SHEAR WALL-FRAME INTERACTION ANALYSIS USING FINITE STRIP AND CONTINUUM METHODS

Thesis submitted in accordance with the requirements of the University of Liverpool for the Degree of Doctor in Philosophy.

by

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April, 1989

ACKNOWLEDGEMENTS

The author is indebted with grateful acknowledgement and sincere appreciation to Mr C. Thomas M.Sc. for his invaluable assistance, guidance and encouragement throughout the whole course of this study.

The author also wishes to express his special appreciation to his wife for her patience and encouragement.

Sincere thanks are due to the other research students of 7th floor, Civil Engineering Department.

SUMMARY

Tall structures can be analysed using the finite strip method or the continuum method. The theoretical development of both methods is described in detail.

Initially both methods are used to analyse various shear wall structures under different loads. The value of the moments in the connecting beams and strains in the walls are compared with the values from experimental models. These results show the validity of using both methods in the analysis of coupled shear walls, including varying thickness in the walls.

Both methods are then extended to cover shear wall-frame systems. This extension has been carried out in three ways:

a) finite strip representation of both wall and frame.

b) finite strip for wall, plane frame for frame.

c) continuum for wall, plane frame for frame.

Results are again given for all three approaches to a number of examples. Again these values are compared with values obtained from experimental models.

The versatility of the finite strip is shown by its application to dyanmic loading of a shear wall-frame structure. The results obtained are compared with experimental models tested on a shaking table.

Computer programs were developed for all three stages. The results

obtained from these programs were checked against previous results from various references.

Finally conclusions are drawn from the results presented and avenues for future research are suggested.

The methods developed are relatively simple and reliable. The relative low storage demands make the methods suitable for use with most mini-computers.

CONTENTS

NOTATION

A = Cross sectional area

a = Clear span of connecting beam

d = Beam depth

E = Elastic modulus

f = Shear area shape factor

G = Shear modulus

H = Height

I = Moment of inertia

M = Moment

m = mode shape

n = mode shape

P = External applied load

t = Thickness or time

Δt = Time step

U = Strain energy

V = Kinetic energy

U_T = Total potential energy

u = X-direction displacement

v = Y-direction displacement

f(x) = X-direction polynomial function

f(y) = Y-direction mode shape function

$T(x)$ = Axial force in the wall

$[B]$ = Displacement

$[C]$ = Damping matrix

$[D]$ = Material property matrix

$[K]$ = Stiffness matrix

$[f]$ = Flexibility matrix

$[M]$ = Mass matrix

$[T]$ = Transformation matrix

$\{F\}$ = External applied load vector

$\{\delta\}$ = Displacement Vector

$\{\dot{\delta}\}$ = Nodal line velocity vector

$\{\ddot{\delta}\}$ = Nodal line acceleration vector

$\{\phi\}$ = Eigenvector vector

W^2 = Eigenvalue

σ = Stress

ε = Strain

ρ = Mass density

v = Poisson's ratio

θ = Rotation

P = Applied load

ε_L = Strain at left hand wall

ε_R = Strain at right hand wall

CHAPTER ONE

1.1 Introduction

High rise buildings consisting of coupled shear wall and frame combinations are one of the most efficient and economical structural systems for resisting lateral forces due to wind or earthquake. The theoretical analysis of this type of structure could be carried out using the finite element method which is one of the most versatile technique to provide accurate and reliable results. However, the finite element method may also prove to be prohibitively expensive and time-consuming especially when fine meshes of elements are needed to yield accurate result. A number of researchers have tried to produce alternative simplified approaches to deal with this type of complex structure. Unfortunately, most of these approaches are only applicable to certain structural configurations.

One simple and yet reliable method is the continuum method. This method assumes that the discrete set of connecting beams are replaced by an equivalent continuous medium.

The finite strip approach is also ideally suited for the analysis of a coupled shear wall. This method possesses great flexibility so that it can be used to analyse a wide variety of wall configurations. The connecting beams may be treated either as an equivalent medium or spandrel beams. Its computation process is relatively simple and suitable for computers with a limited storage capacity.

In this study, it is proposed to utilise the simplification and reliability of these two systems and combine one of them with a frame structure so that the size of computing storage capacity can be relatively reduced and yet does not cause significant loss of accuracy.

To this end, the proposed scheme should be capable of analysing for both static and dynamic loads so that it can be widely used in practice without undue difficulty and minimising hand calculations and simplifying the input data for computers.

1.2 Objectives and Scope of Works

The aim of this thesis is to produce a new approach to the analysis of the highly redundant shear wall-frame structural system so that it consumes less computer time, requires smaller computer storage capacity and is simple to program and use.

The continuum and finite strip approaches, for coupled shear walls, have been successfully developed for static and dynamic analyses by many researchers. So far, no other system has been developed to allow the efficient use of these two methods combined with a framed structure.

In Chapter Two, the general theory of the continuum method is outlined and an equivalent analogous approach is suggested for a coupled shear wall with variable thickness. In the classical approach, it is necessary to redetermine the particular solution and arbitrary constants for each change of lateral loading, boundary conditions and shear wall configuration to solve the differential equations. This can become very cumbersome. The advantage of this proposed method is that it is relatively simple to apply and possesses great flexibility for variable wall thickness.

In Chapter Three, the finite strip method is briefly described. Adjustments and modifications to the previous theory are presented. Owing to the similarity between the finite strip and the finite element methods, an analogy of both is drawn in section 3.2 for reference. For ease of computation, an equivalent approximate method is proposed to convert the connecting beams to a continuous substitute medium.

To support the validity of the continuum and finite strip methods, experimental tests on small scale models were carried out and examples previously investigated by Coull, Puri and Tottenham[19] [20] [21] and Antony and Ganesan[1] were re-analysed and compared. The results of the analyses are shown in a comparative way in Chapter Four.

The main topic of this research is presented in Chapter Five where the theory of wall-frame structure interaction is described in some detail. This Chapter is subdivided into five sections namely introduction, basic concept, theory, evaluation of interaction forces and remarks. This new approach is in principle adopted from a substructure concept with the application of Maxwell's Reciprocal Theorem, stiffness and flexibility methods. The coupled shear wall is idealised as an isolated vertical cantilever wall and modelled by either continuum or finite strip method.

The frame portion is analysed by standard plane frame method. The interaction forces between these two combined substructures are treated as unknown redundants. These interaction forces determine the proportions of forces carried by the coupled shear wall and the magnitudes of action induced in the frame.

In Chapter Six, the reliability and accuracy of the proposed scheme is compared with static, experimental small scale models and other existing methods. For the experiments, perspex was chosen for the models of the coupled shear walls and aluminum for the framed structure.

To check its versatility and efficiency, the scheme is further extended to analyse the structure under dynamic conditions. the results are verified by small scale model tests on a shaking table. The test results and comparison are shown on Chapter Seven.

Computer programming details, conclusions and recommendations are finally given in Chapters Eight and Nine.

References and computer programs are listed at the end of the thesis. ✓

1.3 Review

Most of the previous studies on wall[3] [18] [26] [39] [69] and wall-frame structures have been carried out using either the finite element method or approximate methods[4] [6] [8]. So far, very few researchers have considered a system that allows the efficient utilisation of the continuum and finite strip methods in combination with other structural systems. To understand the behaviour of wall-frame structure, a brief review of each system is given below.

1.3.1 Continuum Method

A coupled shear wall is normally employed as one of the most efficient means of providing rigidity to resist lateral loadings. Many researchers have tried to develop a simplified analysis for this type of structure as it is highly redundant. One of the simplest methods which has been used in the past few years is the continuum method. This method was first used by Chitty[10] [11]. She proposed that the cross bars connecting parallel cantilevers be replaced by an equivalent continuous elastic medium. This reduced the statically indeterminate structure to a relatively simple one. In the paper, the effect of shear deformation has been neglected. Beck[5] further developed the method, applied it to coupled shear walls, taking into account the shear wall deformations due to normal forces. He proposed that all the redundant values be combined into a single unknown function. In this case, only one second order differential equation was required to determine the unknown shear forces, of the medium, for coupled shear walls. Rosman[60] [61] proposed the solution of a second order differential equation in terms of the axial force in the wall. This approach required the least calculations and can be performed easily in a design office. Tso and Biswas[64] have also used the method for approximate seismic load analysis. Coull and Puri[19] have extended the method further to the analysis of coupled shear wall with stepped sectional properties. The discontinuities which occur in the second higher derivatives of the deflection functions were overcome by the introduction of a corrective series. Coull and Puri[21] then considered a coupled shear wall of variable cross sections with different geometric configuration. This method has been further extended to include the effects of shearing deformations in the walls.

Tso and Chan[66], Coull[22] and Danay et al[37] have applied the method to dynamic problems for estimating the free vibration of coupled shear walls.

1.3.2 Frame Analogies

Several papers[57] [59] have been published, in which a coupled shear wall with row openings, has been idealised as an interconnection of walls and beams directly.

Macleod[46] [47] treated the wall sections as line elements with rigid ends and solved by plane frame method. Smith and Girgis[53] [54] [55] [56] have developed two types of analogous frames for analysis of coupled shear walls. They use diagonal bracing members to prevent the interference of the bending and shear stiffness in the walls.

1.3.3 Finite Strip Method

This method idealises the structure as a number of strips in the longitudinal direction. The strips are connected to each other at a joining line along their edges. At the joint formed by two adjacent strips, there exists a relationship between joint forces and displacements.

The method was first introduced by Cheung[32] [33] [34] [35]. It was used initially to model orthotropic plates with certain boundary conditions, then further extended to analyse folded plate structures. Its basic concept is very similar to the finite element method. The main variation for this method is that one of the displacement functions is preset. For dynamic problems, Cheung, Hutton and Kasemset[27] have applied the method to predict the free vibration response of continuous slabs and flat wall structures. In 1978, Cheung and Kasemset[30] used the method to determine the natural frequencies of coupled shear walls with variable thickness.

1.3.4 Wall - Frame Structure

For a wall-frame structure, the method that is most commonly used is to treat the shear wall as an equivalent frame and analyse it by a standard plane frame method. In 1976, Smith and Khan[58] simplified the wall-frame as an analogous plate module and produced charts for determining the equivalent shear and elastic modulus rigidity. This method was only suitable for regular wall-frame structures where the change of member sizes is small.

In 1978, Cheung and Swaddiwudhipong[28] [29] applied the finite strip method to wall-frame structures. The beam eigenfunction was used to model the displacement shape function for tall buildings. This assumption was revised by Worsak, Lee and Karasudhi[72]. They suggested a polynominal shape function to replace the beam eigenfunction because in tall buildings, shear distortion is significant. Both methods only provided approximate results and are only suitable for simple and regular configurations of structures.

CHAPTER TWO

THE CONTINUUM METHOD

2.1 Introduction

For a coupled shear wall with a band of openings as shown in fig (2.1) with constant properties along its height, the band of openings can be effectively treated as a continuous medium. By assuming that points of contraflexure occur at the centre of the connecting medium, a second order differential equation in terms of the wall axial force is formed and solved to derive deflections, moments and shears at required positions.

The accuracy of the solution increases with increasing number of storeys and simple design curves could be used for the analysis. The method is less versatile in dealing with any variation in the wall configuration as for each change of loading system and wall geometry, it is necessary to redetermine the particular solution and arbitrary constants in the differential equations. Suggestion is made for overcoming this limitation.

The continuum method has been extensively explained in many publications (19) (20) (21) (22). Therefore, only the essential parts are presented wherever necessary.

2.2 Theoretical Concept

2.2.1 Basic Assumptions

Assumptions made are :

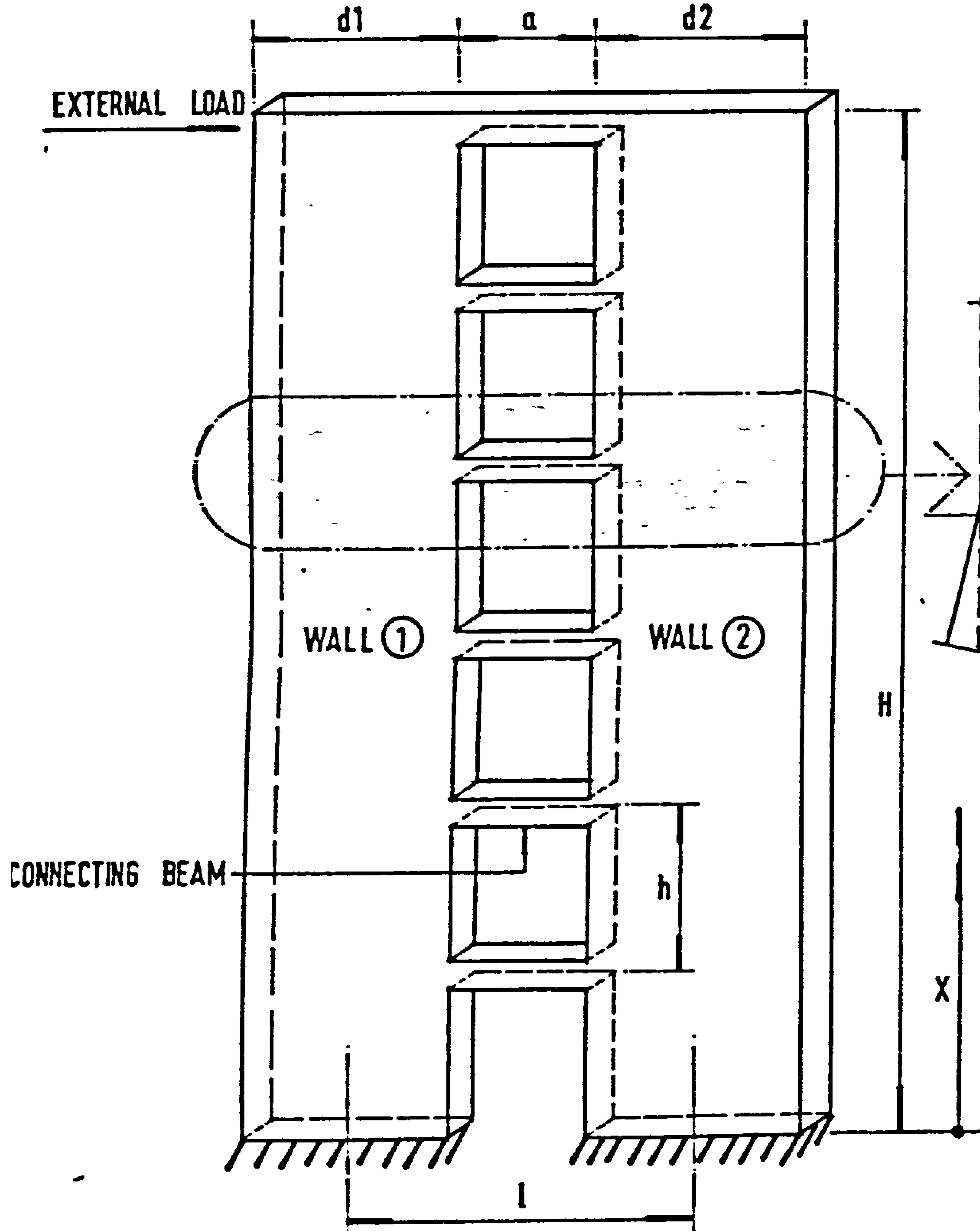
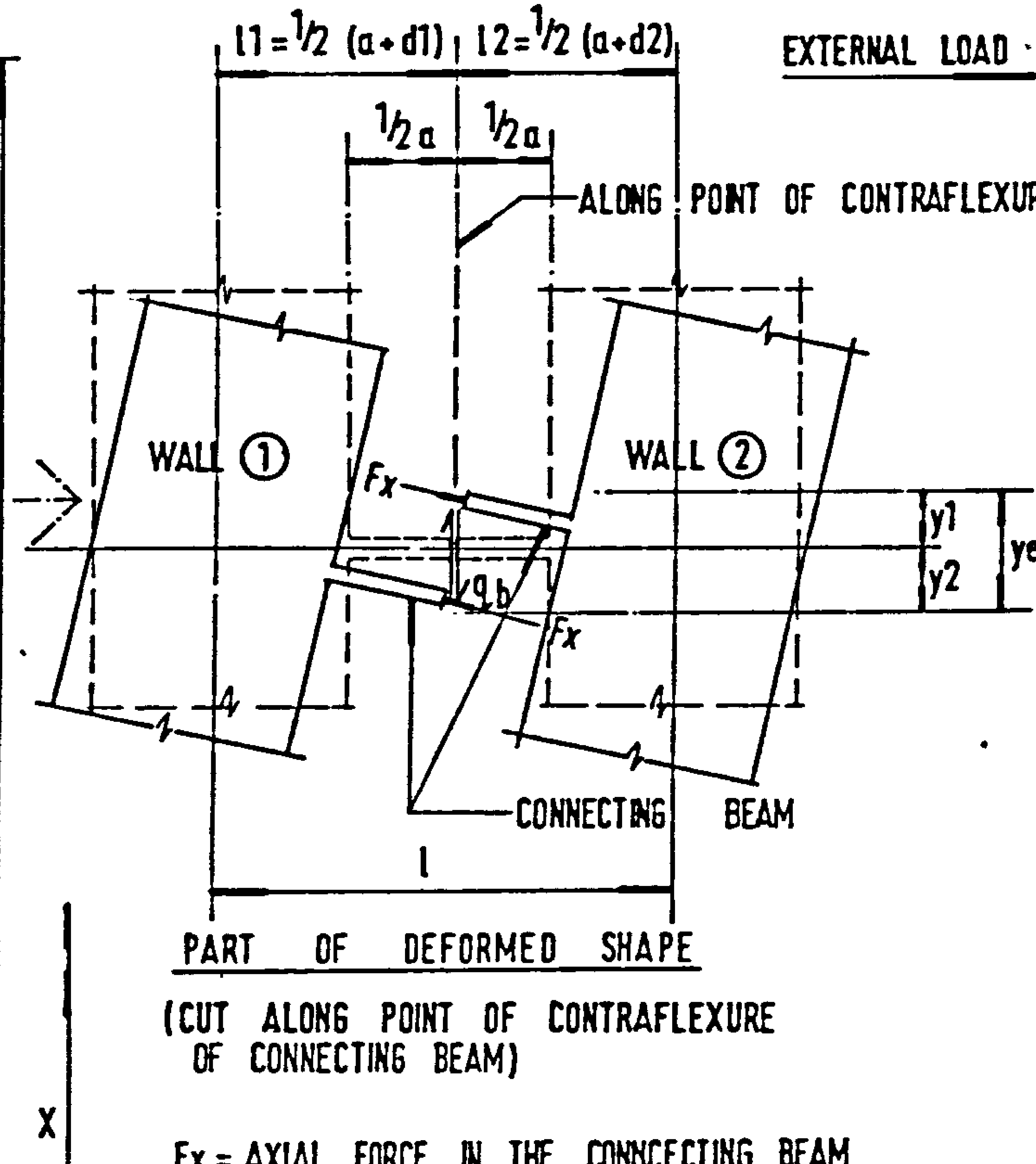


FIG 2·1 (a) ORIGINAL MODEL



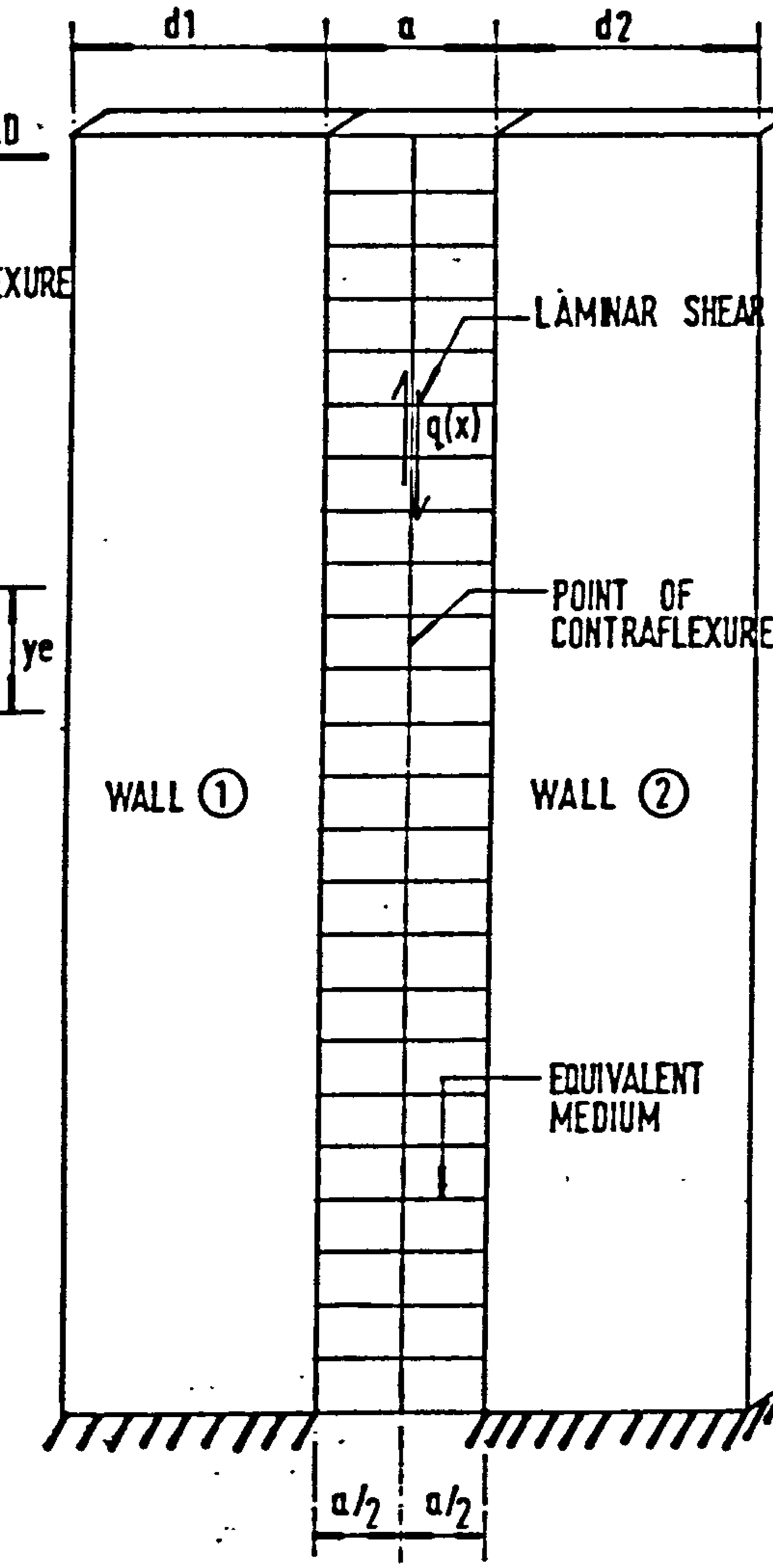


FIG 2·1 (b) EQUIVALENT MODEL

COUPLED SHEAR WALL MODULE

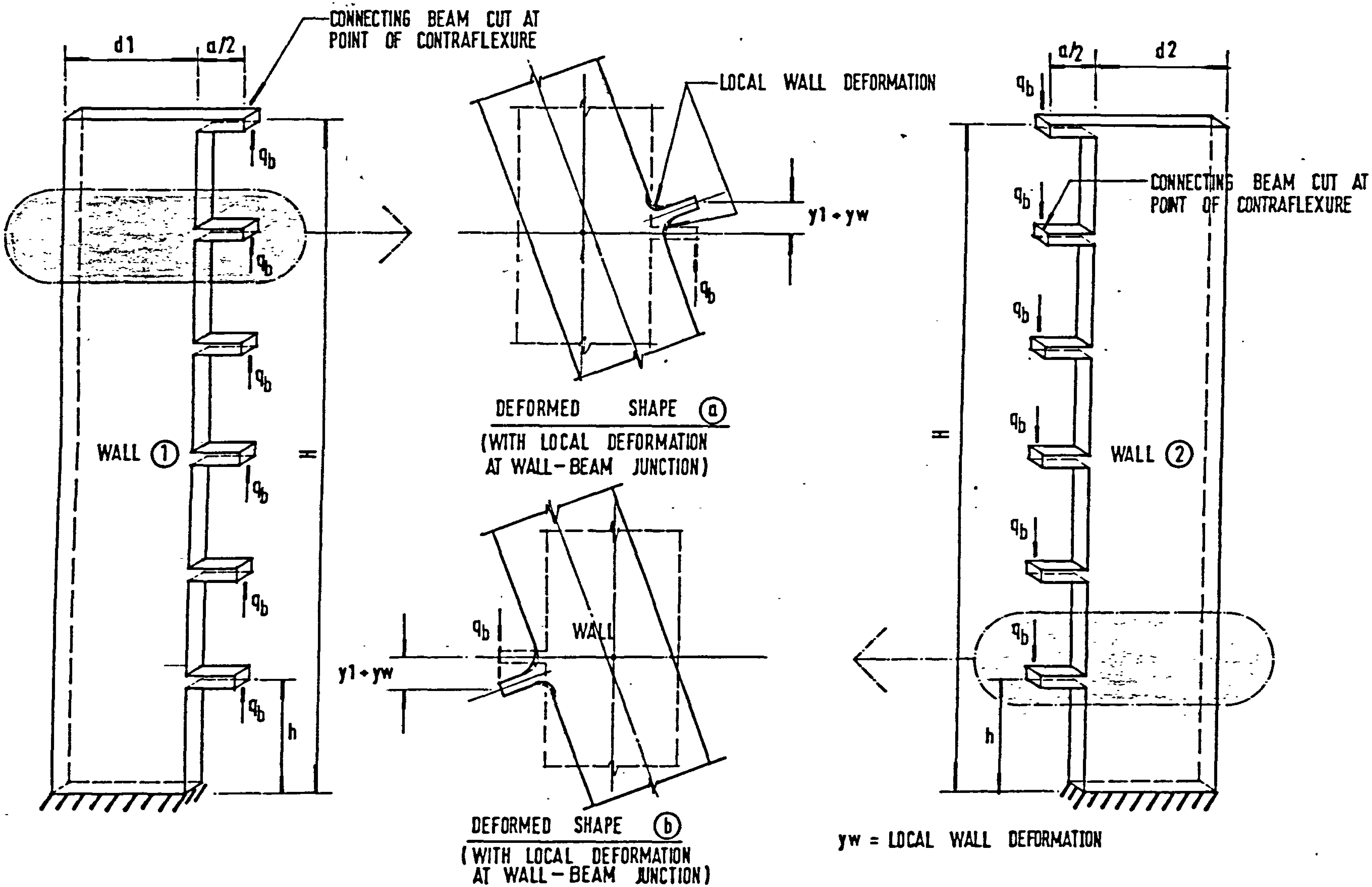


FIG 2.1(c) PORTION OF WALL SUBJECT TO SHEAR FORCE (q_b)

a) Each element of the structure is perfectly elastic.

b) Both walls deflect laterally with a point of contraflexure at mid-span of the connecting beams.

c) The Bernoulli-Navier hypothesis holds for strain distribution.

d) The axial deformation of the connecting beams may be neglected.

2.2.2 Boundary Conditions

When the coupled shear walls are fully restrained at their base and free at the top, two sets of boundary conditions may be used

a) At the top of the cantilever walls, the axial force T(x) is zero.

Hence,

when $x = H$ $T(x) = 0$

b) At the base, no rotation occurs

Hence,

when $x = 0$ $dT(x)/dx = 0$ (this is obtained from compatibility at the base)

where T(x) = axial force in the walls

H = Height of the wall

x = distance of wall measured from the base

2.2.3. Structural Approach

The coupled shear wall is cut through the point of contraflexure of each connecting beams as shown in figs (2.1(a)), (2.1(b)) & (2.2(c)). Once these points are determined, only two systems of forces namely applied load and shear force, will act on the isolated statically determinate cantilever walls. They will be detailed separately.

For compatibility, the total relative displacement under these forces must be equal to zero. Based on this condition and satisfying the compatibility condition of deformation along the cut, the fundamental differential equation in term of axial force in the wall may be established. The method of deriving this unknown axial force T(x) is described below.

a) Applied Load

As the lateral deflections of the cantilever walls are assumed to be the same, the moment due to the external load can be distributed in proportion to their flexural rigidity.

Thus,

$$M_1 = \frac{I_1}{I} M \qquad (1)$$

$$M_2 = \frac{I_2}{I} M \qquad (2)$$

where M = moment due to external load

I_1 = moment of inertia of wall 1

I_2 = moment of inertia of wall 2

$I = I_1 + I_2$

The basic moment - curvature relationship

$$M = EI \frac{d^2y}{dx^2} \quad (3)$$

may be applied to each wall.

Therefore for wall 1, it becomes

$$EI_1 \frac{d^2y}{dx^2} = \frac{I_1}{I} M \quad (4)$$

Similarly for wall 2, it is given by

$$EI_2 \frac{d^2y}{dx^2} = \frac{I_2}{I} M \quad (5)$$

Integrating equations (4) & (5) with respect to the x-axis and applying the boundary conditions to determine their integration constants, the total relative displacement of the walls at the point of contraflexure due to external load (fig(2.1(a)) becomes

$$Y_e = l_1 \frac{dy}{dx} + l_2 \frac{dy}{dx}$$

$$= l \frac{dy}{dx} \quad (6)$$

b) Shear Force

Because of the assumption made in item (b), no moments are present along the cut, but the internal laminar shear q(x) will produce axial force T(x) and bending moment in the walls. The effects of these actions will contribute to the internal deformation in the walls. Details are described below:

i) Flexural Deformation

As the rigidity of connecting beams is much less than the walls, the tip deflection of the connecting beams due to shearing force q(x) acting at mid-span (figs (2.1(a)), (2.1(b)) & (2.1(c)) is

$$\frac{1}{2} Y_f = \int_0^{a/2} \frac{q(x)hx^2}{EI_b} dx + \int_0^{a/2} \frac{q(x)\ fh}{GA} dx \tag{7}$$

Integrating equation (7), it becomes

$$Y_f = \frac{q(x)ha^3}{12EI_b} \left(1 + \frac{12EfI_b}{GAa^2} \right) \tag{8}$$

where q(x) = laminar shearing force at distance x

f = shear area factor of connecting beams

h = floor height

I_b = moment of inertia of connecting beams

ii) Axial Deformation of Walls

As a consequence of axial load, the differential displacement between two walls is

$$Y_a = \int_0^x \frac{T(x)}{A_1E} dx + \int_0^x \frac{T(x)}{A_2E} dx \tag{9}$$

where T(x) = axial force in the walls

A_1 = cross sectional area of Wall 1

A_2 = cross sectional area of wall 2

iii) Displacement Due To Bending

Owing to the moment induced by laminar shear, the flexural deformation of the wall is

$$Y_w = \frac{l^2}{EI}\int_o^x T(x)\,dx \qquad (10)$$

where = distance between centreline of walls 1 & 2

As mentioned before, to maintain the equilibrium of the forces between internal and external actions, compatibility requirements must be introduced. From the diagrams shown in figs (2.1(a)), (2.1(b)) & (2.1(c)), it is clear that laminar compatibility will be satisfied when their total relative displacement is zero. That is,

$$Y_f + Y_a + Y_w - Y_e = 0 \qquad (11)$$

Hence, substituting individual displacement term into equation (11), it becomes

$$l\frac{dy}{dx} = \frac{q(x)ha^3}{12EI_b} + \frac{q(x)fha}{GA} + \left(\frac{l^2}{I} + \frac{1}{A_1} + \frac{1}{A_2}\right)\int_o^x \frac{T(x)}{E}dx \qquad (12)$$

For vertical equilibrium of the element in fig (2.2)

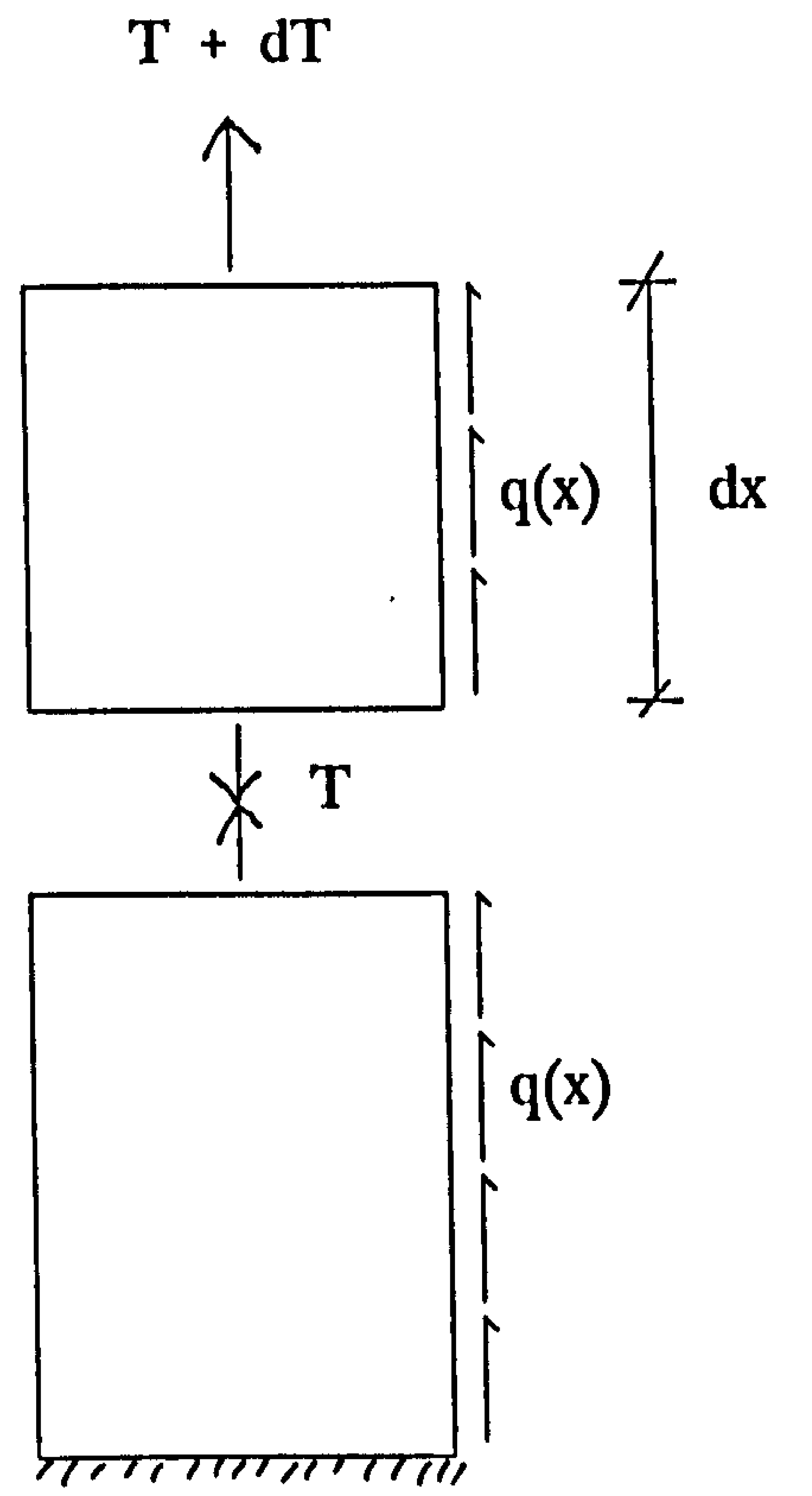


Fig (2.2) - Vertical Equilibrium

$$(T + dT) - T + q(x)\,dx = 0$$

$$q(x) = -\frac{dT}{dx} \tag{13}$$

substituing equation (13) into equation (12), it becomes

$$l\frac{dy}{dx} = \frac{-ha^3}{12EI_b}\frac{dT(x)}{dx} + \frac{fha}{GA}\frac{dT(x)}{dx} + \left(\frac{l^2}{I} + \frac{1}{A_1} + \frac{1}{A_2}\right)\int_0^x \frac{T(x)}{E}dx \tag{14}$$

Differentiating equation (14) with respect to x, the following expression is obtained

$$l\frac{d^2y}{dx^2} = \left(\frac{-d^2T(x)}{dx^2}\right)\left(\frac{ha^3}{12E_b} + \frac{fha}{GA}\right) + \frac{T(x)}{E}\left(\frac{l^2}{I} + \frac{1}{A_1} + \frac{1}{A_2}\right) \tag{15}$$

The effect of the shear deformation term may be replaced by introducing a reduced moment of inertia

$$I_c = \frac{I_b}{1+2.4(\frac{d}{a})^2} \qquad (16)$$

where d = depth of connecting beam

a = clear span of connecting beam

Hence, rearranging equation (15), the differential equation of laminar action is finally formed as

$$\frac{d^2T(x)}{dx^2} - \alpha^2 T(x) = -\beta M \qquad (17)$$

$$\text{where } \alpha^2 = \frac{12I_c}{ha^3}\left(\frac{l^2}{I} + \frac{1}{A_1} + \frac{1}{A_2}\right)$$

$$\beta = \frac{12I_c l}{ha^3 I}$$

M = moment due to external applied load

The solution of equation (17) yields the axial force T(x) induced in the walls.

2.3 Solution

Equation (17) is in the form of a second order differential equation and the general solution is

$$T(x) = A \sinh\kappa x + B \cosh\kappa x + C(x) \tag{18}$$

where $C(x) = \frac{\gamma}{\kappa^2}\left(M + \frac{1}{\kappa^2}\frac{d^2M}{dx^2}\right)$

To complete the solution, the integration constants need to be obtained from the boundary conditions and C(x) is determined from the type and magnitude of external load.

