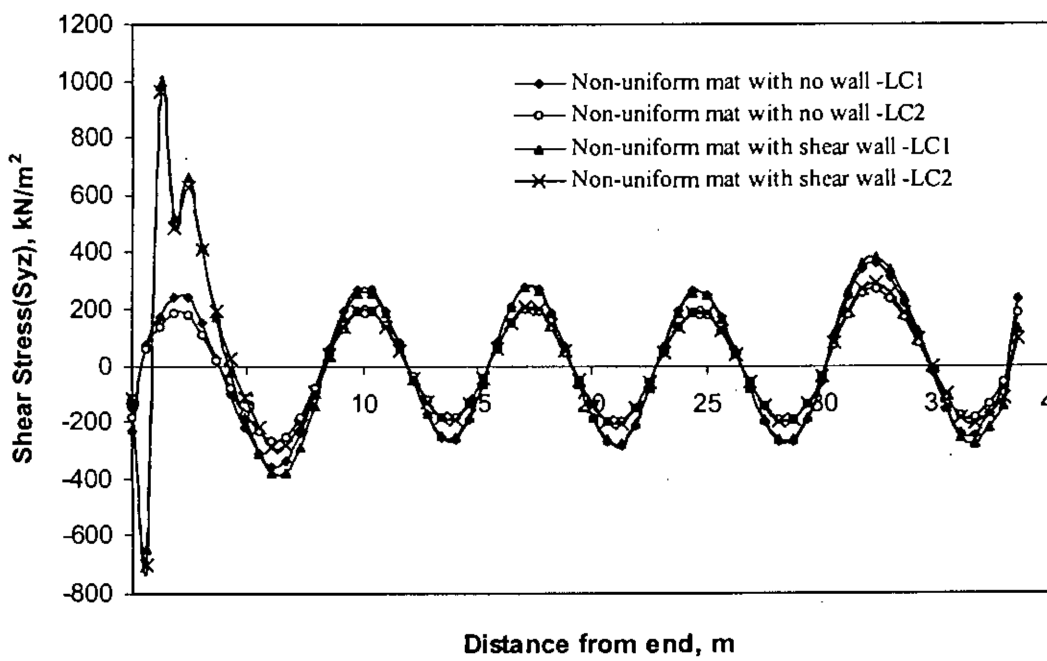

Fig.5.32b Variation in Shear Stress along line transverse to shear wall for non-uniform mat of model-A (along Line-15).

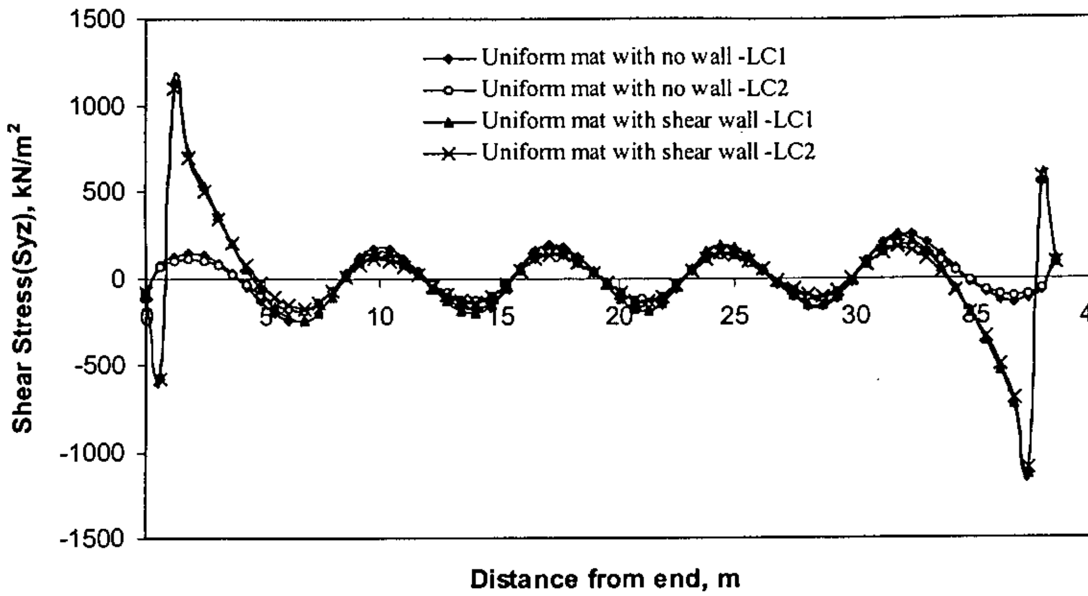

Fig.5.33a Variation in Shear Stress along line transverse to shear wall for uniform mat of model-B (along Line-15).

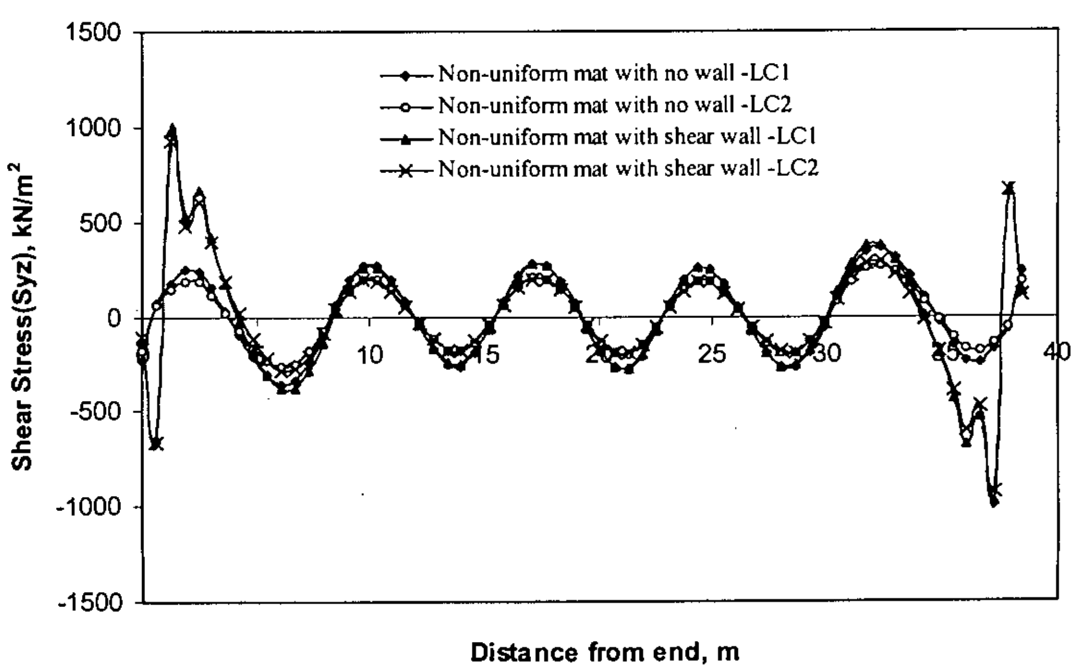

Fig.5.33b Variation in Shear Stress along line transverse to shear wall for non-uniform mat of model-B (along Line-15).

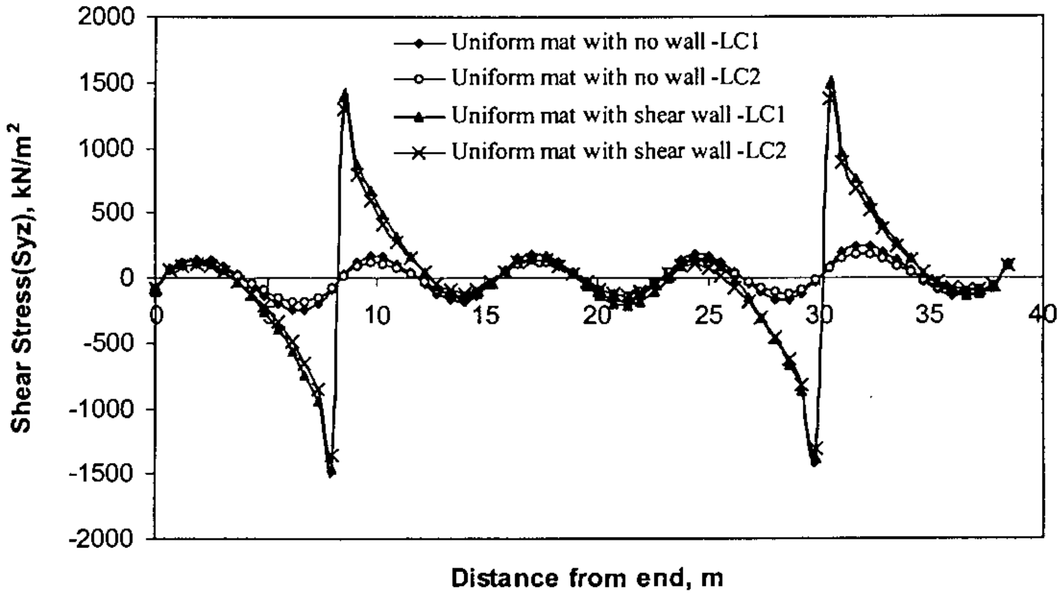

Fig.5.34a Variation in Shear Stress along line transverse to shear wall for uniform mat of model-C (along Line-15).

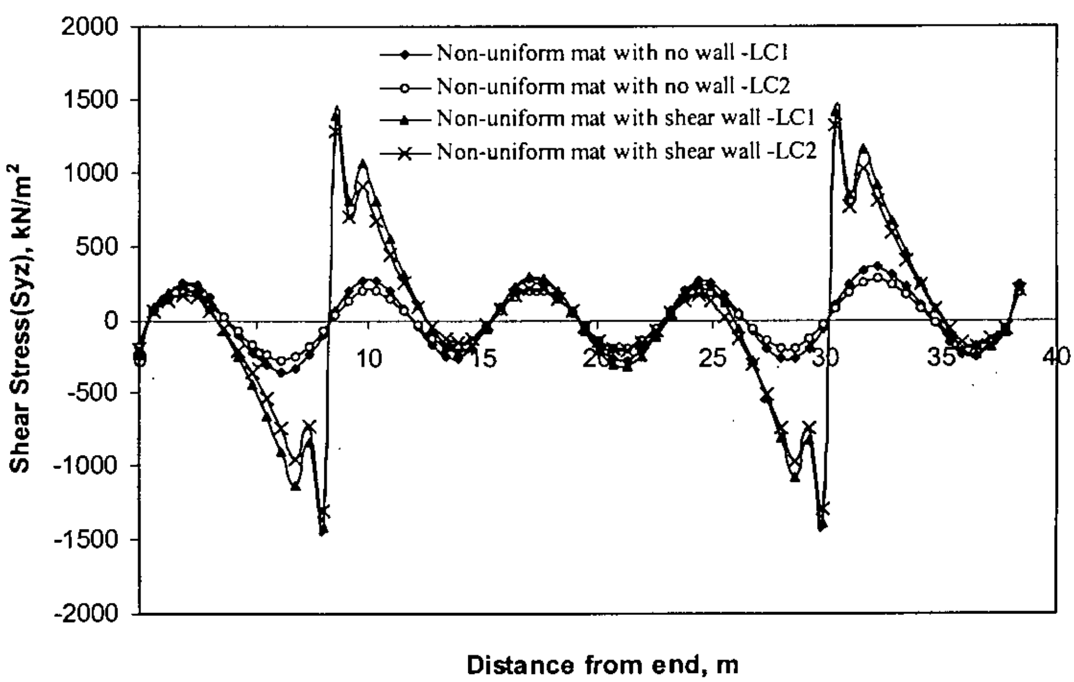

Fig.5.34b Variation in Shear Stress along line transverse to shear wall for non-uniform mat of model-C (along Line-15).

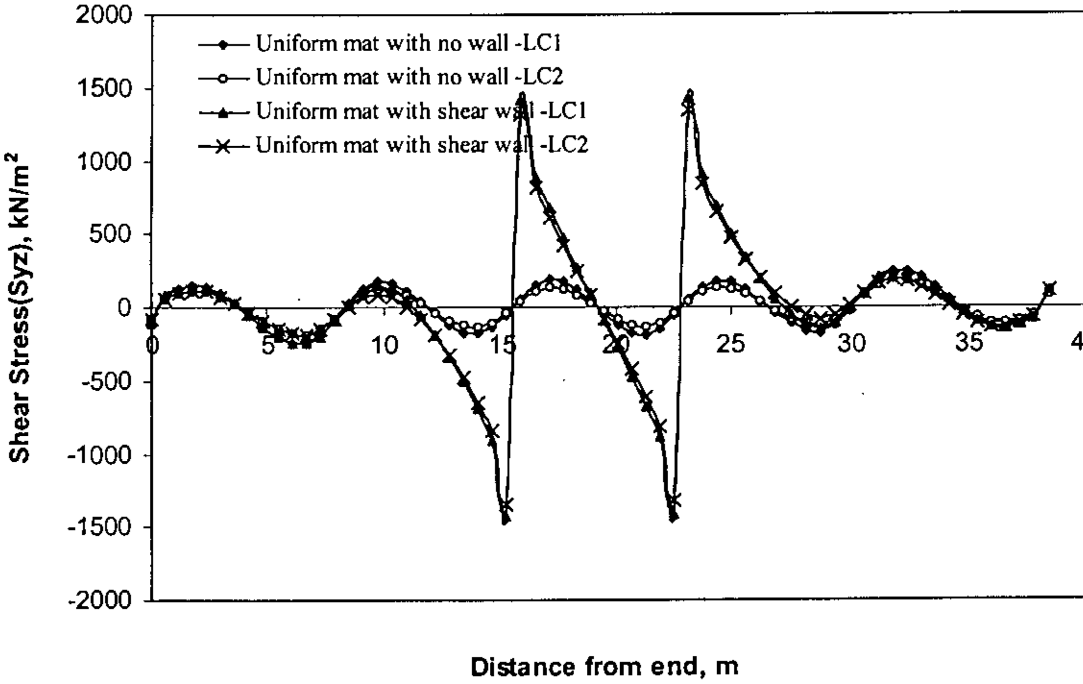

Fig.5.35a Variation in Shear Stress along line transverse to shear wall for uniform mat of model-D (along Line-15).

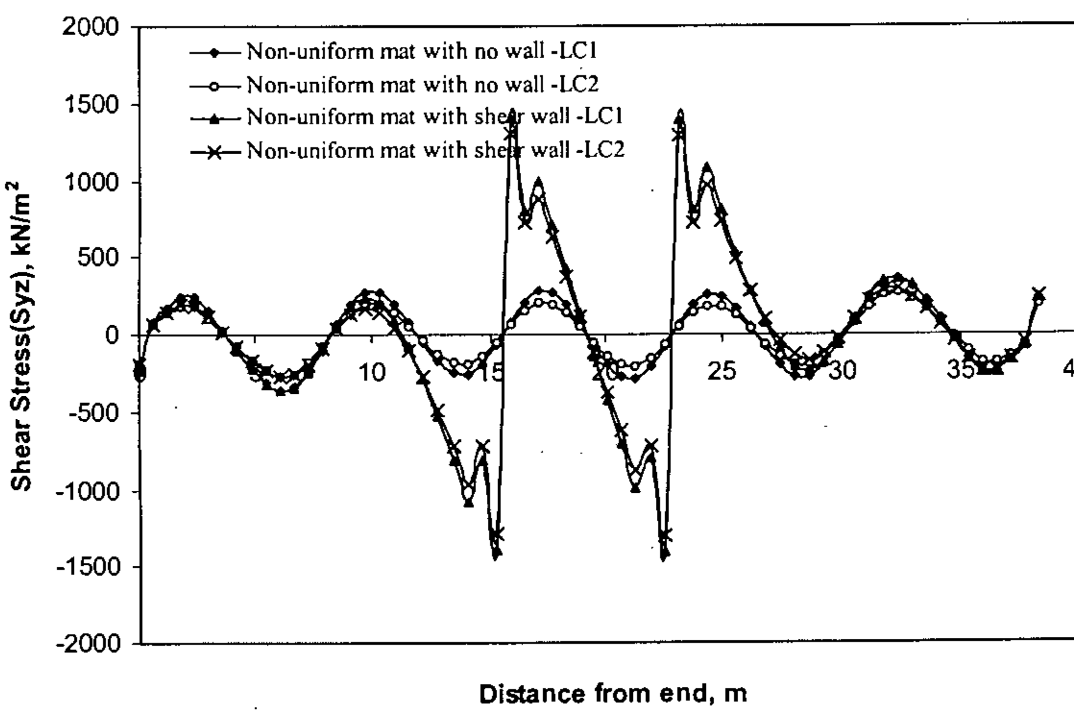

Fig.5.35b Variation in Shear Stress along line transverse to shear wall for non-uniform mat of model-D (along Line-15).

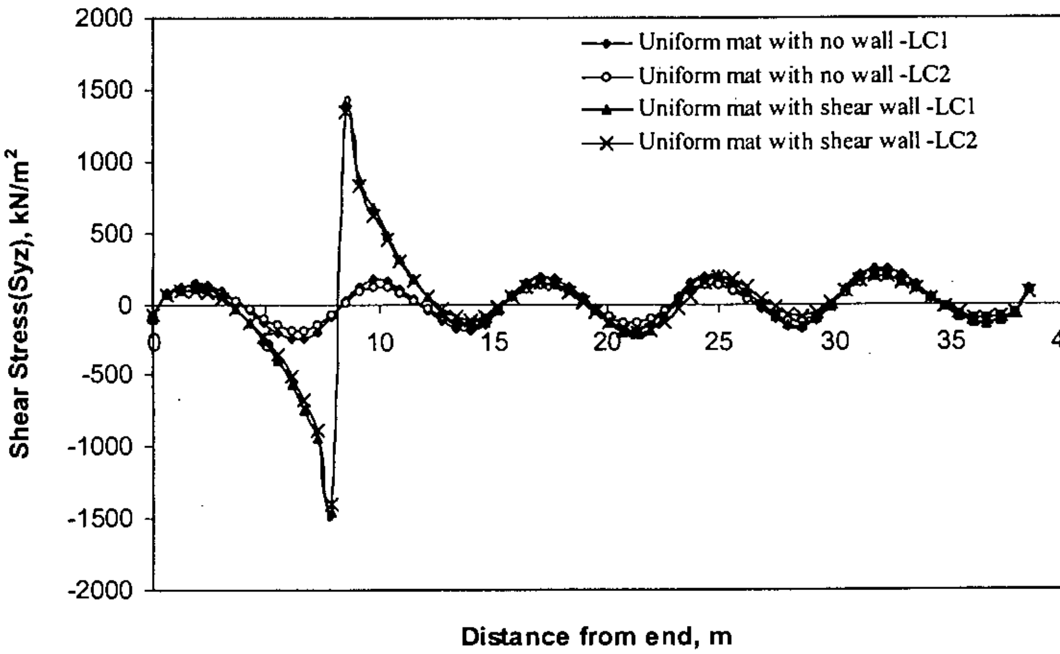

Fig.5.36a Variation in Shear Stress along line transverse to shear wall for uniform mat of model-E (along Line-15).

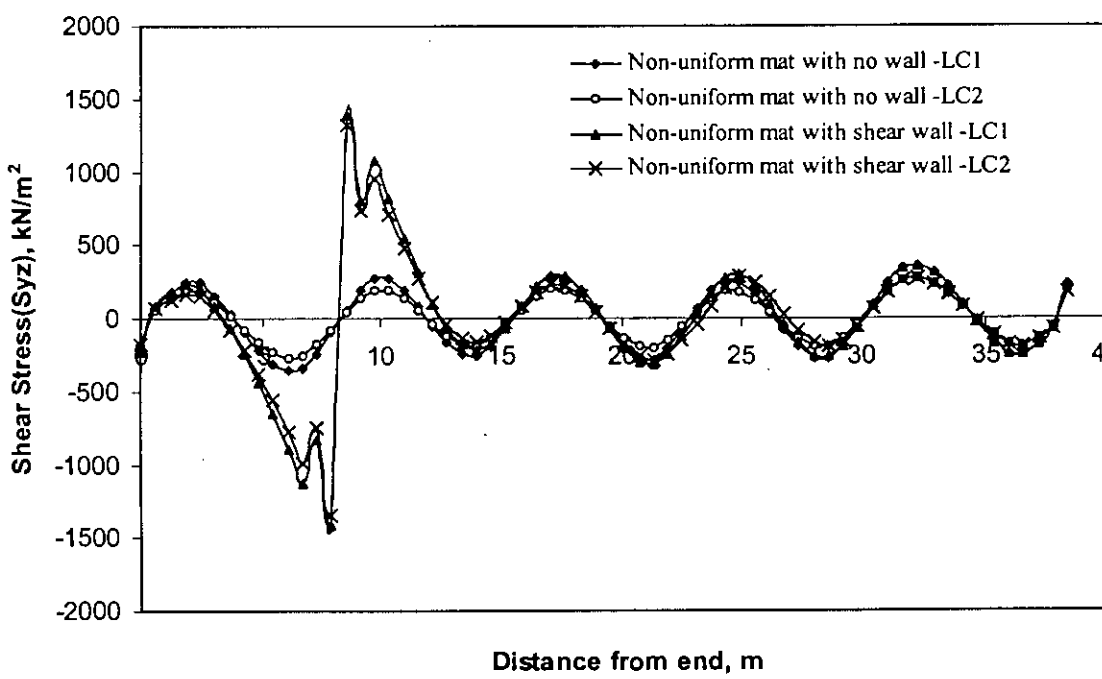

Fig.5.36b Variation in Shear Stress along line transverse to shear wall for non-uniform mat of model-E (along Line-15).

Table 5.7 Variation in Shear Stress for **Non-uniform** Thickness Mat along Short Direction.

	Shear Stress at Face of Shear Wall, kN/m²		**Shear Stress at Mid Span of Panel Adjacent Shear wall, kN/m²**		**Flexural Shear Stress Capacity, kN/m²**
	Load Case-1	Load Case-2	Load Case-1	Load Case-2	
Model-A	695.8	2005.3	209.7	236.3	741.2
Model-B	691.7	1670.2	209.6	220.6	741.2
Model-C	571.3	833.8	195.1	226.1	741.2
Model-D	583.4	1307.9	260.4	306.1	741.2
Model-E	571.9	849.2	195.0	234.0	741.2

Table 5.8 Variation in Shear stress at 'd' Distance from the Face of Shear Wall for Mat along Long Direction.

	Shear Stress at distance 'd' from Face of Wall, kN/m²				**Flexural Shear Stress Capacity, kN/m²**
	Uniform Thickness		**Non-uniform Thickness**		
	Load Case-1	Load Case-2	Load Case-1	Load Case-2	
Model-A	370.9	1016.9	422.3	825.7	741.2
Model-B	370.6	904.8	421.3	745.6	741.2
Model-C	771.2	689.1	937.3	795.5	741.2
Model-D	457.6	856.1	774.9	1094.7	741.2
Model-E	771.1	727.8	937.5	837.9	741.2

Table 5.9 Total Shear Force along the Face of Shear Wall with Shear Force Capacity.

	Total Shear Force of entire width along Face of Wall, kN				Shear Force Capacity*, kN
	Uniform Thickness		Non-uniform Thickness		
	Load Case-1	Load Case-2	Load Case-1	Load Case-2	
Model-A	12586.2	9483.2	11712.1	8840.2	15905.5
Model-B	12595.5	9405.8	11723.2	8752.6	15905.5
Model-C	12361.4	8486.9	12911.0	8941.7	15905.5
Model-D	13707.9	10644.2	13860.3	10835.8	15905.5
Model-E	12360.6	9056.8	12911.6	9427.1	15905.5

*f'_c= 27.6 MPa

5.5 VARIATION IN SETTLEMENT FOR THE PRESENCE OF SHEAR WALL

Mat foundations are commonly used where settlement may be a problem for sites containing erratic deposits or lenses of compressible materials, suspended boulders, etc. The settlement tends to be controlled by lowering soil contact pressures, displacing volume of soil and by bridging effect due to mat rigidity and superstructure-rigidity contribution to the mat. Both overall settlement and point to point differential settlement are important for the purpose of design of mat foundation.

Presence of shear wall on mat foundation brings some significant changes in the deflection pattern of mat foundation. Shear wall loading on mat increases the differential settlement along the column lines. The settlements along different lines for different locations of shear walls are plotted in Fig.5.37 to Fig.5.47. Deflection along other lines for different models are given in Appendix-D. It is evident that for most of the locations the maximum differential settlement occurs along the line of shear wall and this differential settlements are higher for the case of non-uniform mat foundation. The differential settlements are also high along the mid panels adjacent to shear wall line as shown in figures.

Table 5.10 Maximum Differential Settlements along Line of Shear Wall for Different Shear Wall Locations (for subgrade reaction, K_s= 16.0 MN/m^3).

	Differential Settlement (mm)			
	Uniform Mat Foundation		**Non-uniform Mat Foundation**	
	Load Case-1	**Load Case-2**	**Load Case-1**	**Load Case-2**
Model-A	3.38	17.08	11.05	24.66
Model-B	3.38	14.87	11.05	22.15
Model-C	3.00	7.45	9.43	12.68
Model-D	2.94	8.25	9.15	13.07
Model-E	2.99	7.47	9.05	12.45

From the Fig.5.37 to Fig.5.47 and the Table 5.10 to Table 5.12, the following points become evident:

- Presence of shear wall at any location increases the maximum settlement of mat foundation from the settlement without shear wall.
- Maximum differential settlement occurs along the shear wall line.
- For uniform thickness mat the differential settlement is lower than the values for non-uniform mat.
- Lateral load case causes higher differential settlement for any location of shear wall.
- Shear wall at edge of mat causes the most sever differential settlement.. Both symmetrically placed walls and single shear wall at edge causes differential settlement of significant magnitude. For other locations of shear wall causes differential settlement less than 12 mm which is well below than the allowable limit.

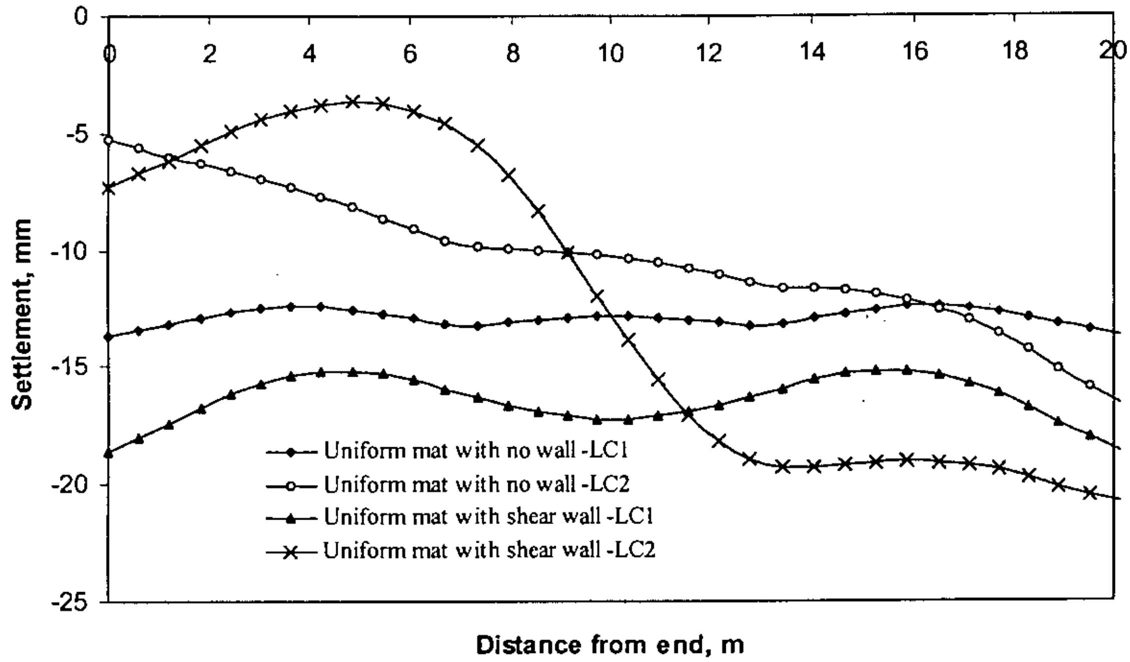

Fig.5.37a Variation in settlement along shear wall line for uniform mat of model-A (along Line-1)

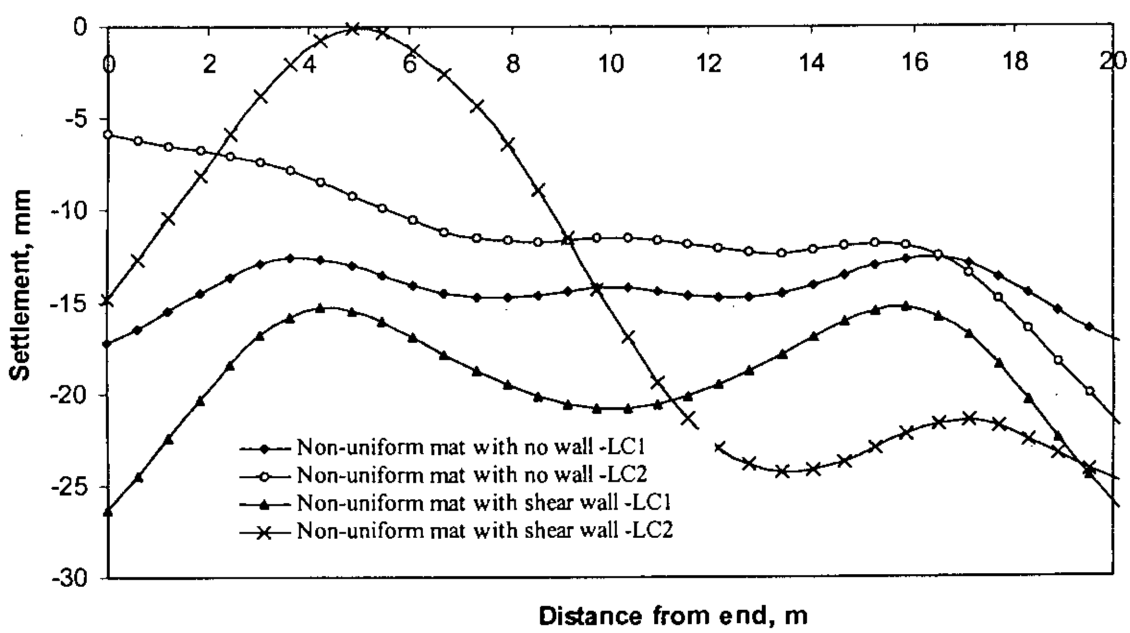

Fig.5.37b Variation in settlement along shear wall line for non-uniform mat of model-A(along Line-1)

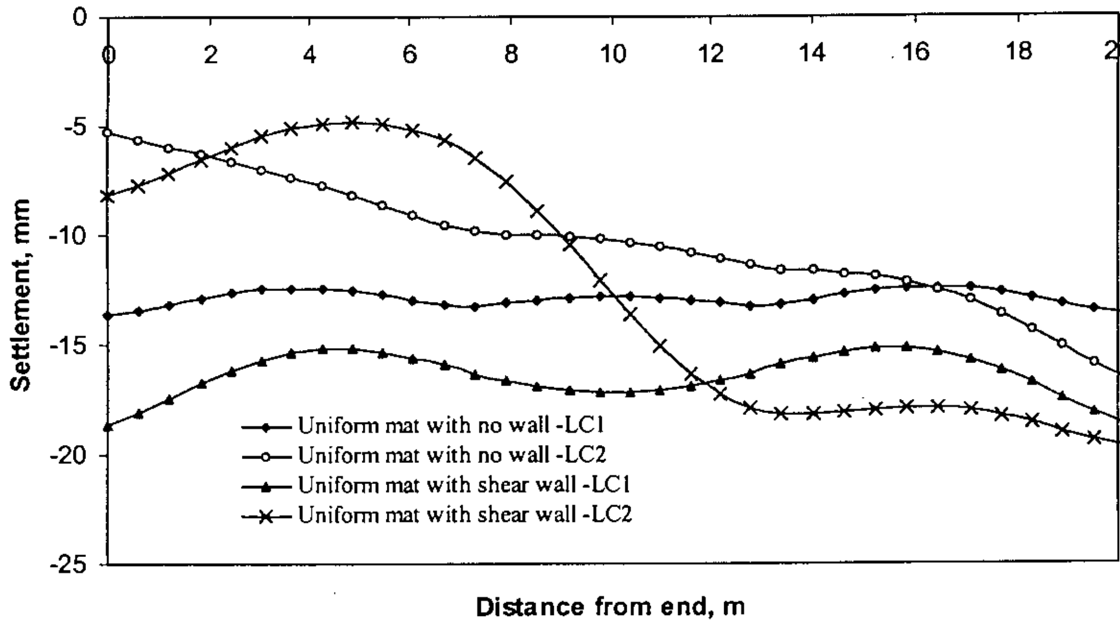

Fig.5.38a Variation in settlement along shear wall line for uniform mat of model-B (along Line-1)

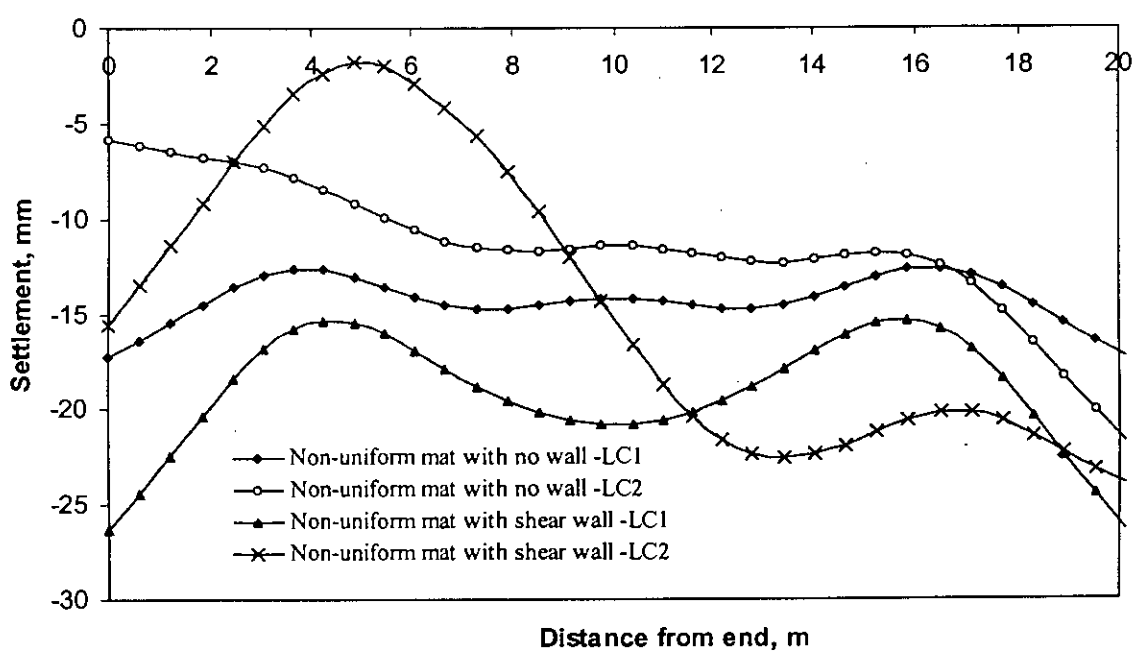

Fig.5.38b Variation in settlement along shear wall line for non-uniform mat of model-B(along Line-1)

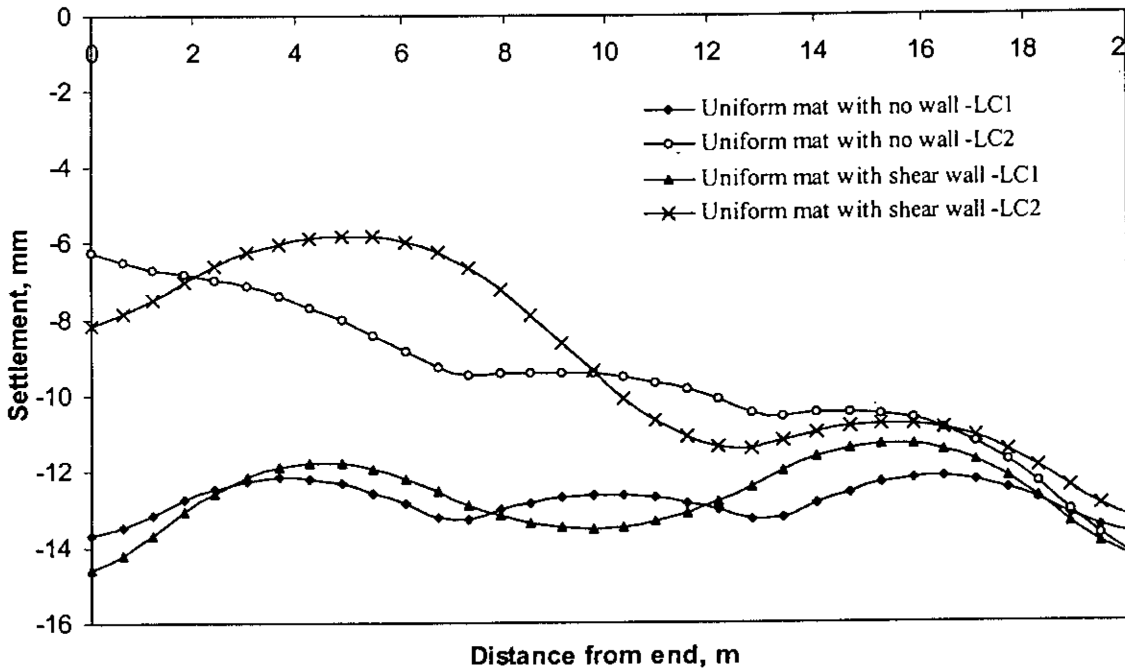

Fig.5.39a Variation in settlement along shear wall line for uniform mat of model-C (along Line-3)

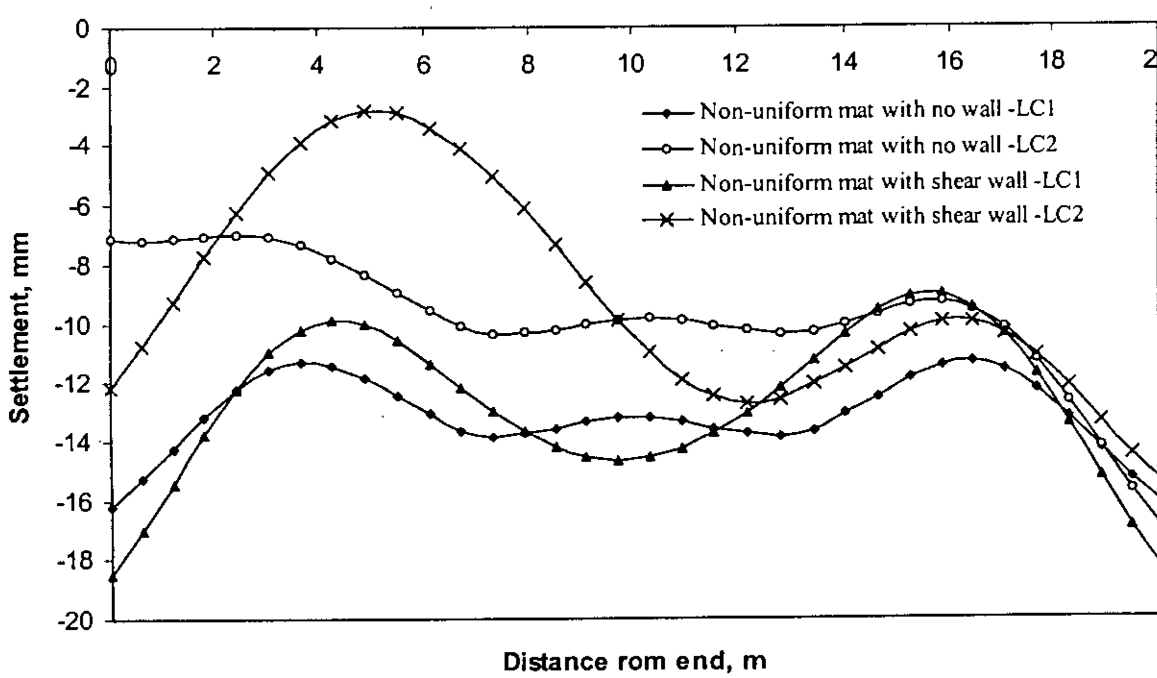

Fig.5.39b Variation in settlement along shear wall line for non-uniform mat of model-C(along Line-3)

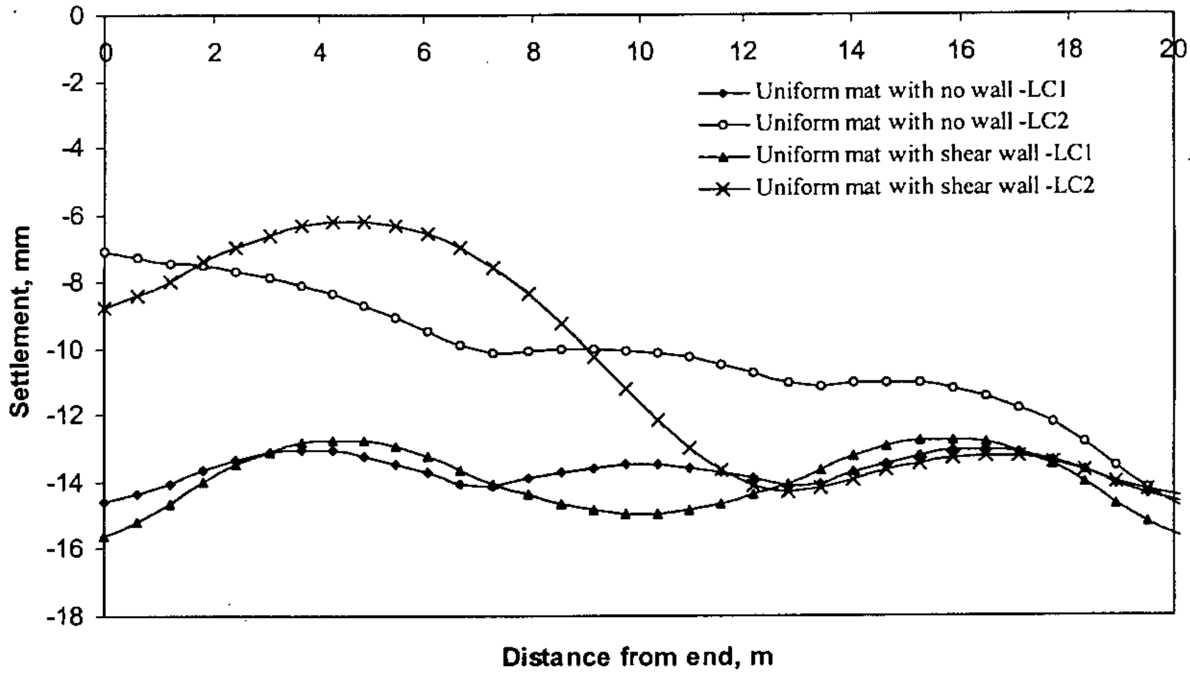

Fig.5.40a Variation in settlement along shear wall line for uniform mat of model-D (along Line-5)

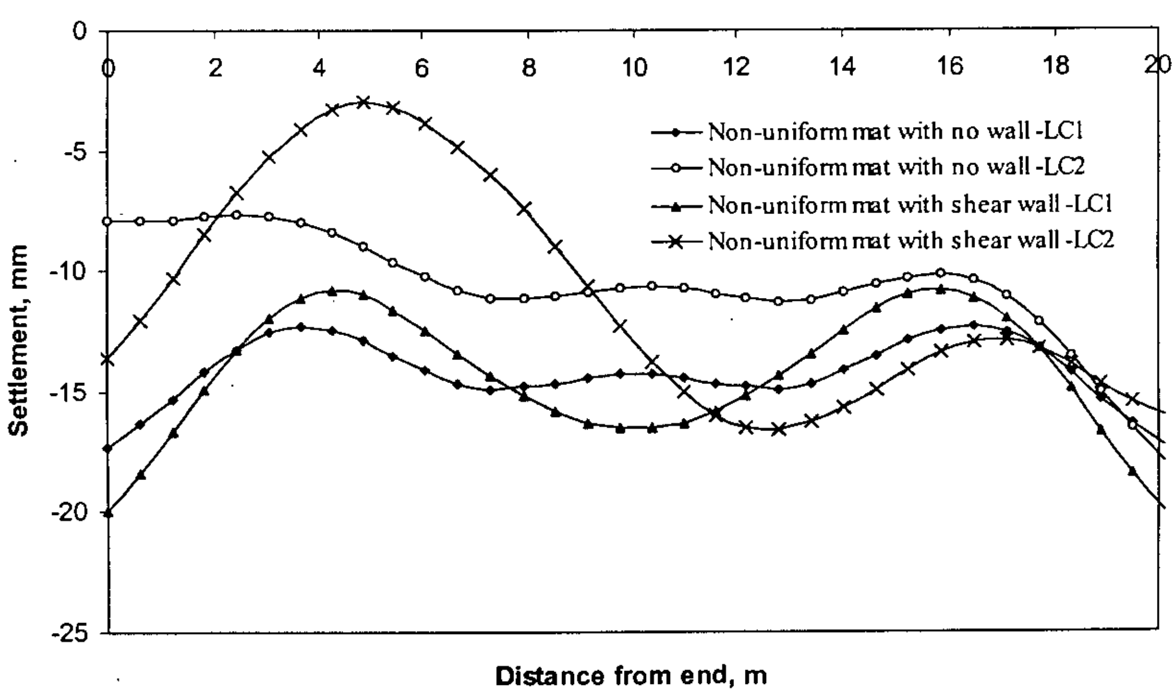

Fig.5.40b Variation in settlement along shear wall line for non-uniform mat of model-D(along Line-5)

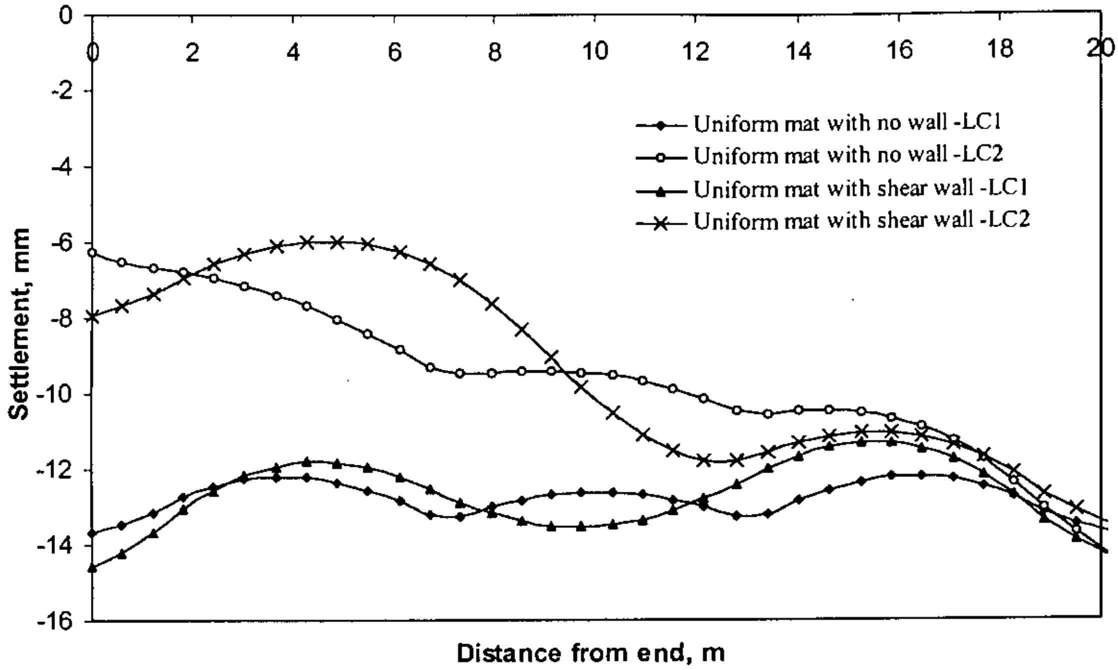

Fig.5.41a Variation in settlement along shear wall line for uniform mat of model-E (along Line-3)

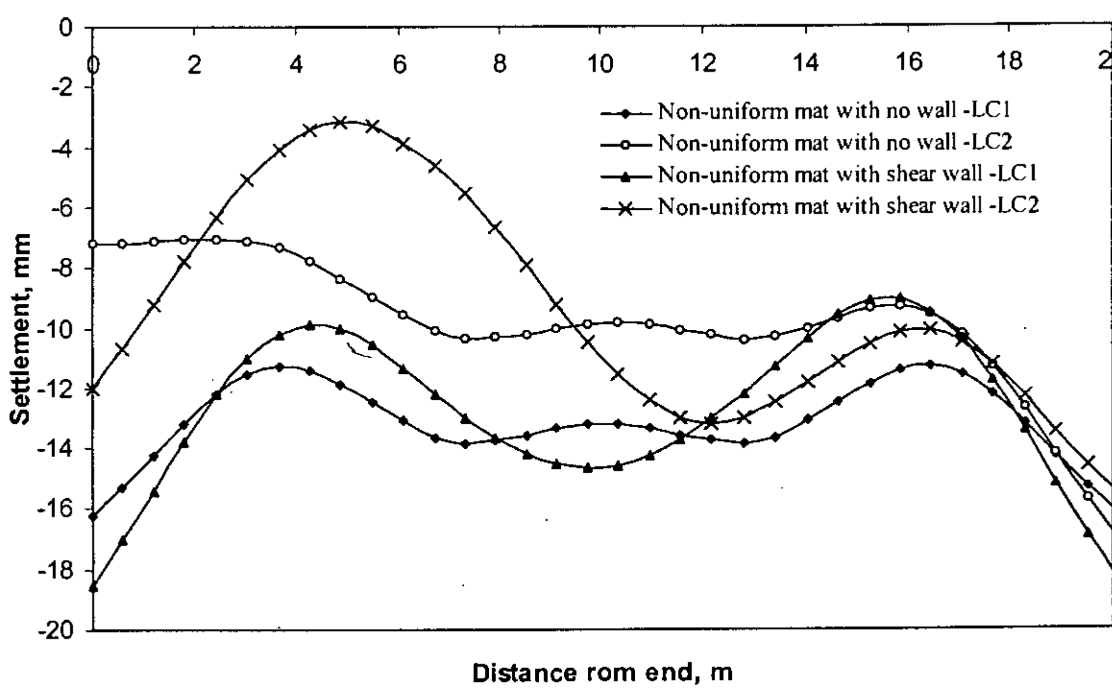

Fig.5.41b Variation in settlement along shear wall line for non-uniform mat of model-E(along Line-3)

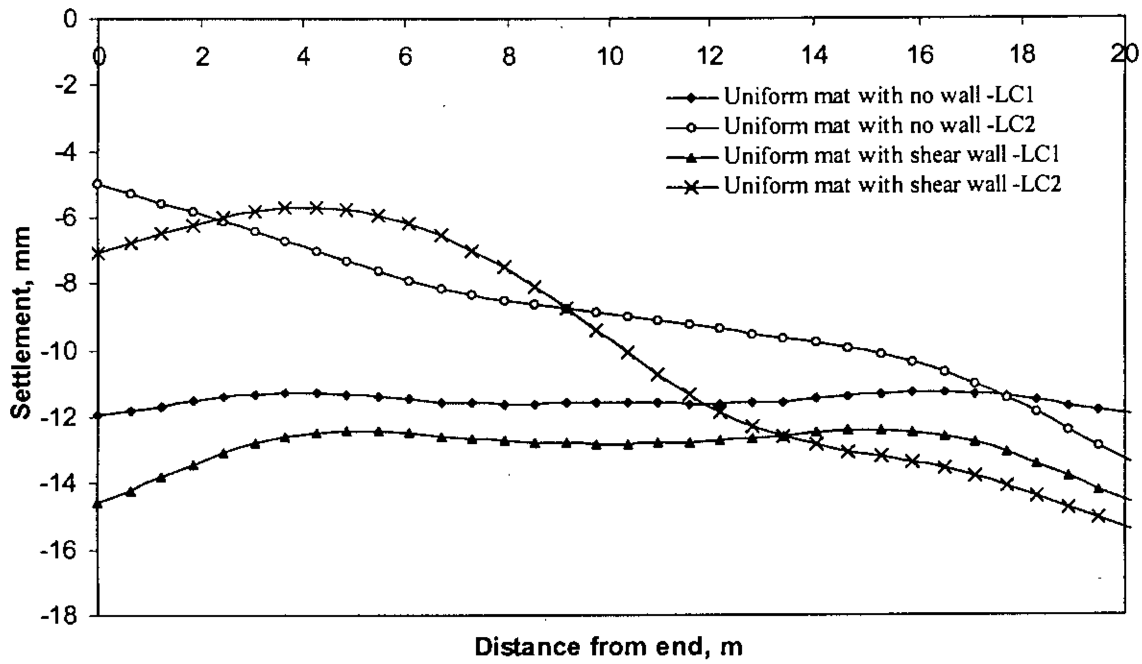

Fig.5.42a Variation in settlement along mid panel adjacent to shear wall line for uniform mat of model-A(along Line-2)

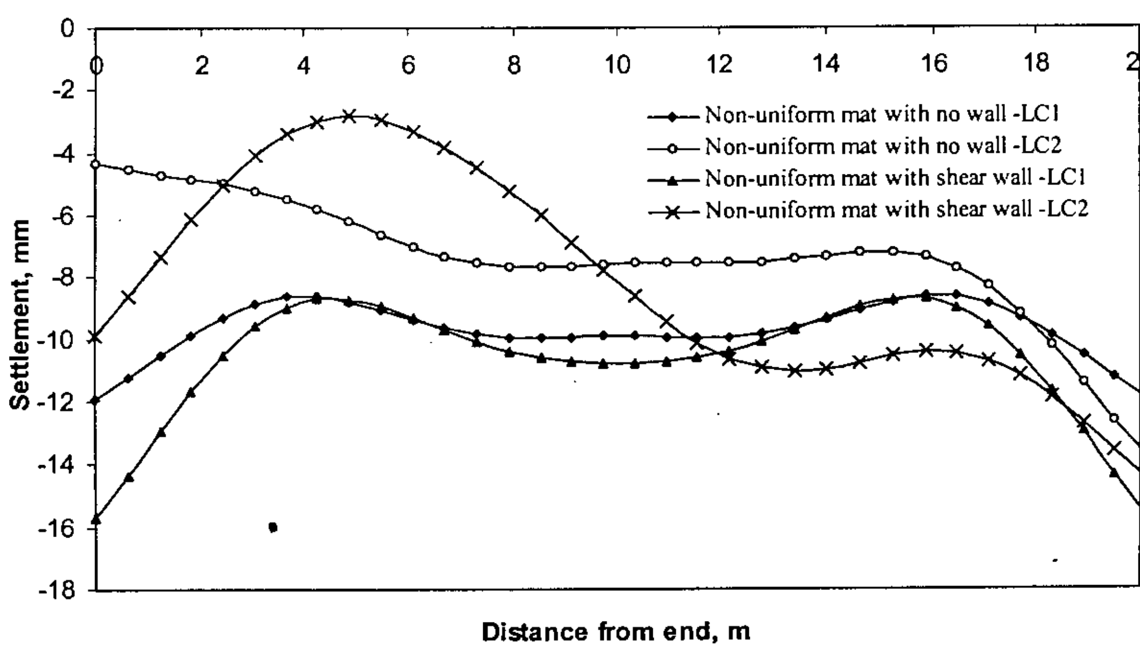

Fig.5.42b Variation in settlement along mid panel adjacent to shear wall line for non-uniform mat of model-A (along Line-2)

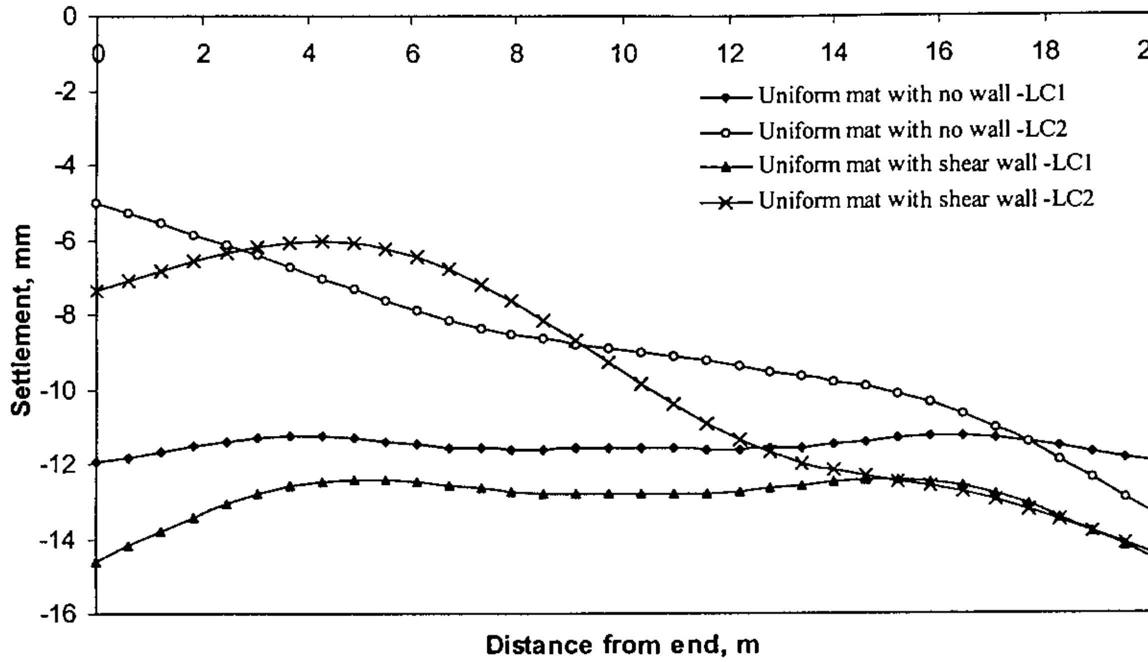

Fig.5.43a Variation in settlement along mid panel adjacent to shear wall line for uniform mat of model-B(along Line-2)

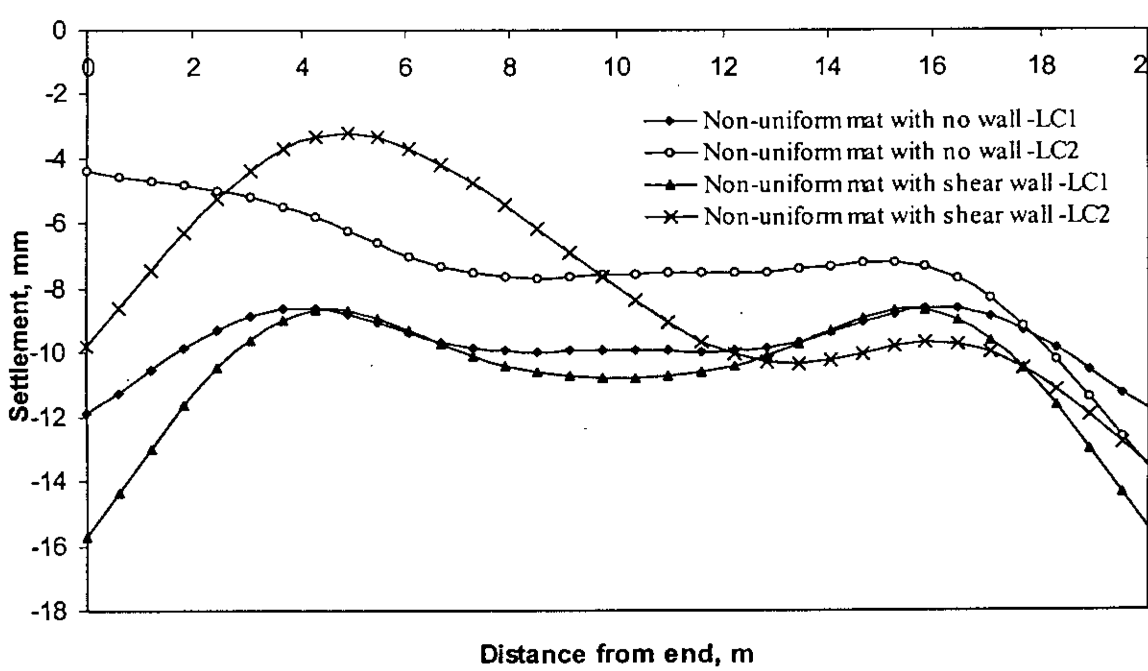

Fig.5.43b Variation in settlement along mid panel adjacent to shear wall line for non-uniform mat of model-B (along Line-2)

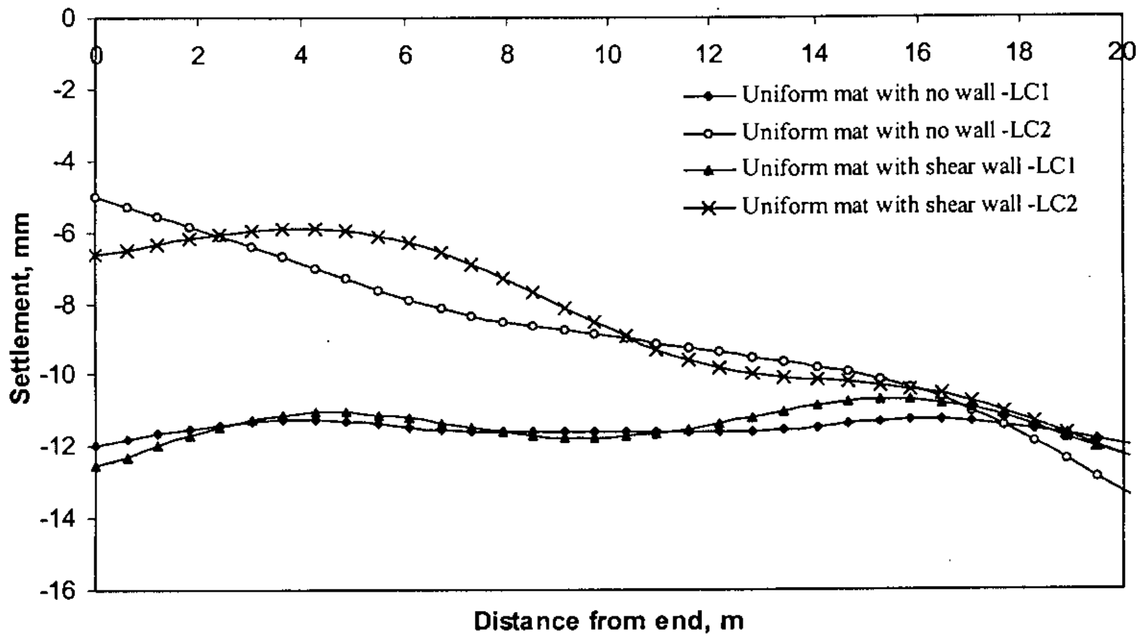

Fig.5.44a Variation in settlement along mid panel adjacent to shear wall line for uniform mat of model-C (along Line-2)

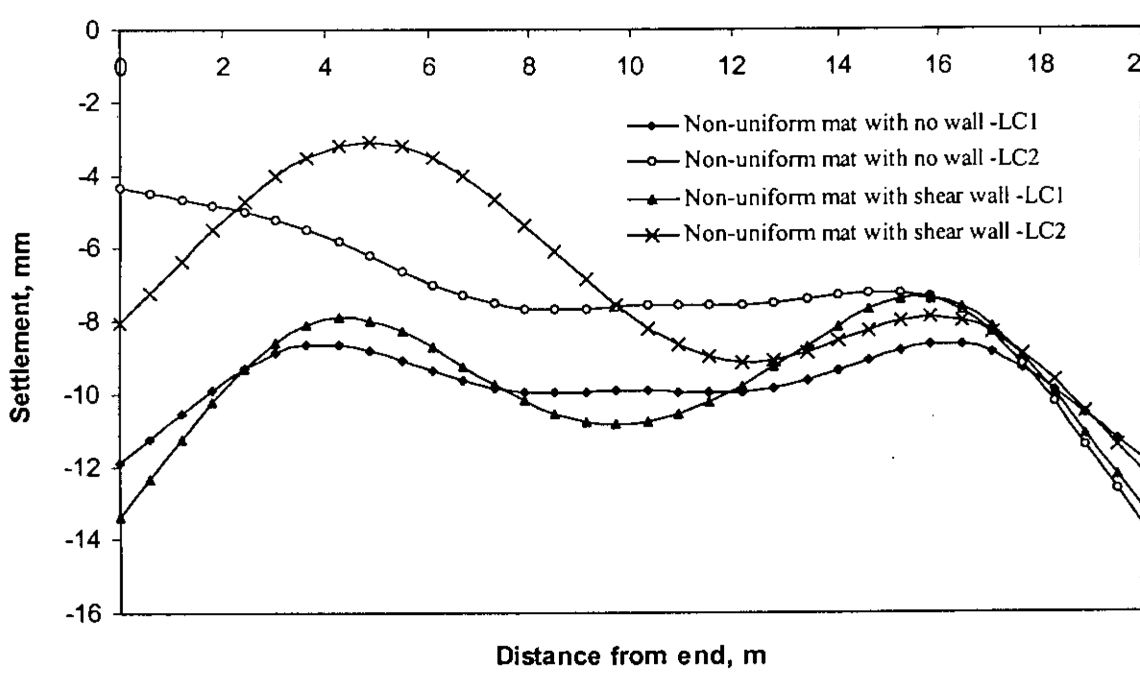

Fig.5.44b Variation in settlement along mid panel adjacent to shear wall line for non-uniform mat of model-C (along Line-2)

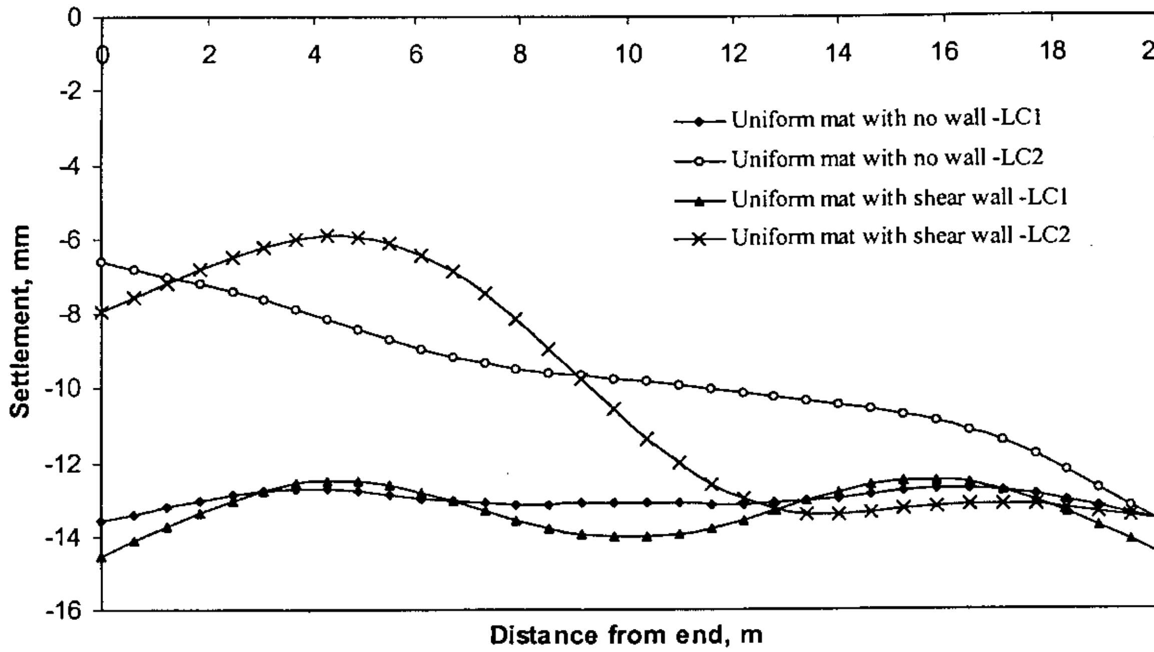

Fig.5.45a Variation in settlement along mid panel adjacent to shear wall line for uniform mat of model-D(along Line-6)

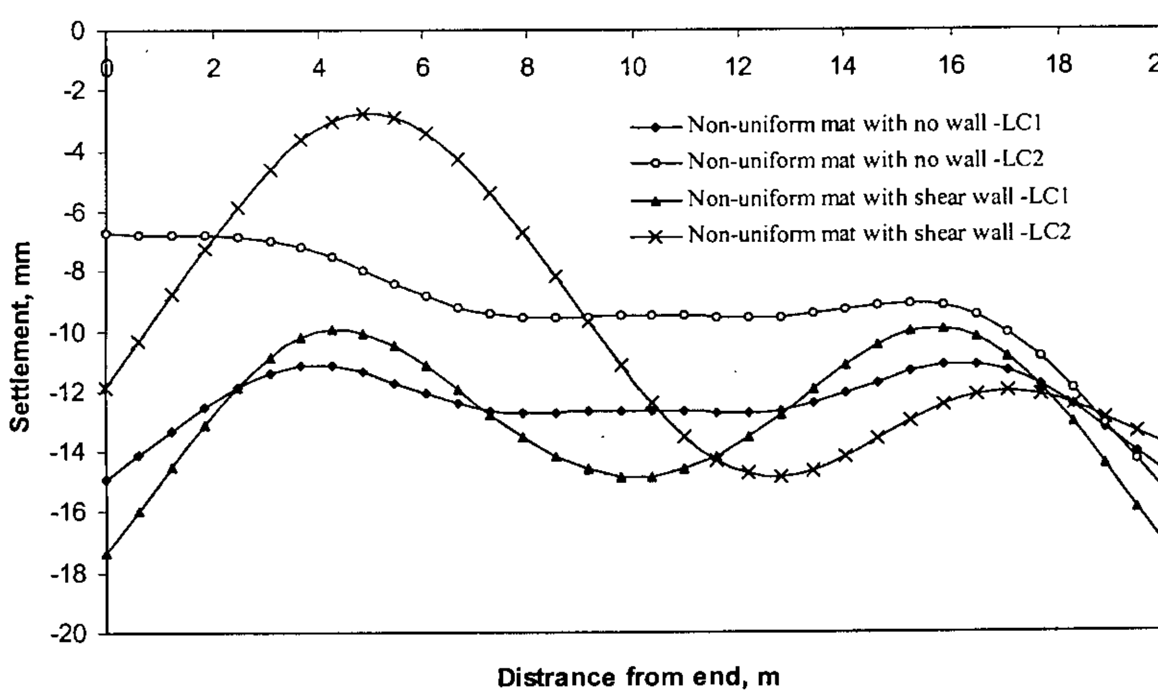

Fig.5.45b Variation in settlement along mid panel adjacent to shear wall line for non-uniform mat of model-D(along Line-6)

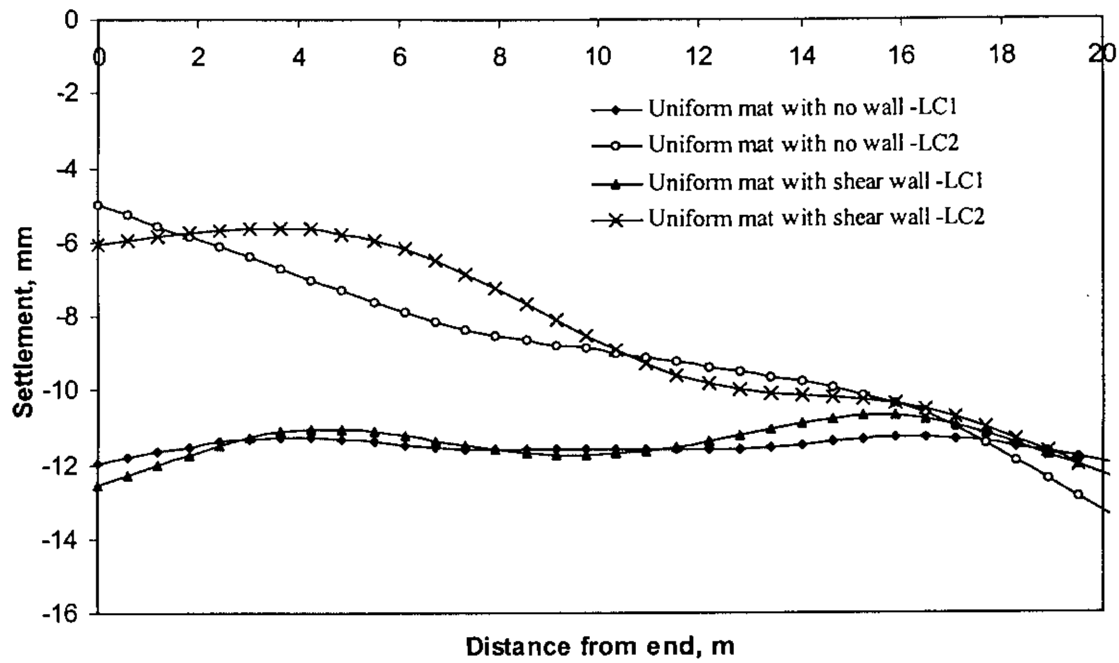

Fig.5.46a Variation in settlement along mid panel adjacent to shear wall line for uniform mat of model-E(along Line-2)

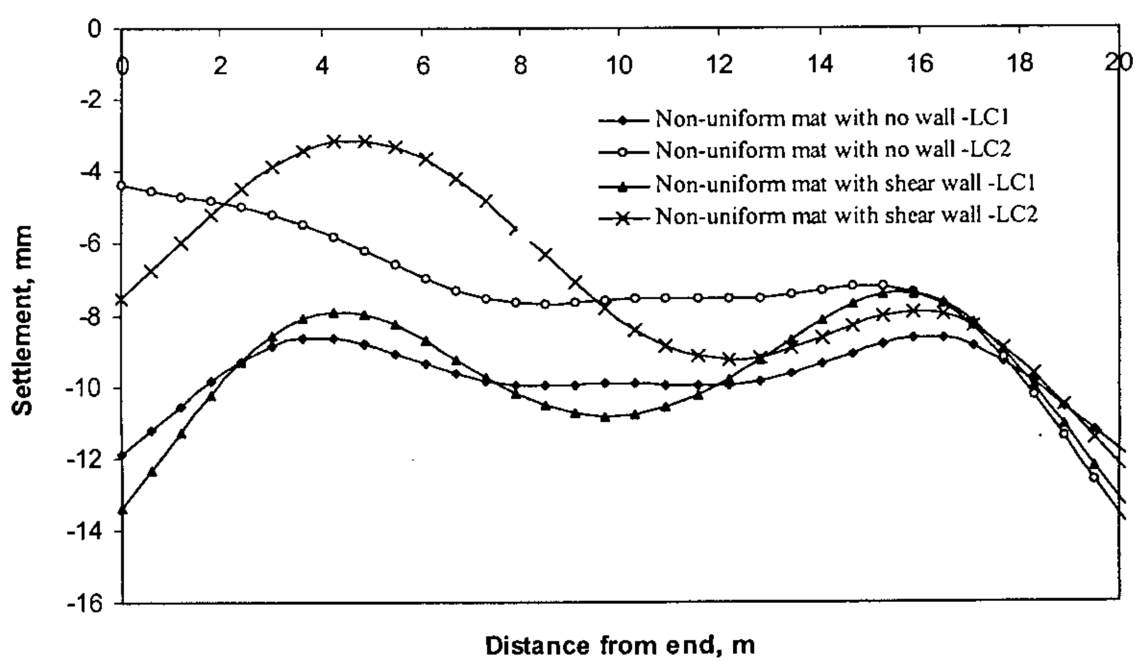

Fig.5.46b Variation in settlement along mid panel adjacent to shear wall line for non-uniform mat of model-E(along Line-2)

Table 5. 11 Differential Settlements along Mid Panel adjacent to Shear Wall for Different Shear Wall Locations.