2.3.1 Displacement

Equations for the displacements of a coupled shear wall are derived using moment-curvature and stress-strain relationships.

a) Lateral Displacement and Slope

At any section a moment will be produced by both the applied loading and the axial force T(x). The moment M_x is given by

$$M_x = M - T(x)l \tag{19}$$

Substituting into the basic moment-curvature relationship produces

$$EI\frac{d^2y}{dx^2} = M - T(x)l \tag{19a}$$

Integrating equation (19a) twice and applying the boundary requirements to evaluate the constants of integration produces equations for the lateral displacement and the slope.

b) Axial Deformation

The vertical stresses in the walls, for a laterally applied load, are

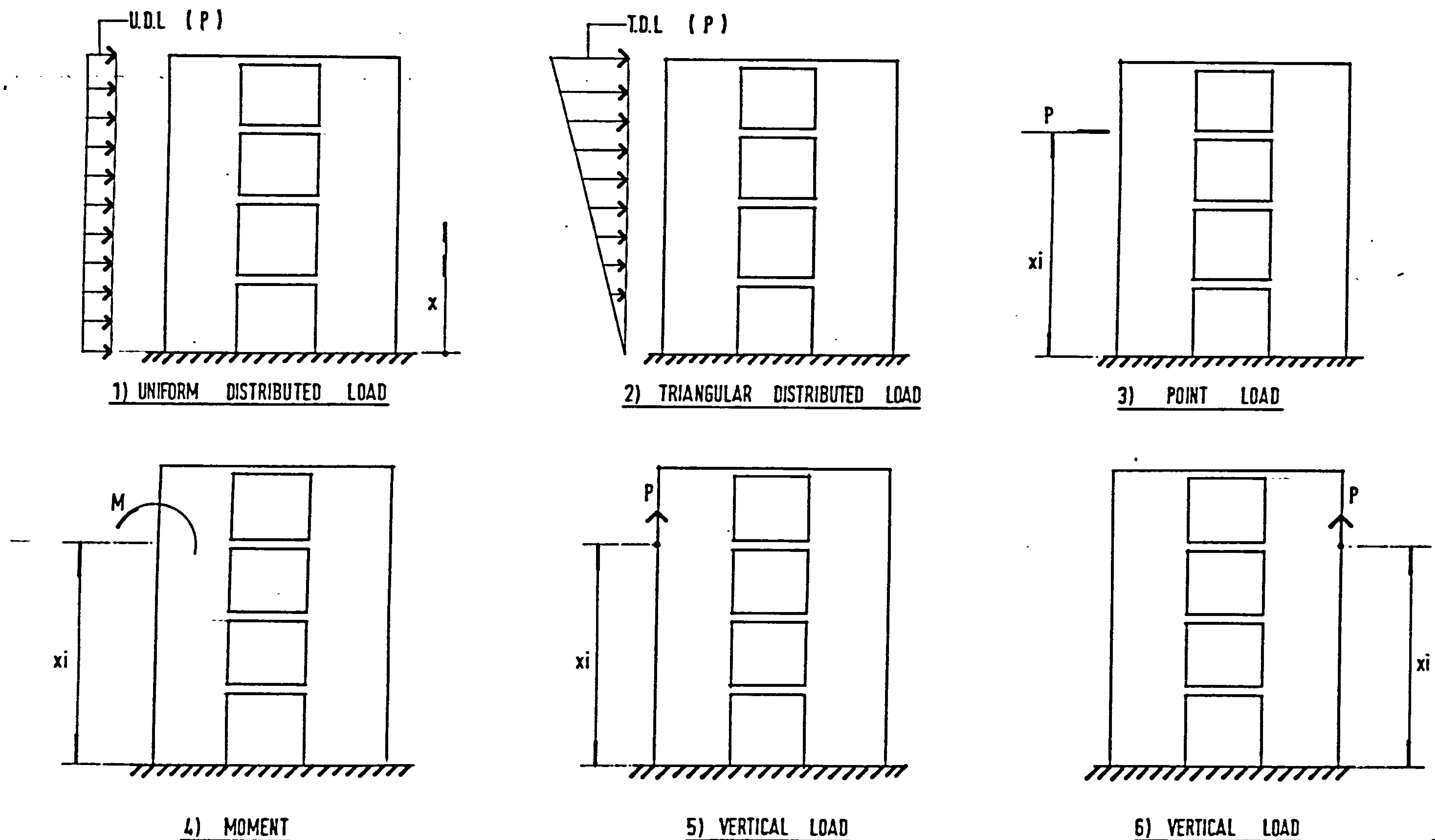


FIG (2.3) DIFFERENT LOAD CASES AT COUPLED SHEAR WALL produced by the axial force T(x) and the moment (M - T(x)l). The strains in the individual walls are given by the following equations

$$\varepsilon_L = \frac{T(x)}{A_1E} \pm (M - T(x)l)\frac{c}{IE} \tag{20a}$$

$$\varepsilon_R = \frac{-T(x)}{A_2E} \pm (M - T(x)l)\frac{c}{IE} \tag{20b}$$

Where

c = distance from the neutral axis of the wall

Integrating the equations (20a) & (20b) once and applying the boundary requirements to evaluate the constants of integration then, equations are obtained for the axial deformation of both walls.

Load cases that are usually encountered in practice and used in this study are shown in fig 2.3.

1) Uniformly Distributed Load

Equations (19a) & (20) are integrated as described above and the following equations obtained

$$EIy = \frac{P}{2}\left(1 - \frac{\beta l}{\kappa^2}\right)\left(Hx^2 - \frac{x^3}{3} + \frac{x^4}{4H}\right) + \frac{\beta Pl}{H\kappa^4}\left(Hx - \frac{x^2}{2}\right)$$

$$+ \frac{\beta Pl}{\kappa^5 \cosh \kappa H}\left(\sinh\kappa(H-x) - \sinh\kappa H - \frac{1}{\kappa H}(1 - \cosh\kappa x)\right) \tag{21a}$$

$$EI\frac{dy}{dx} = \frac{P}{2}\left(1 - \frac{\beta l}{\kappa^2}\right)\left(Hx - x^2 + \frac{x^3}{H}\right) + \frac{\beta Pl}{H\kappa^4}(H - x)$$

$$- \frac{\beta Pl \cosh\kappa(H - x)}{\kappa^4 \cosh\kappa H} + \frac{\beta Pl \sinh\kappa x}{H\kappa^5 \cosh\kappa H} \tag{21b}$$

$$\delta v = \left(\frac{1}{AE} \pm \frac{lc}{IE}\right)\left[\frac{\beta P}{2\alpha^2}\left(Hx - x^2 + \frac{x^3}{3H}\right) - \frac{\beta P}{H\alpha^4}(H - x)\right.$$

$$\left. + \frac{\beta P \sinh\alpha x}{H\alpha^5 \cosh\alpha H} + \frac{\beta P \cosh\alpha(H - x)}{\alpha^4 \cosh\alpha H}\right] \pm \frac{Pc}{2IE}\left(Hx - x^2\right.$$

$$\left. + \frac{x^3}{3H}\right) \qquad (21c)$$

where $A = A_1$ for left hand wall

$A = -A_2$ for right hand wall

2) Triangularly Distributed Load

Equations (19a) & (20) are integrated as previously described and the following equations obtained.

$$EIy = P\left(1 - \frac{\beta l}{\alpha^2}\right)\left(\frac{2Hx^2}{6} - \frac{x^3}{6} + \frac{x^5}{60H^2}\right) + \frac{\beta Pl}{\alpha^4}\left(x + \right.$$

$$\left.\frac{\sinh\alpha(H - x)}{\alpha\cosh\alpha H}\right) - \frac{2\beta Pl}{H^2\alpha^6}\left(x + \frac{1}{\cosh\alpha H} + \frac{\sinh\alpha(H-x)}{\alpha\cosh\alpha H}\right)$$

$$- \frac{2\beta Pl}{H^2\alpha^4}\left(\frac{x^3}{6} - \frac{\cosh\alpha x}{\alpha^2\cosh\alpha H}\right) \qquad (22a)$$

$$EI\frac{dy}{dx} = P\left(1 - \frac{\beta l}{\alpha^2}\right)\left(\frac{2Hx}{3} - \frac{x^2}{2} + \frac{x^4}{12H^2}\right) + \frac{\beta Pl}{\alpha^4}\left(1 - \frac{\cosh\alpha(H-x)}{\cosh\alpha H}\right)$$

$$- \frac{2\beta Pl}{H^2\alpha^6}\left(1 - \frac{\cosh\alpha(H - x)}{\cosh\alpha H}\right) - \frac{2\beta Pl}{H^2\alpha^4}\left(\frac{x^2}{2} - \frac{\sinh\alpha x}{\alpha\cosh\alpha H}\right) \qquad (22b)$$

$$\delta v = \left(\frac{1}{AE} \pm \frac{lc}{IE}\right)\left[-\frac{\beta P}{\alpha^4}\left(1 - \frac{\cosh\alpha(H - x)}{\cosh\alpha H}\right) + \frac{2\beta P}{H^2\alpha^6}\left(1 - \frac{\cosh\alpha(H - x)}{\cosh\alpha H}\right)\right.$$

$$+ \frac{2\beta P}{H^2\kappa^4}\left(\frac{x^2}{2} - \frac{\sinh\kappa x}{\cosh\kappa H}\right) + \frac{\beta P}{\kappa^2}\left(\frac{2Hx}{3} - \frac{x^2}{2} + \frac{x^4}{12H^2}\right)]$$

$$\pm \frac{Pc}{IE}\left(\frac{2Hx}{3} - \frac{x^2}{2} + \frac{x^4}{12H^2}\right) \qquad (22c)$$

3) Horizontal Point Load

As the load is applied at a height of x_l then two distinct ranges are present in the wall.

when $x > x_l$ $\qquad M = 0$

$x < x_l$ $\qquad M = P(x_l - x)$

Integrating equations (19a) & (20) for these two ranges, the constants of integration are evaluated using boundary conditions and compatibility of forces and displacements at $x = x_l$, two sets of equations are obtained for deflections and slope. However, these are reduced to one set of common equations by using the following

$x_l - x = 0 \qquad$ when $x_l < x$

The common equations are as follows

$$EIy = \frac{P}{6}\left(1 - \frac{\beta l}{\kappa^2}\right)(-x^3_l + 3x^2_l + (x_l - x)^3)$$

$$+\frac{\beta Pl}{\kappa^4}(x_l - (x_l - x)) + \frac{\beta Pl}{\kappa^5}\sinh\kappa(x_l - x) + \frac{\beta Pl}{\kappa^5\cosh\kappa H}((1 -$$

$$\cosh\kappa x_l)\sinh\kappa(H - x) - \sinh\kappa H + \sinh\kappa(H - x_l)) \qquad (23a)$$

$$EI\frac{dy}{dx} = \frac{P}{2}\left(1 - \frac{\beta l}{\kappa^2}\right)(x^2_l - (x_l - x)^2) + \frac{\beta Pl}{\kappa^4}(1 - \cosh\kappa(x_l - x))$$

$$- \frac{\beta P l}{\alpha^4 \cosh\alpha H}((1 - \cosh\alpha x_l) \cosh\alpha(H - x)) \qquad (23b)$$

$$\delta v = (\frac{1}{AE} \pm \frac{lc}{IE})\left[\frac{\beta P(1 - \cosh\alpha x_l) \cosh\alpha(H - x)}{\alpha^4 \cosh\alpha H} - \frac{\beta P}{\alpha^4}(1 - \cosh\alpha\right.$$

$$\left.(x_l - x)) + \frac{\beta P}{2\alpha^2}(x^2_l - (x_l - x)^2)\right] \pm \frac{Pc}{2IE}(x^2_l - (x_l - x)^2) \quad (23c)$$

where $A = A_1$ for left hand wall

$A = -A_2$ for right hand wall

4) Moment

As moment is applied at a height x_l, the same procedure as for the horizontal point load is followed. The common equations for this case are as follows

$$EIy = \frac{M}{2}(1 - \frac{\beta l}{\alpha^2})(x^2_l - 2xx_l - (x_l - x)^2) \frac{\beta Ml}{\alpha^4} \cosh\alpha(x_l - x)$$

$$+ \frac{\beta Ml \cosh\alpha(H - x_l)}{\alpha^4 \cosh\alpha H} + \frac{\beta Ml \sinh\alpha(H - x) \sinh\alpha x_l}{\alpha^4 \cosh\alpha H} \qquad (24a)$$

$$EI\frac{dy}{dx} = -M(1 - \frac{\beta l}{\alpha^2})(x_l - (x_l - x)) - \frac{\beta Ml \cosh\alpha(H - x) \sinh\alpha x_l}{\alpha^3 \cosh\alpha H}$$

$$+ \frac{\beta Ml \sinh\alpha(x_l - x)}{\alpha^3} \qquad (24b)$$

$$\delta v = (\frac{1}{AE} \pm \frac{lc}{IE})\left[\frac{\beta M \cosh\alpha(H - x) \sinh\alpha x_l}{\alpha^3 \cosh\alpha H} - \frac{\beta M \sinh\alpha(x_l - x)}{\alpha^3}\right.$$

$$- \frac{\beta M}{\alpha^2} (x_i - (x_i - x)) \Bigg] \pm \frac{Mc}{IE} (x_i - (x_i - x)) \qquad (24c)$$

where $A = A_1$ for left hand wall

$A = -A_2$ for right hand wall

5) Vertical Load (at left hand wall)

As the load is applied at a height x_i two ranges will exist for this load case. Also at $x < x_i$ equation (20a) is modified to

$$\varepsilon_L = \frac{P}{A_1E} + \frac{T(x)}{A_1E} \pm (M - T(x)l)\frac{c}{IE} \qquad (25)$$

Two sets of equations are again obtained but a set of common equations obtained using

$x_i - x = 0$ when $x < x_i$

The common equations are as follows

$$EIy = \frac{Pl\,(\gamma_L - \beta c_1)}{\alpha^4 \cosh\alpha H} (\sinh\alpha(H - x) \sinh\alpha x_i - \cosh\alpha H\alpha \cosh$$

$$(x_i - x) + \cosh\alpha(H - x_i)) - \frac{Pl}{2\alpha^2}(\gamma_L - \beta c_1 - \frac{\alpha^2 c_1}{l}) (x^2_i -$$

$$2xx_i - (x_i - x)^2) \qquad (26a)$$

$$EI\frac{dy}{dx} = \frac{Pl\,(\gamma_L - \beta c_1)}{\alpha^3 \cosh\alpha H} (-\cosh\alpha(H - x) \sinh\alpha xi + \cosh\alpha H$$

$$\sinh\alpha(x_i - x) + \frac{Pl}{\alpha^2} (\gamma_L - \beta c_1 + \frac{\alpha^2 c_1}{l}) (x_i - (x_i - x)) \qquad (26b)$$

Left hand wall

$$\delta v = \pm \frac{Pc_1c}{IE}(x_1 - (x_1 - x)) + \frac{P}{A_1E}(x_1 - (x_1 - x)) + (\frac{1}{A_1E} \pm \frac{lc}{IE})$$

$$(\frac{\gamma_L - \beta c_1}{\kappa^2})[\frac{P\cosh\kappa(H - x)\sinh\kappa x_1}{\kappa\cosh\kappa H} - \frac{P\sinh\kappa(x_1 - x)}{\kappa}$$

$$- (x_1 - (x_1 - x))] \tag{26c}$$

$$\text{where } \gamma_L = \frac{12I_p}{A_1ha^3}$$

At right hand wall, second term of equation (26c) is zero and A_1 replaced by A_2.

6) Vertical Load (at right hand wall)

The procedure is the same as in the previous section except that equation (20b) is modified when $x < x_1$ to

$$\mathcal{E}_R = \frac{P}{A_2E} - \frac{T(x)}{A_2E} \pm (M - T(x)l)\frac{c}{IE} \tag{27}$$

The common equations are as follows

$$EIy = \frac{Pl(\gamma_R - \beta c_4)}{\kappa^4\cosh\kappa H}(-\sinh\kappa(H - x)\sinh\kappa x_1 + \cosh\kappa H$$

$$\cosh\kappa(x_1 - x) - \cosh\kappa(H - x_1)) + \frac{Pl}{2\kappa^2}(\gamma_R - \beta c_4 + \frac{\kappa^2 c_4}{l})$$

$$(x_1^2 - 2xx_1 - (x_1 - x)^2) \tag{27a}$$

$$EI\frac{dy}{dx} = \frac{Pl\,(\gamma_R - \beta c_4)}{\alpha^3 \cosh\alpha H}\,(\cosh\alpha(H - x)\sinh\alpha x_l - \cosh\alpha H \sinh\alpha$$

$$(x_l - x)) - \frac{Pl}{\alpha^2}(\gamma_R - \beta c_4 + \frac{\alpha^2 c_4}{l})\,(x_l - (x_l - x)) \quad (27b)$$

Right hand wall

$$\delta v = \pm\frac{Pc_4c}{IE}(x_l - (x_l - x)) + \frac{P}{A_2E}(x_l - (x_l - x)) + P(\frac{1}{A_2E} \pm \frac{lc}{IE})$$

$$(\frac{\gamma_R - \beta c_4}{\alpha^2})\left[\frac{-\cosh\alpha(H - x)\sinh\alpha x_l}{\cosh\alpha H} + \frac{\sinh\alpha(x_l - x)}{\alpha}\right.$$

$$\left. + (x_l - (x_l - x))\right] \quad (27c)$$

where $\gamma_R = \frac{12I_p}{A_2ha^3}$

At left hand wall, second term of equation (27c) is zero and A_2 replaced by A_1.

2.3.2 Stress Resultants in the Walls

i) Moment

The corresponding bending moments in the walls are given by

$$M_1 = \frac{I_1}{I}(M - T(x)l) \quad (28)$$

$$M_2 = \frac{I_2}{I}(M - T(x)l) \quad (29)$$

ii) Axial Force

The axial force at any level can be obtained by

$$P = \int_{X}^{H} q(x)dx \qquad (30)$$

iii) Shear force

The shear force in the connecting beams is obtained by summing the laminar shear over half a storey height between top and bottom of the required beam. That is

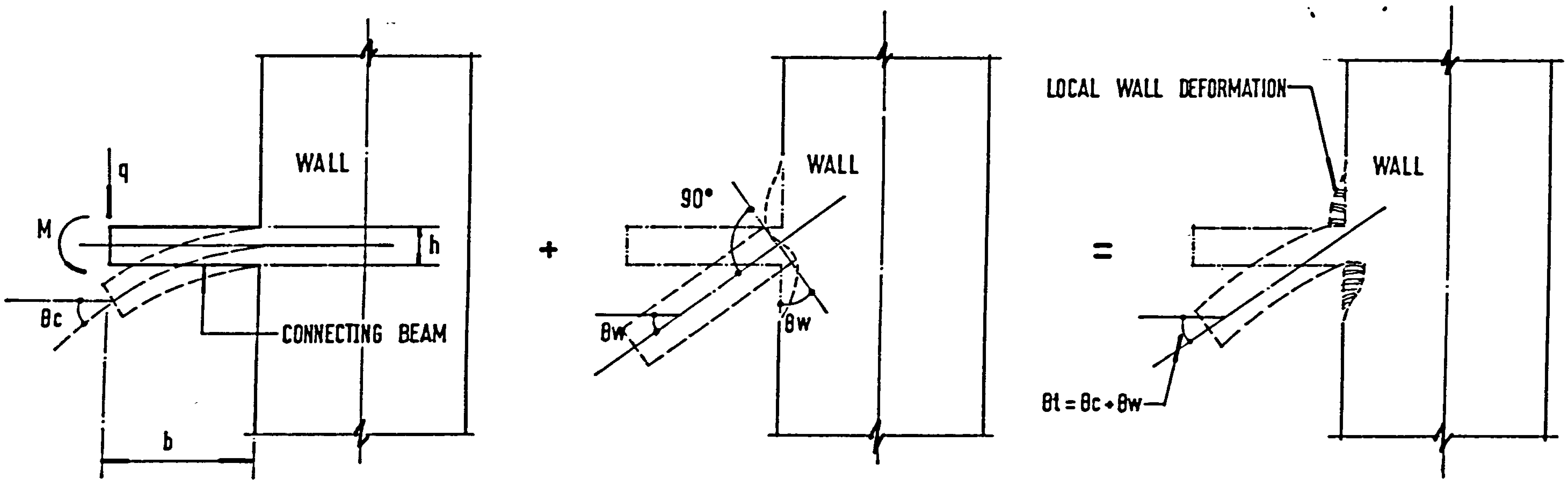
$$q_i = \int_{-h/2}^{h/2} q(x)dx \qquad (31)$$

2.4 Local Deformation at Beam-Wall Junctions

The above values are based on the assumption that a rigid connection exists between the walls and connecting beams. In fact, local wall deformation may occur at beam-wall junctions resulting in a reduction in the interaction. D. Michael[48] has investigated the effects of these deformations and proposed that the flexibility of connecting beams be increased due to local wall elasticity and shear effects. A, different approach is presented below.

As shown in fig (2.4), when a bending moment M is applied at the end of the cantilever, its total end rotation is equal to

$${}_{m} = {}_{c1} + {}_{w1} \qquad (33)$$



a) BEAM END ROTATION

b) WALL FACE ROTATION

c) COMBINED ROTATION

$\theta t = \theta c + \theta w$

$\theta c = \theta s1 + \theta m1$

$\theta w = \theta s2 + \theta m2$

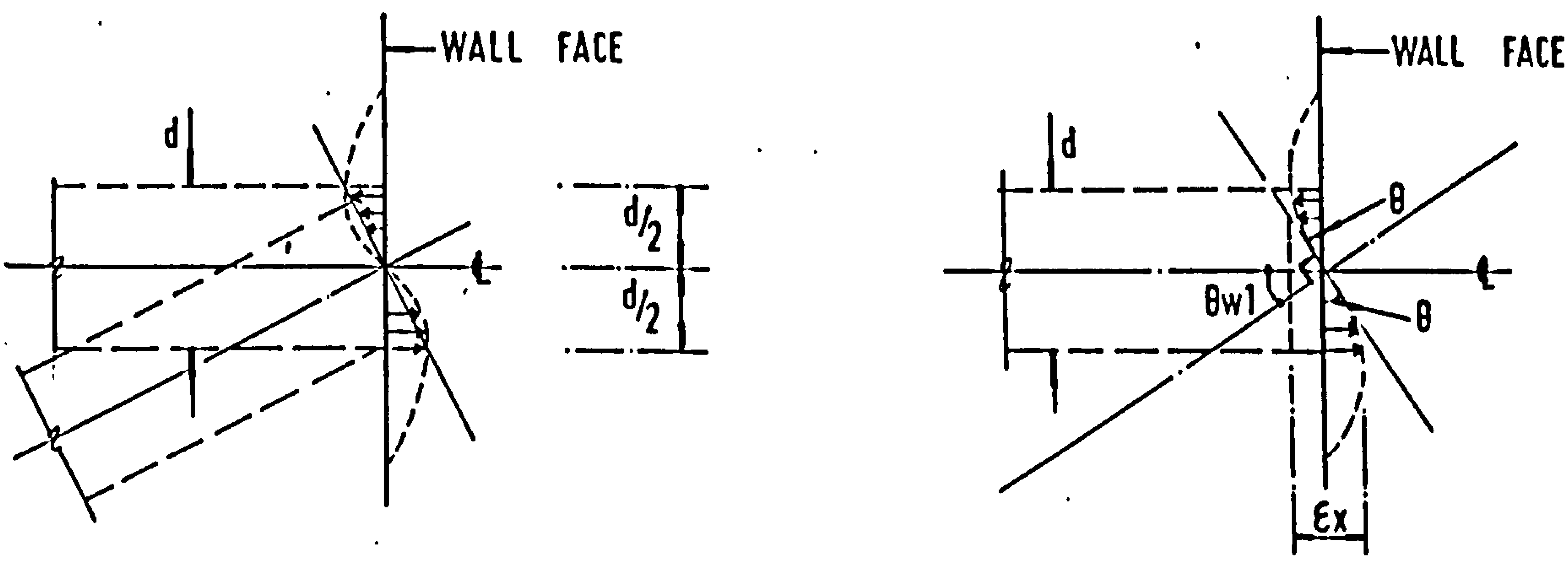
NOTE
SUBSCRIPT 's' = DUE TO SHEAR FORCE
SUBSCRIPT 'm' = DUE TO MOMENT

FIG (2.4) WALL UNDER LOCAL DEFORMATION

where θ_{c1} is beam end rotation and may be written as

$$\theta_{c1} = \int_0^b \frac{M}{EI}\,dx \tag{34}$$

and θ_{w1} is the rotation due to the stresses acting at the wall force. This may be expressed as



a) Wall Face Deformation   b) Wall Face Rotation

$$\sigma_{max} = \frac{Md}{2I} \tag{35}$$

$$\varepsilon_x = \frac{2Md}{2IE}\,\frac{d}{2}$$

$$= \frac{Md^2}{2EI} \tag{36}$$

For small angles

$$\tan\theta \simeq \theta \tag{37}$$

Thus, it may be written

$$\theta = \frac{\varepsilon_x}{d} \cdot$$

$$= \frac{Md}{2EI}$$

$$= \frac{6M}{Ed^2} \qquad (38)$$

To comply with the Bernoulli-Navier hypothesis, plane section remains plane during bending. Thus,

$$\theta_{w1} = \theta = \frac{6M}{Ed^2} \qquad (39)$$

Substituting equations (39) & (34) into equation (33) leads to the following equation

$$\theta_m = \int_0^b \frac{M}{EI} dx + \frac{6M}{Ed^2}$$

$$= \frac{Mb}{EI} \left(1 + 0.5\frac{d}{b}\right) \qquad (40)$$

or it can be rearranged as

$$\theta_m = \frac{M}{EI} (b + 0.5d) \qquad (41)$$

Similarly, its end rotation due to the effect of shearing force q may be expressed as

$$\theta_s = \theta_{c2} + \theta_{w2}$$

$$\doteq \int_0^b \frac{qx}{EI}\,dx + \frac{fq}{Gd} + \frac{6qb}{Ed^2} + \frac{2}{3}\frac{q}{Ed}$$

$$= \frac{q}{2EI}\left(b^2 + bd + \frac{4d^2}{36}\right) + \frac{fq}{Gd} \qquad (42)$$

or approximately equation (42) may be written as

$$\theta_s \doteq \frac{q(b + 0.5d)^2}{2EI} + \frac{fq}{Gd} \qquad (43)$$

where M = moment

q = shear force

θ_w = wall face rotation

θ_c = end rotation of connecting beam

θ_t = total rotation due to the effect of shear and bending moment

b = beam length

d = beam depth

Finally, the total end rotation is expressed as

$$\theta_t = \theta_m + \theta_s \qquad (44)$$

From equations (41) & (43), it can be seen that the flexibility of the connecting beams may be corrected by increasing the effective length by an amount equal to its depth.

This suggestion of extended beam effective length will give accurate results for those slender connecting beams where the wall face rotation is small. For those connecting beams whose depth is large compared to the wall half width, this method of correction may be excessive.

2.5 Variable Thickness

2.5.1 Introduction

A change in the wall configuration produces a discontinuity in the continuum method solution[36] [67] [68]. Coull and Puri[21] corrected for this discontinuity by adding a series of corrective terms to the general solution. In 1968, Coull and Puri[19] proposed an improvement, and simplification, to the above analysis by separating each portion of the walls and transferring the interaction forces from the upper portion of wall to the lower one. The disadvantage of this approach is that for each change of wall configuration it is necessary to redetermine the particular solution and arbitrary integration constants. Later on, Coull et al[20] suggested the use of a numerical approach based on the matrix progression formulation. In 1973, Tso and Chan[65] suggested a method based on the transfer matric technique. This method consists of subdividing the structure into a number of segments.

In practice, the change of wall thickness in lift shafts or stair-wells are normally small compared with the height and width of walls.

Hence, the effect of stress concentration at the change of thickness may not be so critical.

Therefore, a relatively simple hand-method for variable wall thickness subject to applied load is presented and discussed below:

2.5.2 Equivalent Analogous Approach

This approximation is in principle similar to the method proposed by Smith and Khan [58] for a wall-frame structure.

When analysing a structure by a simplified method, a concept of idealising the basic structure is necessary. In this approach, the non-uniform thickness of wall is modified to an equivalent uniform analogous wall which maintains the primary modes of behaviour of the wall.

2.5.2.1 Derivation

A typical wall with two different sections is demonstrated as shown in figs (2.5) & (2.6).

i) Determination of Sectional Area

An axial force is assumed to apply from the top of wall as equivalent module (fig(2.5)). The deformed form of each module is detailed separately.

First, consider the axial deformation in segment (1)

$$d_1 = \int_0^{H-h} \frac{V}{A_1 E} dx \qquad (45)$$

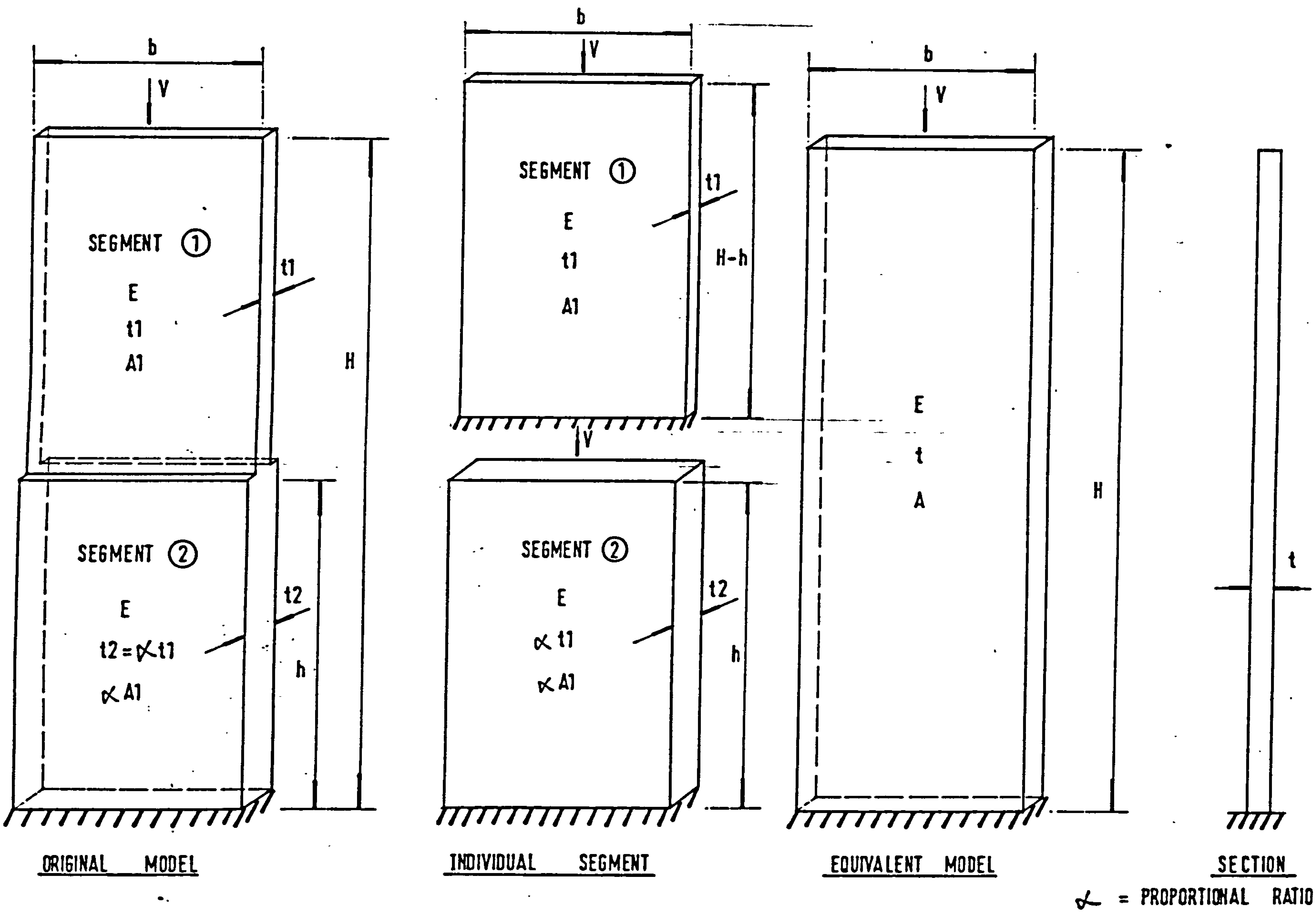


FIG (2.5) WALL MODULE SUBJECT TO VERTICAL LOAD and in segment (2), it becomes

$$d_a = d_1 + \int_0^h \frac{V}{\alpha A_1 E} dx \qquad (46)$$

Secondly, the equivalent module subject to the same amount of axial force may be expressed as

$$d_e = \int_0^H \frac{V}{AE} dx \qquad (47)$$

For the corresponding identification, both systems will have the same identical deformation under same load, that is

$$\int_0^H \frac{V}{AE}\, dx = \int_0^{H-h} \frac{V}{A_1 E}\, dx + \int_0^h \frac{V}{\alpha A_1 E} dx \qquad (48)$$

Rearranging equation (48) and deleting the common terms, the final form becomes

$$\frac{A}{A_1} = \frac{\alpha}{\alpha - \frac{h}{H}(\alpha - 1)} \qquad (49)$$

where A_1 = sectional area of original wall

A = sectional area of equivalent wall module

α = ratio of sectional area between segments (1) &

(2).

ii) Computation of moment of inertia

The second mode of deformation of the wall is due to horizontal force which contributes shear and bending deformation that are dependent on the structural properties, sectional area and moment of inertia. To obtain an equivalence, it is assumed that a horizontal force P acts at the top of the wall as also on the equivalent module (fig 2.6).

The bending and shearing deformations of segment (1) at the change of cross sections are given by

$$\text{Bending } d_m = \int_h^H \frac{Px^2}{EI_1}\, dx \qquad (50)$$

$$\text{Shearing } d_s = \int_h^H \frac{P}{GA_1}\, dx \qquad (51)$$

$$\text{Hence,} \quad d_1 = d_m + d_s$$

Similarly, the deformations of segment (2) are

$$\text{Bending } d_m = \int_0^h \frac{Px^2}{E\alpha I_1}\, dx + \int_0^h \frac{P(H-h)x}{E\alpha I_1}\, dx \qquad (52)$$

$$\text{Shearing } d_s = \int_0^h \frac{P}{G\alpha A_1}\, dx \qquad (53)$$

$$\text{Rotation } d_\theta = \int_0^h \frac{Px}{E\alpha I_1}\, dx + \int_0^h \frac{P(H-h)}{E\alpha I_1}\, dx + \frac{P}{G\alpha A_1} \qquad (53a)$$

FIG (2.6) WALL MODULE SUBJECT TO HORIZONTAL FORCE

$$d_2 = d_m + d_s + d_r \tag{53b}$$

where $d_r = d_\theta^* \ (H\text{-}h)$

The bending and shearing of the equivalent module under similar horizontal force are given by

$$d_e = \int_0^H \frac{Px^2}{EI}\,dx + \int_0^H \frac{P}{GA}\,dx \tag{54}$$

To be equivalent, their total deformation between original and equivalent modules must be equal, that is

$$d_e = d_1 + d_2 \tag{55}$$

Substituting equations (50), (51), (52), (53) & (54) into equation (55), it becomes

$$\frac{H^3}{3EI} + \frac{H}{GA} = \frac{(H\text{-}h)^3}{3EI_1} + \frac{(H\text{-}h)\gamma}{GA_1} + \frac{h^3}{3E\alpha I_1} + \frac{(H\text{-}h)h^2}{E\alpha I_1}$$

$$+ \frac{h}{G\alpha A_1} + \frac{(H\text{-}h)^2 h}{E\alpha I_1} \tag{56}$$

where $G = \dfrac{E}{2(1+v)}$

$A = bd$

$\gamma = 1 + \dfrac{1}{\alpha}$

$I = \dfrac{bd^3}{12}$

Finally, the ratio between original and equivalent walls may be written as

$$\frac{I}{I^1} = \frac{\alpha(2H^3 + (1+v)\,Hb^2)}{2\alpha(H-h)^3 + 2\,h^3 + 6\,(H-h)h^2 + \alpha(H-h)(1+v)b^2 + \beta b^2(1+v) + 6(H-h)^2 h} \quad (57)$$

where I_1 = moment of inertia of original wall

I = moment of inertia of equivalent wall

β = 2H-h

2.6 Remarks

An equivalent analogous approach has been presented for the analysis of coupled shear wall with variable cross sections. Although the particular case of a point load has been detailed, the method can be used to cover other load systems. The advantage of this approach is its simplicity and the basic theory of continuum method with constant wall thickness can be applied directly to the analysis without the need for further modification. Any number of thickness variations may be considered by using the equivalent structural properties.

The values of $\frac{A}{A_1}$ & $\frac{I}{I_1}$ are the ratios between the original and equivalent walls. These ratios depend only on the wall geometry as the Poison's ratio value is the same for both the original and equivalent system. The flexibility of the beam-wall junctions and the shearing deformation may be included in the analysis.