	Differential Settlement (mm)			
	Uniform Mat Foundation		Non-uniform Mat Foundation	
	Load Case-1	Load Case-2	Load Case-1	Load Case-2
Model-A (Along line-2)	2.18	9.66	7.02	11.64
Model-B (Along line-2)	1.87	8.42	7.01	10.48
Model-C (Along line-2)	1.63	6.42	5.96	9.17
Model-D (Along line-6)	2.03	7.64	7.34	11.11
Model-E (Along line-2)	1.62	6.71	5.95	9.14

Table 5. 12 Percent Increase in Differential Settlements for Shear Wall Presence along Line of Shear Wall.

	Percent Increase in Differential Settlement for Shear Wall Presence	
	Uniform Mat Foundation	Non-uniform Mat Foundation
Model-A	51.2	55.3
Model-B	31.9	39.6
Model-C	6.8	27.7
Model-D	7.8	28.1
Model-E	6.4	25.3

5.6 EFFECT OF LOCATION OF SHEAR WALL

Shear walls and shear cores are used at almost every location on the building plan. These are used symmetrically in pairs and also found as a single shear wall or shear core in building. In the present study shear walls are placed at different locations and at different numbers.

5.6.1 Effect on Bending Moment

Presence of shear wall influences the pattern of moment in the mat foundation significantly. Variation in bending moment is most significant for the presence of shear wall at the edge of mat foundation. Shear wall at edges of uniform mat increases the mid span negative moment by nearly 30% of the moment produced if only columns were used. Increase in negative moment for locations other than edge is below or near 10 %. Table 5.1 shows that most sever change in bending moment occur when the shear wall is placed at edge. One wall at an end or two walls one at each end has nearly the effect on the bending moment. Fig.5.7 to Fig.5.21 indicate these variations.

5.6.2 Effect on Shear Stress

Location of shear wall causes some difference in the shear stress of mat foundation. Shear wall at the edge has got the most influence on shear stress at the face of shear wall. Mid panel shear stresses are not very significant for any location of shear wall. From Table 5.6 and Table 5.9 it is clear that the shear stresses for the case of model-A and model-B are of high magnitude. In both the models the location of shear wall is at edge of mat. More over, variation in shear stress is more pronounced for the case of non-uniform mat.

5.6.3 Effect on Settlement

Effect of shear wall loading on settlement of mat foundation is more pronounced in the case of shear walls at the edge. Table 5.10 shows that the most significant differential settlements occur for model-A and model-B. For any other locations differential settlement is well below the acceptable limit. Variation in deflection is higher for the case of non-uniform thickness mat.

5.7 EFFECT OF NON-SYMMETRIC PLACEMENT OF SHEAR WALL

In the present study shear wall has been placed symmetrically and non-symmetrically on the plan of mat. It is observed that in regard of bending moment the symmetrically and non-symmetrically placed shear walls have nearly the same effect for both uniform and non-uniform thickness mat. Table 5.1 and Table5 .2 indicate that negative moments at the mid panel are not much affected by the symmetry of shear wall on mat plan.

Shear stresses at face of shear wall and at mid panel close to shear wall are higher for single shear wall.

From the point of differential settlement, location of shear wall is important. Symmetry in shear wall placement has no significant influence.

5.8 DISCUSSION ON FINDINGS OF SHEAR WALL EFFECT

Presence of shear wall brings considerable changes in loading on mat foundation. Column transfers load on a smaller part of area. On the other hand shear wall convey major portion of lateral load to mat as line load. Structural response of mat to shear wall loading is presented by its variation in bending moment, shear stress and deflection. These parameters are important for design of mat with shear wall.

Significant variation is observed for bending moment. Negative moment at the mid of panel faces significant change for presence of shear wall. Previous studies show that for the case of mat with column loading the negative moment decreases with the decrease in reduced thickness at mid section, But shear wall presence results a considerable increase in the mid panel negative moment due to presence of reduced thickness at the mid panels. Increase in negative moment is high for the panel adjacent to shear wall. Table 5.3 shows that the increase in negative moment both for uniform and non-uniform mat is nearly thirty percent higher for shear wall presence at the edge of mat. Shear wall at intermediate location produces negative moments well below the flexural capacity of the section with minimum reinforcement. For non-uniform mat with reduced thickness 60% of mat thickness, the negative moments produced are higher than the flexural capacity of the section. Negative moments for uniform mat in most of locations can be taken by the minimum reinforcement. But for the panel adjacent to shear wall and for the exterior panels negative moment crosses the negative moment capacity of the section for some location of shear wall. So, higher amount of reinforcement is required to resist negative moments in the panels close to shear wall. For example, in the case of uniform mat of model-A, maximum bending moment in the mid of panel adjacent to shear wall is 1172.9 kN-m/m but just one panel away the value of the maximum moment at mid panel is 665.9 kN-m/m. More over it is seen from Table 5.3 that negative moment produced in panels away from shear wall of non-uniform mat can be resisted by reduced thickness but with the reinforcement required for minimum reinforcement criteria of mat thickness. For shear wall location other than at edge, the negative moments produced in mid panels adjacent to shear wall are close to the moment capacity with reduced thickness but with the reinforcement calculated from minimum criteria of mat thickness.

It is also found that the changes in positive moment along column lines parallel to shear wall are not significant. Moments for direction perpendicular to shear wall is quite low if shear wall is not on the mat. When shear wall is present significant concentration of positive moment occurs under the shear wall. Change in moments under shear wall along direction perpendicular at some cases are very high. Shear wall location at the edge of mat causes pronounced variation in moment under shear wall. Shear wall location in any intermediate place between edges causes less variation in bending moment. The change in long direction moment is more pronounced for non-uniform mat.

Flexural shear stress produced along the line between column lines is well below the flexural shear capacity of the section. All the locations of shear wall produces less amount of shear stress in the mid panel. Shear stress at face of shear wall for lateral load combination is high. But total shear force along the shear wall face is lower than the total shear force capacity of the section. So local increase in shear stress will not impart enough threat to the mat.

Overall settlement of mat foundation increases due to the presence of shear wall. Differential settlement of mat foundation also increases significantly. For non-uniform thickness mat the differential settlement is high for shear wall presence at the edge of mat. For uniform thickness mat the differential settlement caused by shear wall in any mid position on mat is well below the tolerable limit.

Differential settlements along lines in between column lines are not much for both uniform and non-uniform thickness mat.

The study reveals that the shear wall location at the edge of mat has the most significant influence on mat behaviour.

CHAPTER 6

DESIGN OF MAT FOUNDATION WITH SHEAR WALL

6.1 GENERAL

An understanding of the actual behaviour of mat with shear wall is essential to ensure economy in design. Present study focuses on the influence of shear wall presence on mat foundation. It reveals considerable changes in mat behaviour due to shear wall on it. So commonly practised design methods of uniform and non-uniform mat foundation are to be adjusted to cope with the shear wall effect on it. Ultimate strength design method of American Concrete Institute is followed for the design.

6.2 DIFFICULTIES IN FORMULATING THE MAT BEHAVIOR

Mat foundation is a simple structure. Once everything is set by the engineers and architects for a particular project, it has a relatively small number of parameters to be dealt with, such as elastic properties of mat material, modulus of subgrade reaction of the supporting soil and mat thickness. Difficulty with the formulation of the characteristics of mat arises from its loading pattern.

Structurally mat acts integrally with the building frame it supports. Mat resists loads which do not act on it directly but comes through the frame. Generally, to analyse mat, moments and axial forces produced in response to external loads acting on the frame is calculated first and applied on mat later.

Magnitude of load on mat varies mainly depending on column spacing, number of bay and number of stories. Shear wall presence in superstructure causes considerable changes in loading on mat. Mat foundation is provided beneath the super structure to distribute the load to substratum.

Available approximate solutions for mat foundation with uniform and non-uniform thickness are results of various parametric studies of many people. The methods are for column loading only.

The reactive soil pressure under mat is not uniform but varies a lot along the span. High reactive soil pressure acts under the column, shear wall and their surrounding zones. This pressure is less away from the column face, near the midspan. In finite element analysis, soil is generally modeled with spring elements. Modulus of subgrade reaction is concentrated at the corner nodes of element. Reaction of spring represents the soil pressure.

6.3 GENERAL DESIGN REQUIREMENTS FOR MAT FOUNDATION

Mat is a two-way flexural member supporting super structures and directly supported by soil. Naturally, design of mat is governed by deflection, bending moment and shear force considerations. In order to be structurally safe, mat must be strong enough to resist the moments and shears produced by the column and shear wall loads. Settlement of mat must also be within allowable limits.

6.3.1 Settlement Requirements For Mat Foundation

Flotation effect and plate behaviour enable most settlements to be limited to tolerable magnitudes. Also, it is easier to conceal any reasonable amount of overall settlement by providing higher plinth level initially. A problem of considerable concern is differential settlement, which may induce detrimental stresses in the superstructure. This is why strict control of differential settlement is necessary.

McDonals and Skempton (1955), Fled (1965) and Grant et. al. (1974) conducted comprehensive study on settlement of large number of constructed buildings. All these sources, give rise to a conclusion that for mat foundation on clay, recommended design differential settlement is 64 to 102 mm and for satisfactory differential settlement should never be greater than 76 to 126 mm. For mat on sand the respective ranges are 38 to 64 mm and 50 to 76 mm. These are however safe ranges determined from only statistical surveys. According to USSR building code, acceptable slope between two points of mat supporting concrete frame structures is 0.002, with an average maximum settlement of 102 mm. Study by Terzaghi and Peck(1967) recommends most widely accepted thumb rule that expected maximum settlement for mat should be 50 mm and expected differential settlement would be less than 20 mm.

According to BNBC, allowable or limiting settlement of a building structure will depend on nature of the structure, the foundation and the soil. As a general rule, a total settlement of 25 mm and a differential settlement of 20 mm between the columns in most buildings shall be considered safe for buildings on isolated footings. Buildings on mat can usually tolerate greater total settlements.

6.3.2 Design of Mat Under Bending Moment

Design of mat for bending moment is straight forward. Since mat suffers from two directional bending, strips of mat is selected in two perpendicular directions and the strips are designed as beams for critical positive (upside compression) and negative (bottom side compression) moments. ACI Code restricts that a minimum steel ratio be maintained for any section, both near the top and near the bottom of mat. Although design positive moments should be those at the faces of the columns according to ACI Code.

Formula used for calculation are given below.

Effective Depth , d = t - clear cover.

Steel Ratio , ρ = A_s/bd

Maximum Steel ratio, ρ_{max} = $0.75 \times 0.85 \times \beta_1 \times \frac{f_c'}{f_y} \times \frac{87000}{87000 + f_y}$

$$\beta_1 = 0.85 - 0.05 \times \frac{f_c' - 4000}{1000} \, and \, 0.65 \le \beta_1 \le 0.85$$

Minimum Steel ratio, ρ_{min} = $200/f_y$ (f_y in psi)

Ultimate Moment capacity, M_u = $\varphi \rho f_y b d^2 (1 - 0.59 \frac{\rho f_y}{f_c'})$

6.3.3 Design of Mat Under Shear Force

Perhaps the most important design criteria for mat foundation is the shear force. Since mat is a plate structure, shear reinforcements is avoided for practical considerations. Instead mat is made sufficiently thick to withstand shear. Presence of heavy column loads concentrated on very small areas makes considerations of punching shear, in addition to flexural shear, essential. As per ACI Code, punching shear is calculated as the total shear force acting on the surface of a peripheral section around the column under consideration, taken at distance d/2 from each face of that column, where d is the effective depth of mat. Physically, punching shear is the column load less the total soil pressure under the punching area of that column. Both the flexural and punching shear stresses must be lower than the respective ACI shear capacities of the mat section. According to ACI Code, flexural shears are to be considered at a distance d away from the column faces.

ACI design formula for shear capacities are

Ultimate punching shear strength, $v_{pu} = 4\varphi\sqrt{f'_c}$

Ultimate flexural shear strength, $v_{fu} = 2\varphi\sqrt{f'_c}$

Where φ is the strength reduction factor and equal to 0.85. f'_c is the concrete strength in psi.

6.4 PROSPECT OF NON-UNIFORM THICKNESS OF MAT WITH SHEAR WALL

Studies by Morshed (1996), Sutradhar (1999) and Rahman (2001) reveal that response of mat foundation with column loading follows regular trend. They have established that the mid span flexural shear is quite low and the shear can be taken only by thickness 54.5% of the mat thickness calculated from punching criteria. Their studies also show that the design of mat foundation is mostly governed by the minimum reinforcement criteria for resisting the bending moment. The Reduced thickness, t_r for mat with non-uniform thickness at midspan is also governed by negative moment. As midspan thickness decreases negative moment decreases and the capacity of the section also decreases. A thickness 60% of mat thickness with minimum reinforcement is sufficient to resist the negative moment at mid section.

The present study has revealed that use of shear wall increases the mid span negative moment significantly. For any location of shear wall, negative moment at adjacent mid span/ spans and the negative moment in the exterior spans increases. Present study shows that reduction of thickness in mid span causes rapid increase in negative moment when shear wall is used. Negative moment produced close to shear wall is considerably higher than the moment capacity of the section with minimum reinforcement. In the present study the maximum value of negative moment in the adjacent panel to shear wall is found to be 722.4 kN-m/m and the least value found is 403.8 kN-m/m. But all the cases the moment capacity with minimum reinforcement of the corresponding section is 280.2 kN-m/m. For uniform thickness mat, negative moment can increase up to 30% depending on the location of shear wall. And this increase in negative moment of uniform mat brings the moment of the section higher or close to the section moment capacity with minimum reinforcement. But for both uniform and non-uniform mat the negative moment at panel away from shear wall do not suffer significant change due to presence of shear wall. So the thickness of mat at the negative moment zone of panels away from shear wall can be reduced. But different combination of thicknesses for the same mat may not be desirable. It is found, Table5.3, that negative moments in panel adjacent to shear wall can be resisted by reduced thickness with reinforcement calculated from minimum criteria of mat thickness for shear wall locations other than edge.

In the present study it is found that flexural shear at the mid part between column lines remain well below the section flexural shear stress capacity. So the use of shear wall does not change the mid panel flexural shear to a value that requires additional attention. But the shear stresses at distance 'd' from the face of shear wall as shown in Table 5.8 are not low. Stresses at the face of wall are higher than the section's concrete shear capacity. As mat is a plate type structure local increase in shear stress will not cause failure. In Chapter 4, it has been shown that along the line of critical section flexural shear has higher shear stresses at some portion of the line, but total flexural shear capacity along the line is much higher than the total shear force acting along the line. Table 5.9 also shows that total shear force acting along the face of shear wall for entire width is below the total shear force capacity of the width. So, it is seen that flexural shear will not cause any problem for mat foundation with shear wall placed on it.

Presence of shear wall on mat foundation significantly increases differential settlement of mat. It was observed that the shear wall at the edge of mat causes the highest amount of differential settlement both for uniform and non-uniform mat. Parametric study in Chapter 4 shows that the decrease in subgrade reaction causes a rapid increase in deflection. So for subgrade reaction lower than 16 MN/m^3 will cause much higher differential settlement.

6.5 DESIGN RECOMMENDATIONS FOR MAT FOUNDATION WITH SHEAR WALLS

The present study recommends the use of uniform thickness for panels of mat foundation which are close to shear wall.

For structural design of mat, differential settlement is more important than total settlement. For structural consideration of a building, column to column differential settlement is the main concern. Use of shear wall in superstructure increases this differential settlement. For soil with low uniform subgrade reaction, use of uniform thickness can reduce the differential settlement.

Fig.5.17 to Fig.5.21 shows the long direction moment variation for column and shear wall loading. Magnitude and variation in bending moment is low for the case of column loading. In case of shear wall loading high positive and negative moments are produced below the shear walls. This variation remains significant for the panel adjacent to shear wall. Moments along long direction in panel far from shear walls are small enough to be resisted by minimum reinforcement.

Salient design recommendations are given below:

- Uniform thickness should be preferred for panel close to shear wall for mat foundation. Thickness should be calculated from the punching criteria. Ninety-five percent of the maximum column load can be used to calculate minimum thickness required as prescribed in methods by Rahman and Morshed. Thickness calculated in this way has been found to be satisfactory.

- When negative moment in panel adjacent to shear wall is less than the moment capacity of the section with minimum reinforcement, then middle strip of every panels where negative moment is produced would be dominated by minimum reinforcement criteria for uniform mat.

- Positive moment perpendicular to the direction of shear wall increases significantly for presence of shear wall. For rectangular mat with column, the minimum reinforcement is sufficient to resist the moments in long direction. But when shear walls are present then higher amount of reinforcement is required.

- Significant local increase in shear stress is found at face of shear wall. But overall shear force along the face of shear wall acting in the entire width, is always found to be less than the capacity of section to withstand shear force. Thus flexural shear does not pose any threat to mat.

- Additional attention is required for designing the reinforcement of panels close to shear wall. Equal attention is required for designing the reinforcement of exterior panel as the exterior panels also suffer significant change in parameters for any location of shear wall.

- Shear walls at the edges of mat requires care as the influence of shear wall on mat is found to be most significant when shear walls are placed at the edge of mat. Special consideration is necessary to control the differential settlement of mat when shear wall is at the edge of mat and the subgrade reaction of soil is low.

- Reduced thickness can be used for mat with shear walls for shear wall location in some intermediate place. At that case reduced thickness (60% of mat thickness) with reinforcement calculated from minimum criteria of mat thickness is found to be sufficient for mid of panels away from shear wall.

CHAPTER 7

CONCLUSION

7.1 GENERAL

Mat foundation is a relatively heavy and costly structure. Optimum design of mat foundation has always been engineer's dream. Various analysis and design methods and guidelines focused on structural behaviour of mat. But variation in mat behaviour for presence of shear wall was not duly addressed in those methods. An appropriate design guideline for mat with shear wall to achieve overall economy is a strong urge for concerned people. Non-uniform thickness mat is also another way of achieving economy in design. General approach of the methods for non-uniform mat was followed to investigate the future of mat foundation with non-uniform thickness for shear wall presence. The specific objective of this study was to understand the behaviour of mat foundation with shear wall loading. Parametric study on two significant parameters, modulus of subgrade reaction and smaller thickness, has been carried out in this investigation. Each parameter has been widely varied within the practical range. On the basis of this extensive study design recommendations have been made for mat with shear wall.

7.2 SUMMARY OF THE FINDINGS FROM THIS INVESTIGATION

The present study has focused specifically on the behaviour of uniform and non-uniform mat foundation with shear wall. The significant differences in the mat response to shear wall loading and to the column loading have become obvious from this investigation.

Parametric study reveals that both soil subgrade reaction and mat-thickness have considerable effect on the behaviour of mat with shear wall. Shear wall on mat foundation causes higher differential settlement than the settlement caused due to the absence of shear wall. Differential settlement is most significant along the line of shear wall. Mat on soil with high subgrade reaction undergoes less settlement. Increase in subgrade reaction from 8.0 MN/m^3 to 32.0 MN/m^3 causes a reduction in settlement of mat nearly seventy to ninety percent at some points. Variation in subgrade reaction has less impact on variation of bending moment and shear stress. Displacement has been identified as the most sensitive to the variation of subgrade reaction for mat with shear wall. This settlement problem is higher for soil with low subgrade reaction.

Bending moment and deflection has been found to vary considerably due to the variation in smaller thickness at zones of negative moment. Negative moment at mid span increases with increase in smaller thickness at that zone. Shear wall location at edge of mat is found to be most critical and a reduced thickness higher than 80% of mat thickness is sufficient to resist negative moment at mid zones for that case. For other locations of shear wall, further reduced thickness may be used in negative moment zone.

Study shows that for both uniform and non-uniform mat amount of overall settlement is high. Differential settlements are higher with the presence of shear wall, non-uniform mat faces even higher differential settlement. For uniform mat, differential settlement is found to increase up to 52% over that for frame superstructure in the present study. Increase in differential settlement for shear wall location other than edge is not much significant. But for any location of shear wall, differential settlement is comparatively high for non-uniform mat.

Shear wall placed at the edge of foundation causes the most significant variation in different design parameters like bending moment, shear and settlement of mat foundation. Shear walls at edges increase the negative moment and settlement of foundation. The change in negative moment in the panel adjacent to shear wall is found to be as much as 30%. Percent increase in negative moment in adjacent panel is nearly the same for uniform and non-uniform mat. Presence of shear wall at any intermediate locations has less significant variation in moment, shear and settlement.

It has been found that high positive moment is produced below the shear wall. Additional attention is required for resisting that positive moment under shear wall.

Panels adjacent to shear walls face the most significant variation in different design parameters like bending, settlement. So design of panels adjacent to shear wall need to be done with special care. The panels away from the shear wall suffer insignificant change in different design parameters. Bending moment and shear stress produced in the panel away from the shear wall are nearly the same as those produced when no shear wall is used.

Shear wall presence in the intermediate locations other than the edges of mat has insignificant effect on mat behaviour. Except the moments produced in the column lines and shear wall lines, other intermediate moments can be resisted by minimum reinforcement. When shear wall is placed on edge of mat, additional attention is required to control differential settlement and bending moment.

Non-uniform mat with shear wall can be economical if the location of shear wall is at some intermediate place on mat. In those cases the mid panel negative moments can be resisted by reduced thickness with reinforcement calculated for minimum criteria of mat thickness. The study reveals that thickness at the middle of panels away from shear wall can be reduced up to 40% for any location of shear wall.

7.3 RECOMMENDATIONS FOR THE FUTURE STUDY

The following recommendations are presented based on the present study for future study

- In the present study influence of planer shear wall has been investigated. Effect of Lift core, T-shape, L-shape shear walls on mat foundation has to be investigated.

- Behaviour of irregularly shaped mat, mat with punches, mat with irregular location of shear wall and non-uniform column spacing may be studied for loading from shear wall and lift core.
- Dynamic soil-mat interaction may be analysed using FE method.
- The interaction of mat soil by using appropriate interface element and incorporating soil non-linearity may be investigated.
- Soil and mat have been modelled as linearly elastic material in the current study. A non-linear analysis may be performed.
- Three dimensional shear wall-mat interaction may be studied.

REFERENCES

ACI Committee 436 (at present committee 336), (1966), "Suggested Design Procedure for Combined Footing and Mats", *ACI Journal Proceedings*, 63(10), 1041-1057.

Ahmad, S., Irons, B.M. and Zienkiewicz, O.C. (1970), "Analysis of Thick and Thin Shell Structures by Curved Finite Elements", *International Journal of Numerical Methods in Engineering*, 2, 419-451.

Ahmad, S. (1969), "Curved Finite Elements in the Analysis of Solid, Shell and Plate Structures", Ph.D. Thesis, College of Swansea.

Arora, K.R., (1992), "Soil Mechanics and Foundation Engineering", 1st Ed., Standard Publishers and Distributors, New Delhi.

Bangladesh National Building Code (BNBC), (1993), " Foundation", Art 3.9, pp. 6-69.

Bathe, K.J. (1976), "Numerical Methods in Finite Element Analysis", 1st Ed., Prentice Hall Inc., New Jersey.

Bowels, J.E. (1988), "Foundation Analysis and Design", 4th Ed., McGraw Hill Book Co., New York.

Bowels, J.E. (1974), "Analytical and Computer Methods in Foundation Engineering", 1st Ed., McGraw Hill Book Co., New York.

Bowels, J.E. (1986). "Mat Design", *ACI Journal*, 83(6), pp.1010-1017.

Broms C.E. (2000), "Elimination of flat plate punching failure Mode", *ACI Structural Journal*, .97, pp.94-101.

Chilton, D.S. and Wekezer, J.W. (1990), "Plates on Elastic Foundation", *Journal of Structural Engineering*, ASCE, 116(11), pp.3236-3241.

Coull, A. and Smith, S.B(1991), " Tall Building Structures: Analysis and Design", John Wiley & Sons,Inc. New York. pp.79-91

Coull, A. and Mukherjee,P.R.(1974),"Coupled Shear Walls with General Support Conditions", Proceedings of Conference on Tall Buildings, Kuala Lumpur, pp.4.24-4.30

Das, B. M. (1983), "Advanced Soil Mechanics", 1st ed., Hemisphere Publishing Corporation, Washington.

Desalvo, G.J. and Swanson, J.A. (1994), " Ansys-user manual", Swanson analysis system Inc., Houston, Pa.

Deryck, N. and Severn, R.N. (1960), "Stresses in Foundation Rafts", *Proceedings, The Institute of Civil Engineers (London)*, Vol. 20(2). pp.293-304.

Deryck, N., and Severn, R.N. (1960), "Stresses in Foundation rafts", *Proceedings, The Institution of Civil Engineers (London)*, 15(1), pp.35-48.

Gupta, A. and Patel, A.N.(1996), "Rational Analysis of Mat Foundations Using Finite Element Technique", *Proceedings, The International Seminar on Civil Engineering Practice in the Twenty first Century*, Roorkee, 1, pp.149-159.

Grant, R. et. al. (1974), " Differential Settlement of Buildings", JGED, ASCE, 100(9), pp.973-991.

Hemsley, J.A. (1987), "Elastic Solutions for Axisymetrically Loaded Circular Raft with Free or Clamped Edges Founded on Winkler Springs or a Half-space", *Proceedings, The Institute of Civil Engineers (London)*, 83(2), pp.61-90.

Hemsley, J.A. (1988), "Plane Elastostatic Flexure of an Infinite Plate on a Half Space", *Proceedings, The Institute of Civil Engineers (London)*, 85(2), pp.629-664.

Hetenyi, M. (1946), "Beams on Elastic foundation", 1st Ed., University of Michigan Press, En Arbor.

Horvath, J.S. (1983), "New Subgrade Model Applied to Mat Foundations", *Journal of Geotechnical Engineering*, ASCE, 109(12), pp.1567-1587.

Horvath, J.S. (1993), "Modulus of Subgrade reaction: New Perspective", *Journal of Geotechnical Engineering*, ASCE, 109(12), pp.1591-1596.

Hossain, T.R. (1993), "Comparative Study of the Analysis Techniques of Mat Foundation", M.Sc. Thesis, BUET, Dhaka.

Irons, B. and Ahmad, S. (1980), "Techniques of Finite Elements", 1st Ed., Ellis Horwood Ltd., Chichester.

Khan, F.R and Sbarouns,J.A(1964), " Interaction of Shear Wall and Frames", Journal of Structural Division, Proceedings of ASCE90, pp285-335

Korenov E. J. (1960), " Bearing capacity of footings in Pile driving", JSMFD, ASCE, 87(4), pp.124-145.

Krishnamoorthy, C.S. (1987), "Finite Element Analysis : Theory and Programming", 1st ed., Tata McGraw Hill Publishing Co. Ltd., New Delhi.

Liou G. S. and Lai S.C. (1996), "Structural analysis model for mat foundation", *Journal of Structural Engineering,* ASCE, 122(9), pp.1114-1117.

Mician, R. (1985), "Discussion on a Simplified Method for Design of Mat on Elastic Foundation (paper by Shukla, S.N.)", *ACI Journal,* pp.584-586.

Molla, M.A.S. (1995), "Finite Element Analysis of Footings and Mat foundations", M.Sc. Thesis, BUET, Dhaka.

Morshed A.S.M. (1996), "A Design Rationale for Mat Foundation Based on Finite Element Analysis", M.Sc. Thesis, BUET, Dhaka,

Nilson A.H. (1997), "Design of Concrete Structures", Twelfth Edition, McGraw Hill Book Co., New York.

Rahman, S.M. (2001), "An Improved Design Approach for Mat Foundation with Variable Thickness", M.Sc. Thesis, BUET, Dhaka,

Schueller, W.(1977), "High-rise Building Structures", John Wiley & Sons,Inc. New York.

Scott, R.F. (1981). "Foundation Analysis", 1st Ed., Prentice Hall Inc., New Jersey.

Selvadurai, A.P.S. "Elastic Analysis of Soil Foundation Interaction", Developments in Geotechnical Engineering, Vol. 17, Elsevier Scientific Publishing Company, New York.

Shukla, S.N. (1984), "A Simplified Method for Design of Mats on Elastic Foundation", *ACI Journal*, 81(5), pp.469-475.

Schleicher, F. (1968), "Kreisplatten aut Elastischer Unterlage", Julius Springer, Berlin.

Sutradhar A.(1999), "An Improved Design Rationale for Mat Foundation Based on Finite Element Analysis", M.Sc. Thesis, BUET, Dhaka.

Steven C. Ball and James S. N. (1984), "Computer Analysis and Design of Large Mat foundation", *Journal of Structural Engineering*, ASCE, 110(5).

Teng, W.C. (1999), "Foundation design", 13 th Ed., Prentice Hall of India Private Limited, New Delhi.

Zimmermann A. (1958), " A method to estimate modulus of subgrade reaction", *Soils and foundations*, Tokyo, Japan, 12(3), pp.1 -17.

APPENDIX A

SHELL93: 8 NODE STRUCTURAL SHELL ELEMENT

A.1 BRIEF DESCRIPTION OF SHELL93 ELEMENT

Shell93 is an eight node structural element of ANSYS library function. Shell93 is well suited to model curved elements. Typical shell elements are shown in Fig A.1. The element has six degrees of freedom at each node: translations in the nodal x, y, z directions and rotations about the x, y, z axes. The deformed shapes are quadratic in both in-plane directions. The element has bending effect, transverse shear deformation, plasticity, stress stiffening, large deflection and large strain capabilities.

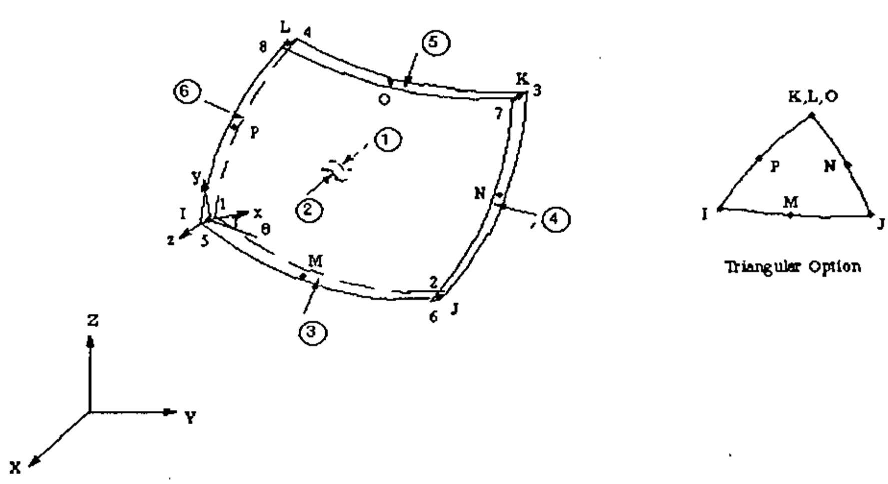

Fig. A.1 SHELL93: 8 node structural shell

A.1.1 Geometric Definition of the Element:

The geometry, node locations and the co-ordinate system for this element are shown in Fig. A.1. The element is defined by eight nodes, four thickness and the orthotropic material properties. Mid-side nodes may not be removed from this element. A triangular shaped element may be formed by defining the same node number for nodes K, L and O. Orthotropic material directions correspond to the element coordinate directions.

The element x and y axis are in the plane of the element. The element may have variable thickness. The thickness is assumed to vary smoothly over the area of the element, with the thickness input at the corner nodes.

A.1.2 Loading of the Element

Pressures may be input as surface loads on the element faces. Positive pressures act into the element. Edge pressures are input as force/unit length. Temperatures may be input as element body loads at the corner.

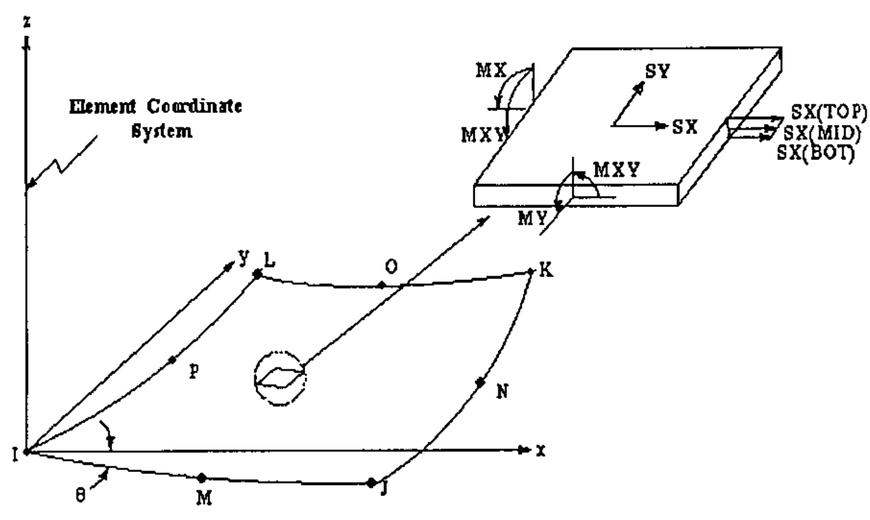

Fig. A.2 SHELL 93 stress output

A.2 OUTPUT DATA

The solution output associated with the elements is in two forms: (a) nodal displacements included in the overall nodal solution, and (b) additional element output is shown in table A.1. Several items are illustrated in Fig. A.2. The element stress directions and force resultants are parallel to the element coordinate system.

Table A.1 Shell93 Element input and output definitions

Name	Definition
EL	Element number and name
NODES	Nodes –I, J, K, L,M, N,O,P
MAT	Material number
THICK	Average thickness
S: INT	Stress Intensity
S:EQV	Equivalent stress
EPEL : X,Y,Z, XY, YZ, XZ	Elastic Strains
S: 1, 2, 3	Principal Stresses
T (X, Y ,XY)	In plane element X,Y, and XY forces
M (X, Y, XY)	Element X, Y, and XY moments.
N (X, Y)	Out-of-plane element X and Y shear forces.

A.3 ASSUMPTIONS AND RESTRICTIONS

Zero area elements are not allowed. This occurs most often whenever the elements are not numbered properly. Zero thickness elements or elements tapering down to zero thickness at any corner are not allowed. The applied transverse thermal gradient is assumed to vary linearly through the thickness. Shear deflections are included in this element. The element may produce inaccurate stress under thermal loads for double curved warped domains.

APPENDIX B

COMBIN14 : SPRING DAMPER ELEMENT

B.1 BRIEF DESCRIPTION OF THE ELEMENT

Combin14 has longitudinal or torsional capability in one, two, or three dimensional applications. The longitudinal spring–damper option is a uniaxial tension-compression element with up to three degrees of freedom at each node: translations in the nodal x, y and z directions, no bending or torsion is considered. The torsional spring damper option is a purely rotational element with three degrees of freedom at each node: rotations about the x, y, and z axis. No bending or axial load is considered.

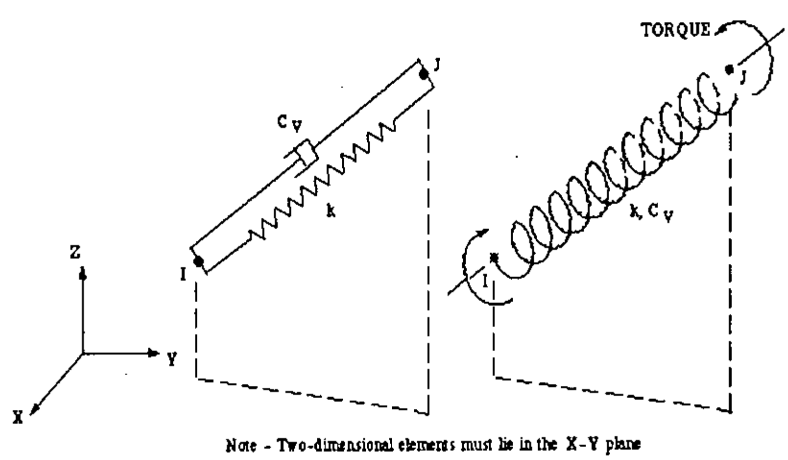

Fig. B.1 COMBIN14 spring damper

The spring damper element has no mass. Masses can be added by using the appropriate mass element. The spring or the damping capability may be removed from the element.

B.1.1 Geometric Definition of the Element

The geometry, node locations and the coordinate system for this element is shown in Fig. B.1. The element is defined by two nodes, a spring constant and damping coefficient c_{v1} and c_{v2}. The damping capability is not used for static and undamped modal analyses. The longitudinal constant has units of force/unit length.

The element has option for defining the element as a one dimensional element. With this option the element operates in the nodal coordinate system.

B.2 OUTPUT DATA

The solution output associated with the element is in two forms: (a) nodal displacements included in the overall nodal solution, and (b) additional element output is shown in table B.1.

Table B.1 COMBIN14 element input and output definitions.

Name	Definitions
EL	Element Number
NODES	Nodes - I, J
CENT: X, Y, Z	Center Location XC, YC, ZC
FORC or TORQ	Spring Force or Moment
RATE	Spring Constant

B.3 ASSUMPTIONS AND RESTRICTIONS

The length of the element must not be zero, since the node locations determine the spring orientation. The longitudinal element stiffness of the spring acts along the length of the spring. The element allows only a uniform stress in the spring. The element can be modified to act along only one degree of freedom and no moment effects are included.

In this study the element has only one degree of freedom. This degree of freedom is specified in the nodal coordinate system and is the same for both nodes.

APPENDIX C

MACRO USED FOR ANALYSIS

C.1 GENERAL

Macro is a text file, which can be called from ANSYS command line. Commands are written in this file. This is used for modeling, solution and viewing output of the structure. This is one type of sub-programming. A macro file can invoke another macro file. A set of macro files has been used for modeling, solution and post processing purpose. Text files as macro files are given for prospective researchers.

Following six files are used to model a mat foundation of twelve storied building of five bays with variable thickness, solution and for post processing purpose.

C.2 MODELING OF NON-UNIFORM MAT FOUNDATION WITH SHEAR WALL.

File 1: Param.txt

```
! !***************************
!SETTING THE PARAMETERS
!***************************

!************************
!Generating the nodes
!************************

*dim,a,,130
*set,a(1),1,1,1,1,1,1,1,1,1,1
*set,a(11),1,1,1,1,1,1,1,1,1,1
*set,a(21),1,1,1,1,1,1,1,1,1,1
*set,a(31),1,1,1,1,1,1,1,1,1,1
*set,a(41),1,1,1,1,1,1,1,1,1,1
*set,a(51),1,1,1,1,1,1,1,1,1,1
*set,a(61),1,1,1,1,1,1,1,1,1,1
```

```
*set,a(71),1,1,1,1,1,1,1,1,1,1
*set,a(81),1,1,1,1,1,1,1,1,1,1
*set,a(91),1,1,1,1,1,1,1,1,1,1
*set,a(101),1,1,1,1,1,1,1,1,1,1
*set,a(111),1,1,1,1,1,1,1,1,1,1
*set,a(121),1,1,1,1,1,1,1,1,1,1


*dim,b,,70
*set,b(1),1,1,1,1,1,1,1,1,1,1
*set,b(11),1,1,1,1,1,1,1,1,1,1
*set,b(21),1,1,1,1,1,1,1,1,1,1
*set,b(31),1,1,1,1,1,1,1,1,1,1
*set,b(41),1,1,1,1,1,1,1,1,1,1
*set,b(51),1,1,1,1,1,1,1,1,1,1
*set,b(61),1,1,1,1,1,1,1,1,1,1


!row1 starting node in x-dir
*set,ndr1st,1
*set,x1,0
*set,y1,0
*set,z1,0

!row1 ending node in x-dir
*set,ndr1end,127
*set,x2,126
*set,y2,0
*set,z2,0

!number of rows in z-dir
*set,totrow,67
!spacing of rows in Z-dir
*set,spzrow,1

!generating nodes (copying) in y-dir.
!number of y copy
*set,nycopy,2
!spacing of rows in y-dir
*set,spyrow,-4

!Starting node of free end nodes of springs of row1
*set,sprndst,ndr1end*totrow+1

!Ending node of free end nodes of springs of row1
*set,spr1nden,(ndr1end*totrow+ndr1end)
```

```
!*******************************
!Defining the Material Properties
!*******************************
!material properties ex,poisson's ratio for Shell Element
*set,ex1,5.19e5
*set,nuxy1,0.15

!Defining Element Type to be used
!shell93,combin14 with key opt2 is used

! setting element numbers
*set,elr1st,1
*set,elr1end,(ndr1end-1)/2
*set,elshlst,((ndr1end-1)/2)*((totrow-1)/2)
*set,spr1rep,(totrow+1)/2

! setting spring numbers for first row
*set,spr1,elshlst+1
*set,spr1end,(elshlst+(ndr1end+1)/2)

! setting spring numbers for last row
*set,sprlast,spr1+(spr1rep-1)*(spr1end-spr1+1)
*set,sprlaend,spr1end+(spr1rep-1)*(spr1end-spr1+1)


! number of springs in first X-row.

*set,sprxnum,spr1end-spr1+1
```

File 2: Realcon.txt

```
! Declaration of element real constants
!number of real constant sets for shell
*set,shset,10
!Defining Various thickness
*set,a1,3.5
*set,b1,2.00
*set,spring,400
!Shell thickness Set1
*set,th11,a1
*set,th12,a1
*set,th13,a1
*set,th14,a1
```

```
!Shell thickness Set2
*set,th21,b1
*set,th22,b1
*set,th23,b1
*set,th24,b1
!Shell thickness Set3
*set,th31,b1
*set,th32,b1
*set,th33,a1
*set,th34,b1
!Shell thickness Set4
*set,th41,b1
*set,th42,a1
*set,th43,a1
*set,th44,b1
!Shell thickness Set5
*set,th51,b1
*set,th52,a1
*set,th53,b1
*set,th54,b1
!Shell thickness Set6
*set,th61,b1
*set,th62,b1
*set,th63,a1
*set,th64,a1
!Shell thickness Set7
*set,th71,b1
*set,th72,b1
*set,th73,b1
*set,th74,a1
!Shell thickness Set8
*set,th81,a1
*set,th82,b1
*set,th83,b1
*set,th84,a1
!Shell thickness Set9
*set,th91,a1
*set,th92,b1
*set,th93,b1
*set,th94,b1
!Shell thickness Set10
*set,th101,a1
*set,th102,a1
*set,th103,b1
*set,th104,b1
! spring constant sets for mat central, side, corner
```

```
!spring Constant set for central
*set,sprcon1,spring
!spring Constant set for side
*set,sprcon2,spring/2
!spring Constant set for corner
*set,sprcon3,spring/4


!Real Constant Sets For Shells upto number of shell set.

r,1,th11,th12,th13,th14
r,2,th21,th22,th23,th24
r,3,th31,th32,th33,th34
r,4,th41,th42,th43,th44
r,5,th51,th52,th53,th54
r,6,th61,th62,th63,th64
r,7,th71,th72,th73,th74
r,8,th81,th82,th83,th84
r,9,th91,th92,th93,th94
r,10,th101,th102,th103,th104

! Spring Constant Set for springs after shell set

r,shset+1,sprcon1
r,shset+2,sprcon2
r,shset+3,sprcon3
```

File 4: Model.txt

```
!Entering into Pre-Processor  mode

/prep7
/TITLE, MAT FOUNDATION WITH SHEAR WALL
! Calling input parameters
*use,param.txt
!pnum,lab,key          ( 0 : off, 1 : on)
/pnum,node,0

!Generating nodes in X-direction
i=1
*do,ndx,ndr1st,ndr1end,1
n,ndx,x1,y1,z1
x1=x1+a(i)
i=i+1
```

```
*enddo

!fill,ndr1st,ndr1end
!ngen,itime,inc,node1,node2,ninc,dx,dy,dz,space

!Generating nodes Z direction  copying row 1
i2=0
i=1
*do,ndz,2,totrow,1
spzrow=b(i)
ngen,2,ndr1end,ndr1st+i2*ndr1end,ndr1end+i2*ndr1end,1,0,0,spzrow
i2=i2+1
i=i+1
*enddo
!copying nodes in X-Z plane  to another X-Y plane
ngen,nycopy,ndr1end*totrow,ndr1st,ndr1end*totrow,1,0,spyrow,0
/units,si

!Setting material properties for Shell elements
mp,ex,1,ex1
mp,nuxy,1,nuxy1

! Defining element type
et,1,shell93
et,2,combin14,0,2

!Calling real constants for elements
*use,realcon.txt

/pnum,elem,0   !(0 : off, 1 : on)
!Generation of  structural shell elements
type,1
mat,1
real,1
en,elr1st,2*ndr1end+1,ndr1st,ndr1st+2,2*ndr1end+3,ndr1end+1,ndr1st+1,ndr1end+3,2*n
dr1end+2
!egen,itime,ninc,iel1,iel2,ieinc,tinc,rinc,cinc
egen,(ndr1end-1)/2,2,elr1st,elr1st
egen,(totrow-1)/2,2*ndr1end,elr1st,elr1end

!Generation of  spring elements
type,2
real,shset+1
en,spr1,ndr1st,sprndst
egen,(ndr1end+1)/2,2,spr1,spr1
egen,spr1rep,2*ndr1end,spr1,spr1end
```

```
/eshape,1
! Modification of  uniform mat to non uniform mat foundation.
*use,emod.txt

! Setting spring constants for all springs
*use,emodsp.txt

! Defining support condition and symmetry condition.
*use,support.txt

! Calling loads on the model.
*use,load.txt
```

File 5 : Support.txt

```
! Defining support condition
*do,i,0,totrow-1,2
d,sprndst+i*ndr1end,all,,,spr1nden+i*ndr1end,2
*enddo

!Defining symmetry condition
d,ndr1st+(totrow-1)*ndr1end,rotx,,,ndr1end*totrow,2
d,ndr1st+(totrow-1)*ndr1end,uz,,,ndr1end*totrow,2

d,ndr1end,rotz,,,ndr1end*totrow,2*ndr1end
d,ndr1end,ux,,,ndr1end*totrow,2*ndr1end
```

File 6: emod.txt

```
! This page will be used to convert the shell real constants
! This page will be used to convert the mat foundation with constant thickness to mat
!foundation with non-uniform thickness.

! This page will be used to convert the shell real constants
FLST,2,48,2,ORDE,32
FITEM,2,190
FITEM,2,-192
FITEM,2,202
FITEM,2,-204
FITEM,2,214
FITEM,2,-216
FITEM,2,226
FITEM,2,-228
```

```
FITEM,2,238
FITEM,2,-240
FITEM,2,250
FITEM,2,-252
FITEM,2,832
FITEM,2,-834
FITEM,2,844
FITEM,2,-846
FITEM,2,856
FITEM,2,-858
FITEM,2,868
FITEM,2,-870
FITEM,2,1450
FITEM,2,-1452
FITEM,2,1462
FITEM,2,-1464
FITEM,2,1474
FITEM,2,-1476
FITEM,2,1486
FITEM,2,-1488
FITEM,2,1498
FITEM,2,-1500
FITEM,2,1510
FITEM,2,-1512
EMODIF,P51X,REAL,4,

FLST,2,1535,2,ORDE,194
FITEM,2,5
FITEM,2,-11
FITEM,2,17
FITEM,2,-23
FITEM,2,29
FITEM,2,-35
FITEM,2,41
FITEM,2,-47
FITEM,2,53
FITEM,2,-59
FITEM,2,68
FITEM,2,-74
FITEM,2,80
FITEM,2,-86
FITEM,2,92
FITEM,2,-98
FITEM,2,104
FITEM,2,-110
FITEM,2,116
```

```
FITEM,2,-122
FITEM,2,131
FITEM,2,-137
FITEM,2,143
FITEM,2,-149
FITEM,2,155
FITEM,2,-161
FITEM,2,167
FITEM,2,-173
FITEM,2,179
FITEM,2,-185
FITEM,2,194
FITEM,2,-200
FITEM,2,206
FITEM,2,-212
FITEM,2,218
FITEM,2,-224
FITEM,2,230
FITEM,2,-236
FITEM,2,242
FITEM,2,-248

FITEM,2,253
FITEM,2,-567

FITEM,2,572
FITEM,2,-578
FITEM,2,584
FITEM,2,-590
FITEM,2,596
FITEM,2,-602
FITEM,2,608
FITEM,2,-614
FITEM,2,620
FITEM,2,-626
FITEM,2,635
FITEM,2,-641
FITEM,2,647
FITEM,2,-653
FITEM,2,659
FITEM,2,-665
FITEM,2,671
FITEM,2,-677
FITEM,2,683
FITEM,2,-689
FITEM,2,698
```

```
FITEM,2,-704
FITEM,2,710
FITEM,2,-716
FITEM,2,722
FITEM,2,-728
FITEM,2,734
FITEM,2,-740
FITEM,2,746
FITEM,2,-752
FITEM,2,761
FITEM,2,-767
FITEM,2,773
FITEM,2,-779
FITEM,2,785
FITEM,2,-791
FITEM,2,797
FITEM,2,-803
FITEM,2,809
FITEM,2,-815
FITEM,2,824
FITEM,2,-830
FITEM,2,836
FITEM,2,-842
FITEM,2,848
FITEM,2,-854
FITEM,2,860
FITEM,2,-866
FITEM,2,872
FITEM,2,-878

FITEM,2,887
FITEM,2,-941
FITEM,2,950
FITEM,2,-1004
FITEM,2,1013
FITEM,2,-1067
FITEM,2,1076
FITEM,2,-1130
FITEM,2,1139
FITEM,2,-1193

FITEM,2,1202
FITEM,2,-1208
FITEM,2,1214
FITEM,2,-1220
FITEM,2,1226
```

```
FITEM,2,-1232
FITEM,2,1238
FITEM,2,-1244
FITEM,2,1250
FITEM,2,-1256
FITEM,2,1265
FITEM,2,-1271
FITEM,2,1277
FITEM,2,-1283
FITEM,2,1289
FITEM,2,-1295
FITEM,2,1301
FITEM,2,-1307
FITEM,2,1313
FITEM,2,-1319
FITEM,2,1328
FITEM,2,-1334
FITEM,2,1340
FITEM,2,-1346
FITEM,2,1352
FITEM,2,-1358
FITEM,2,1364
FITEM,2,-1370
FITEM,2,1376
FITEM,2,-1382
FITEM,2,1391
FITEM,2,-1397
FITEM,2,1403
FITEM,2,-1409
FITEM,2,1415
FITEM,2,-1421
FITEM,2,1427
FITEM,2,-1433
FITEM,2,1439
FITEM,2,-1445
FITEM,2,1454
FITEM,2,-1460
FITEM,2,1466
FITEM,2,-1472
FITEM,2,1478
FITEM,2,-1484
FITEM,2,1490
FITEM,2,-1496
FITEM,2,1502
FITEM,2,-1508
```

```
FITEM,2,1513
FITEM,2,-1827

FITEM,2,1832
FITEM,2,-1838
FITEM,2,1844
FITEM,2,-1850
FITEM,2,1856
FITEM,2,-1862
FITEM,2,1868
FITEM,2,-1874
FITEM,2,1880
FITEM,2,-1886
FITEM,2,1895
FITEM,2,-1901
FITEM,2,1907
FITEM,2,-1913
FITEM,2,1919
FITEM,2,-1925
FITEM,2,1931
FITEM,2,-1937
FITEM,2,1943
FITEM,2,-1949
FITEM,2,1958
FITEM,2,-1964
FITEM,2,1970
FITEM,2,-1976
FITEM,2,1982
FITEM,2,-1998
FITEM,2,1994
FITEM,2,-2000
FITEM,2,2006
FITEM,2,-2012
FITEM,2,2021
FITEM,2,-2027
FITEM,2,2033
FITEM,2,-2039
FITEM,2,2045
FITEM,2,-2051
FITEM,2,2057
FITEM,2,-2063
FITEM,2,2069
FITEM,2,-2075
EMODIF,P51X,REAL,2,
```

```
FLST,2,14,2,ORDE,14
FITEM,2,193
FITEM,2,205
FITEM,2,217
FITEM,2,229
FITEM,2,241
FITEM,2,835
FITEM,2,847
FITEM,2,859
FITEM,2,871
FITEM,2,1453
FITEM,2,1465
FITEM,2,1477
FITEM,2,1489
FITEM,2,1501
EMODIF,P51X,REAL,5,

FLST,2,14,2,ORDE,14
FITEM,2,579
FITEM,2,591
FITEM,2,603
FITEM,2,615
FITEM,2,627
FITEM,2,1209
FITEM,2,1221
FITEM,2,1233
FITEM,2,1245
FITEM,2,1839
FITEM,2,1851
FITEM,2,1863
FITEM,2,1875
FITEM,2,1887
EMODIF,P51X,REAL,7,

FLST,2,14,2,ORDE,14
FITEM,2,571
FITEM,2,583
FITEM,2,595
FITEM,2,607
FITEM,2,619
FITEM,2,1213
FITEM,2,1225
FITEM,2,1237
FITEM,2,1249
FITEM,2,1831
FITEM,2,1843
```

```
FITEM,2,1855
FITEM,2,1867
FITEM,2,1879
EMODIF,P51X,REAL,9,
```

File 6 :Emodsp.txt

```
! This page will be used to convert the spring real constants

*do,sprnum,spr1+1,spr1end-1,1
emodif,sprnum,real,12
*enddo
*do,sprnum,sprlast+1,sprlaend-1,1
emodif,sprnum,real,12
*enddo
*do,sprnum,spr1+sprxnum,sprlast-sprxnum,sprxnum
emodif,sprnum,real,12
*enddo
*do,sprnum,spr1end+sprxnum,sprlaend-sprxnum,sprxnum
emodif,sprnum,real,12
*enddo
emodif,spr1,real,13
emodif,spr1end,real,13
emodif,sprlast,real,13
emodif,sprlaend,real,13
```

C.3 SOLUTION OF THE MODEL

File 1 : Solu.txt

```
/solu
/stat,solu
Solve
```

C.5 POST PROCESSING OF THE RESULTS

Post processing of the results is done by graphical editor.

APPENDIX-D

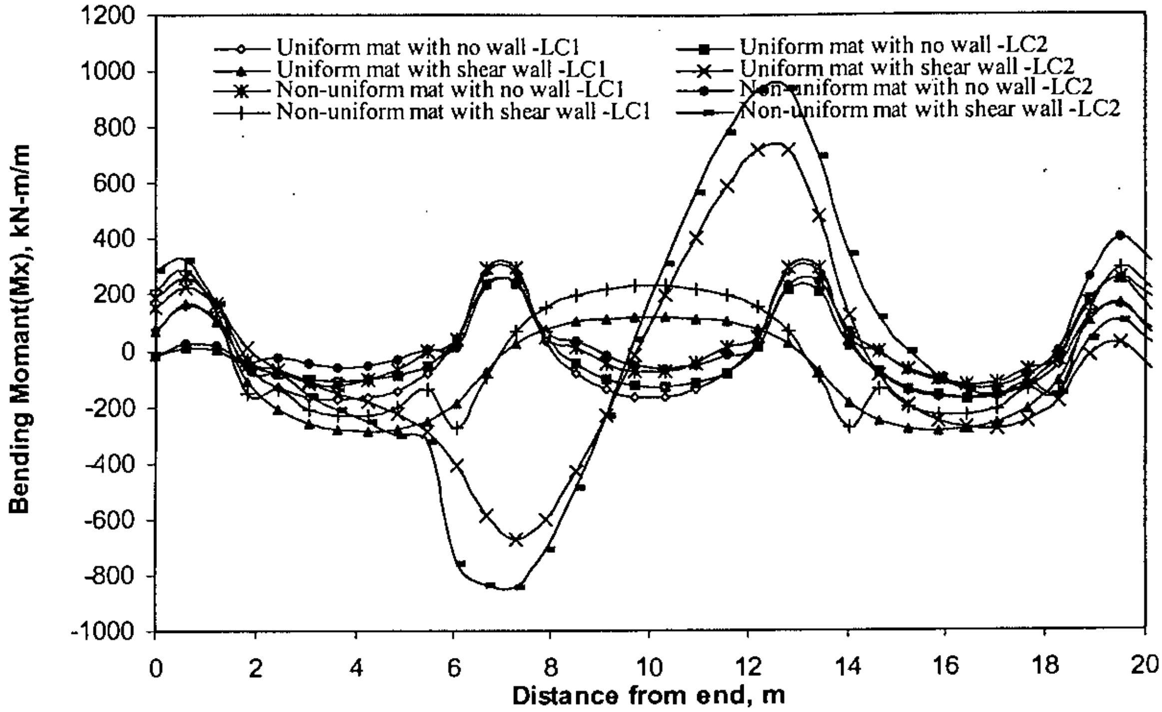

Fig.D-A1 Variation in Bending Moment along **line 1** for mat of **Model-A.**

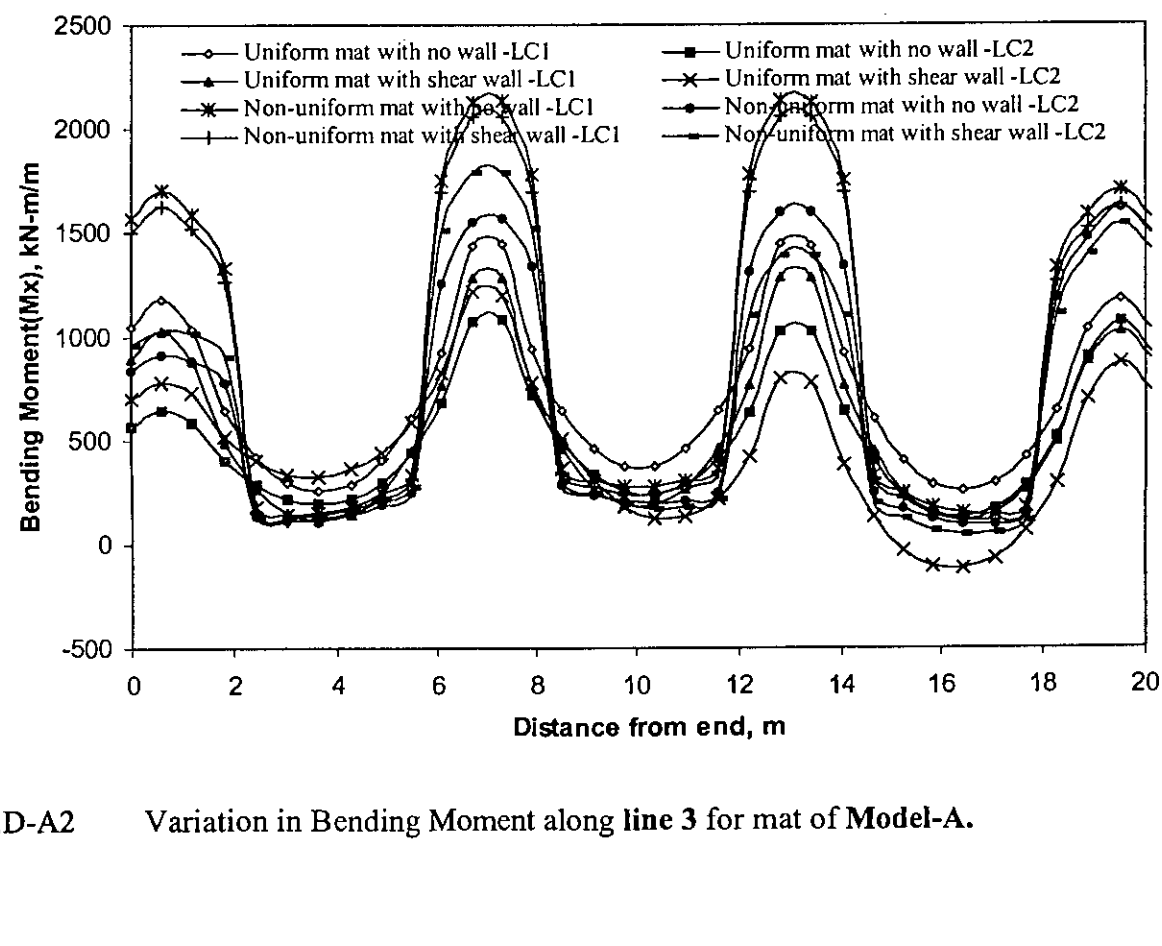

Fig.D-A2 Variation in Bending Moment along **line 3** for mat of **Model-A.**

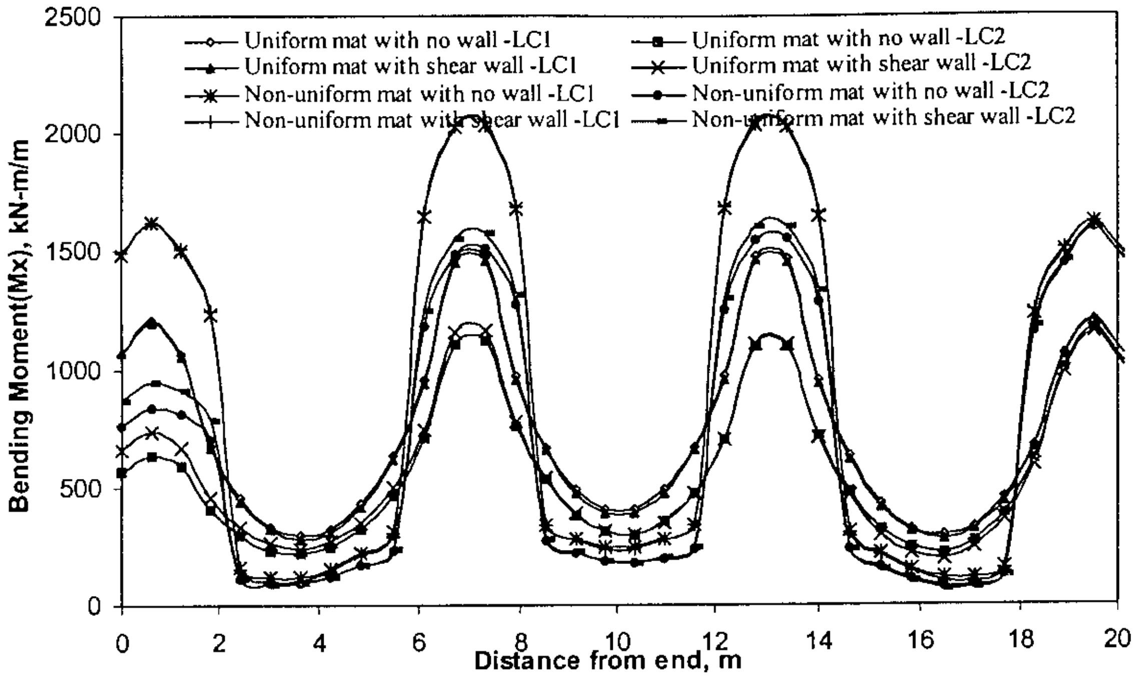

Fig.D-A3 Variation in Bending Moment along **line 5** for mat of **Model-A.**

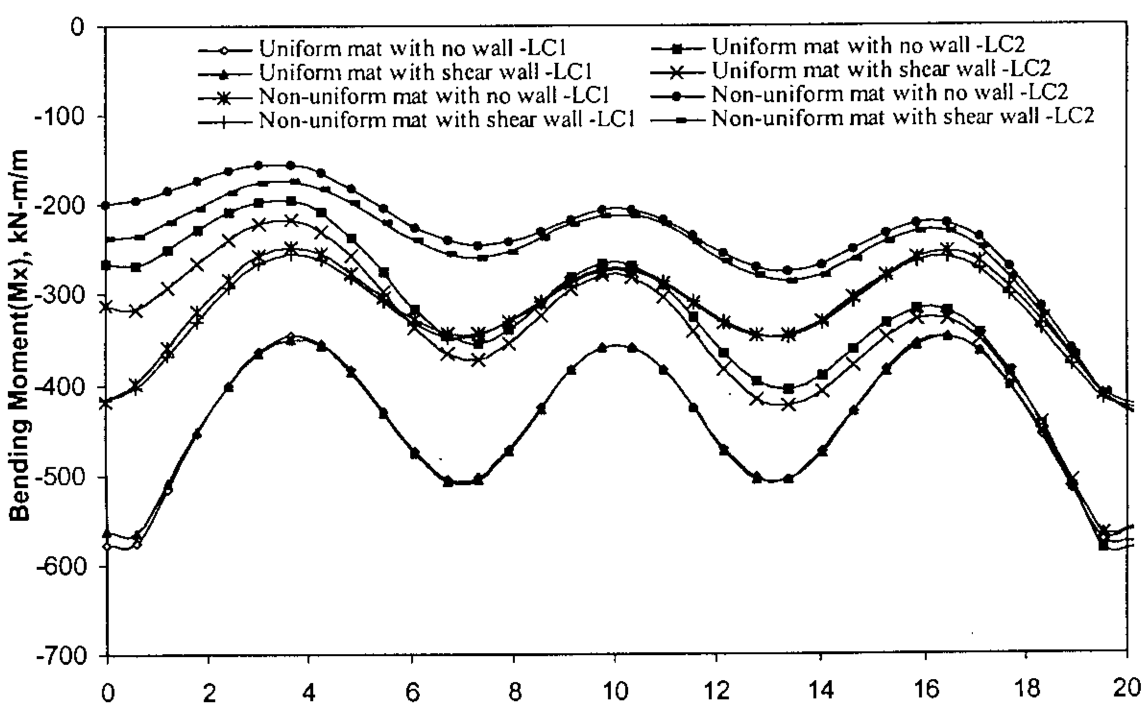

Fig.D-A4 Variation in Bending Moment along **line 6** for mat of **Model-A.**

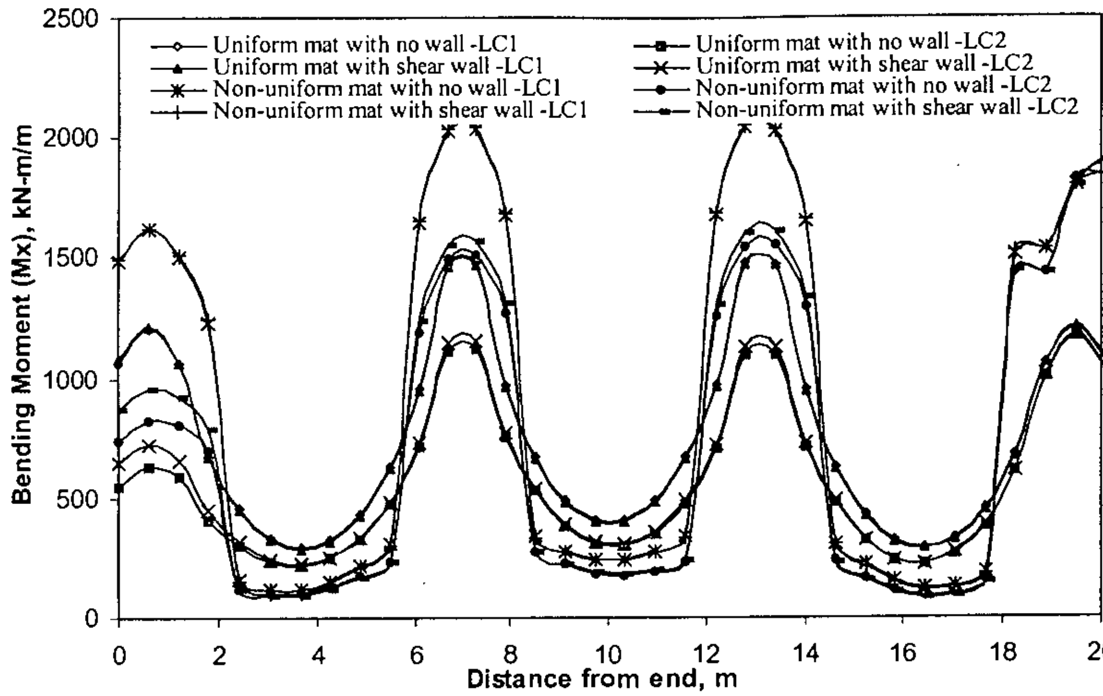

Fig.D-A5 Variation in Bending Moment along **line 7** for mat of **Model-A.**

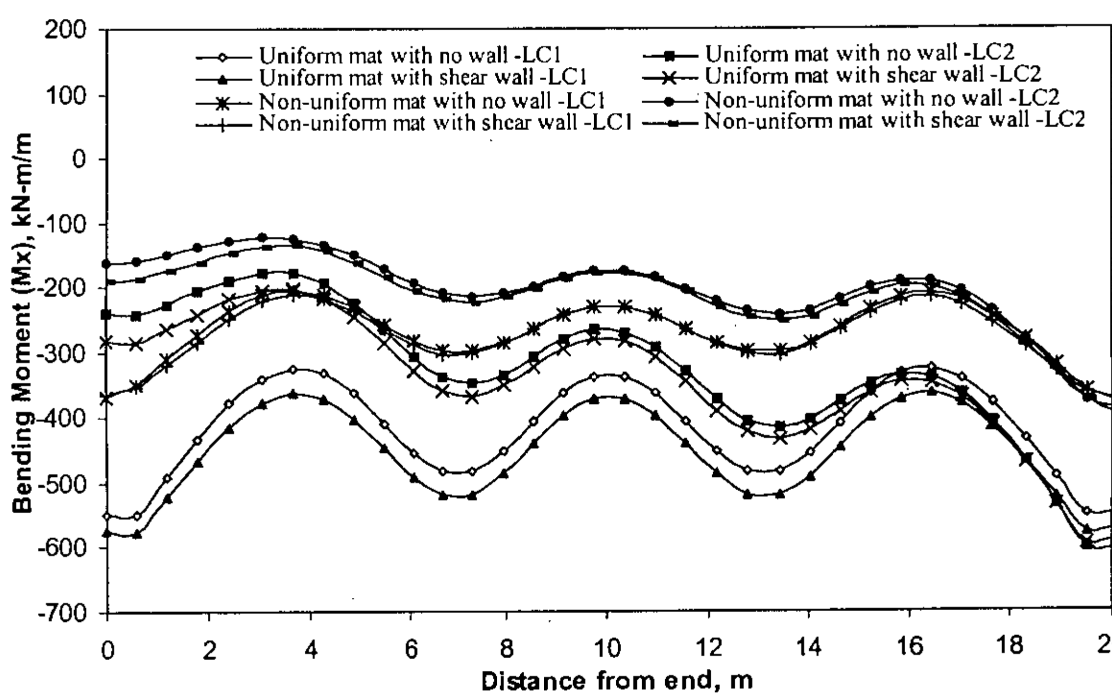

Fig.D-A6 Variation in Bending Moment along **line 8** for mat of **Model-A.**

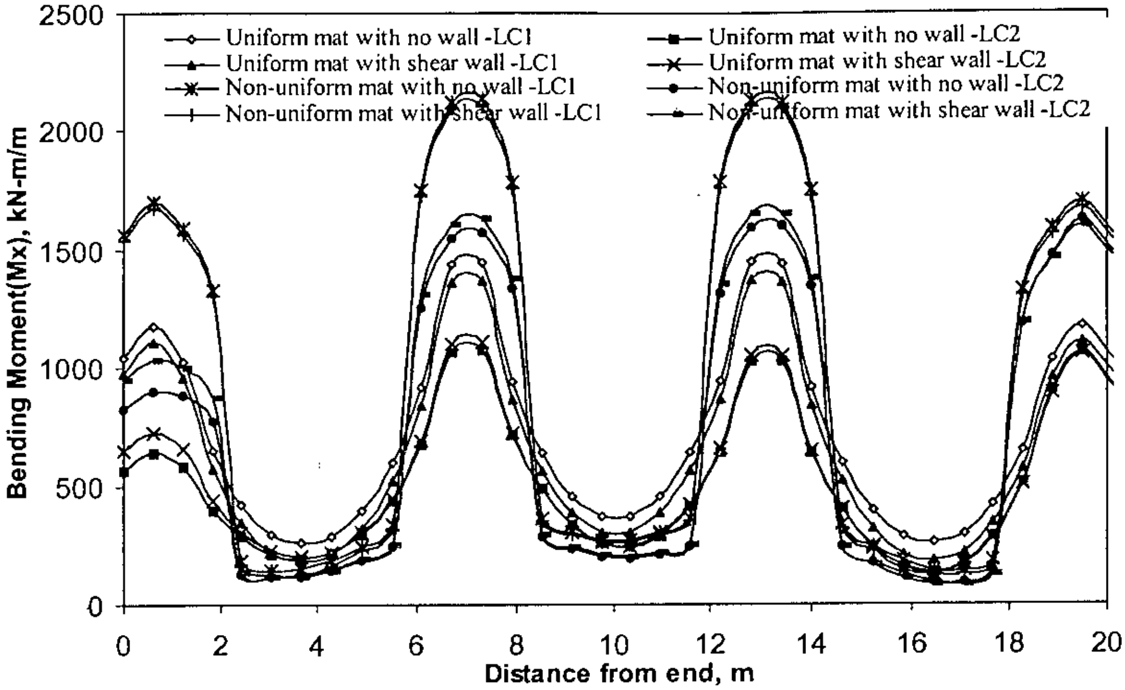

Fig.D-A7 Variation in Bending Moment along **line 9** for mat of **Model-A.**

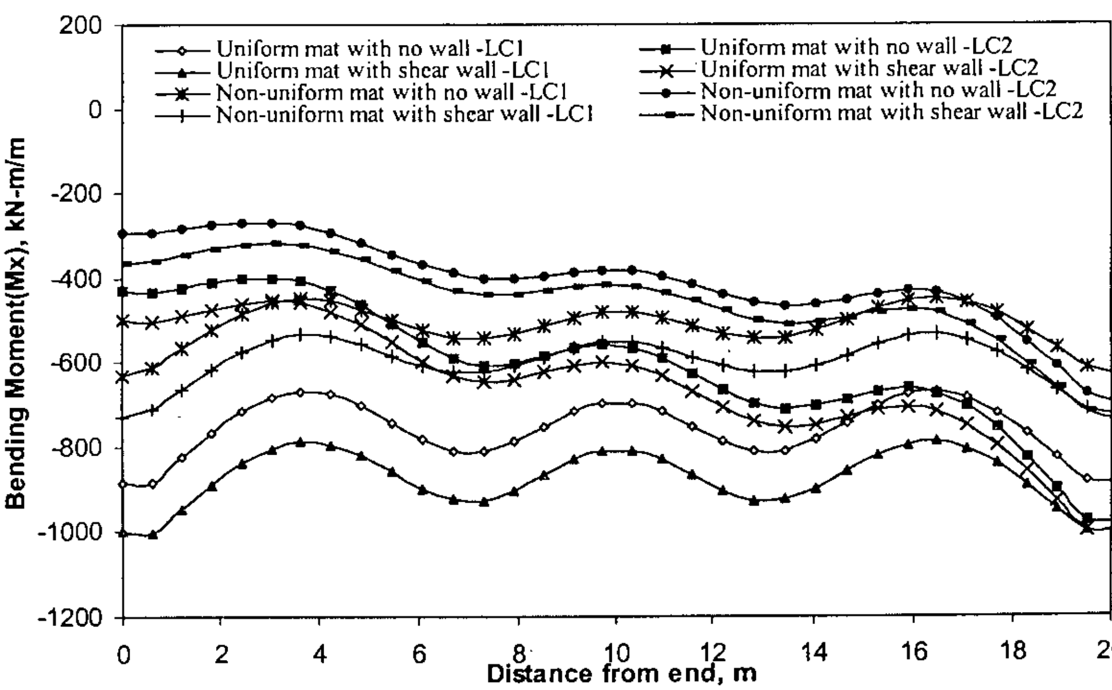

Fig.D-A8 Variation in Bending Moment along **line 10** for mat of **Model-A.**

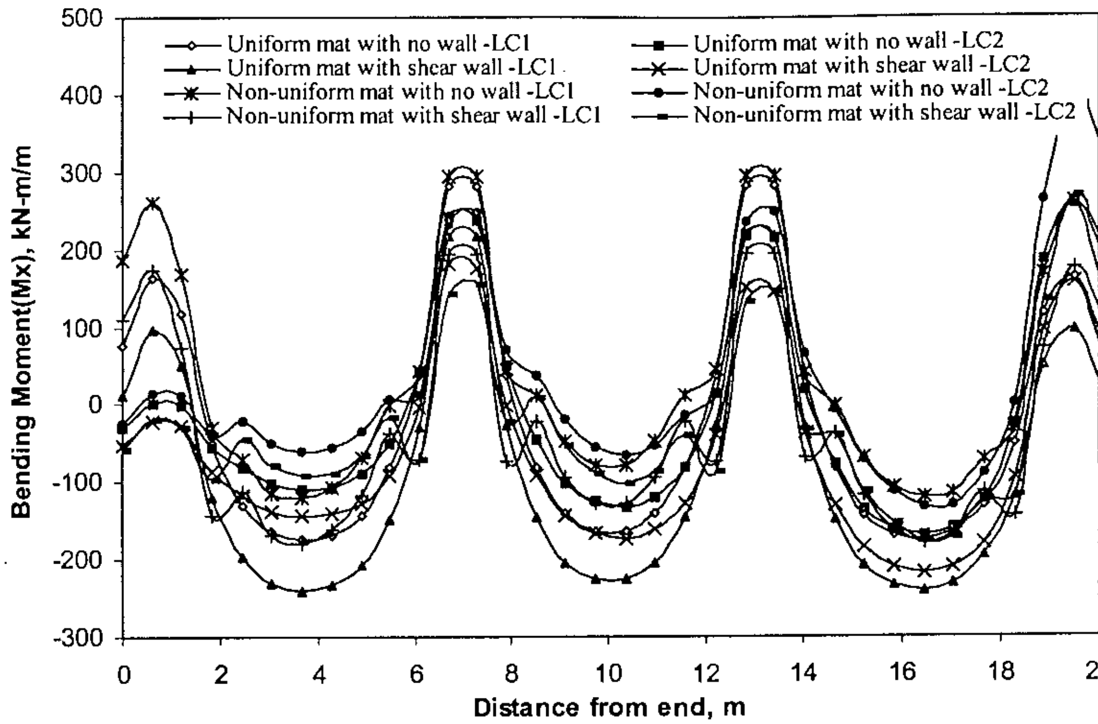

Fig.D-A9 Variation in Bending Moment along **line 11** for mat of **Model-A.**

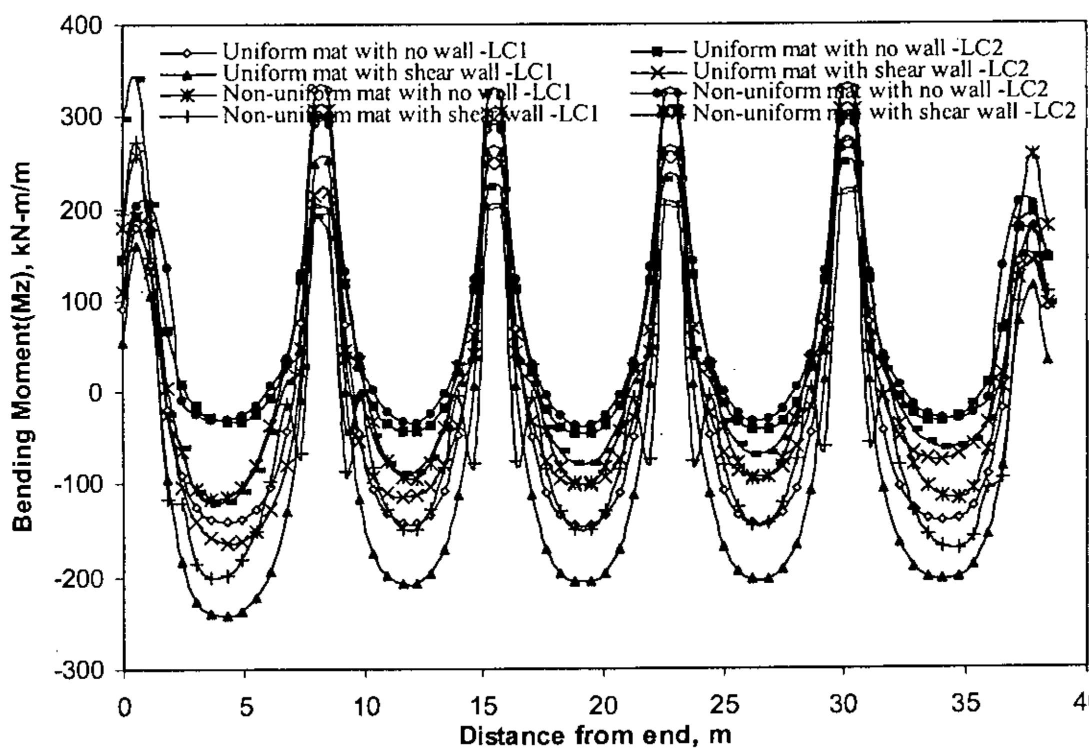

Fig.D-A10 Variation in Bending Moment along **line 12** for mat of **Model-A.**

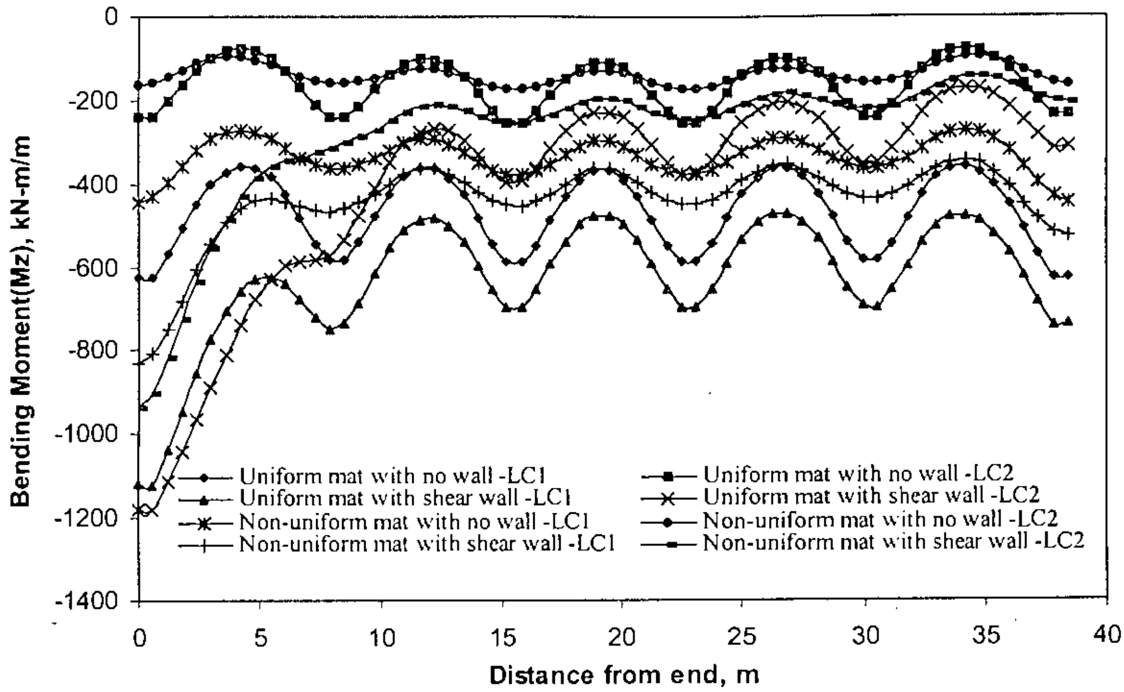

Fig.D-A11 Variation in Bending Moment along **line 13** for mat of **Model-A.**

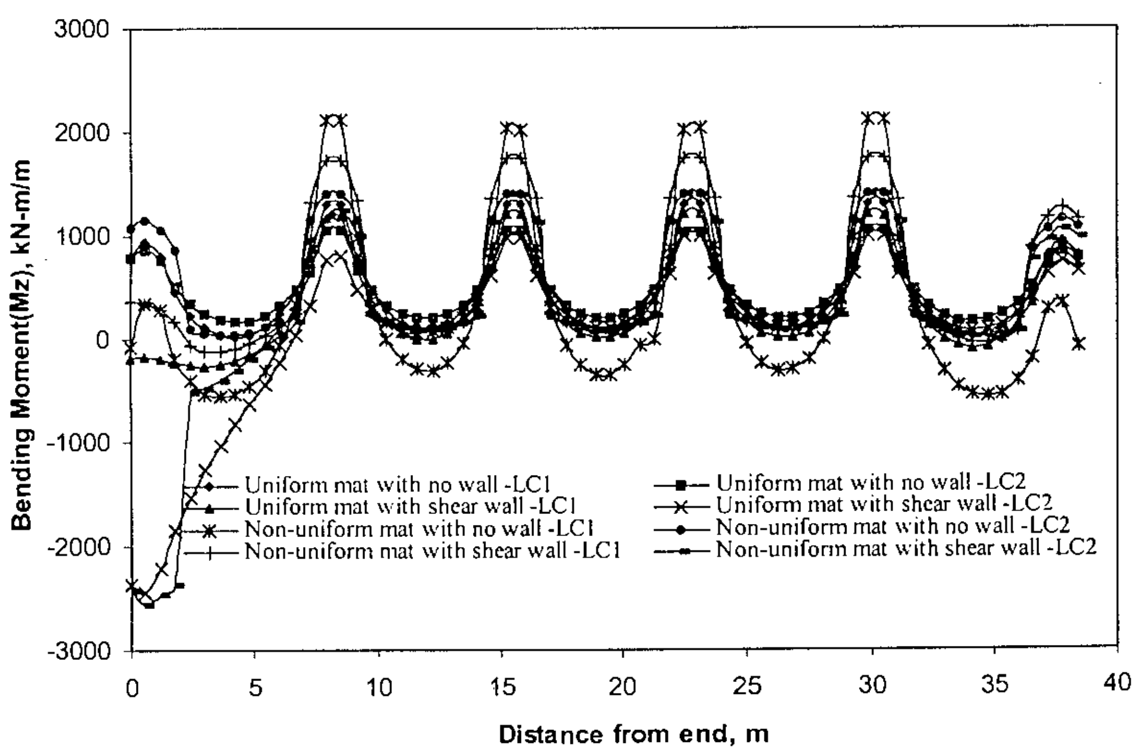

Fig.D-A12 Variation in Bending Moment along **line 14** for mat of **Model-A.**

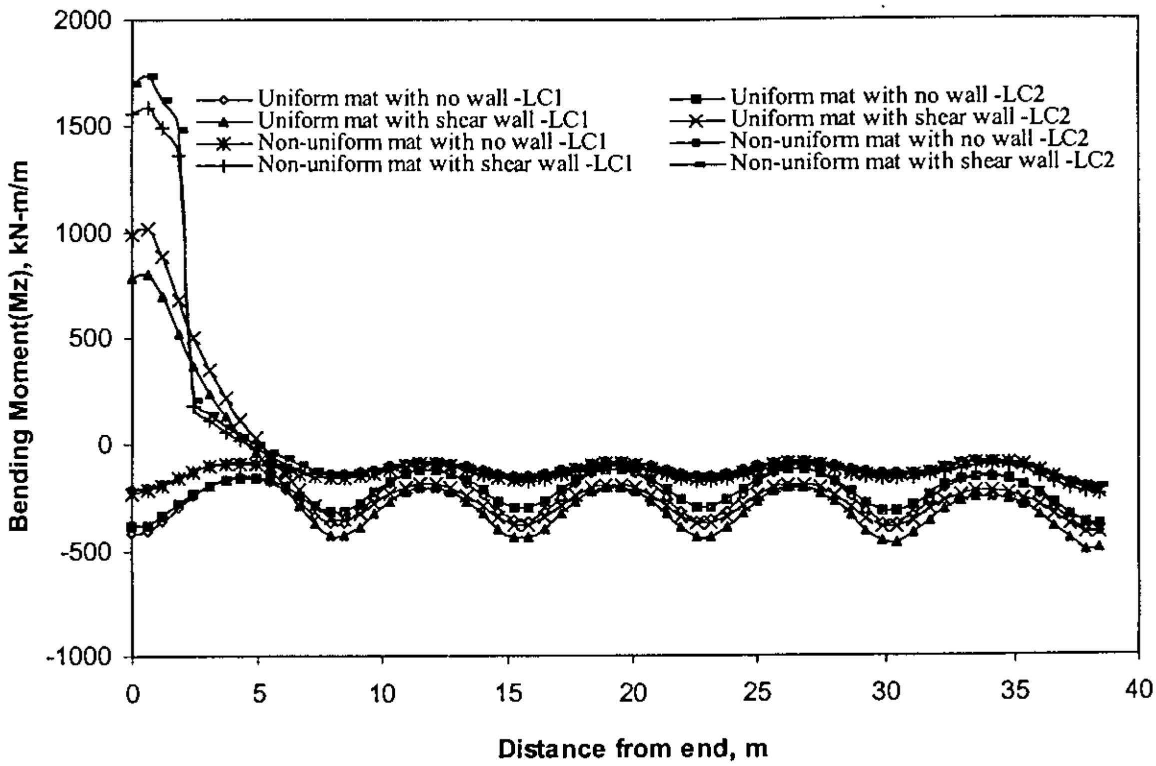

Fig.D-A13 Variation in Bending Moment along **line 15** for mat of **Model-A.**

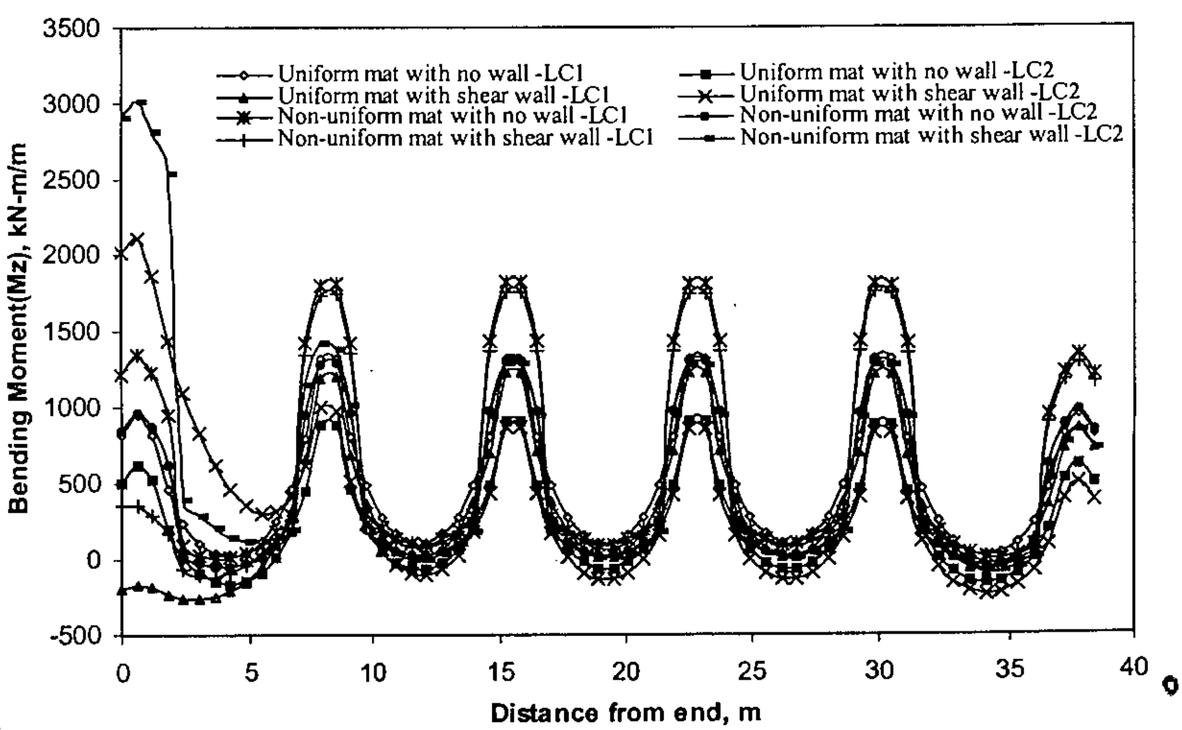

Fig.D-A14 Variation in Bending Moment along **line 16** for mat of **Model-A.**

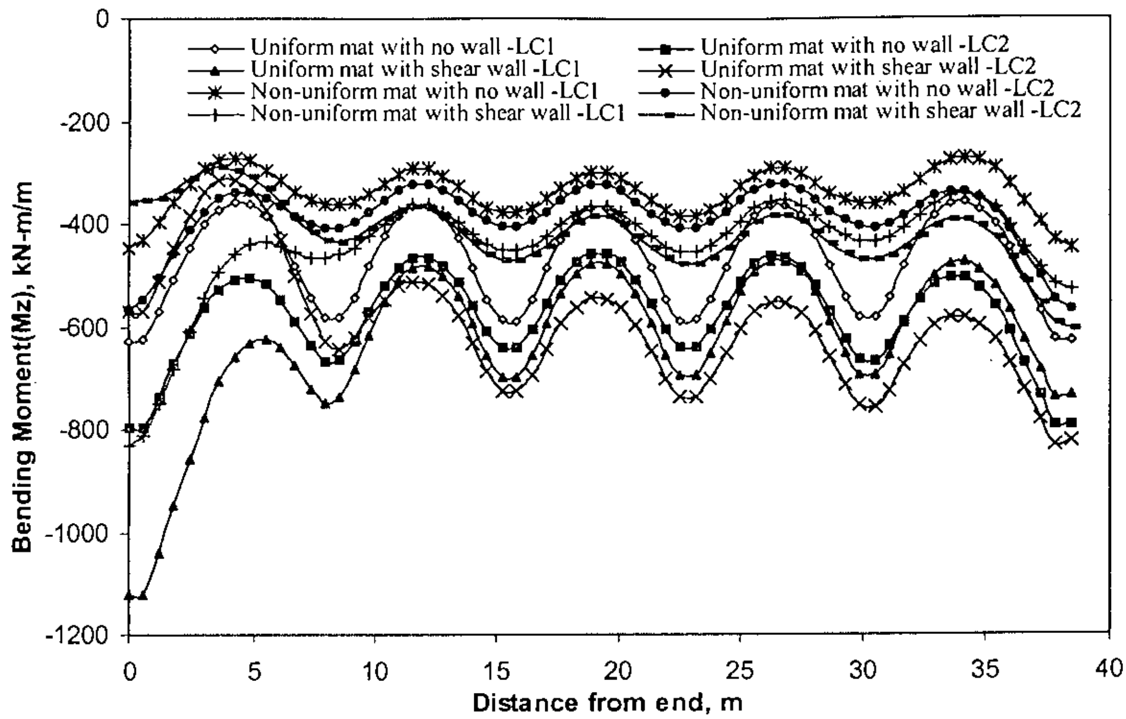

Fig.D-A15 Variation in Bending Moment along **line 17** for mat of **Model-A.**

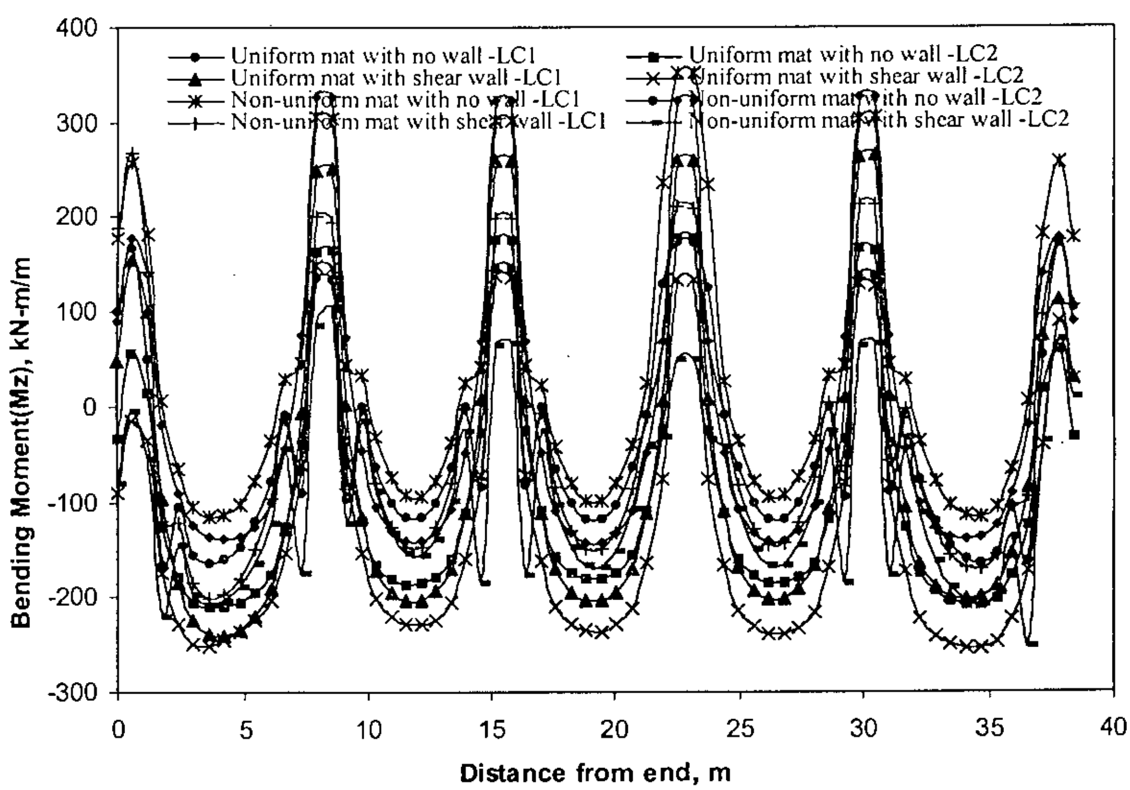

Fig.D-A16 Variation in Bending Moment along **line 18** for mat of **Model-A.**

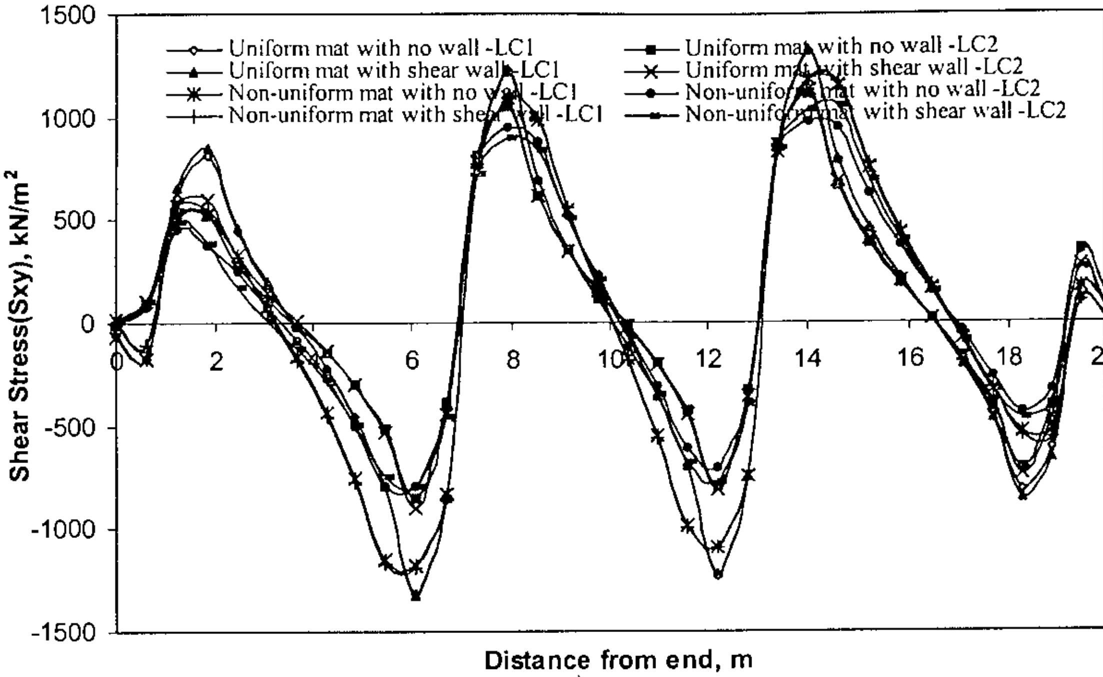

Fig.D-A17 Variation in Shear Stress along **line 3** for mat of **Model-A.**

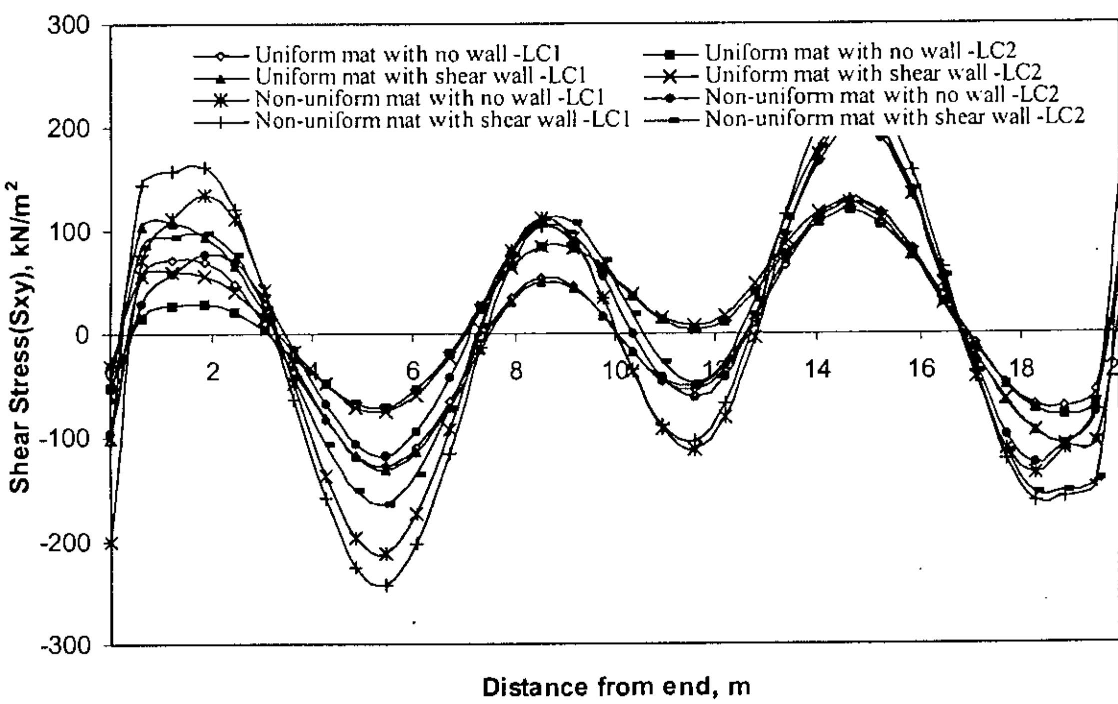

Fig.D-A18 Variation in Shear Stress along **line 4** for mat of **Model-A.**

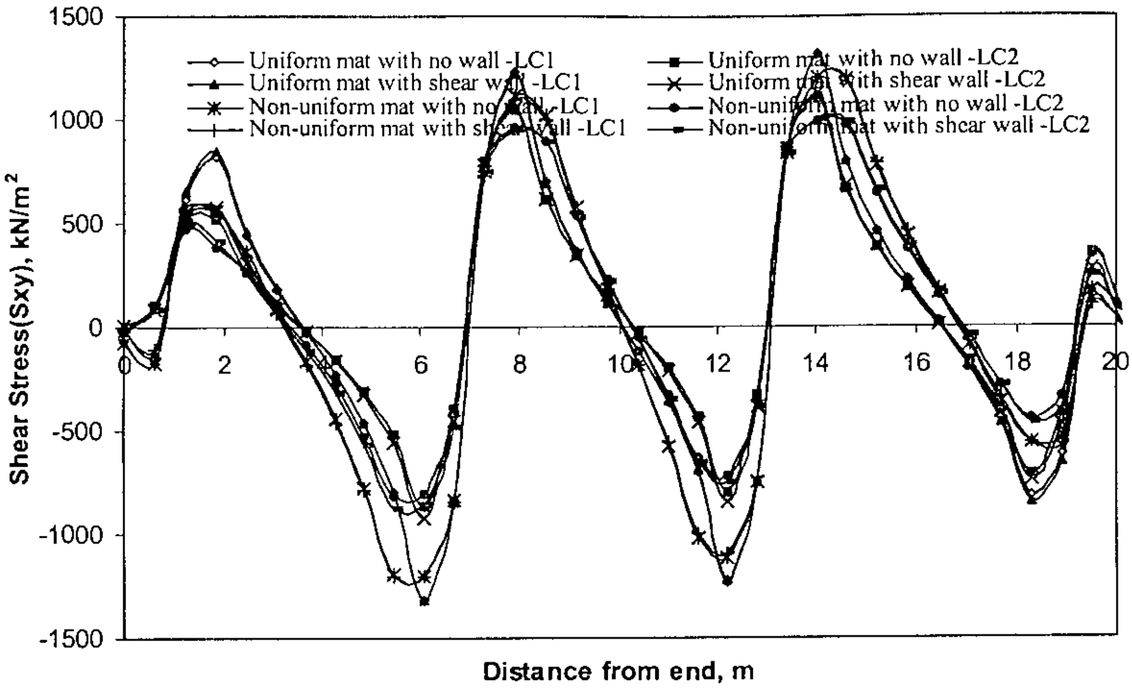

Fig.D-A19 Variation in Shear Stress along **line 5** for mat of **Model-A.**

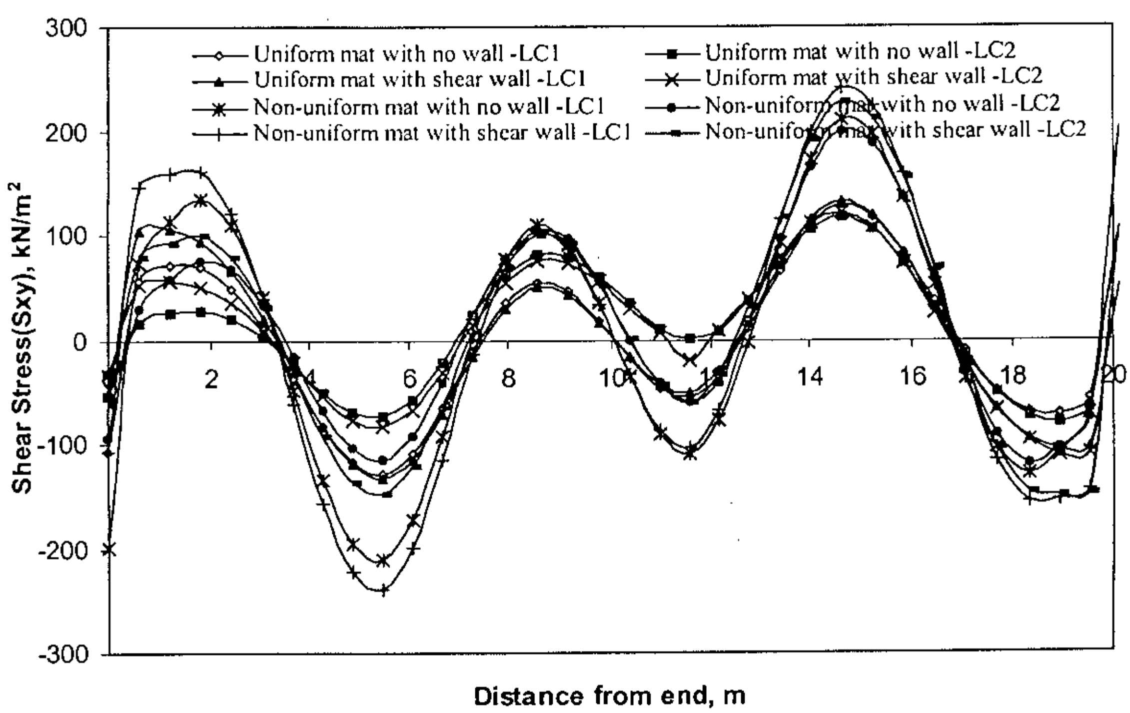

Fig.D-A20 Variation in Shear Stress along **line 6** for mat of **Model-A.**

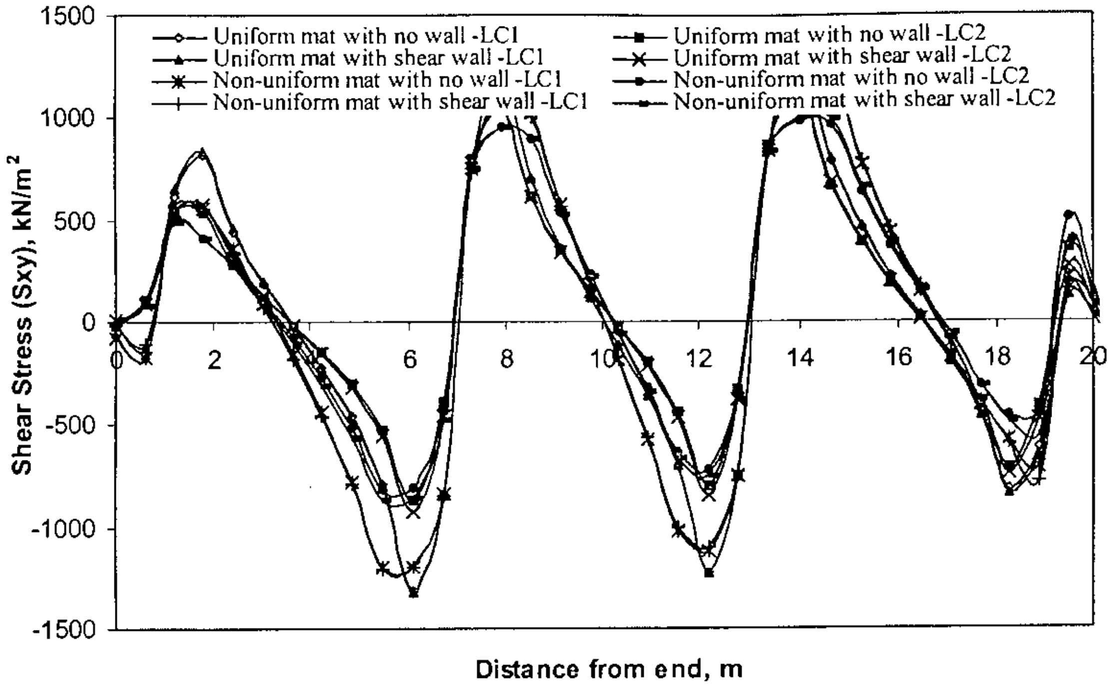

Fig.D-A21 Variation in Shear Stress along **line 7** for mat of **Model-A.**

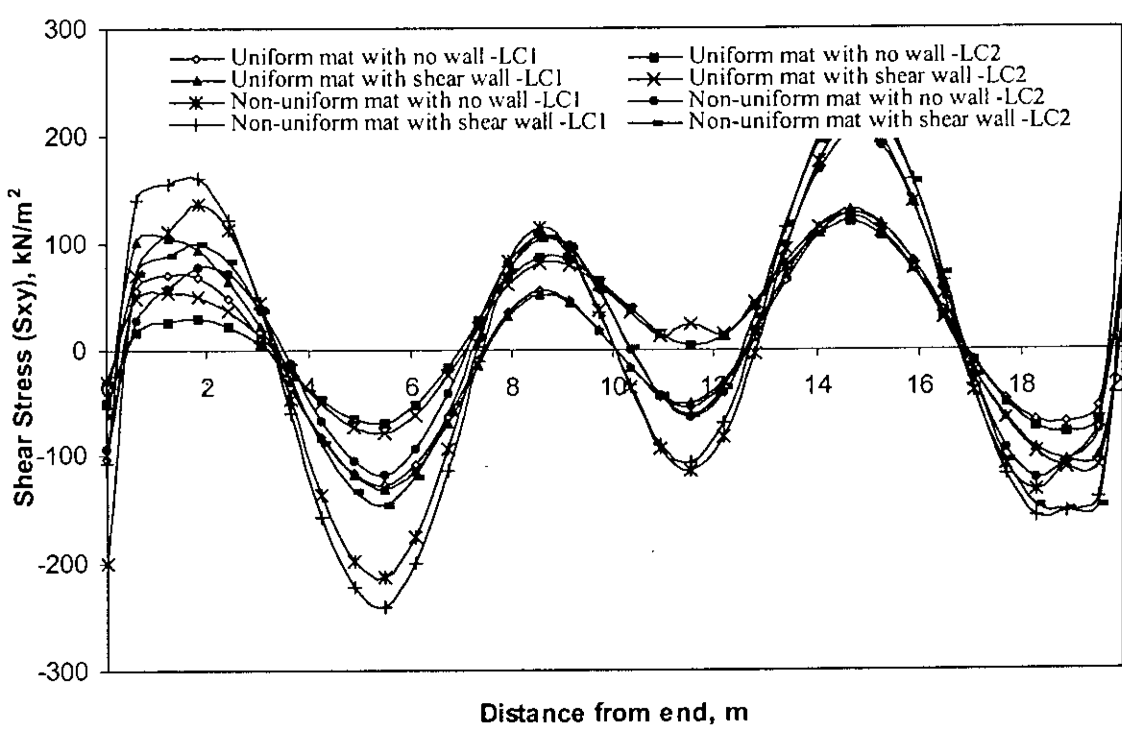

Fig.D-A22 Variation in Shear Stress along **line 8** for mat of **Model-A.**

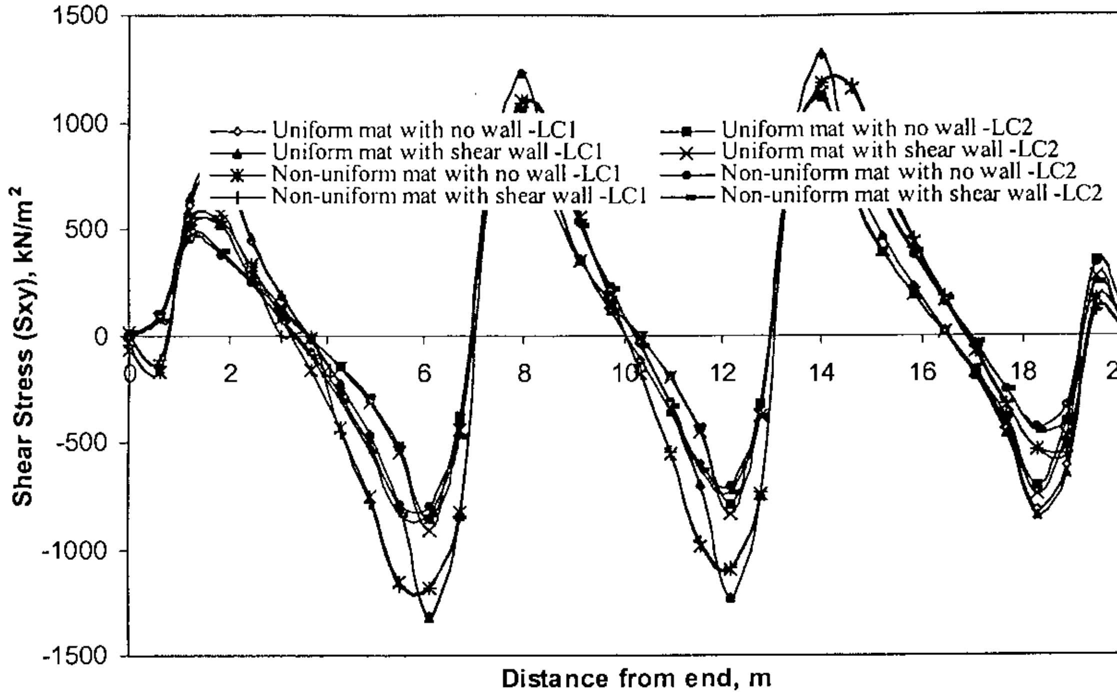

Fig.D-A23 Variation in Shear Stress along **line 9** for mat of **Model-A.**

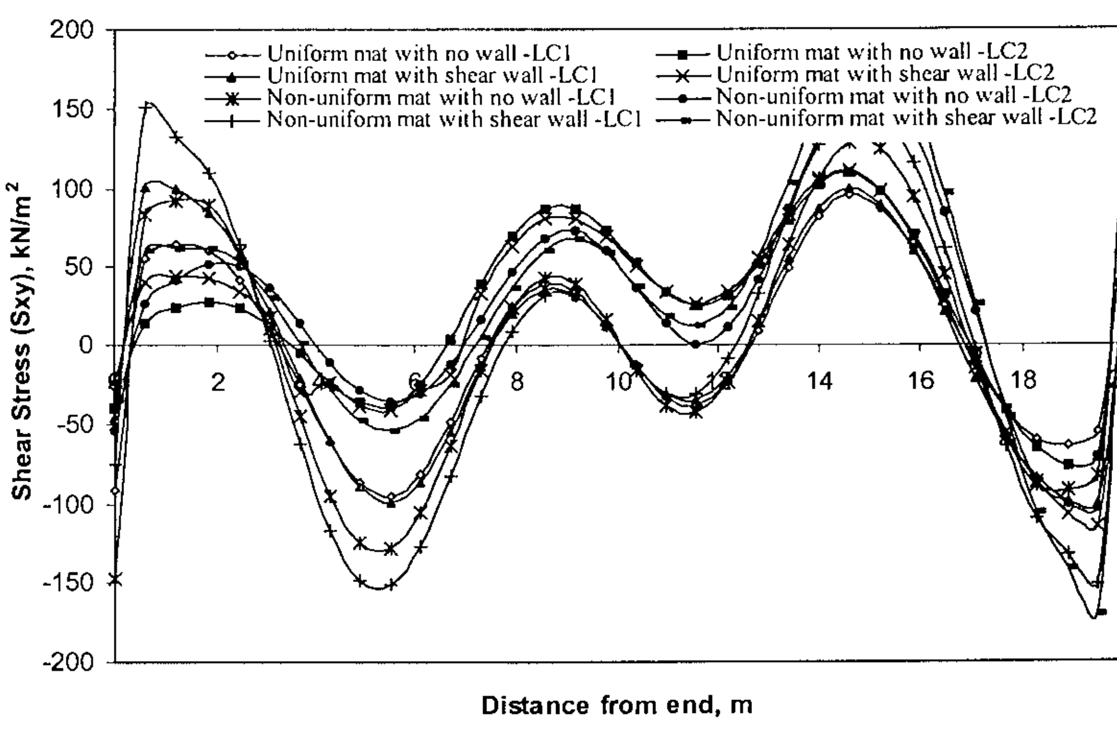

Fig.D-A24 Variation in Shear Stress along **line 10** for mat of **Model-A.**

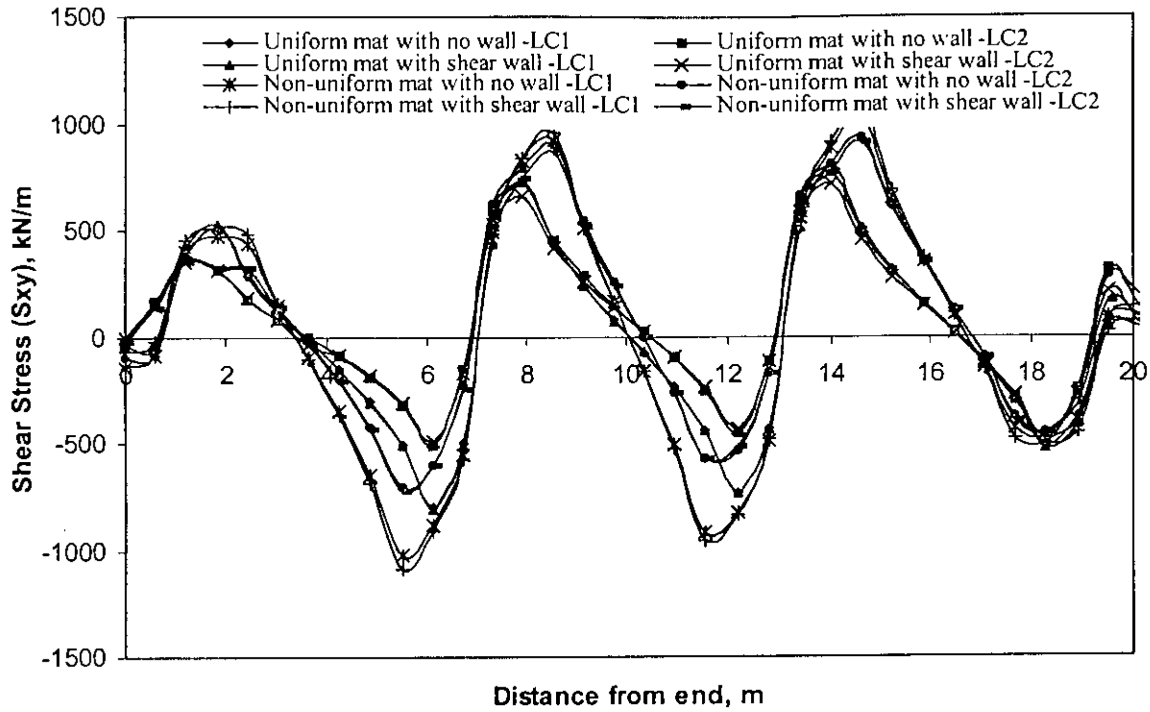

Fig.D-A25 Variation in Shear Stress along **line 11** for mat of **Model-A.**

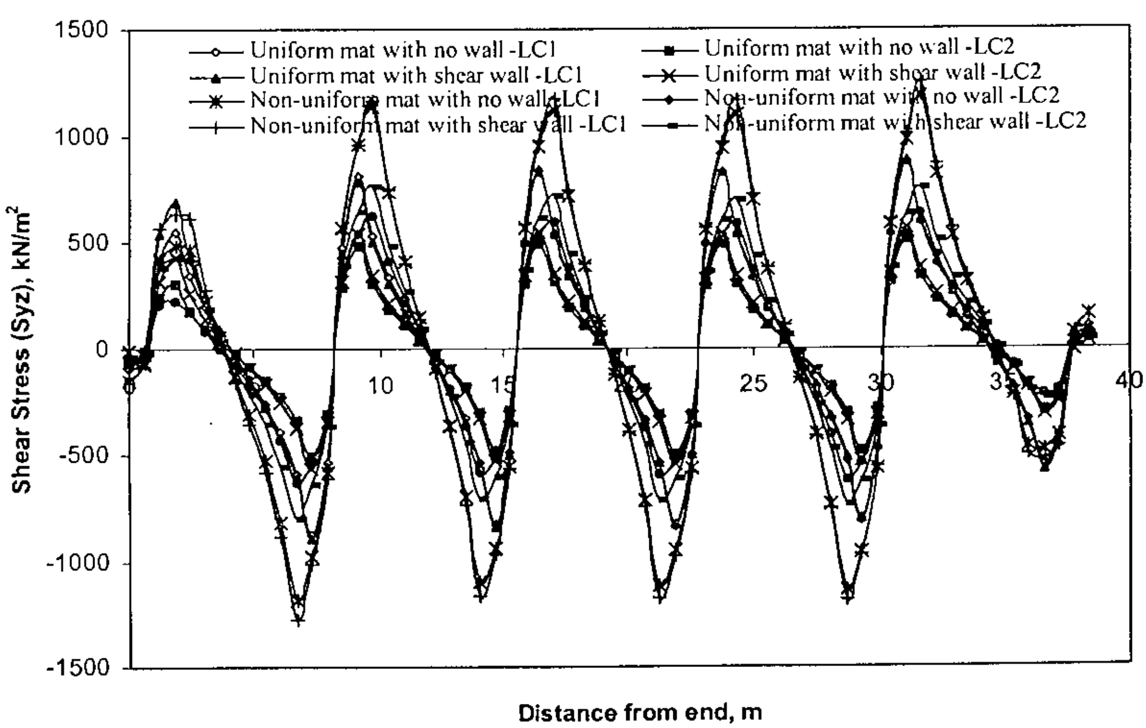

Fig.D-A26 Variation in Shear Stress along **line 12** for mat of **Model-A.**

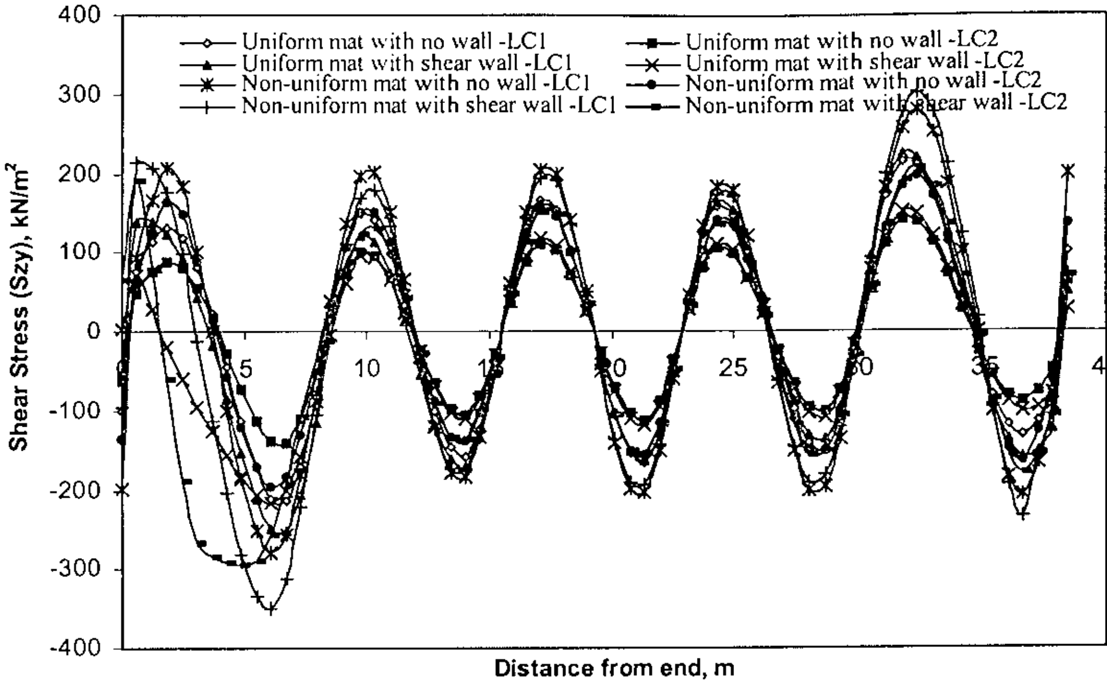

Fig.D-A27 Variation in Shear Stress along **line 13** for mat of **Model-A.**

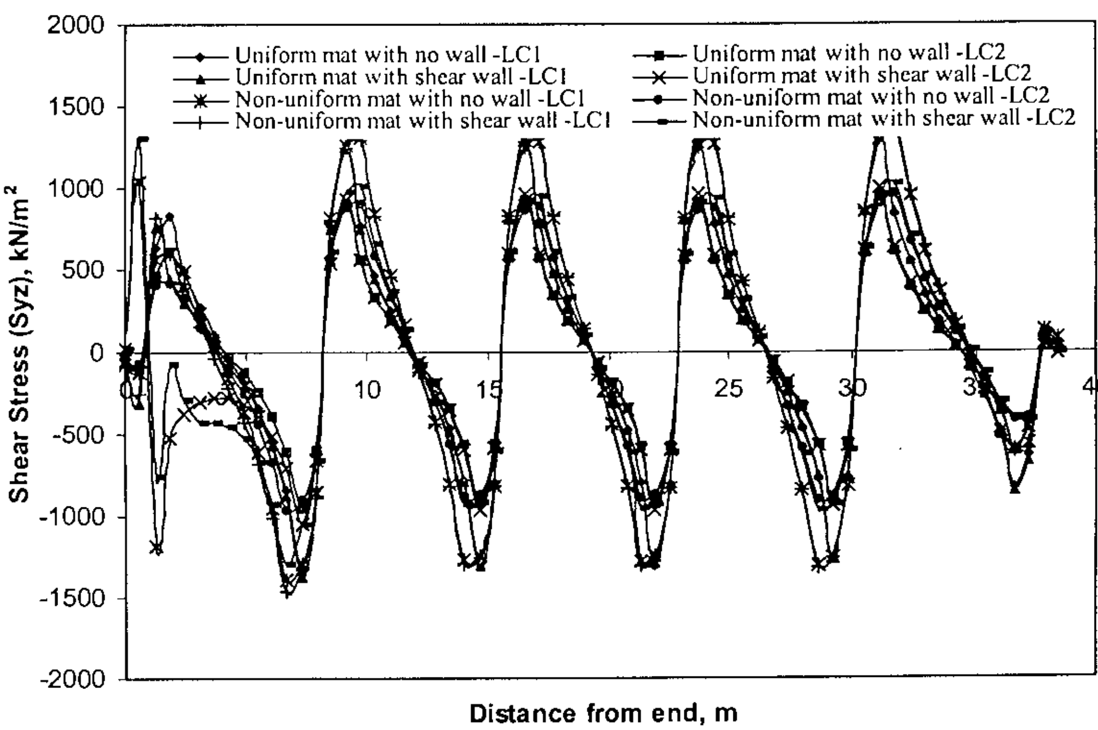