In practice, this approximate method may be adequate to predict the overall behaviour of the structure under load for trial design as well as to obtain the rapid approximate answer as the changes of wall

CHAPTER THREE

FINITE STRIP METHOD

3.1 Introduction

The finite element technique is a versatile tool for analysing structures of any complex configuration. However it requires large storage capacity in the computer and is relatively time-consuming. To reduce these values, the finite strip method has been developed. It is based on the same principle of energy minimization as that applied in the finite element method. It has considerable advantages over the finite element method for certain types of structures. In this approach, the structure is idealised as a series of strips attached to each other at nodal lines (fig 3.1). Normally, each strip spans the whole length of the structure. The displacement shape function in the longitudinal direction is chosen so that the boundary conditions are satisfied as well as representing the complete displacement of the structure. A simple polynomial function is employed in the transverse direction to comply with the inter-strip compatibility conditions. The stiffness matrix of the strip, with preset end conditions, can be established from the strain-stress relationship in terms of the nodal displacement parameters. The loading system can be represented by a point load, line load, distributed load or a moment acting on the structure or a combination. The thickness of each strip is usually constant but can vary in the cross section. For a two dimensional problem, the basic known shape function is assumed in a

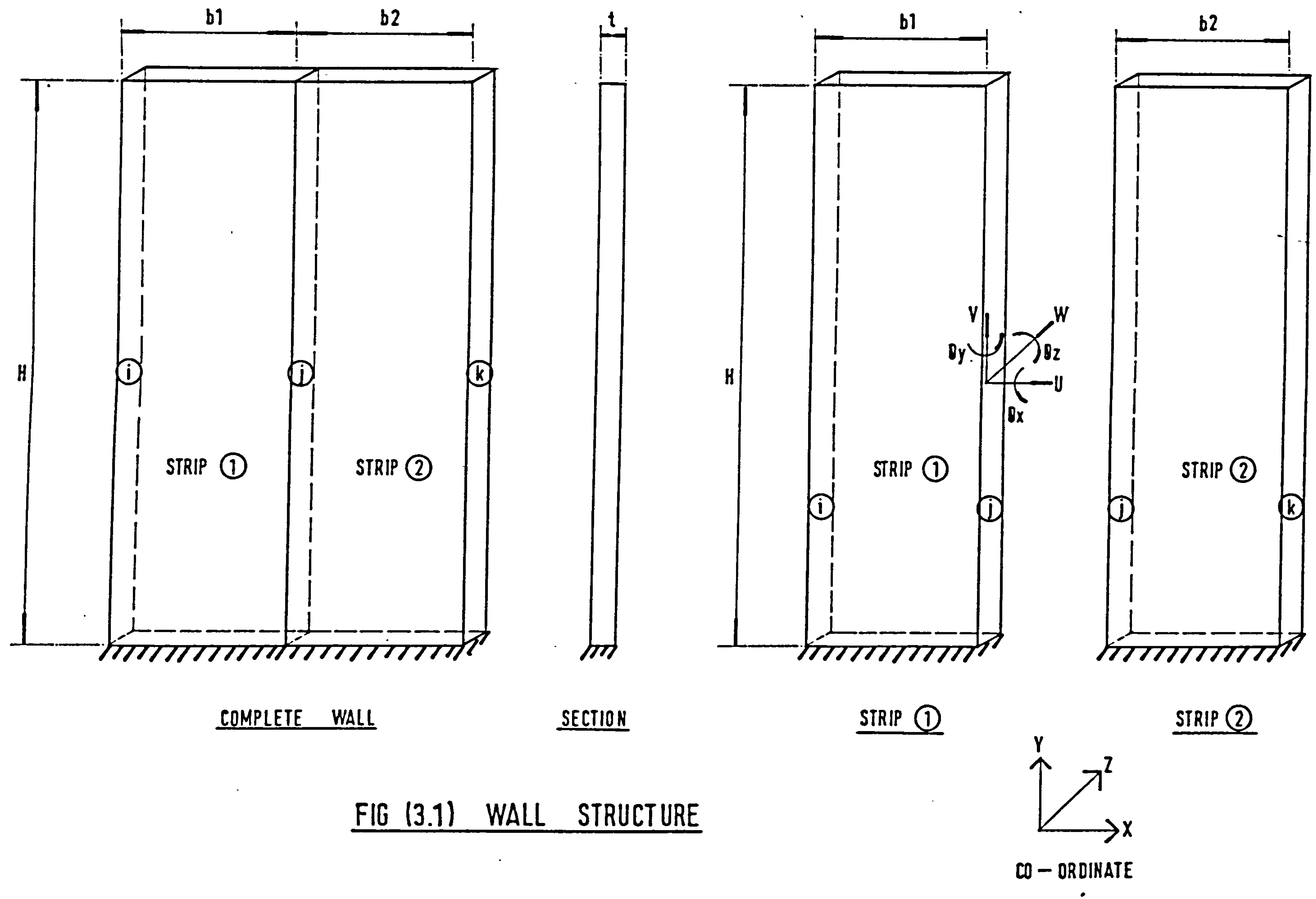


FIG (3.1) WALL STRUCTURE

certain direction. Thereby, it reduces to a one dimensional problem.

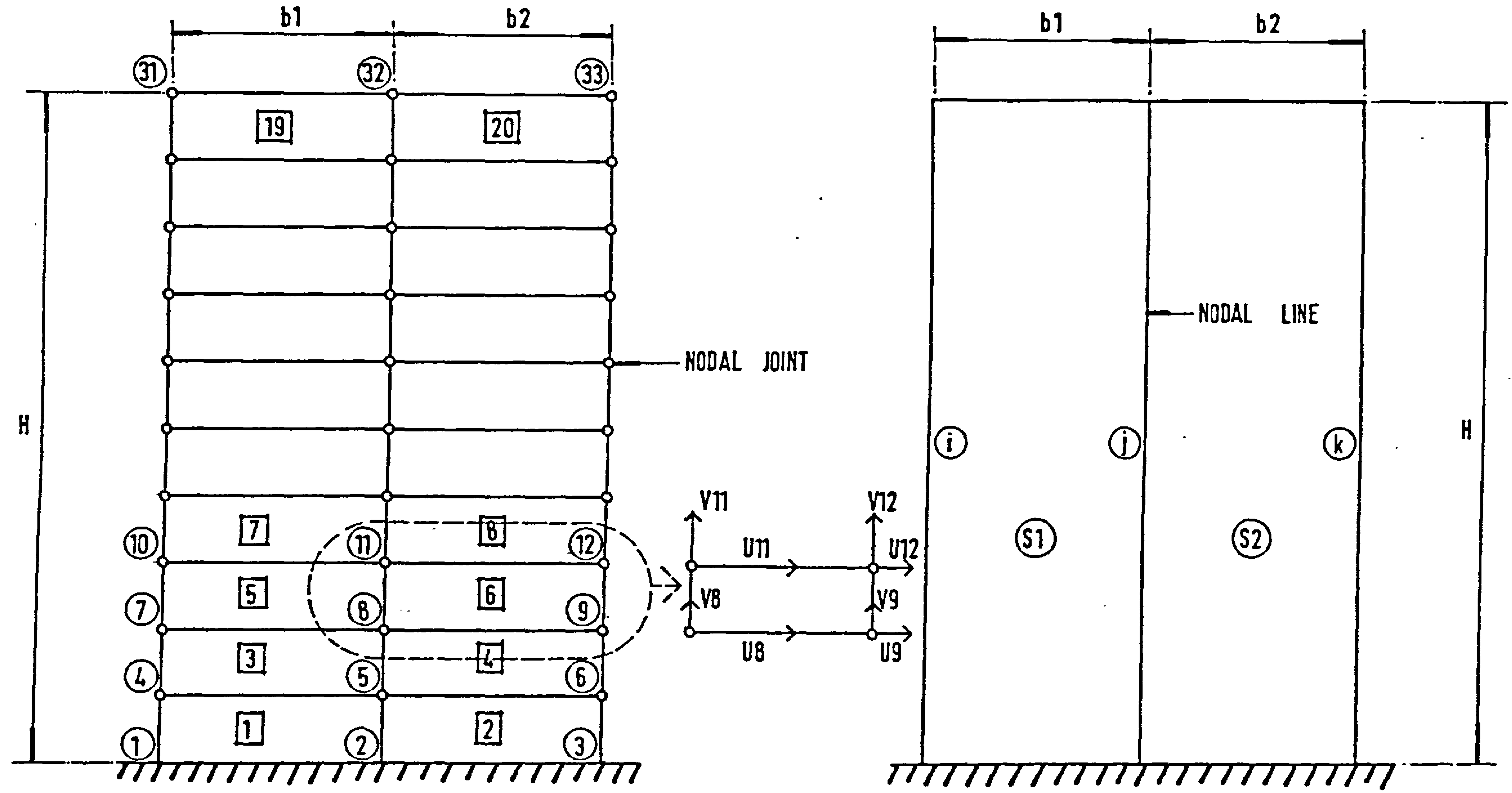
This approach is particularly suitable for structures with a simple configuration so that their displacements can be modelled by a series of mode shapes which converge rapidly to the exact solution for the complete displacements of the structure.

3.2 Comparision between Finite Strip and Finite Element Methods

A short comparison is presented here to outline the main differences between the finite strip and finite element methods before demonstrating the process of formulating the finite strip.

3.2.1 Idealisation and Shape Functions

Finite Element	Finite Strip
a) The structure is divided into a number of small elements in both longitudinal and transverse directions and are connected to each other at interconnection points (Fig (3.2)).	The structure is only divided in the longitudinal direction and the strips are connected to each other along nodal lines.
b) The displacement parameters	The displacement parameters are



FINITE ELEMENT
(IN – PLANE)

BANDWIDTH = 4 ✱ 2 = 8
NDF = 30 x 2 = 60
ELEMENTS = 20

FINITE STRIP
(IN – PLANE)

BANDWIDTH = 2 x 2 = 4
NDF = 3 x 2 = 6
STRIPS = 2

✱ NDF DENOTES NUMBER OF DEGREE OF FREEDOM

FIG (3.2) DISCRETISATION OF WALL STRUCTURE

of an in-plane structure are described by two functions $U, V = \phi(x,y)$ where $\phi(x,y)$ is an unknown polynomial function in x and y directions.	also described by two functions $u = [f(x), f(y)]$ $v = [f(x), f'(y)]$ where f(x) is an unknown polynomial function in x direction only while f(y) is a preset known mode shape function which satisfies the boundary conditions at both ends.
c) For in-plane structure, it is a two-dimensional problem .	It is only a one-dimensional problem.
d) Boundary conditions are introduced during assembling of overall stiffness matrix.	Boundary conditions are preset.

3.2.2 Compatibility Conditions

Finite Element	Finite Strip
Compatibility conditions are only satisfied at connecting points but violated along the line joining two elements. The displacement functions are only assumed to be continuous over the nodal points. Therefore the accuracy depends on the number of subdivided meshes.	Compatibility conditions have to be satisfied on the lines joining two strips. The displacement functions are continuous over the nodal lines.

3.2.3 Stiffness Matrix

Finite Element	Finite Strip
a) Singularity of the stiffness matrix is possible usually due to zero terms in the main diagonal.	Due to preset condition, the stiffness matrix will never be singular.
b) The total number of degrees of freedom depends on the number of nodal points (fig(3.2)).	The total number of degrees of freedom depends on the number of nodal lines. Therefore, the bandwidth is relatively small (fig (3.2)).

3.2.4 Obtained Displacements

Finite Element	Finite Strip
The obtained displacements represent the actual value of displacement at each node.	The obtained displacements are only the mode shapes of each nodal line. The total displacement at each required point is computed in terms of the obtained mode shapes.

However both methods use the concept of virtual work and minimisation of total potential energy to form the stiffness matrix.

3.3 Displacement Shape Functions

The displacement shape function used for a strip has the form f(x) * f(y), in which f(y) is a series of mode shapes that satisfies the boundary conditions at the ends and f(x) is a polynomial with unknown coefficients.

3.3.1 Longitudinal Shape Function f(y)

Two types of admissible functions can be adopted for the analysis:

a) Beam Eigenfunction

This function has been successfully and extensively used in modelling the displacement behaviour of plates and shells (33) (34). Its form is a series of mode shapes that are derived from the differential equation of a vibrating beam. That is

$$Y^{IV} = \frac{\mu^4}{a^4} Y \tag{1}$$

A particular solution of the above equation (1) depeneds on the required end conditions. For coupled shear wall structures, in practice there are two types of conditions that might be normally encountered:

i) The coupled shear wall is rigidly restrained at the base and free at the top.

Solving the above equation (1) for the relevant boundary conditions, it produces the following function.

$$Y_m^{U,W} = \sin y_m - \sinh y_m - K_m (\cos y_m - \cosh y_m) \tag{2}$$

where $K_m = \dfrac{(\sin\mu_m + \sinh\mu_m)}{(\cos\mu_m + \cosh\mu_m)}$

$$y_m = \frac{\mu_m y}{H}$$

where 'm' subscript denotes series of mode shapes

y = dimension in longitudinal direction

H = height of strip

'u' & 'w' superscripts are displacement parameters in 'U' and 'W' directions

$$\mu_{1,2,..m} = 1.875099,\ 4.694040,\ 7.854759,\ .....(2m-1)\pi/2$$

ii) When the coupled shear wall is supported on a frame structure, the displacement function of the inter-strips is obtained assuming both ends free. In satisfying the end conditions, the function is given as

$$Y_1^{U,W}(y) = 1 \qquad \mu_1 = 0$$

$$Y_2^{U,W}(y) = 1-\frac{2y}{H} \qquad \mu_2 = 1$$

$$y_m = \frac{\mu_m y}{H}$$

$$Y_m^{U,W} = \sin y_m + \sinh y_m - K_m(\cos y_m + \cosh y_m) \tag{3}$$

where $K_m = \dfrac{(\sin\mu_m - \sinh\mu_m)}{(\cos\mu_m - \cosh\mu_m)}$

$$\mu_{3...m} = 4.7300,\ 7.8532,\ 10.9960,\ ....(2m-3)\pi/2$$

$m = 3,4,$ ....

For the vertical displacement, the mode shape may be taken either in the form

$$Y_m^V(y) = dY_m^U(y)/dy \tag{4}$$

or by simply using the vibrating beam function as

$$Y_m^V(y) = \sin[(2m-1)\pi \frac{y}{2}] \qquad (5)$$

The above shape function produces an accurate and reliable profile for a structure where bending is the donimant deformation. Whenever the shear deformation is significant the above function will slightly underestimate the displacements.

b) Polynomial Function

In some forms of structures the shear forces and deformations are significant. Therefore, any function used to represent deformation must include both shear and bending deformation. Recently a series of polynomial functions has been developed that allows for both types of deformation.

The form of the function is as shown below

$$Y_m(y) = \sum_{n=1}^{m} (-1)^{n-1} \frac{(n+m)!}{(m-n)!(n+1)!(n-1)!} \left(\frac{y}{H}\right)^n \qquad (6)$$

where m & n are series of mode shapes.

It can be seen that the first mode of the above series is a straight line that approximates to the shear deformation. The other modes are similar to the beam eigenfunctions representing the bending deformations.

3.3.2 Transverse Function f(x)

A polynomial function f(x) is employed to describe the transverse displacement field of the strips. The set of admissable functions used are given as

i) A linear polynomial of the 1st degree for the in-plane 'U' and 'V' displacements.

ii) A cubic polynomial of the third degree for out of plane 'W' displacement and 'θ_y' rotation.

Both functions will be detailed whenever they are required.

3.4 Formulation of Element Stiffness

The in-plane forces and out of plane forces are not coupled in their actions. Therefore, it is convenient to describe both cases separately and then combine them to produce an overall stiffness matrix. The formulation of the strip stiffness matrix is similar to the finite element technique.

3.4.1 In-plane

The displacement of a strip can be described by two parameters, U & V in the x and y directions. These are assumed to be, in some form, governed by their general term values at the nodal joints.

$$U = [A_1] \left\{ \begin{matrix} U_i \\ U_j \end{matrix} \right\} \qquad (7)$$

$$V = [A_2] \begin{Bmatrix} V_i \\ V_j \end{Bmatrix} \tag{8}$$

where U_i, V_i, U_j & V_j are the displacement vectors at nodes 'i' & 'j' and $[A_1]$ & $[A_2]$ are functions.

A set of displacement functions which can satisfy the boundary conditions in 'x' and 'y' directions are

$$U = \sum_{m=1}^{r} [(1-\frac{x}{b})U_{im} + (\frac{x}{b})U_{jm}]Y^{u}_{m} \tag{9}$$

$$V = \sum_{m=1}^{r} [(1-\frac{x}{b})V_{im} + (\frac{x}{b})V_{jm}]Y^{v}_{m} \tag{10}$$

where U_{im}, U_{jm}, V_{im} & V_{jm} are the generalised displacement parameters of the m^{th} term at the nodal lines.

In matrix form

$$\begin{Bmatrix} U \\ V \end{Bmatrix} = \sum_{m=1}^{r} [f_{pm}] \{\delta_m\} \tag{11}$$

$$\text{where } [f_{pm}] = \sum_{m=1}^{r} \left[\begin{array}{c|c|c|c} (1-\frac{x}{b})Y^{u}_{m} & 0 & (\frac{x}{b})Y^{u}_{m} & 0 \\ \hline 0 & (1-\frac{x}{b})Y^{v}_{m} & 0 & (\frac{x}{b})Y^{v}_{m} \end{array} \right] \tag{12}$$

$$\delta_{pm} = \{U_{im} \quad V_{im} \quad U_{jm} \quad V_{jm}\}^T \tag{13}$$

The strains at a point in the region are given by

$$\varepsilon_x = \frac{\partial u}{\partial x}, \ \varepsilon_y = \frac{\partial v}{\partial y} \quad \text{and} \quad \gamma_{xy} = \frac{\partial u}{\partial y} + \frac{\partial v}{\partial x}$$

In matrix form

$$\{\varepsilon\} = \begin{bmatrix} \varepsilon_x \\ \varepsilon_y \\ \gamma_{xy} \end{bmatrix} \begin{bmatrix} \frac{\partial}{\partial x} & 0 \\ 0 & \frac{\partial}{\partial y} \\ \frac{\partial}{\partial y} & \frac{\partial}{\partial x} \end{bmatrix} \begin{bmatrix} u \\ v \end{bmatrix} = \sum_{m=1}^{r} [B_{pm}]\{\delta_m\} \tag{14}$$

The stresses are given as

$$\{\sigma_p\} = [D_p]\{\varepsilon\} \tag{15}$$

where $[D_p]$ = the structural property matrix

'p' subscript denotes in-plane

and matrix $[B_{pm}]$ may be written as

$$[B_{pm}] = \begin{bmatrix} -\frac{1}{b}Y_m^u & 0 & \frac{1}{b}Y_m^u & 0 \\ 0 & (1-\frac{x}{b})\frac{\partial Y_m^v}{\partial y} & 0 & (\frac{x}{b})\frac{\partial Y_m^v}{\partial y} \\ (1-\frac{x}{b})\frac{\partial Y_m^u}{\partial y} & -(\frac{1}{b})Y_m^v & (\frac{x}{b})\frac{\partial Y_m^u}{\partial y} & (\frac{1}{b})Y_m^v \end{bmatrix}$$

or equation (15) may be expressed as

$$\{\sigma_p\} = [D_p]\sum_{m=1}^{r}[B_{pm}]\{\delta_m\} \tag{16}$$

The potential energy due to loads applied to the strip is given as the product of the load and its displacement

$$V_p = -\int_o^a\int_o^b (\{U\}\{P_u\} + \{V\}\{P_v\})\, dxdy$$

$$= -\int_o^a\int_o^b \begin{Bmatrix} U \\ V \end{Bmatrix}^T \begin{Bmatrix} P_u \\ P_v \end{Bmatrix} dxdy \qquad (17)$$

where $\{P_u\}$ and $\{P_v\}$ are the load vectors in the x and y direction respectively.

The above equation may be written in term of mode shapes as

$$V_p = -\sum_{m=1}^{r} \{\delta_m\}^T [f_{pm}]^T \{P\} \qquad (18)$$

Then, the total potential energy can be expressed as

$$U_T = U_e + V_p \qquad (19)$$

Applying the principle of minimisation of total potential energy and differentiating equation (19) with respect to each nodal displacement.

Then,

$$\frac{\partial U_T}{\partial \{\delta\}} = 0 \qquad (20)$$

The total energy of the strip in its deformed state is the sum of the strain energy in the strip and the potential energy due to external loads acting on the strip.

The elastic strain energy of a strip may be written as

$$U_e = \frac{1}{2}\int_0^a\int_0^b (\sigma_x \varepsilon_x + \sigma_y \varepsilon_y + \tau_{xy}\gamma_{xy})\, dxdy \qquad (21)$$

or in matrix form

$$U_e = \frac{1}{2}\int_0^a\int_0^b \{\varepsilon\}^T\, [D]\, \{\varepsilon\}\, dxdy \qquad (22)$$

Substituting equations (16) & (14) into equation (21), it becomes

$$U_e = \frac{1}{2}\int_0^a\int_0^b \{\delta_p\}^T\, [B_p]^T\, [D_p]\, [B_p]\, \{\delta_p\}\, dxdy \qquad (23)$$

Expressing equation (23) in term of mode shapes, it may be written as

$$U_e = \frac{1}{2}\sum_{m=1}^{r}\sum_{n=1}^{r} \{\delta_m\}^T\, [K^p_{mn}]\, \{\delta_n\} \qquad (24)$$

where $[K^p_{mn}]$ becomes the stiffness matrix of the strip and is given as

$$[K^p_{mn}] = \int_0^a\int_0^b [B_{pm}]^T\, [D_p]\, [B_{pn}]\, dxdy \qquad (25)$$

Substituting equations (24) and (18) into equation (19) and differentiating produces

$$\int_0^a \int_0^b [B_{pm}]^T [D_p] [B_{pn}] \{\delta_m\} \, dxdy - \int_0^a \int_0^b [f_{pm}]^T \{P\} \, dxdy = 0 \quad (26)$$

or in shortened form,

$$[K^p_{mn}] \ \{\delta_m\} - \{F_m\} = 0 \quad (27)$$

where $[K^p_{mn}]$ = Stiffness matrix of the strip

$\{F_m\}$ = Applied load vector

$\{\delta_m\}$ = Displacement vector

For 'r' series of modes, the stiffness matrix becomes

$$\sum_{m=1}^{r} \sum_{n=1}^{r} [K^p_{mn}] = \begin{bmatrix} K^p_{11} & K^p_{12} & \cdots & K^p_{1r} \\ K^p_{21} & K^p_{22} & \cdots & K^p_{2r} \\ \vdots & \vdots & & \vdots \\ K^p_{r1} & K^p_{r2} & \cdots & K^p_{rr} \end{bmatrix} \quad (28)$$

3.4.2 Bending

Only one displacement parameter 'W' normal to the plane of the strip is required to describe the deformed state. The displacement function that satisfies the boundary conditions may also be expressed as a series of mode shapes. This varies linearly in the longitudinal 'y' direction and cubically in the transverse 'x' direction.

$$W = [C_1]\begin{bmatrix} W_i \\ \Theta_i \\ W_j \\ \Theta_j \end{bmatrix} \quad (29)$$

$$\text{or} \quad = \sum_{m=1}^{r} [f_{bm}]\{\delta_m\} \quad (30)$$

where W_i, Θ_i, W_j & Θ_j are the displacement and rotation vector at node 'i' & 'j' and $[C_1]$ is functions.

The displacement function is given as

$$W = \left(1 - \frac{3x^2}{b^2} + \frac{2x^3}{b^3}\right)W_i + \left(x - \frac{2x^2}{b} + \frac{x^3}{b^2}\right)\Theta_i + \left(\frac{3x^2}{b^2} - \frac{2x^3}{b^3}\right)W_j + \left(\frac{x^3}{b^2} - \frac{x^2}{b}\right)\Theta_j \quad (31)$$

The curvatures of the strip in bending are given by

$$\begin{bmatrix} Xxx \\ Xyy \\ Xxy \end{bmatrix} = \begin{bmatrix} -\frac{\partial W}{\partial x^2} \\ -\frac{\partial^2 W}{\partial y^2} \\ 2\frac{\partial^2 W}{\partial x \partial y} \end{bmatrix} \quad (32)$$

or in shortened form

$$\{x\} = \sum_{m=1}^{r} [B_{bm}] \{\delta_m\} \qquad (33)$$

The strain energy of the strip may be derived directly from the stress resultants rather than the stresses. The relationship between the moment - curvature is given as

$$\begin{bmatrix} Mx \\ My \\ Mxy \end{bmatrix} = \begin{bmatrix} Dx & D_1 & 0 \\ D_1 & Dy & 0 \\ 0 & 0 & Dxy \end{bmatrix} \begin{bmatrix} Xxx \\ Xyy \\ Xxy \end{bmatrix} \qquad (34)$$

The total potential energy of the strip in bending is equal to the sum of the strain energy of the deformed strip and the potential energy due to the applied load.

where the strain energy may be written as

$$U_e = \frac{1}{2} \int_0^a \int_0^b (MxXxx + MyXyy + MxyXxy)\, dxdy \qquad (35)$$

or equation (35) may be expressed in terms of mode shapes

$$U_e = \frac{1}{2} \sum_{m=1}^{r} \sum_{n=1}^{r} \{\delta_m\}^T [K^b_{mn}] \{\delta_n\} \qquad (35a)$$

where,

$$[K^b_{mn}] = \int_0^a \int_0^b [B_{bm}]^T \; [D_b] \; [B_{bn}] \; dxdy \tag{35b}$$

and the potential energy is

$$V_b = - \int_0^a \int_0^b \{f_{bm}\}^T \{\delta_m\}^T \{P\} \, dxdy \tag{35c}$$

The equation of total potential energy with respect to nodal displacment is

$$U_T = U_e + V_b \tag{36}$$

Differentiating equation (36) with respect to each nodal displacement, produces

$$\int_0^a \int_0^b [B_{bm}]^T \; [D_b] \; [B_{bn}] \; \{\delta_m\} \; dxdy - \int_0^a \int_0^b [f_{bm}]^T \{P\} \, dxdy = 0 \tag{37}$$

or in shortened form

$$[K^b_{mn}] \{\delta_m\} - \{F^b_m\} = 0 \tag{38}$$

where $[K^b_{mn}]$ = bending stiffness matrix of strip

$\{F^b_m\}$ = load vector

For 'r' series of modes, the bending stiffness matrix may be written as

$$\sum_{m=1}^{r}\sum_{n=1}^{r}[K_{mn}^{b}] = \begin{bmatrix} K_{11}^{b} & K_{12}^{b} & \cdots & K_{1r}^{b} \\ K_{21}^{b} & K_{22}^{b} & \cdots & K_{2r}^{b} \\ \vdots & \vdots & & \vdots \\ K_{r1}^{b} & K_{r2}^{b} & \cdots & K_{rr}^{b} \end{bmatrix} \tag{39}$$

3.4.3 Combined Stiffness Matrix

For a strip which is subjected to a combination of flexural and in-plane actions, its stiffness matrix may be composed from the individual stiffness of $[K_m^p]$ and $[K_{mn}^b]$.

Since the in-plane and flexural effects of the strip are uncoupled, the combined stiffness matrix may be treated in such a way that the individual action can be solved separately.

The partitioned matrix is given as

$$[K_{mn}] = \begin{bmatrix} K_{mn}^{p} & 0 \\ 0 & K_{mn}^{b} \end{bmatrix} \tag{40}$$

The force and displacement vectors will take the form

$$\text{Force vector } \{F_m\} = \begin{bmatrix} P_i^u \\ P_i^v \\ P_j^u \\ P_j^v \\ P_i^w \\ M_i \\ P_j^w \\ M_j \end{bmatrix} \tag{41}$$

$$\text{Displacement Vector } \{\delta_m\} = \begin{bmatrix} U_{im} \\ V_{im} \\ U_{jm} \\ V_{jm} \\ W_{im} \\ \theta_{im} \\ W_{jm} \\ \theta_{jm} \end{bmatrix} \tag{42}$$

3.4.4 Generalising Strip Stiffness Matrix

When the strip is not in a global coordination system, the following transformations are required

$$\text{Force vector } \{F_m\}^* = [T]\,\{F_m\} \tag{43}$$

$$\text{Displacement vector } \{\delta_m\}^* = [T]^{-1}\{\delta_m\} \tag{44}$$

$$\text{Stiffness matrix } [K_{mn}]^* = [T]^{-1}[K_{mn}]\,[T] \tag{45}$$

where [T] & $[T]^{-1}$ are coordinate transformation matrices

'*' superscript denotes in global axis

Finally the equilibrium equations in global axis are given as

$$[K_{mn}]^*\{\delta_m\}^* = \{\bar{F}_m\}^* \tag{46}$$

Once the stiffness matrix of the total structure is formed by assembling all the strip stiffnesses in global coordinate system, the unknown displacement may be solved in usual way by any suitable solver.

It is worthwhile to note that the overall stiffness matrix is in a banded matrix form and its bandwidth depends on the nodal difference of two nodal lines.

3.4.5 Remarks

The merits of this matrix over the finite element technique are:

i) There are no zero terms along the main diagonal of stiffness matrix because of preset condition of shape function.

ii) The bandwidth is relatively small and it is unnecessary to impose any further boundary conditions.

3.5 Applied Load

The formulation of the load vector is not as straightforward as in the finite element technique. Each applied load has to be expressed in terms of the mode shapes instead of its actual value.

i) uniform or triangular load

$$\{F_m\} = \int_o^a \int_o^b [f_m]^T \{q\}\, dxdy$$

$$= \{q\} \int_o^a f(x)dx \int_o^b f_m(y)dy \qquad (47)$$

where $\{q\}$ = applied load vector

ii) Point Load at Arbitrary Point

For a concentrated point load, integration is not necessary. It may be expressed as the load multiplied by the corresponding displacement shape function

$$\{P_m\} = \sum_{i=1}^{n} \{P_i\} f_m (y_i) \tag{48}$$

where n = total number of point loads

y_i = the position of point load at point 'i'

iii) Non-uniform load

This may be obtained by summing up each section of load as

$$\{F_m\} = \sum_{i=1}^{n} \int_0^a \int_{bi-1}^{bi} [f_{im}]^T \{q_i\} \, dxdy$$

$$= \sum_{i=1}^{n} \{q_i\} \int_0^a f(x)dx \int_{bi-1}^{bi} f_m(y_i)dy \tag{49}$$

where b_{i-1} & b_i are the height at each segment level

iv) Line Load

This may be expressed as

$$\{F_m\} = \{q\} \int_0^b f_m(y)dy \tag{50}$$

However, for an applied load acting inside a strip instead of a nodal line, the nodal forces corresponding to that applied load will be used instead of the actual inside load.

3.6 Variable Thickness

To allow for variation in the wall properties, the stiffness matrices as given in equations (25) and (35b) may be modified as

i) In-plane

$$[K^p_{mn}] = \sum_{i=1}^{n} \int_{a_{i-1}}^{a_i} \int_{0}^{b} [B_{pm}]^T \, [D_{pi}] \, [B_{pn}] \, dxdy \qquad (51)$$

ii) Bending

$$[K^b_{mn}] = \sum_{i=1}^{n} \int_{a_{i-1}}^{a_i} \int_{0}^{b} [B_{bm}]^T \, [D_{bi}] \, [B_{bn}] \, dxdy \qquad (52)$$

where n = total number of wall variations

i = property numbering

$[K^p_{mn}]$ & $[K^b_{mn}]$ are stiffness matrices for in-plane and bending respectively

$[D_{pi}]$ & $[D_{bi}]$ are material property matrices for in-plane and bending respectively.

3.7 Connecting Beams

The stiffness matrix of a beam element, connecting walls or line elements, may be derived in one of two ways:

a) The beam is considered as a strip and the stiffness matrix can be derived in the same way as previously described.

b) The usual slope deflection equations are used.

The second method has the disadvantage that additional equations are required to fully satisfy compatibility conditions. In deriving the stiffness matrix of a strip only the translations U and V are used. The slope deflection equations also use the rotation, Θ at the end of the connecting beam. Therefore, relationships are required between this rotation at the end of the connecting beam and the translations in the strip.

Three methods that are currently in use are described below:

3.7.1 Method 1 - Contraint Technique (fig (3.3))

This technique has been used with the finite element method to model a joint between a wall and a beam. Three approaches have been used.

a) Al Mahaidi & Nilson[2] proposed two constraints. For a small angle the rotation at the end of the beam is compatible with the x-direction displacement of the strip.

Hence, $$\frac{1}{d_b}(U_k - U_i) + \Theta_j = 0 \qquad (53)$$

The displacements at modes i, j and k are assumed to be on a straight line. Therefore,

$$\frac{1}{2}(U_i + U_k) - U_j = 0 \qquad (54)$$

b) Later, two proposals were suggested by Antony and

FIG. (3.3) ANTONY AND GANESAN'S CONSTRAINT METHODS

Ganesan[1]. Firstly, the nodes i & k are allowed to move to any suitable position. Hence

$$\frac{1}{d_b}(U_k - U_l) + \Theta_j = 0 \qquad (55)$$

Secondly, they assumed that the relative rotation of the connecting beam and the tangent to the connecting beam would be zero. Thus,

$$\frac{1}{d_{jl}}(V_j - V_l) - \Theta_j = 0 \qquad (56)$$

c) Littler[73] has combined the above proposals and used the three combined constraints at the joint to evaluate a Lagrange multiplier 'λ'.

3.7.2 Method 2 - Direct Interpretation

For compatibility conditions, the rotation of the beam and the wall face at the joint must be equal. Thus, the rotation of the beam may be expressed in term of the preset shape function f(y) as

$$\Theta_z \text{ (beam)} = -\sum_{m=1}^{r} U \frac{\partial Y^u(y)}{\partial y} \qquad (57)$$

where U = displacement parameter

$Y^u(y)$ = preset shape function in y - direction

'u' superscript denotes shape function corresponding to 'U' displacement

3.7.3 Method 3 - Direct Formulation

Two terms involving rotation are introduced into the displacement function. The polynomial for the displacement function is modified from a linear function to the following cubic function.

$$V = \left(1 - \frac{3x^2}{b^2} + \frac{2x^3}{b^3}\right)V_i + \left(x - \frac{2x^2}{b} + \frac{x^3}{b^2}\right)\Theta_{zi} + \left(\frac{3x^2}{b^2} - \frac{2x^3}{b^3}\right)V_j$$

$$+ \left(\frac{x^3}{b^2} - \frac{x^2}{b}\right)\Theta_{zj} \qquad (58)$$

The above polynomial interpolation function is derived from standard beam theory. A short description is presented to show its derivation.

When the cantilever wall deforms, its vertical deformation which may be obtained from the following differential equation.

$$\frac{d^4\delta_v(x)}{dx^4} = q \qquad (59)$$

where q = the vertical load

If 'q' is equal to zero, the general solution to equation (59) may be written as

$$\delta_v(x) = C_1 + C_2x + C_3x^2 + C_4x^3 \qquad (60)$$

After substituting the boundary conditions to equation (60) it becomes

$$\begin{bmatrix} V_i \\ \theta_i \\ V_j \\ \theta_j \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 1 & b & b^2 & b^3 \\ 0 & 1 & 2b & 3b^2 \end{bmatrix} \begin{bmatrix} C_1 \\ C_2 \\ C_3 \\ C_4 \end{bmatrix} \quad (61)$$

or in shortened form, it is written as

$$\{a\} = [A]\,\{C\} \quad (62)$$

Thus,

$$\{C\} = [A]^{-1}\,\{a\} \quad (63)$$

Finally, its polynomial function f(x) along x-direction is given as

$$f(x) = [1,x,x^2,x^3] \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ -\frac{3}{b^2} & -\frac{2}{b} & \frac{3}{b^2} & -\frac{1}{b} \\ \frac{2}{b^3} & \frac{1}{b^2} & -\frac{2}{b^3} & \frac{1}{b^2} \end{bmatrix} \begin{bmatrix} V_i \\ \theta_i \\ V_j \\ \theta_j \end{bmatrix} \quad (64)$$

where b = the distance between two nodes in x-direction.

3.8 Line Element

The element is similar to a strip. It is used to model the long column in the frame structure. Its stiffness matrix may be formulated either by the same process as a strip element or by directly applying basic beam theory to obtain the stress resultants from the following relationship.

$$\text{strain} \quad \varepsilon = \frac{\partial F(y)}{\partial y} \tag{65}$$

$$\text{stress} \quad \sigma = D\varepsilon \tag{66}$$

Then, moment curvature relationship can be expressed as

$$M = D\,\frac{\partial^2 \overset{u,v,w}{F(y)}}{\partial y^2} \tag{67}$$

The stiffness matrix of the line element is

$$K_{mn} = \int_0^a [B_m]^T\,[\bar{D}]\,[B_n]\,\{\delta_m\}\,dy \tag{68}$$

where $[\bar{D}]$ is material rigidity matrix in term of stress resultants and may be written as

$$[\bar{D}] = \begin{bmatrix} \frac{AG}{f} & & & & & -\frac{AG}{f} \\ & EA & & & & \\ & & \frac{AG}{f} & \frac{AG}{f} & & \\ & & & EI_x & & \\ & & & & Gr_J & \\ & & & & & EI_Z \end{bmatrix} \tag{69}$$

where G= shear rigidity of line element

f = shear shape factor

r_J = torsional constant

and where [B] is the preset mode shape matrix for displacements U, V & W and rotations Θx, Θy & Θz and is given as

$$[B] = \begin{bmatrix} \frac{\partial F^u(y)}{\partial y} & & & & & -\frac{\partial F^u(y)}{\partial y} \\ & \frac{\partial F^v(y)}{\partial y} & & & & \\ & & \frac{\partial F^w(y)}{\partial y} & \frac{\partial F^w(y)}{\partial y} & & \\ & & & \frac{\partial^2 F^w(y)}{\partial y^2} & & \\ & & & & \frac{\partial F^w(y)}{\partial y} & \\ & & & & & \frac{\partial^2 F^u(y)}{\partial y^2} \end{bmatrix} \qquad (70)$$

where $F^u(y)$, $F^v(y)$ & $F^w(y)$ are preset mode shape functions with respect to each displacement parameter.

Substituting equations (69) & (70) into equation (68), the stiffness matrix of the line element may be obtained.

3.9 Transformation Matrix

The formulation of the stiffness matrix for each type of element has been briefly described in section 3.4. The resulting displacement functions are shown in fig (3.3) and fig (3.4).