Fig.D-A28 Variation in Shear Stress along **line 14** for mat of **Model-A.**

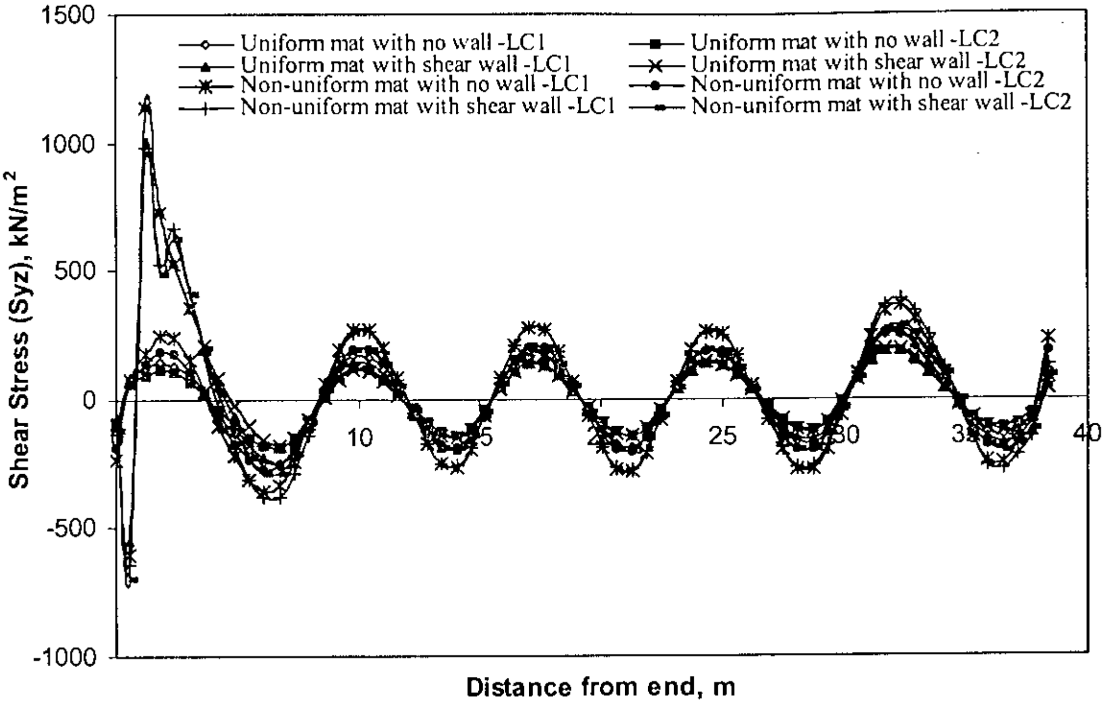

Fig.D-A29 Variation in Shear Stress along **line 15** for mat of **Model-A.**

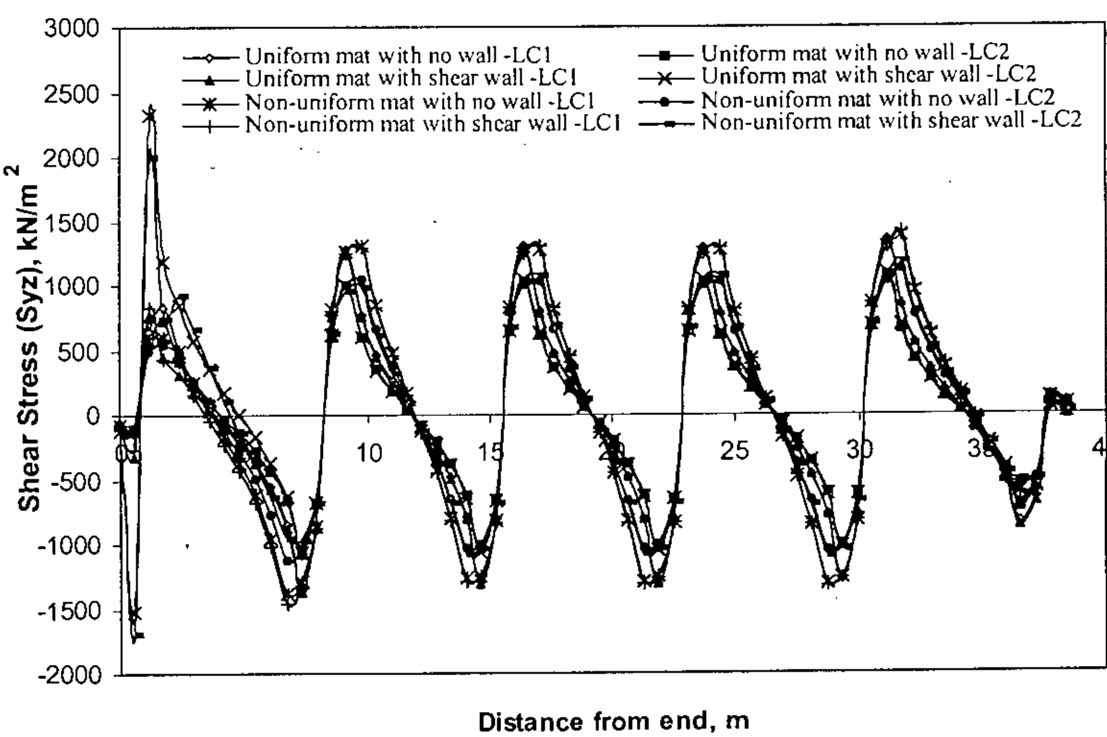

Fig.D-A30 Variation in Shear Stress along **line 16** for mat of **Model-A.**

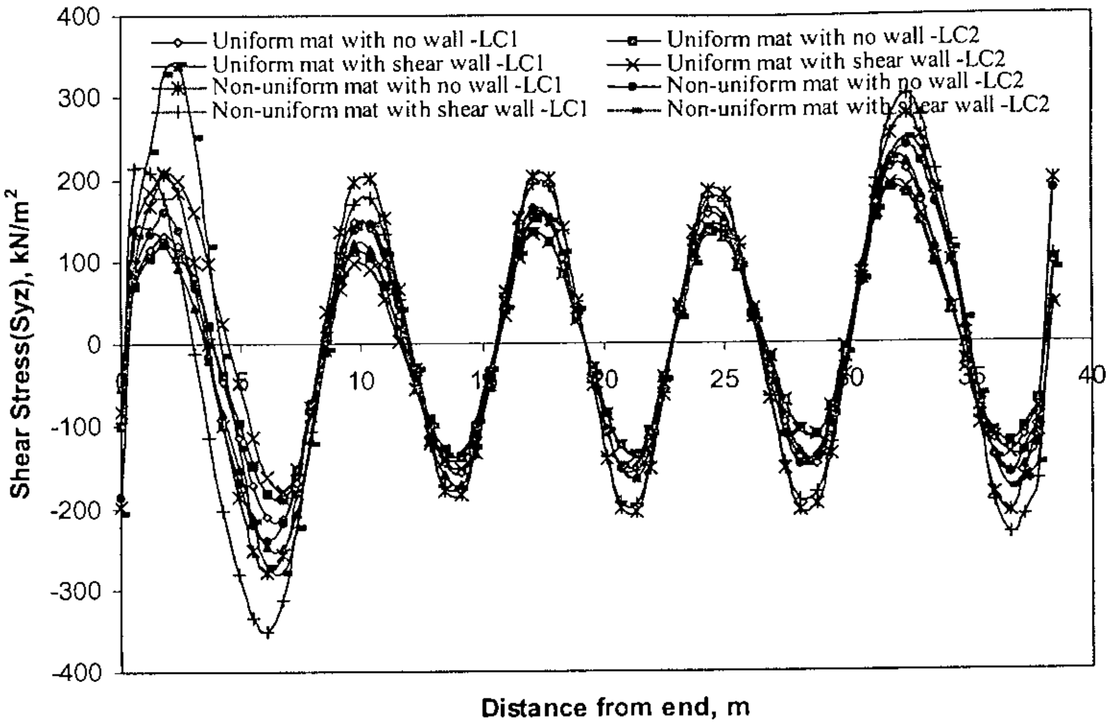

Fig.D-A31 Variation in Shear Stress along **line 17** for mat of **Model-A.**

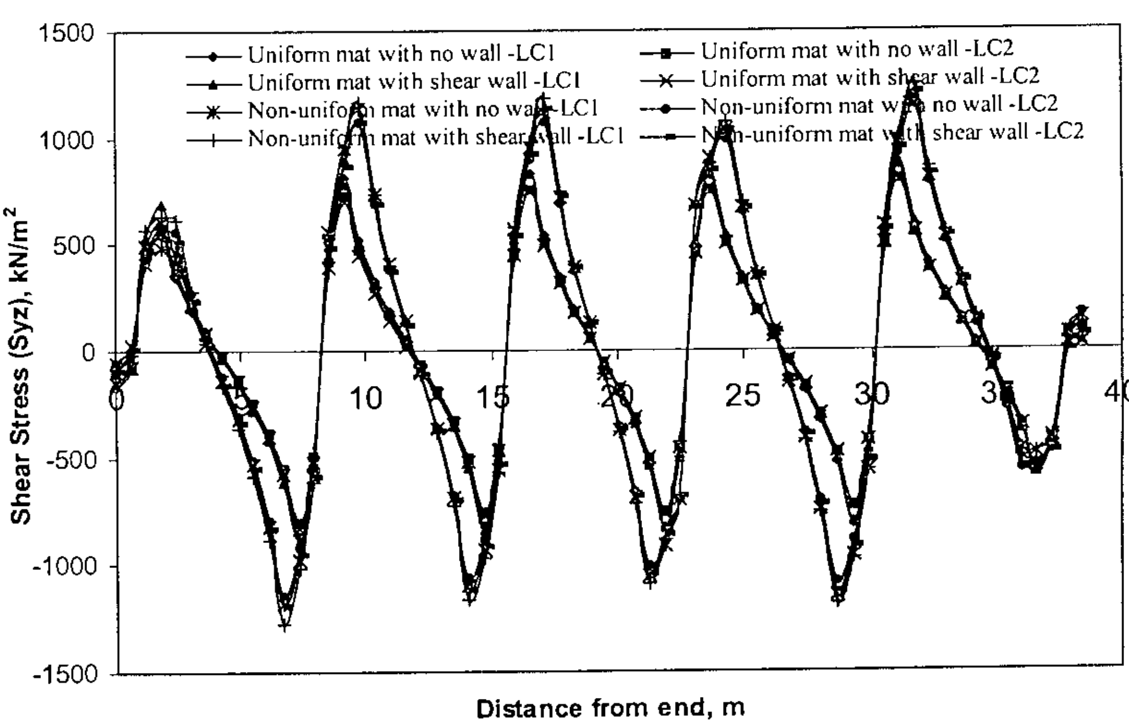

Fig.D-A32 Variation in Shear Stress along **line 18** for mat of **Model-A.**

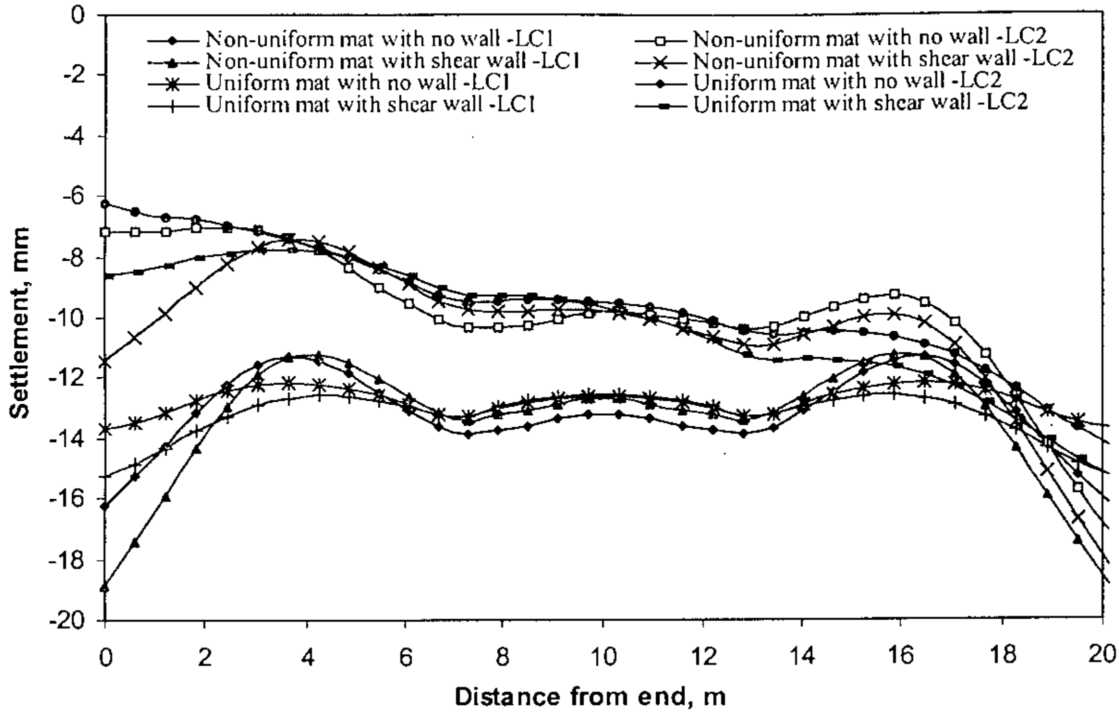

Fig.D-A33 Variation in Settlement along **line 3** for mat of **Model-A.**

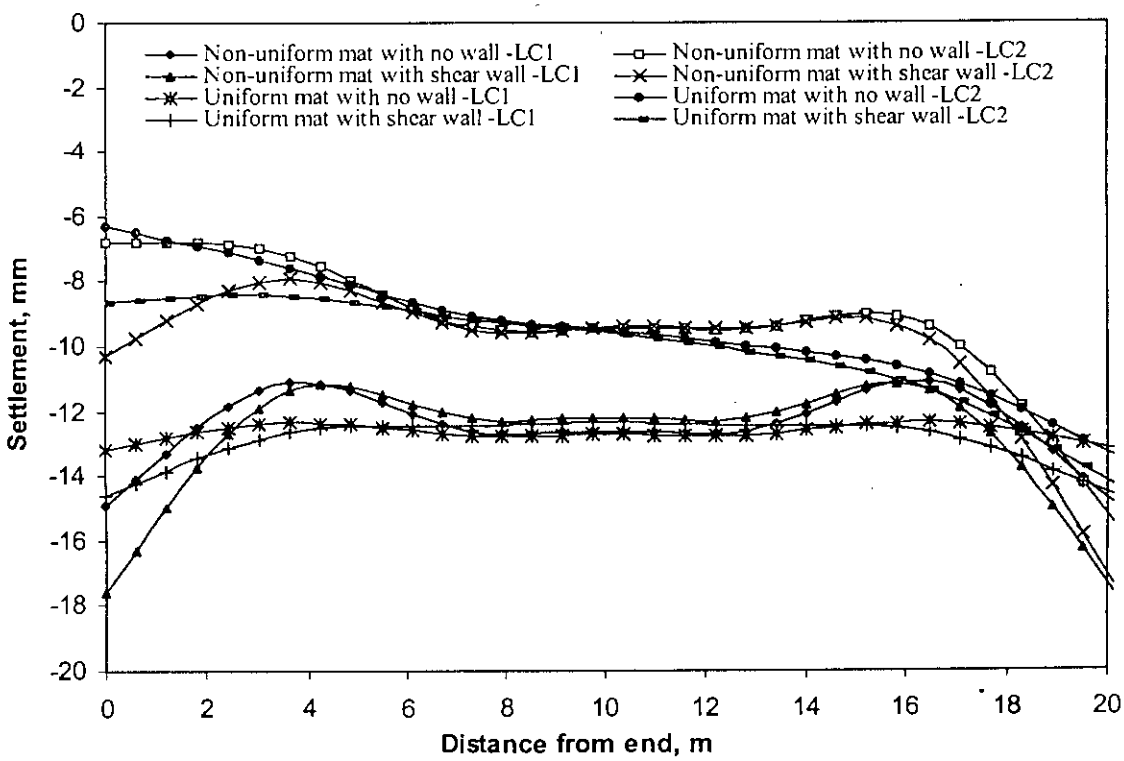

Fig.D-A34 Variation in Settlement along **line 4** for mat of **Model-A.**

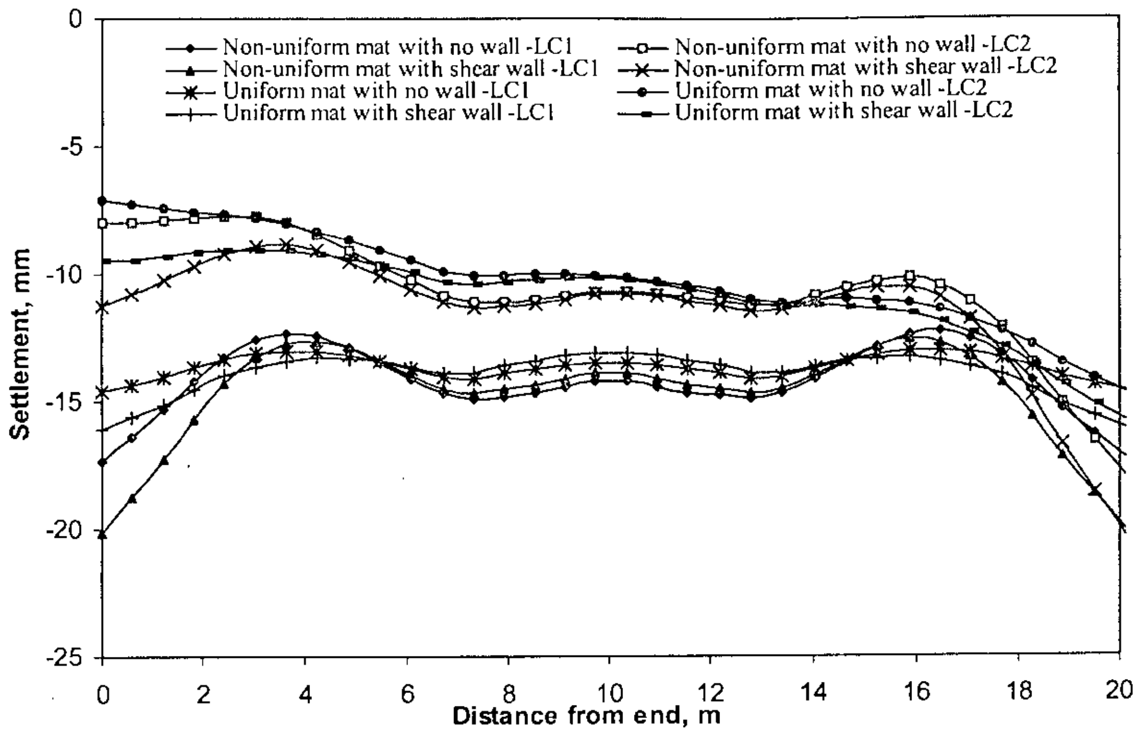

Fig.D-A35 Variation in Settlement along **line 5** for mat of **Model-A.**

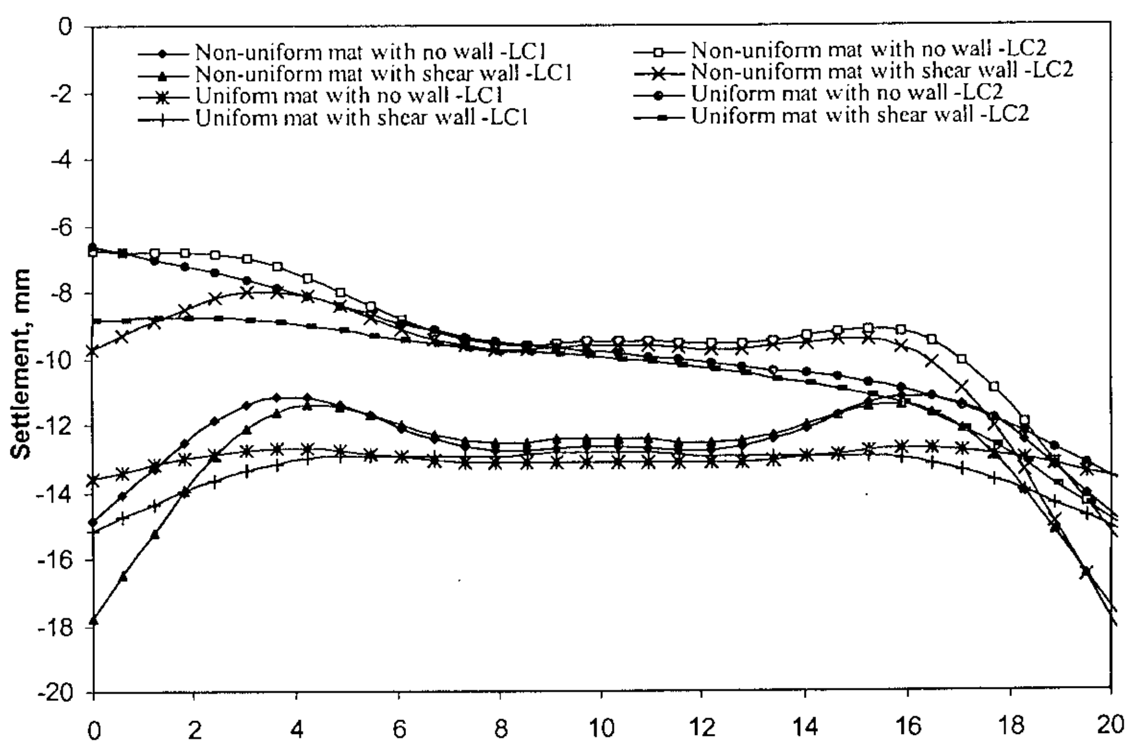

Fig.D-A36 Variation in Settlement along **line 6** for mat of **Model-A.**

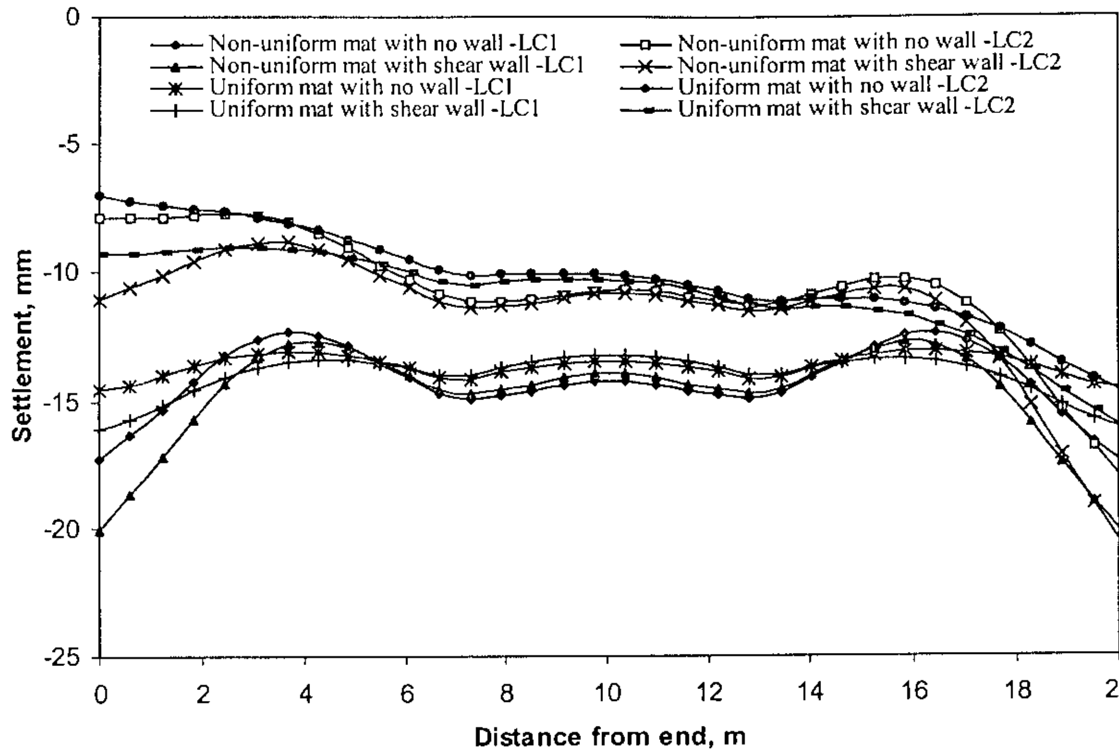

Fig.D-A37 Variation in Settlement along **line 7** for mat of **Model-A.**

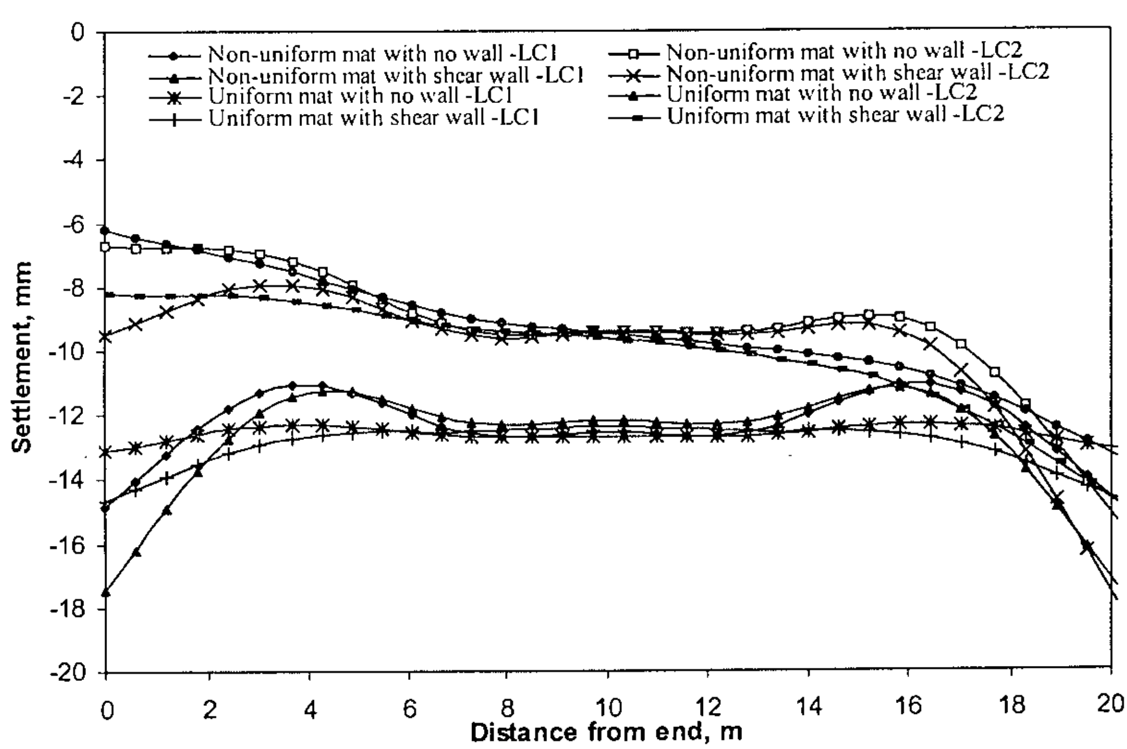

Fig.D-A38 Variation in Settlement **line 8** for mat of **Model-A.**

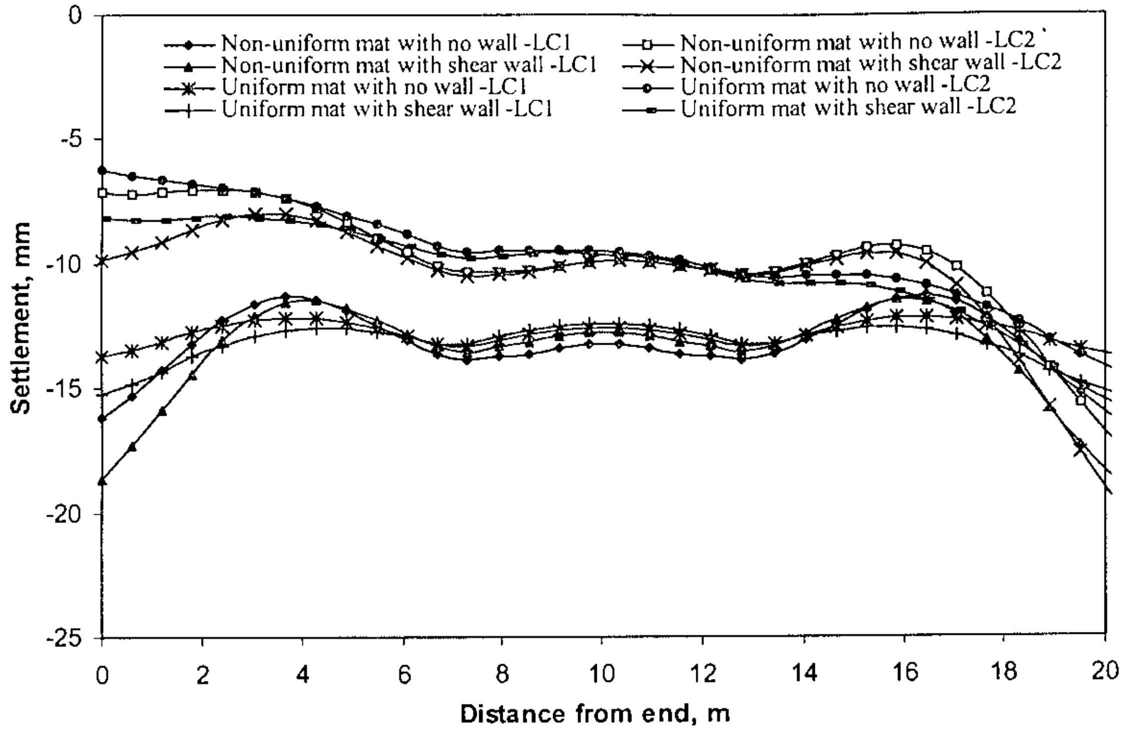

Fig.D-A39 Variation in Settlement along **line 9** for mat of **Model-A.**

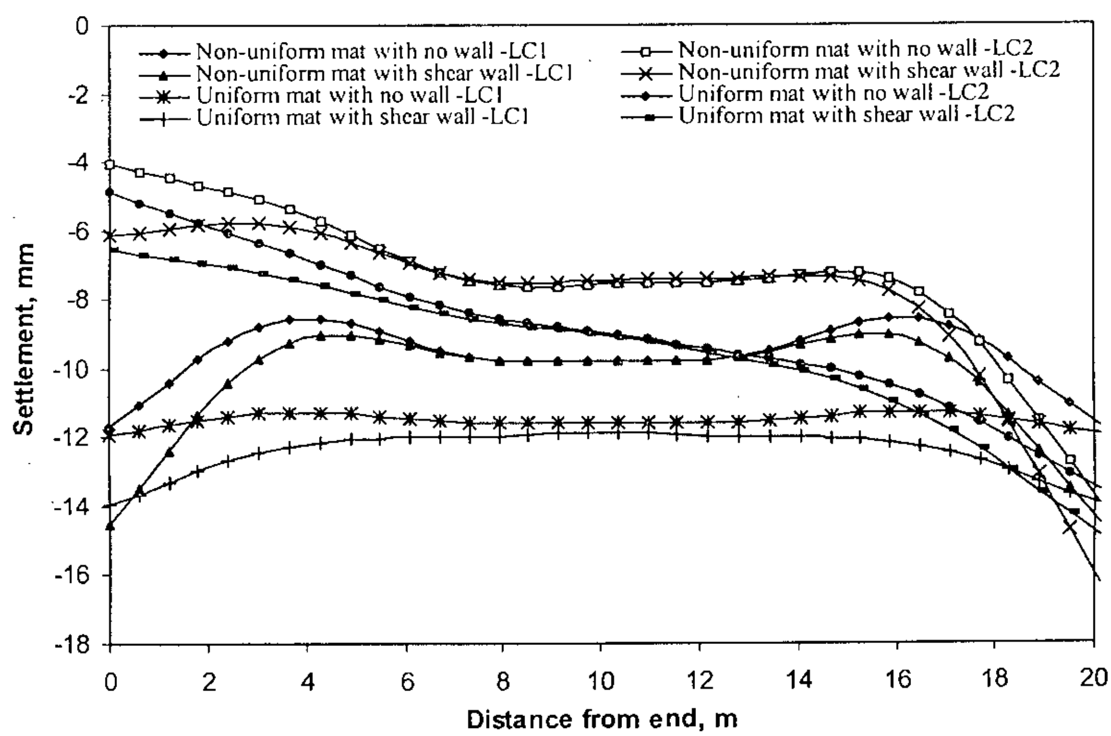

Fig.D-A40 Variation in Settlement along **line 10** for mat of **Model-A.**

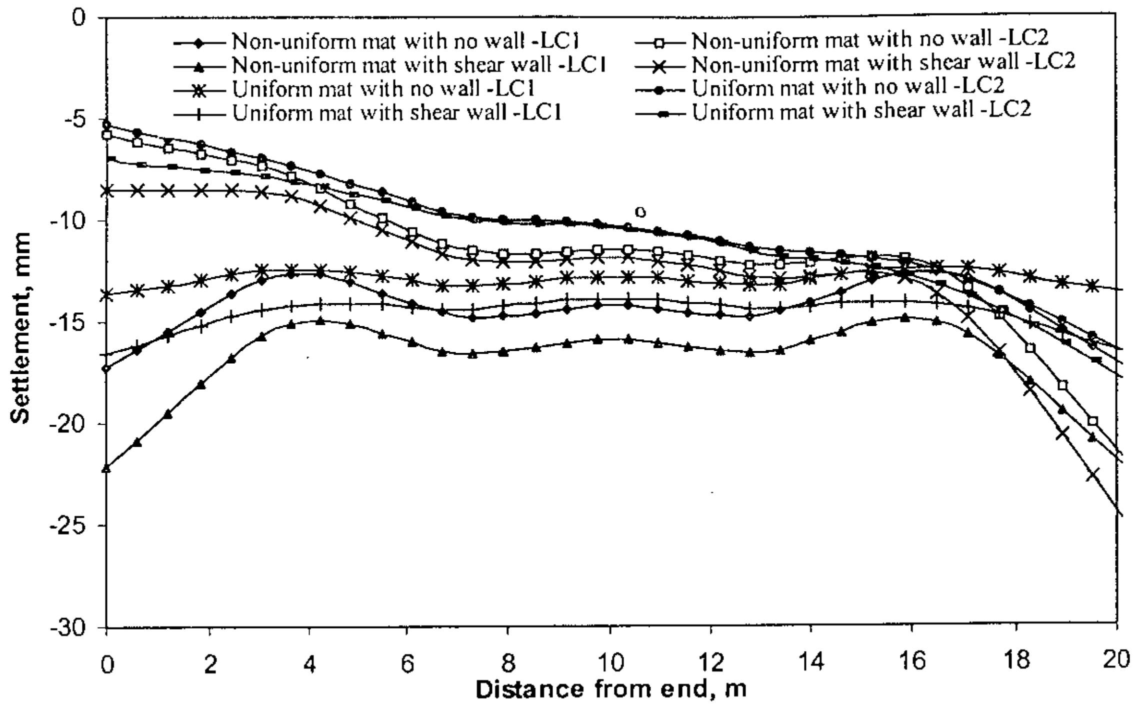

Fig.D-A41 Variation in Settlement along **line 11** for mat of **Model-A.**

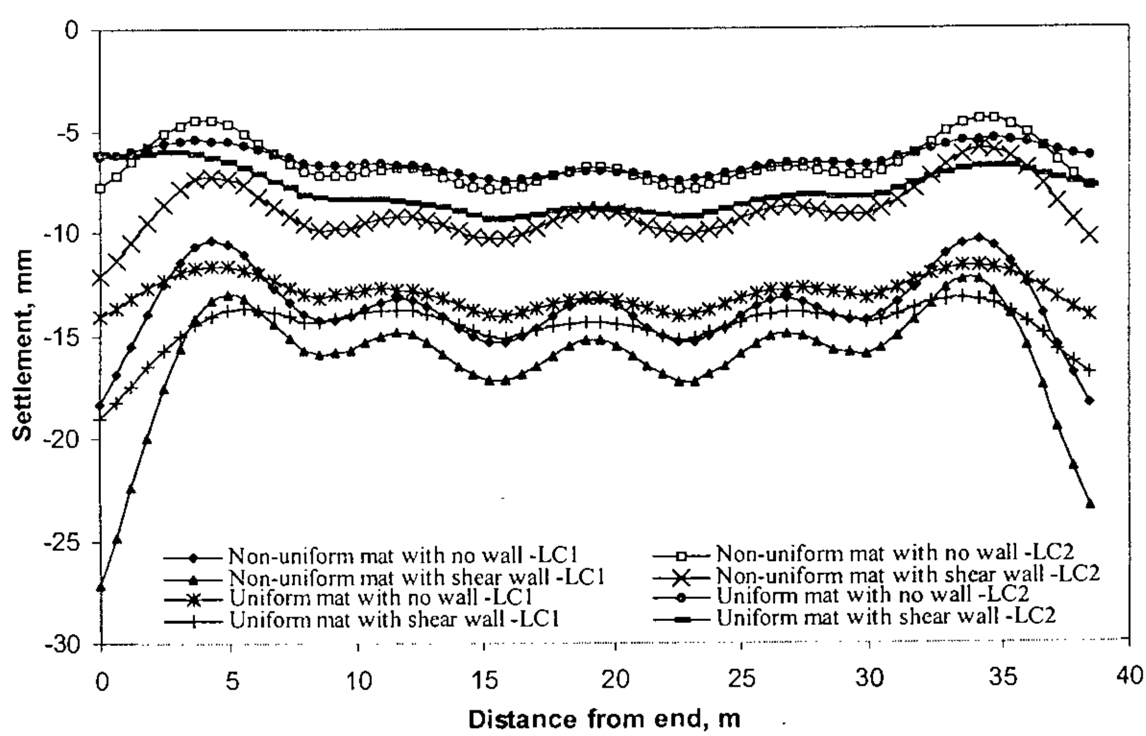

Fig.D-A42 Variation in Settlement along **line 12** for mat of **Model-A.**

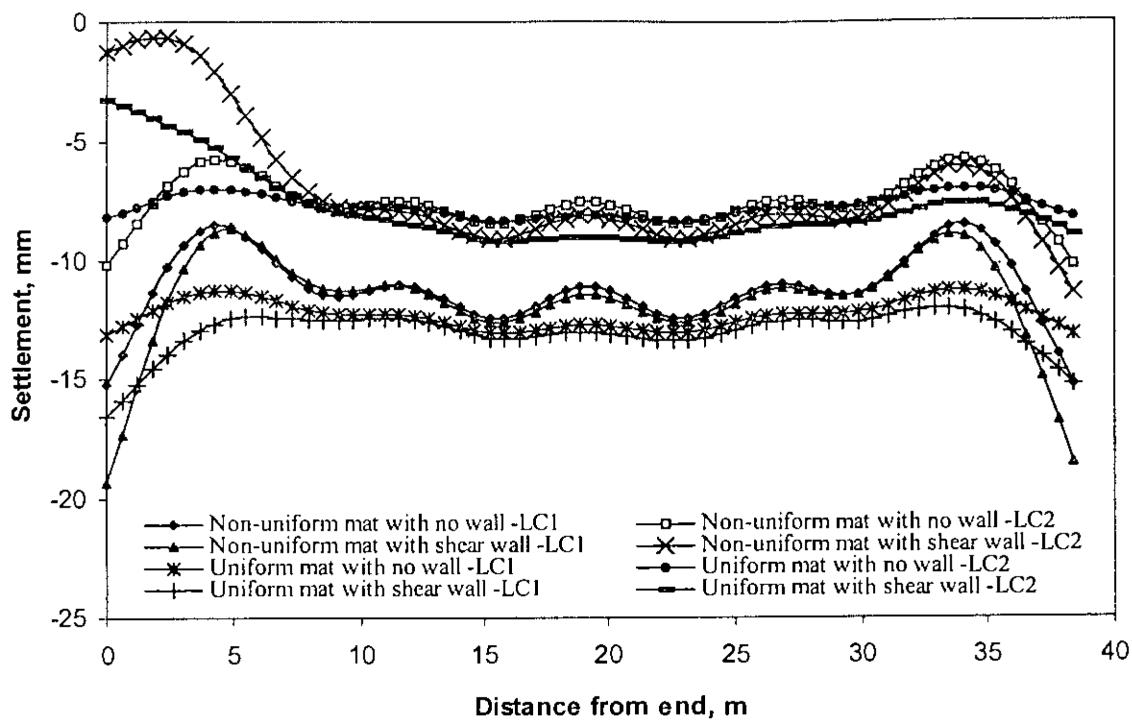

Fig.D-A43 Variation in Settlement along **line 13** for mat of **Model-A.**

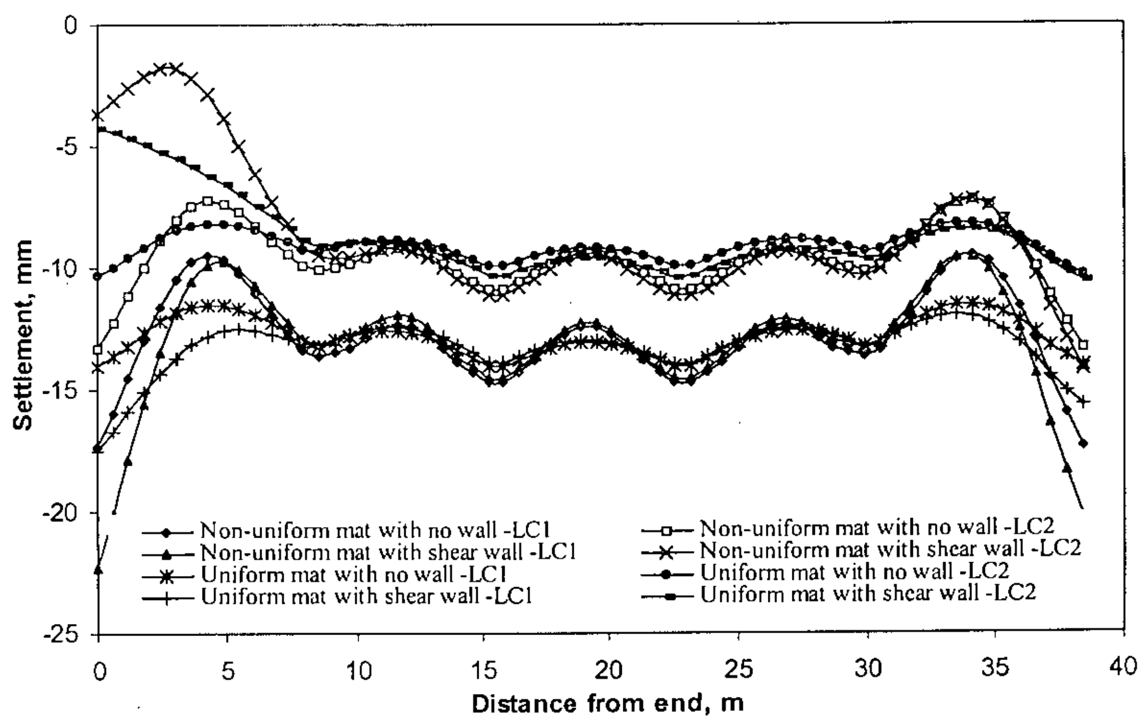

Fig.D-A44 Variation in Settlement along **line 14** for mat of **Model-A.**

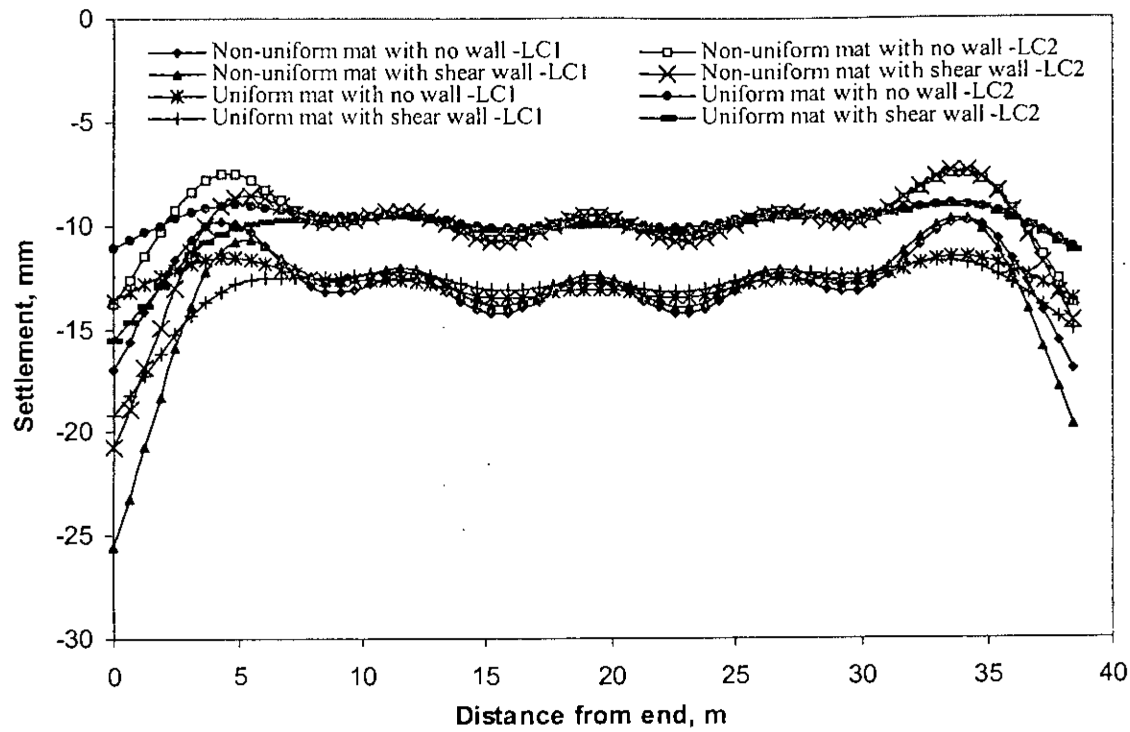

Fig.D-A45 Variation in Settlement along **line 15** for mat of **Model-A.**

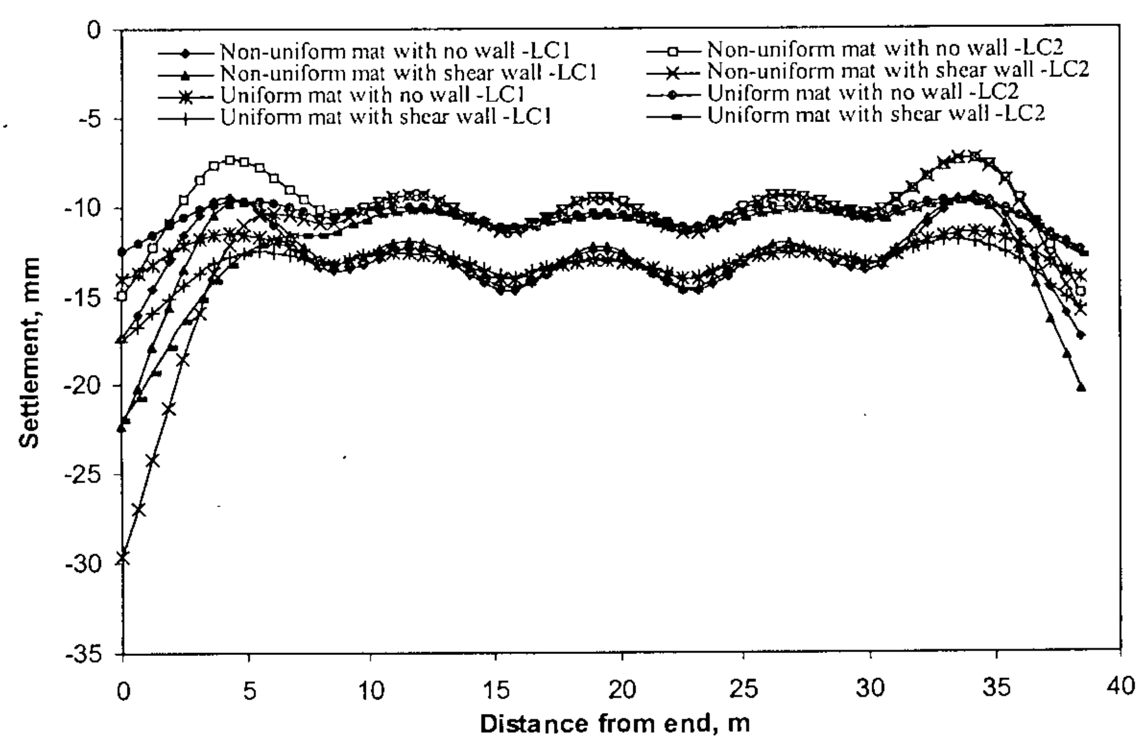

Fig.D-A46 Variation in Settlement along **line 16** for mat of **Model-A.**

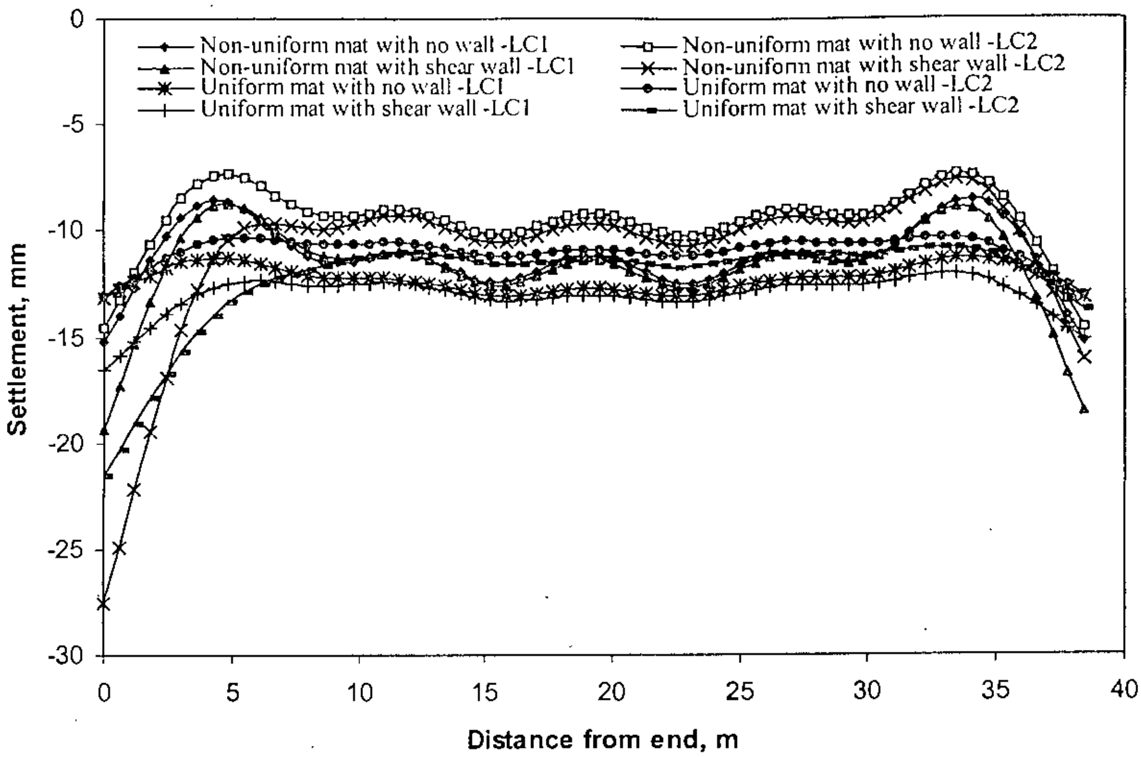

Fig.D-A47 Variation in Settlement along **line 17** for mat of **Model-A.**

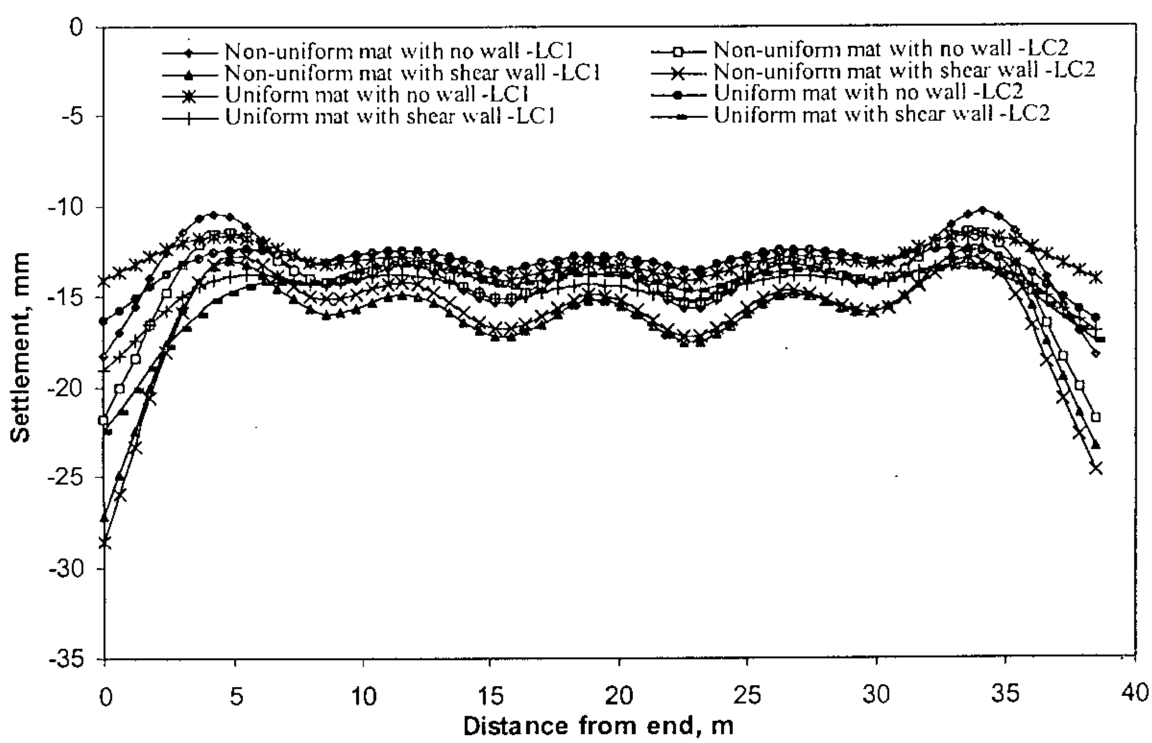

Fig.D-A48 Variation in Settlement along **line 18** for mat of **Model-A.**

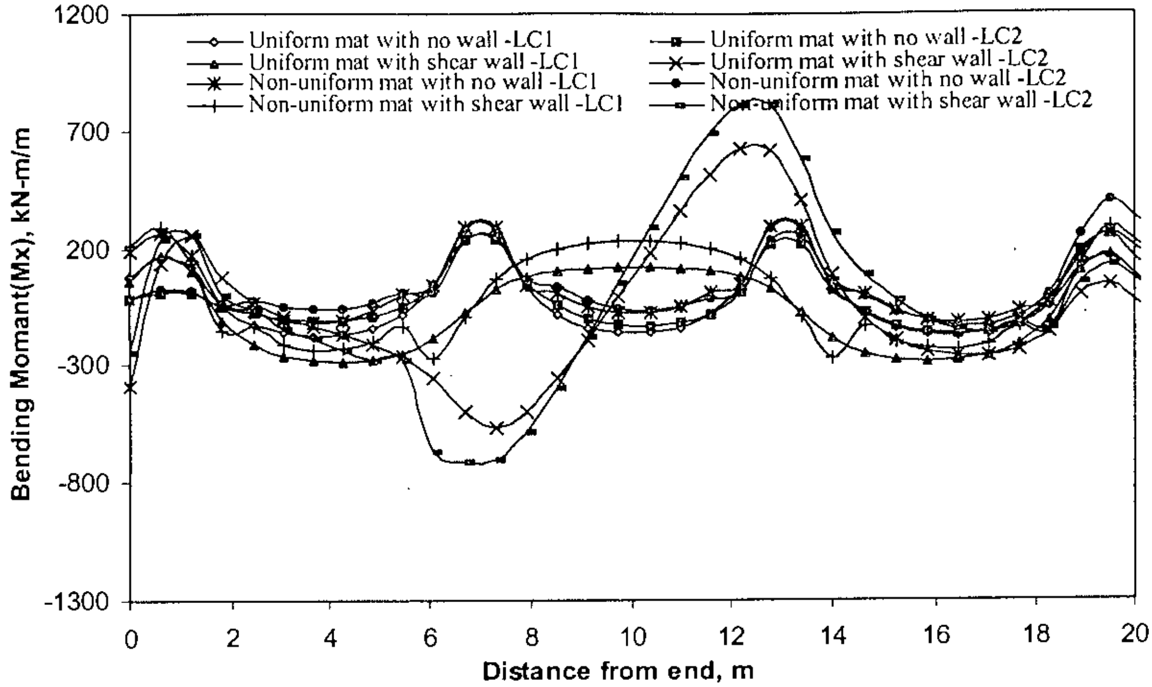

Fig.D-B1 Variation in Bending Moment along **line 1** for mat of **Model-B.**

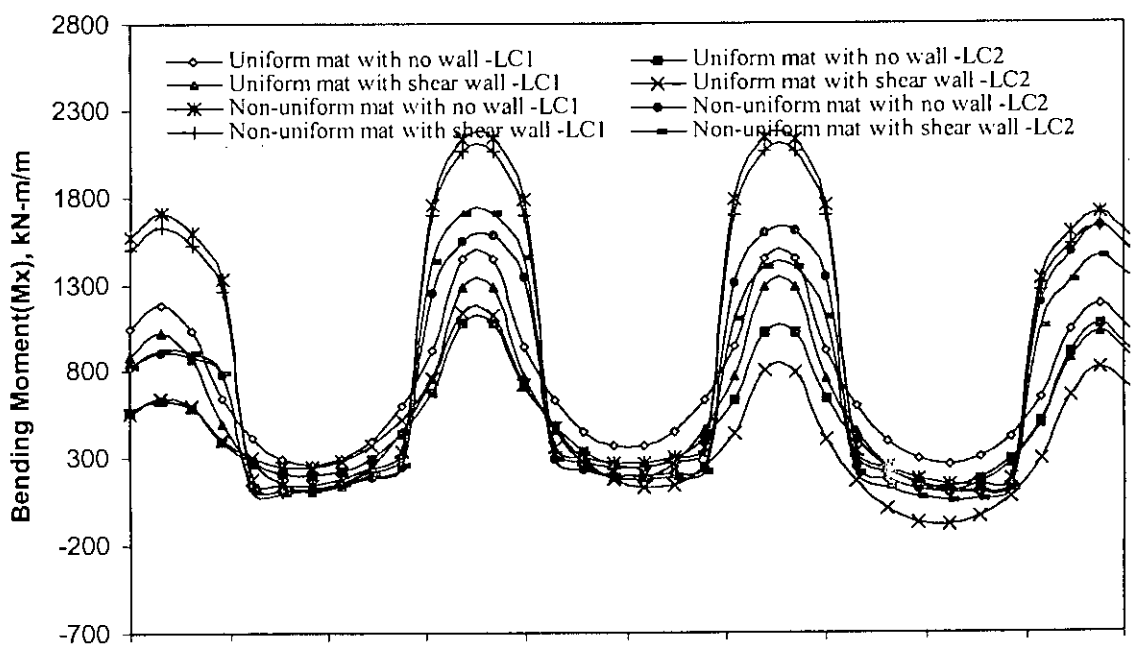

Fig.D-B2 Variation in Bending Moment along **line 3** for mat of **Model-B.**

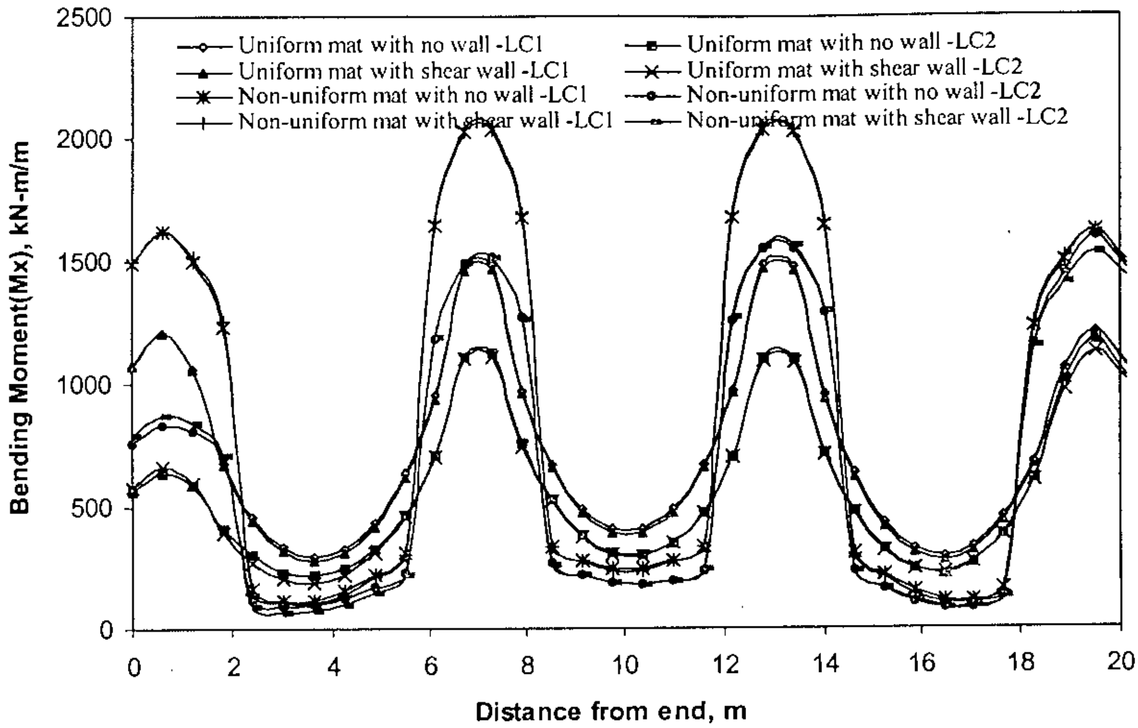

Fig.D-B3 Variation in Bending Moment along **line 5** for mat of **Model-B.**

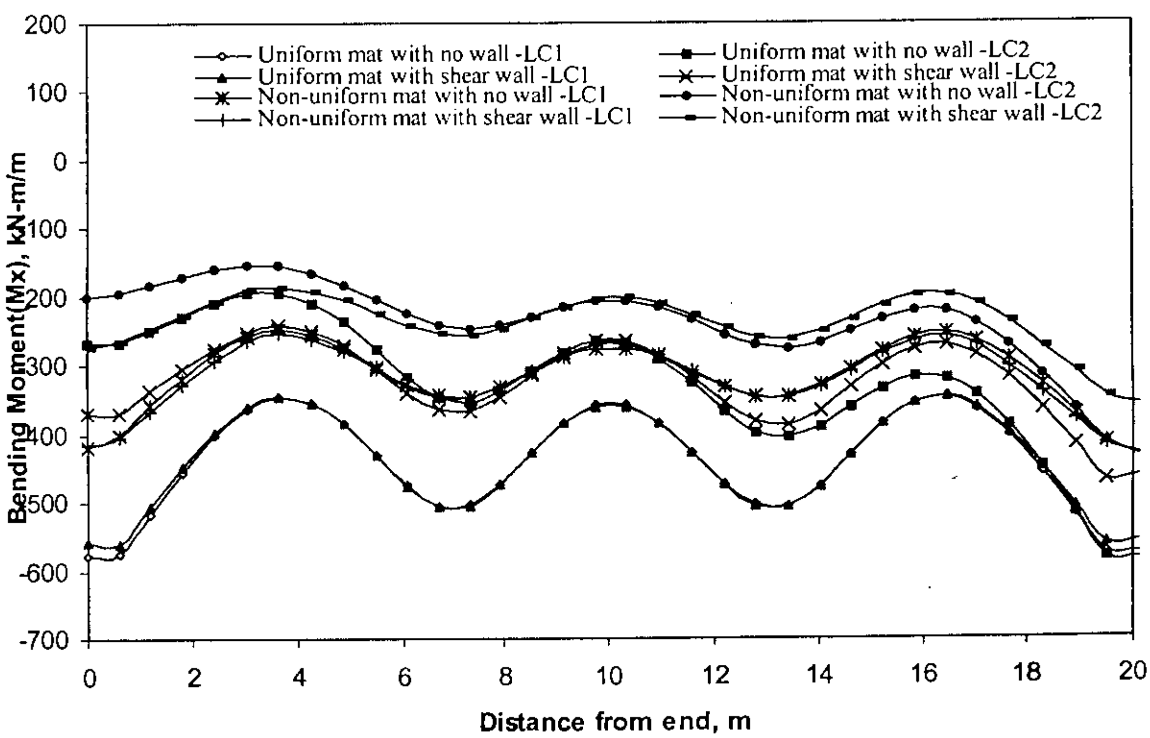

Fig.D-B4 Variation in Bending Moment along **line 6** for mat of **Model-B.**

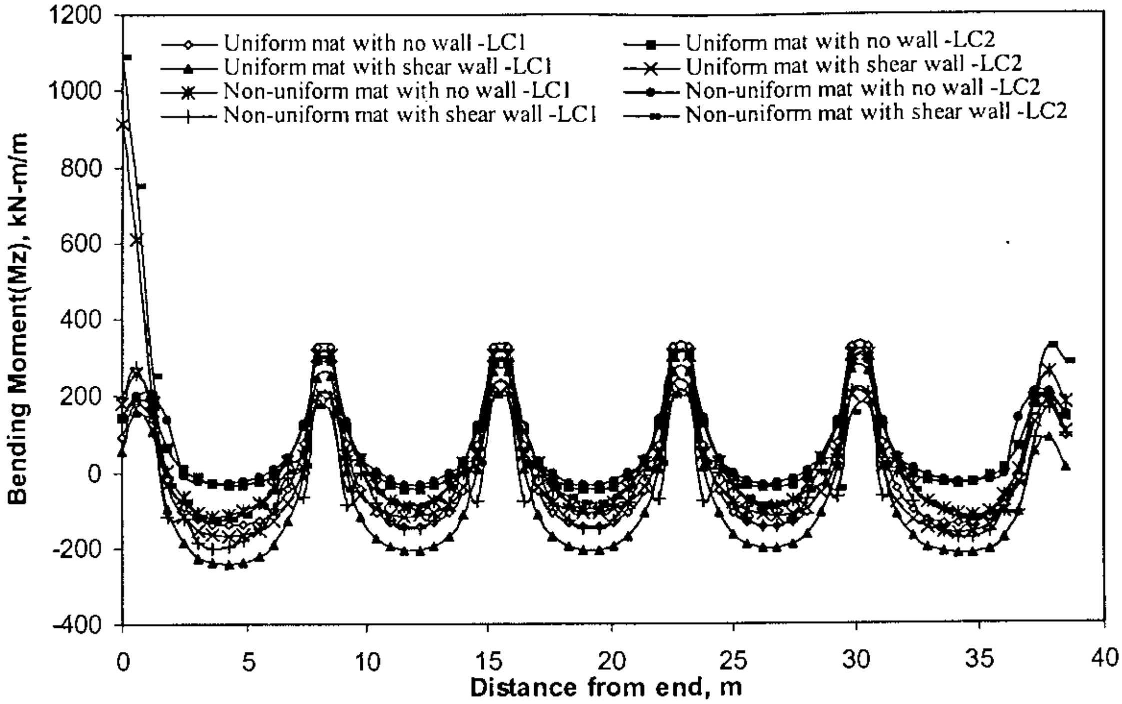

Fig.D-B5 Variation in Bending Moment along **line 12** for mat of **Model-B.**

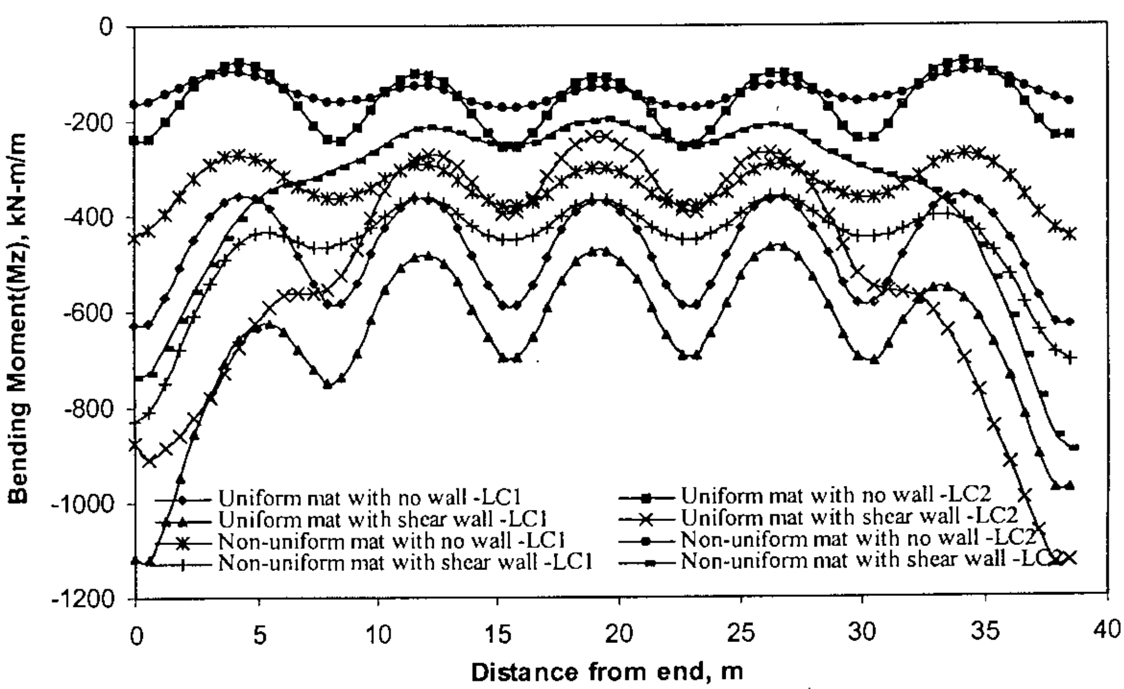

Fig.D-B6 Variation in Bending Moment along **line 13** for mat of **Model-B.**

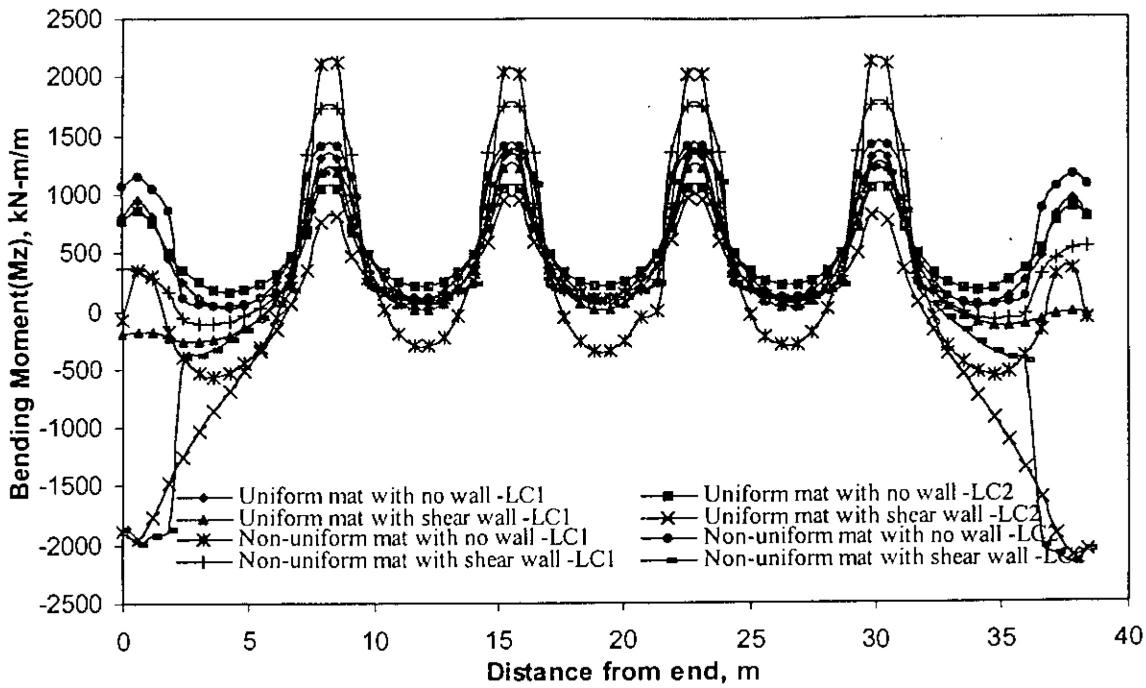

Fig.D-B7 Variation in Bending Moment along **line 14** for mat of **Model-B.**

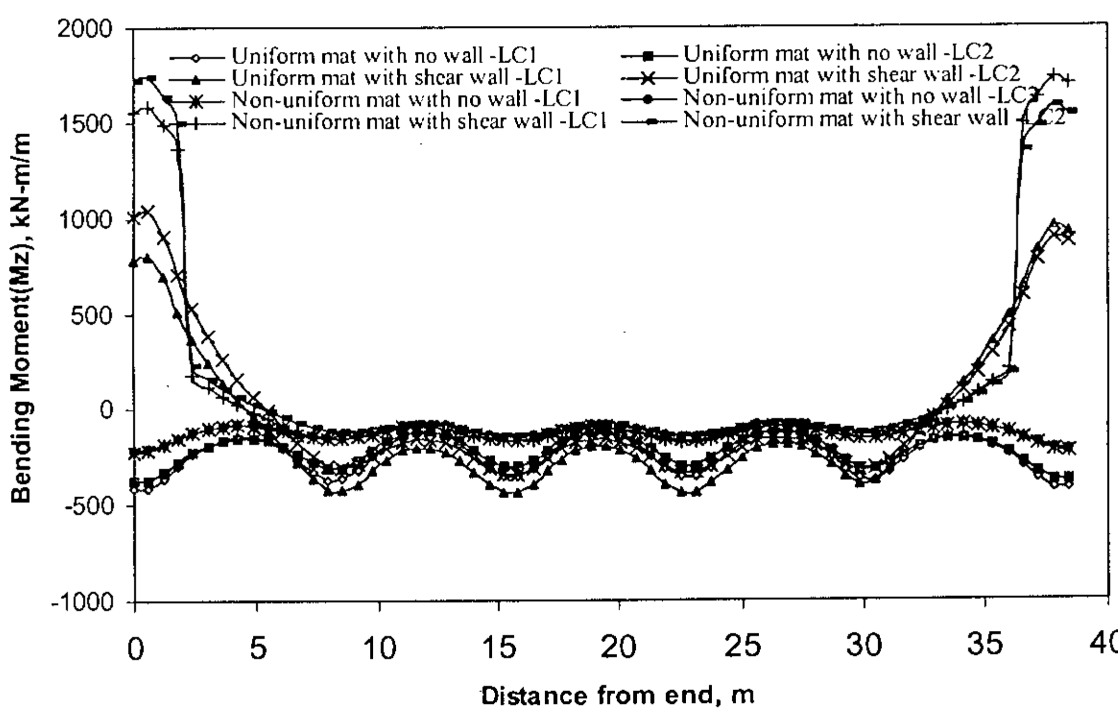

Fig.D-B8 Variation in Bending Moment along **line 15** for mat of **Model-B.**