In order to satisfy compatibility conditions between different elements three methods were suggested in section 3.7. The first method proposed displacement constraints by various authors. In the other two methods the rotation is represented as a function of displacement. As these two methods are easier to incorporate into the finite strip method, they are the ones used to produce a transformation matrix. For the structures considered, a transformation matrix may be required for:

a) strip element to beam element (fig (3.4))

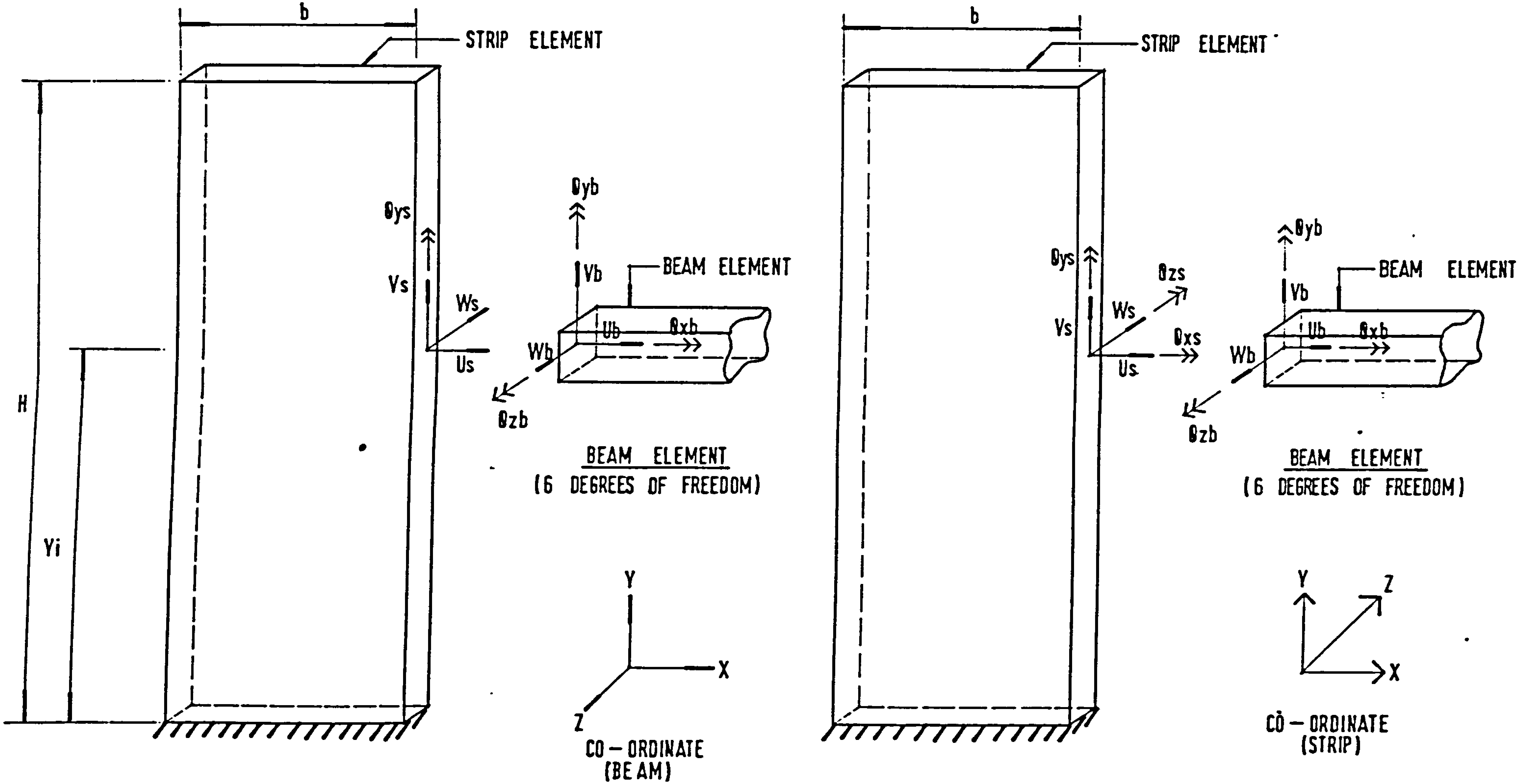
b) line element to beam element (fig(3.5))

As the procedure for both is the same only the first will be described. However, two types of strip elements are considered:

a) Strip with 4 Degrees of Freedom

As it can be seen from fig (3.4a), the displacement parameters for the strip are U, V W and Θy. The beam has two additional parameters Θx and Θz. To be compatible with each other, a compatibility matrix is established to convert the displacement parameters of the connecting beam to those of the strip. The conversion matrix is given as

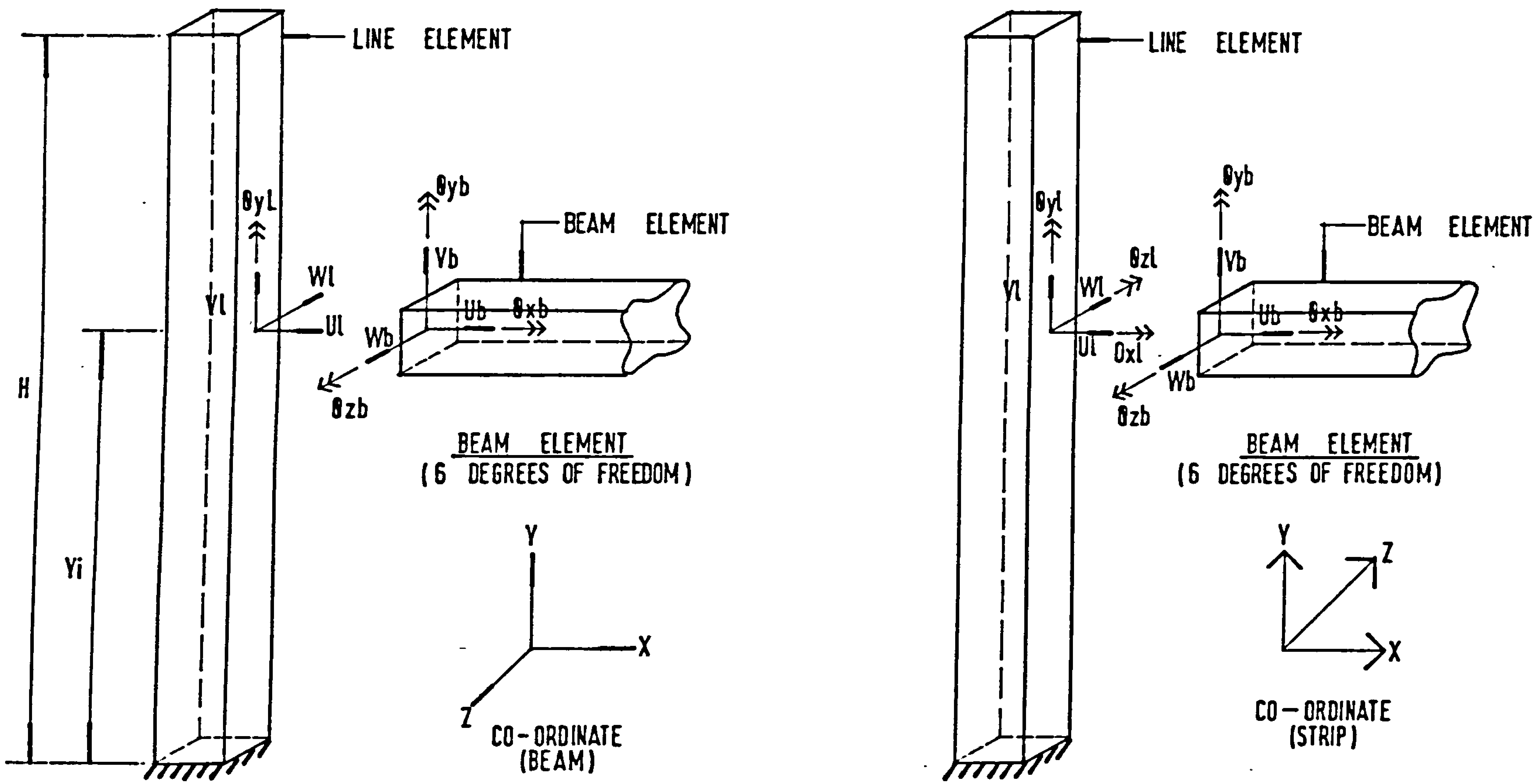
$$\begin{bmatrix} U_{bi} \\ V_{bi} \\ \Theta_{zbi} \\ W_{bi} \\ \Theta_{xbi} \\ \Theta_{ybi} \end{bmatrix} = \begin{bmatrix} F^{u}(y) & & & \\ & F^{v}(y) & & \\ -\dfrac{\partial F^{u}(y)}{\partial y} & & & \\ & & -F^{w}(y) & \\ & & -\dfrac{\partial F^{w}(y)}{\partial y} & \\ & & & F^{w}(y) \end{bmatrix} \begin{bmatrix} U_{i} \\ V_{i} \\ W_{i} \\ \Theta_{yi} \end{bmatrix} \qquad (71)$$



a) STRIP WITH 4 DEGREES OF FREEDOM

b) STRIP WITH 6 DEGREES OF FREEDOM

FIG (3.4) STRIP AND BEAM ELEMENTS



a) LINE ELEMENT WITH 4 DEGREES OF FREEDOM

b) LINE ELEMENT WITH 6 DEGREES OF FREEDOM

FIG (3.5) LINE AND BEAM ELEMENTS

and for the strip, it may be expressed as

$$U_{si} = F^{u}(y)U_{i} \tag{72}$$

$$V_{si} = F^{v}(y)V_{i} \tag{73}$$

$$W_{si} = F^{w}(y)W_{i} \tag{74}$$

$$\Theta_{ysi} = F^{w}(y)\Theta_{yi} \tag{75}$$

where s = strip

b = connecting beam

i = nodal line 'i'

n & m = series of mode shapes

b) Strip with 6 Degrees of Freedom

The strip and connecting beam have the same displacement and rotation parameters as shown in fig(3.4b). The compatibility matrix is simple and straightforward, and is given as

$$\begin{bmatrix} U_{bi} \\ V_{bi} \\ \Theta_{zbi} \\ W_{bi} \\ \Theta_{xbi} \\ \Theta_{ybi} \end{bmatrix} = \begin{bmatrix} F^{u}(y) & & & & & \\ & F^{v}(y) & & & & \\ & & F^{v}(y) & & & \\ & & & -F^{w}(y) & & \\ & & & & \frac{\partial F^{w}(y)}{\partial y} & \\ & & & & & F^{w}(y) \end{bmatrix} \begin{bmatrix} U_{i} \\ V_{i} \\ \Theta_{zi} \\ W_{i} \\ \Theta_{xi} \\ \Theta_{yi} \end{bmatrix} \tag{76}$$

and for the strip it may be written as

$$U_{si} = F^u(y)U_i \tag{77}$$

$$V_{si} = F^v(y)V_i \tag{78}$$

$$\Theta_{zsi} = F^v(y)\Theta_{zi} \tag{79}$$

$$W_{si} = F^w(y)W_i \tag{80}$$

$$\Theta_{xsi} = \frac{\partial F^w(y)}{\partial y}\Theta_{xi} \tag{81}$$

$$\Theta_{ysi} = F^w(y)\Theta_{yi} \tag{82}$$

3.9.1 Remarks

The accuracy and reliability of this approach is closely dependent on the choice of the relevant preset mode shape function. This function has to be versatile so that for any type of structural configuration it can represent the complete displacement field of the structure which is under investigation. To obtain more accurate results, Method 3 is recommended although the size of the matrix is increased.

3.10 Equivalent Approximate Method

When different types of elements are used then compatibility conditions have to be considered. Shear wall structures can be represented by strip elements and beam elements. However if the beams could be replaced by a continuous medium only strip elements need be used.

The replacement of the beams by the continuous medium is the approximation made in the continuum method. In this method it is assumed that the connecting beams have points of contraflexure at mid-point and carry no axial forces so that at these points only shear force exists as shown in fig (3.6).

The cantilevers, either side of the points of contraflexure, are replaced by a continuous medium. In order that the medium is equivalent to the connecting beams it can be seen from fig (3.6) that

$$q_b = q(x) * h \tag{83}$$

Also the deflections at the points of contraflexure must be equal.

The cantilevers will deform in bending and shear. So for a tip load of q_b and a span a/2 the tip deflection (Y_b) is given by the standard formulae

$$Y_b = \frac{q_b a^3}{24 E_b I_b} + \frac{q_b f a}{2 G_b A_b} \tag{84}$$

where f = shear shape factor

Assuming the material is isotropic, then

$$G_b = \frac{E_b}{2(1+v)} \tag{85}$$

Substituing equations (83) and (85) into equation (84)

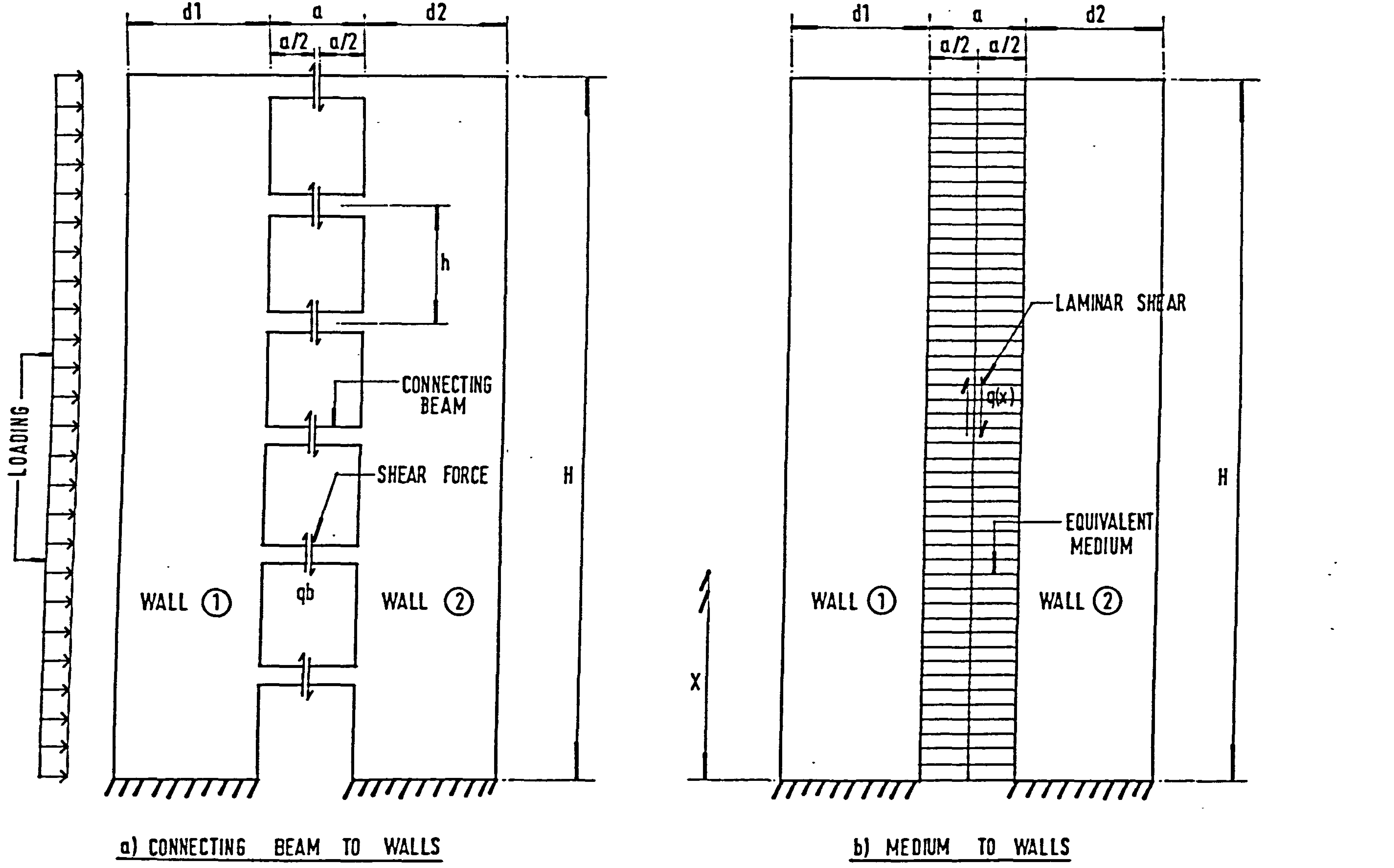


FIG (3.6) COUPLED SHEAR WALL MODULE

produces

$$Y_b = \frac{q_x h a^3}{24E_b I_b} + \frac{q_x h a f 2(1+v)}{2E_b A_b} \tag{86}$$

The equivalent medium will deform predominantly in shear due to its overall depth. Assuming that the bending deformation is negligible, the deflection at the point of contraflexure is given by

$$Y_m = \frac{q_x a 2(1+v)}{2E_m t} \tag{87}$$

where t = thickness of medium

As the equivalent medium is to be compatible with the cantilevers

$$Y_b = Y_m \tag{88}$$

Substituting equations (86) and (87) into equation (88), it becomes

$$\frac{q_x h a^3}{24E_b I_b} + \frac{q_x h a f 2(1+v)}{2E_b A_b} = \frac{q_x a 2(1+v)}{2E_m t} \tag{89}$$

For a connecting beam

$$I = \frac{td^3}{12} \tag{90}$$

$$A = td \qquad (91)$$

Substituting equations (90) and (91) into equation (89) and rearranging, it becomes

$$\frac{E_m}{E_b} = \frac{1}{\frac{h}{d}\left(\frac{a^2}{2(1+v)d^2}+f\right)} \qquad (92)$$

Now the connecting beams may be replaced by a strip element with the modulus E_m given by equation (92). As the structure consists entirely of strip elements no compatibility requirements are needed.

3.11 General Remarks

The theory and concept of finite strip for the elastic analysis of a coupled shear wall and a frame structure have been briefly presented in this chapter. General computer programs for the analysis of coupled shear walls and combinations of coupled shear walls with the frame structures, based on above theory, have been developed and will be described in Chapter eight. The accuracy of this method compared with theoretical and experimental results is shown in Chapters four and six.

As can be seen from the derivations the economy of computer storage and solution time is due to the presetting of the boundary conditions. The structure is idealised in such a way as to reduce the number of joints compared to the finite element method. This reduces the number of simultaneous equations to be solved.

The shape functions developed so far produce accurate values for both vertical and horizontal deflections. However, they produce a zero value for the shearing stress at the base of the structure. Therefore, approximate base values are calculated at a short distance from the actual base.

CHAPTER FOUR

COMPARISION OF ANALYTICAL AND EXPERIMENTAL RESULTS FOR COUPLED SHEAR WALLS

4.1 Introduction

To verify the accuracy of the finite strip and continuum methods, several examples are considered. The results of the analyses using these two methods are compared with those obtained using other methods as well as experimental investigations. The examples are presented in two groups.

4.2 Comparision of Analytical Aspects with Previous Examples

Eight examples dealing with different configurations of coupled shear walls are presented and described below.

4.2.1 Equal or Unequal Connecting Beam Spacings

A planar coupled shear wall previously studied by Antony and Ganesan(1) is reconsidered here. The positions of the connecting beams and all structural details and material properties are shown in Fig (4.1). The structure was analysed for a series of lateral point loads at each floor level. The maximium lateral and vertical displacements and stress distributions computed by finite element technique, with constraint conditions at junctions, are compared with the finite strip method with and without the effects of local deformation at wall-beam junctions.

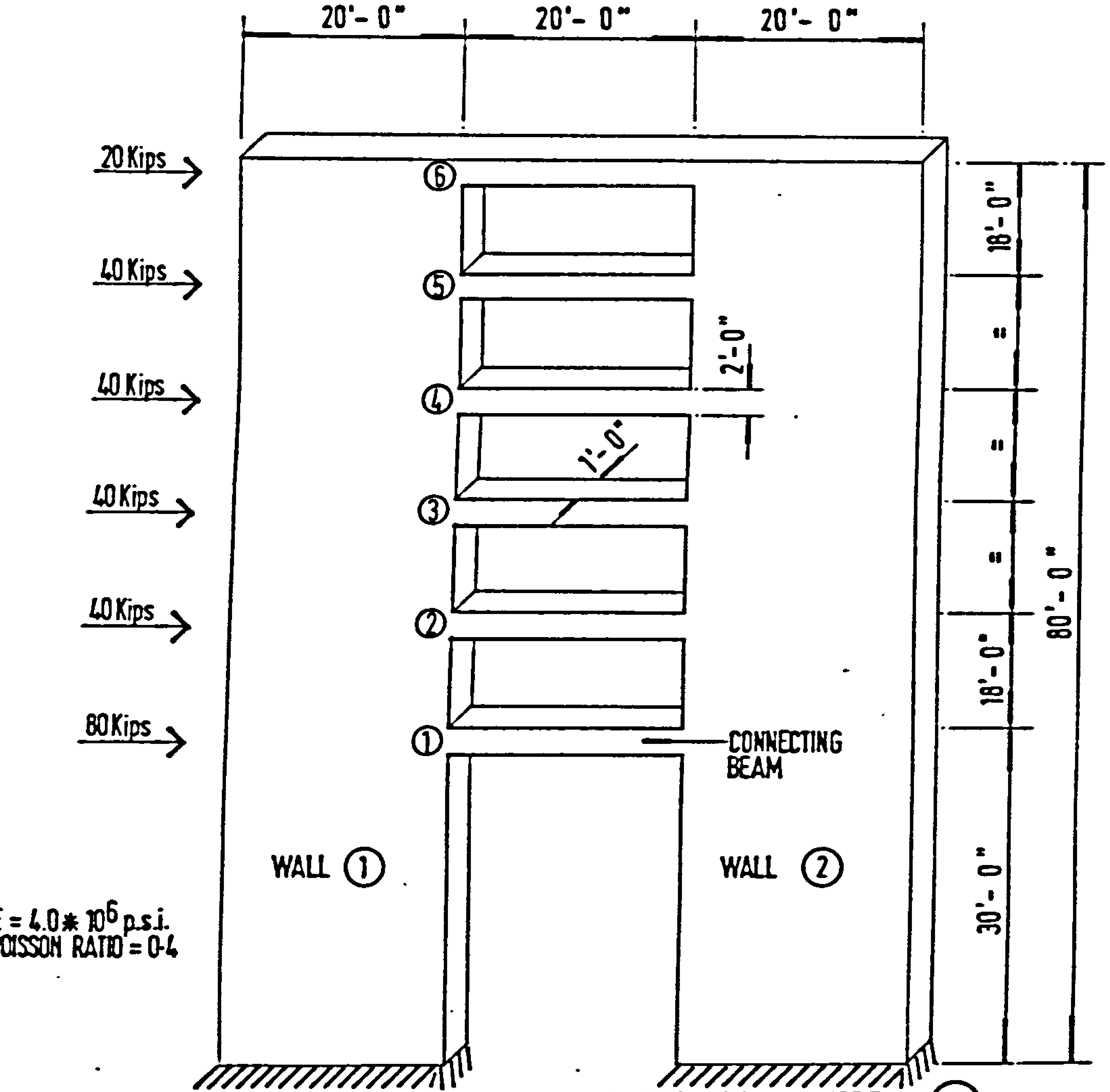


FIG (4·1) COUPLED SHEAR WALL MODEL ①
(DIFFERENT CONNECTING BEAM SPACING AND LOADING)

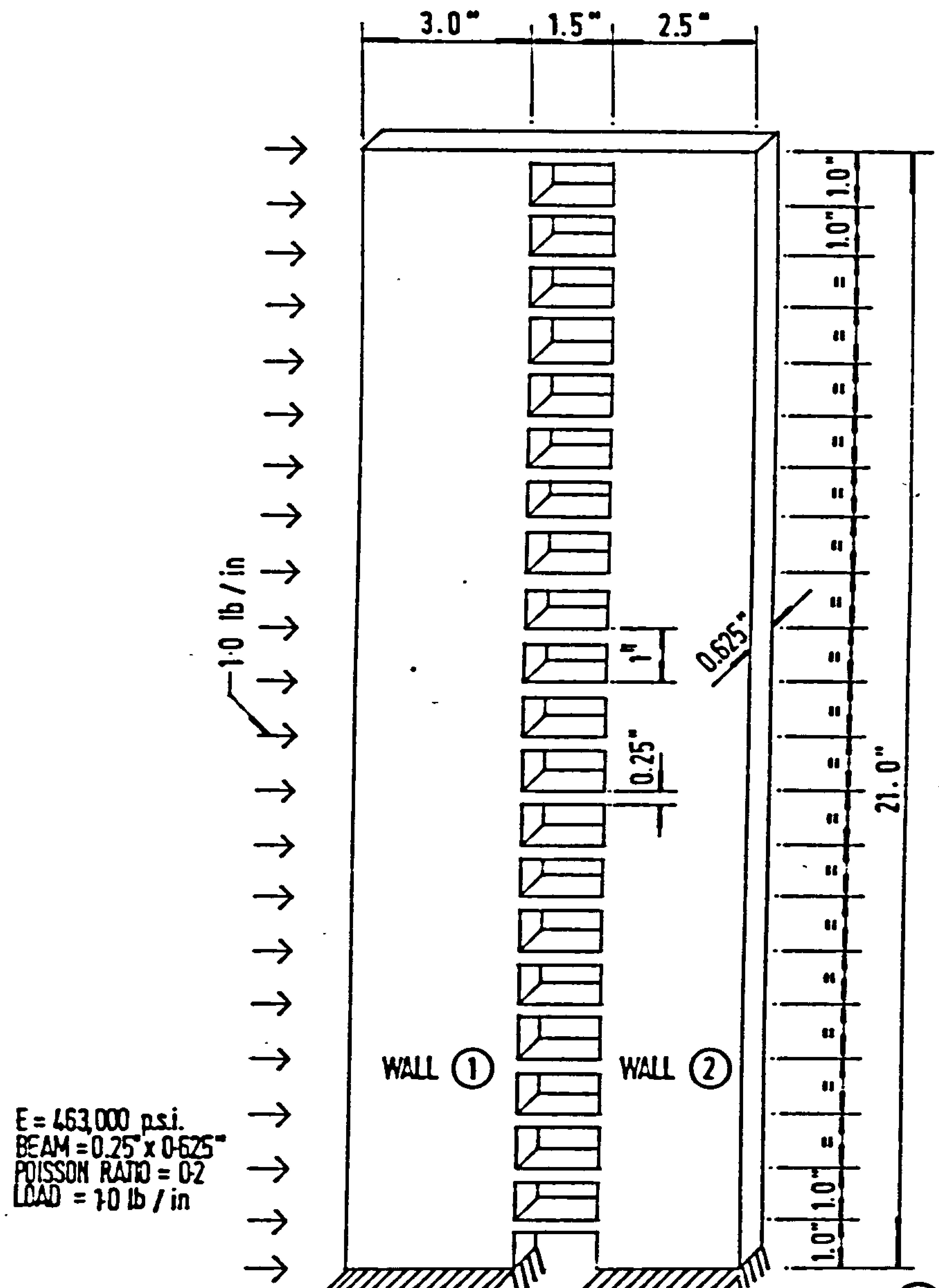


FIG (4·2) COUPLED SHEAR WALL MODEL ②
(DIFFERENT WALL DIMENSIONS)

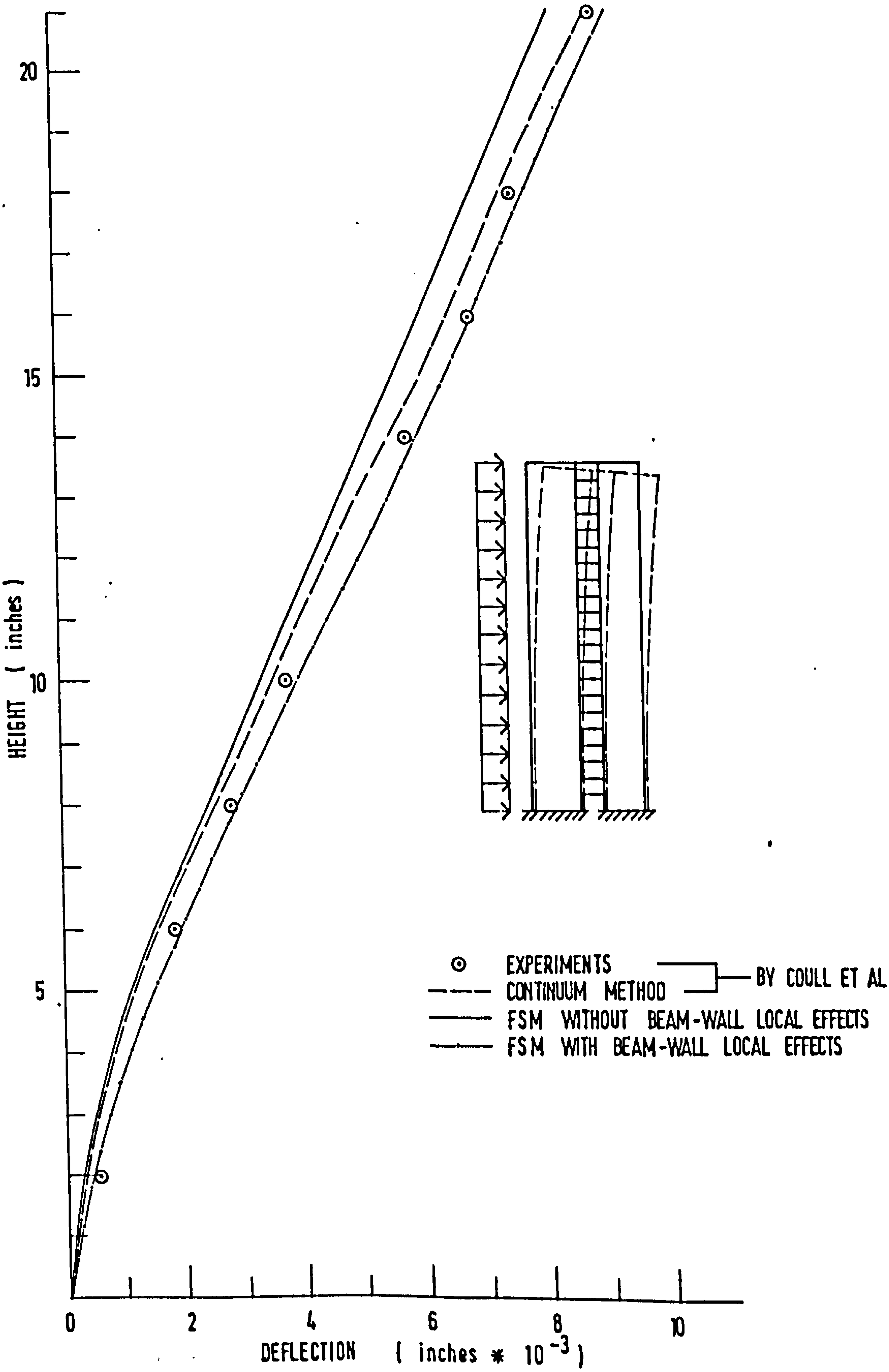


FIG (4.3) DEFLECTION PROFILE FOR MODEL (2)

TABLE 4-1 MAXIMUM STRESS AND DISPLACEMENTS FOR WALL

CASE OF STUDY	NOS. OF ELEMENTS USED	NOS. OF NODES	N L M	DEGREE OF FREEDOM	C P U TIME (SECOND)	MAX 'U' DISPL (inches)	MAX 'V' DISPL (inches)	MAX 'Y' (lb/in^2)
1	198	250	12	504	30.49	0.2724	0.0439	702.61
2	198	250	12	504	29.63	0.2741	0.0441	703.77
3	222	280	24	576	37.45	0.2712	0.0436	661.16
4	264	334	NIL	648	40.19	0.2115	0.0342	593.77
5	3	4	NIL	8	1.52	0.242	0.0385	626.8
6	3	4	NIL	8	1.53	0.250	0.0395	636.5

CASES 1 TO 4 WERE STUDIED BY OTHERS USING THE FINITE ELEMENT METHOD WITH CONSTRAINT METHOD
CASE 5 IS BY FINITE STRIP METHOD WITHOUT CONSIDERING LOCAL DEFORMATION
CASE 6 IS BY FINITE STRIP METHOD WITH CONSIDERING LOCAL DEFORMATION
WHERE 'NLM' DENOTES NUMBER OF LAGRANGIAN MULTIPLIER USED

TABLE 4-2 — MOMENTS AND SHEAR FORCE AT ENDS OF CONNECTING BEAMS FOR MODEL (1)

CONNECTING BEAM	FINITE ELEMENT METHOD BY ANTONY AND GANESAN			FINITE STRIP METHOD					
				WITH LOCAL WALL DEFORMATION			WITHOUT LOCAL WALL DEFORMATION		
	Mab (kip – ft)	Mba (kip – ft)	P (kip)	Mab (kip – ft)	Mba (kip – ft)	P (kip)	Mab (kip – ft)	Mba (kip – ft)	P (kip)
1	31.37	31.60	11.30	50.5	50.2	19.6	56.0	55.8	20.1
2	38.75	38.27	6.5	55.9	55.8	22.1	61.7	61.7	22.3
3	40.29	39.79	31.66	58.2	58.3	21.7	64.2	64.2	21.8
4	41.33	41.06	26.40	59.2	59.3	20.4	64.9	65.1	20.5
5	41.10	40.89	23.42	58.2	58.5	18.0	63.7	63.9	17.9
6	38.78	38.48	19.56	57.6	57.9	13.4	63.0	63.3	13.2

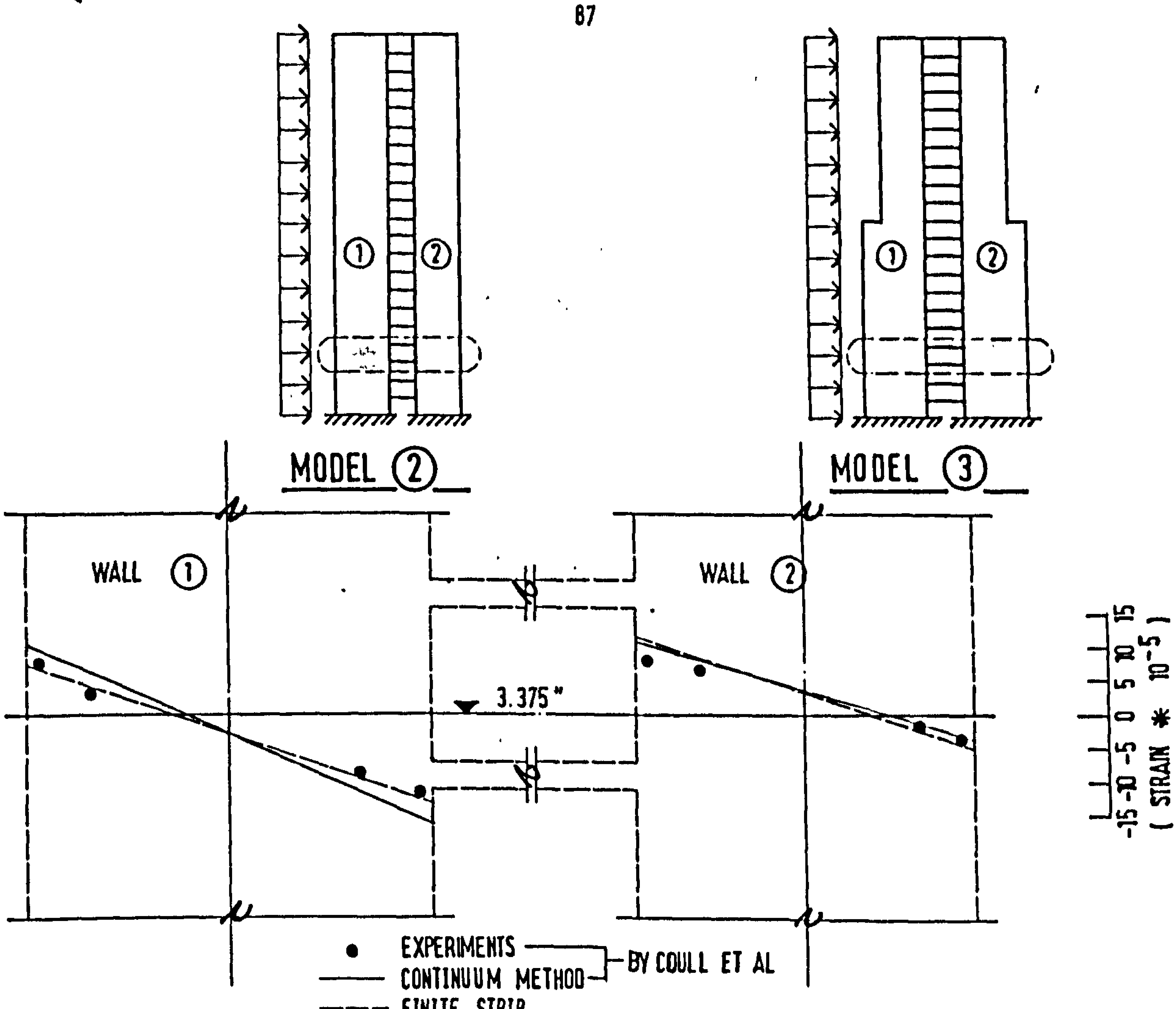


FIG (4.4) STRESS DISTRIBUTION FOR MODEL ②

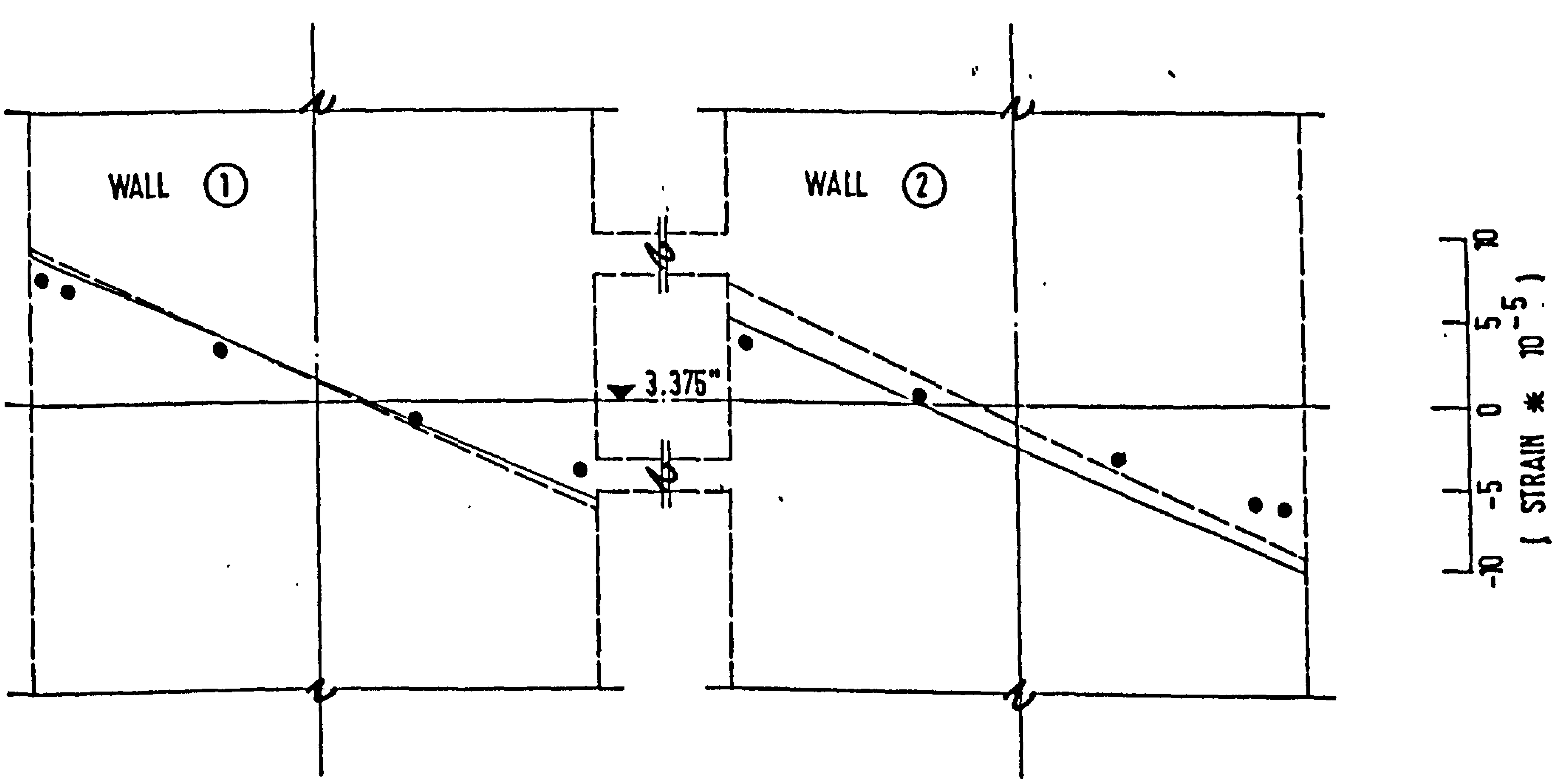


FIG (4.5) STRESS DISTRIBUTION FOR MODEL ③

The comparative results are presented in Table 4-1 for maximum stress and displacements in the wall. In Table 4-2, the end moments of the connecting beams are compared.

Another model with equal connecting beam spacing is shown in fig (4.2). This model which was previously investigated by Coull, Puri and Tottenham[20] is reanalysed using the finite strip method for a lateral uniformly distributed load. Its displacement shape and stress distributions are shown in figs (4.3) to (4.5).

4.2.2 Symmetrical and Asymmetrical Stepped Wall Configuration

Two models analysed by Coull and Puri[20] are shown in figs (4.6) & (4.7). Both were analysed for a lateral uniformly distributed load of 1.0 lb/in. The finite strip method has been used to reanalyse both models so that a comparison of the results can be made.

The deflected shape of both models under the applied loading is shown in figs (4.8) & (4.9). It can be seen for both models that the local wall-beam junction effect has a considerable effect on the finite strip results.

Both the continuum and finite strip methods produce values very close to the experimental results.

The stress distribution in the wall for both models is shown in figs (4.5) & (4.10). The finite strip results are shown relative to the experimental and theoretical results produced by Coull et al. Again both theoretical values agree reasonably well with the experimental results.

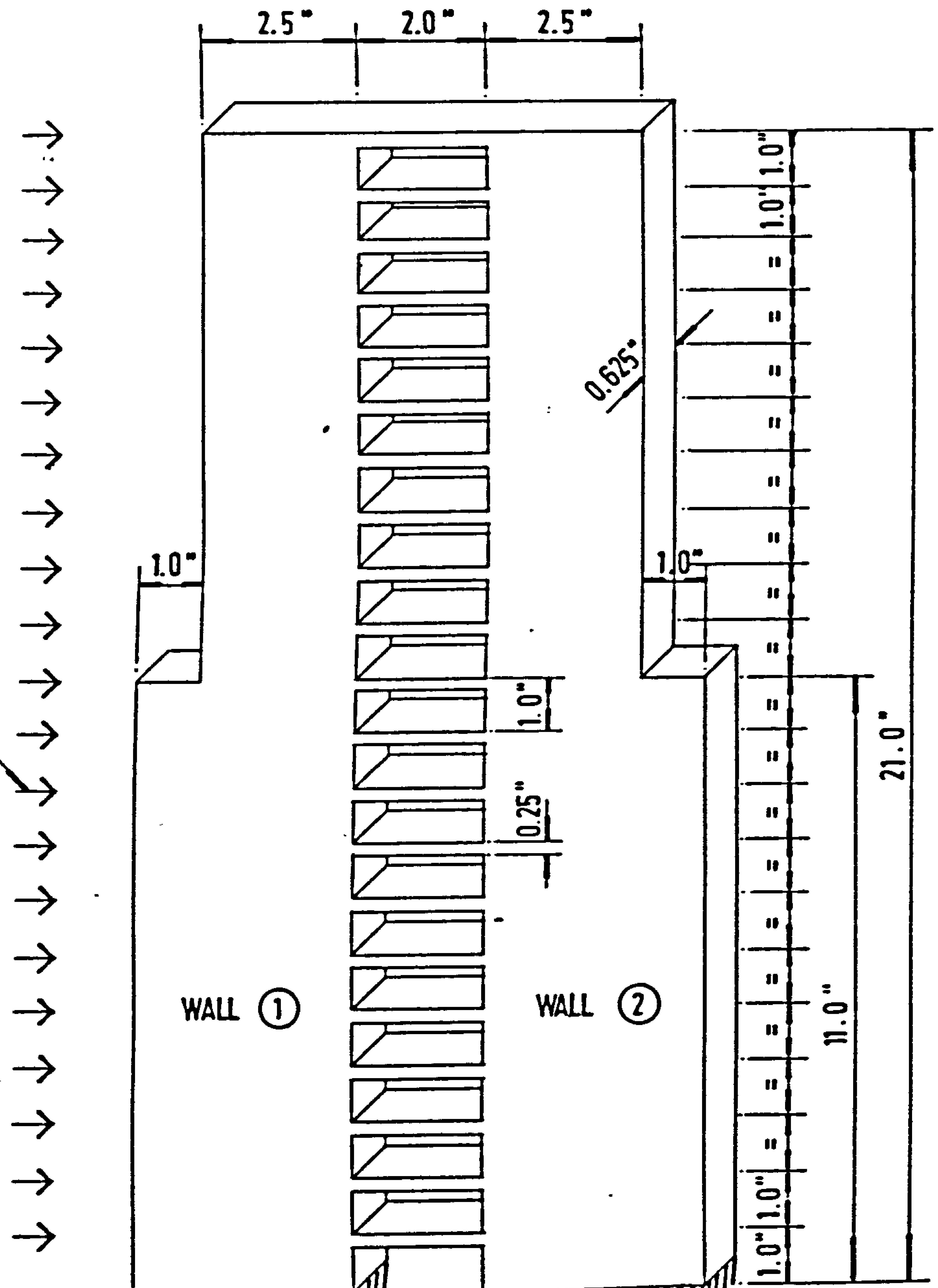


FIG (4·6) COUPLED SHEAR WALL MODEL ③
(WITH VARIOUS STEPS)

E= 467,000 p.s.i.
POISSON RATIO = 0·2

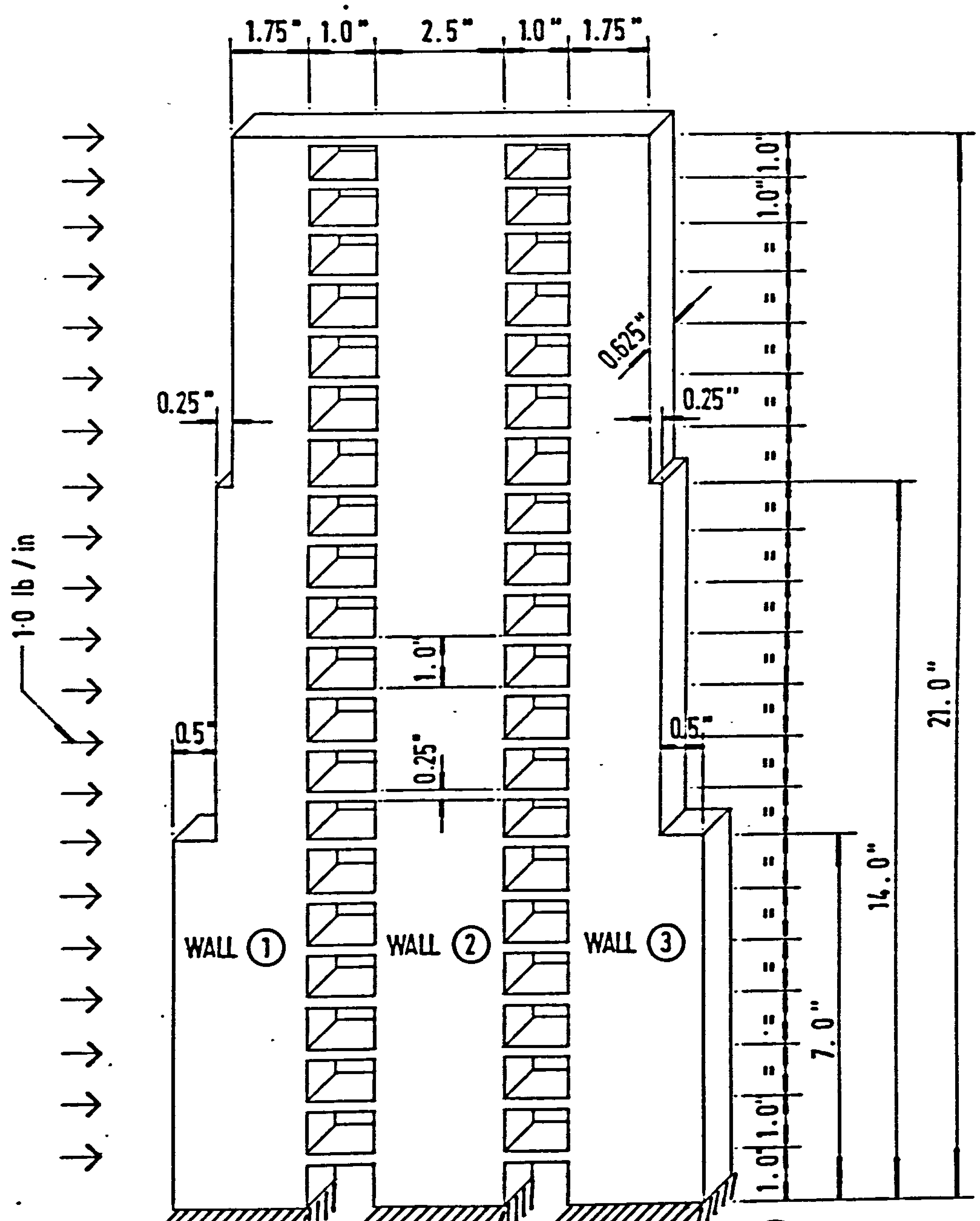


FIG (4·7) COUPLED SHEAR WALL MODEL ④
(WITH VARIOUS STEPS)

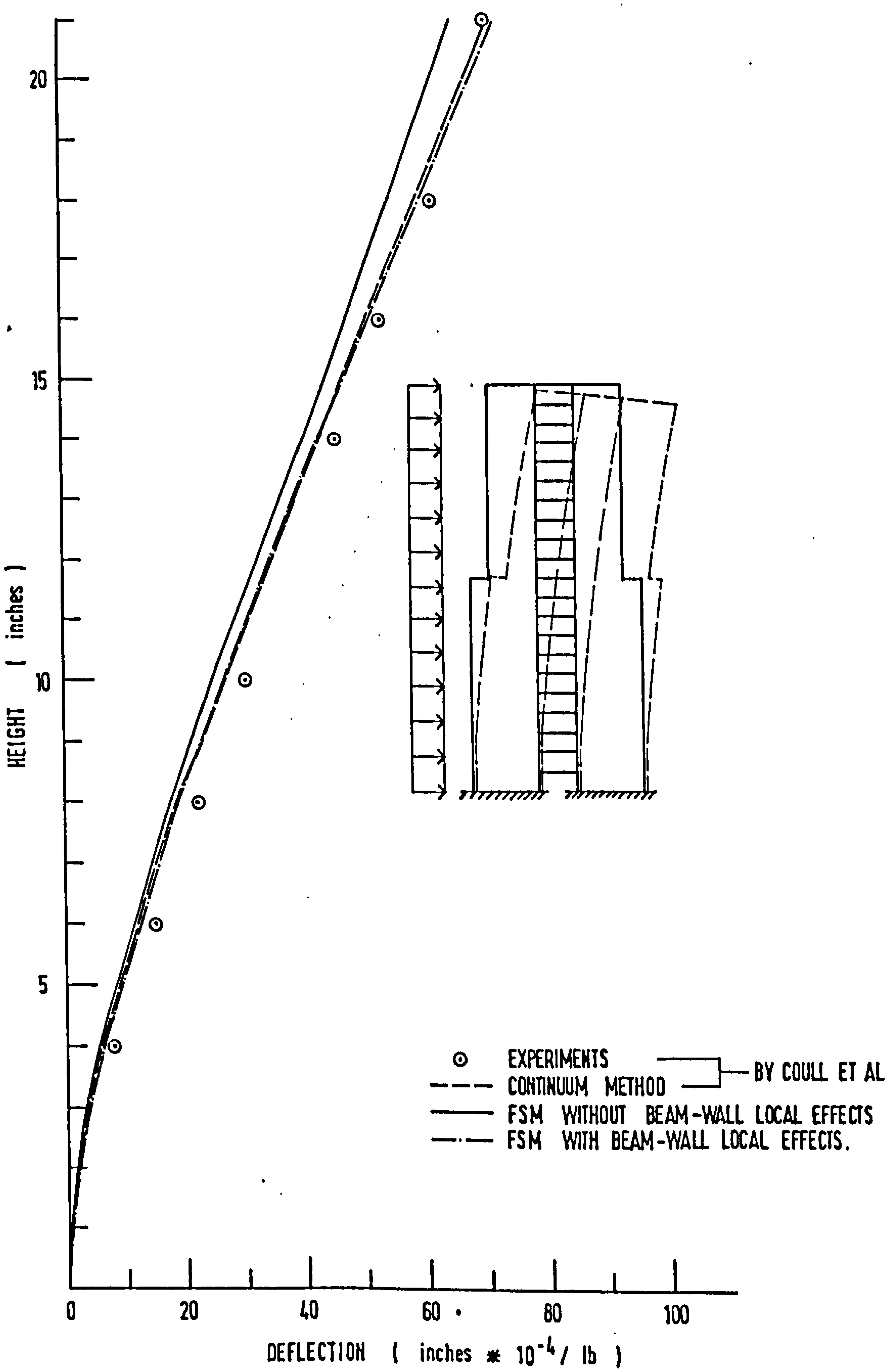


FIG (4.8) DEFLECTION PROFILE FOR MODEL ③

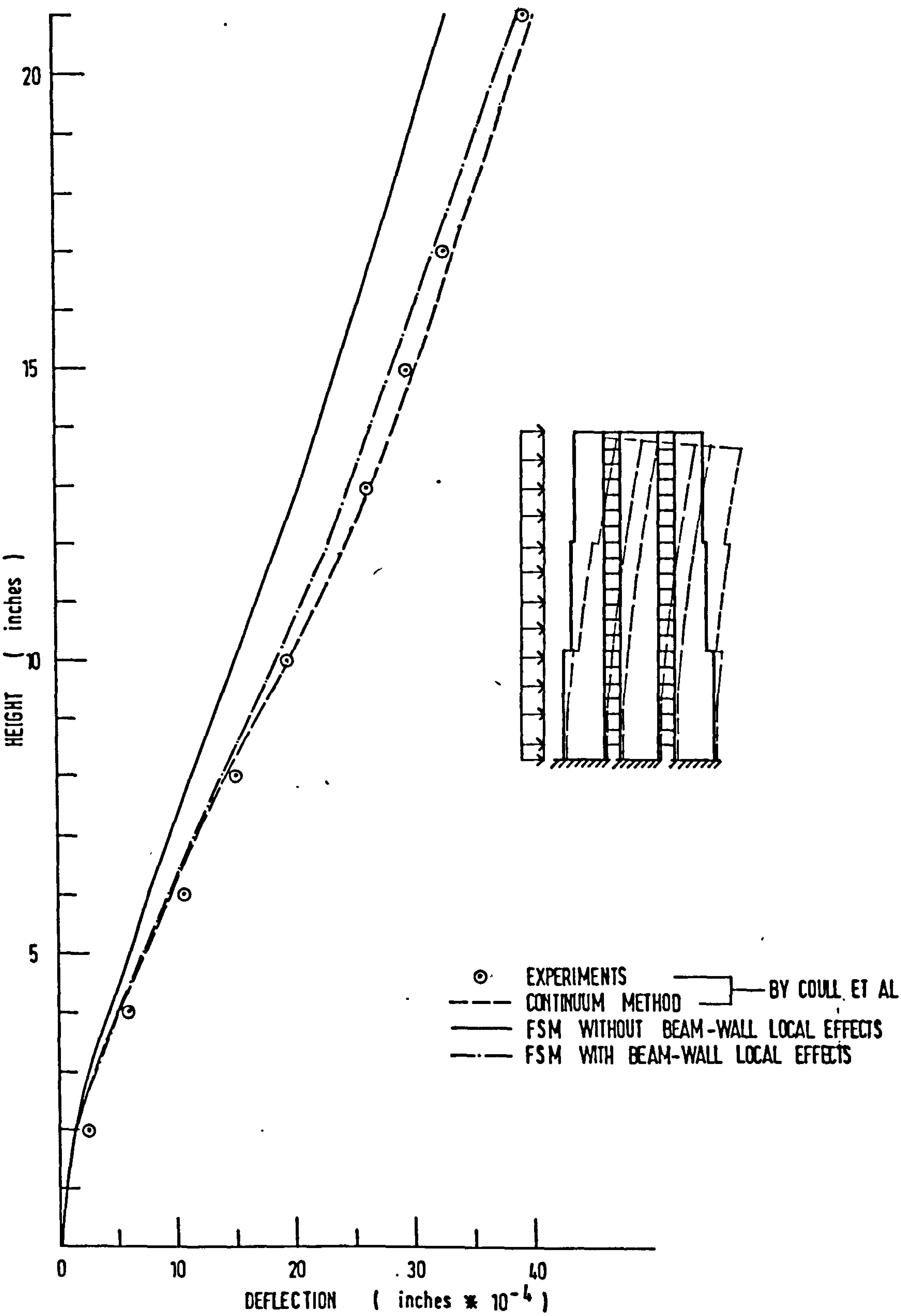


FIG (4.9) DEFLECTION PROFILE FOR MODEL (4)

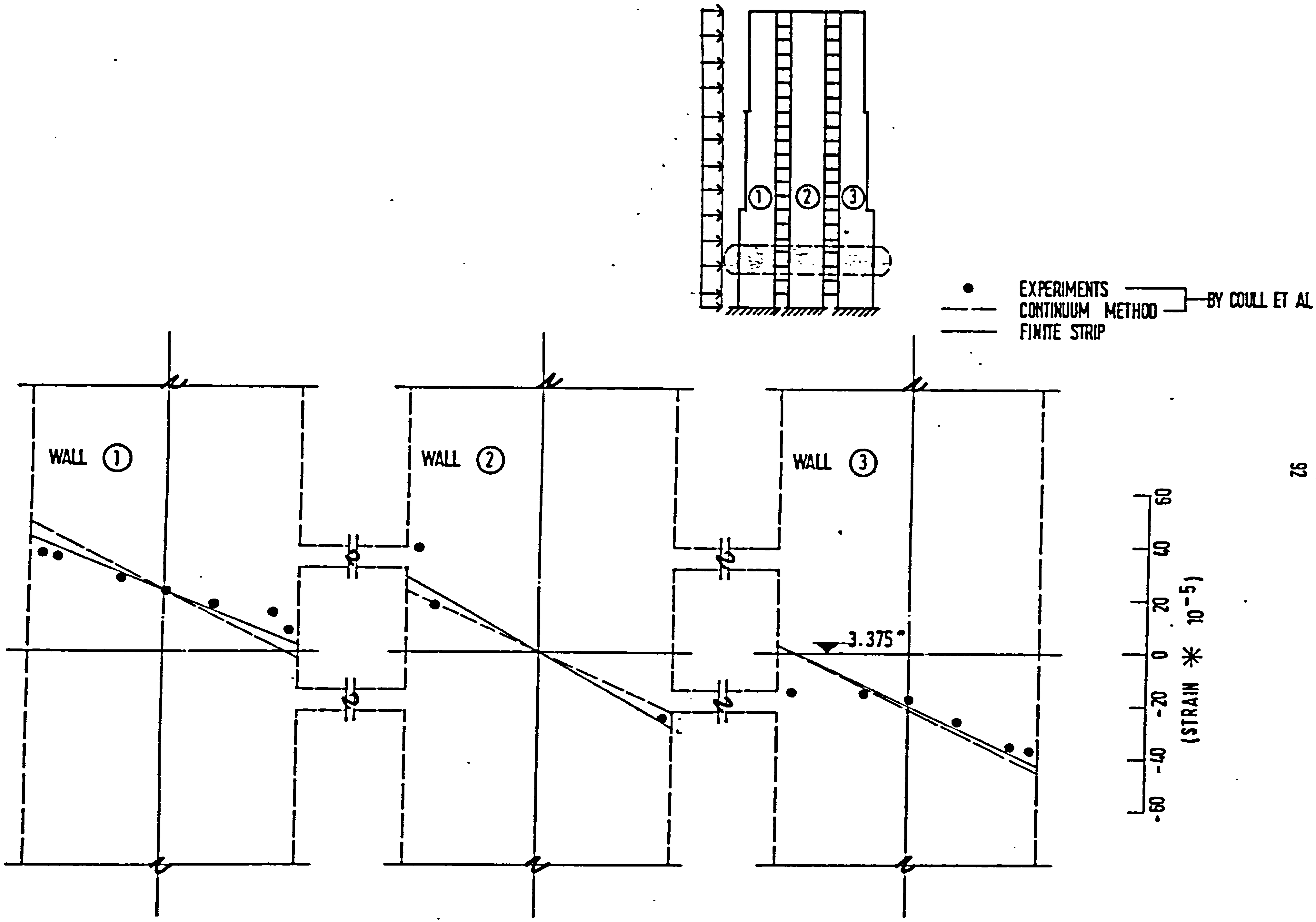


FIG (4-10) STRESS DISTRIBUTION FOR MODEL 4

4.2.3. Walls with Variable Thickness

The variation of the thickness of the wall was also considered by Coull et al (19). Two models were analysed, using the continuum method, and their dimensions are shown in figs (4.11) & (4.14). Both models were analysed for a lateral uniformly distributed load of 1.0 lb/in and a tip point load of 21.0 lbs respectively.

Both walls have been reanalysed using the finite strip method for the same load condition. Again the local wall-beam junction effect has been included in the finite strip method.

The lateral deflection of the walls is shown in figs (4.15) to (4.18). The finite strip method, with local wall-beam effect, produces values comparable with the theoretical and experimental values obtained by Coull et al.

The vertical stress distribution at various levels in the walls are shown in figs (4.19) to (4.22). Again good agreement is obtained between the finite strip values and those obtained by Coull et al.

4.3 Static Experimental Models

Six experimental coupled shear wall models with various connecting beam lengths, different wall sizes, both symmetrical and assymetrical walls, and variable thickness, were tested. These models were machined from perspex sheets, as its low modulus of elasticity will give reasonable deflections under small loads. The configuration of each model is given in

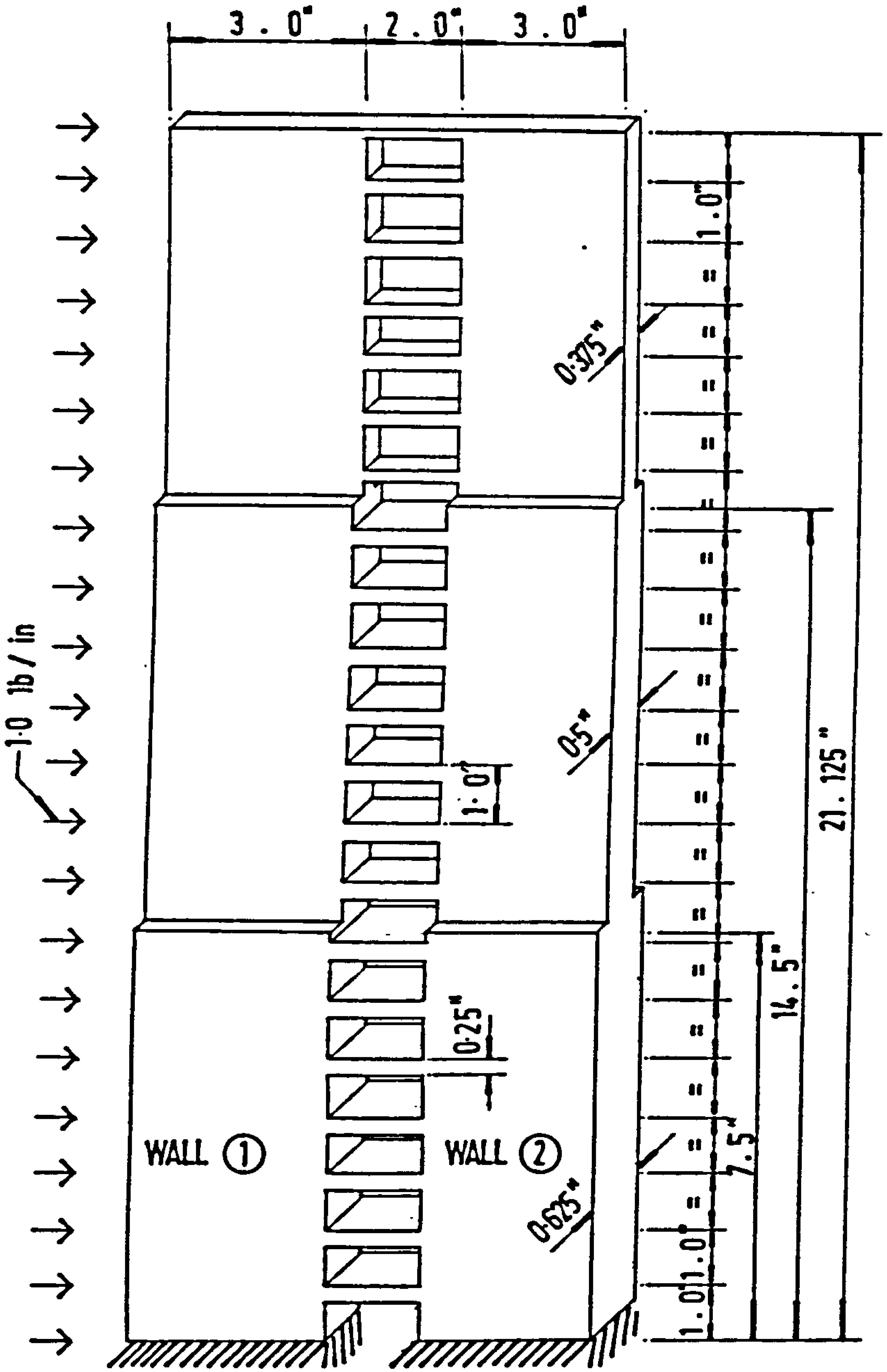


FIG (4·11) COUPLED SHEAR WALL MODEL ⑤
(DIFFERENT WALL THICKNESS)

E = 440,000 p.s.i.
Poisson Ratio = 0·2

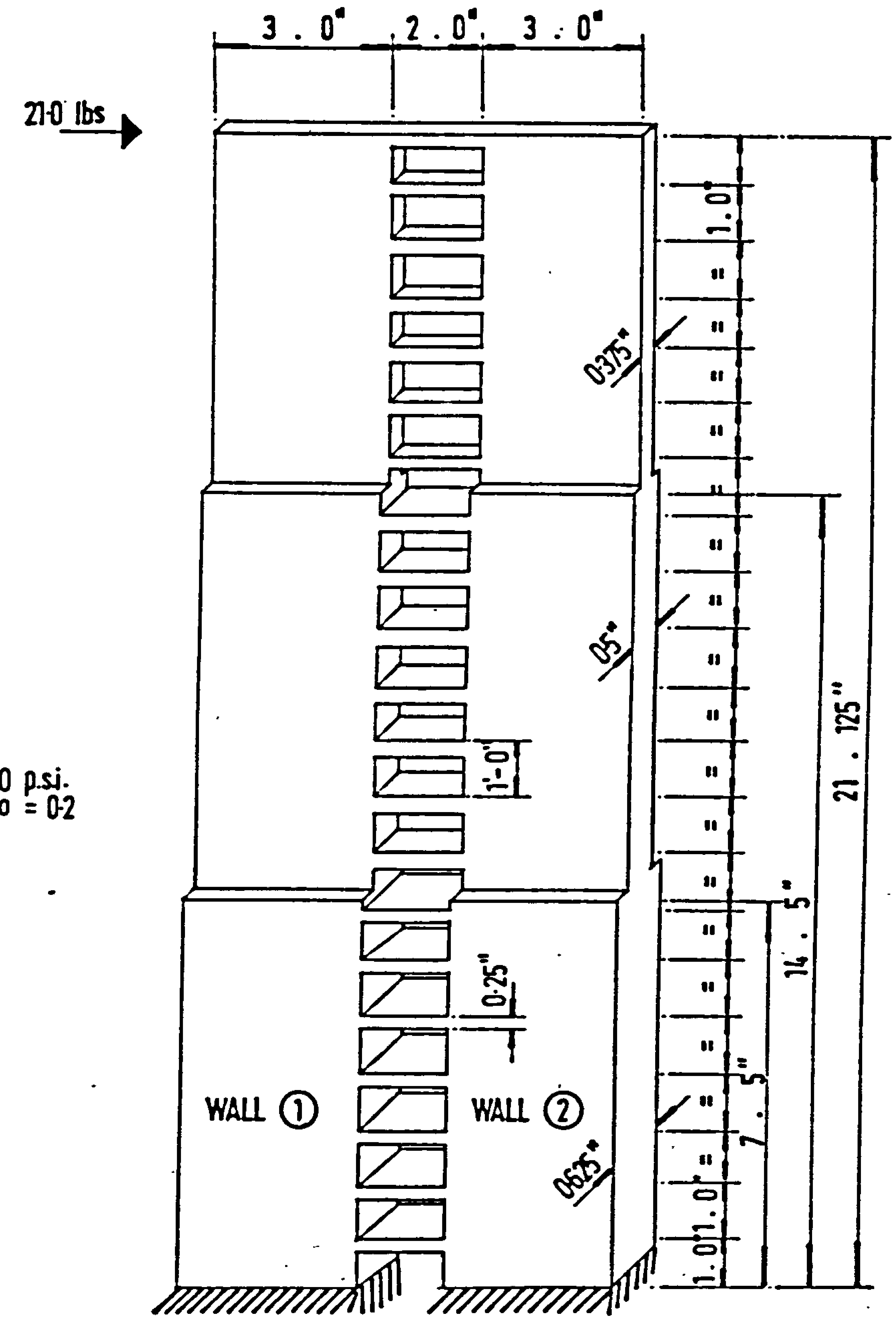


FIG (4·12) COUPLED SHEAR WALL MODEL ⑥
(DIFFERENT WALL THICKNESS)

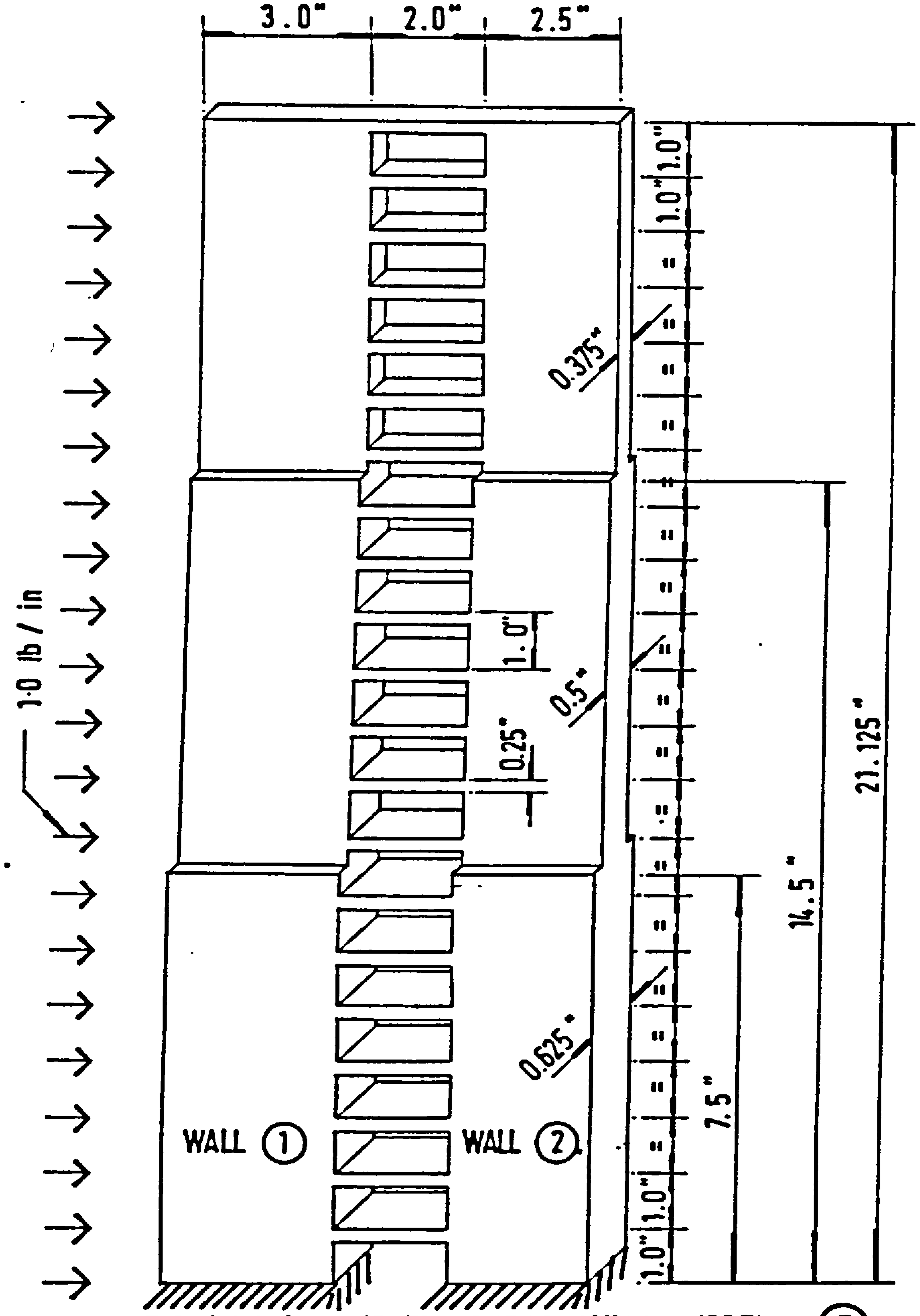


FIG (4.13) COUPLED SHEAR WALL MODEL ⑦

(DIFFERENT WALL THICKNESS AND DIMENSION)

E = 440,000 p.s.i.
POISSON RATIO = 0.2

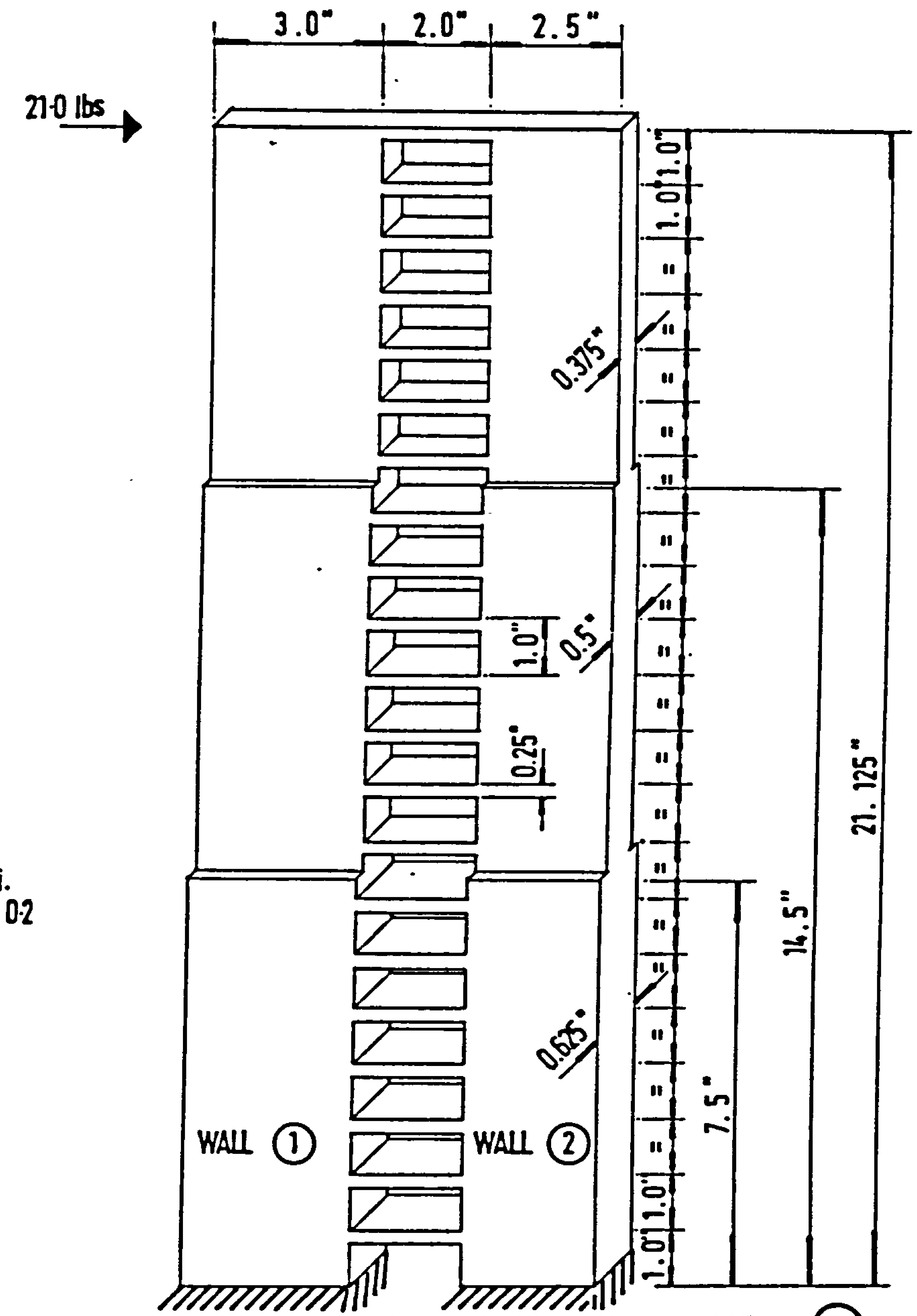


FIG (4.14) COUPLED SHEAR WALL MODEL ⑧

(DIFFERENT WALL THICKNESS AND DIMENSION)