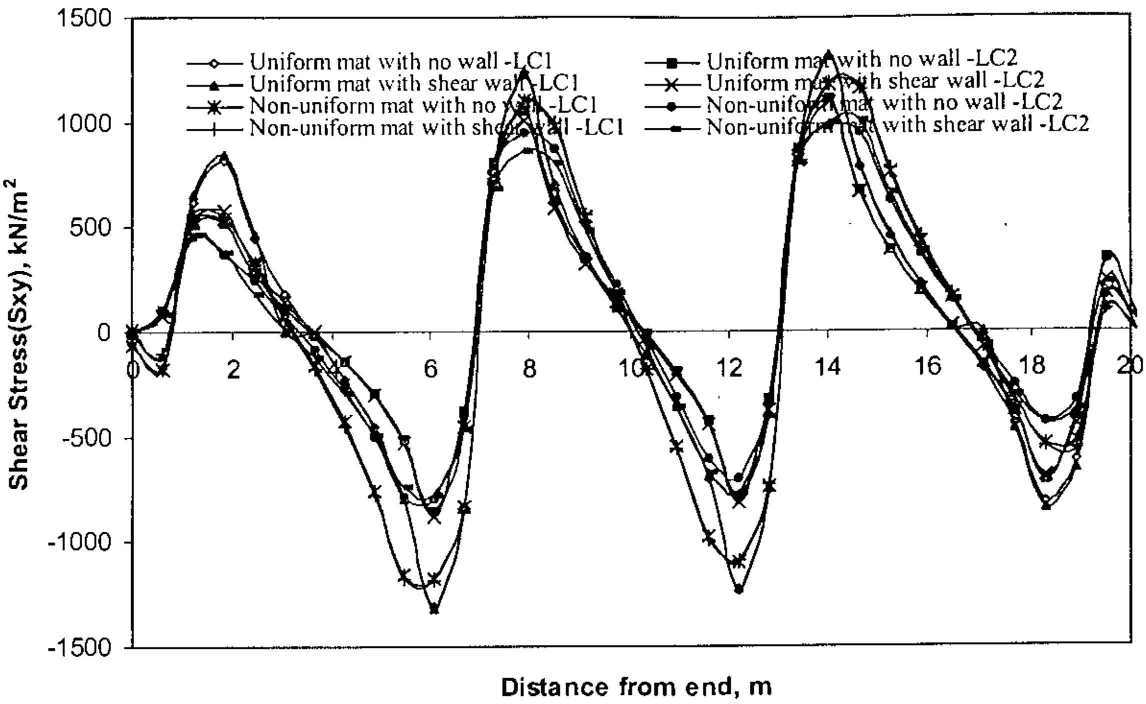

Fig.D-B9 Variation in Shear Stress along **line 3** for mat of **Model-B.**

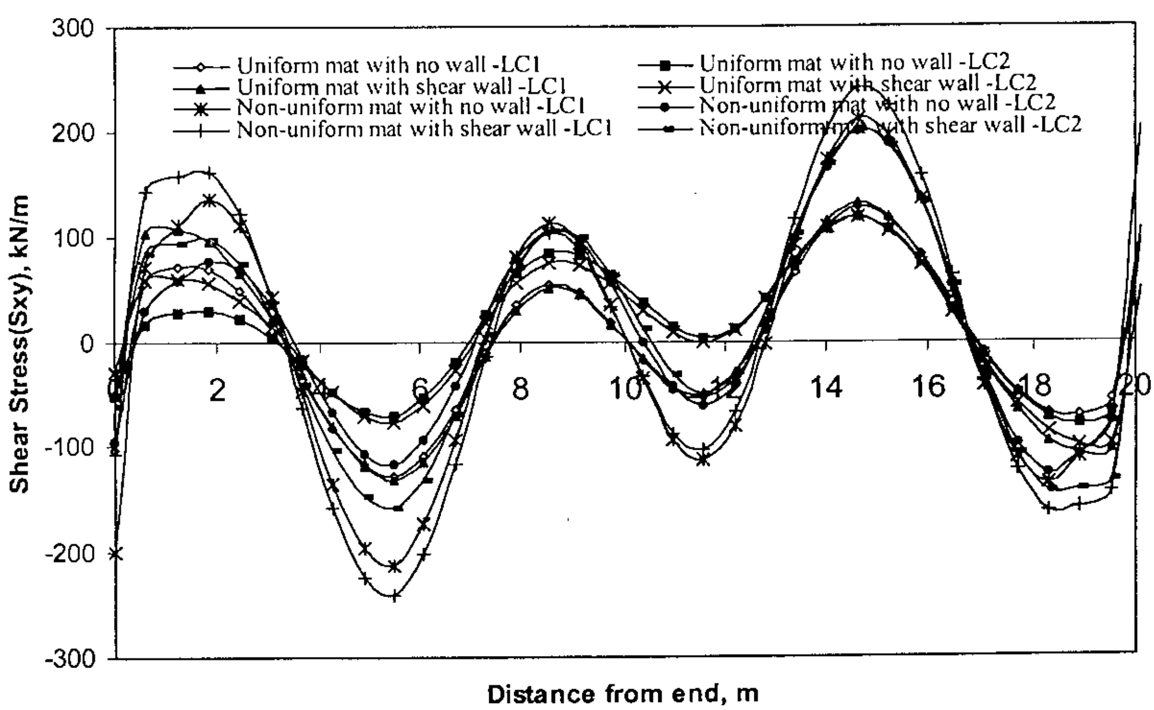

Fig.D-B10 Variation in Shear Stress along **line 4** for mat of **Model-B.**

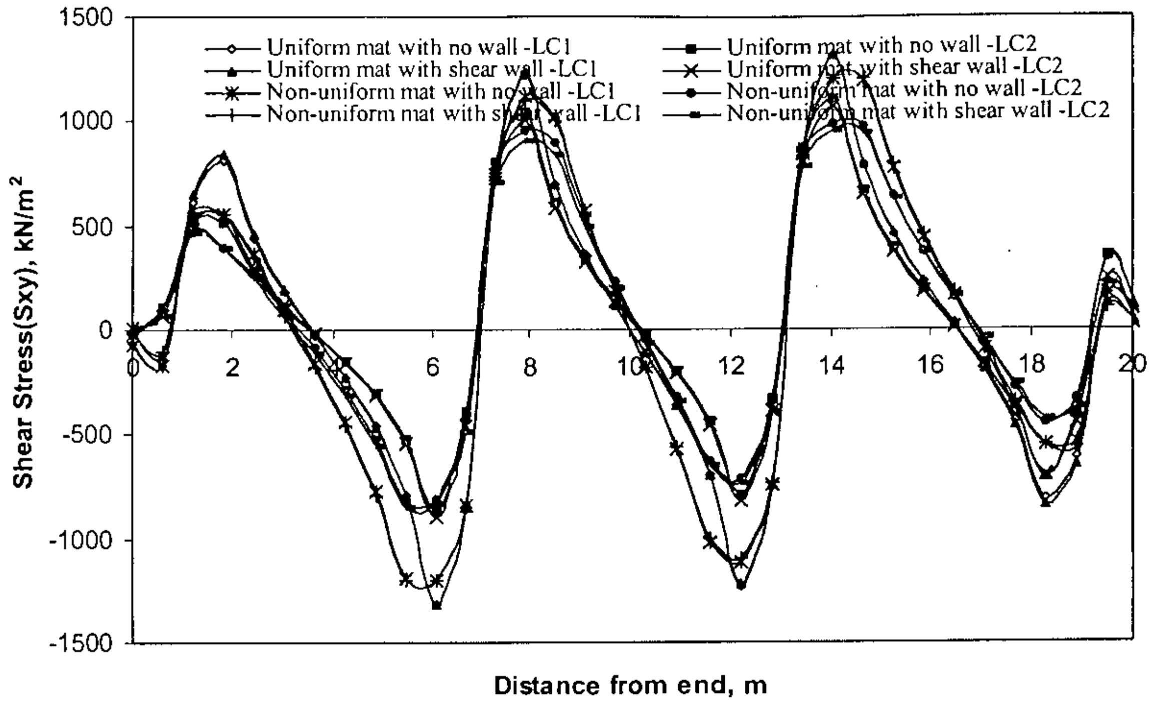

Fig.D-B11 Variation in Shear Stress along **line 5** for mat of **Model-B.**

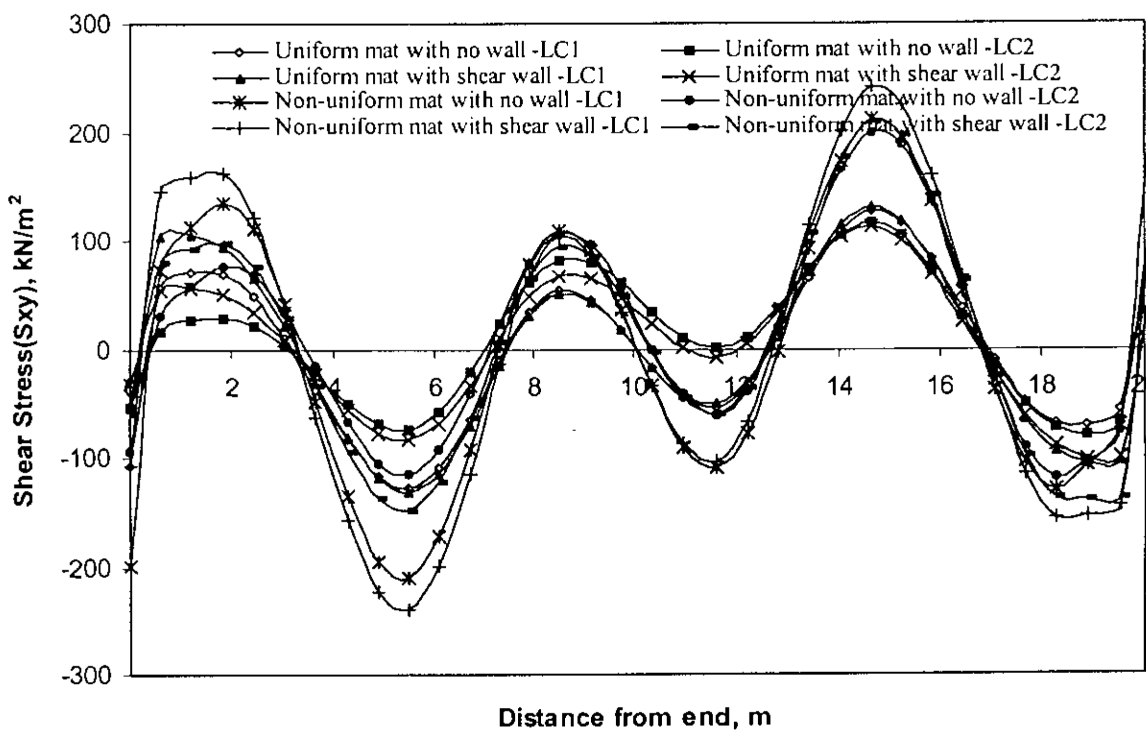

Fig.D-B12 Variation in Shear Stress along **line 6** for mat of **Model-B.**

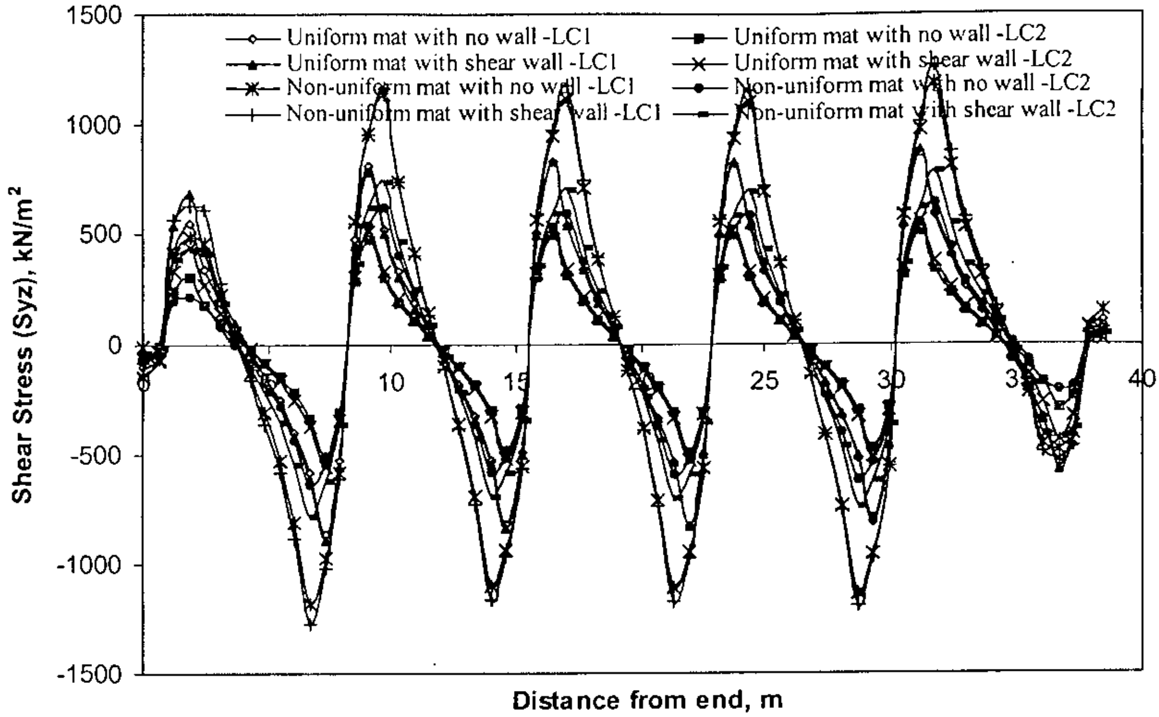

Fig.D-B13 Variation in Shear Stress along **line 12** for mat of **Model-B.**

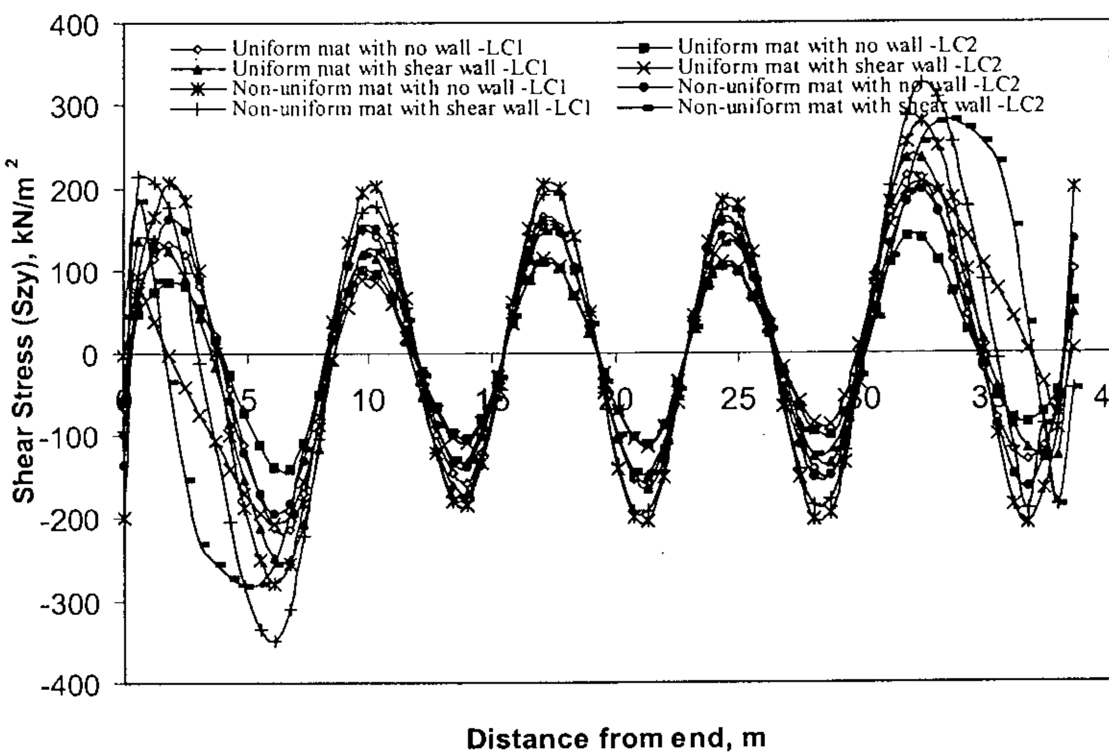

Fig.D-B14 Variation in Shear Stress along **line 13** for mat of **Model-B.**

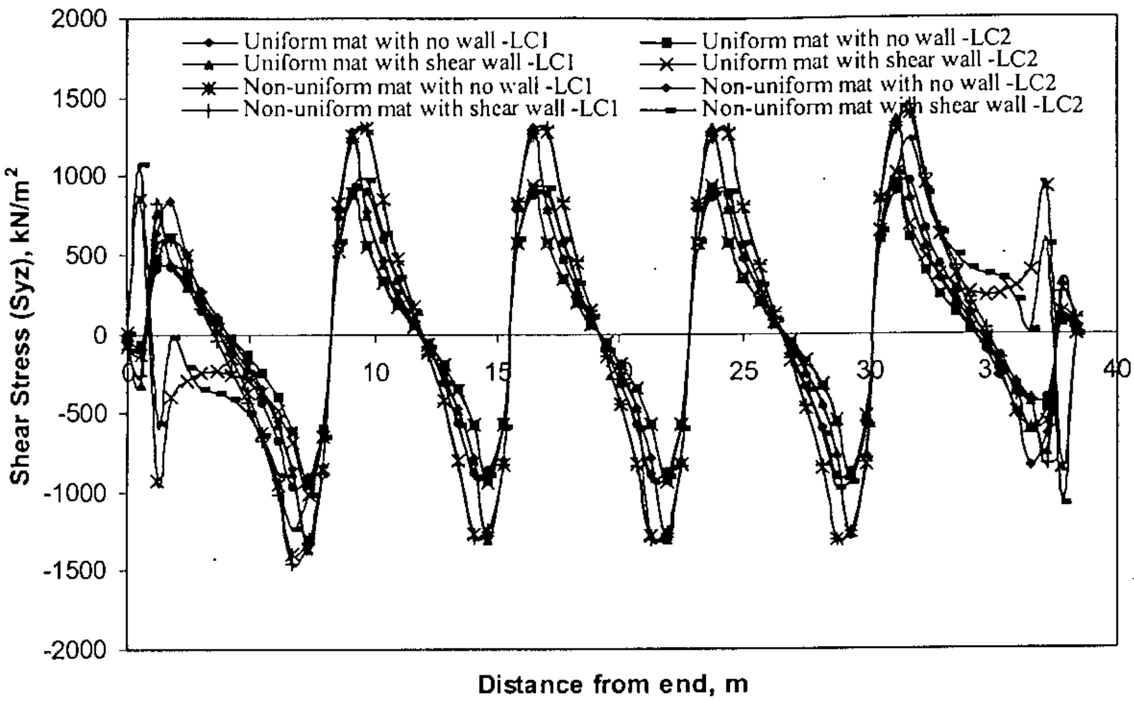

Fig.D-B15 Variation in Shear Stress along **line 14** for mat of **Model-B.**

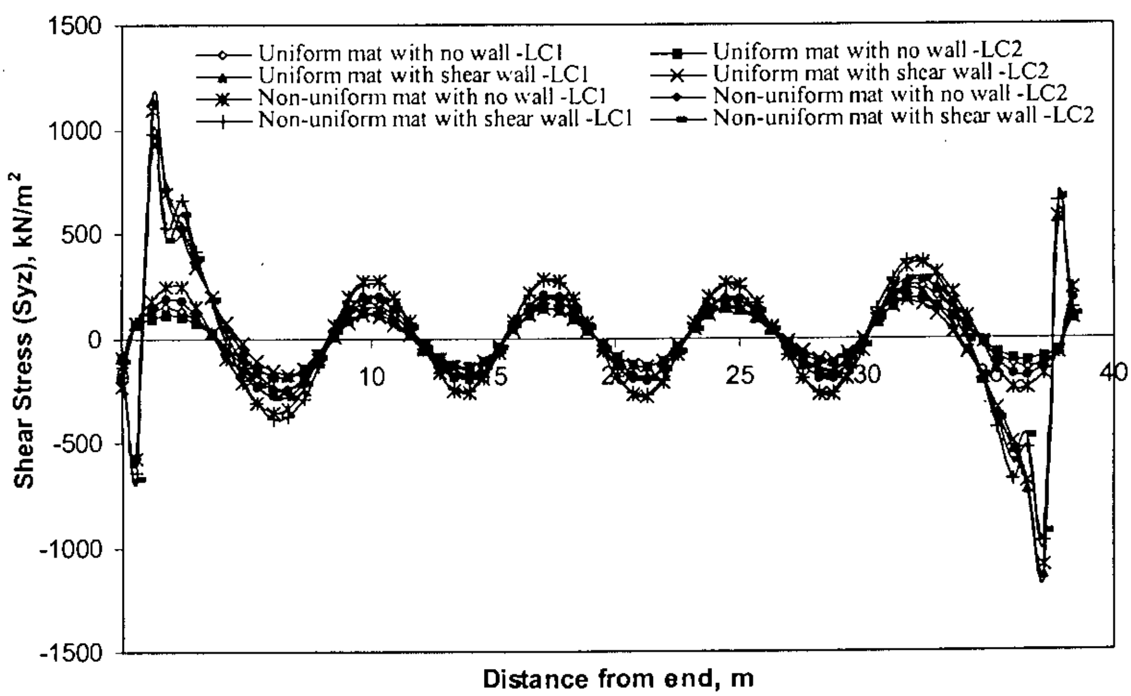

Fig.D-B16 Variation in Shear Stress along **line 15** for mat of **Model-B.**

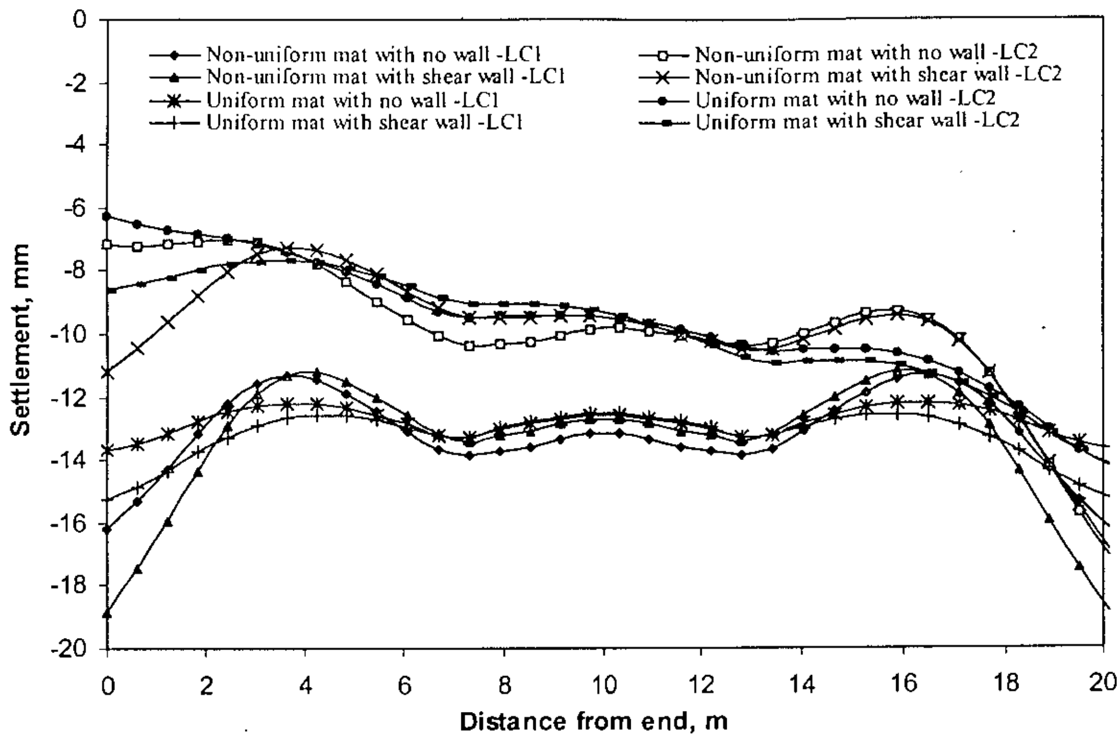

Fig.D-B17 Variation in Settlement along **line 3** for mat of **Model-B.**

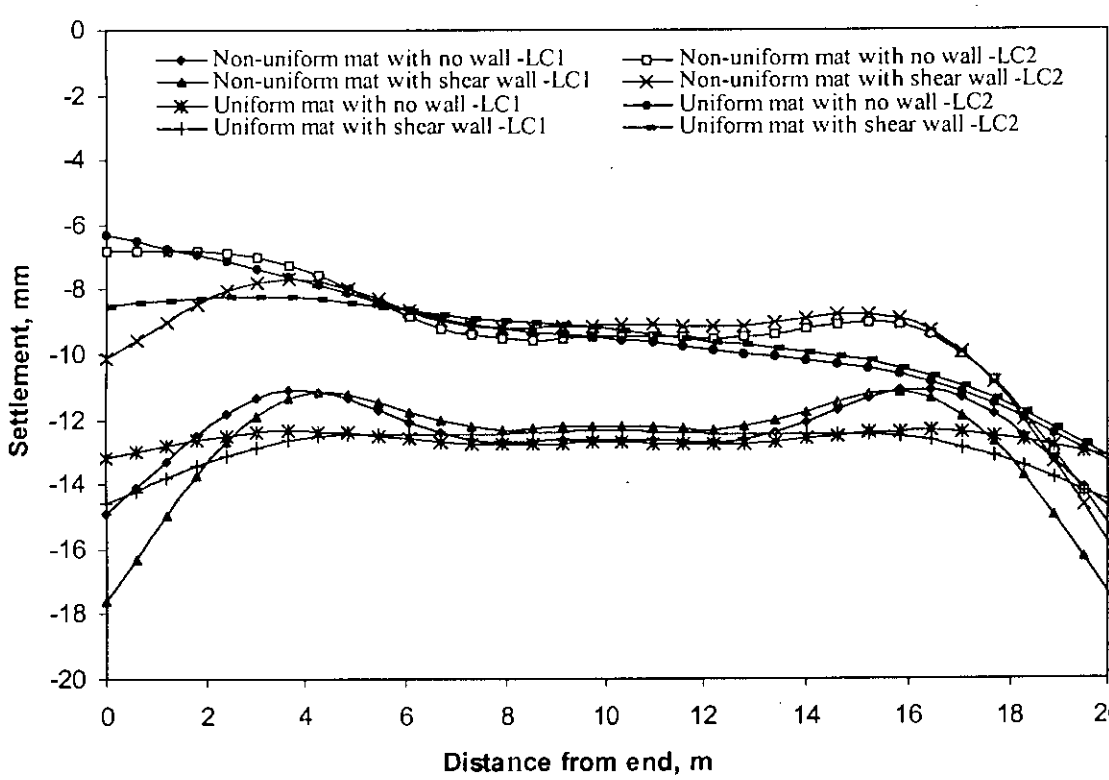

Fig.D-B18 Variation in Settlement along **line 4** for mat of **Model-B.**

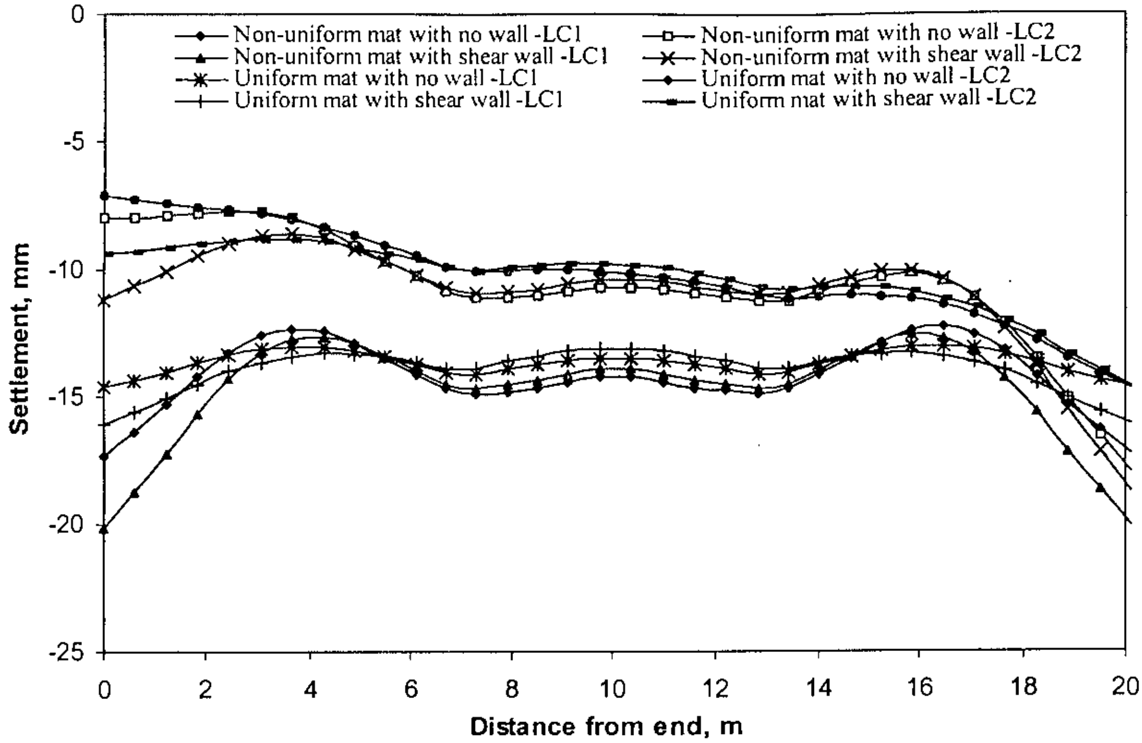

Fig.D-B19 Variation in Settlement along **line 5** for mat of **Model-B.**

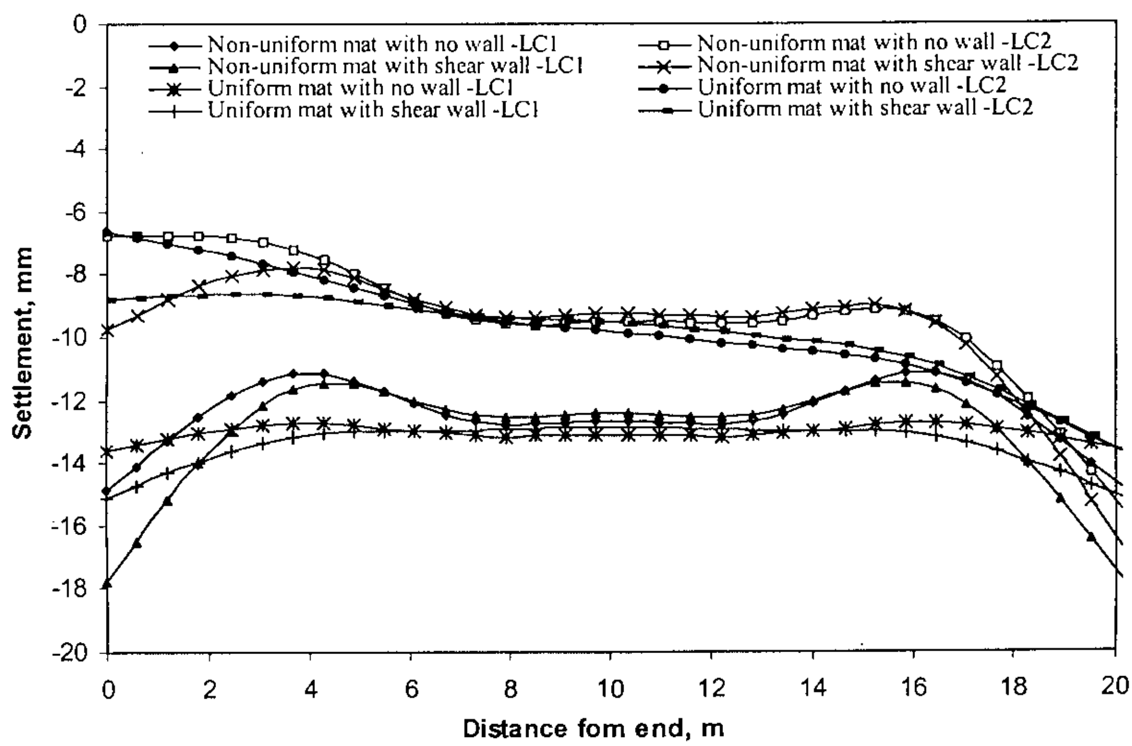

Fig.D-B20 Variation in Settlement along **line 6** for mat of **Model-B.**

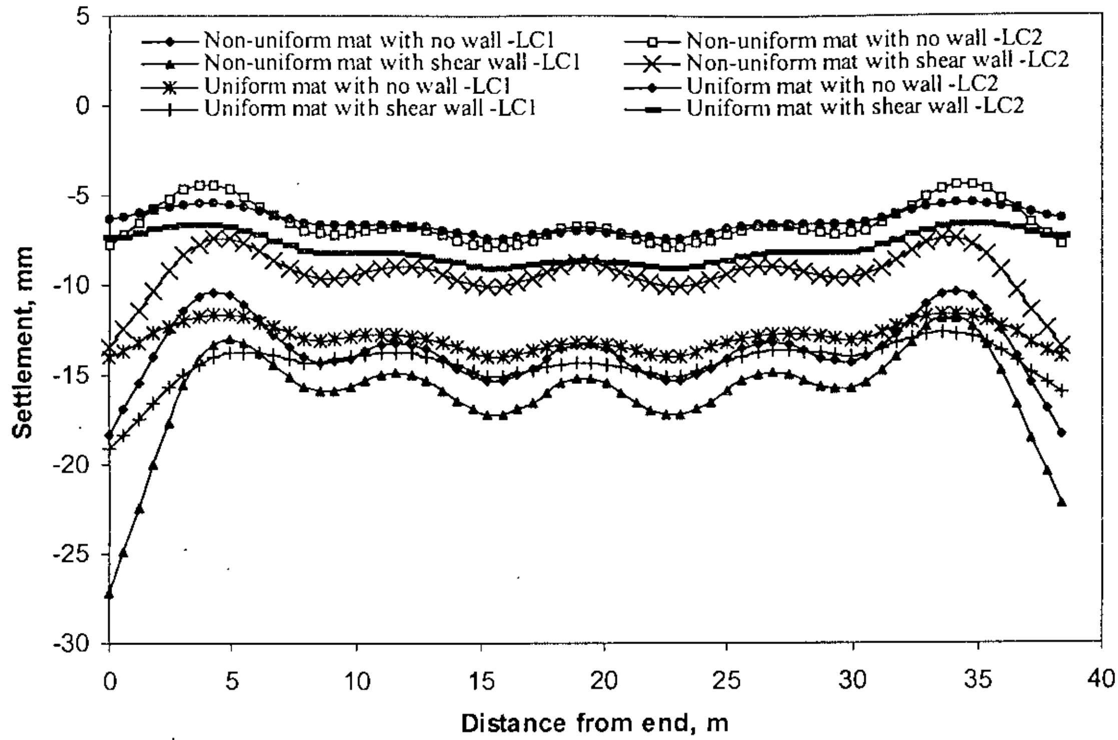

Fig.D-B21 Variation in Settlement along **line 12** for mat of **Model-B.**

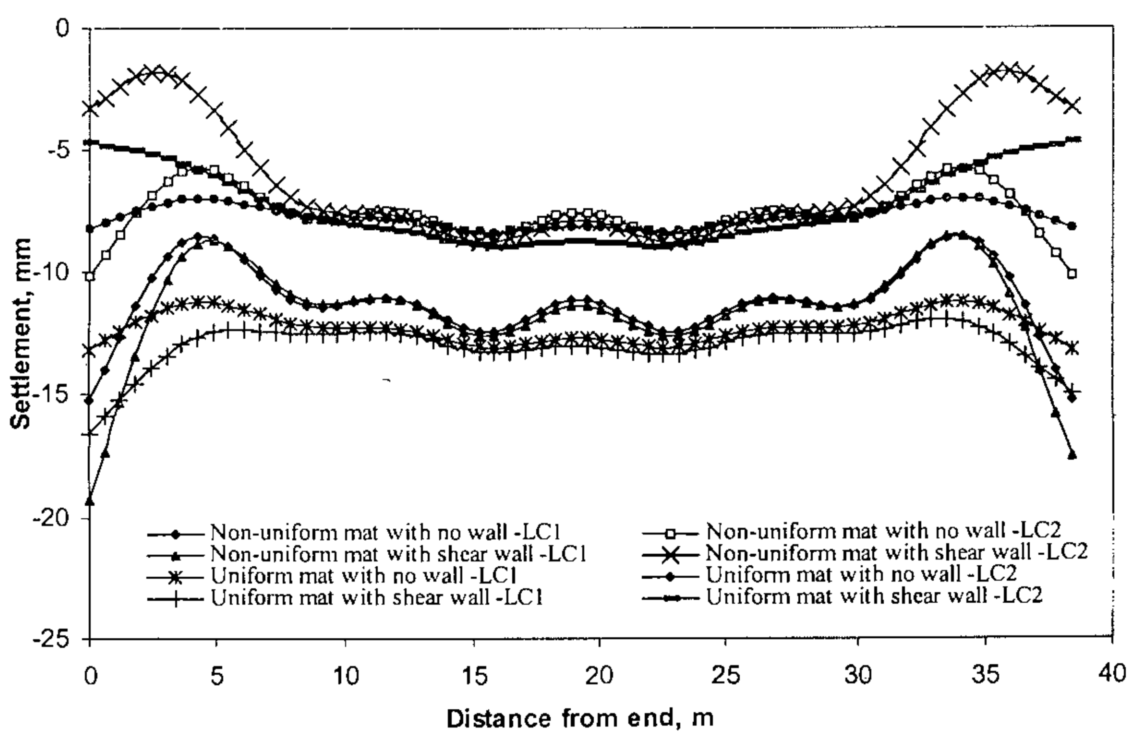

Fig.D-B22 Variation in Settlement along **line 13** for mat of **Model-B.**

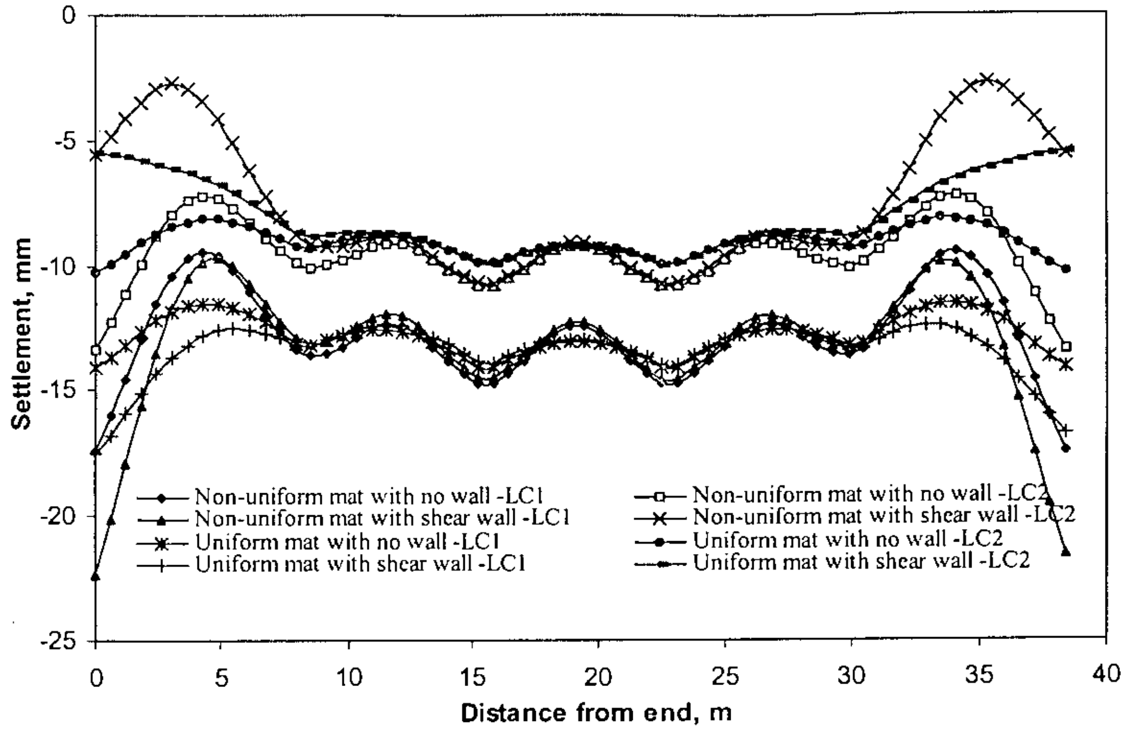

Fig.D-B23 Variation in Settlement along **line 14** for mat of **Model-B.**

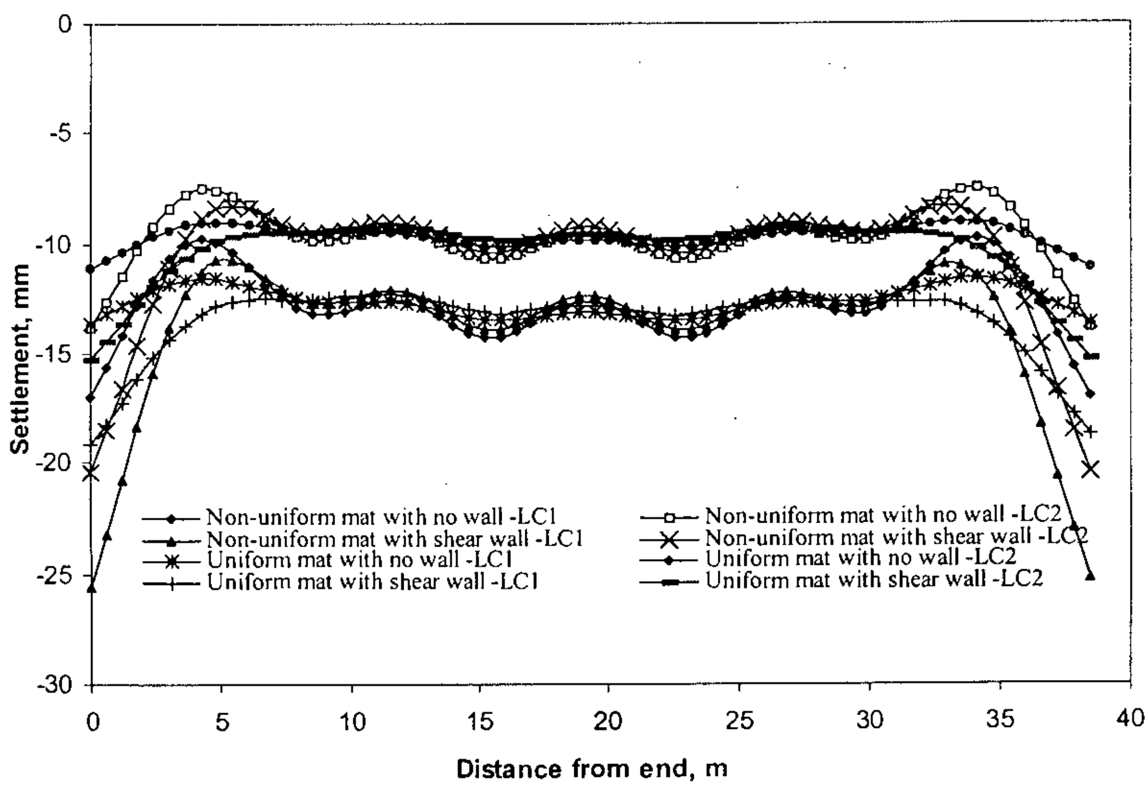

Fig.D-B24 Variation in Settlement along **line 15** for mat of **Model-B.**

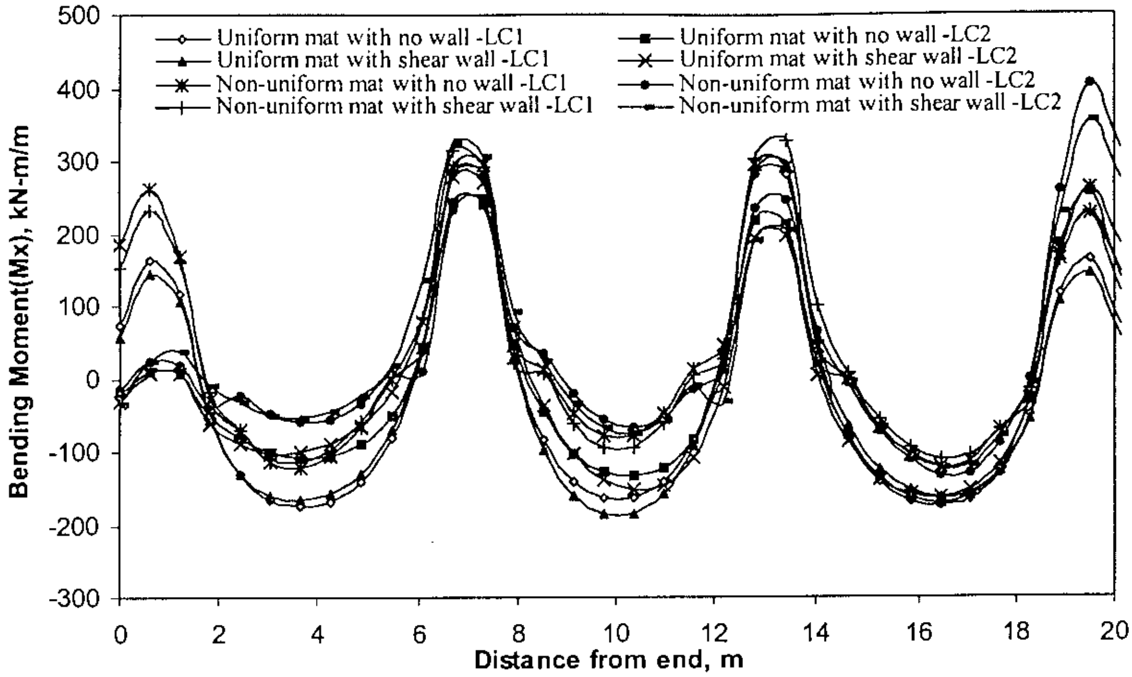

Fig.D-C1 Variation in Bending Moment along **line 1** for mat of **Model-C.**

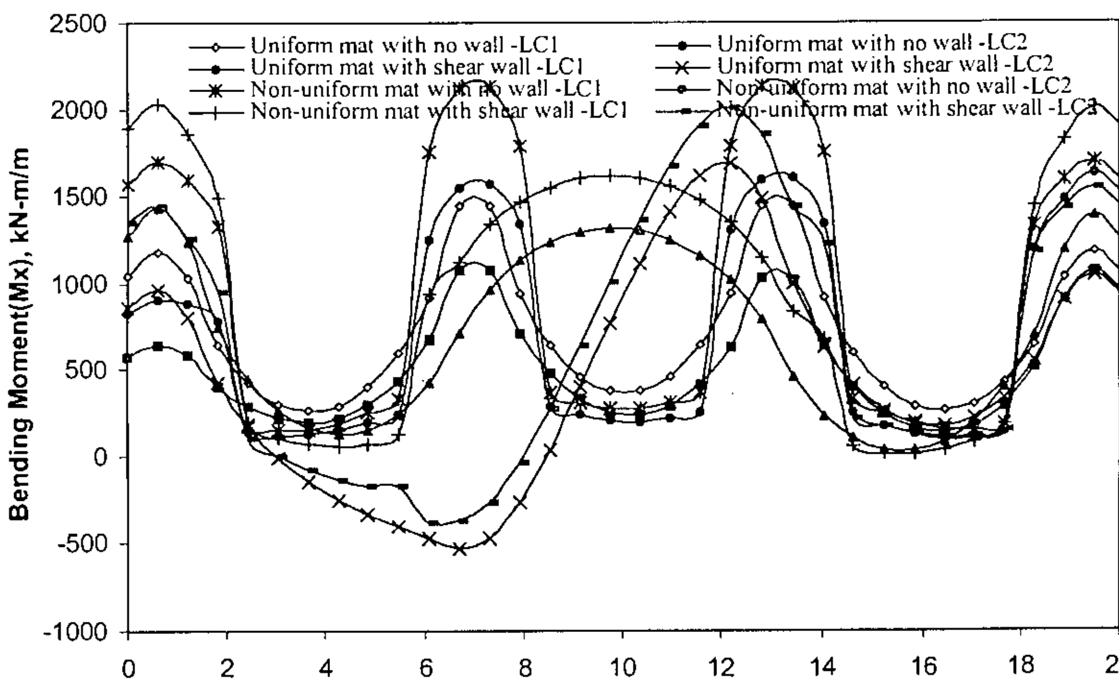

Fig.D-C2 Variation in Bending Moment along **line 3** for mat of **Model-C.**

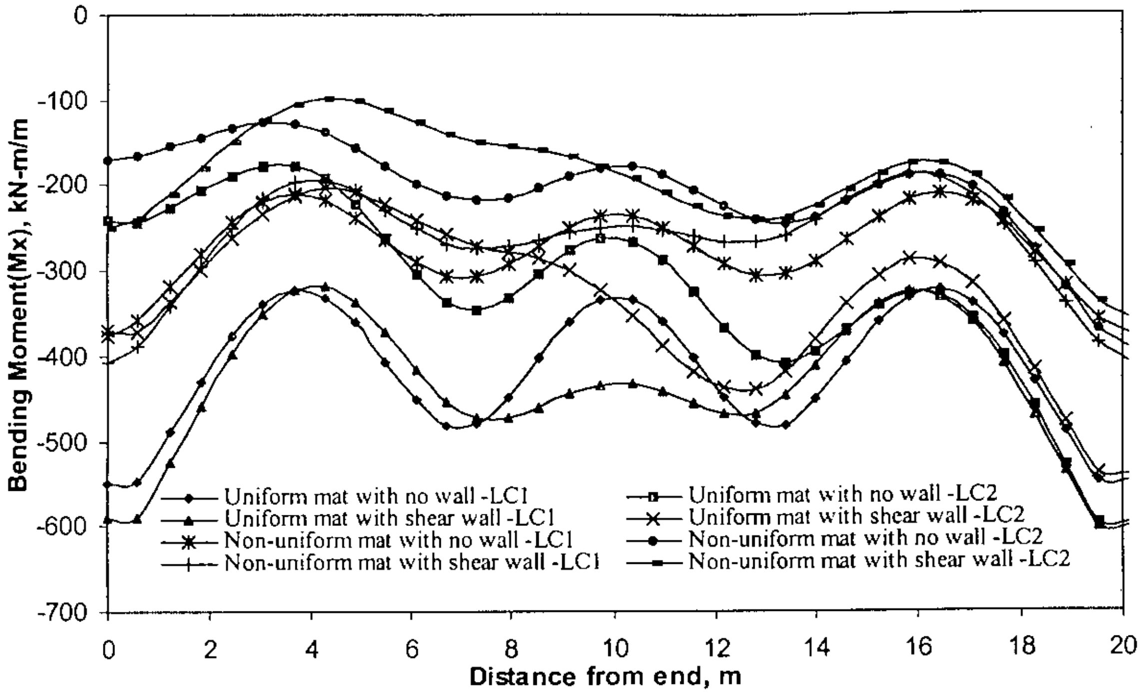

Fig.D-C3 Variation in Bending Moment along **line 4** for mat of **Model-C.**

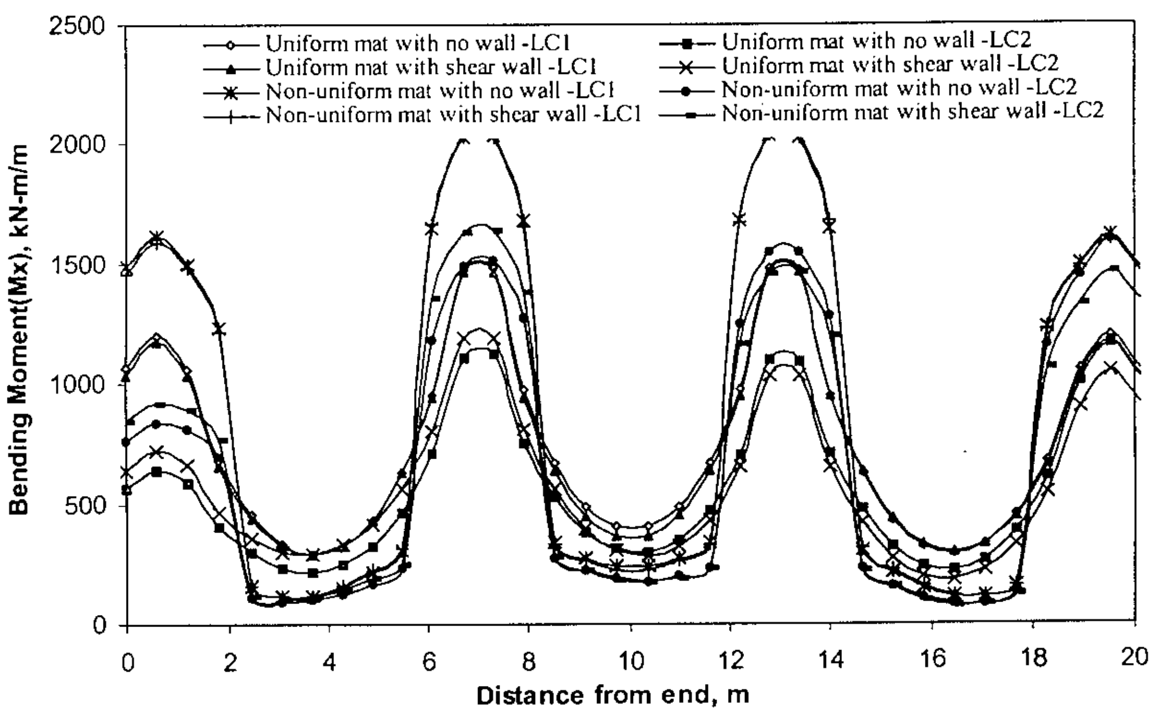

Fig.D-C4 Variation in Bending Moment along **line 5** for mat of **Model-C.**

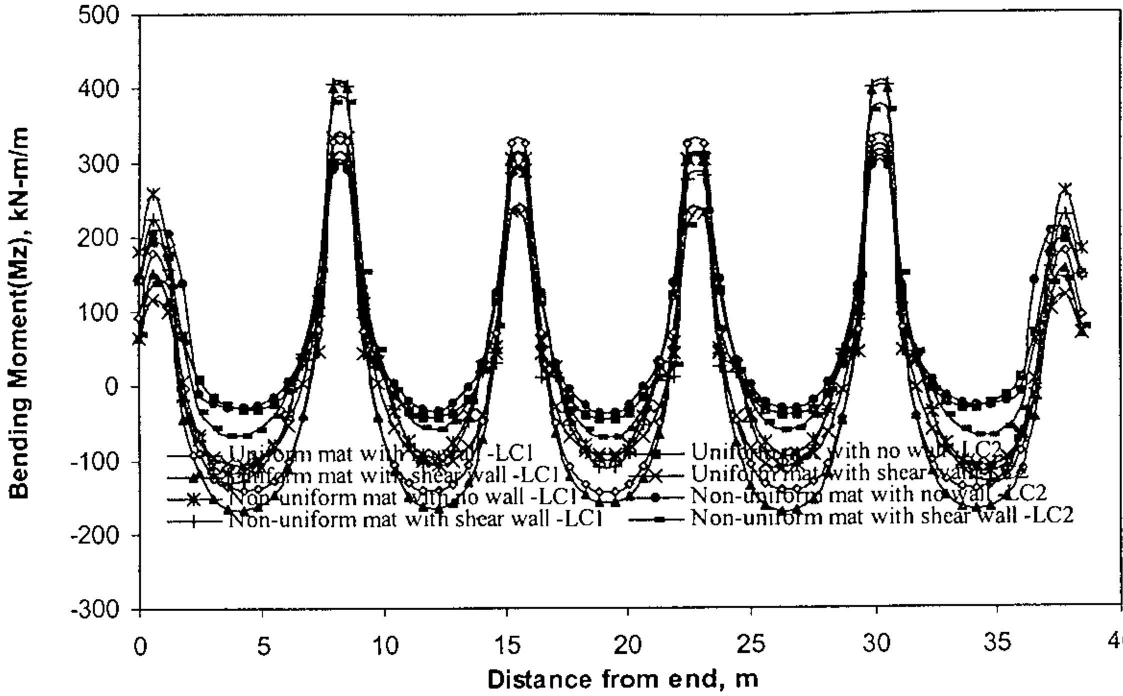

Fig.D-C5 Variation in Bending Moment along **line 12** for mat of **Model-C.**

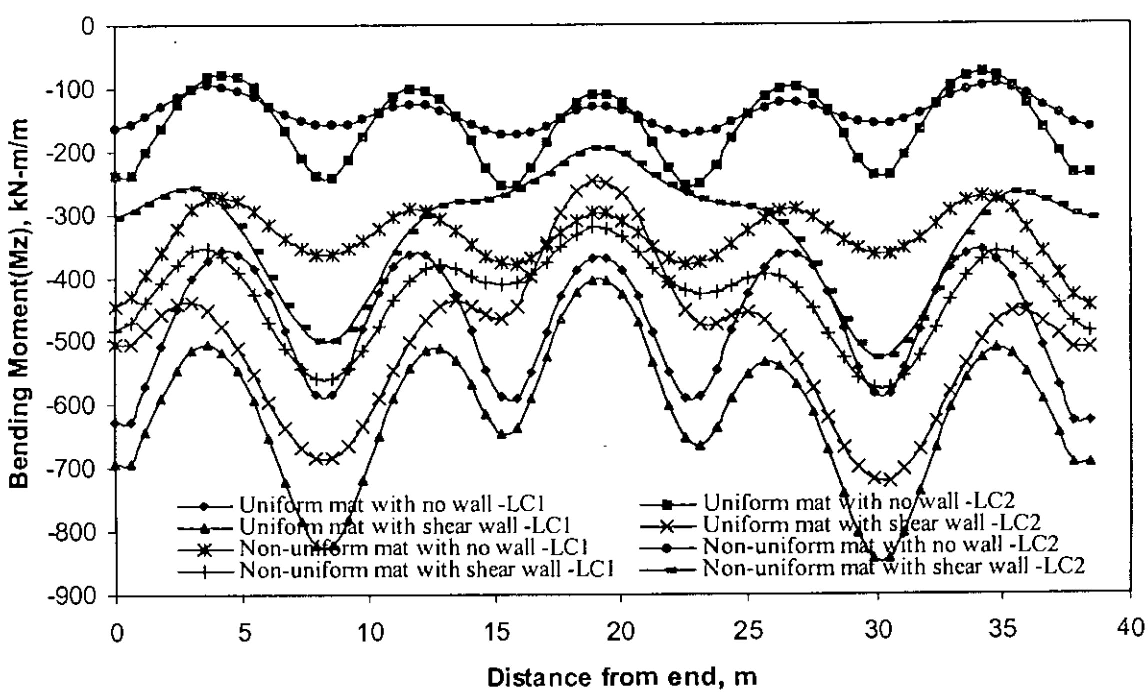

Fig.D-C6 Variation in Bending Moment along **line 13** for mat of **Model-C.**

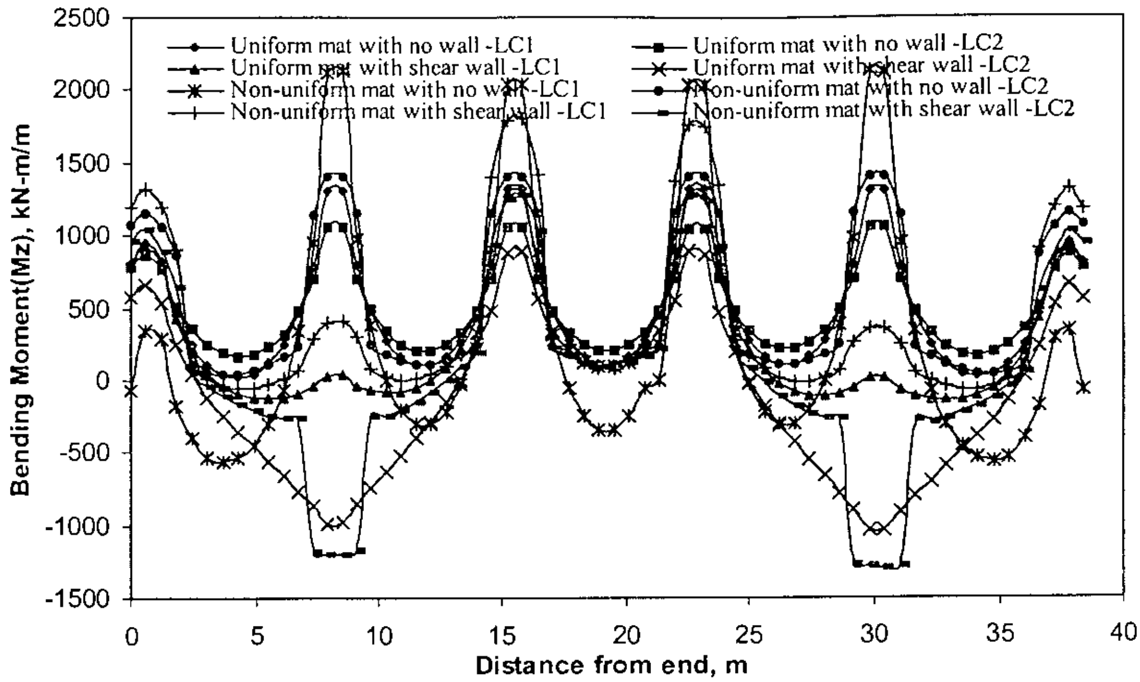

Fig.D-C7 Variation in Bending Moment along **line 14** for mat of **Model-C.**

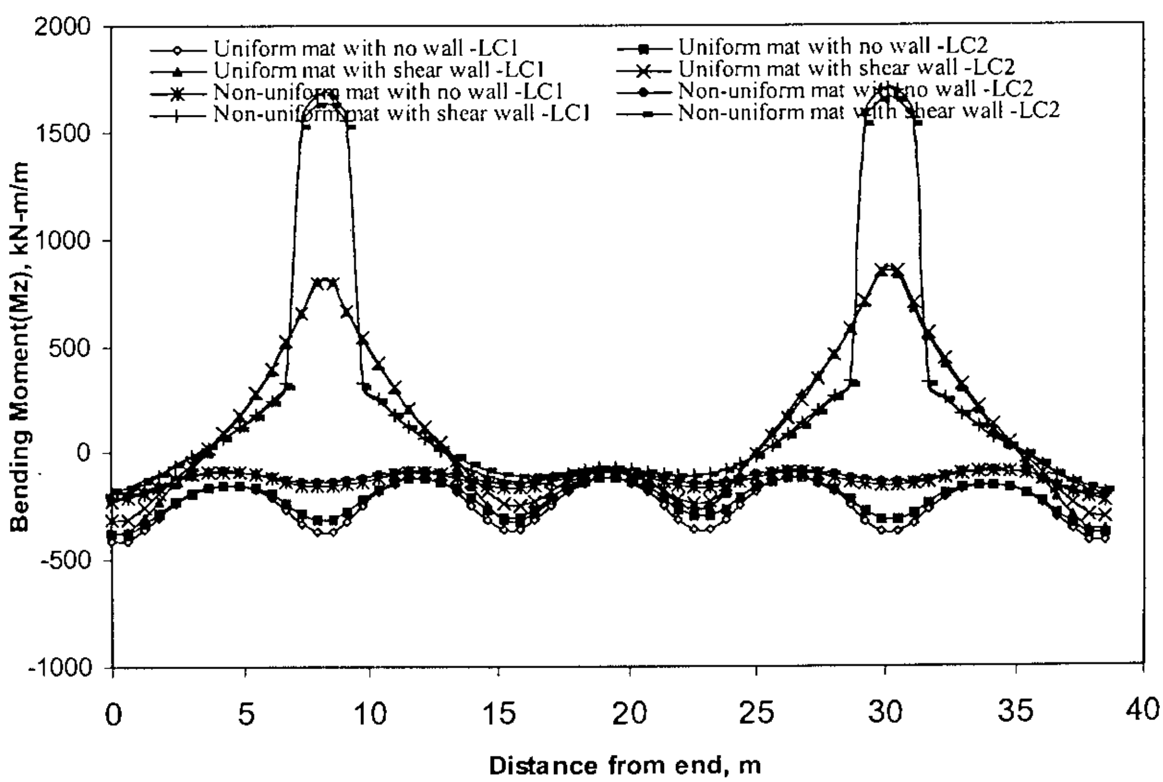

Fig.D-C8 Variation in Bending Moment along **line 15** for mat of **Model-C.**

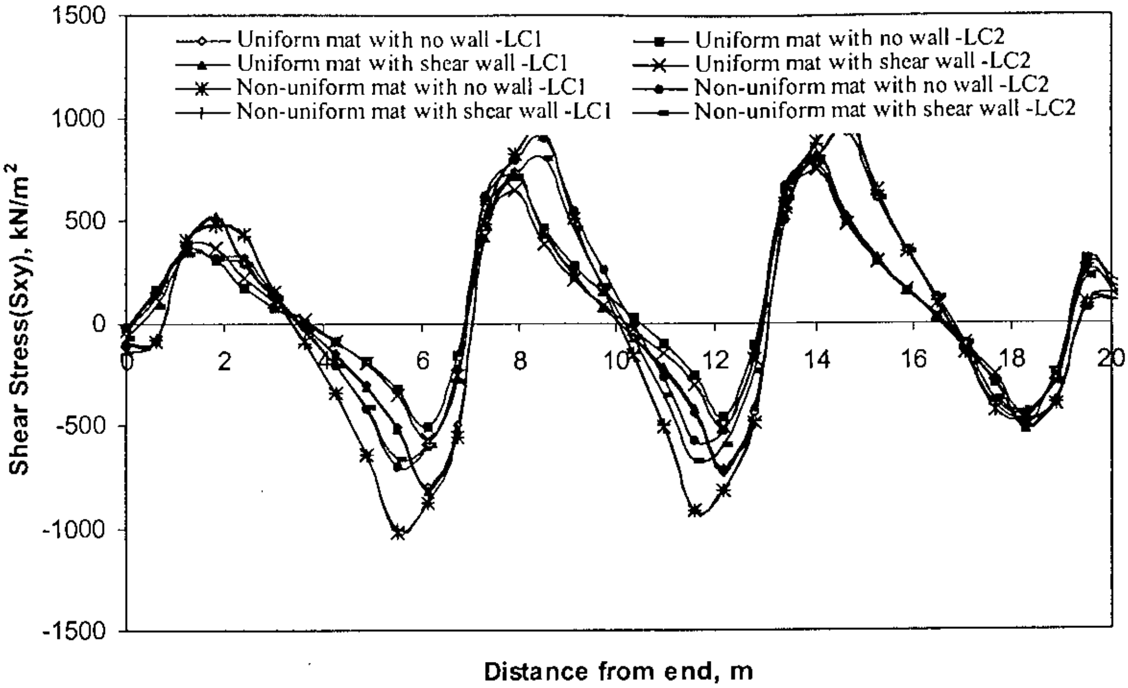

Fig.D-C9 Variation in Shear Stress along **line 1** for mat of **Model-C.**

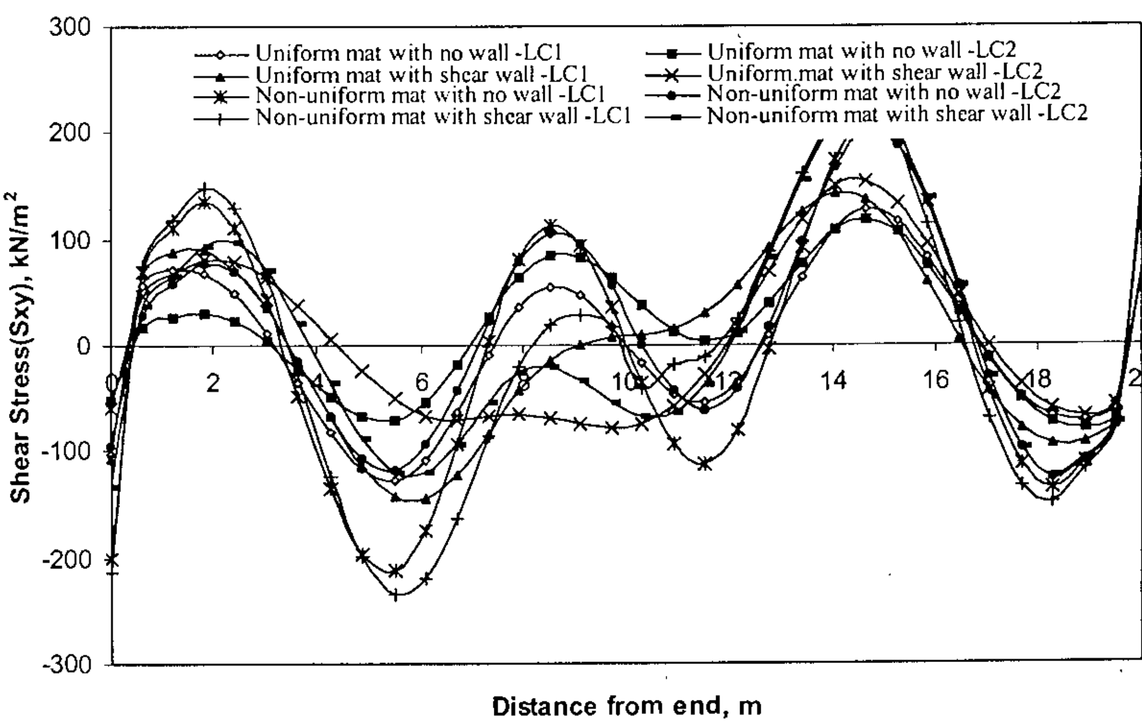

Fig.D-C10 Variation in Shear Stress along **line 4** for mat of **Model-C.**

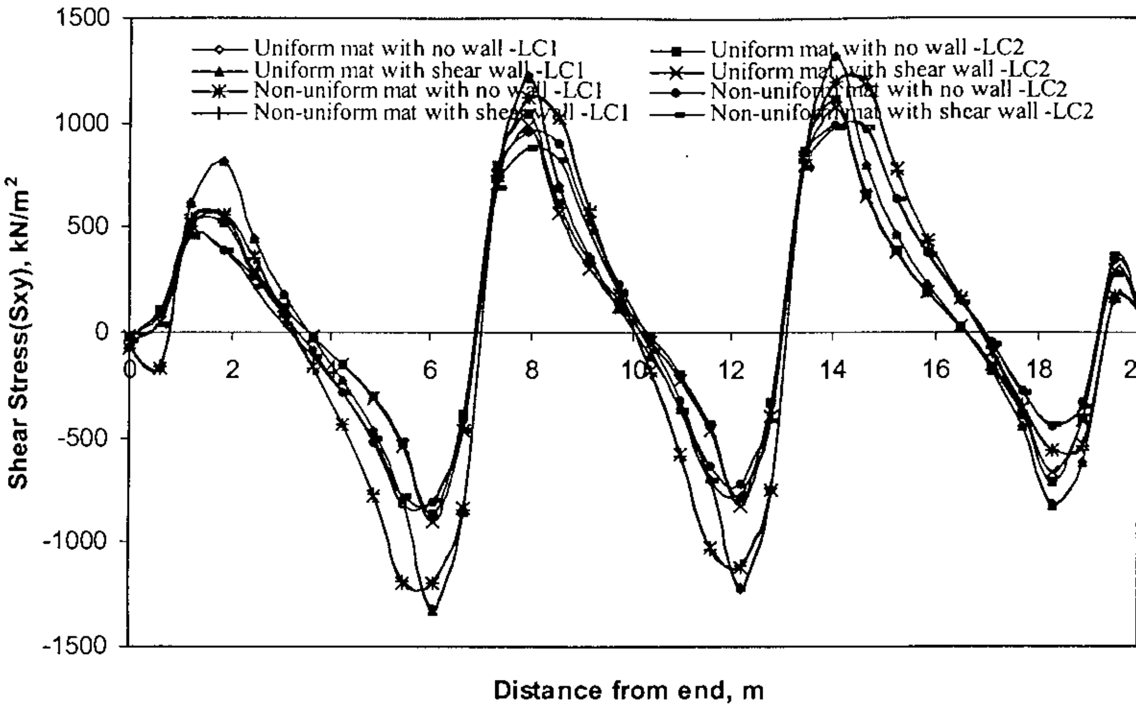

Fig.D-C11 Variation in Shear Stress along **line 5** for mat of **Model-C.**

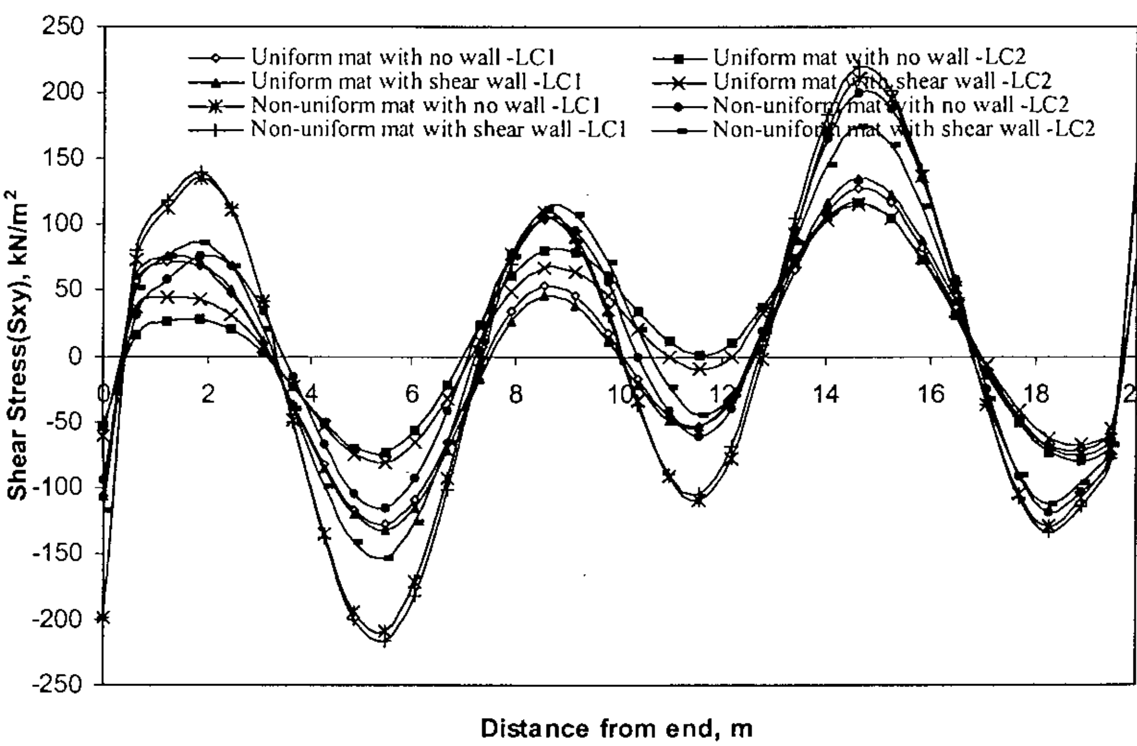

Fig.D-C12 Variation in Shear Stress along **line 6** for mat of **Model-C.**