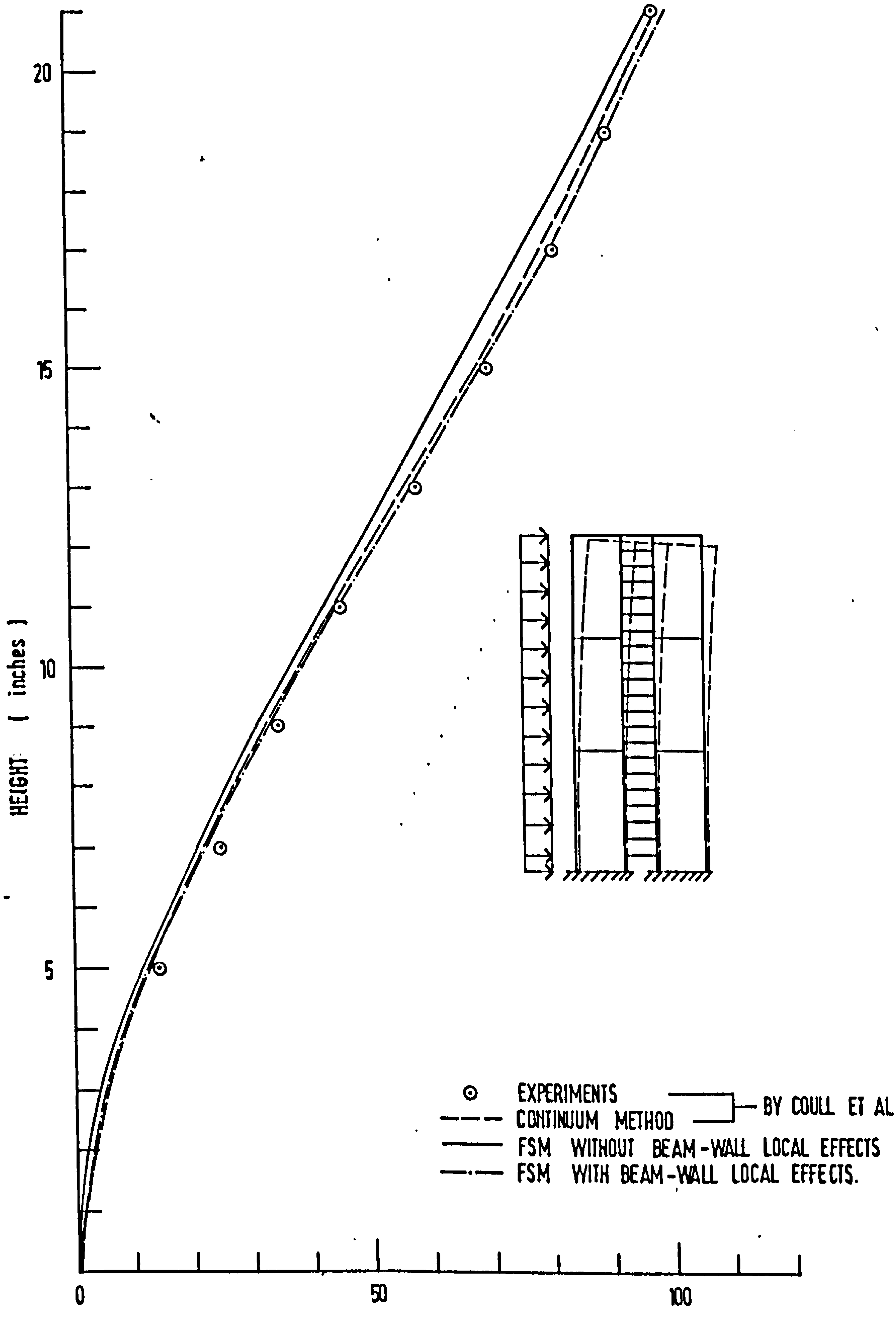


FIG (4.15) DEFLECTION PROFILE FOR MODEL ⑤

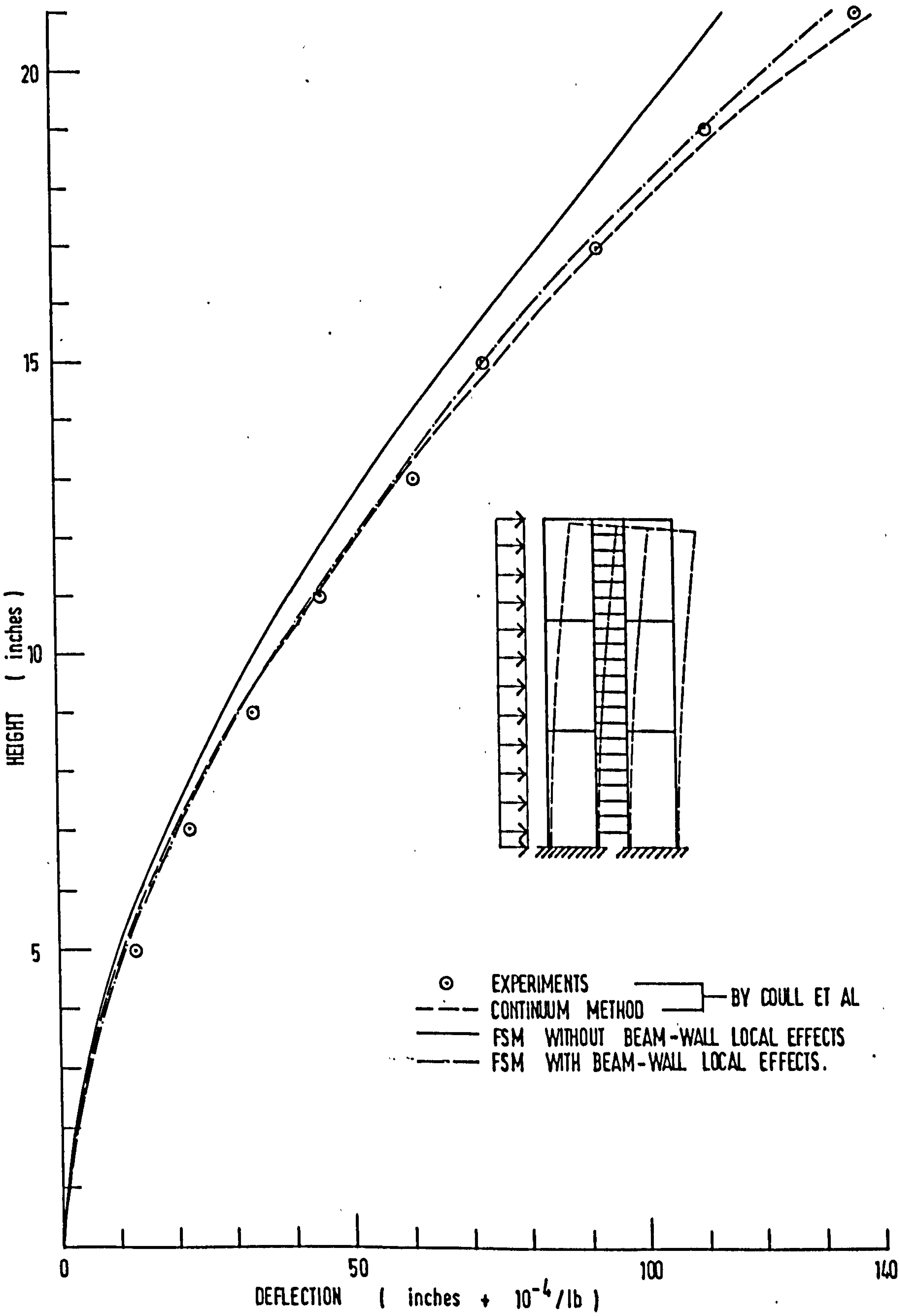


FIG (4.16) DEFLECTION PROFILE FOR MODEL (6)

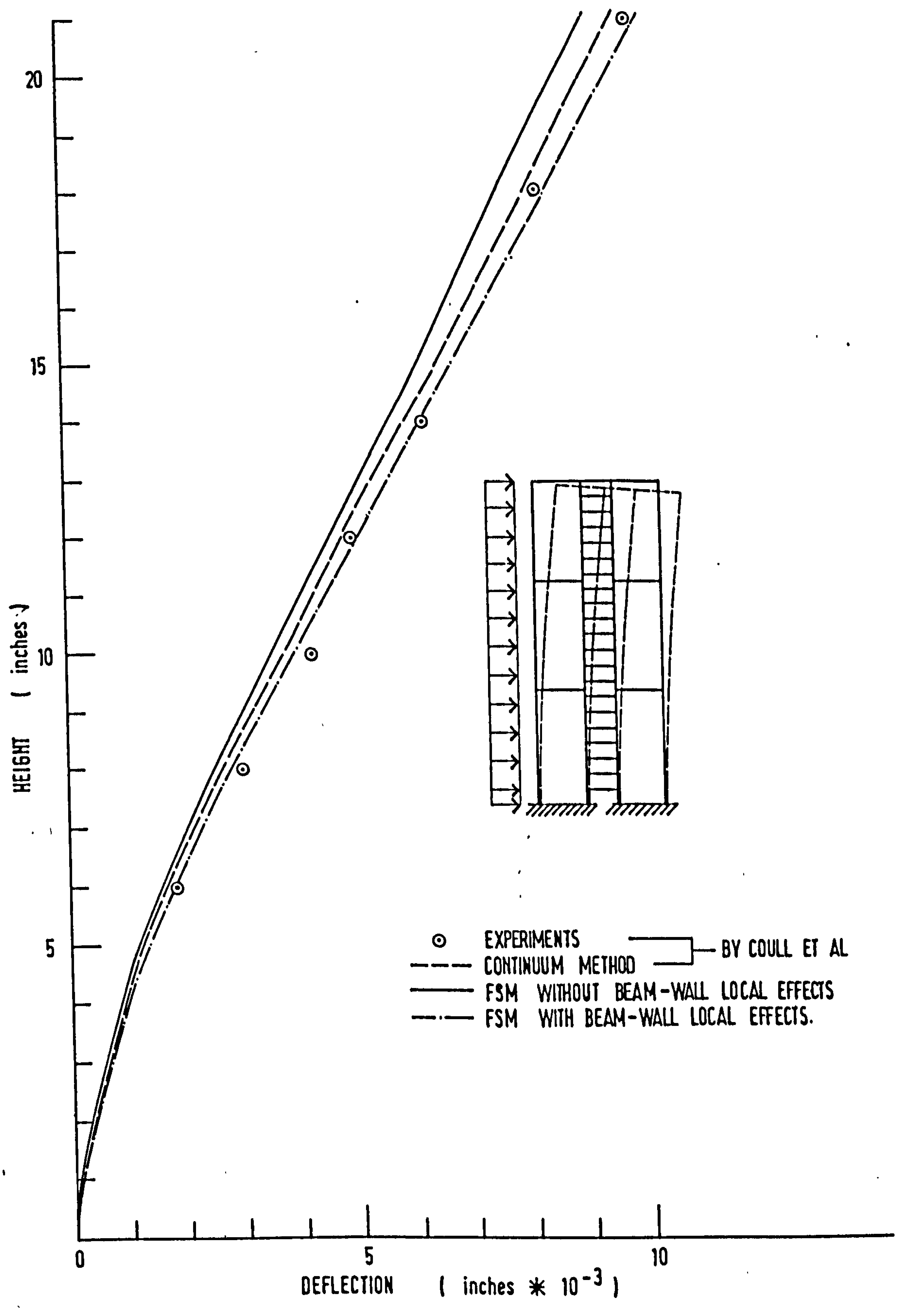


FIG (4.17) DEFLECTION PROFILE FOR MODEL (7)

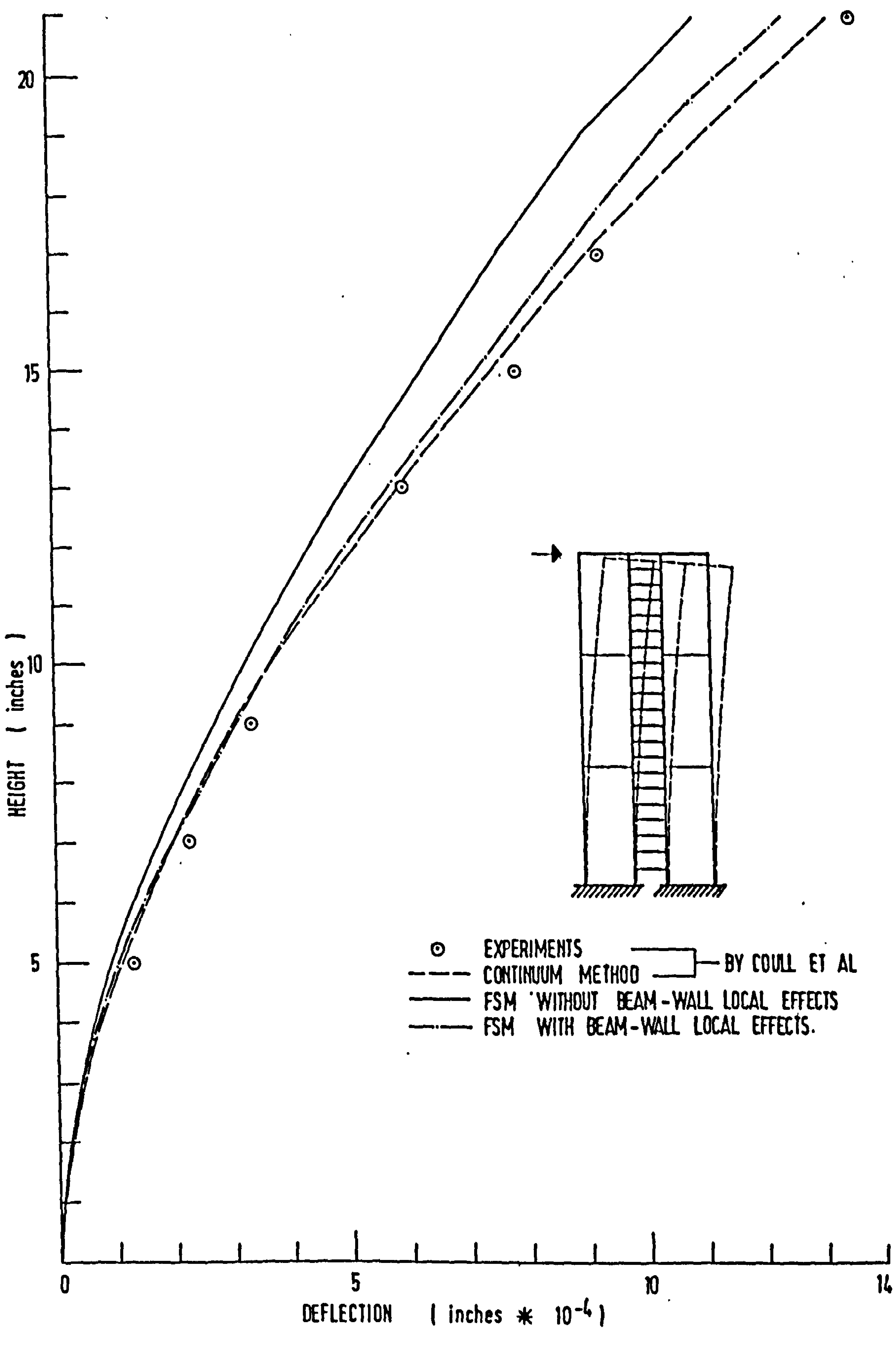


FIG (4.18) DEFLECTION PROFILE FOR MODEL (8)

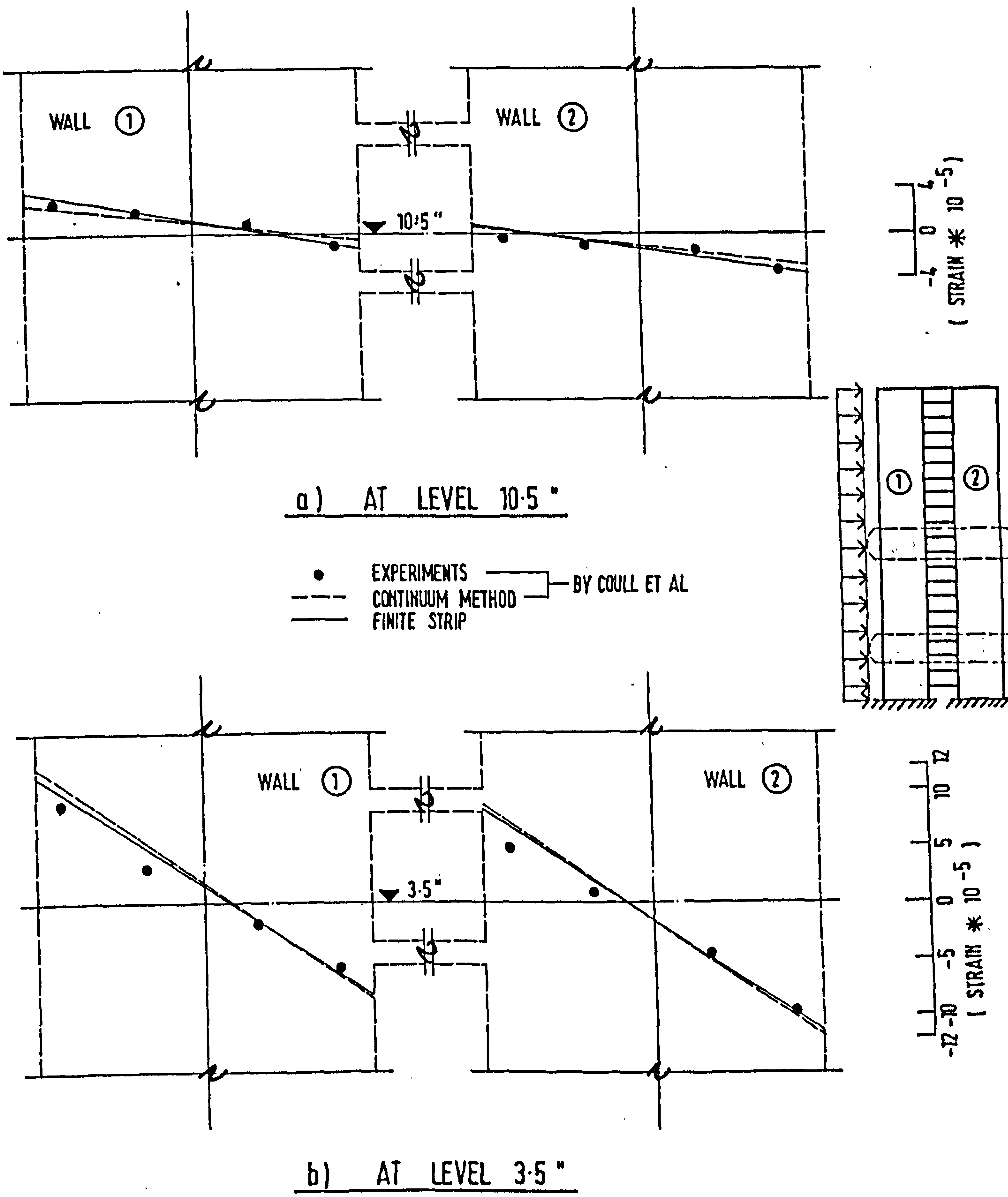


FIG (4.19) STRESS DISTRIBUTION FOR MODEL ⑤

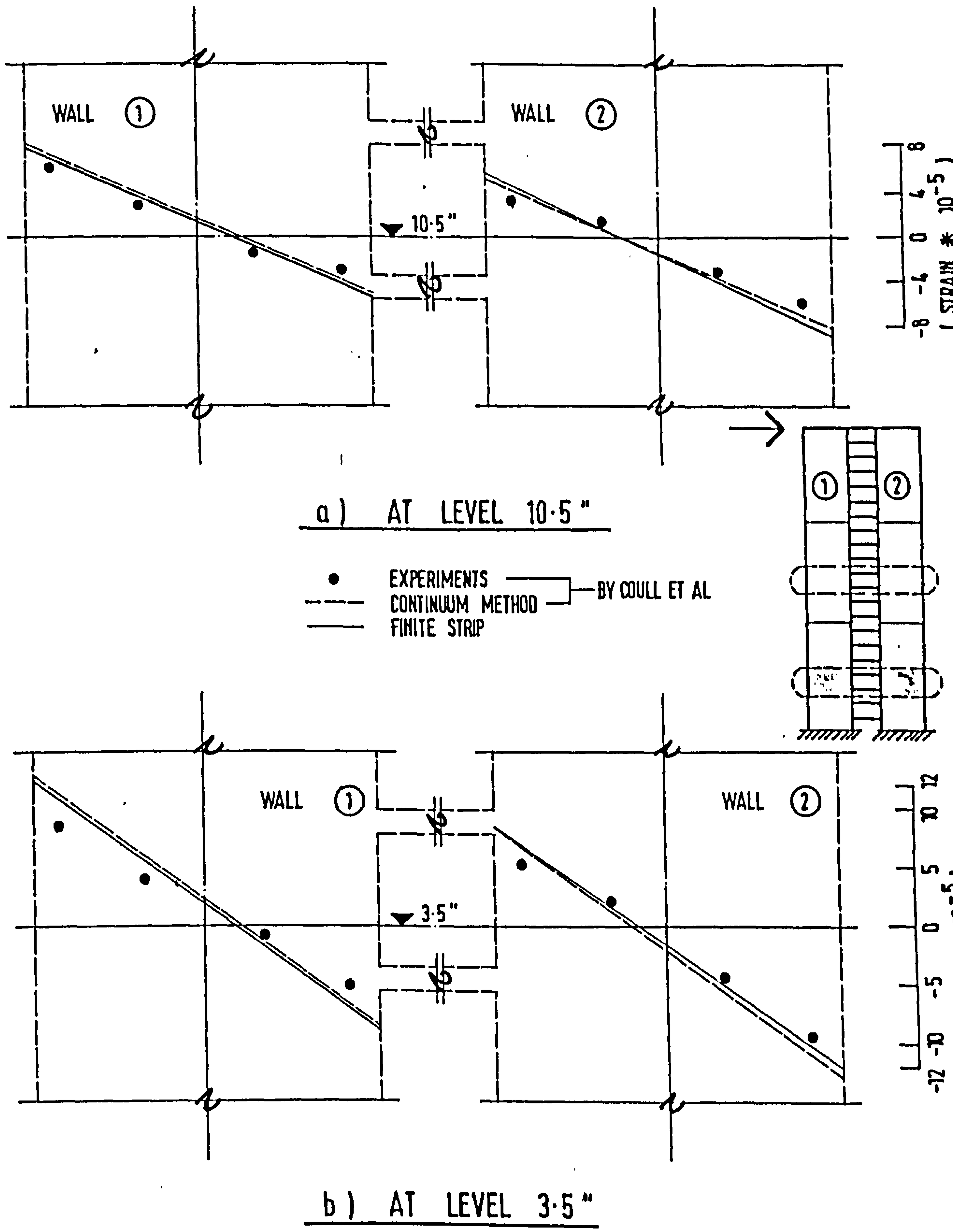


FIG (4.20) STRESS DISTRIBUTION FOR MODEL ⑥

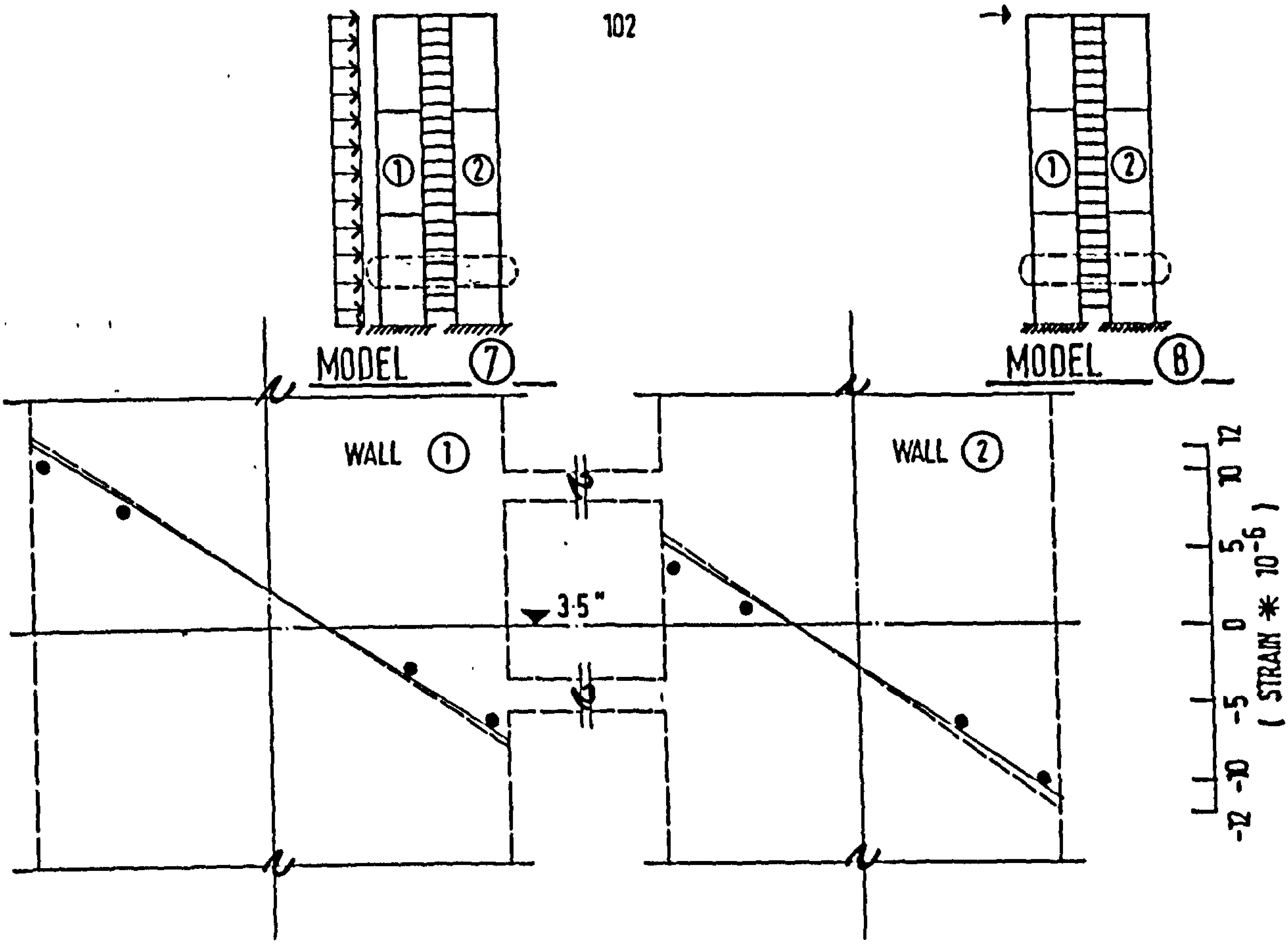


FIG (4.21) STRESS DISTRIBUTION FOR MODEL ⑦

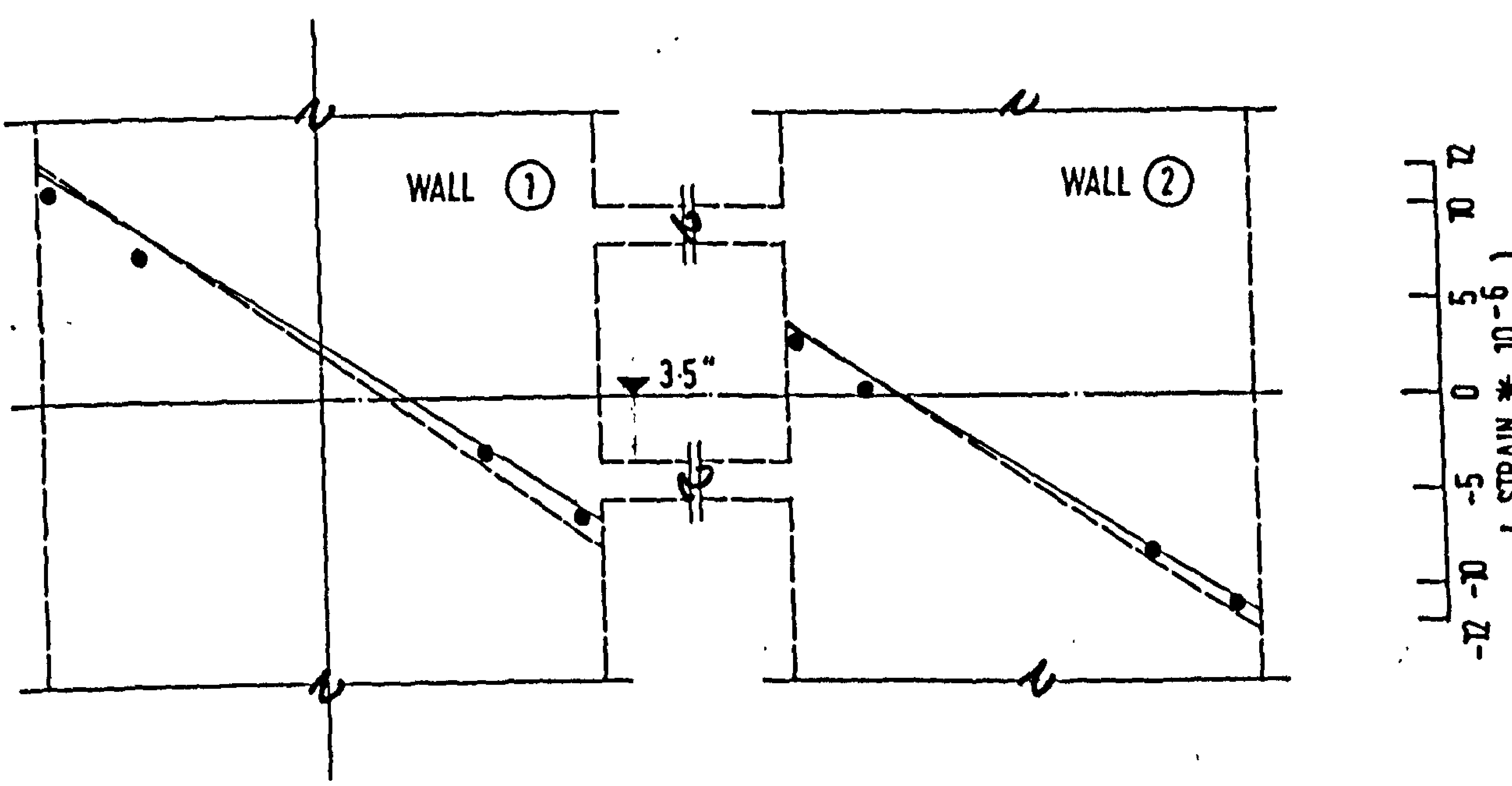


FIG (4.22) STRESS DISTRIBUTION FOR MODEL ⑧

- ● EXPERIMENTS — BY COULL ET AL
- – – – CONTINUUM METHOD — BY COULL ET AL
- ——— FINITE STRIP

figs (4.23) to (4.28).

4.3.1 Experimental Setting

The models were clamped rigidly at the base by bolting through a steel angle on each side to avoid any possible translation or rotation. The load was applied at the free end via a proving ring and the deflections were measured by dial gauges which were fixed on an independent vertical steel bar and positioned at every storey level for measuring the horizontal deflections. The vertical stresses, σ_y in each wall were obtained by a set of electrical resistance strain gauges fixed to the walls. Two connecting beams at levels 29.42 and 44.13 cm were strain gauged to evaluate the end moments.

The modulus of elasticity E was calibrated by applying loads to a solid model which was cut from the same sheet of material as the test models, and the deflections measured with dial gauges. Applying beam theory, with the inclusion of shear deformation, the average value of the modulus of elasticity of the models was determined as 3.2×10^6 N/cm^2.

4.3.2 Experimental Results

The local deflection curves for all six models are shown in figs (4.29) to (4.34). Again it can be seen that introducing the wall-beam effect produces a close agreement between the finite strip and experimental values of deflections.