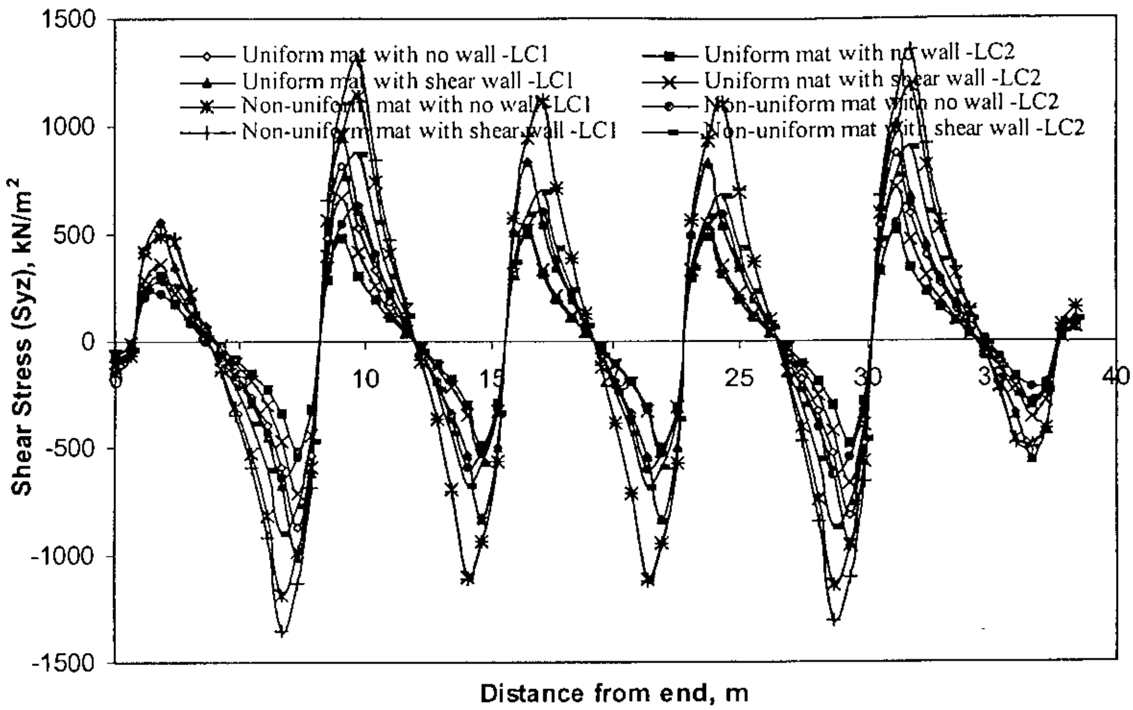

Fig.D-C13 Variation in Shear Stress along **line 12** for mat of **Model-C.**

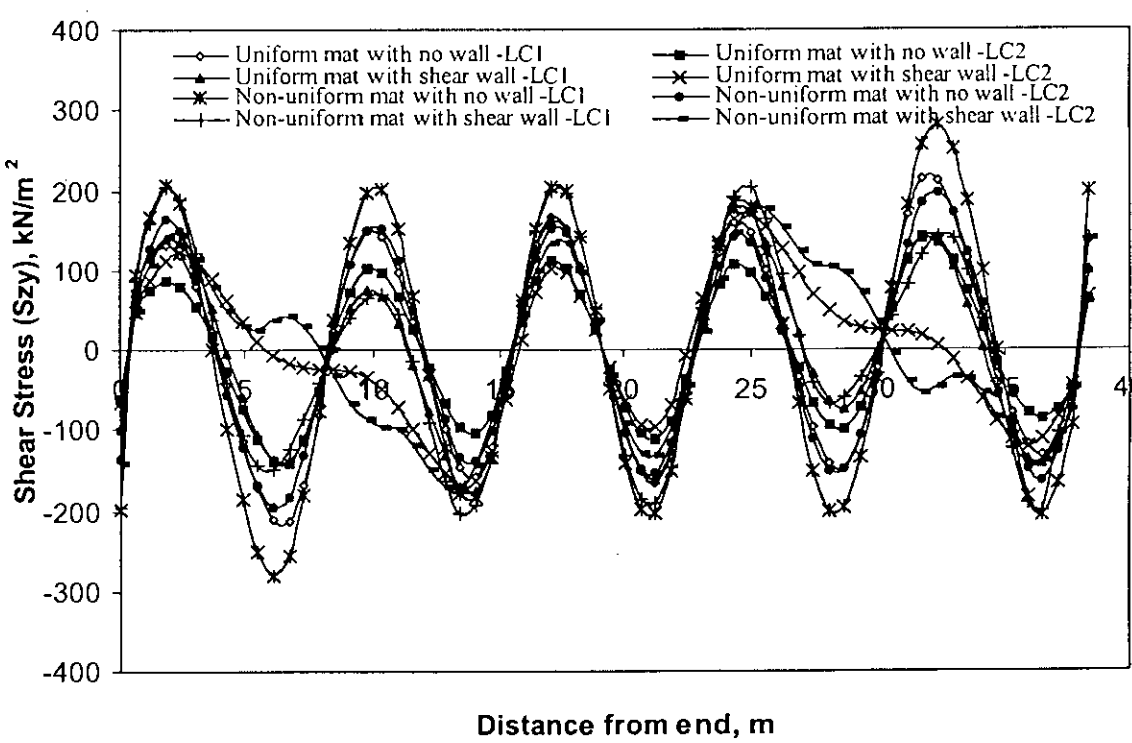

Fig.D-C14 Variation in Shear Stress along **line 13** for mat of **Model-C.**

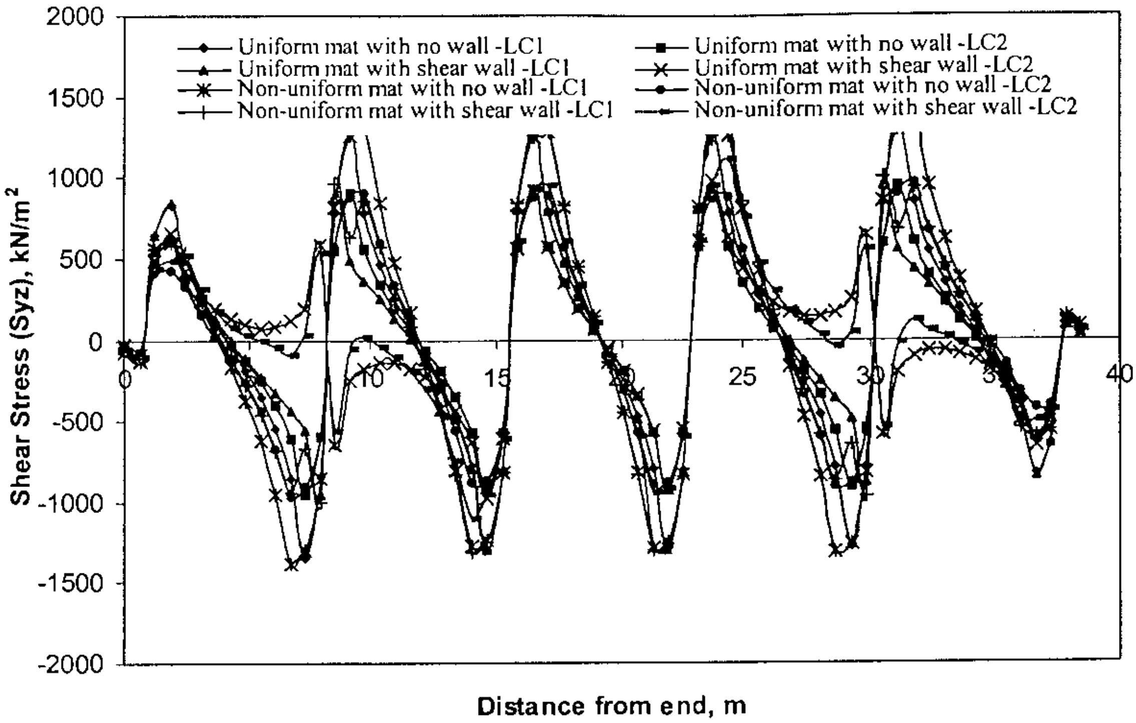

Fig.D-C15 Variation in Shear Stress along **line 14** for mat of **Model-C.**

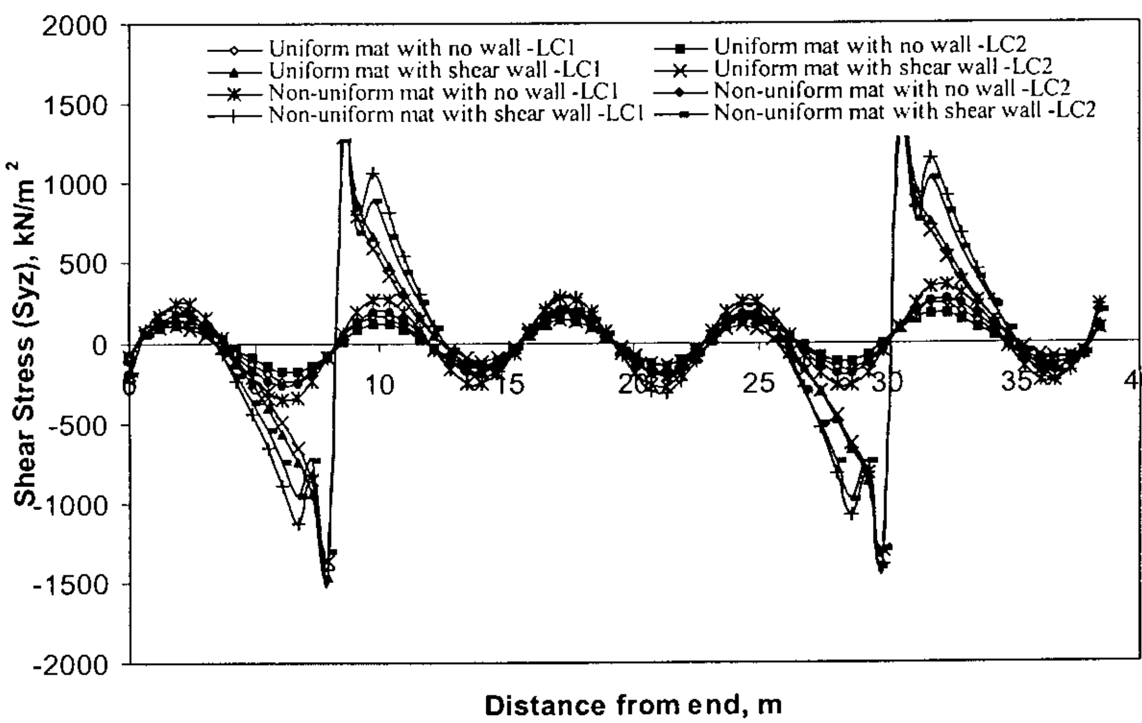

Fig.D-C16 Variation in Shear Stress along **line 15** for mat of **Model-C.**

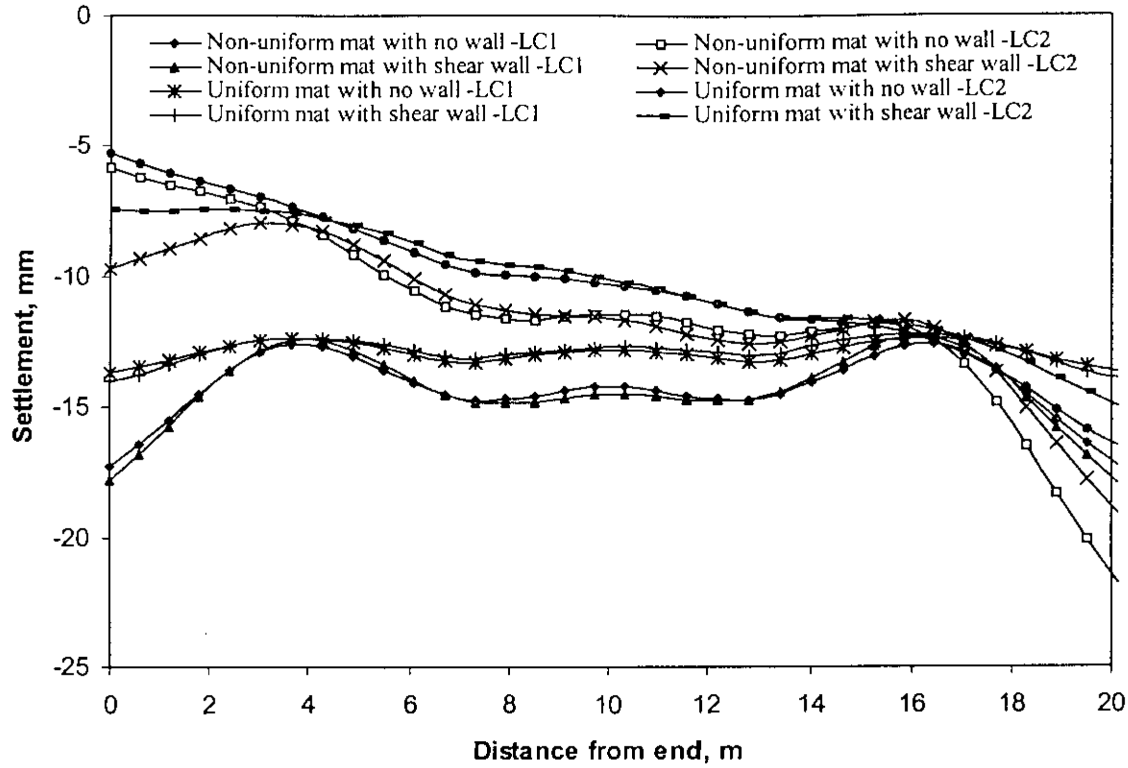

Fig.D-C17 Variation in settlement along **line 1** for mat of **Model-C.**

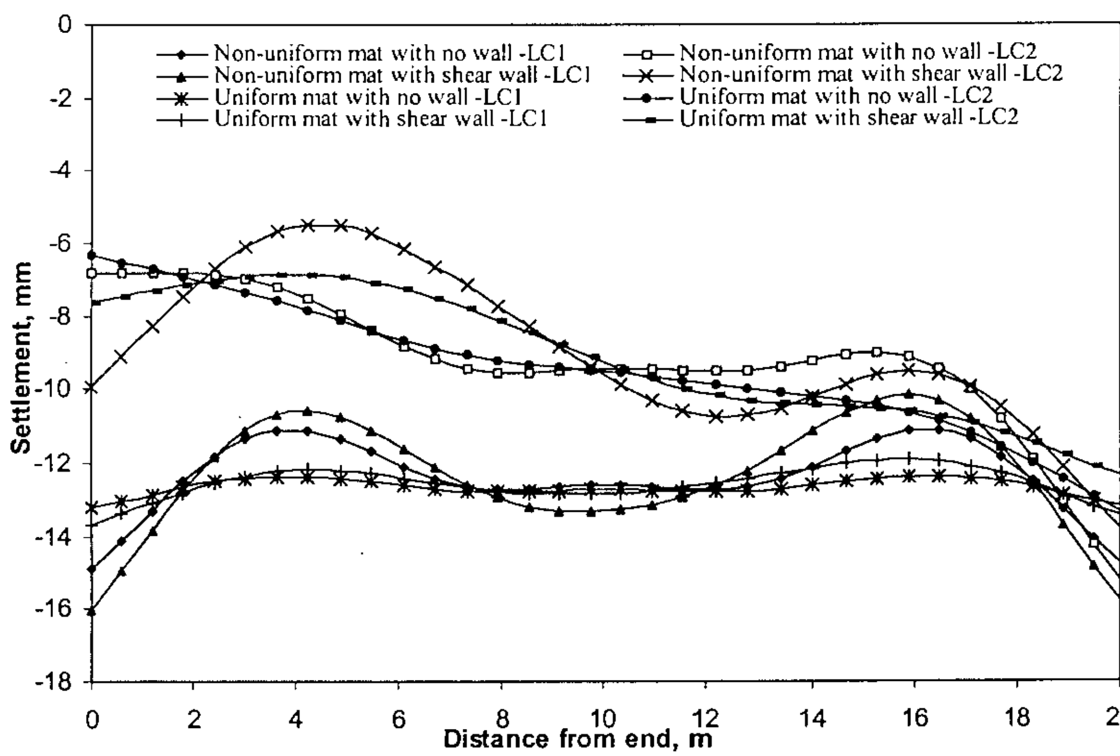

Fig.D-C18 Variation in settlement along **line 4** for mat of **Model-C.**

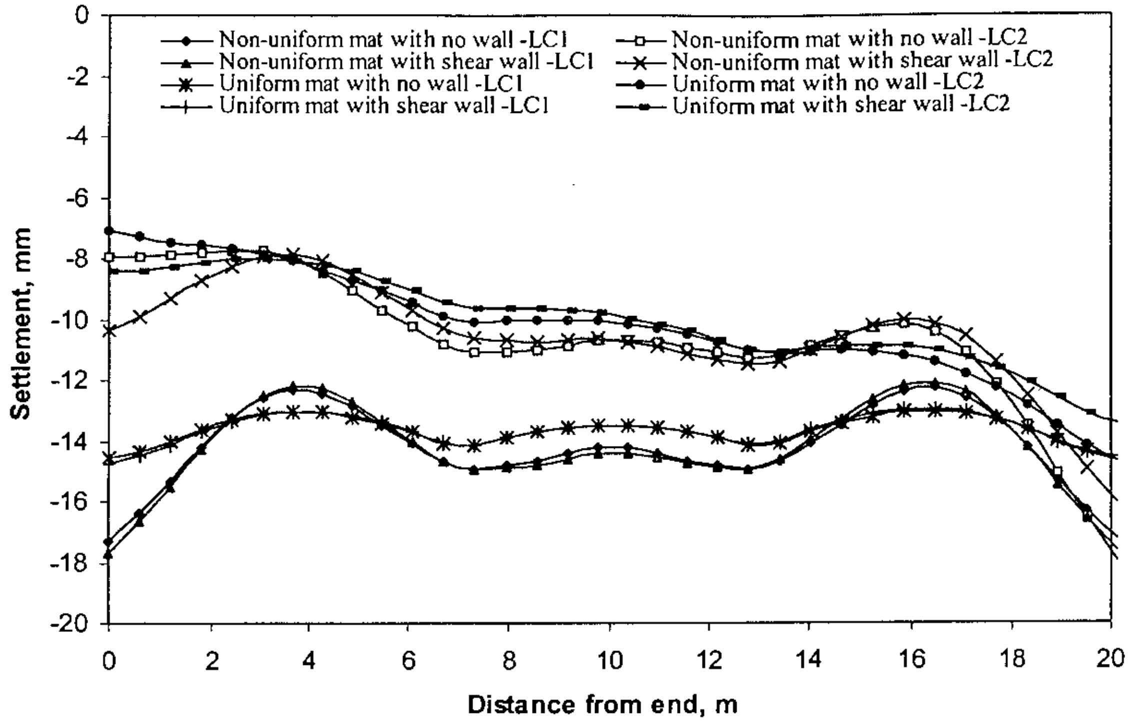

Fig.D-C19 Variation in settlement along **line 5** for mat of **Model-C.**

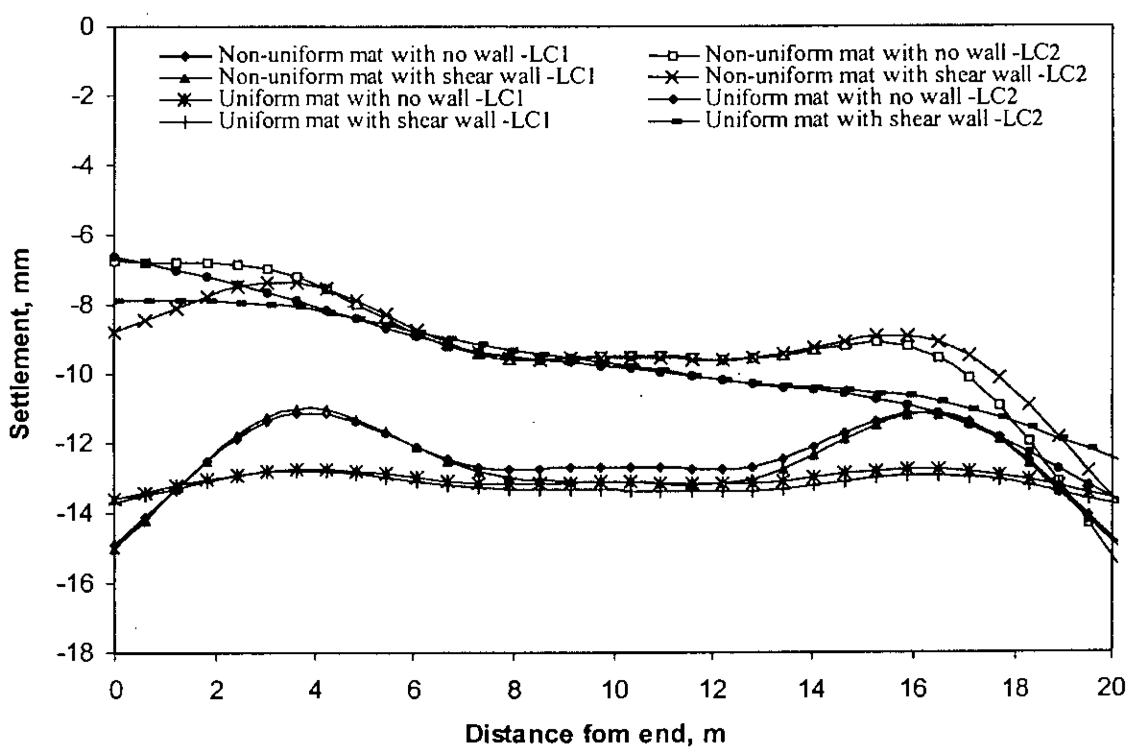

Fig.D-C20 Variation in settlement along **line 6** for mat of **Model-C.**

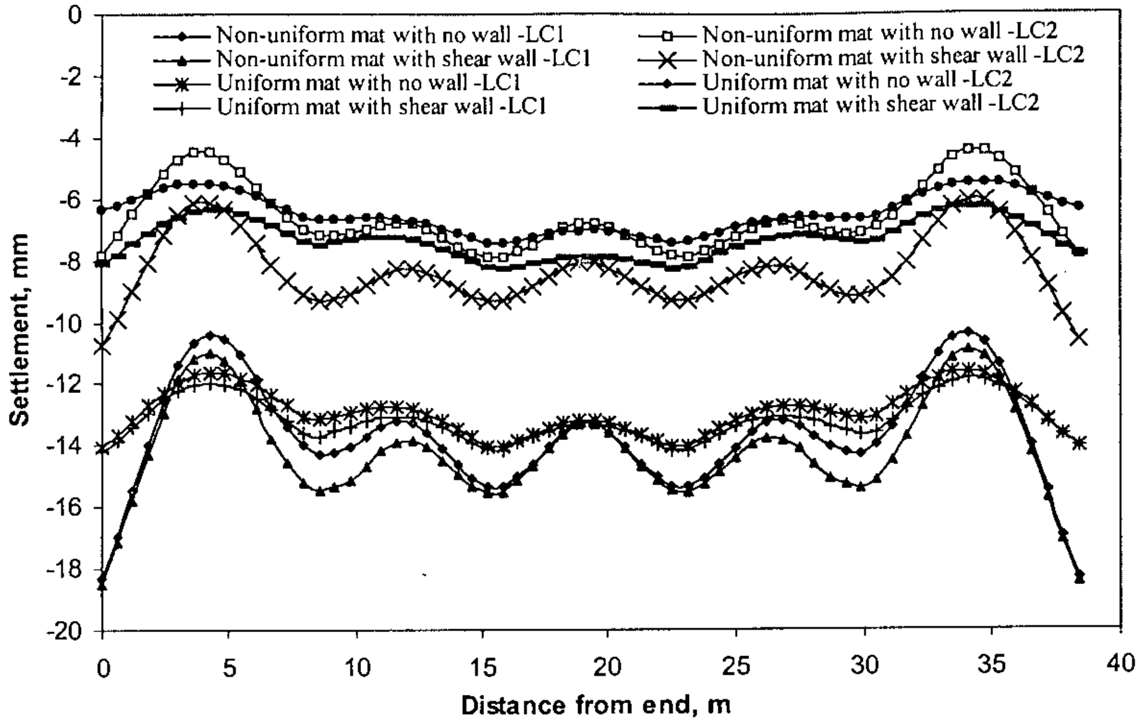

Fig.D-C21 Variation in settlement along **line 12** for mat of **Model-C.**

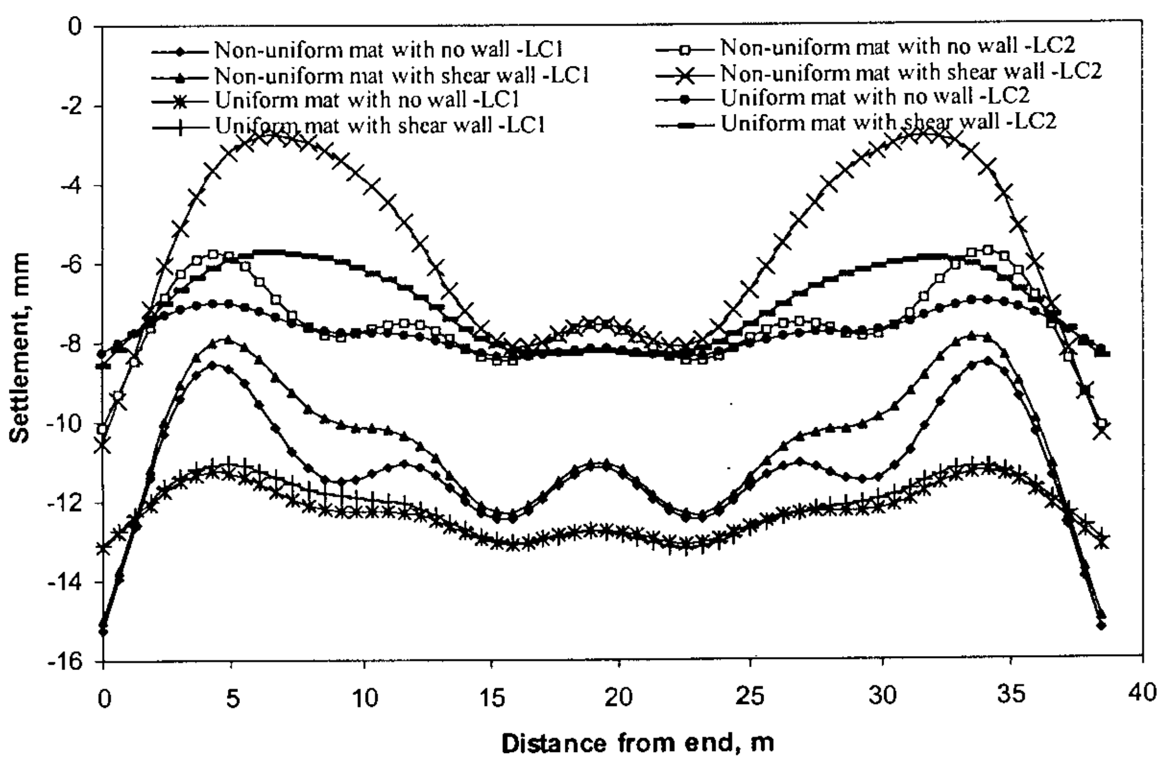

Fig.D-C22 Variation in settlement along **line 13** for mat of **Model-C.**

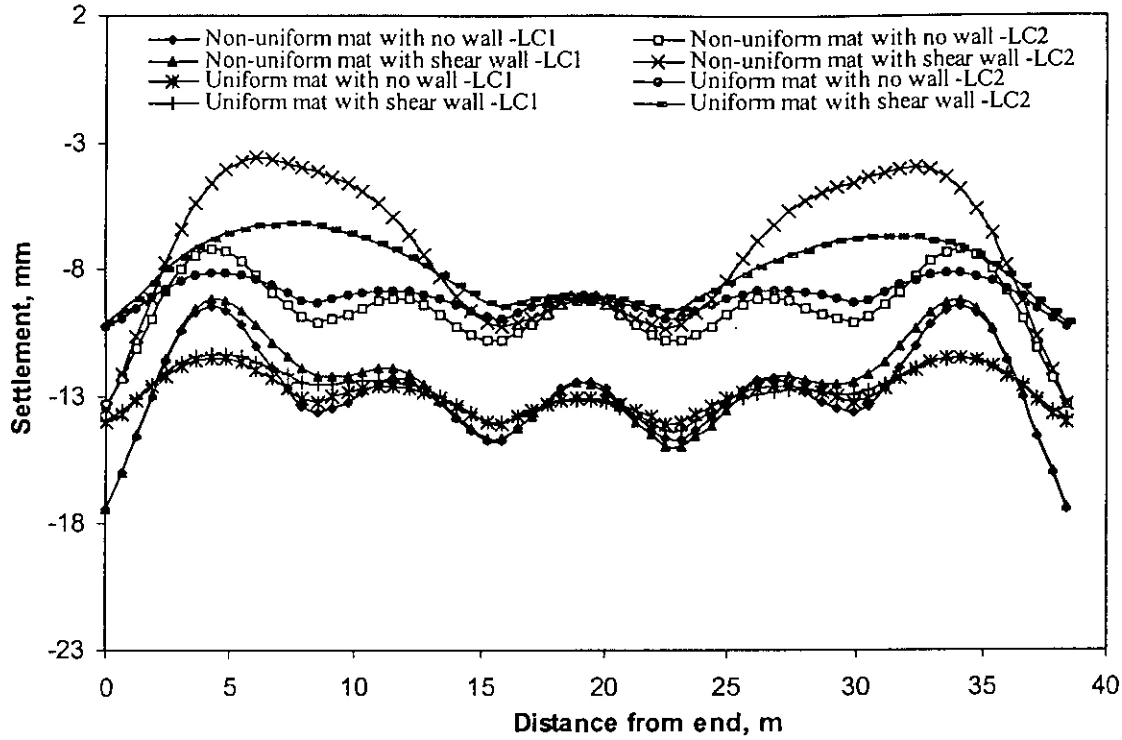

Fig.D-C23 Variation in settlement along **line 14** for mat of **Model-C.**

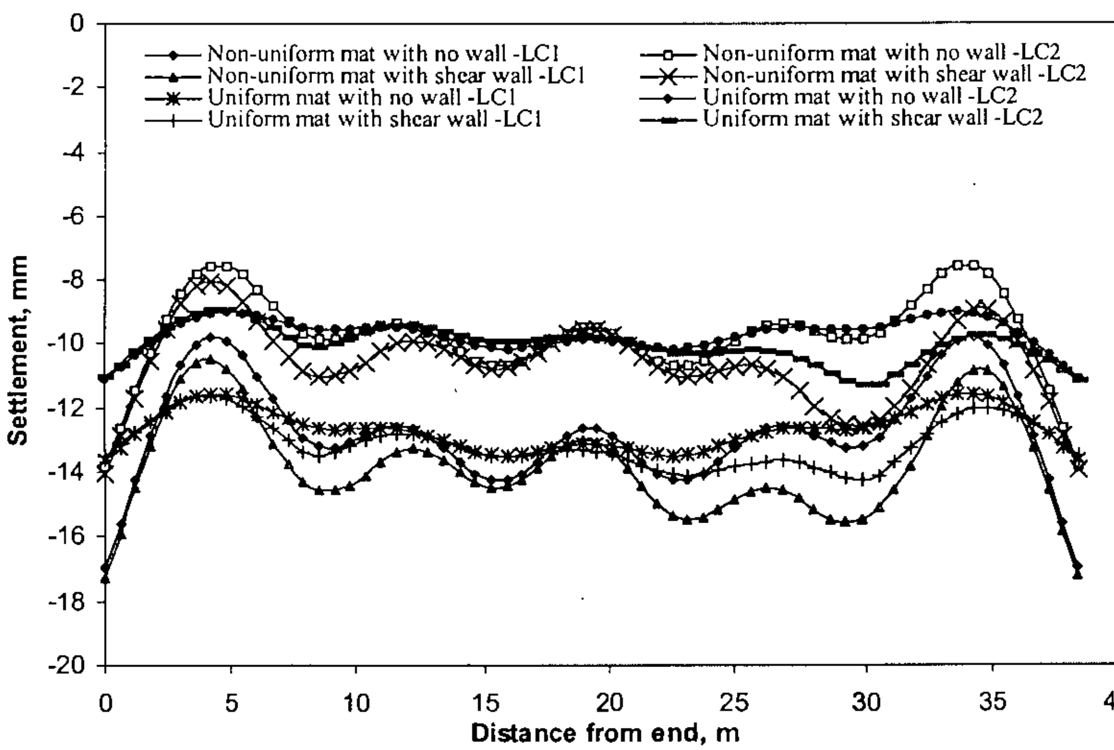

Fig.D-C24 Variation in settlement along **line 15** for mat of **Model-C.**

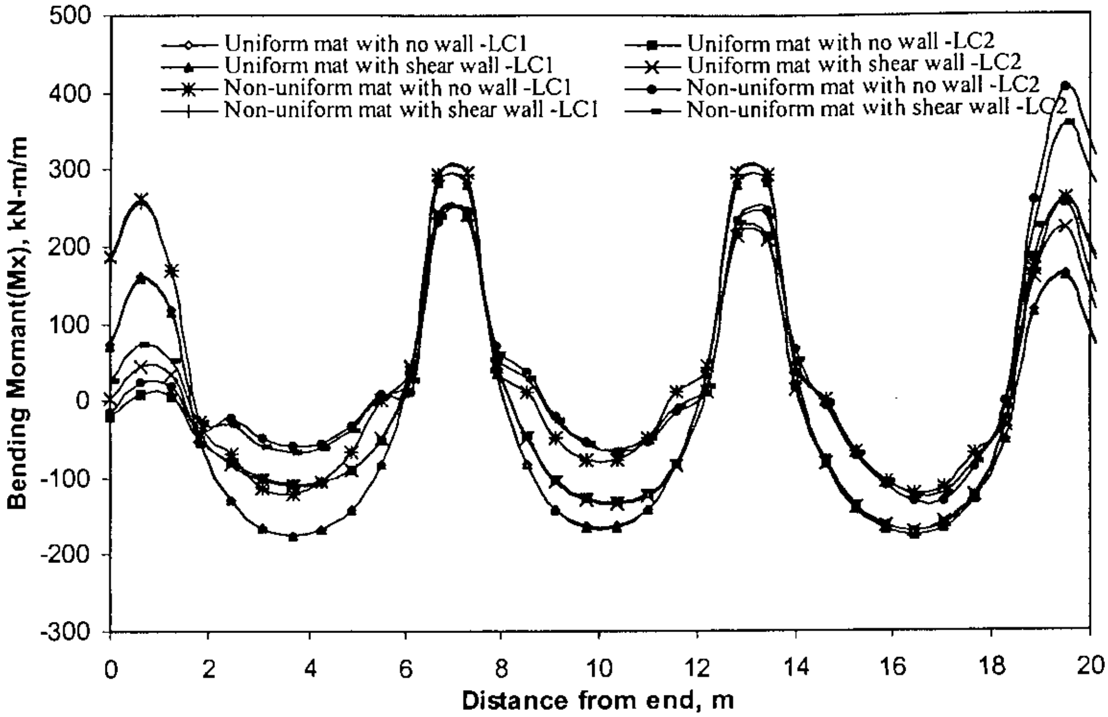

Fig.D-D1 Variation in Bending Moment along **line 1** for mat of **Model-D.**

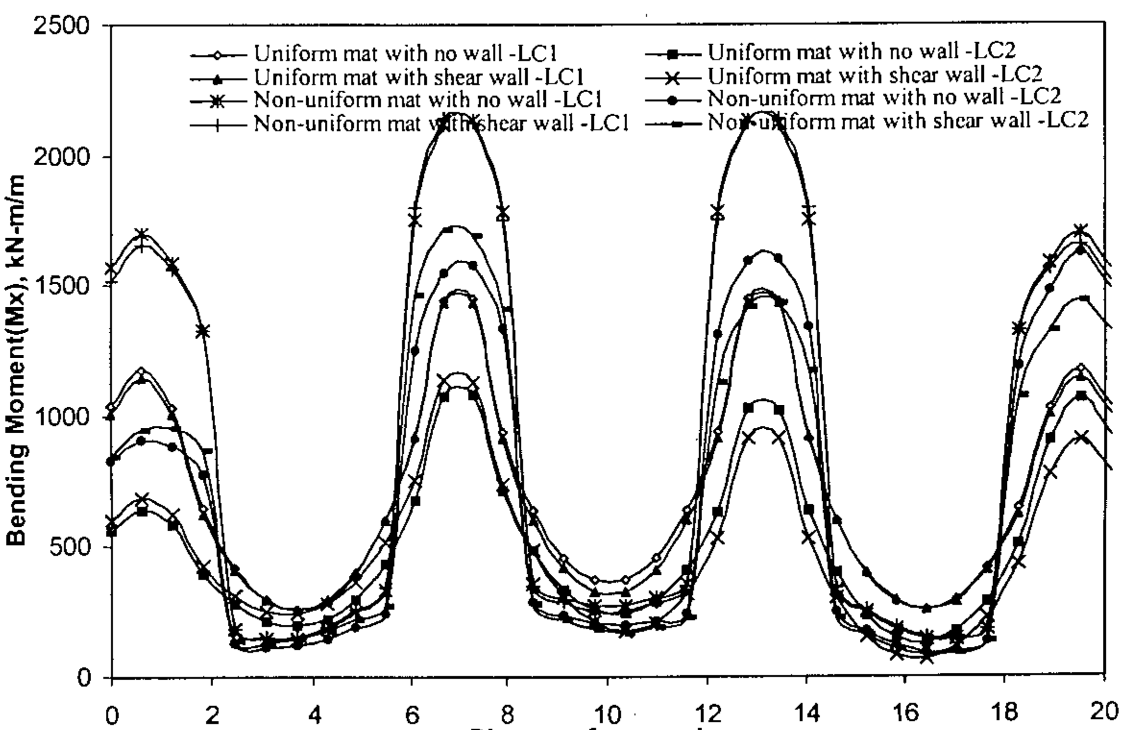

Fig.D-D2 Variation in Bending Moment along **line 3** for mat of **Model-D.**

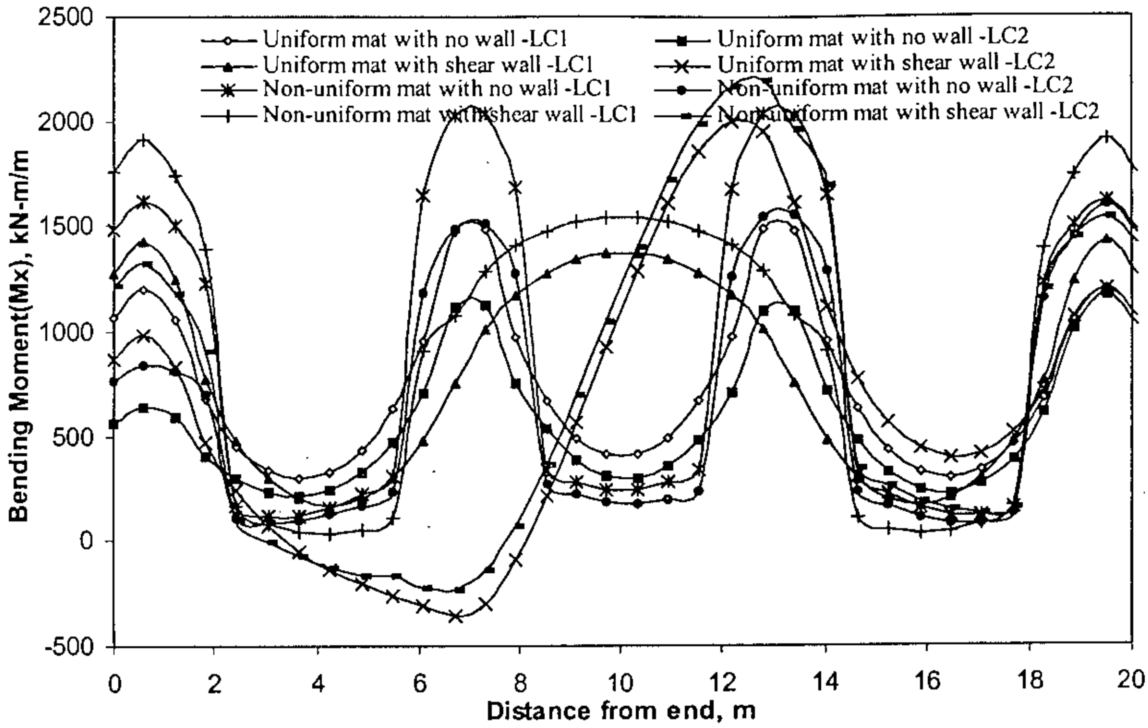

Fig.D-D3 Variation in Bending Moment along **line 5** for mat of **Model-D.**

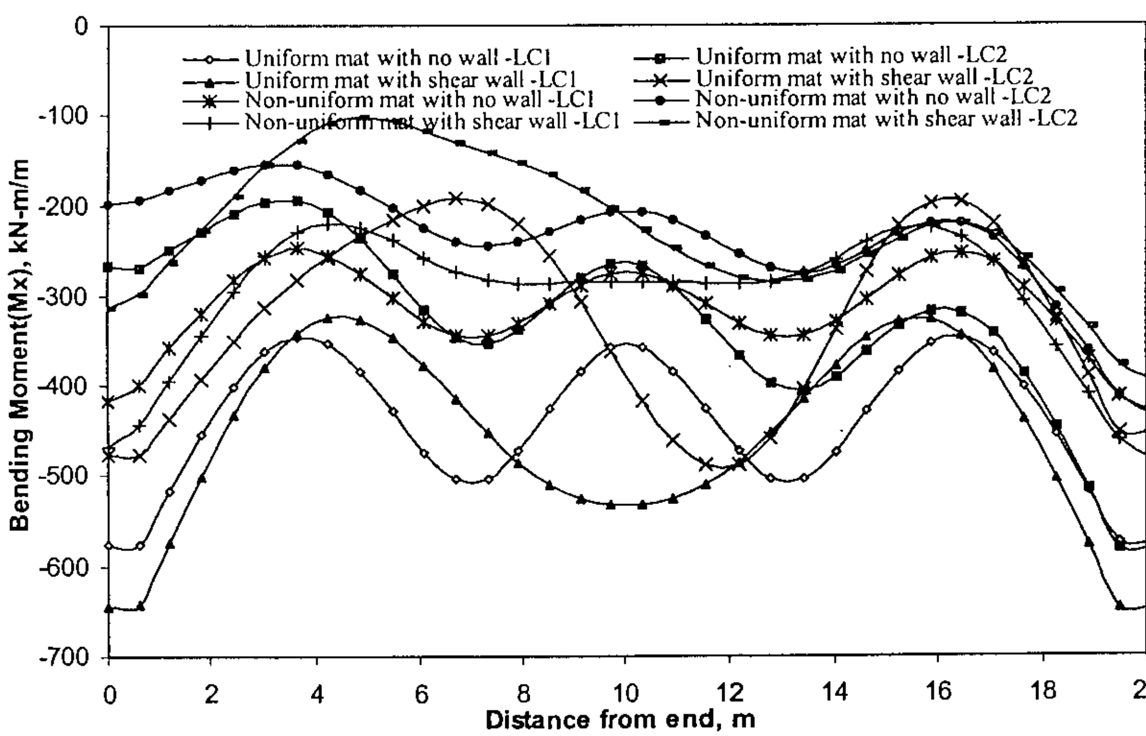

Fig.D-D4 Variation in Bending Moment along **line 6** for mat of **Model-D.**

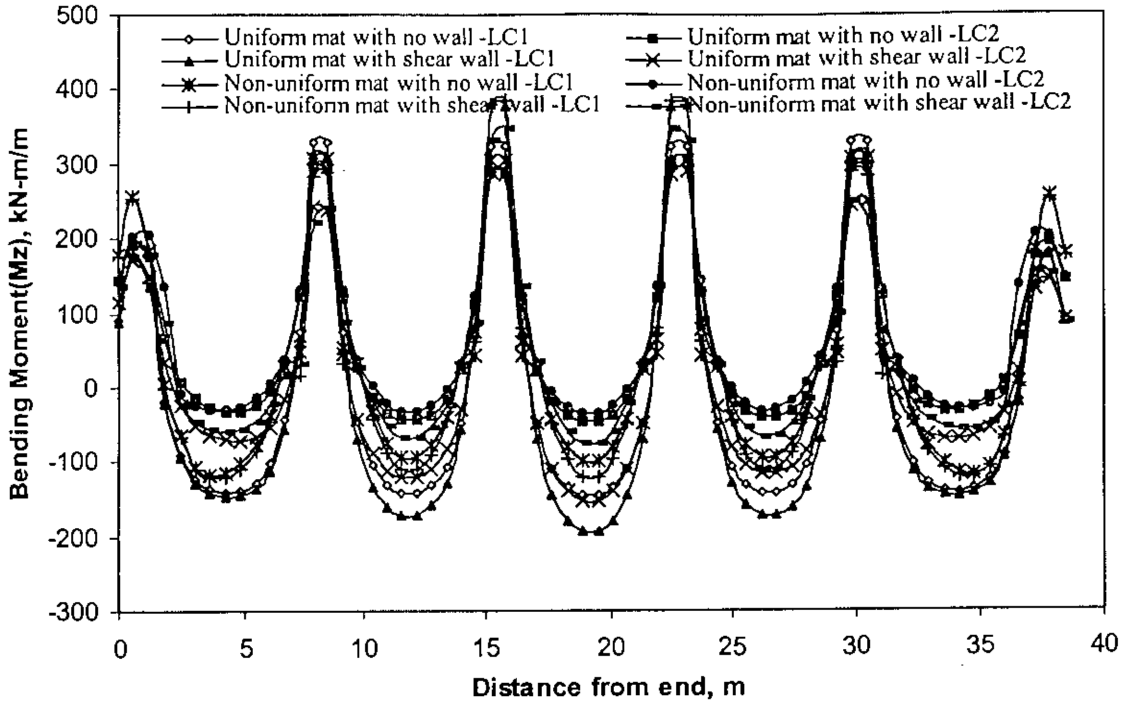

Fig.D-D5 Variation in Bending Moment along **line 12** for mat of **Model-D.**

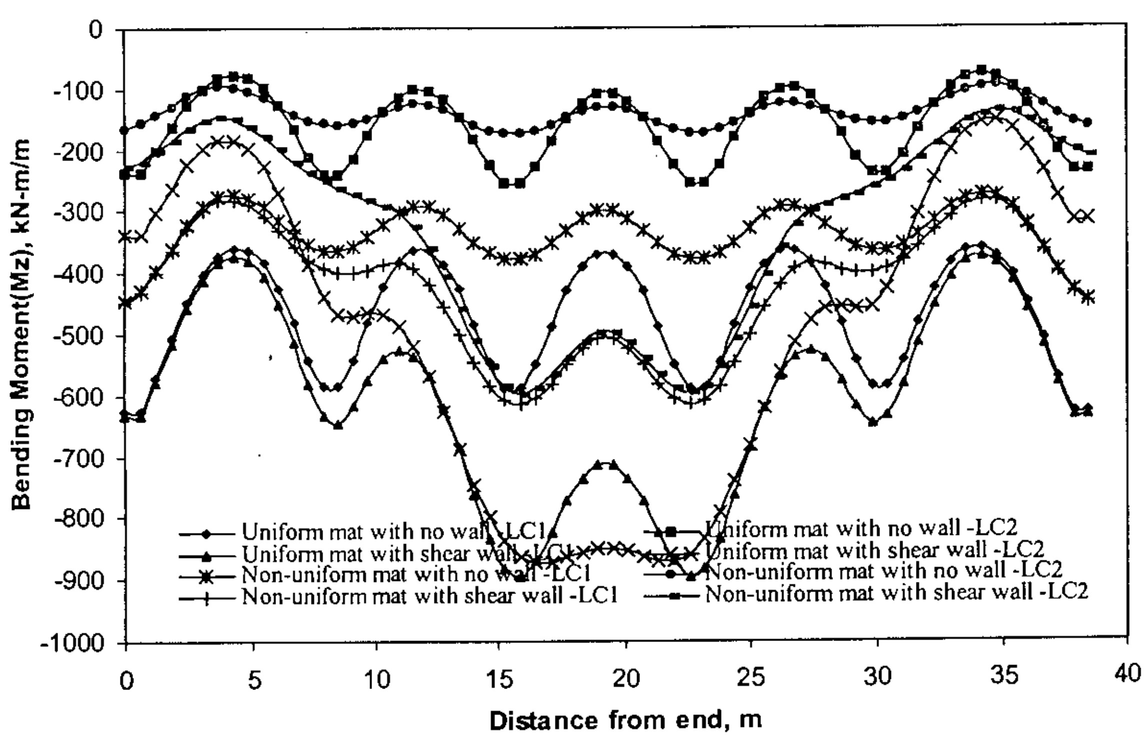

Fig.D-D6 Variation in Bending Moment along **line 13** for mat of **Model-D.**

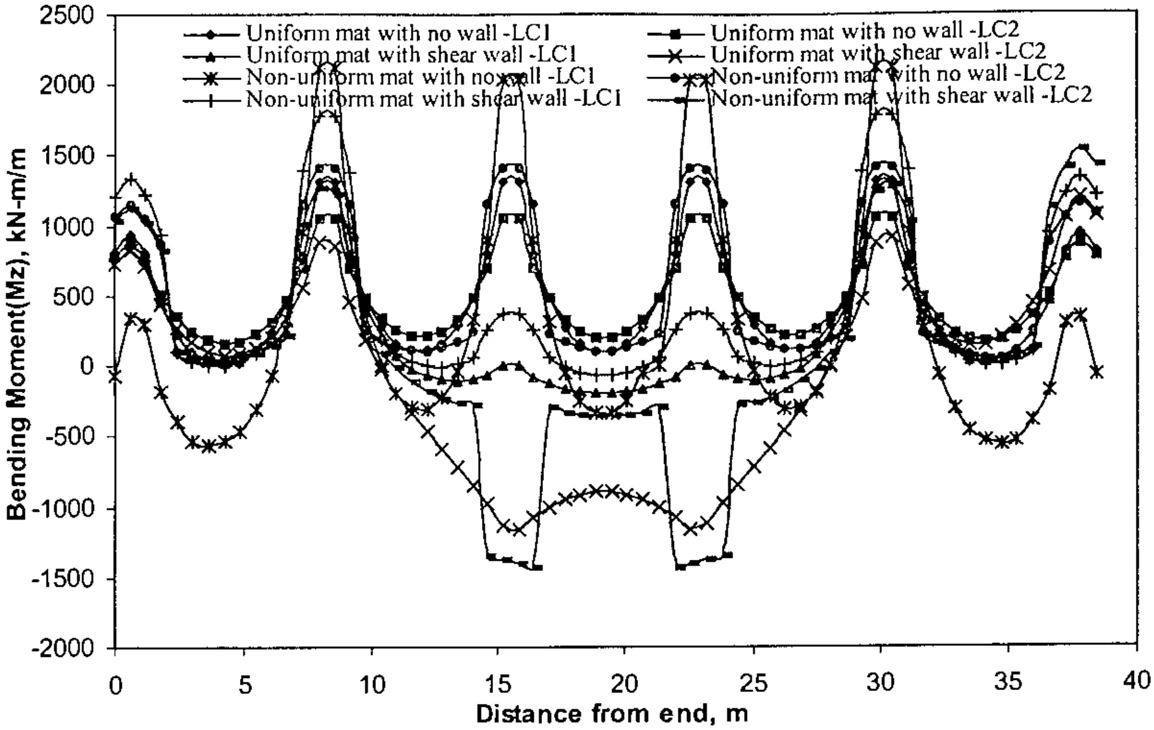

Fig.D-D7 Variation in Bending Moment along **line 14** for mat of **Model-D.**

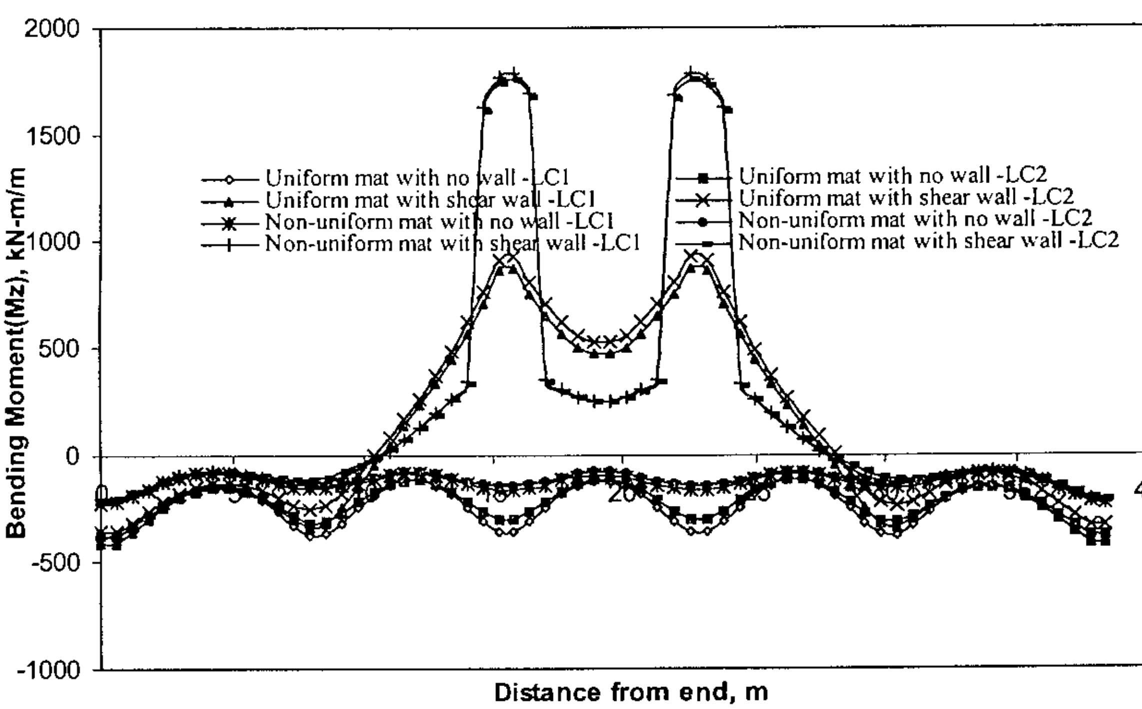

Fig.D-D8 Variation in Bending Moment along **line 15** for mat of **Model-D.**

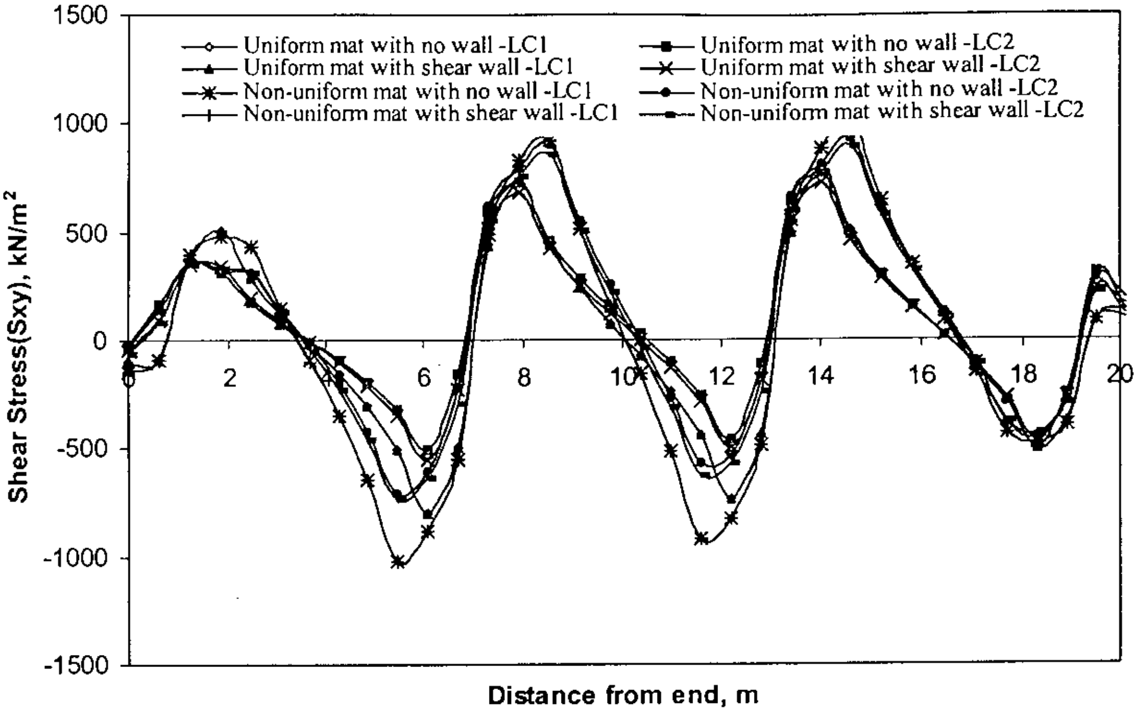

Fig.D-D9 Variation in Shear Stress along **line 1** for mat of **Model-D.**

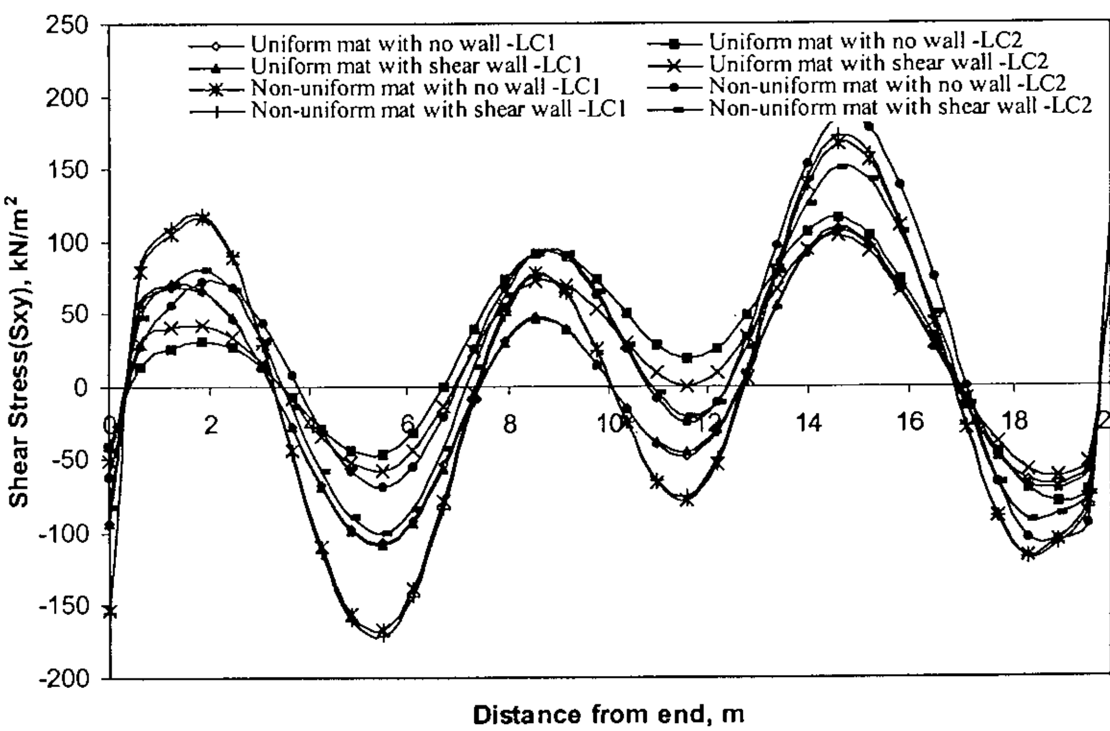

Fig.D-D10 Variation in Shear Stress along **line 2** for mat of **Model-D.**

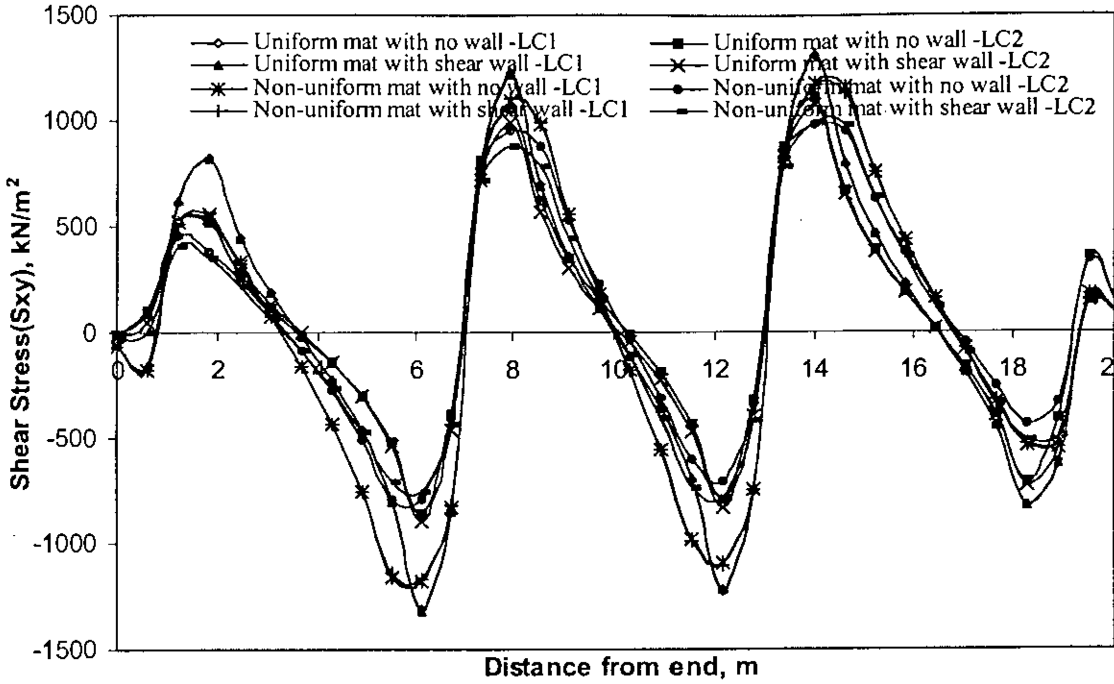

Fig.D-D11 Variation in Shear Stress along **line 3** for mat of **Model-D.**

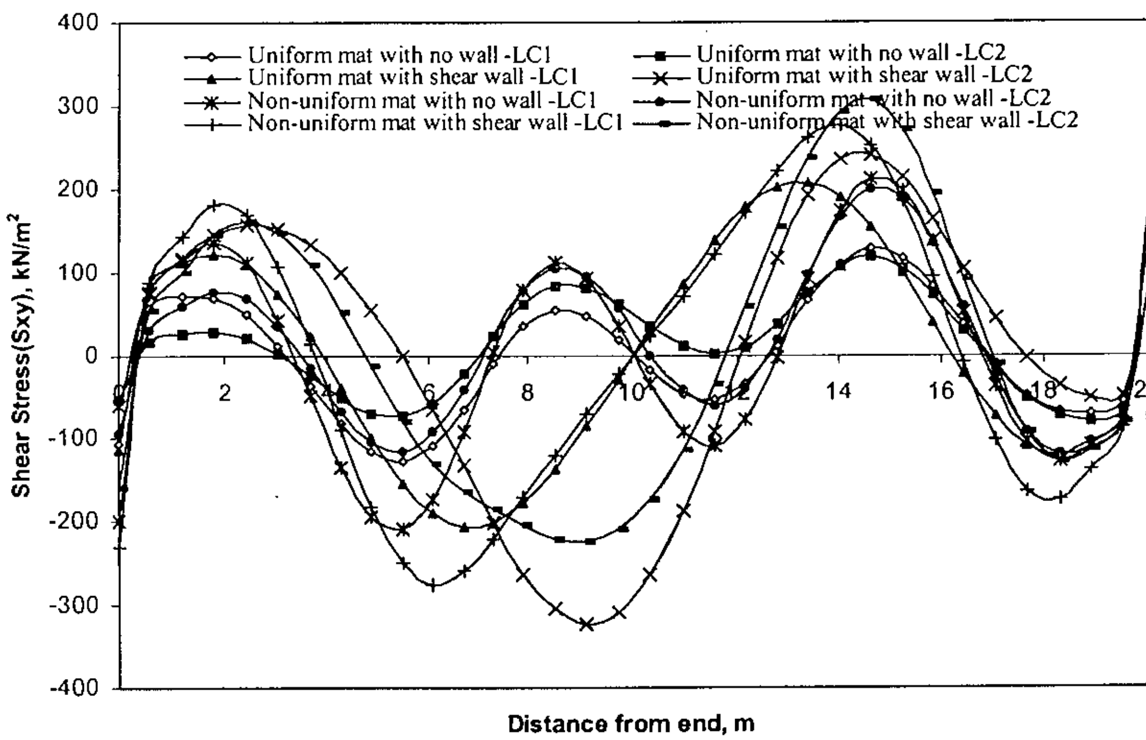

Fig.D-D12 Variation in Shear Stress along **line 6** for mat of **Model-D.**

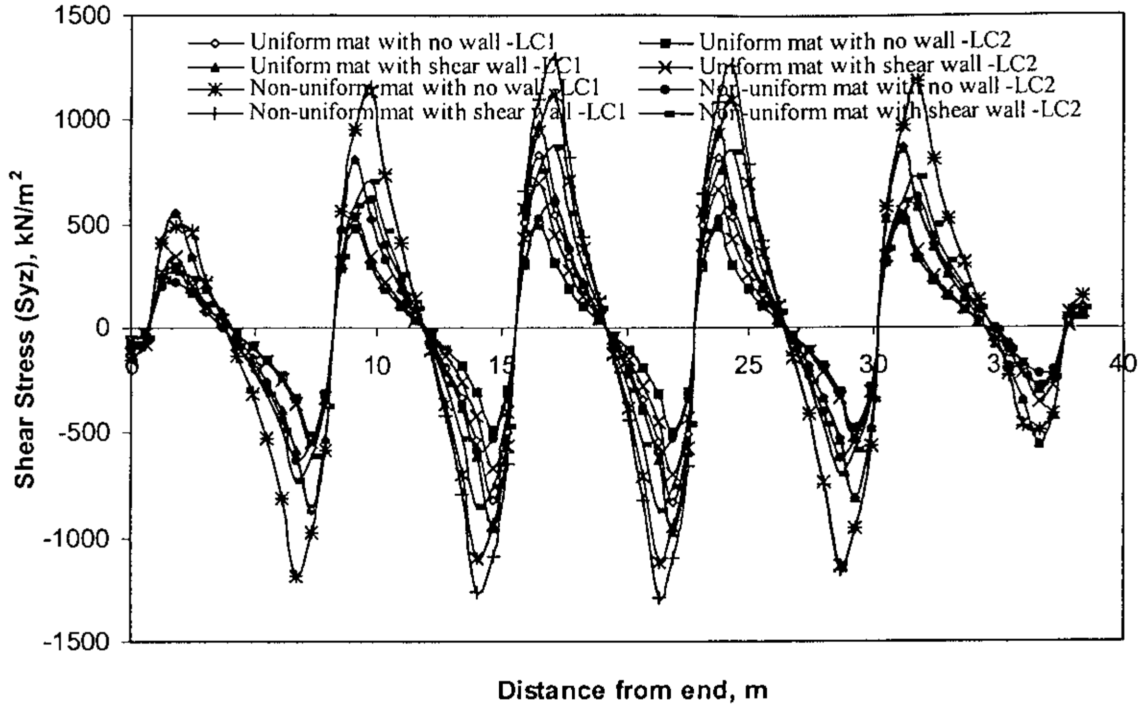

Fig.D-D13 Variation in Shear Stress along **line 12** for mat of **Model-D.**

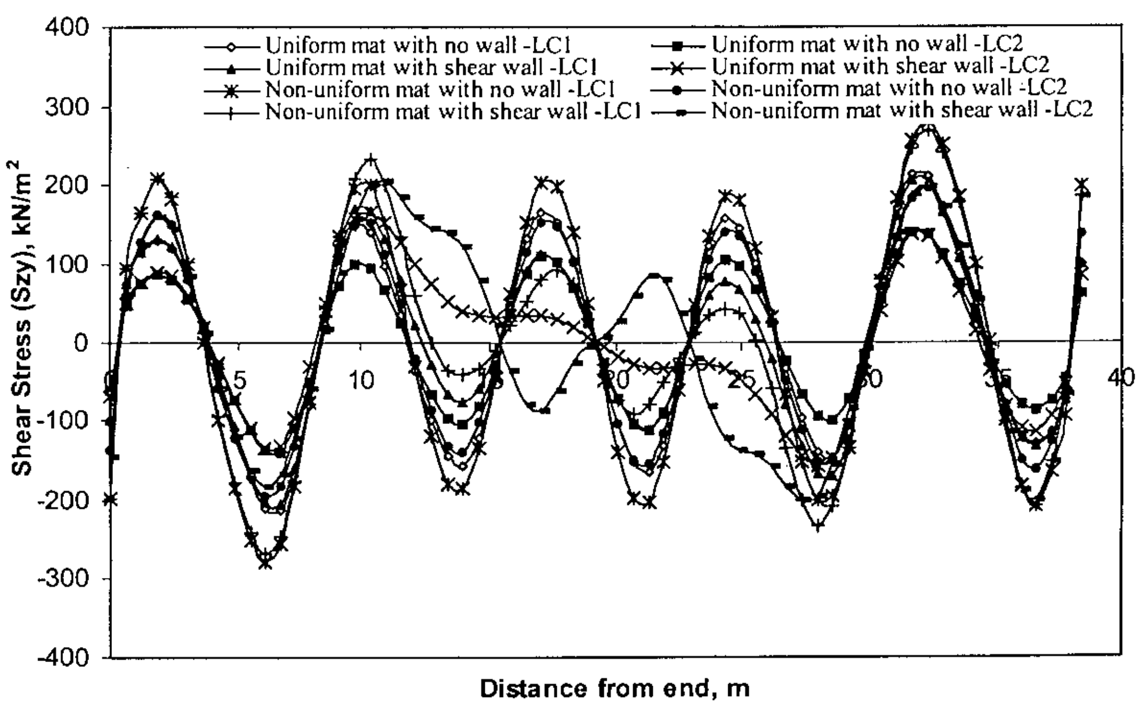

Fig.D-D14 Variation in Shear Stress along **line 13** for mat of **Model-D.**

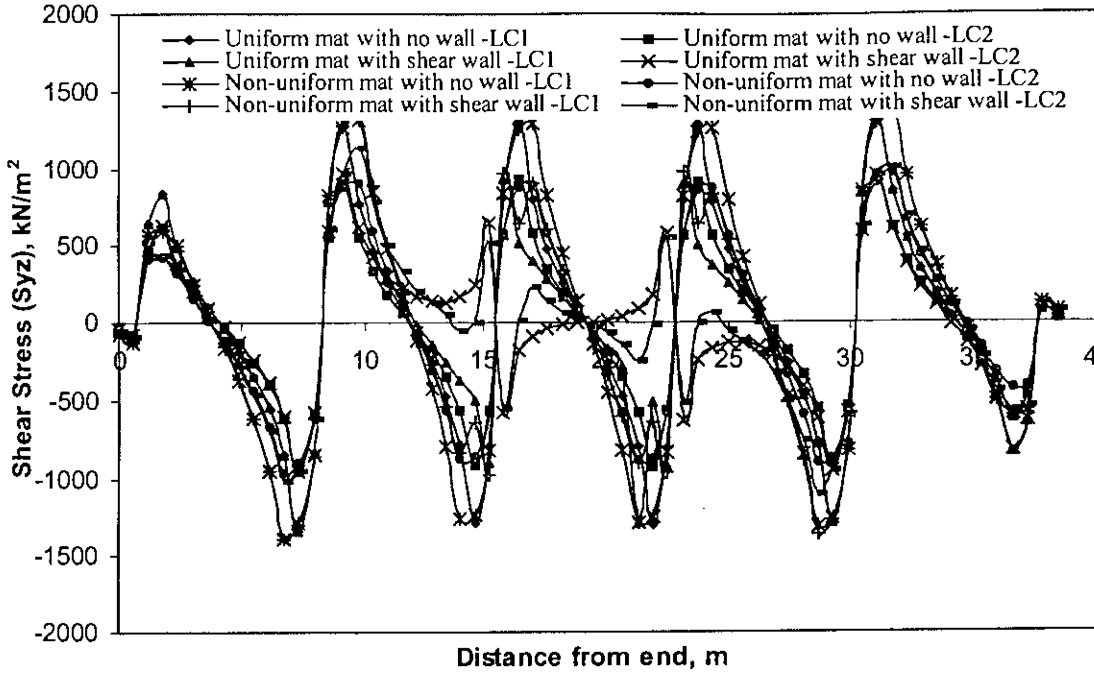

Fig.D-D15 Variation in Shear Stress along **line 14** for mat of **Model-D.**

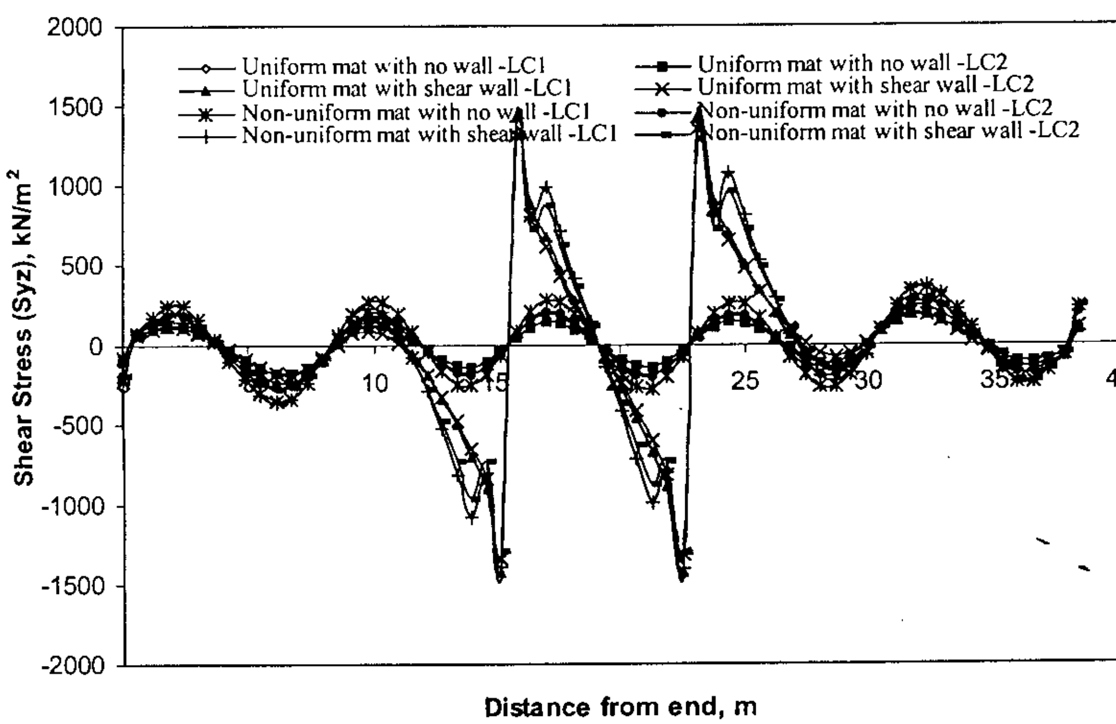

Fig.D-D16 Variation in Shear Stress along **line 15** for mat of **Model-D.**

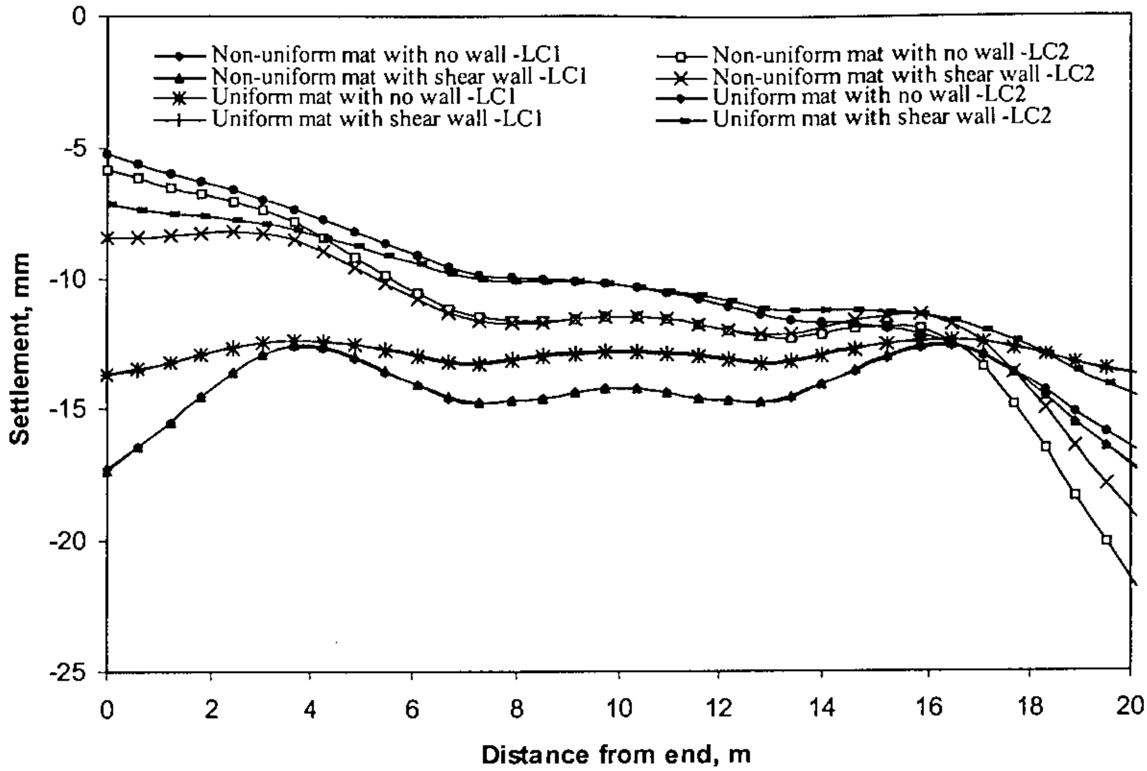

Fig.D-D17 Variation in settlement along **line 1** for mat of **Model-D.**

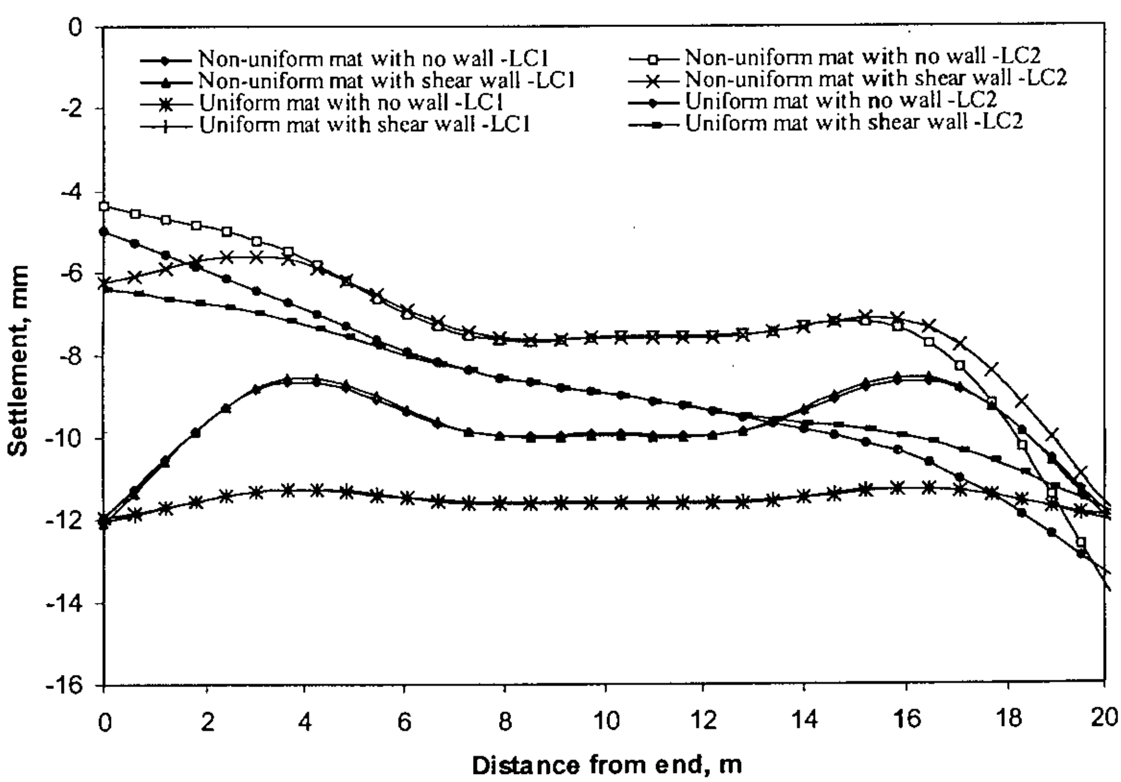

Fig.D-D18 Variation in settlement along **line 2** for mat of **Model-D.**

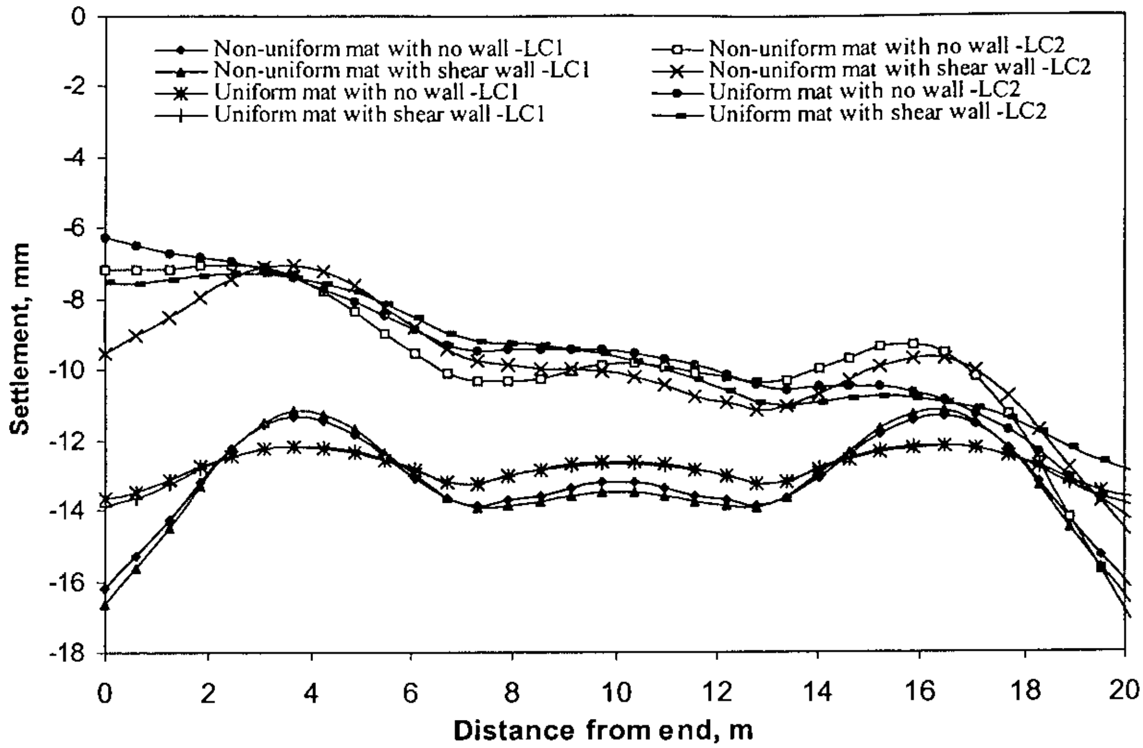

Fig.D-D19 Variation in settlement along **line 3** for mat of **Model-D.**

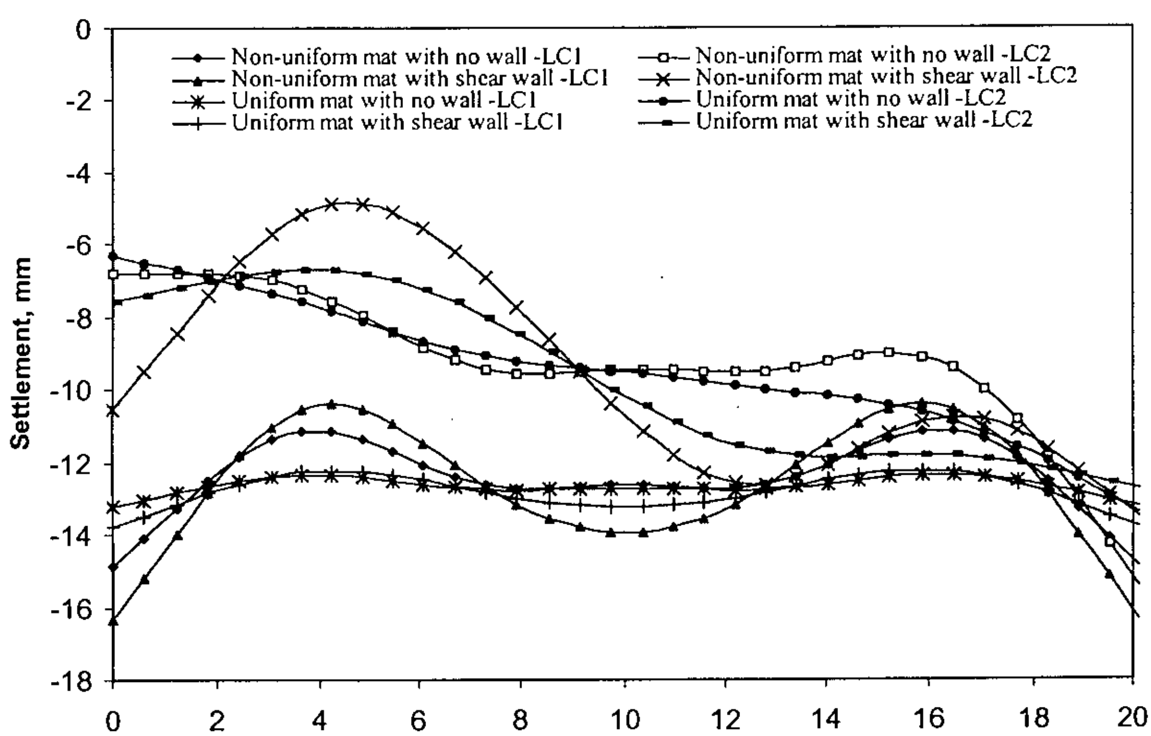

Fig.D-D20 Variation in settlement along **line 4** for mat of **Model-D.**

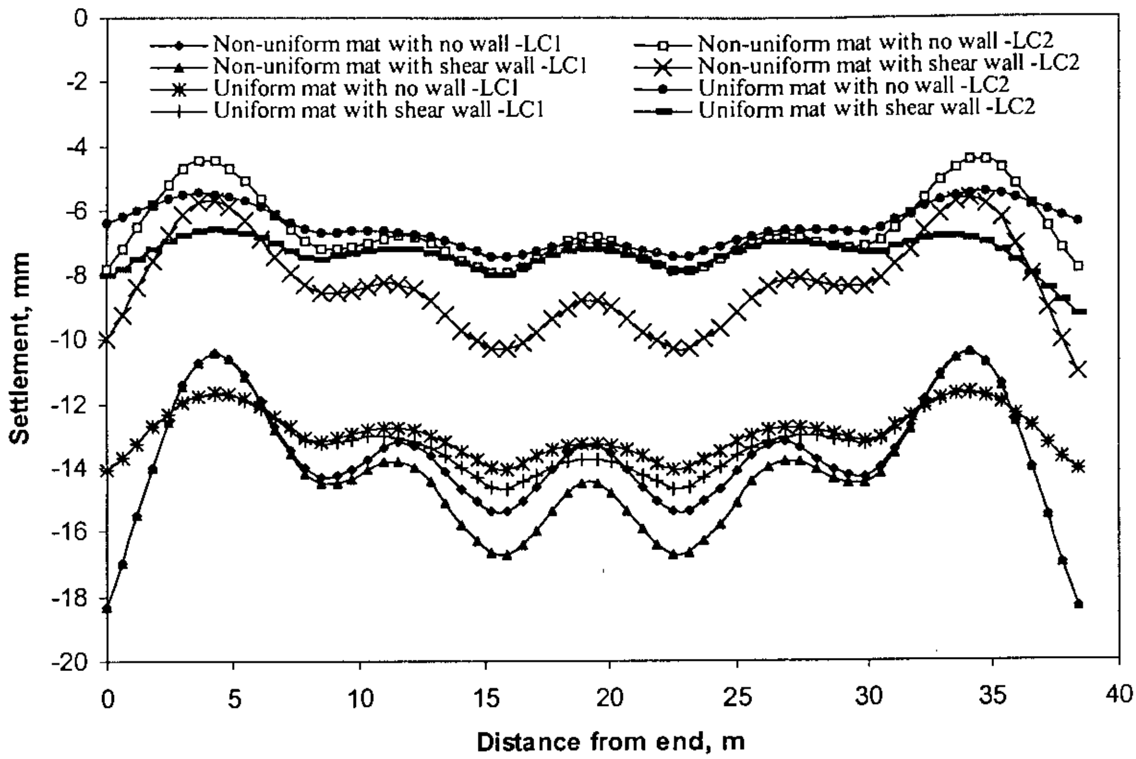

Fig.D-D21 Variation in settlement along **line 12** for mat of **Model-D.**

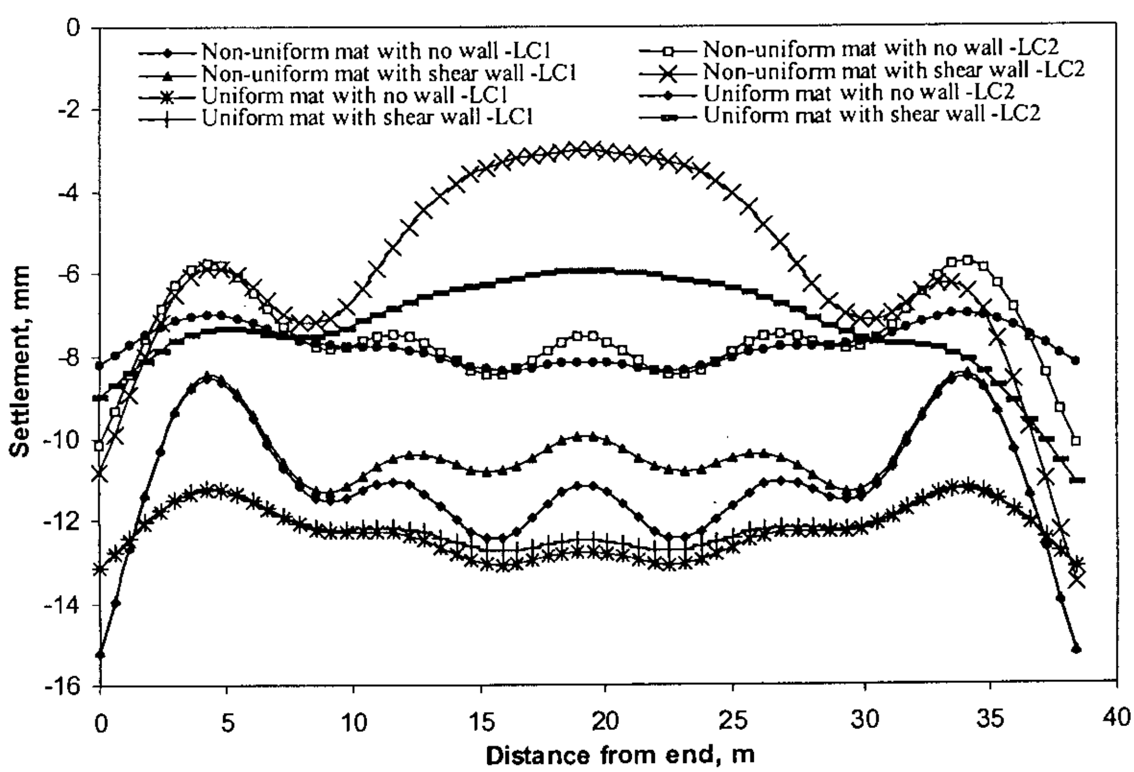

Fig.D-D22 Variation in settlement along **line 13** for mat of **Model-D.**

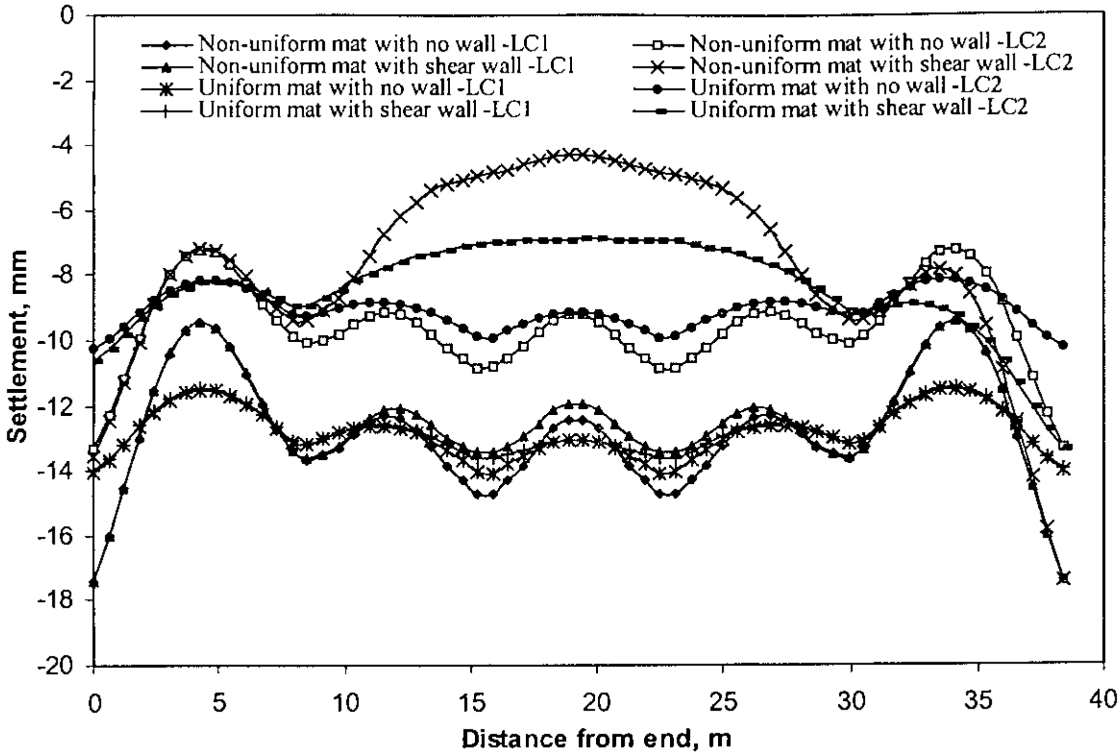

Fig.D-D23 Variation in settlement along **line 14** for mat of **Model-D.**

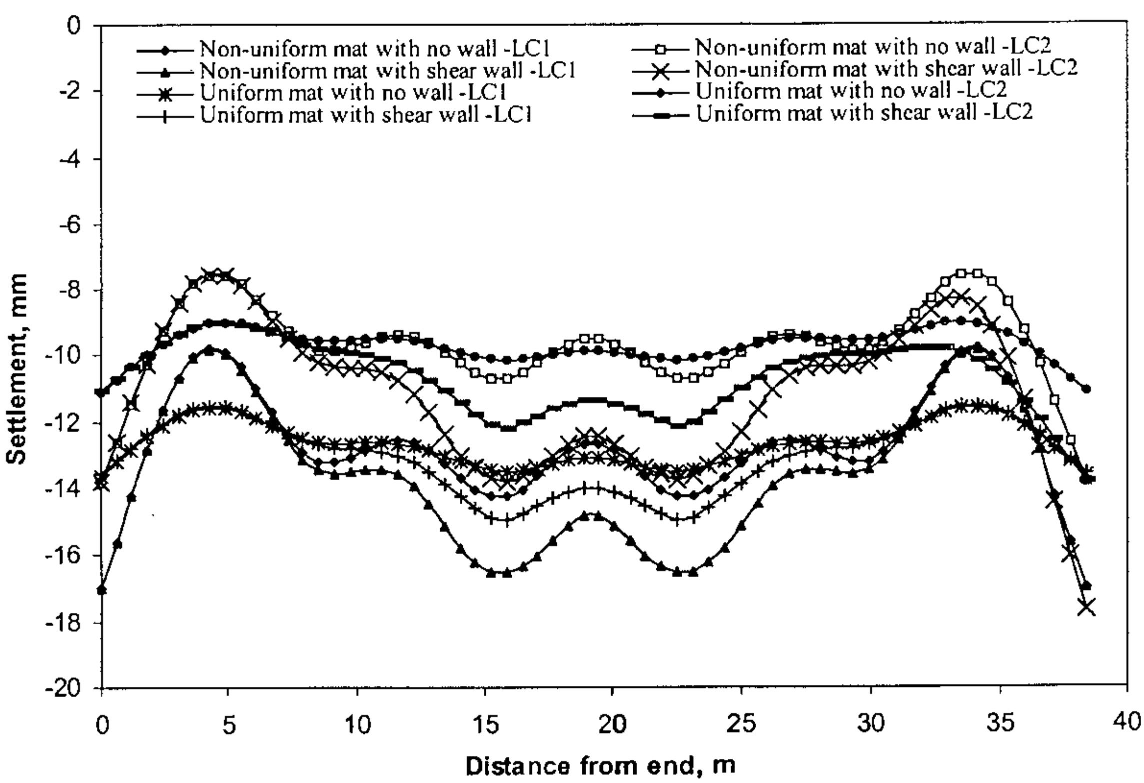

Fig.D-D24 Variation in settlement along **line 15** for mat of **Model-D.**

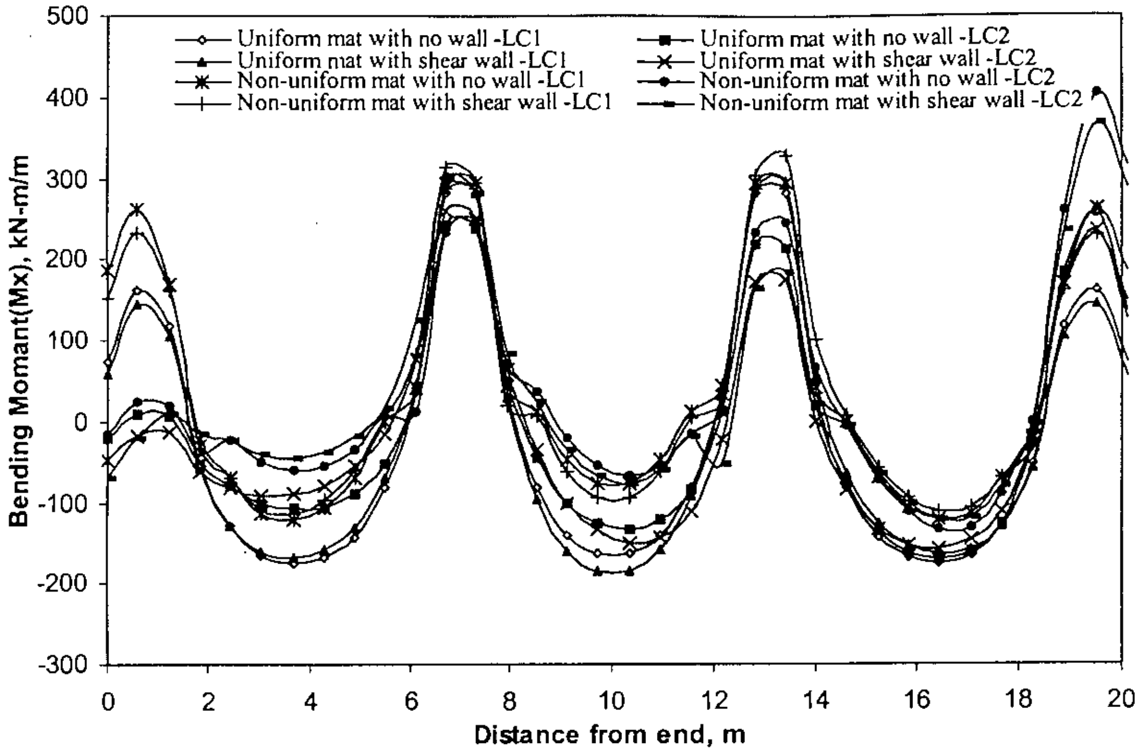

Fig.D-E1 Variation in Bending Moment along **line 1** for mat of **Model-E.**

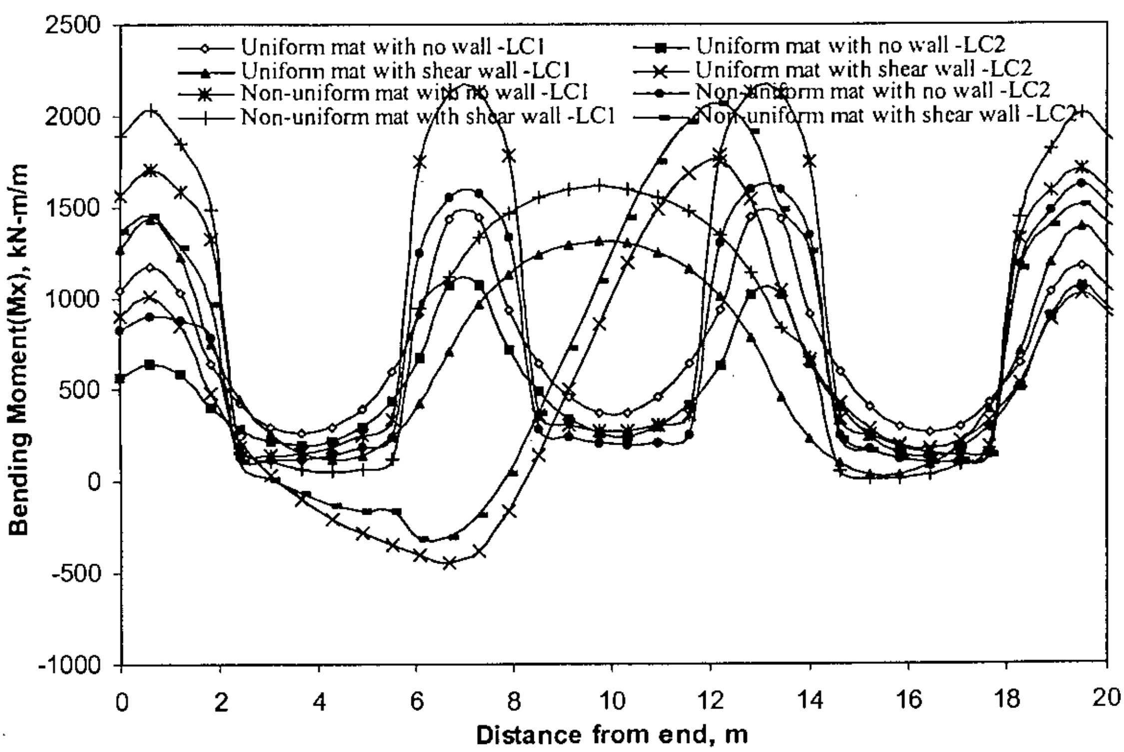

Fig.D-E2 Variation in Bending Moment along **line 3** for mat of **Model-E.**

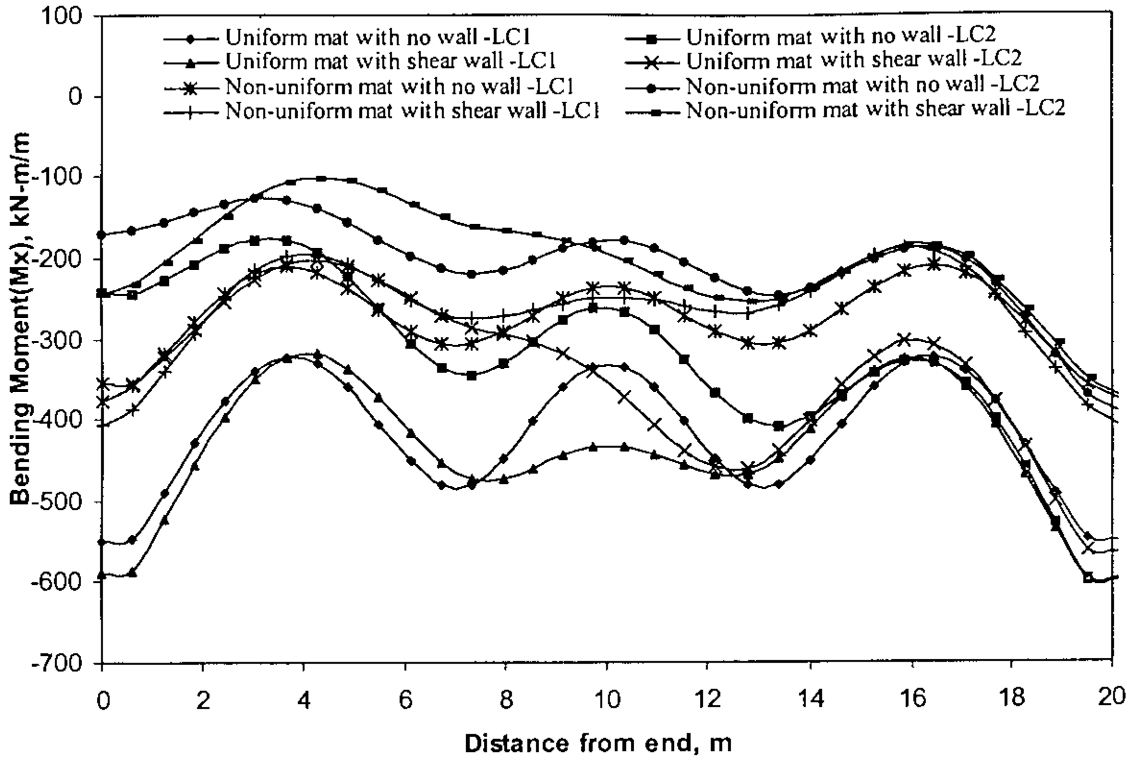

Fig.D-E3 Variation in Bending Moment along **line 4** for mat of **Model-E.**

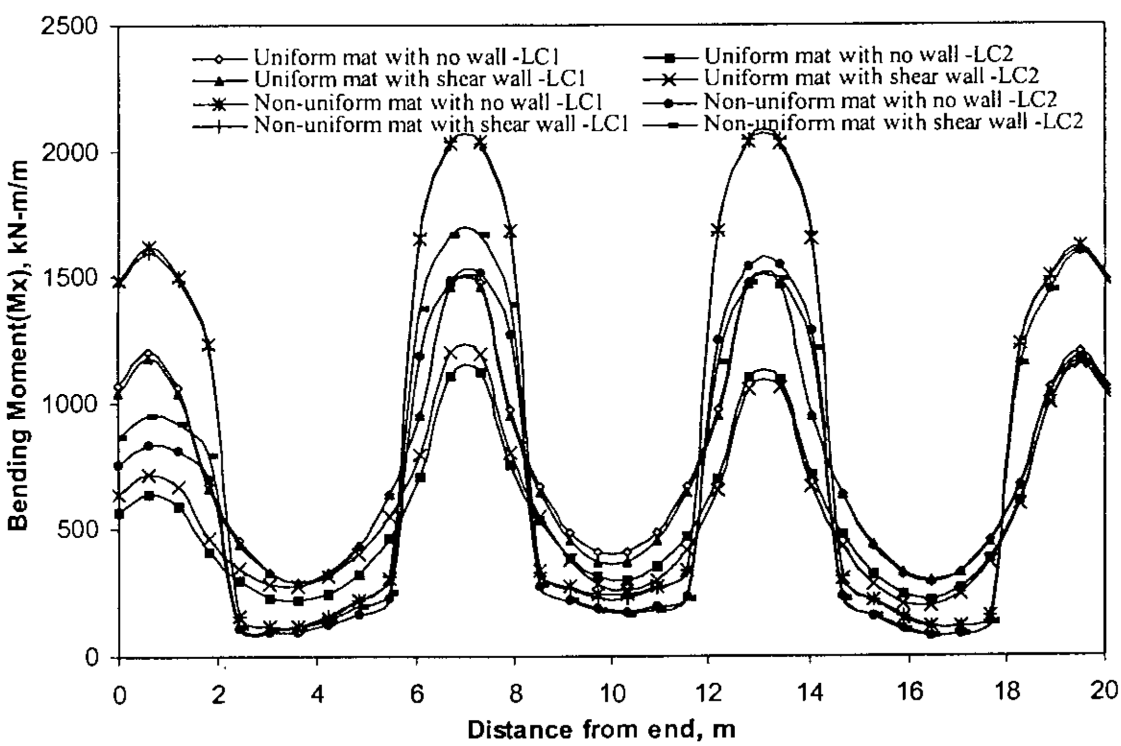

Fig.D-E4 Variation in Bending Moment along **line 5** for mat of **Model-E.**

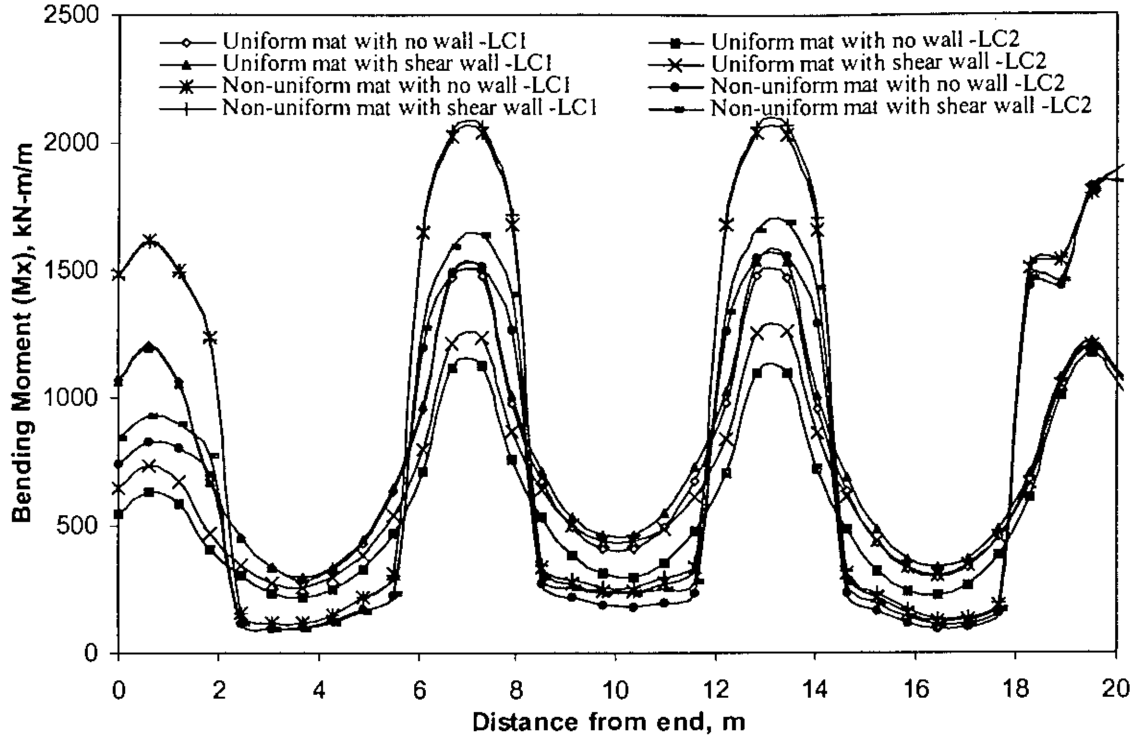

Fig.D-E5 Variation in Bending Moment along **line 7** for mat of **Model-E.**

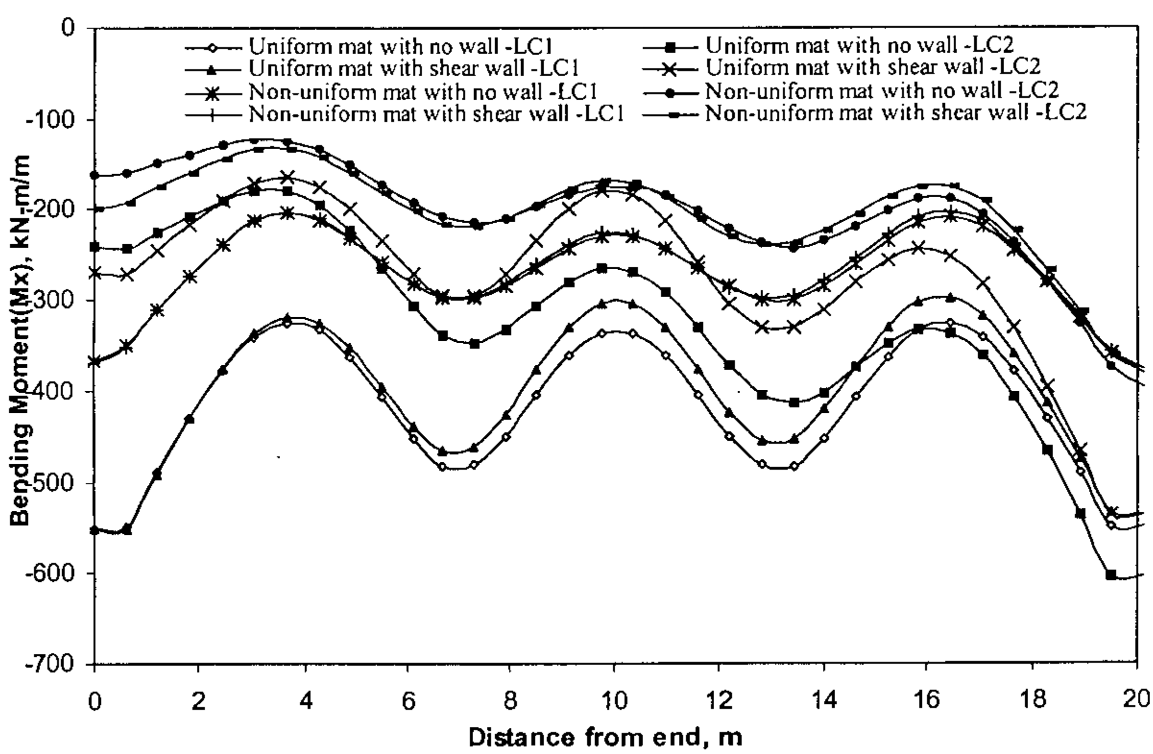

Fig.D-E6 Variation in Bending Moment along **line 8** for mat of **Model-E.**

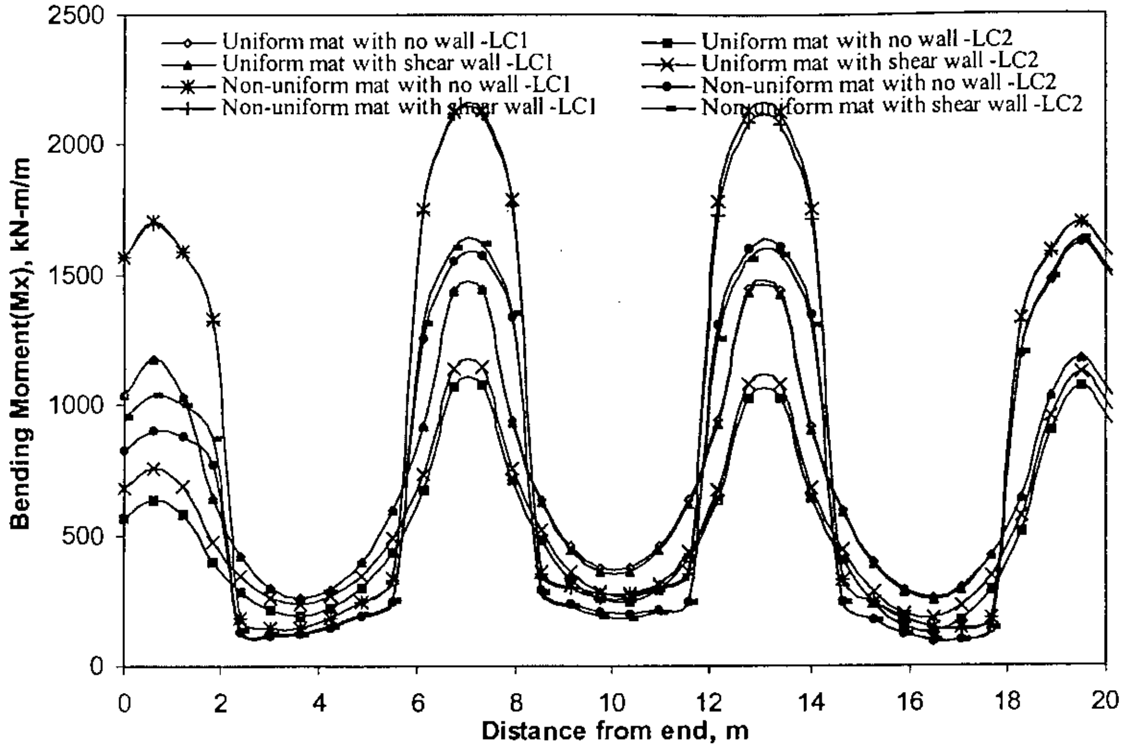

Fig.D-E7 Variation in Bending Moment along **line 9** for mat of **Model-E.**

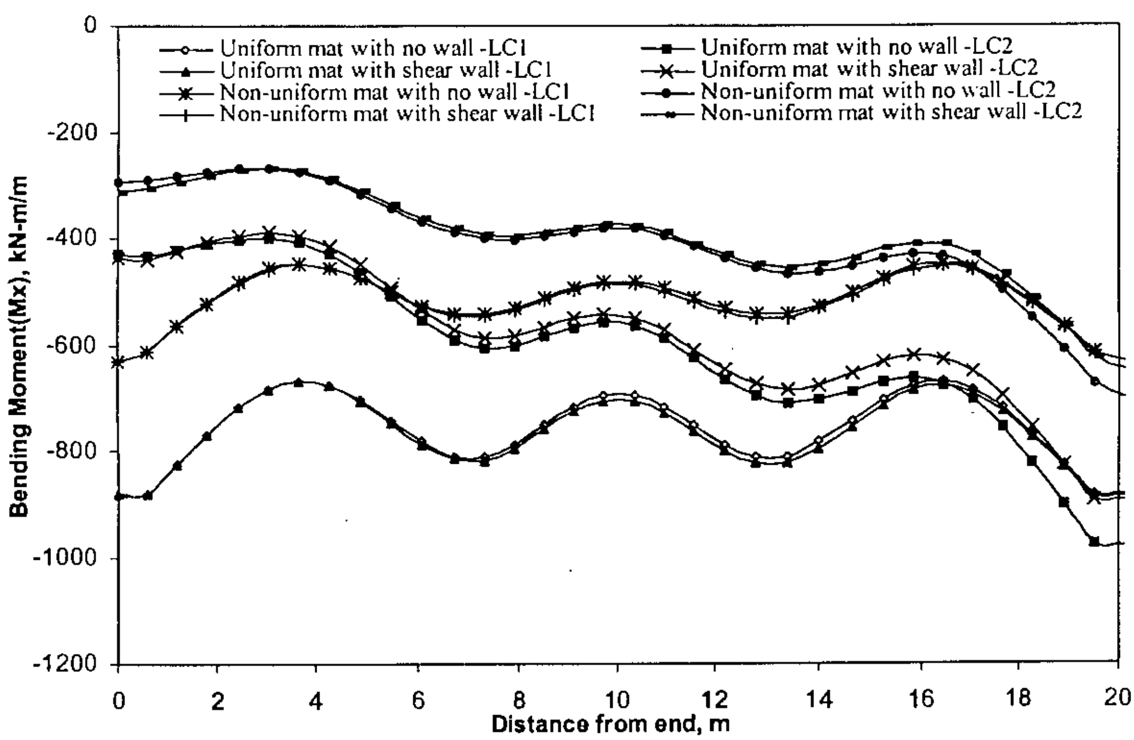

Fig.D-E8 Variation in Bending Moment along **line 10** for mat of **Model-E.**

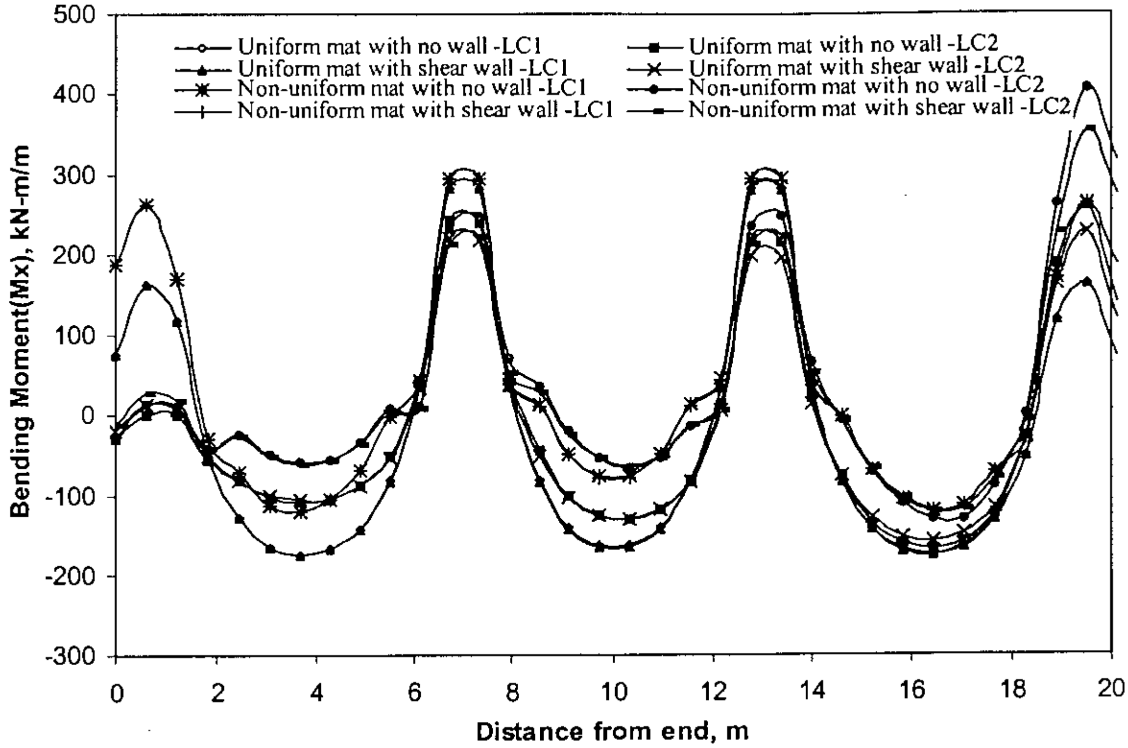

Fig.D-E9 Variation in Bending Moment along **line 11** for mat of **Model-E.**

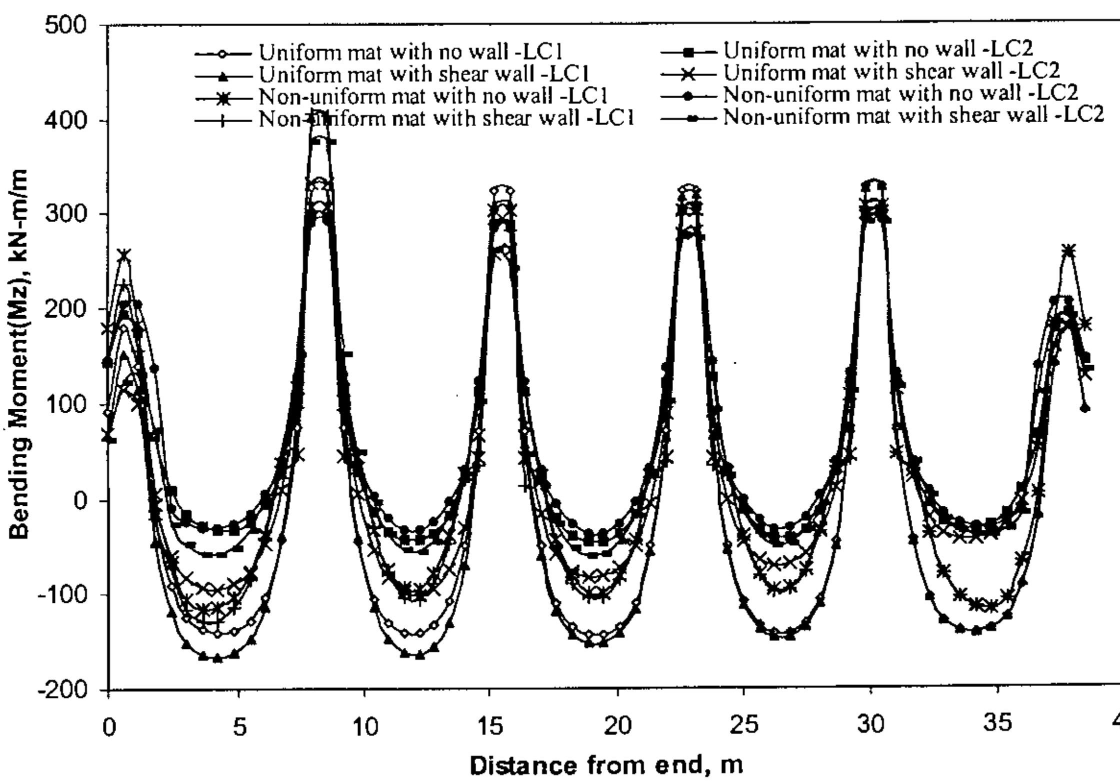

Fig.D-E10 Variation in Bending Moment along **line 12** for mat of **Model-E.**

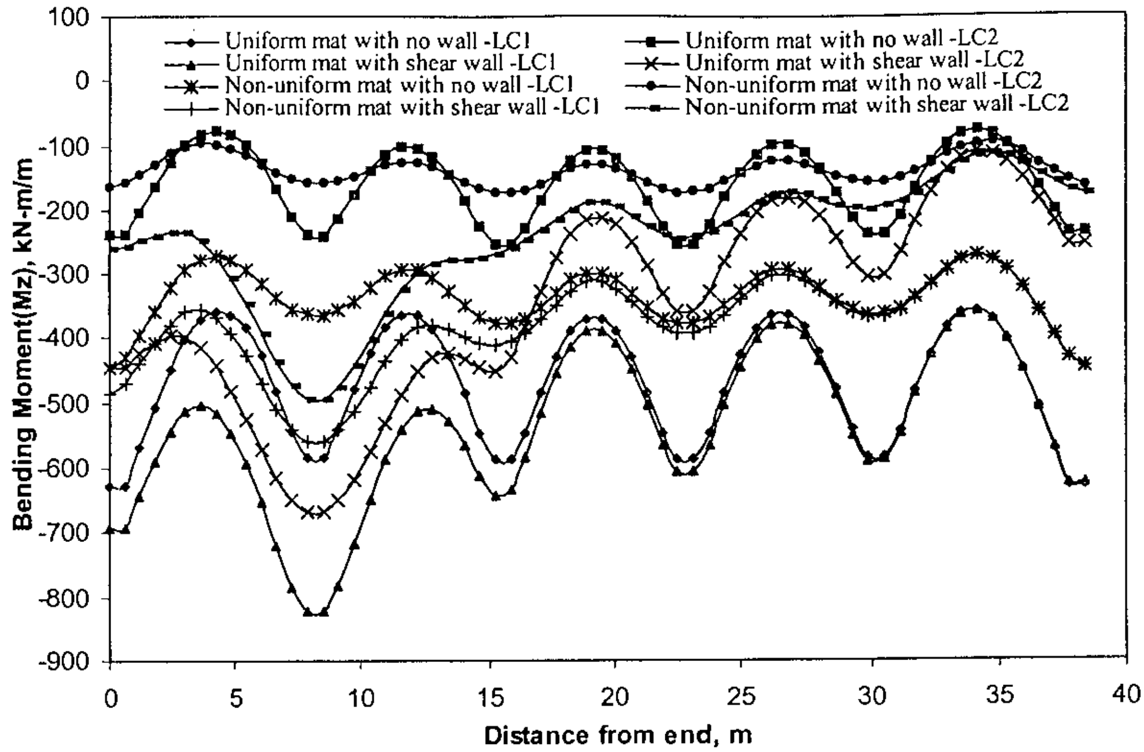

Fig.D-E11 Variation in Bending Moment along **line 13** for mat of **Model-E.**

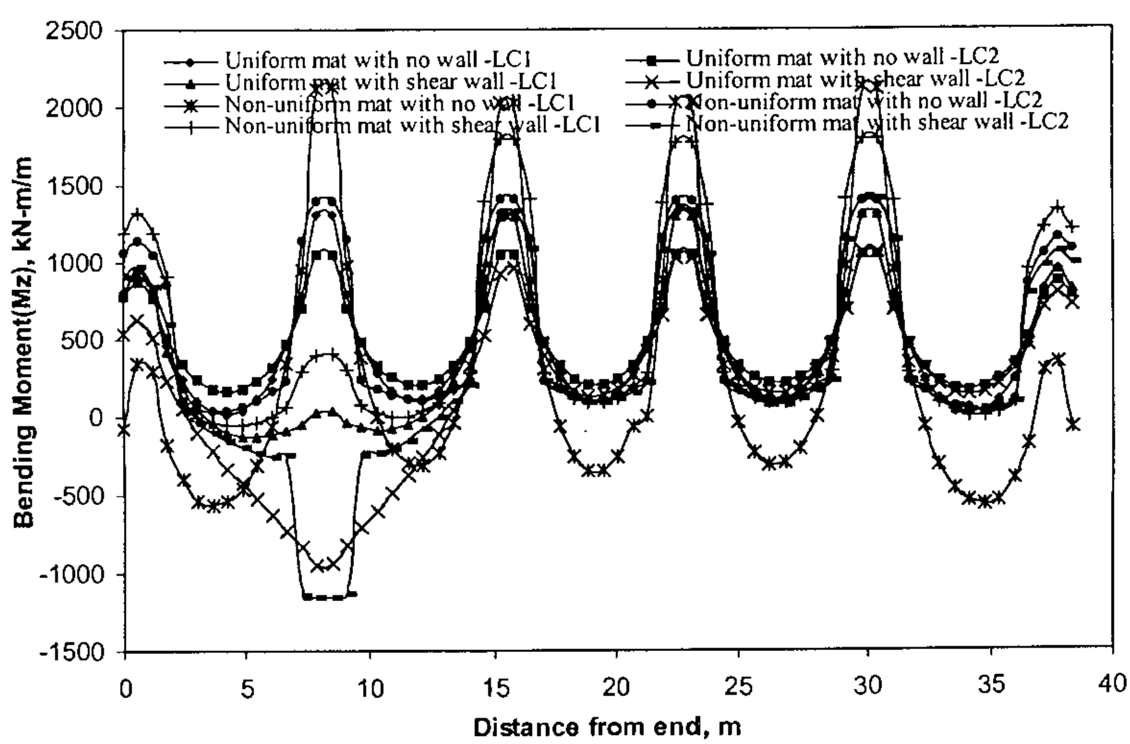

Fig.D-E12 Variation in Bending Moment along **line 14** for mat of **Model-E.**

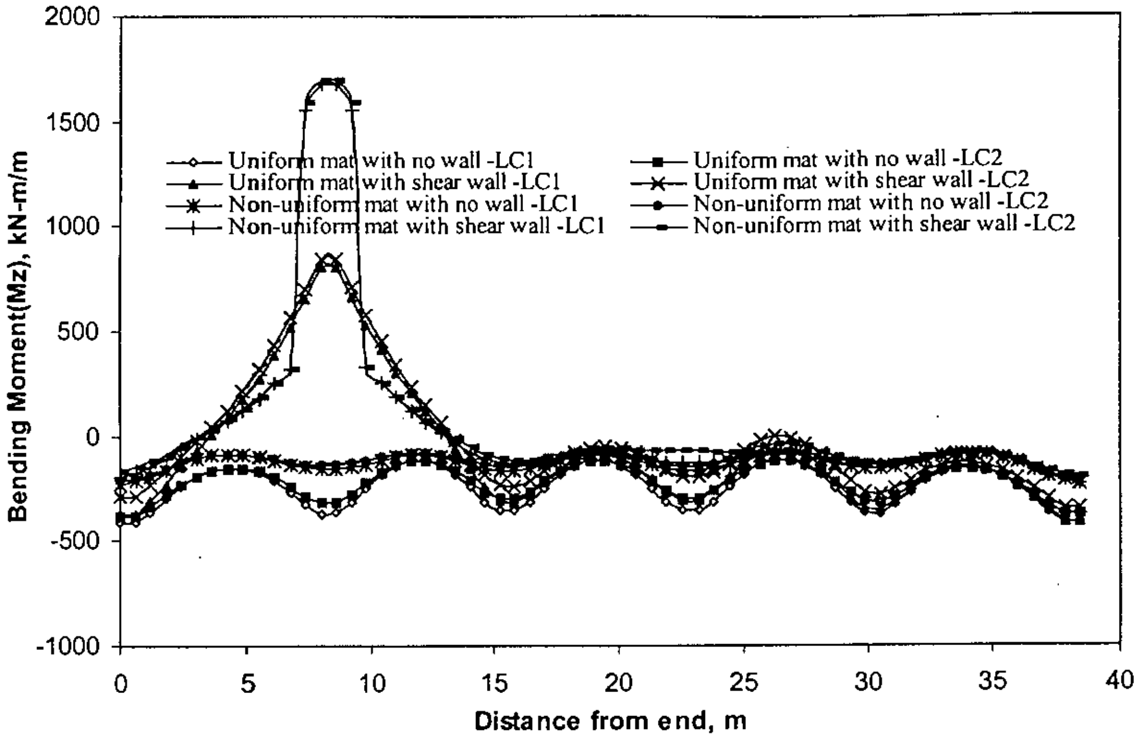

Fig.D-E13 Variation in Bending Moment along **line 15** for mat of **Model-E.**

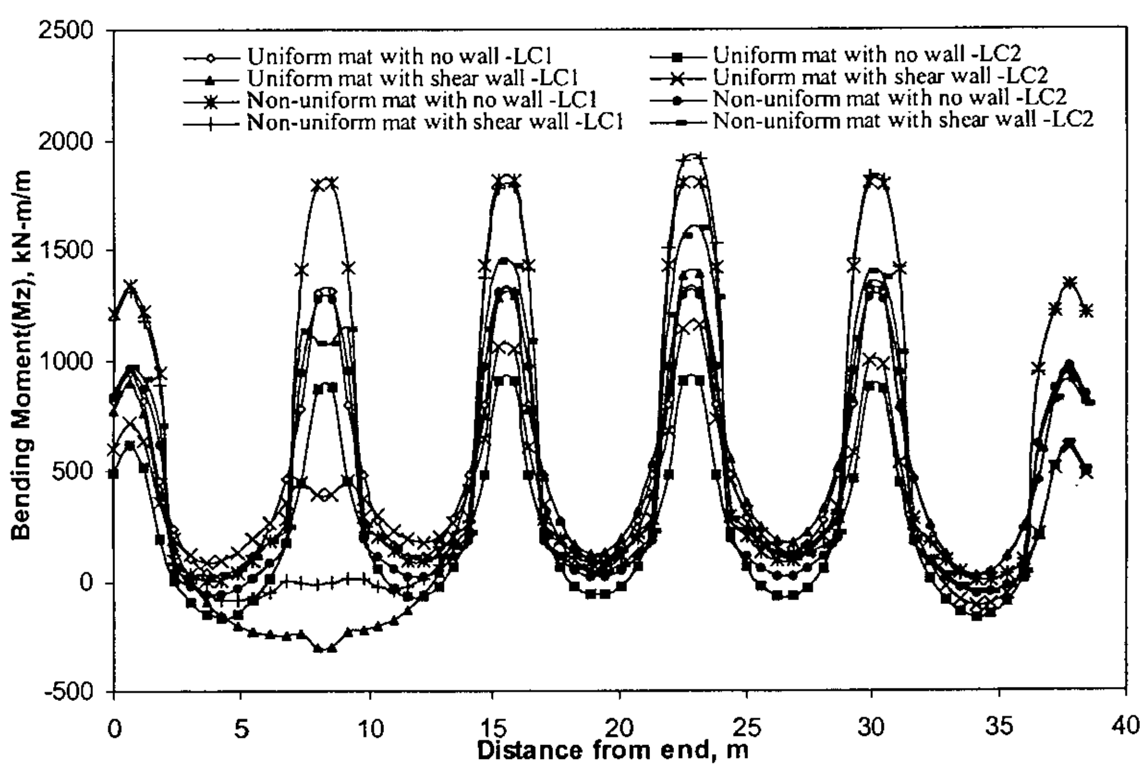

Fig.D-E14 Variation in Bending Moment along **line 16** for mat of **Model-E.**

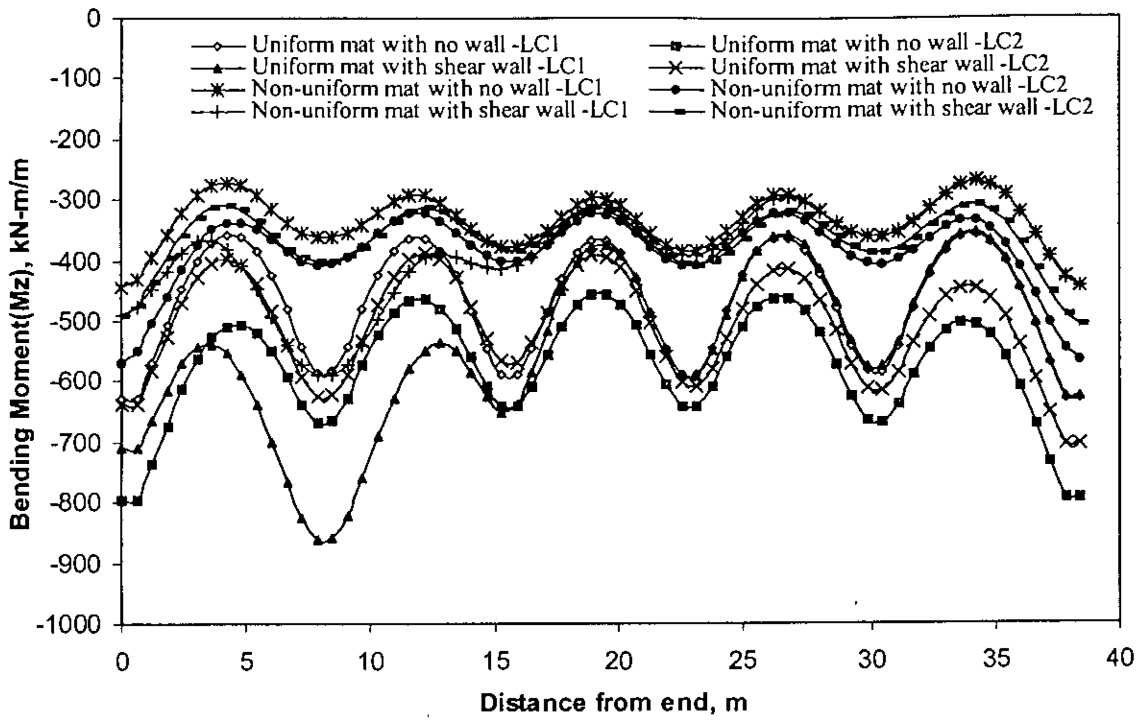

Fig.D-E15 Variation in Bending Moment along **line 17** for mat of **Model-E.**

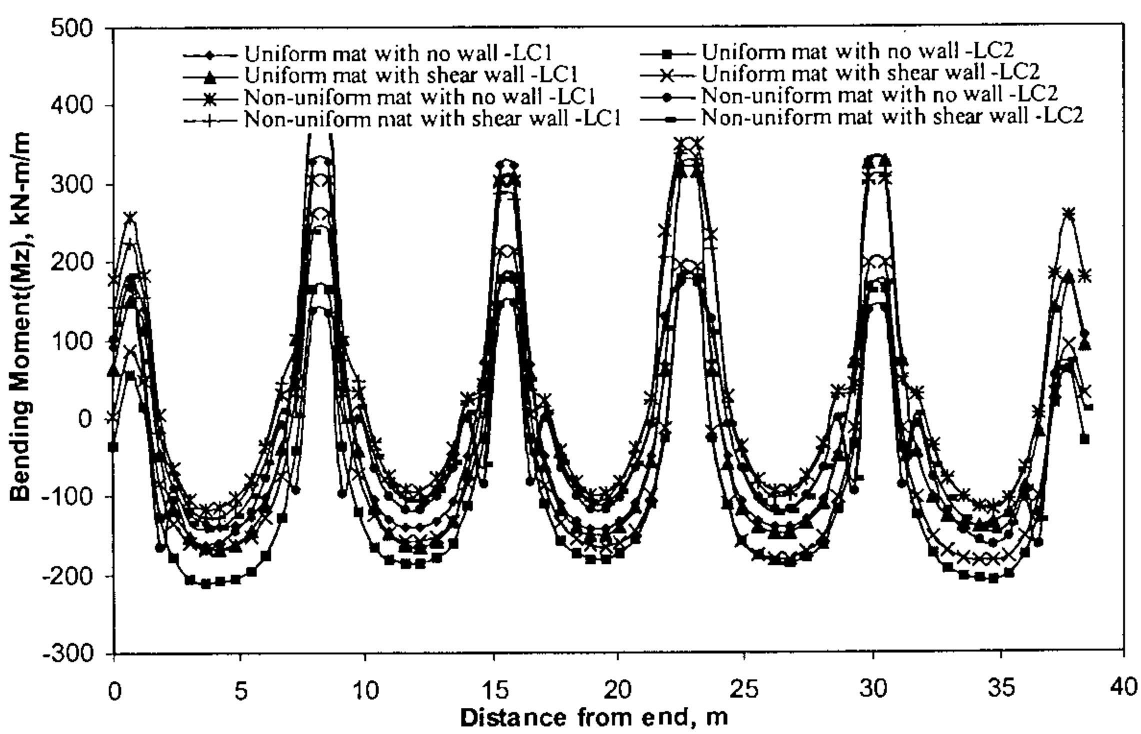

Fig.D-E16 Variation in Bending Moment along **line 18** for mat of **Model-E.**

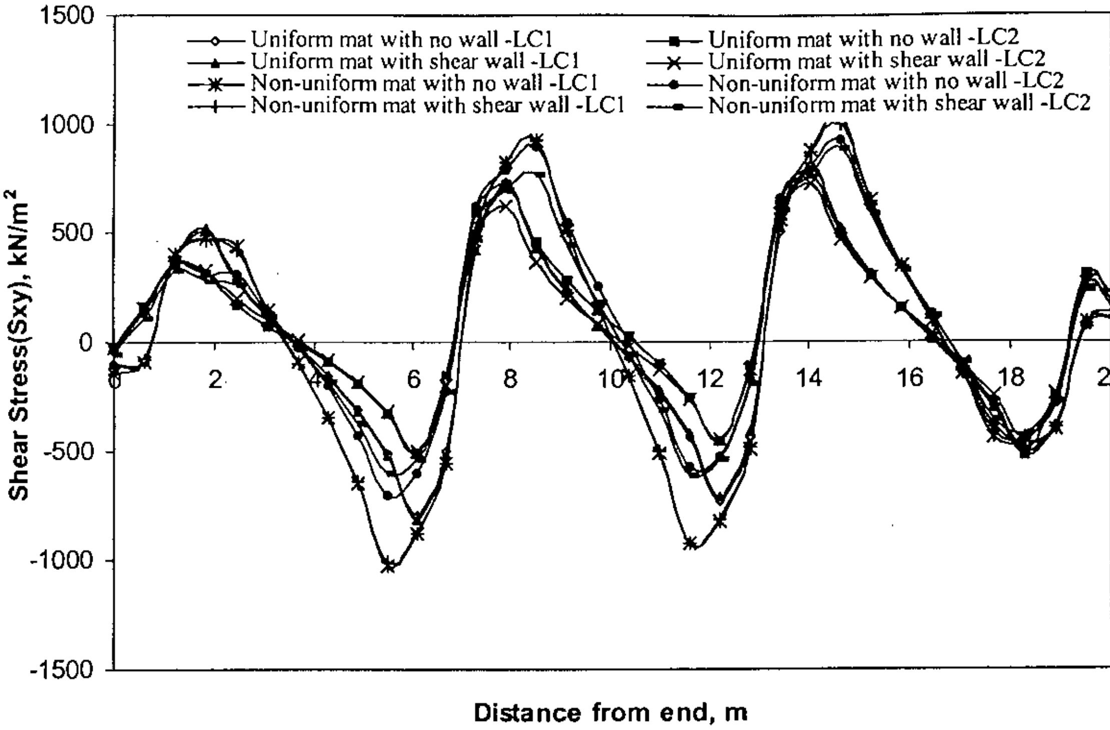

Fig.D-E17 Variation in Shear Stress along **line 1** for mat of **Model-E.**

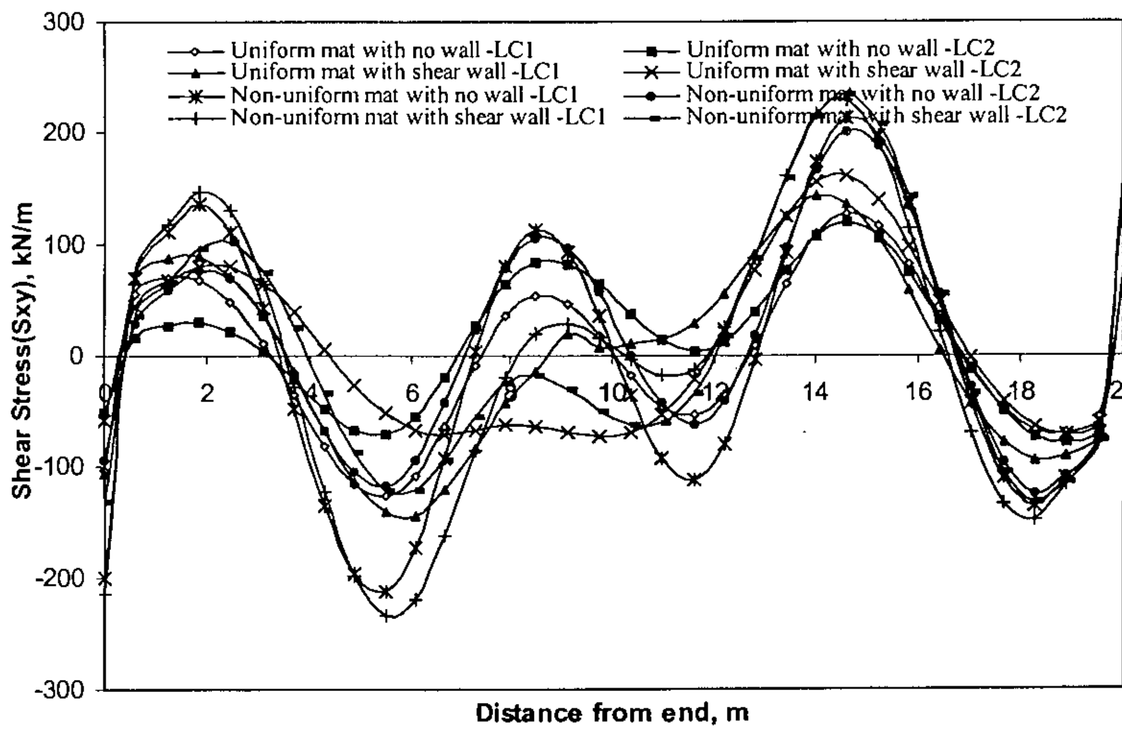

Fig.D-E18 Variation in Shear Stress along **line 4** for mat of **Model-E.**

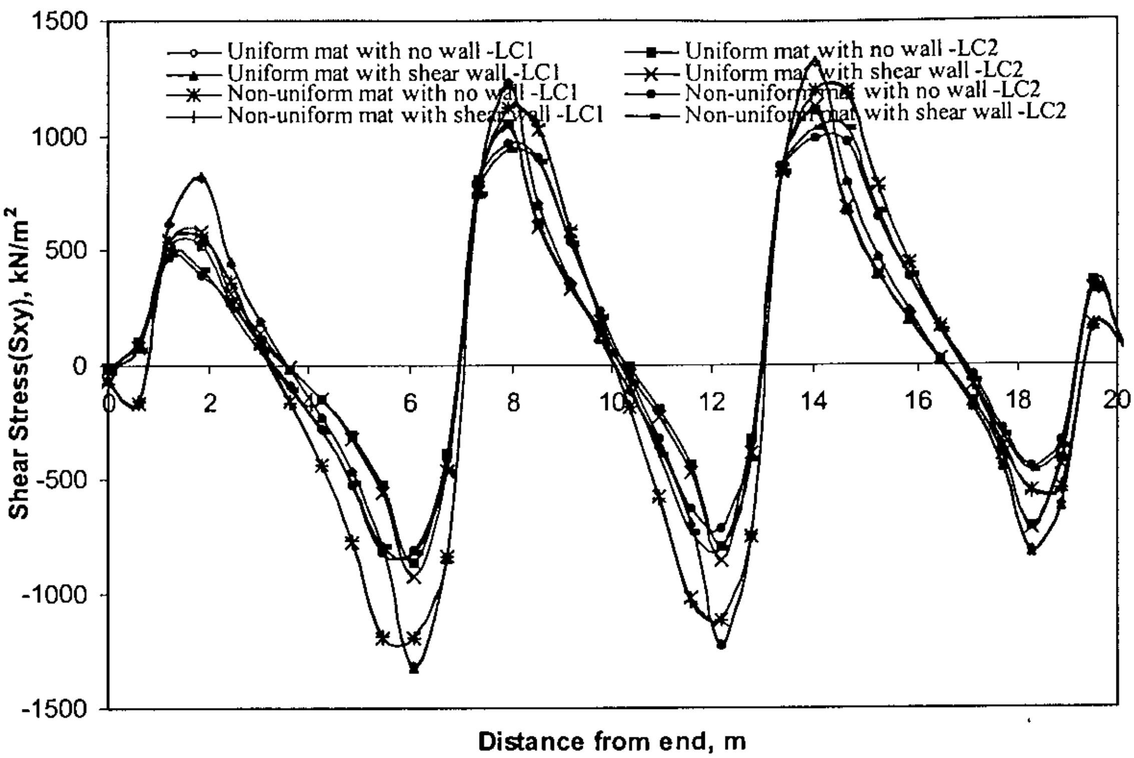

Fig.D-E19 Variation in Shear Stress along **line 5** for mat of **Model-E.**

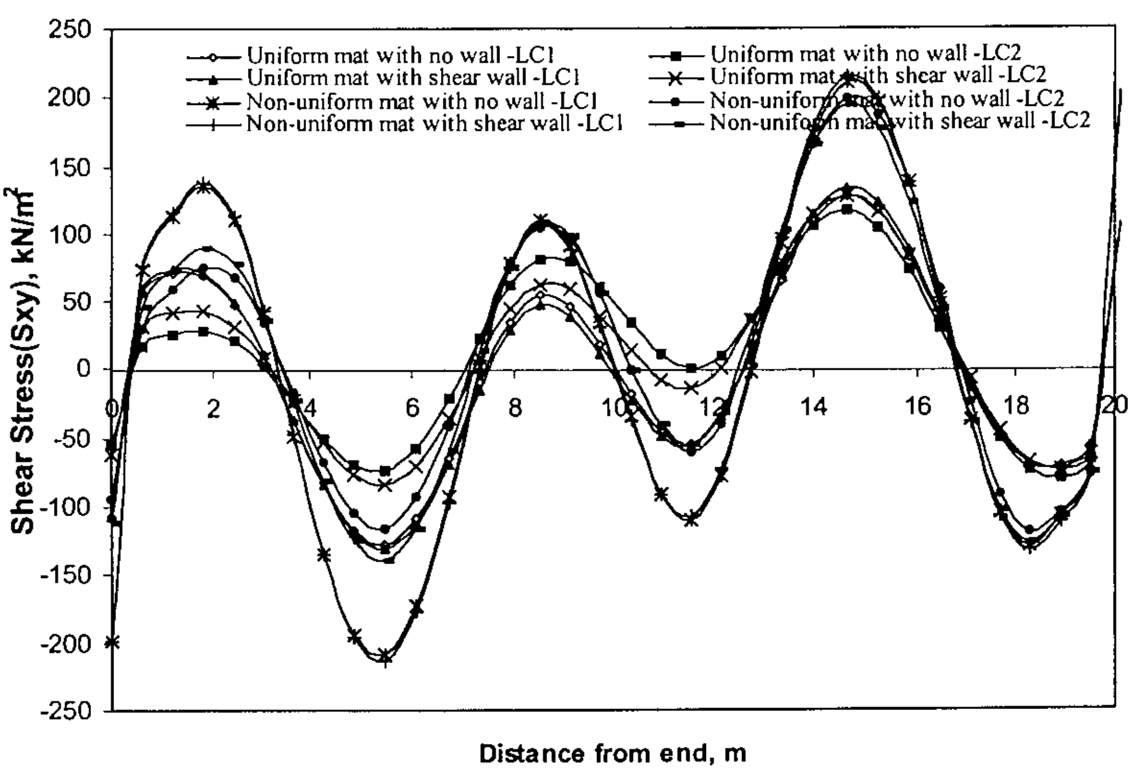

Fig.D-E20 Variation in Shear Stress along **line 6** for mat of **Model-E.**