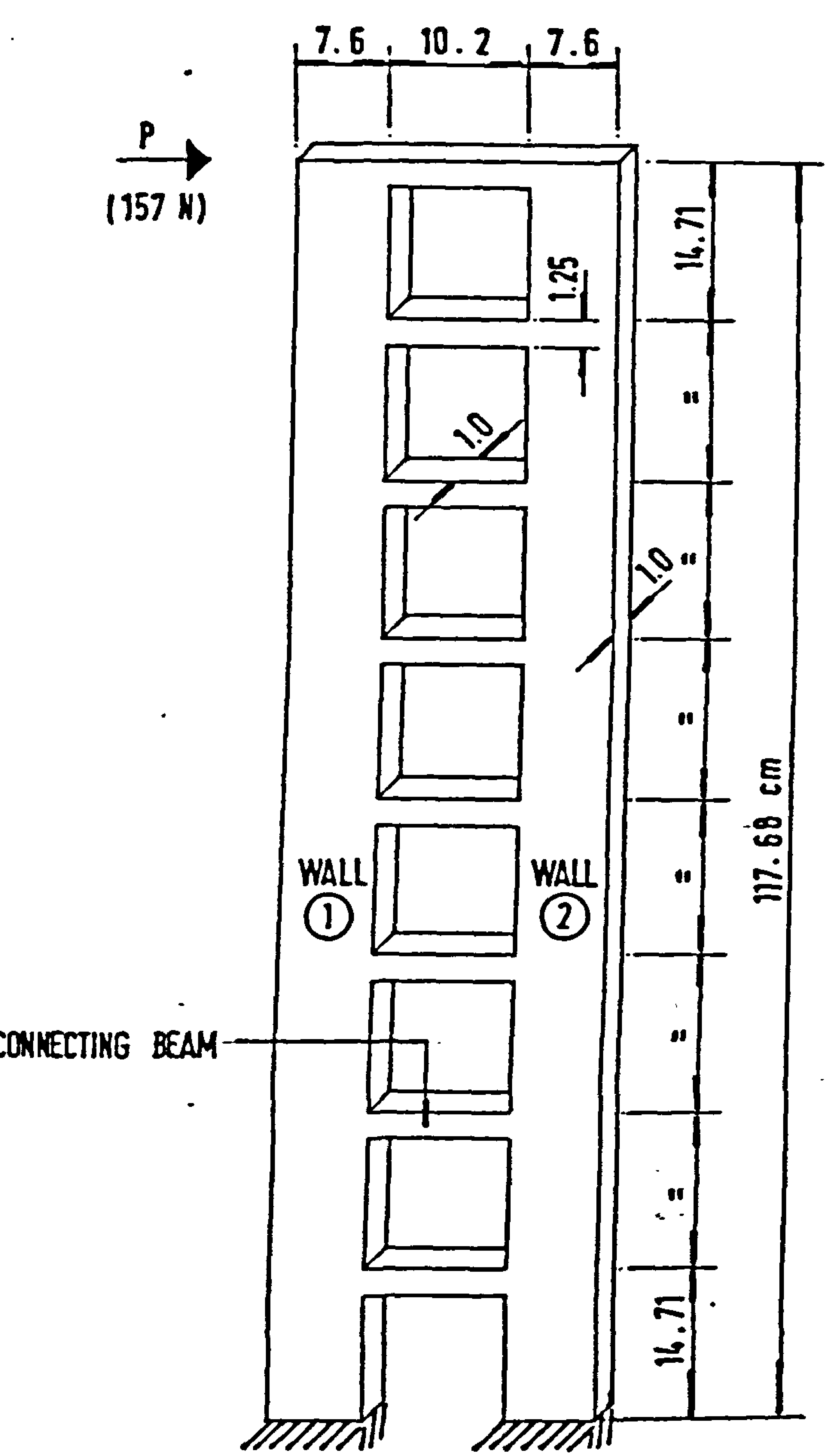


FIG (4·23) COUPLED SHEAR WALL MODEL ⑨

$E = 3.2 * 10^6$ N/cm^2
POISSON RATIO = 0.2

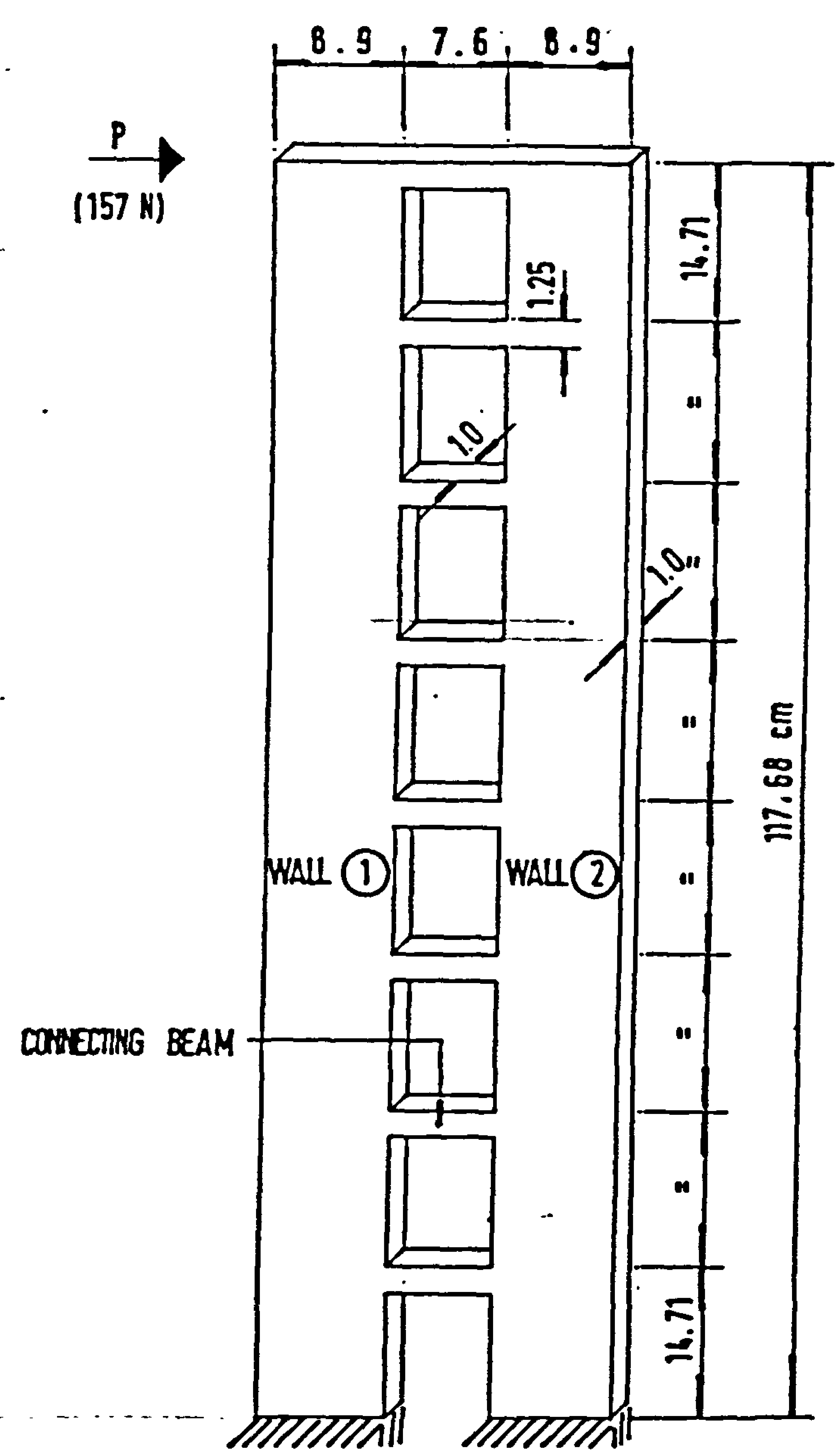


FIG (4·24) COUPLED SHEAR WALL MODEL ⑩

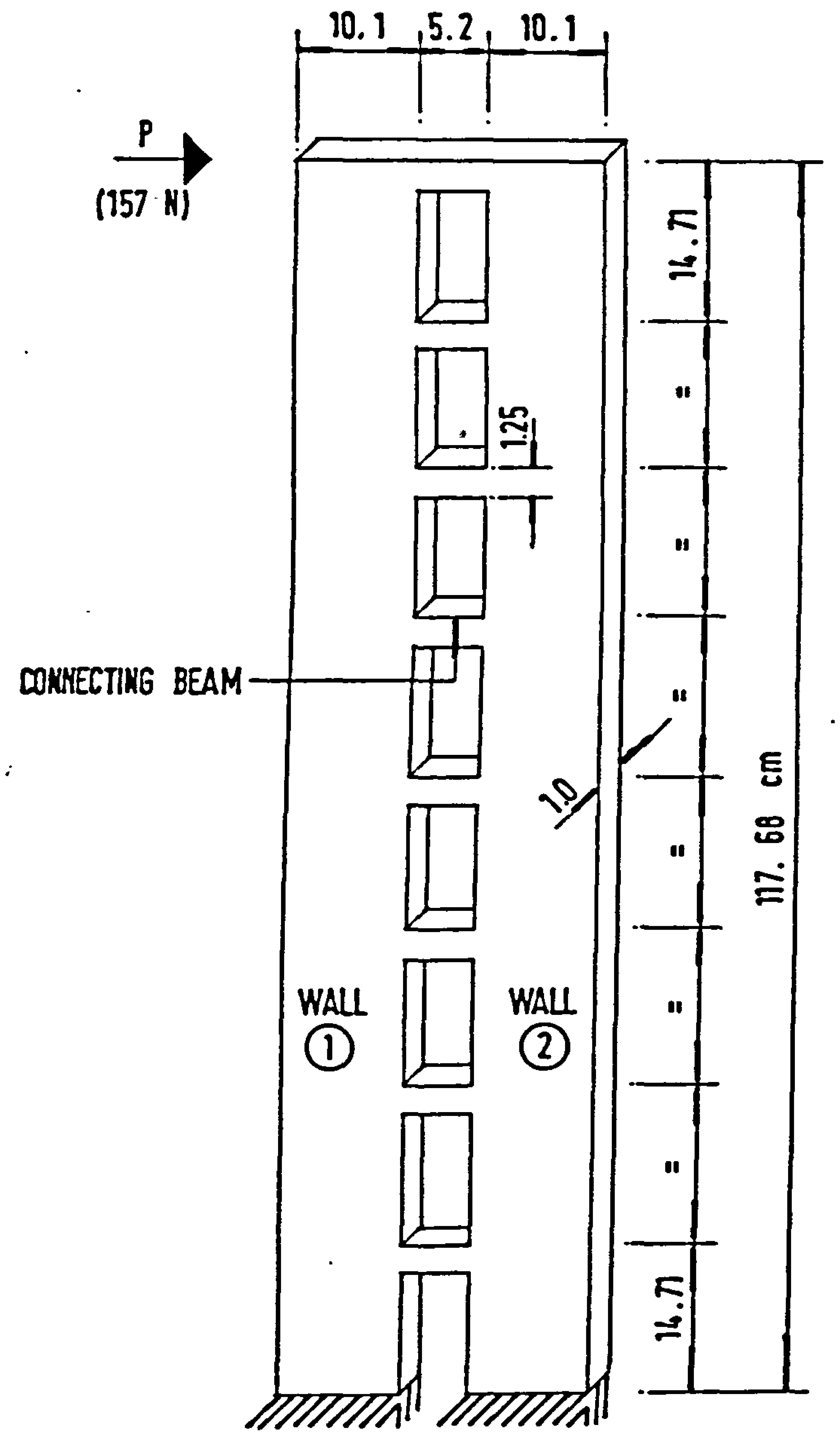


FIG (4.25) COUPLED SHEAR WALL MODEL ⑪

E = 3.2 ∗ 10^6 N/cm^2
POISSON RATIO = 0.2

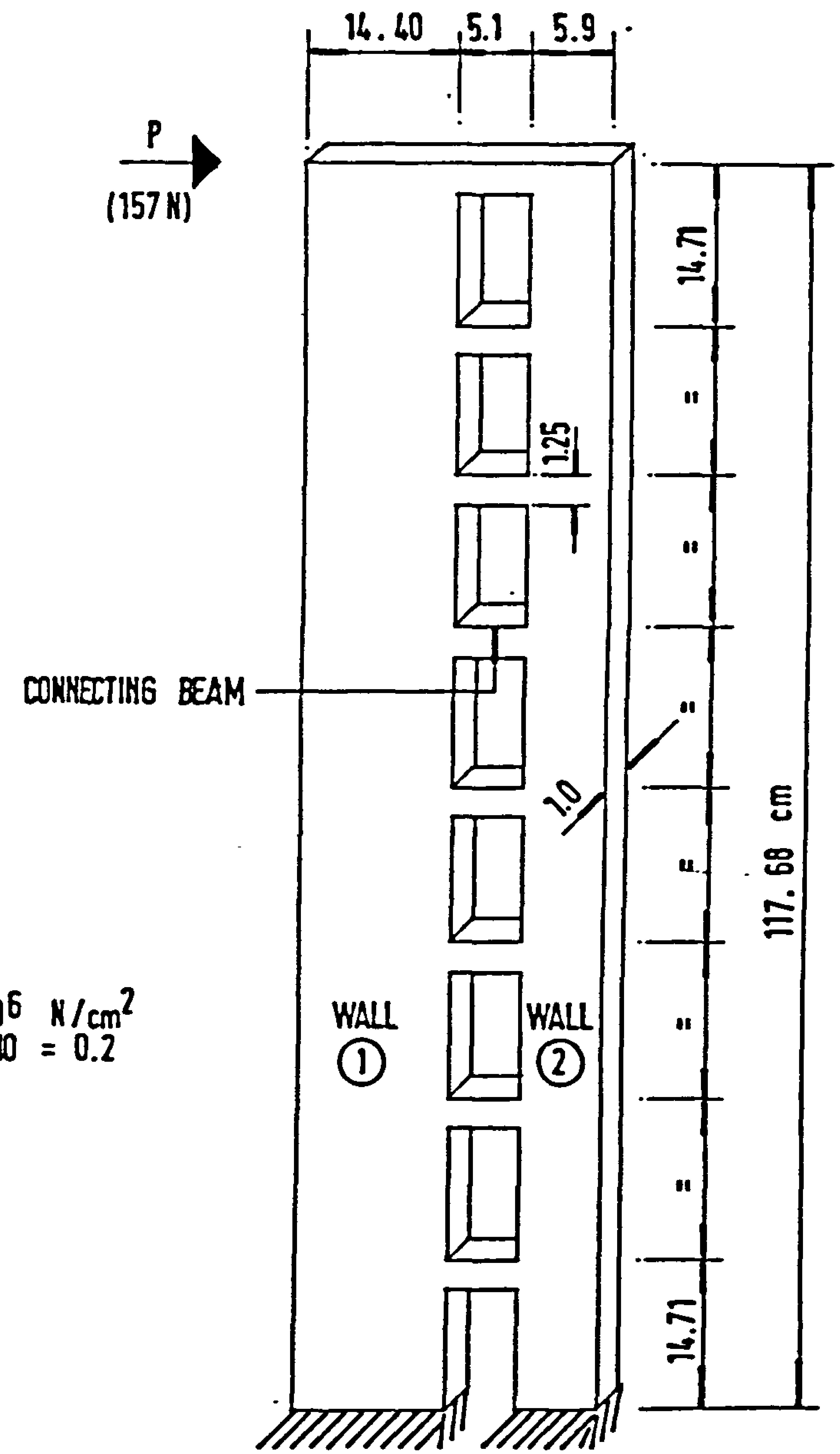


FIG (4.26) COUPLED SHEAR WALL MODEL ⑫

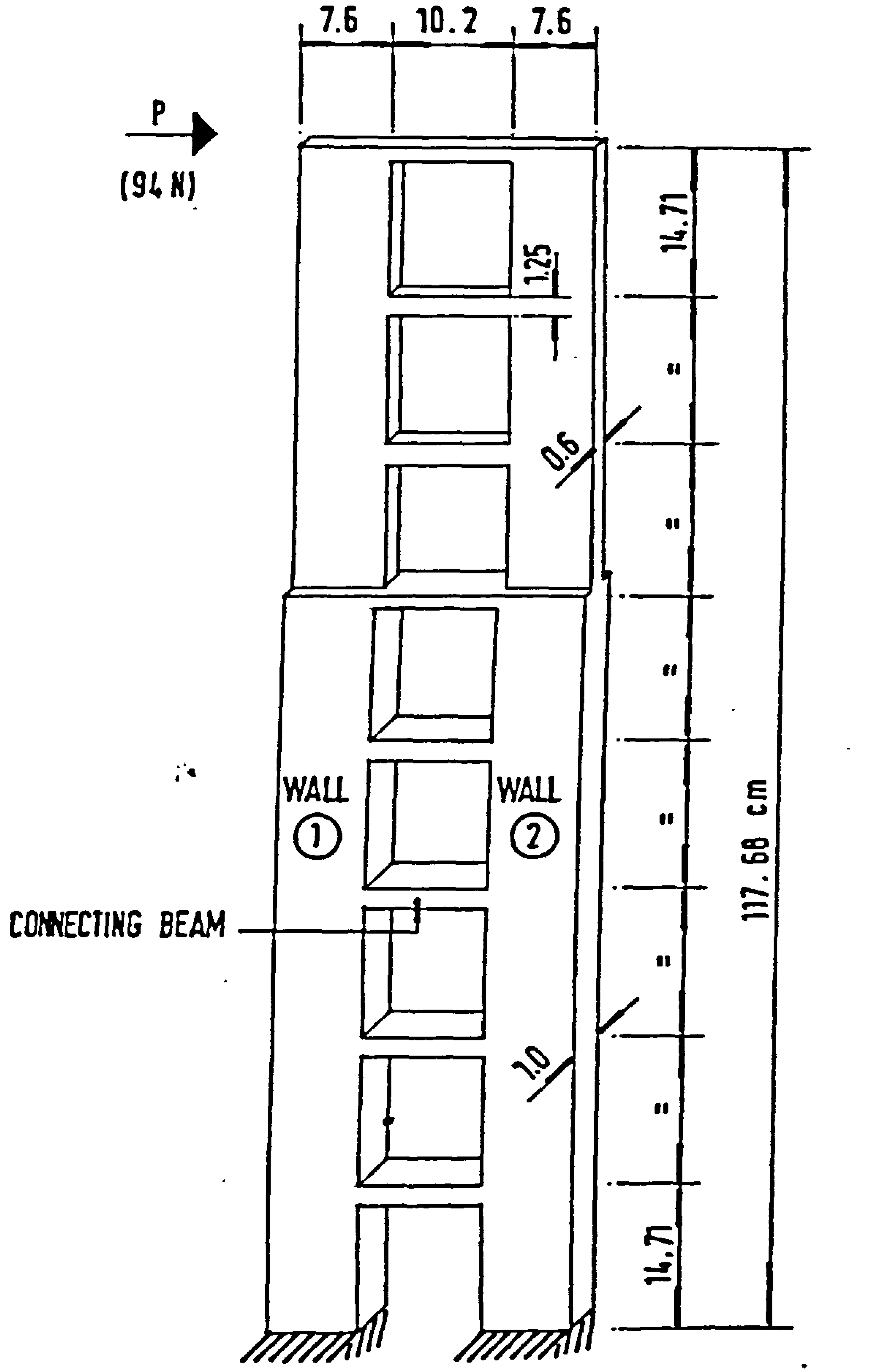


FIG (4·27) COUPLED SHEAR WALL MODEL ⑬

E = 3.2 * 10^6 N/cm^2
POISSON RATIO = 0.2

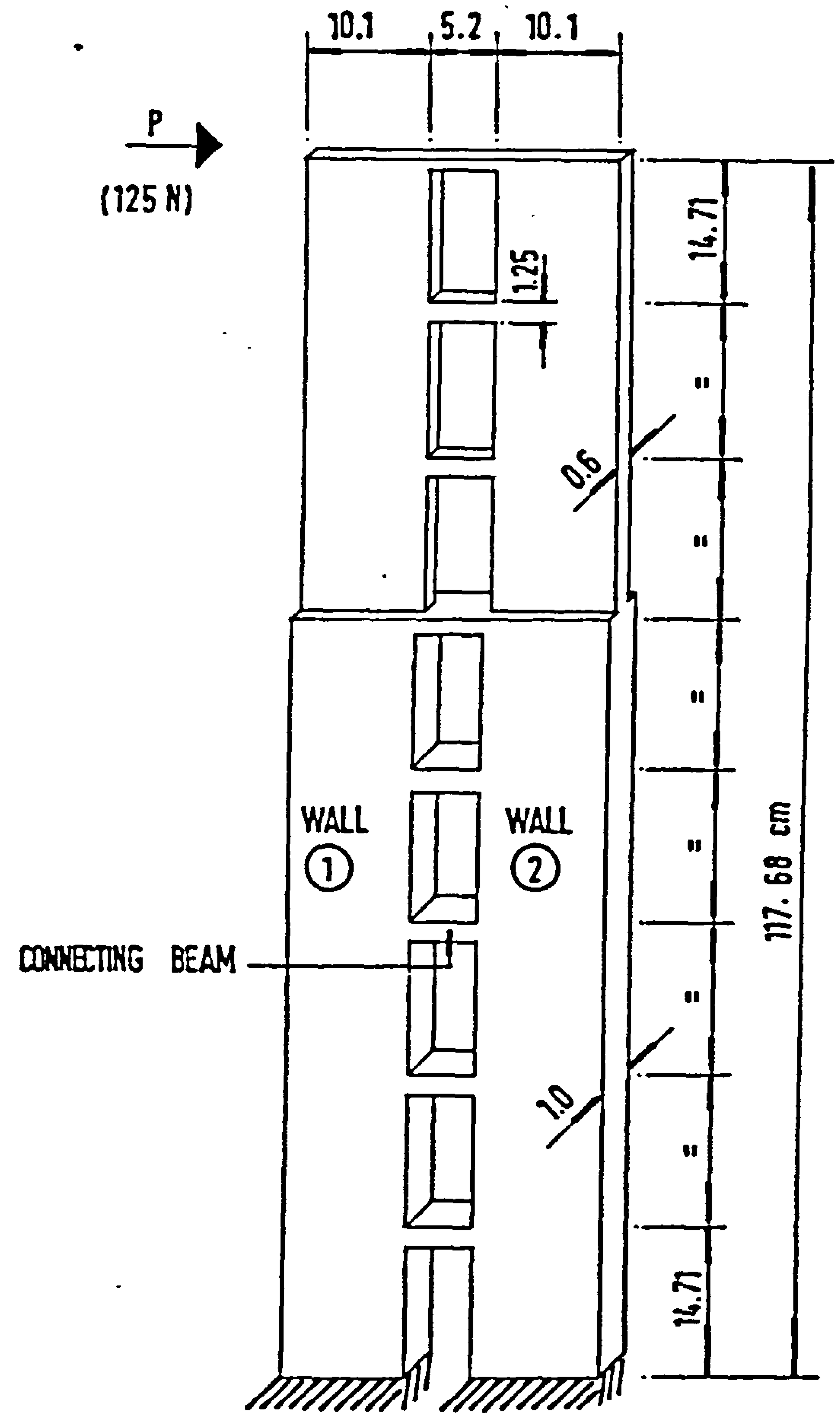


FIG (4·28) COUPLED SHEAR WALL MODEL ⑭

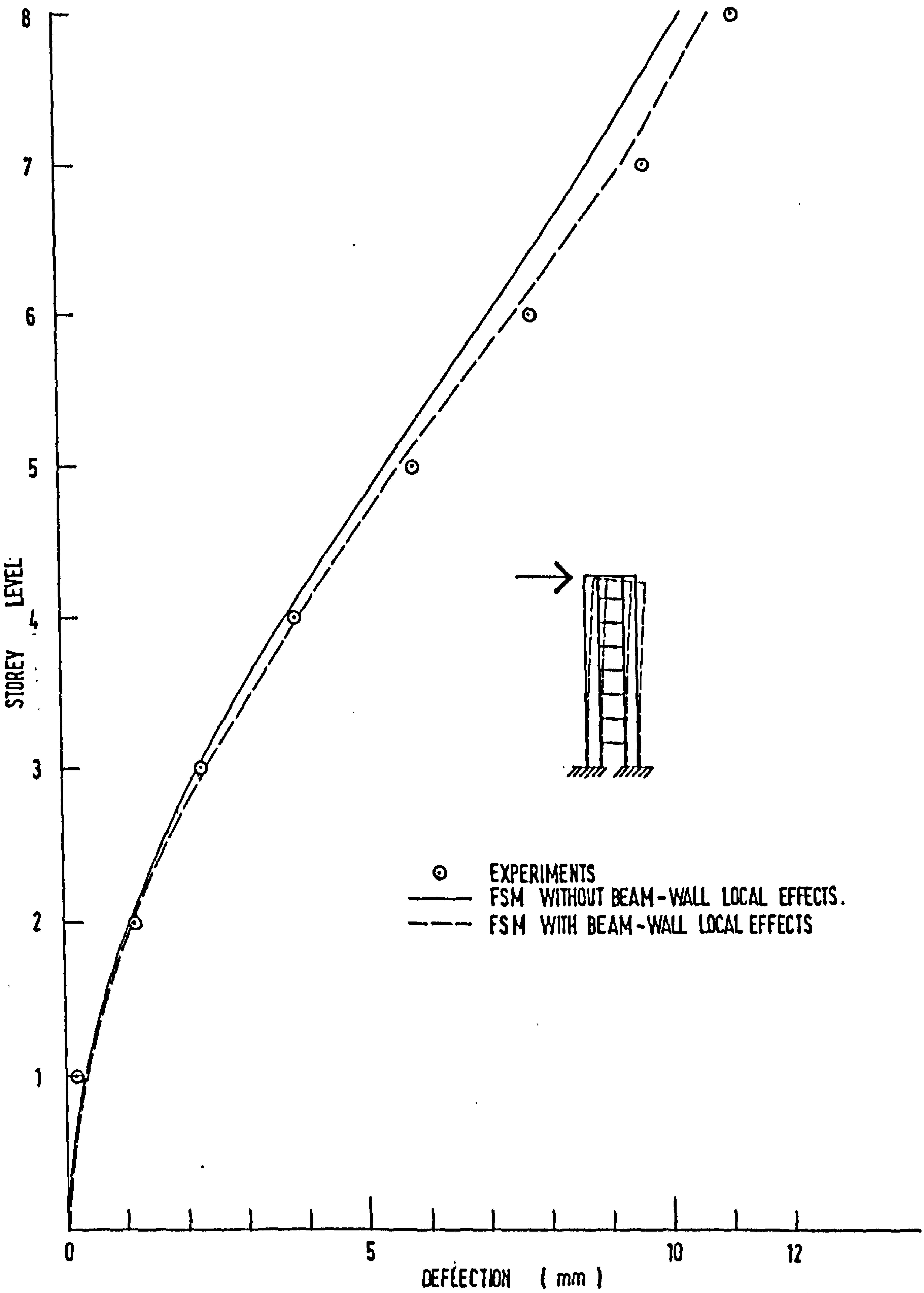


FIG (4.29) DEFLECTION PROFILE FOR MODEL (9)

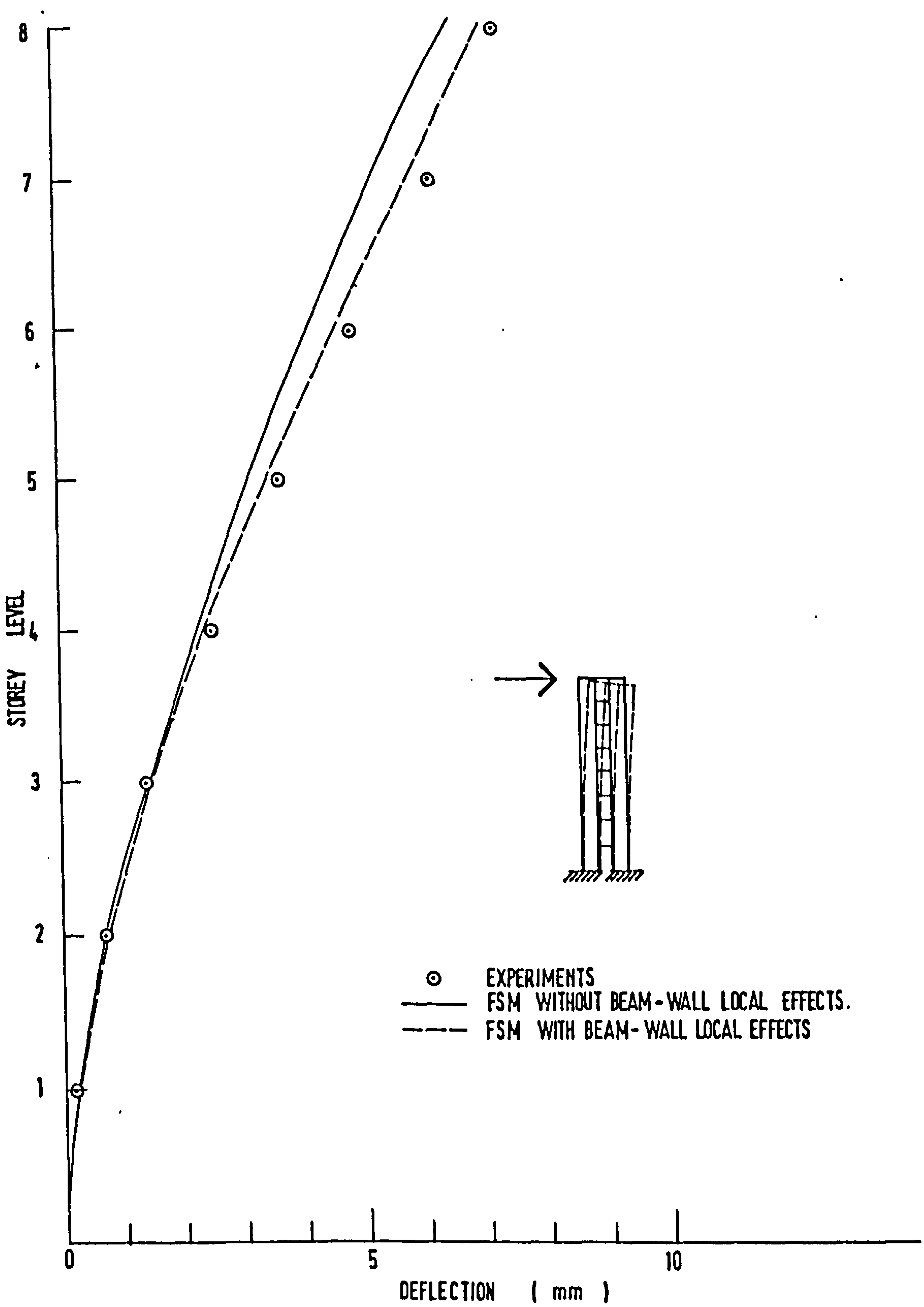


FIG (4.30) DEFLECTION PROFILE FOR MODEL (10)

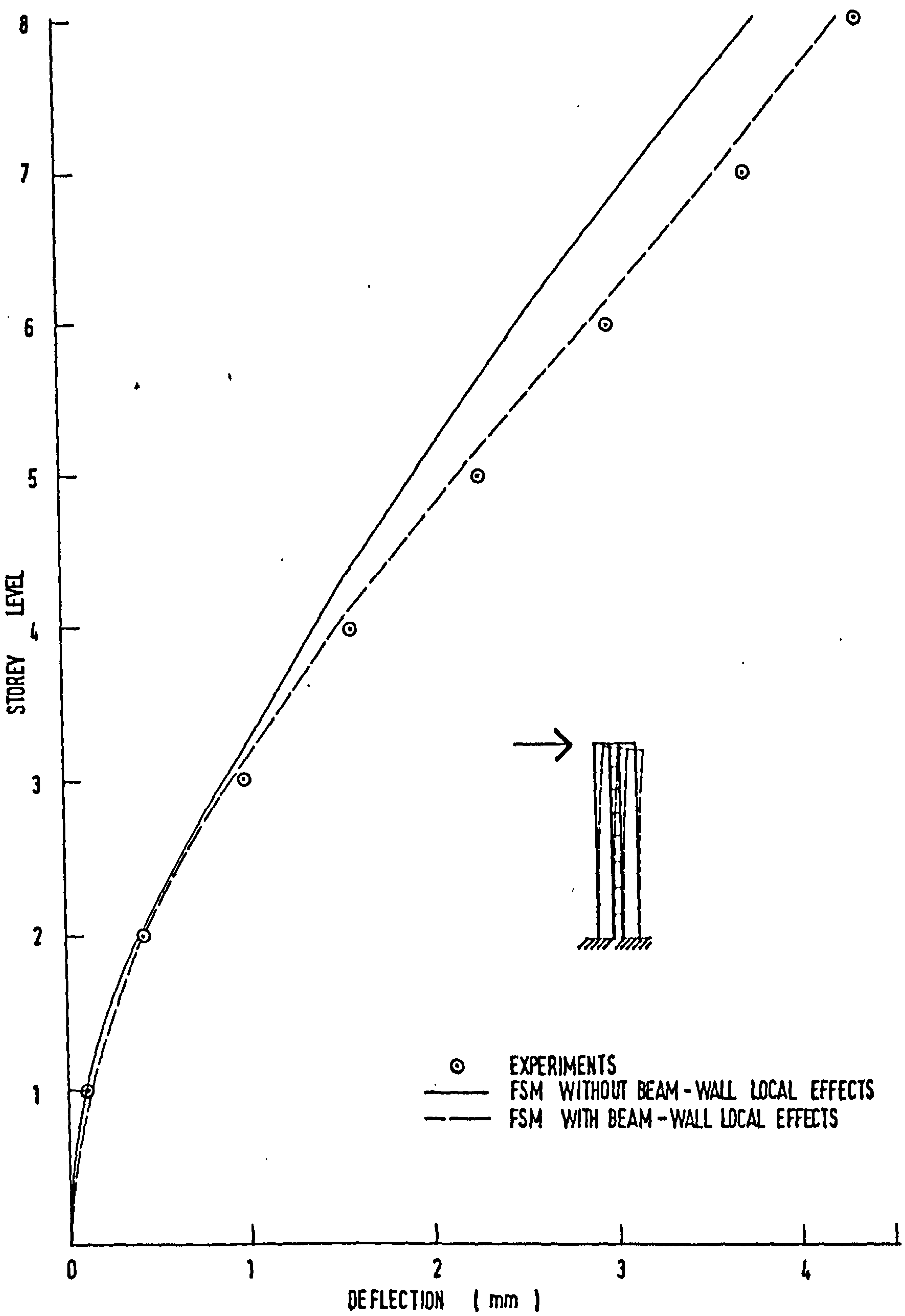


FIG (4.31) DEFLECTION PROFILE FOR MODEL (11)

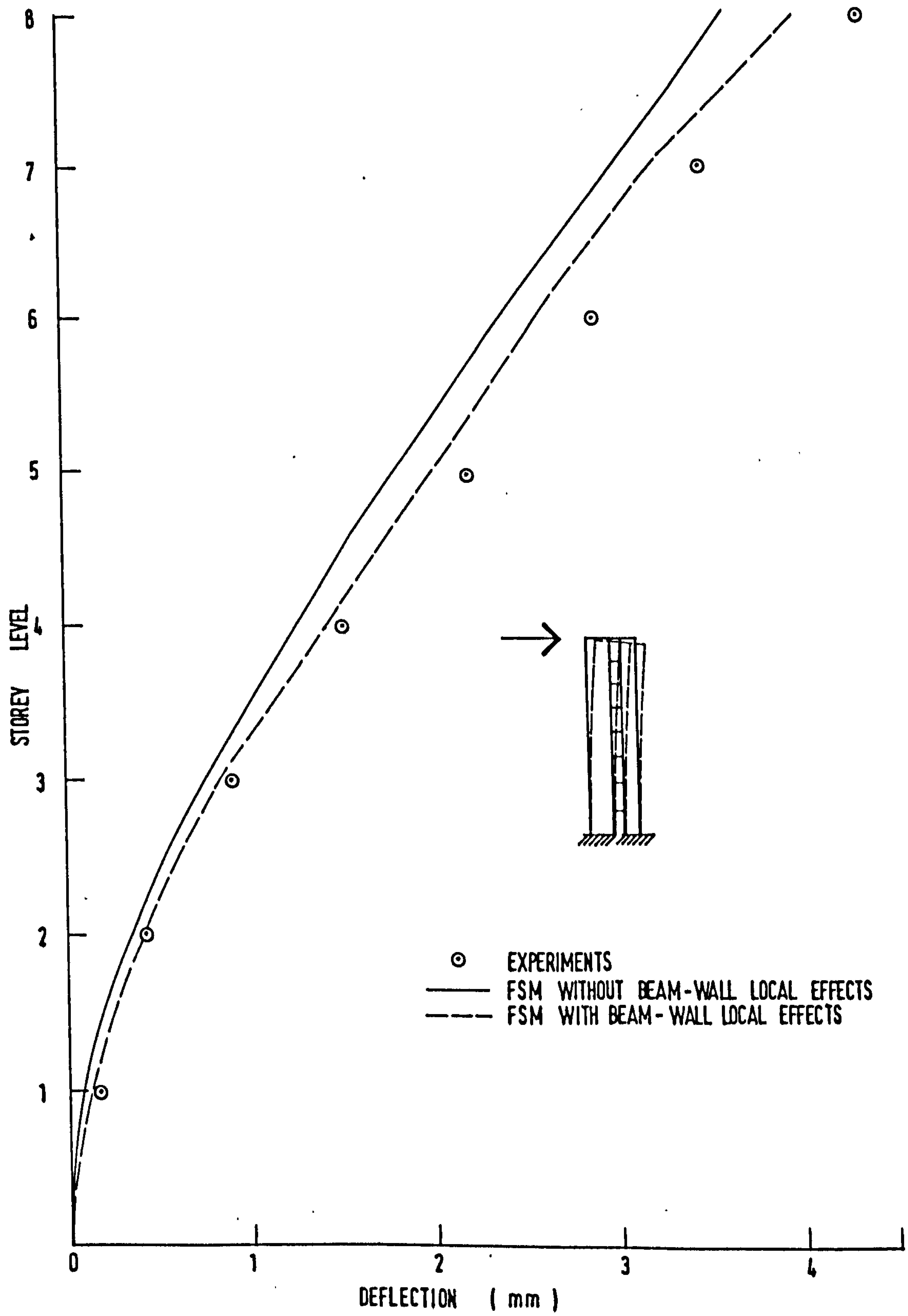


FIG (4.32) DEFLECTION PROFILE FOR MODEL (12)

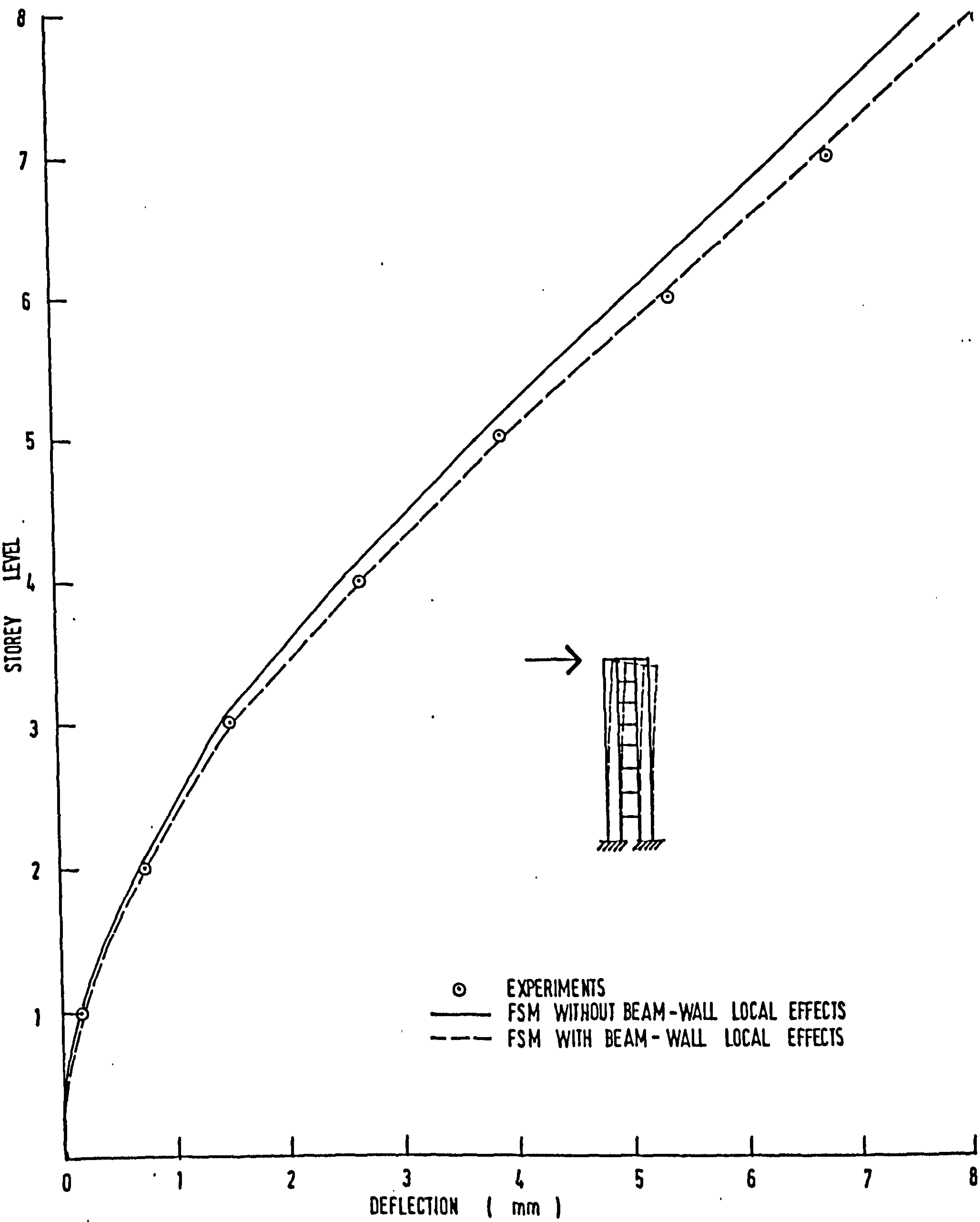


FIG (4.33) DEFLECTION PROFILE FOR MODEL (13)

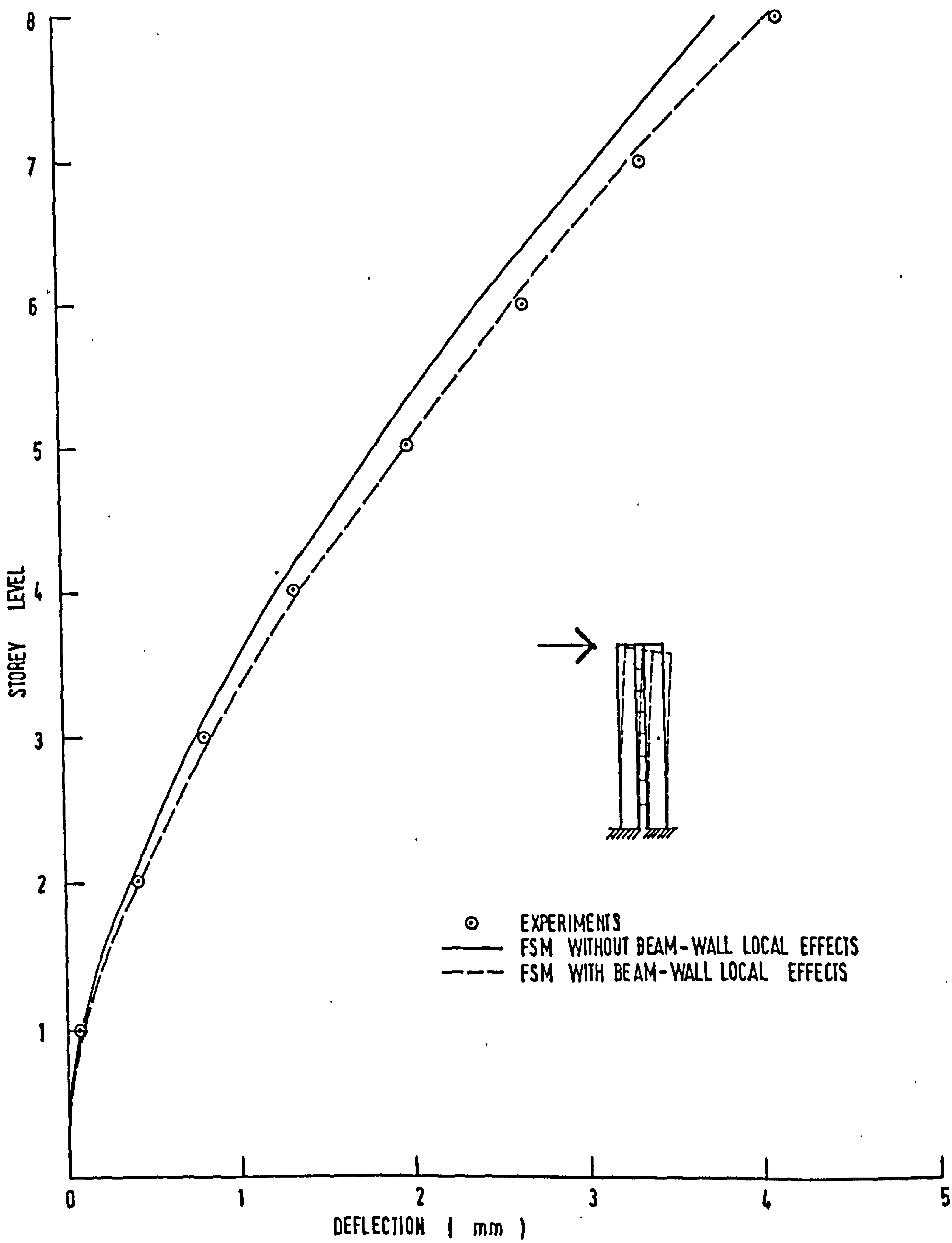


FIG (4.34) DEFLECTION PROFILE FOR MODEL (14)