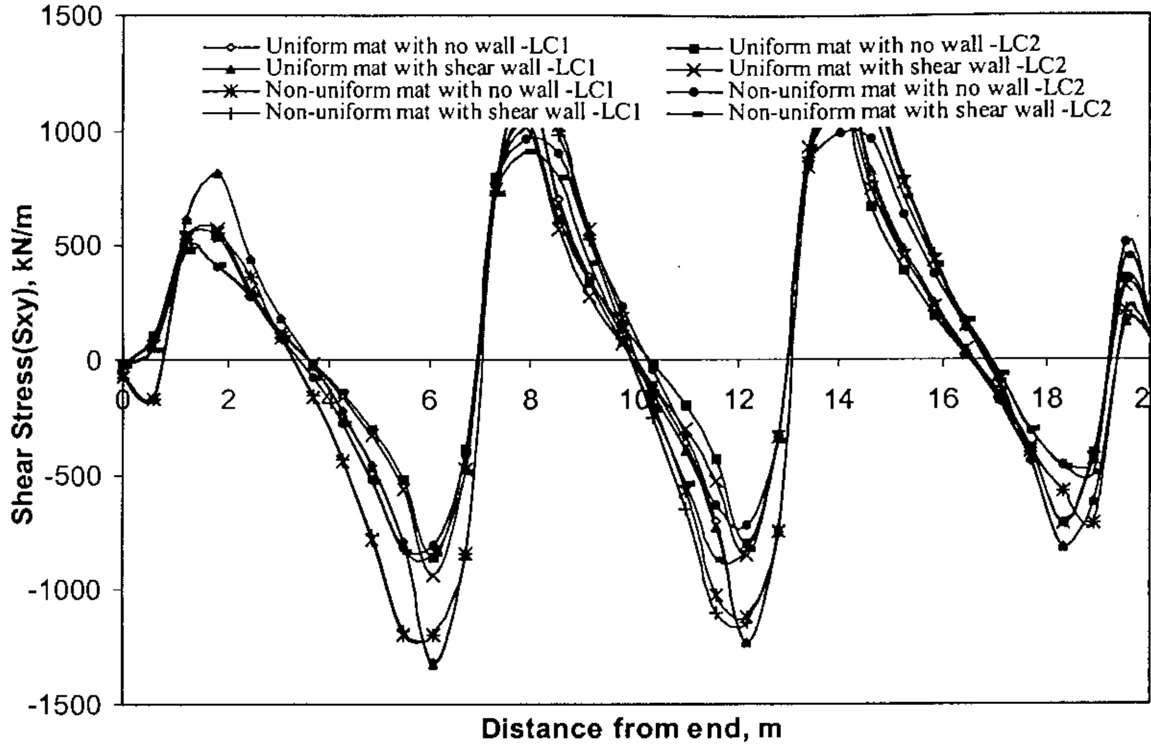

Fig.D-E21 Variation in Shear Stress along **line 7** for mat of **Model-E.**

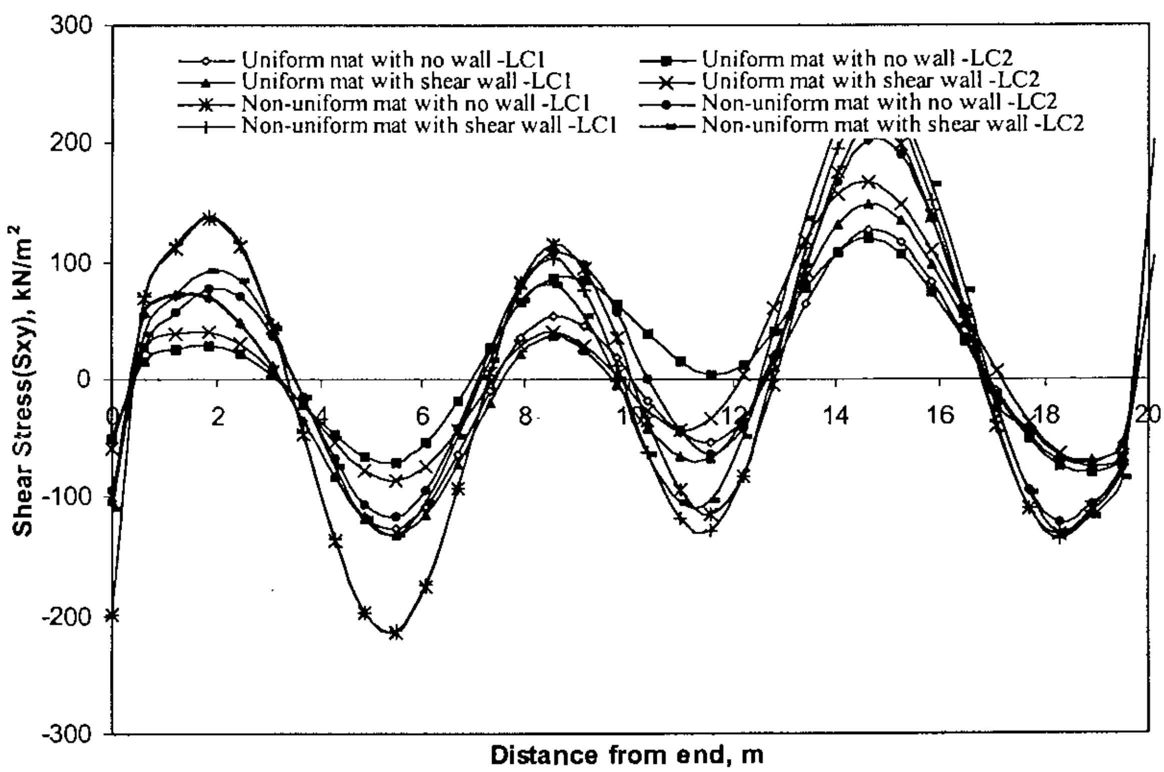

Fig.D-E22 Variation in Shear Stress along **line 8** for mat of **Model-E.**

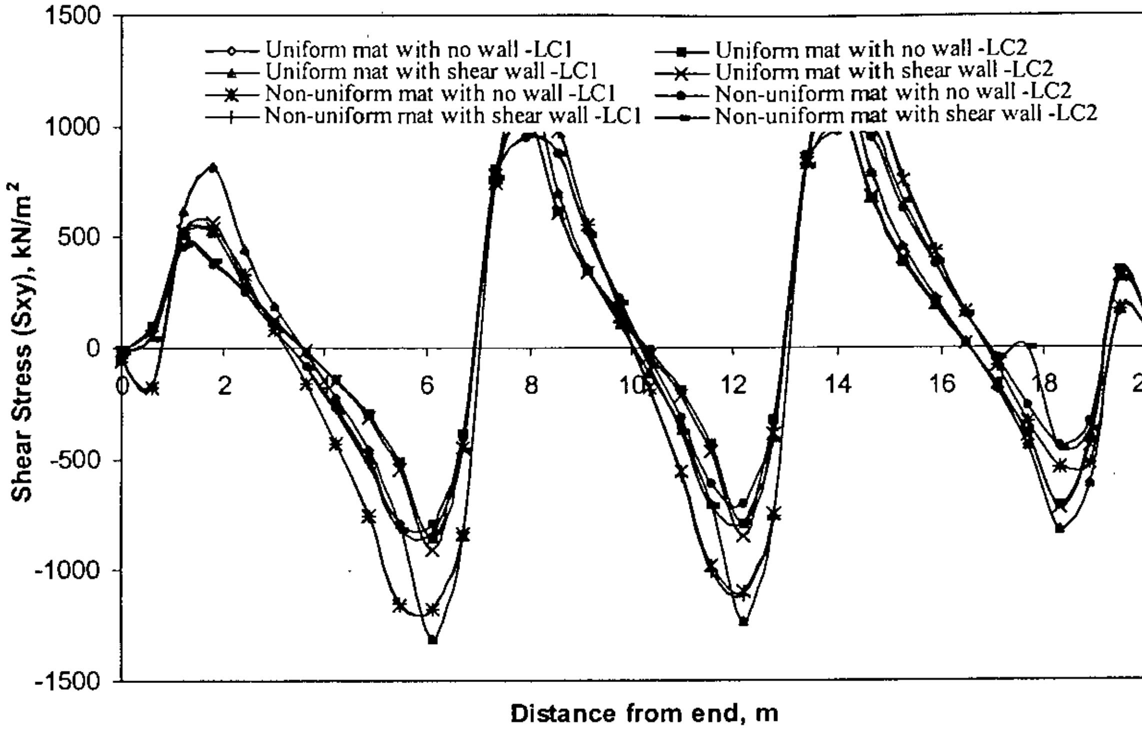

Fig.D-E23 Variation in Shear Stress along **line 9** for mat of **Model-E.**

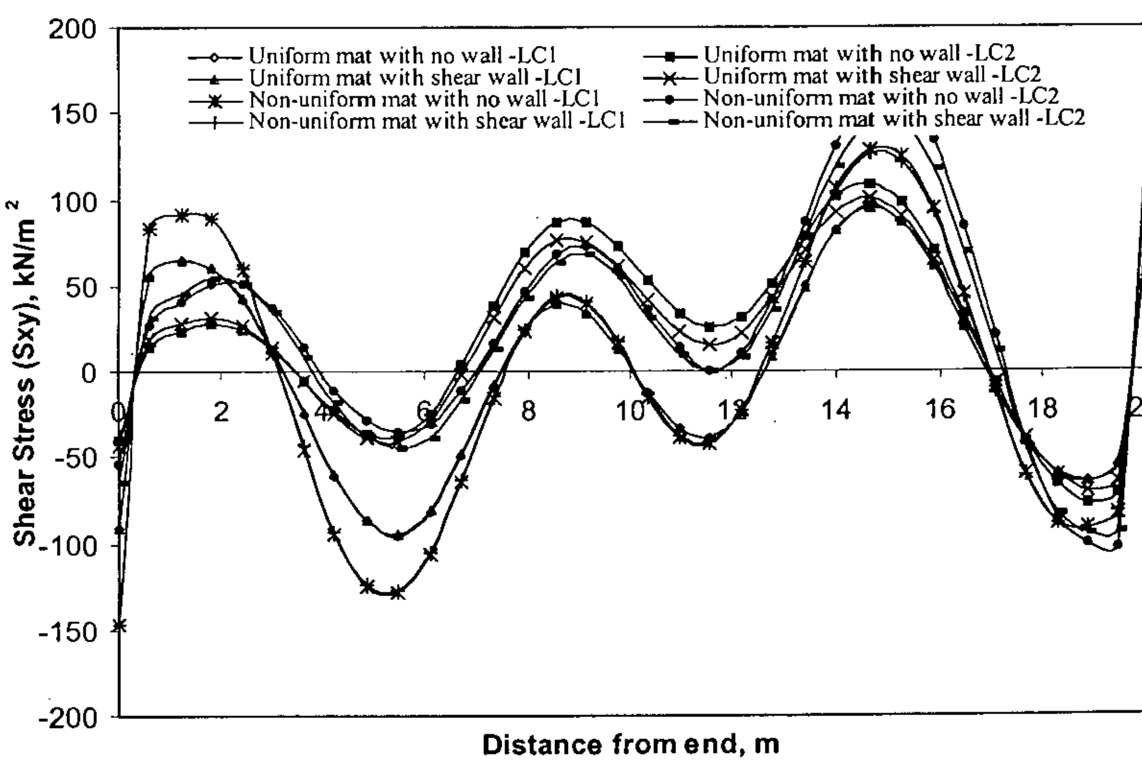

Fig.D-E24 Variation in Shear Stress along **line 10** for mat of **Model-E.**

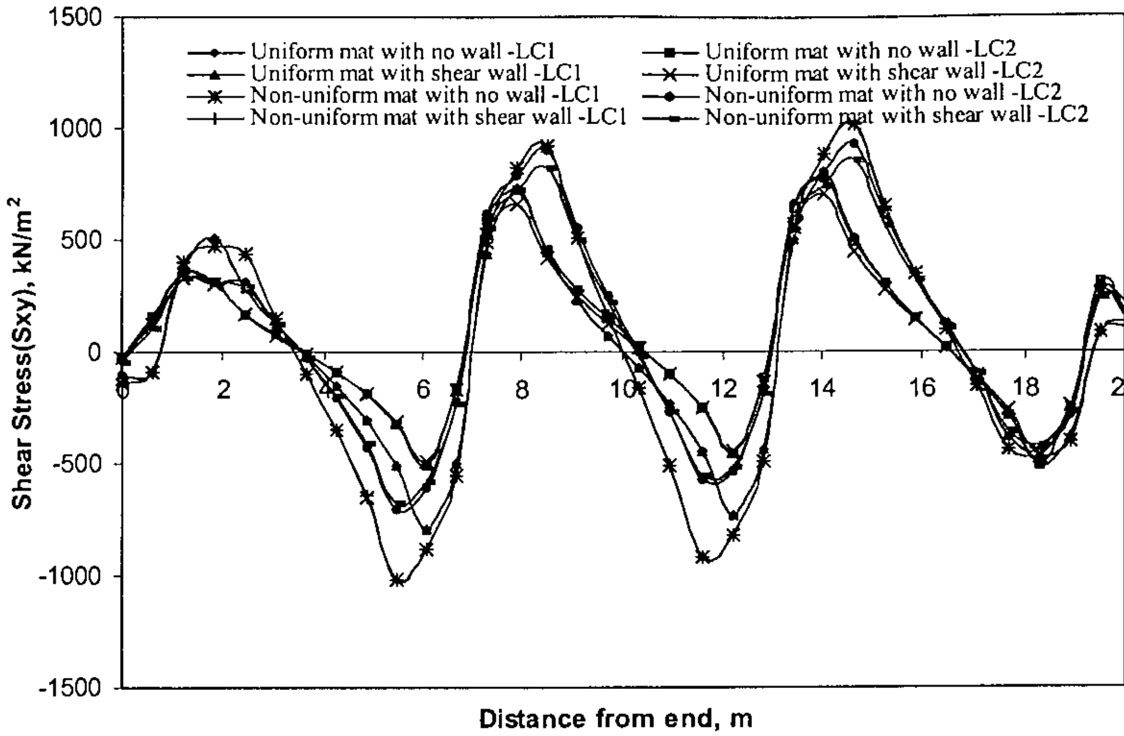

Fig.D-E25 Variation in Shear Stress along **line 11** for mat of **Model-E.**

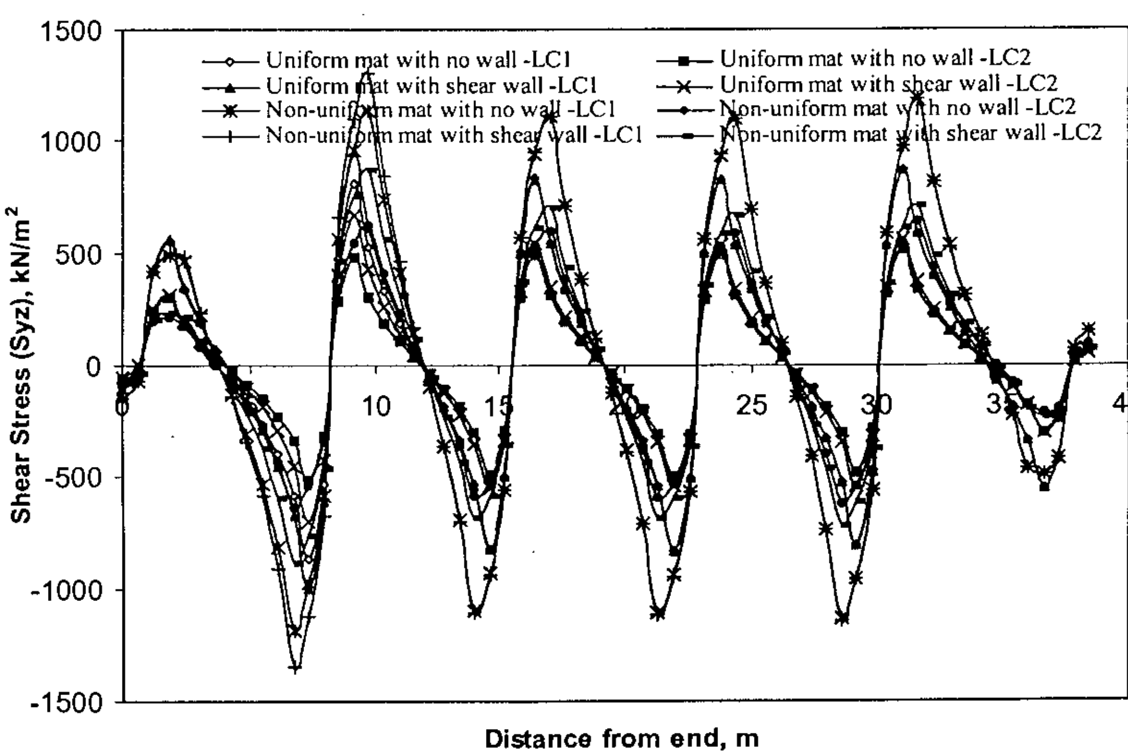

Fig.D-E26 Variation in Shear Stress along **line 12** for mat of **Model-E.**

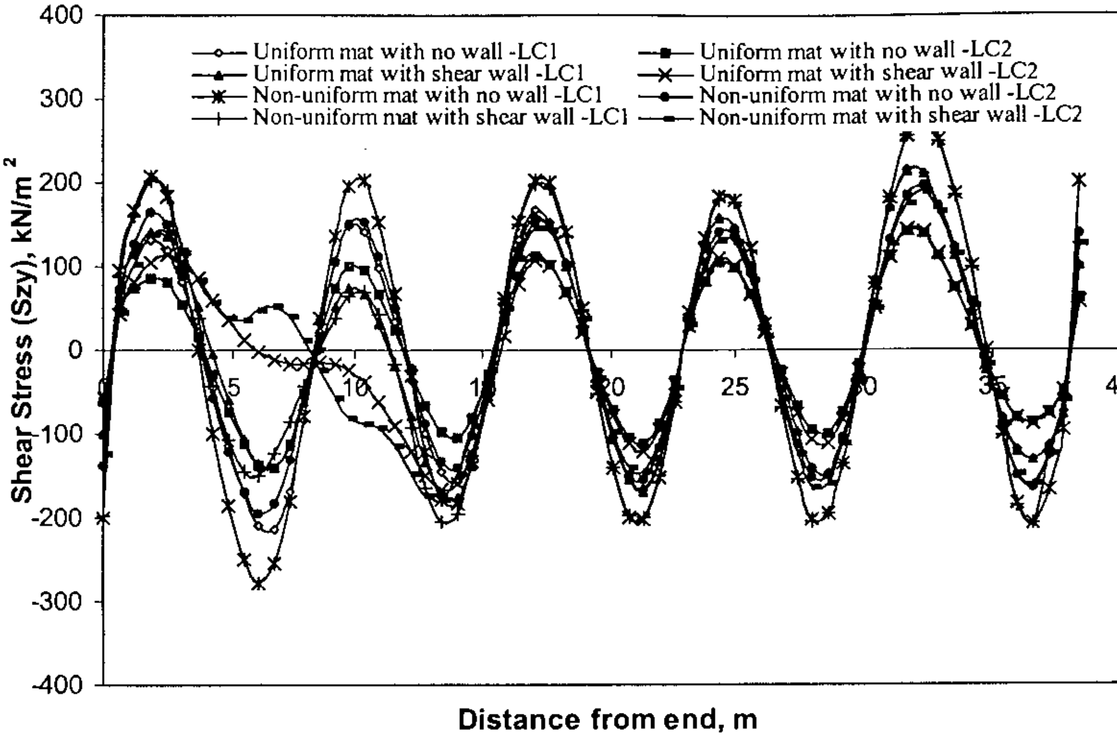

Fig.D-E27 Variation in Shear Stress along **line 13** for mat of **Model-E.**

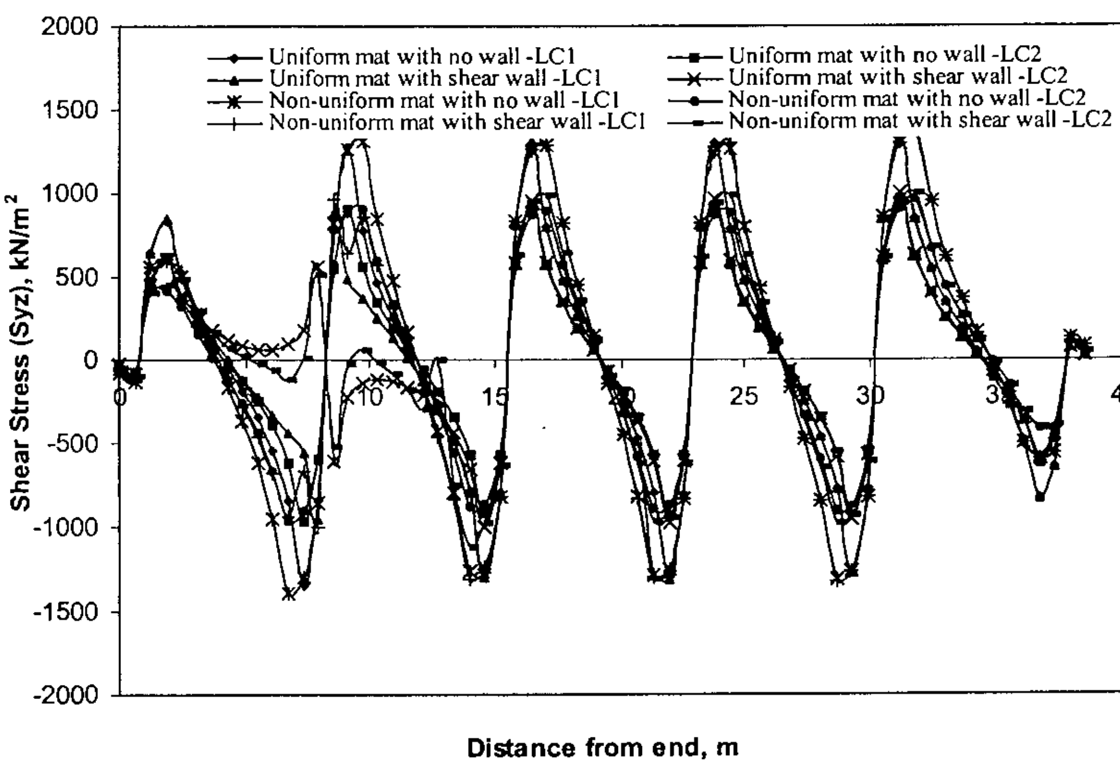

Fig.D-E28 Variation in Shear Stress along **line 14** for mat of **Model-E.**

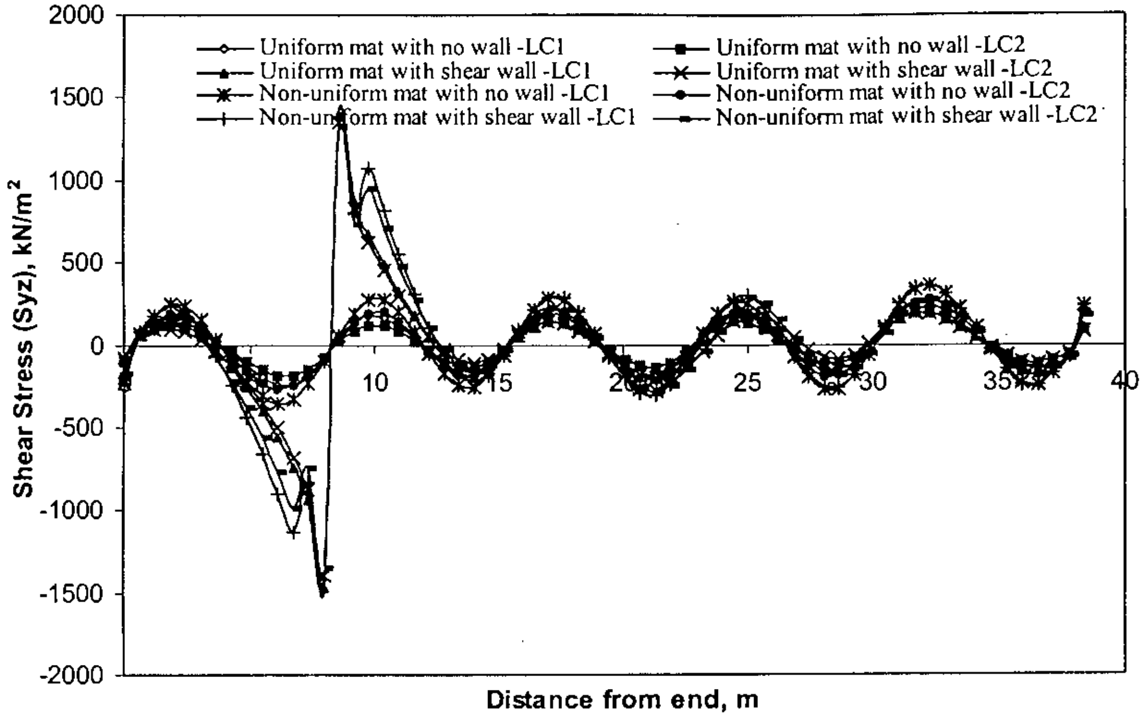

Fig.D-E29 Variation in Shear Stress along **line 15** for mat of **Model-E.**

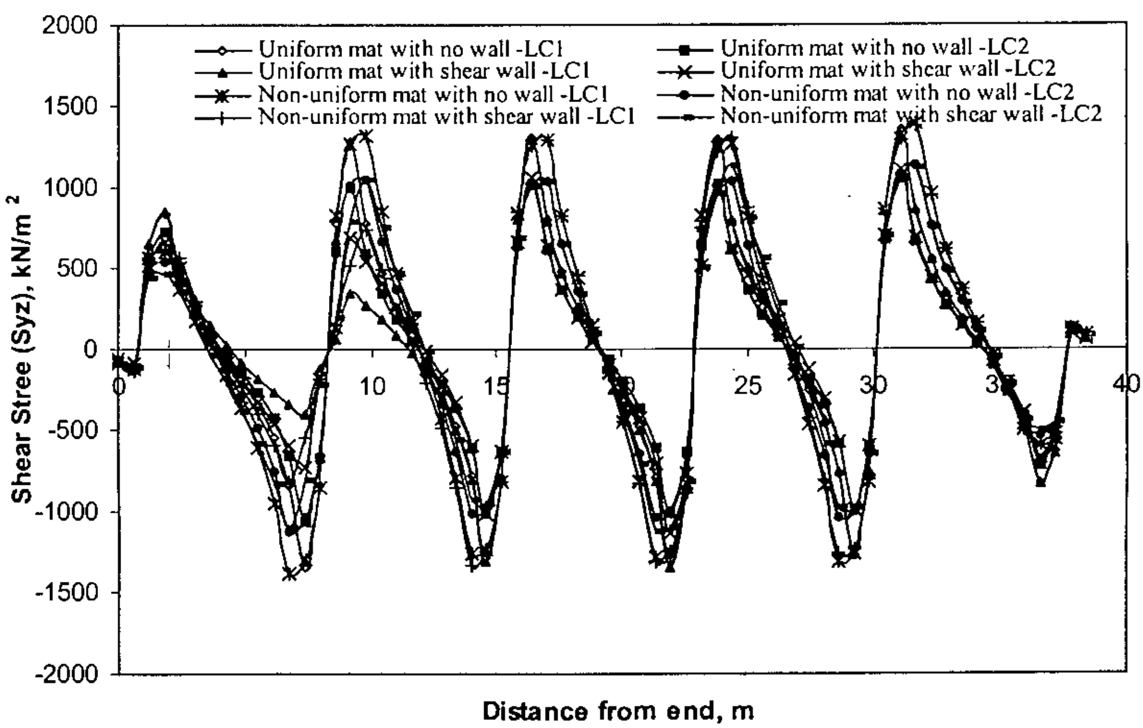

Fig.D-E30 Variation in Shear Stress along **line 16** for mat of **Model-E.**

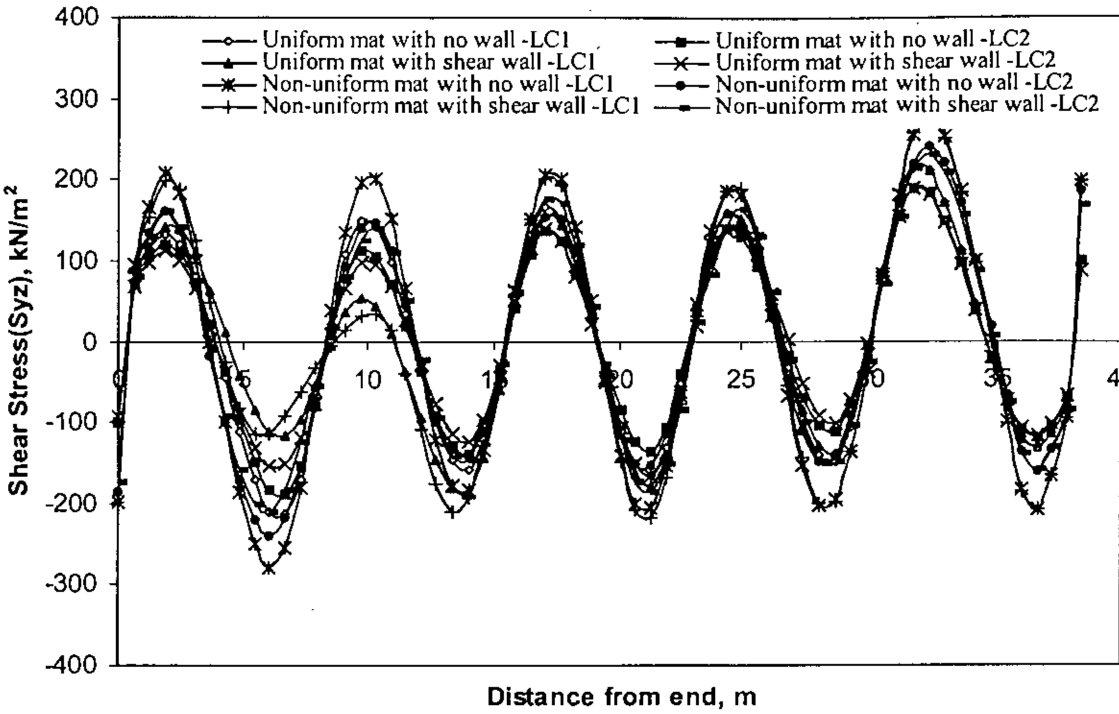

Fig.D-E31 Variation in Shear Stress along **line 17** for mat of **Model-E.**

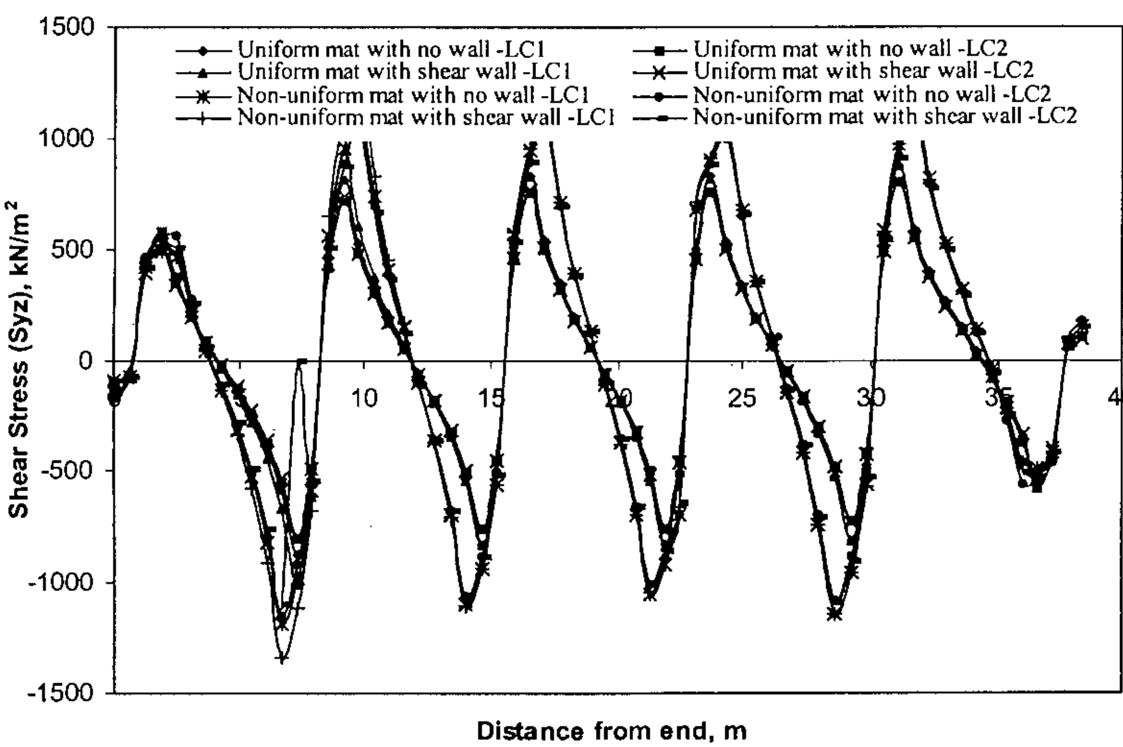

Fig.D-E32 Variation in Shear Stress along **line 18** for mat of **Model-E.**

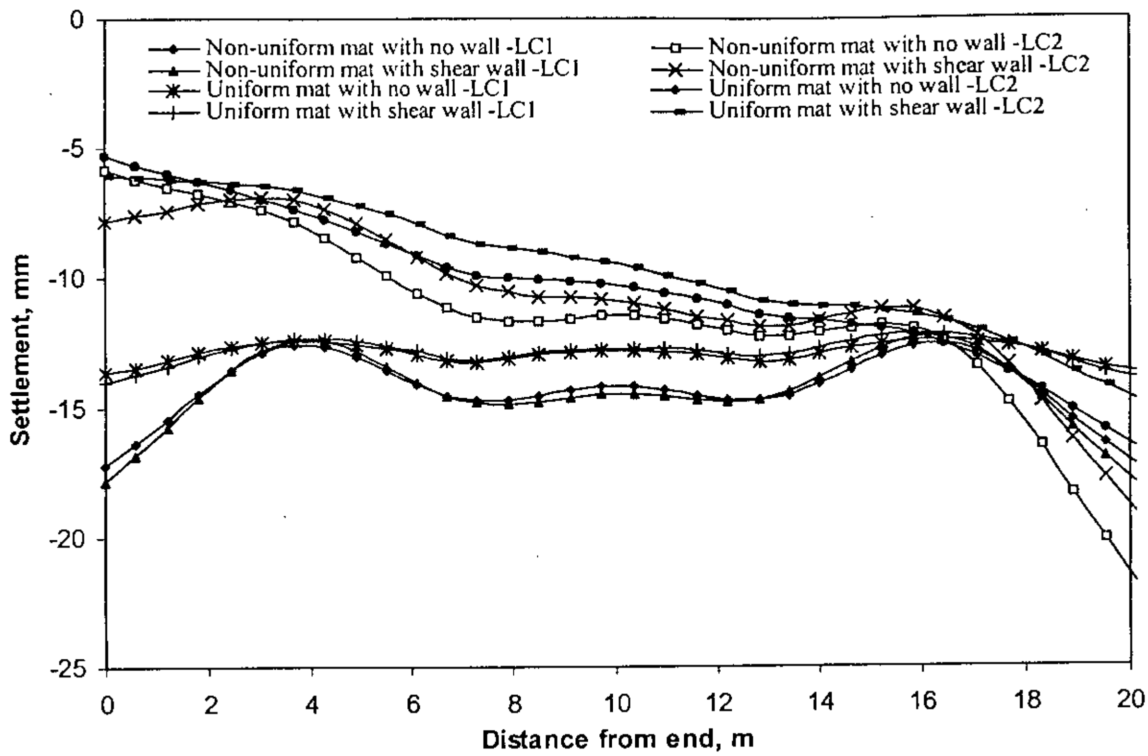

Fig.D-E33 Variation in Settlement along **line 1** for mat of **Model-E.**

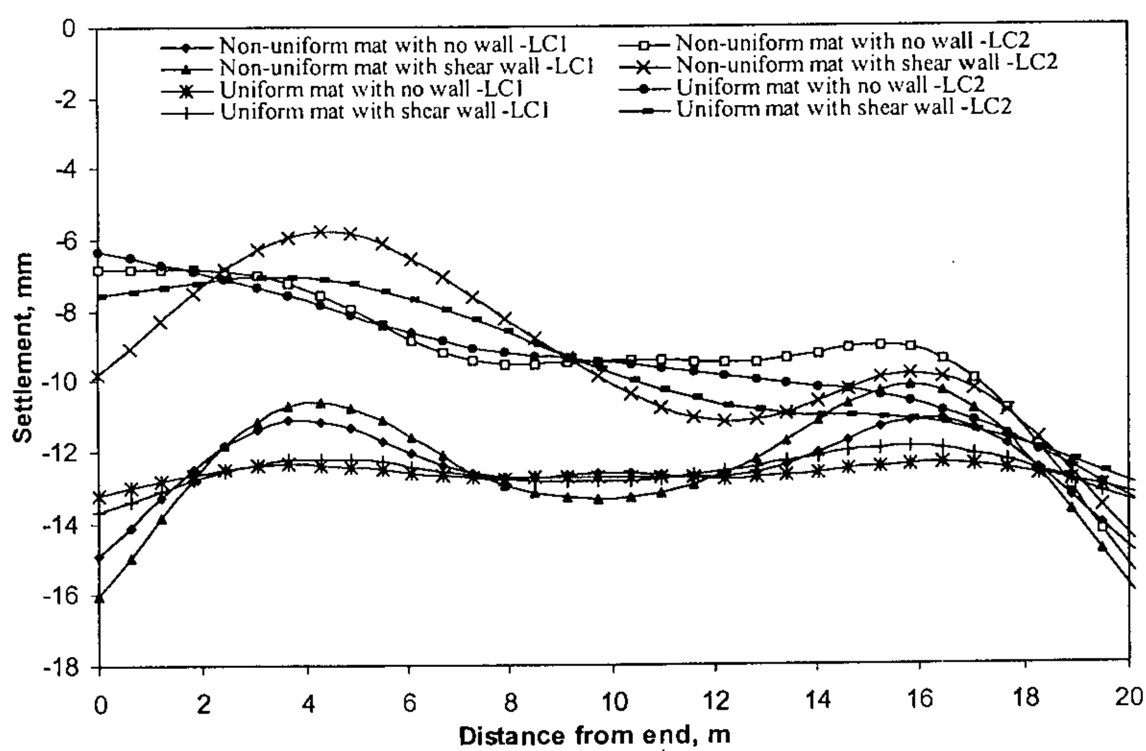

Fig.D-E34 Variation in Settlement along **line 4** for mat of **Model-E.**

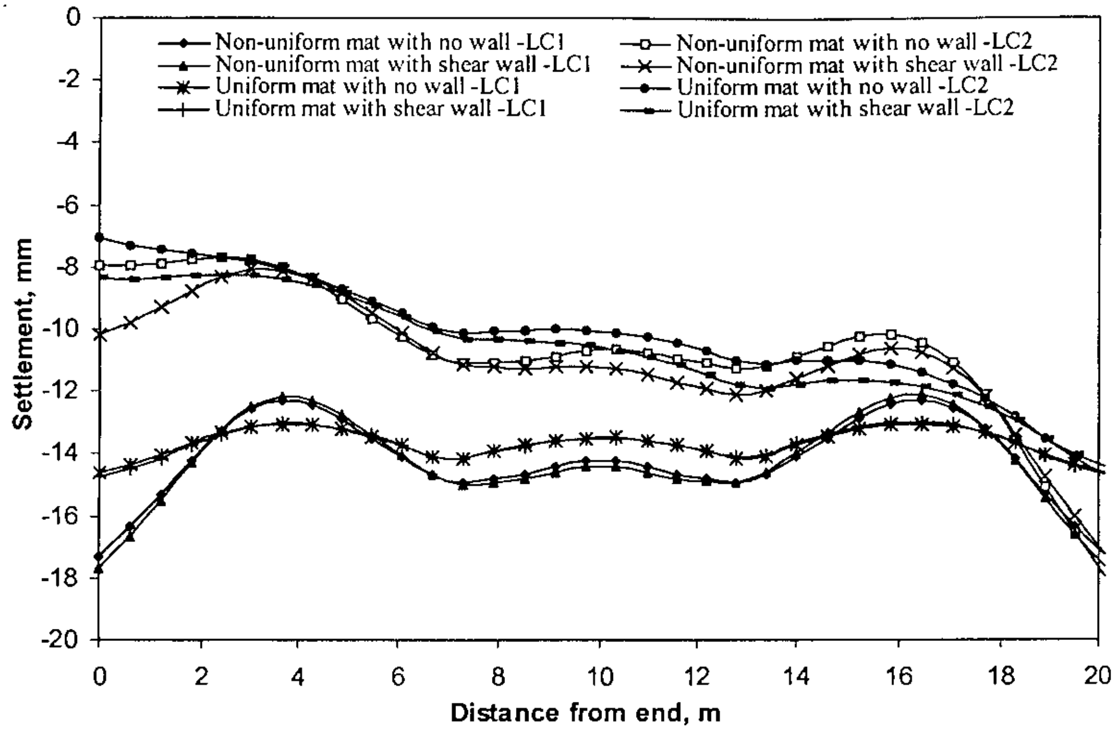

Fig.D-E35 Variation in Settlement along **line 5** for mat of **Model-E.**

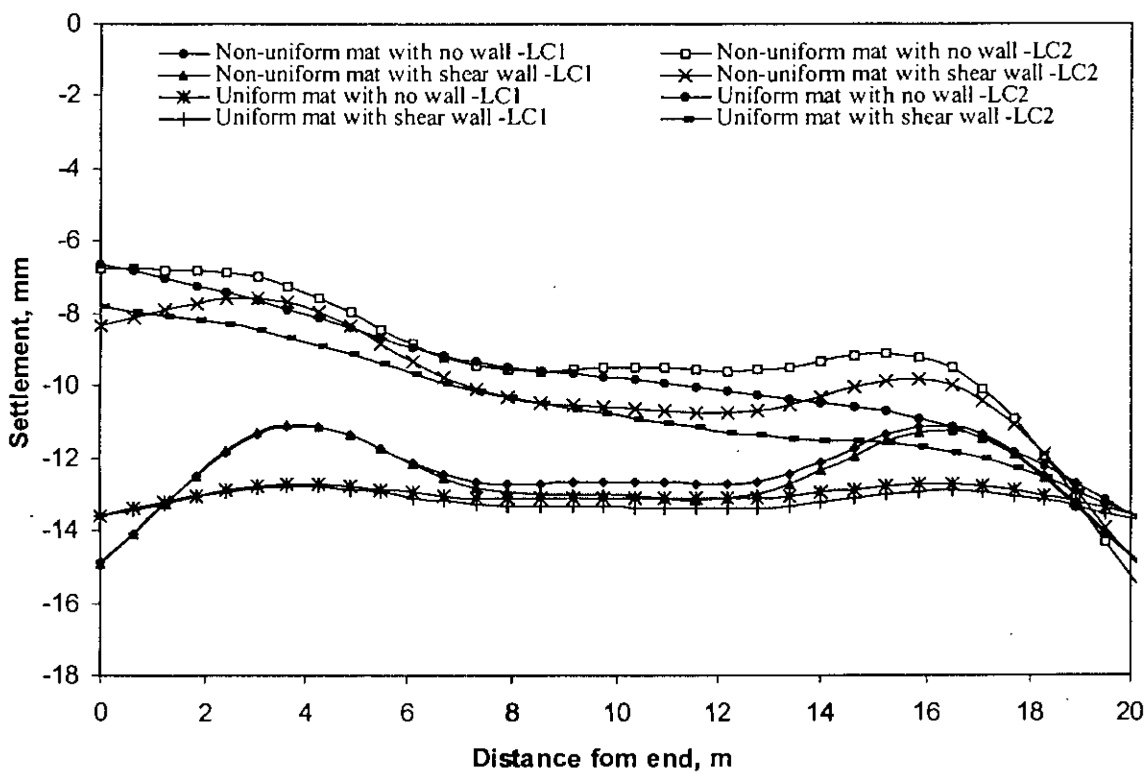

Fig.D-E36 Variation in Settlement along **line 6** for mat of **Model-E.**

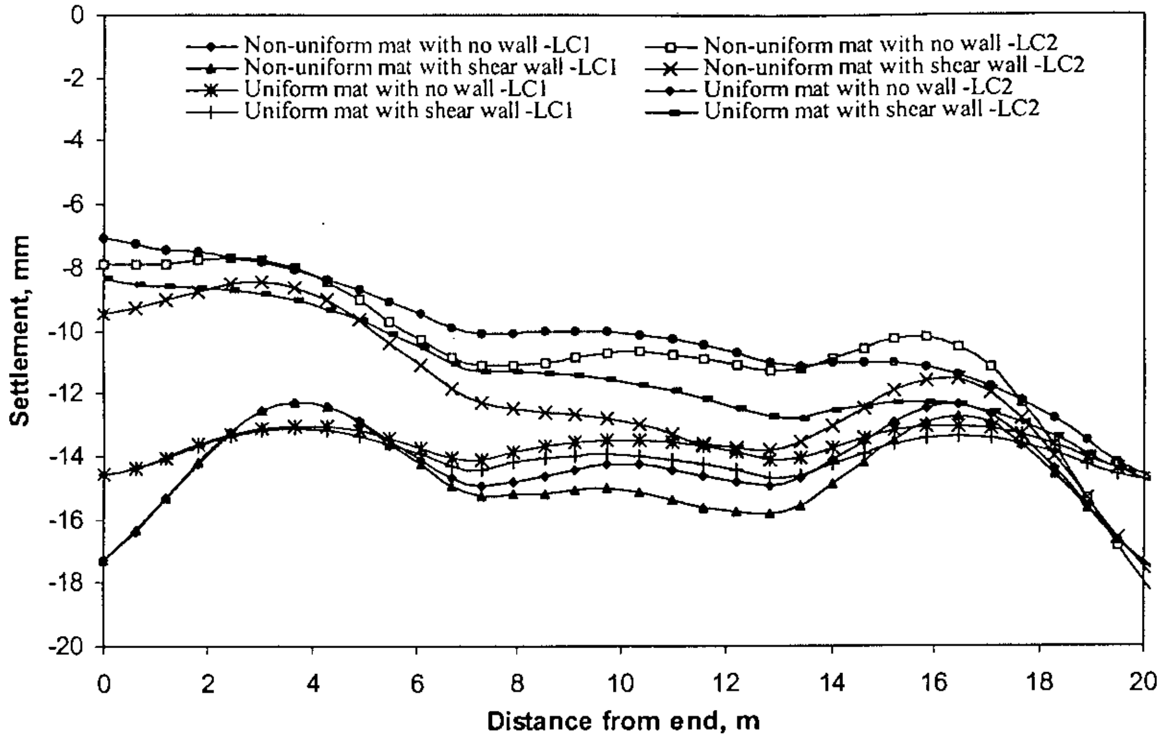

Fig.D-E37 Variation in Settlement along **line 7** for mat of **Model-E.**

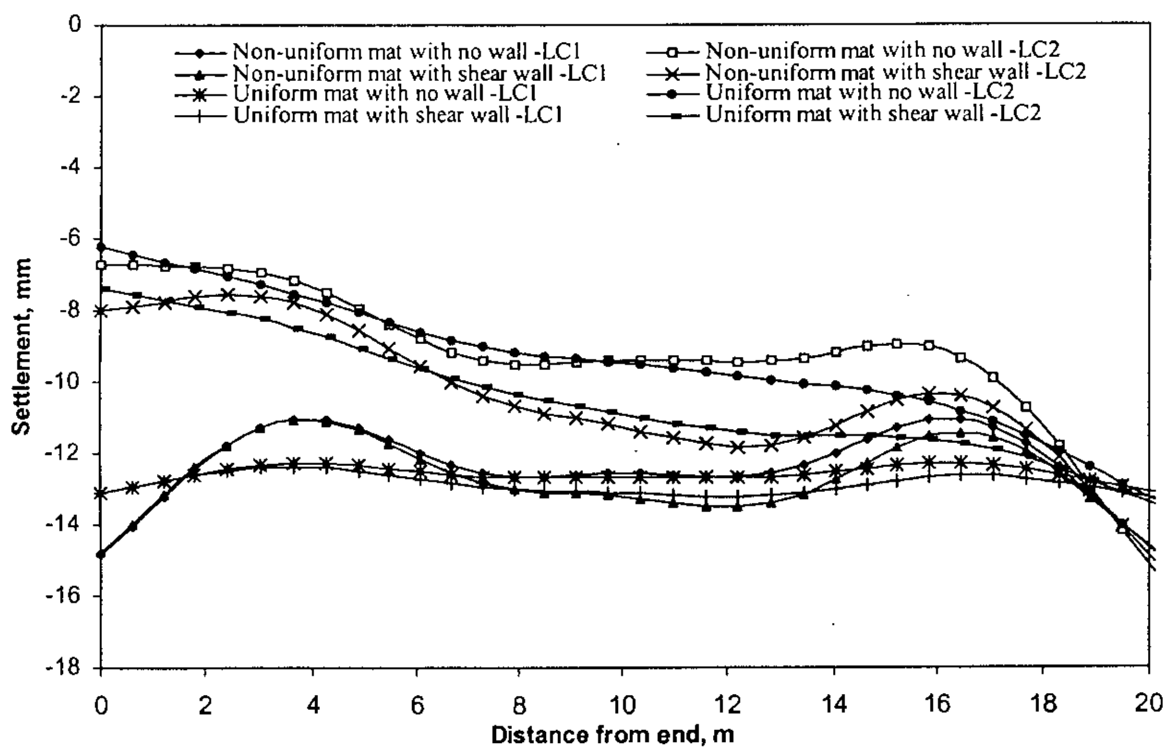

Fig.D-E38 Variation in Settlement **line 8** for mat of **Model-E.**

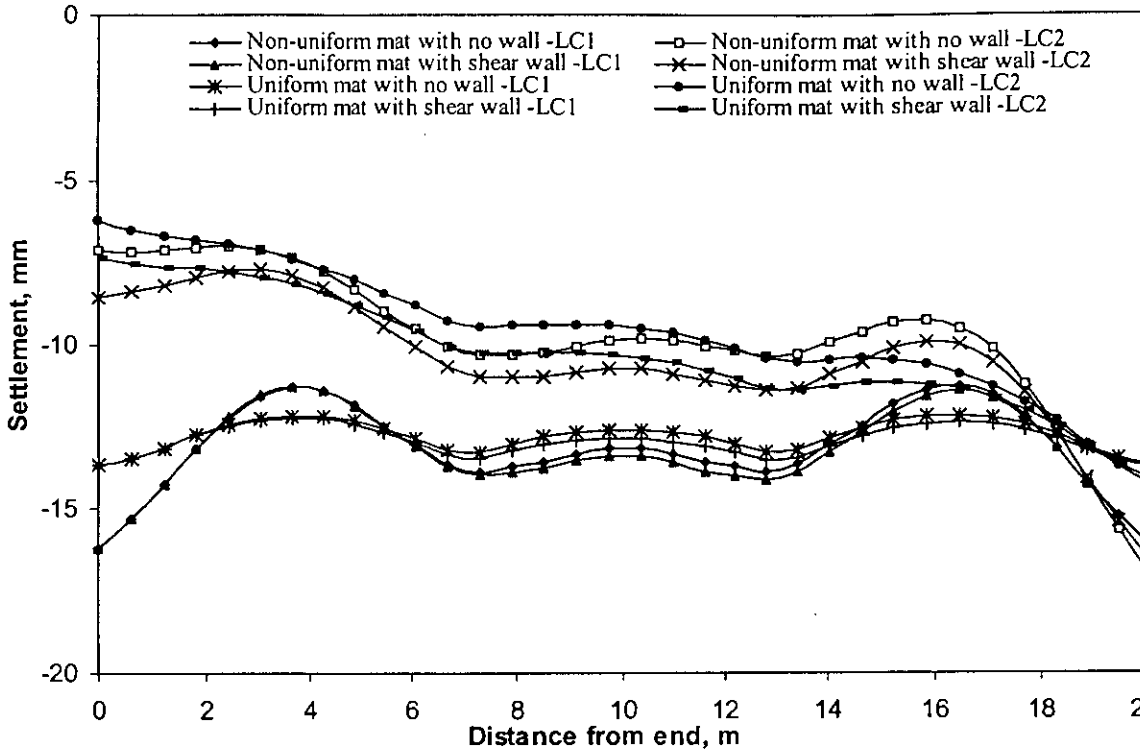

Fig.D-E39 Variation in Settlement along **line 9** for mat of **Model-E.**

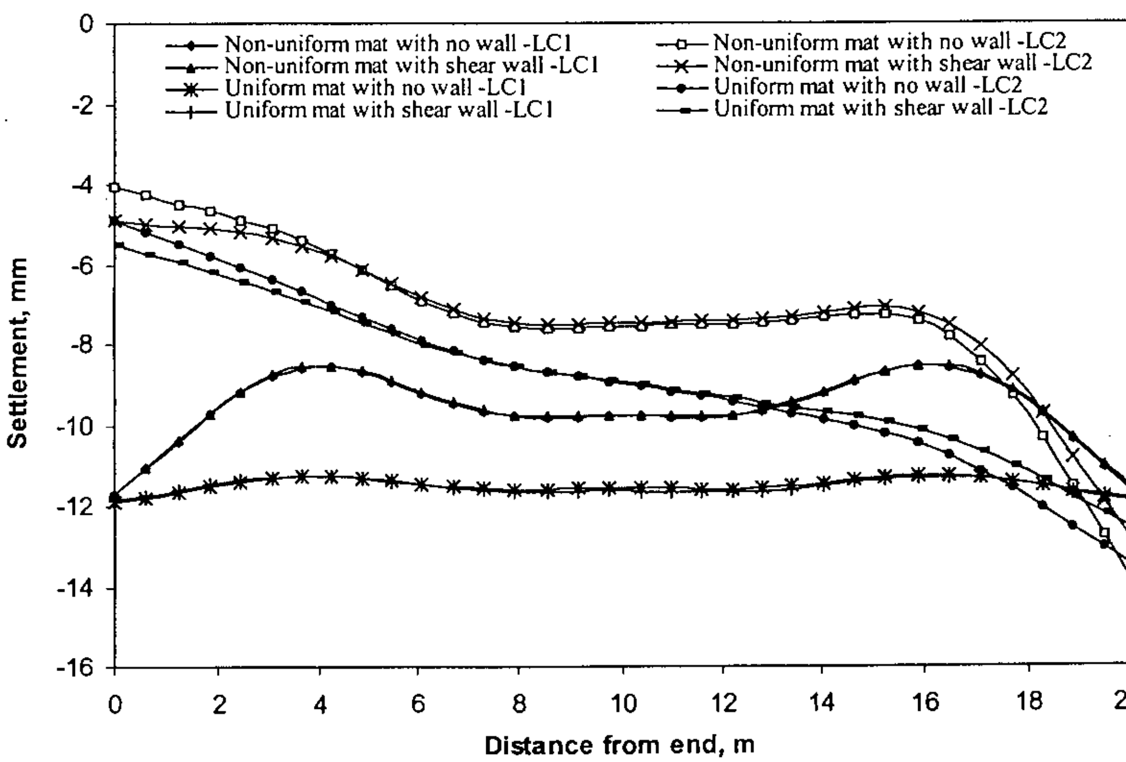

Fig.D-E40 Variation in Settlement along **line 10** for mat of **Model-E.**

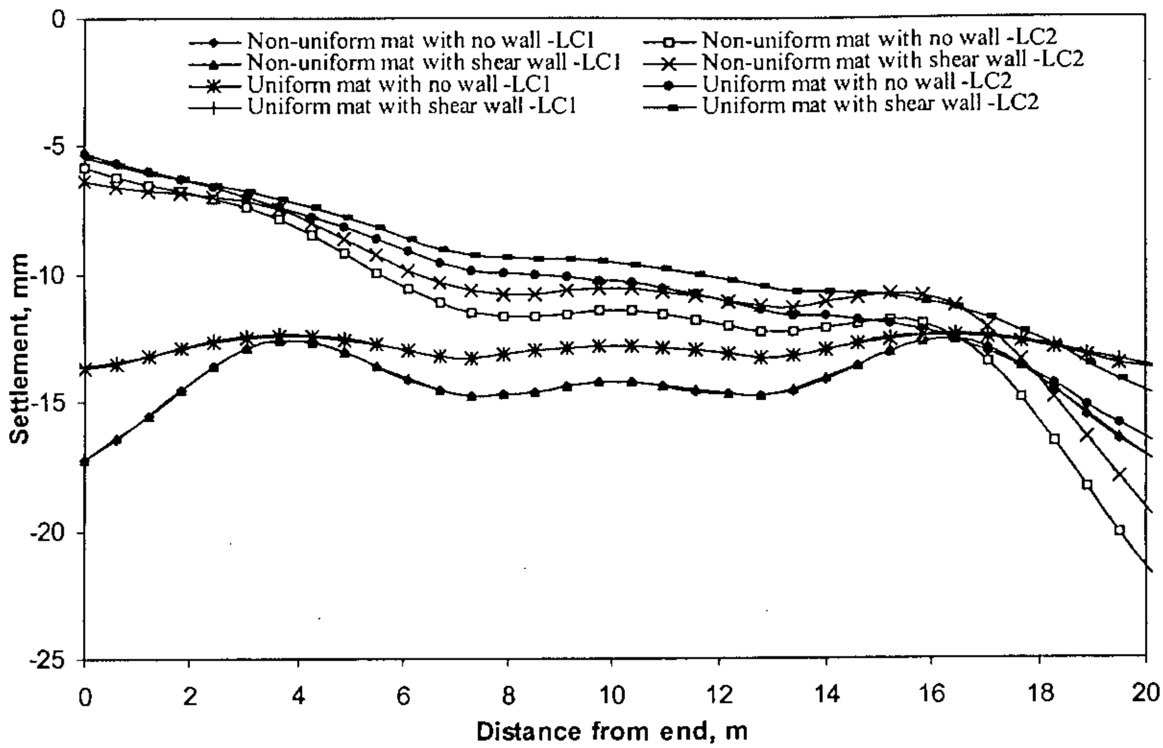

Fig.D-E41 Variation in Settlement along **line 11** for mat of **Model-E.**

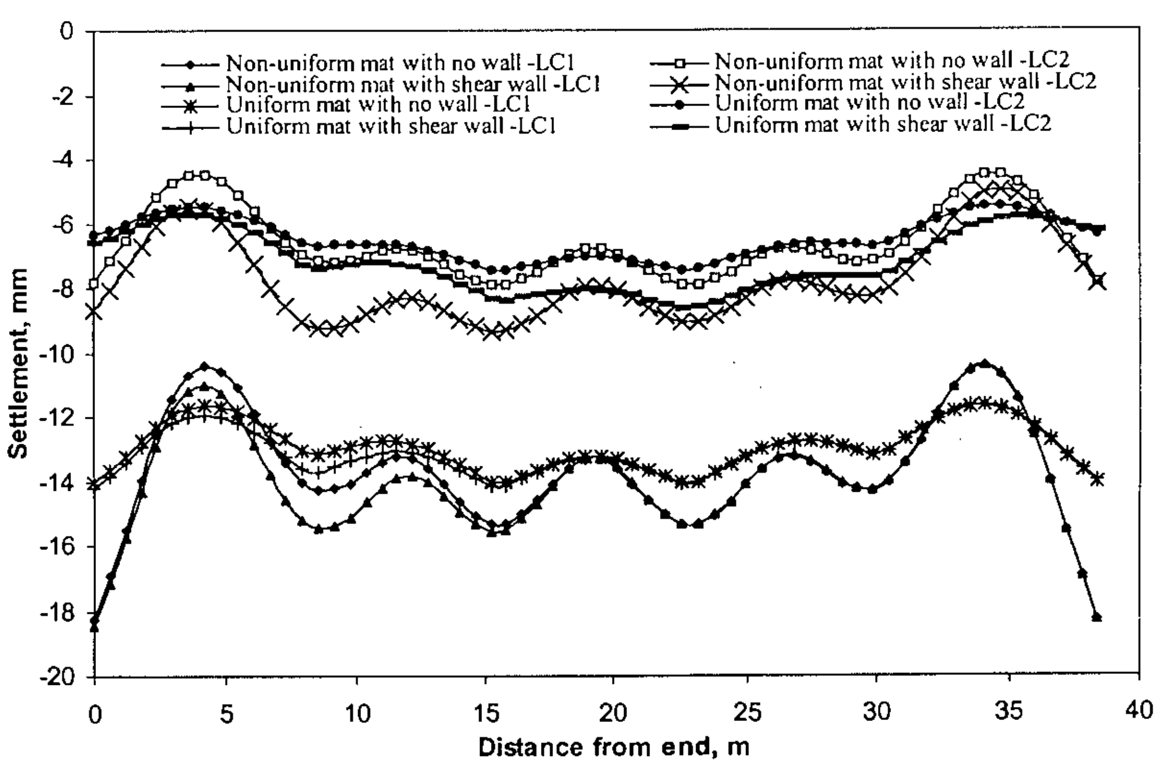

Fig.D-E42 Variation in Settlement along **line 12** for mat of **Model-E.**

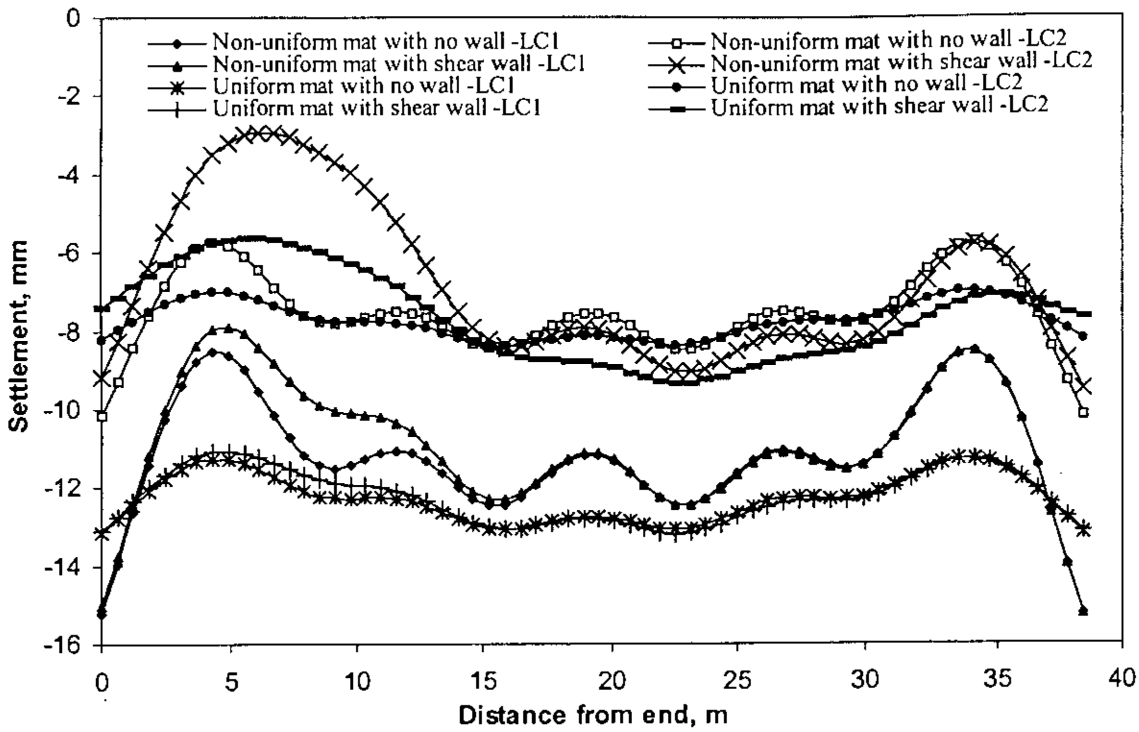

Fig.D-E43 Variation in Settlement along **line 13** for mat of **Model-E.**

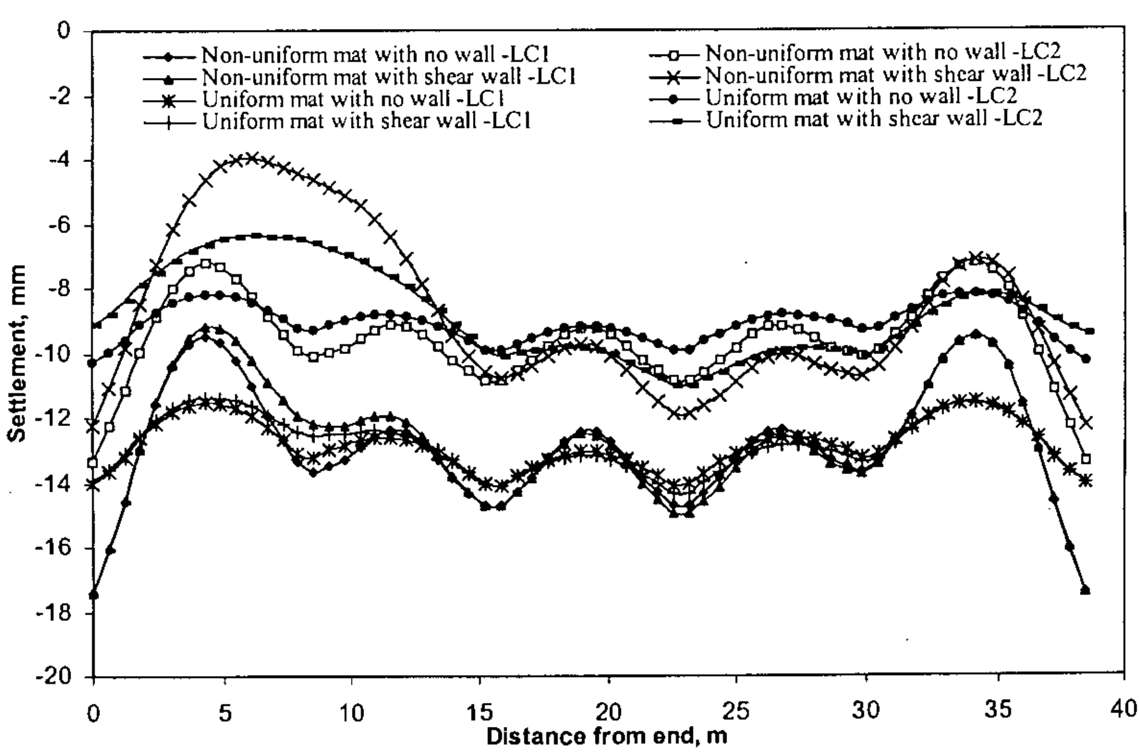

Fig.D-E44 Variation in Settlement along **line 14** for mat of **Model-E.**

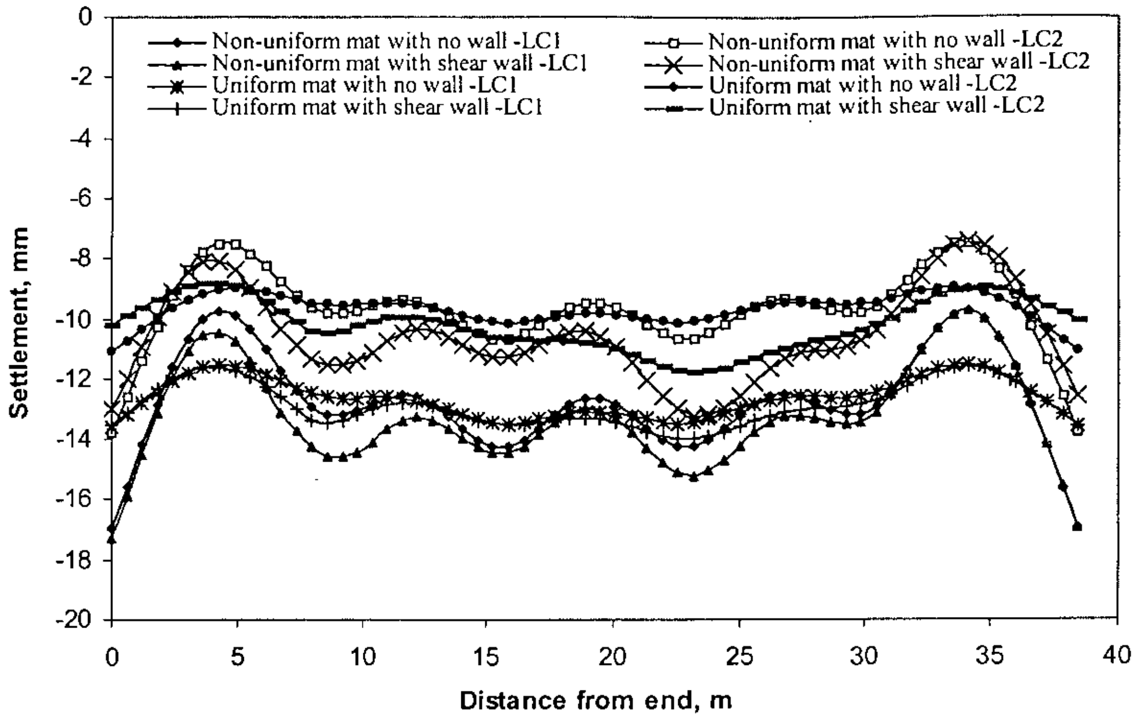

Fig.D-E45 Variation in Settlement along **line 15** for mat of **Model-E.**

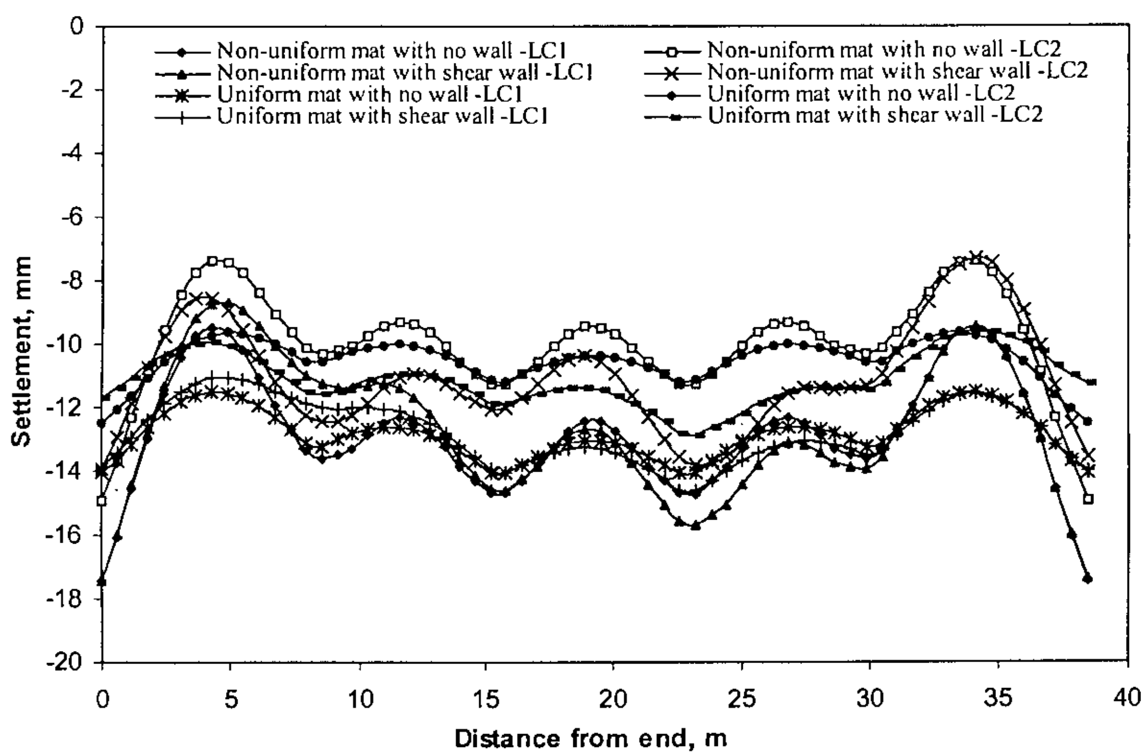

Fig.D-E46 Variation in Settlement along **line 16** for mat of **Model-E.**

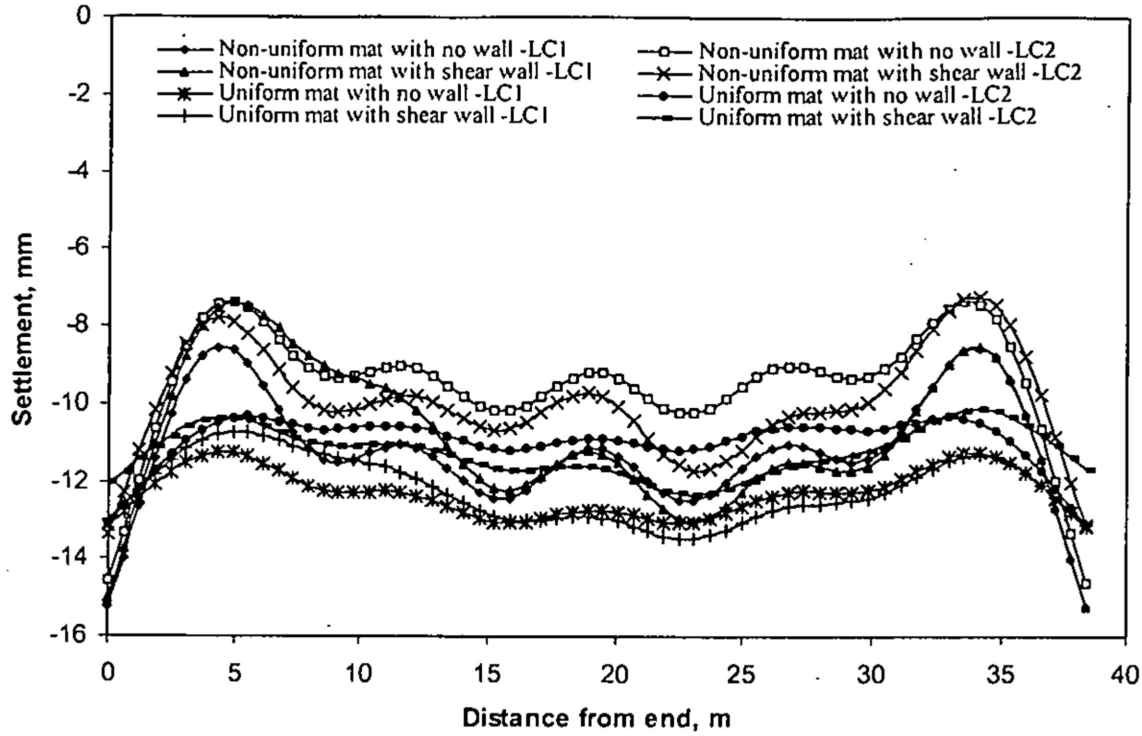

Fig.D-E47 Variation in Settlement along **line 17** for mat of **Model-E.**

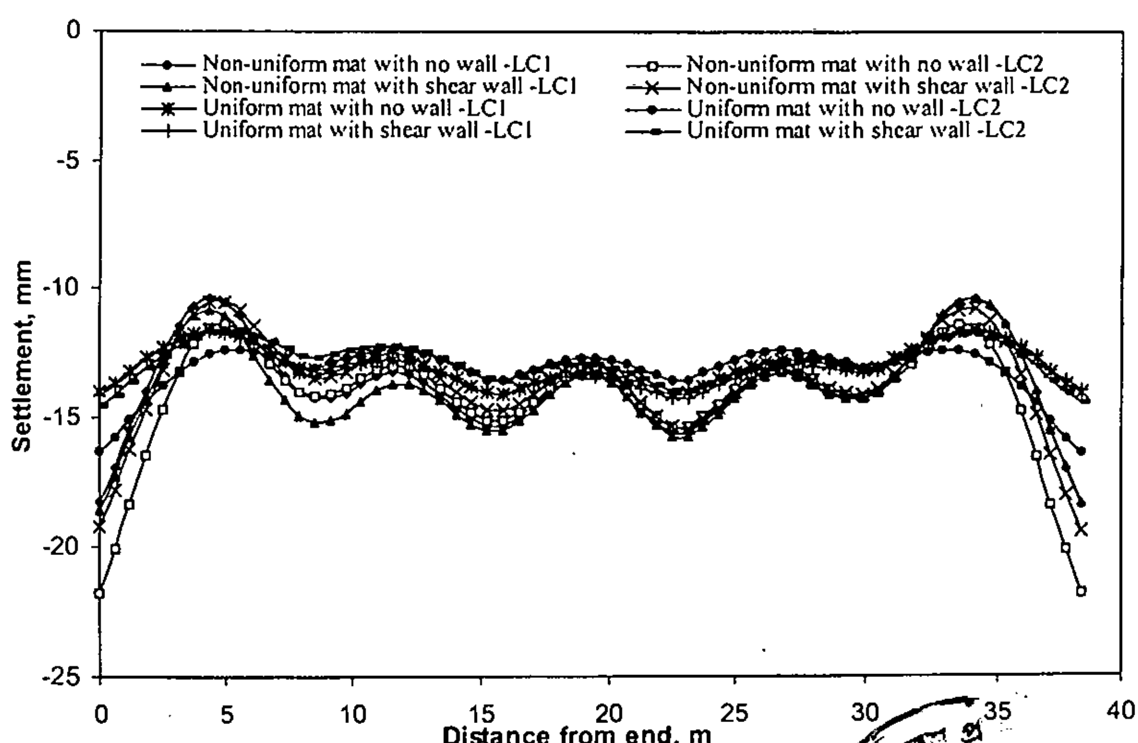

Fig.D-E48 Variation in Settlement along **line 18** for mat of **Model-E.**