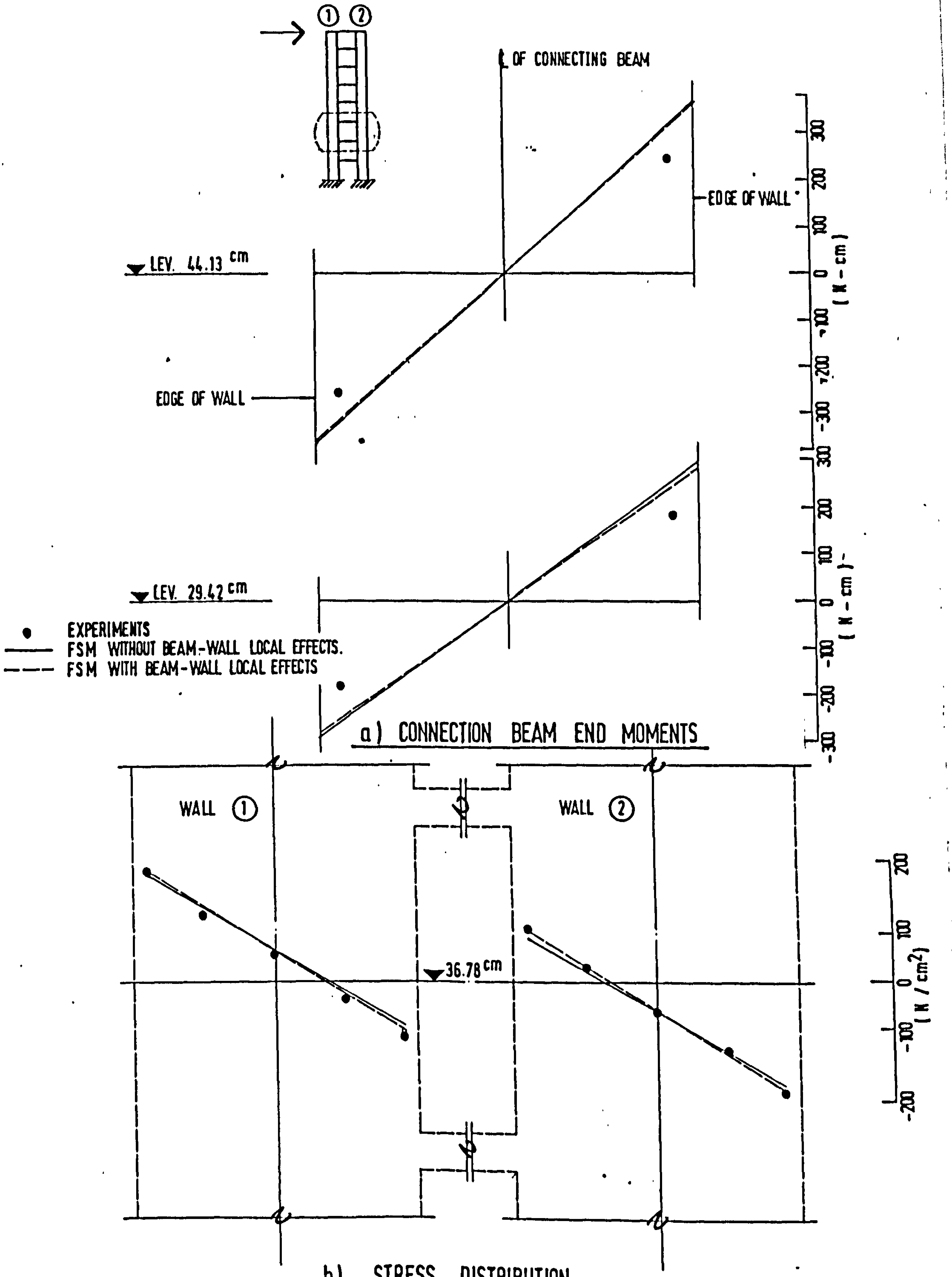
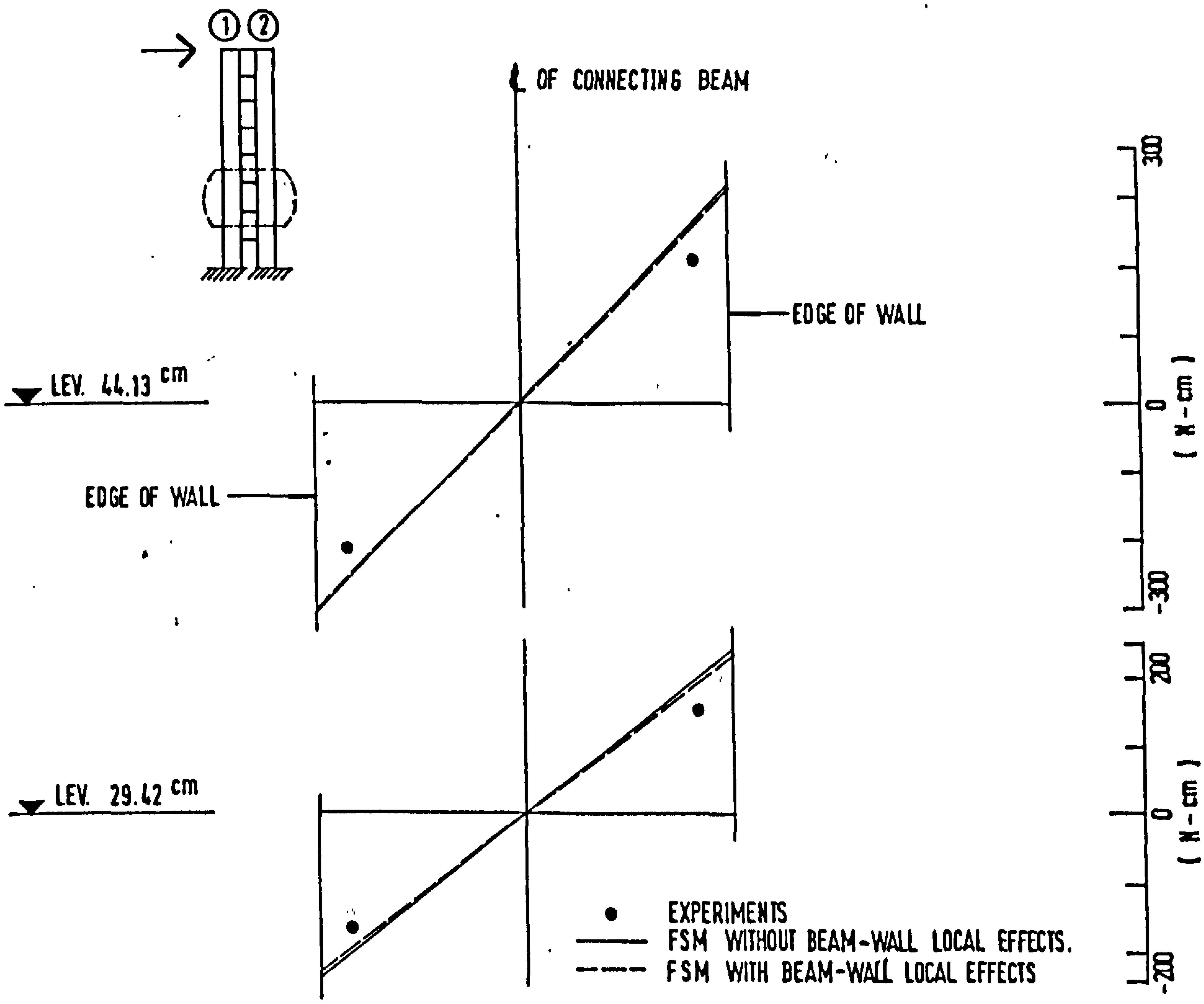
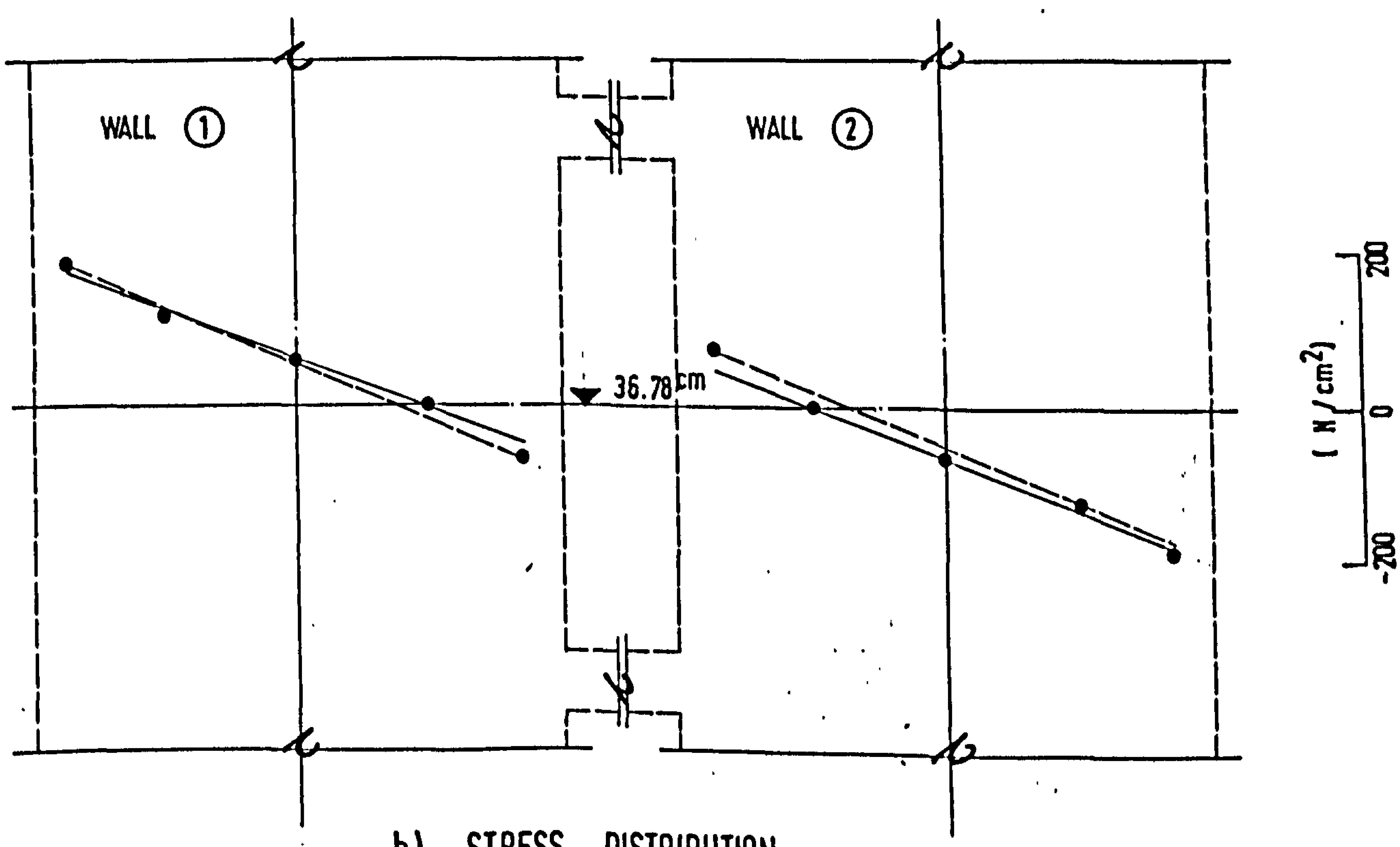


FIG (4.35) MOMENTS AND STRESSES FOR MODEL (9)

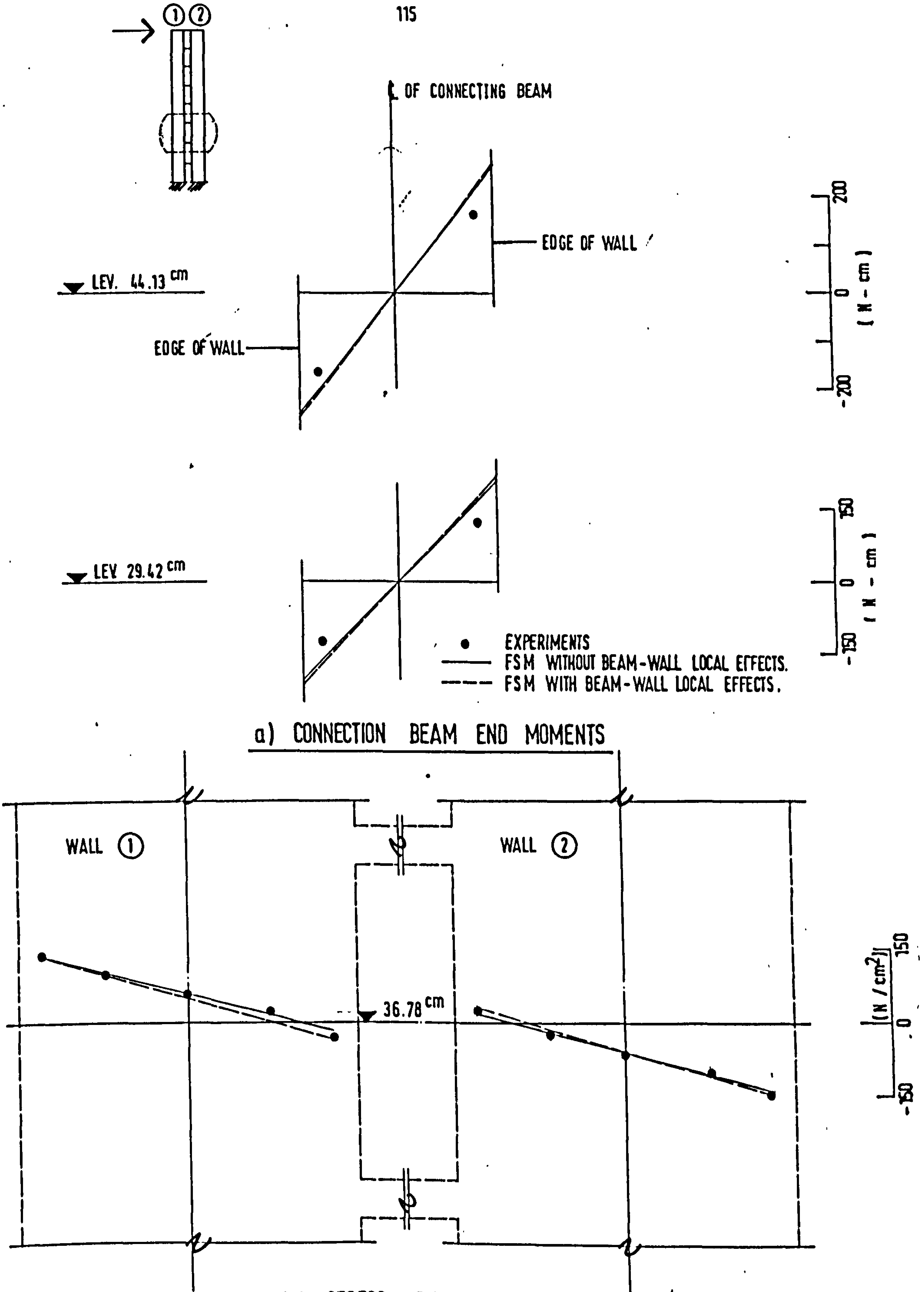


a) CONNECTING BEAM END MOMENTS



b) STRESS DISTRIBUTION

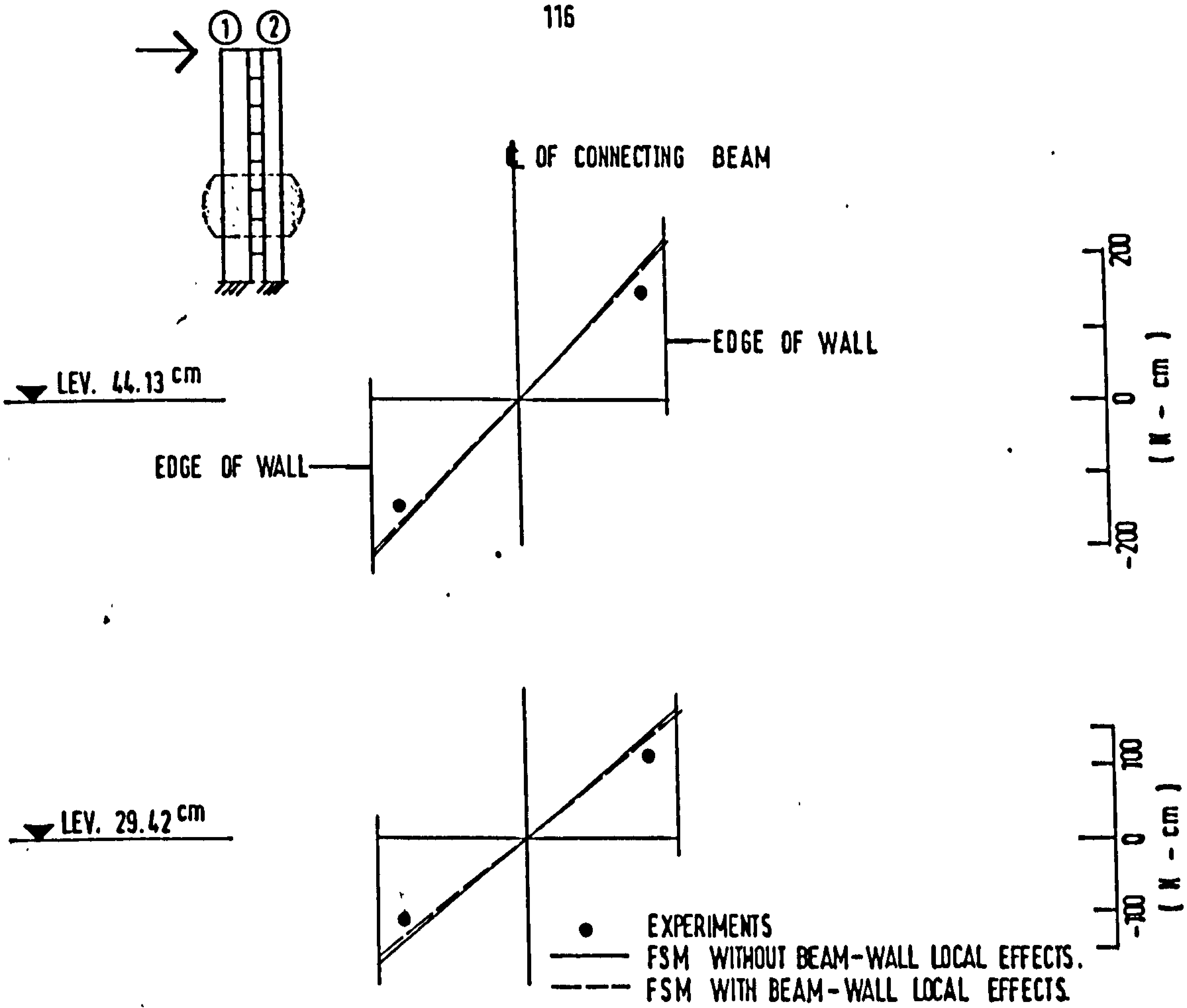
FIG (4.36) MOMENTS AND STRESSES FOR MODEL ⑩



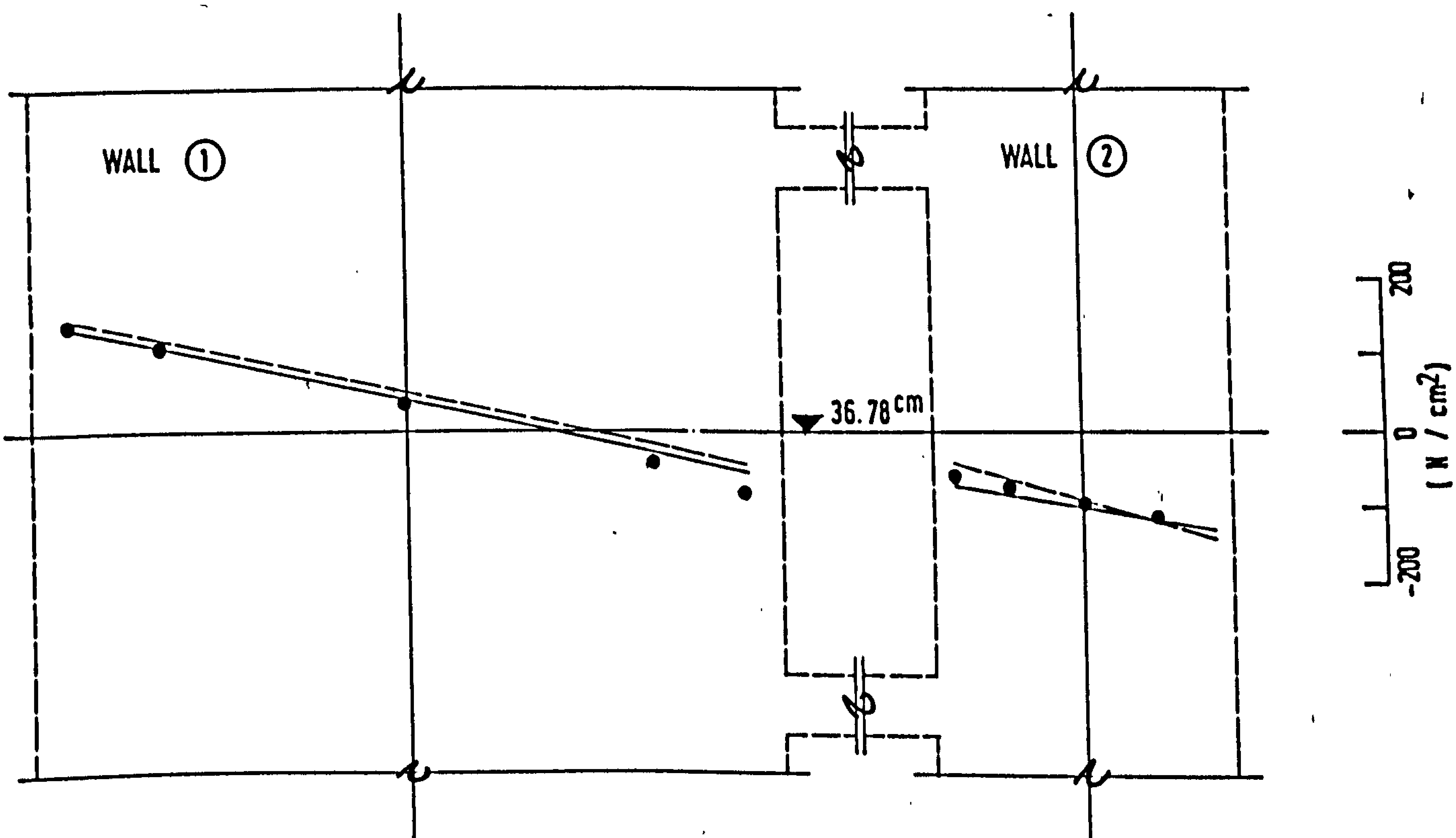
a) CONNECTION BEAM END MOMENTS

b) STRESS DISTRIBUTION

FIG (4.37) MOMENTS AND STRESS DISTRIBUTION FOR MODEL ⑪



a) CONNECTION BEAM END MOMENTS



b) STRESS DISTRIBUTION

FIG (4.38) MOMENTS AND STRESS DISTRIBUTION FOR ⑫

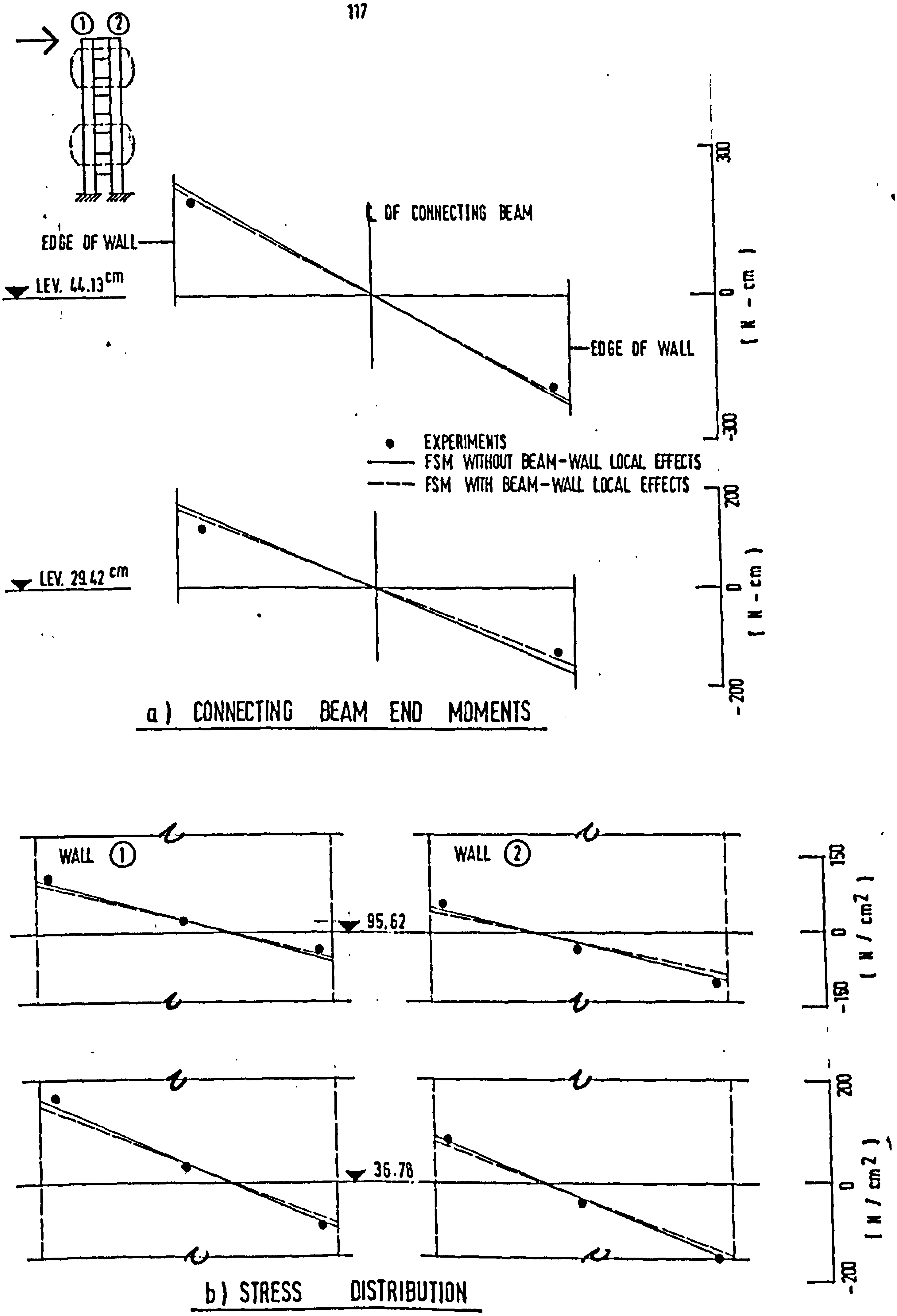


FIG (4.39) MOMENTS AND STRESS DISTRIBUTION FOR MODEL ⑬

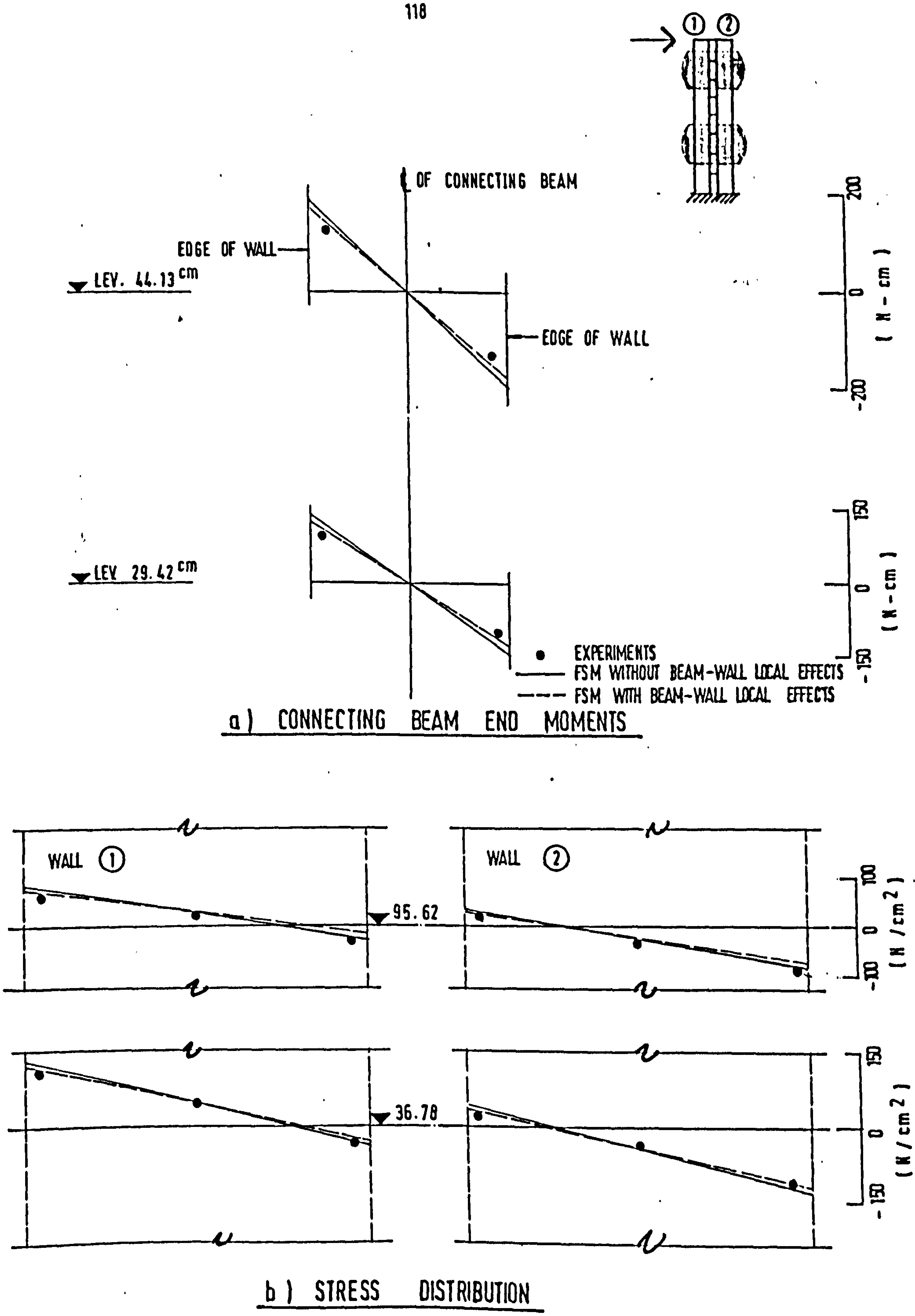


FIG (4.40) MOMENTS AND STRESS DISTRIBUTION FOR MODEL ⑭

The variation of vertical wall stresses and connecting beam end moments are shown in figs (4.35) to (4.40).

The variation of vertical wall stresses were measured at a height of 36.78 cm from the base of the models. It can be seen for all six models that close agreement was obtained between theoretical and experimental values.

The connecting beams at 29.42 cm and 44.13 cm above the base of the models were strain gauged. The results for all the models show that the finite strip results overestimate the end moments. Allowing for the flexibility of the wall-beam junction does not influence the values a great deal. It can be seen that as the length of the beams increases so does the finite strip overestimate. This tends to suggest that the constant local effect proposed by Michael is not quite correct.

4.4 Conclusion

The lateral deflection results for all the models show that the finite strip method always produces conservative values compared to the other methods. This difference is decreased by allowing for local deformation at the wall beam junctions as suggested by Michael. The continuum method produces values of deflections very close to the experimental values obtained.

The connecting beam moments are also overerstimated for all model when the finite strip method is used. The local deformation effect at the wall beam junction reduces these values slightly.

These results suggest

(a) the finite strip method should always include the local wall beam junction effect to obtain accurate results.

(b) the shape function used in the finite strip analysis accurately represents the vertical deflection but not the horizontal deflection.

(c) the rotation given by the shape function is dependent upon both u and v displacements. This can be seen in the variation of the overstimation of the connecting beam moments with their increasing flexibility.

CHAPTER FIVE

WALL-FRAME ANALYSIS

5.1 Introduction

A combination of shear wall and frame, as shown in fig (5.1), is often used in multi-storey structures[13] [38] [40] [43]. The usual assumption is that the shear wall will resist lateral forces, whilst the frame will carry the majority of the vertical loads.

Initially the analysis of such a combination was very basic. It was assumed that the total force (V) at any level was divided amongst the elements in proportion to their stiffness. Therefore, the force (V_i) in element 'i' is given simply by

$$V_i = \left(\frac{K_i}{\sum_{S=1}^{n} K_s} \right) V \qquad (1)$$

where $K_i = \dfrac{12EI_i}{l_i^3(1+\phi)}$

ϕ = shear deformation parameter

Unfortunately this approach is oversimplified and can produce quite erroneous results.

Several approximate methods[22] [24] [25] [40] [45] [50] have been developed. Generally most of these are restricted to particular types of loading or equivalent modelling of the wall. Again, unless great care is

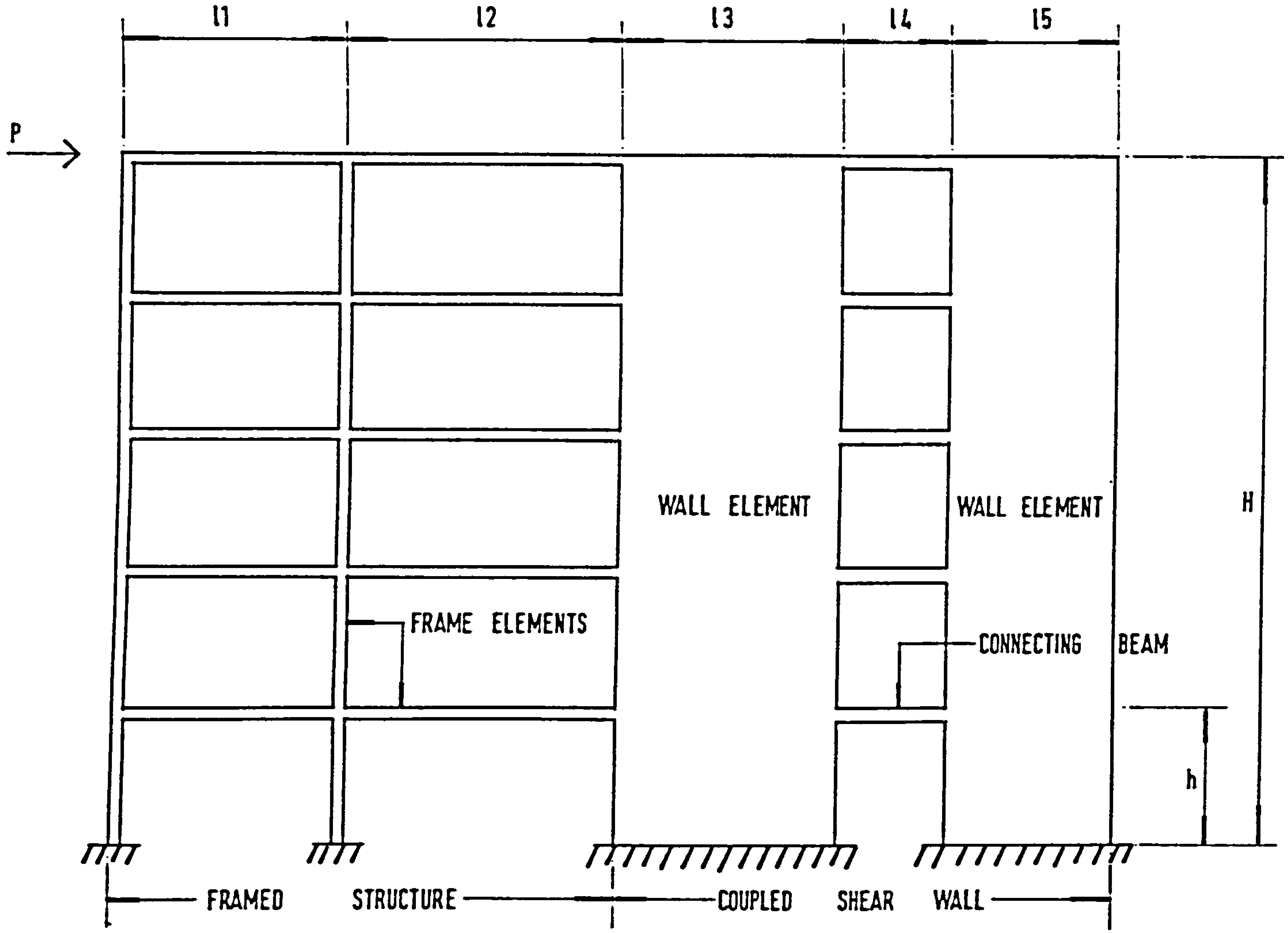


FIG (5.1) STRUCTURAL MODULE

taken, erroneous results can be produced.

The first method to analyse the system without any approximation was the finite element method. Unfortunately due to the nature of the structure, it requires a fairly large storage area and time. Development of the finite strip method reduced both the storage and time.

In this Chapter a method is proposed that will reduce the storage and time even further. In Chapters two and three it has been shown how both the finite strip and the continuum methods can be used to analyse a coupled shear wall, even with variable thickness.

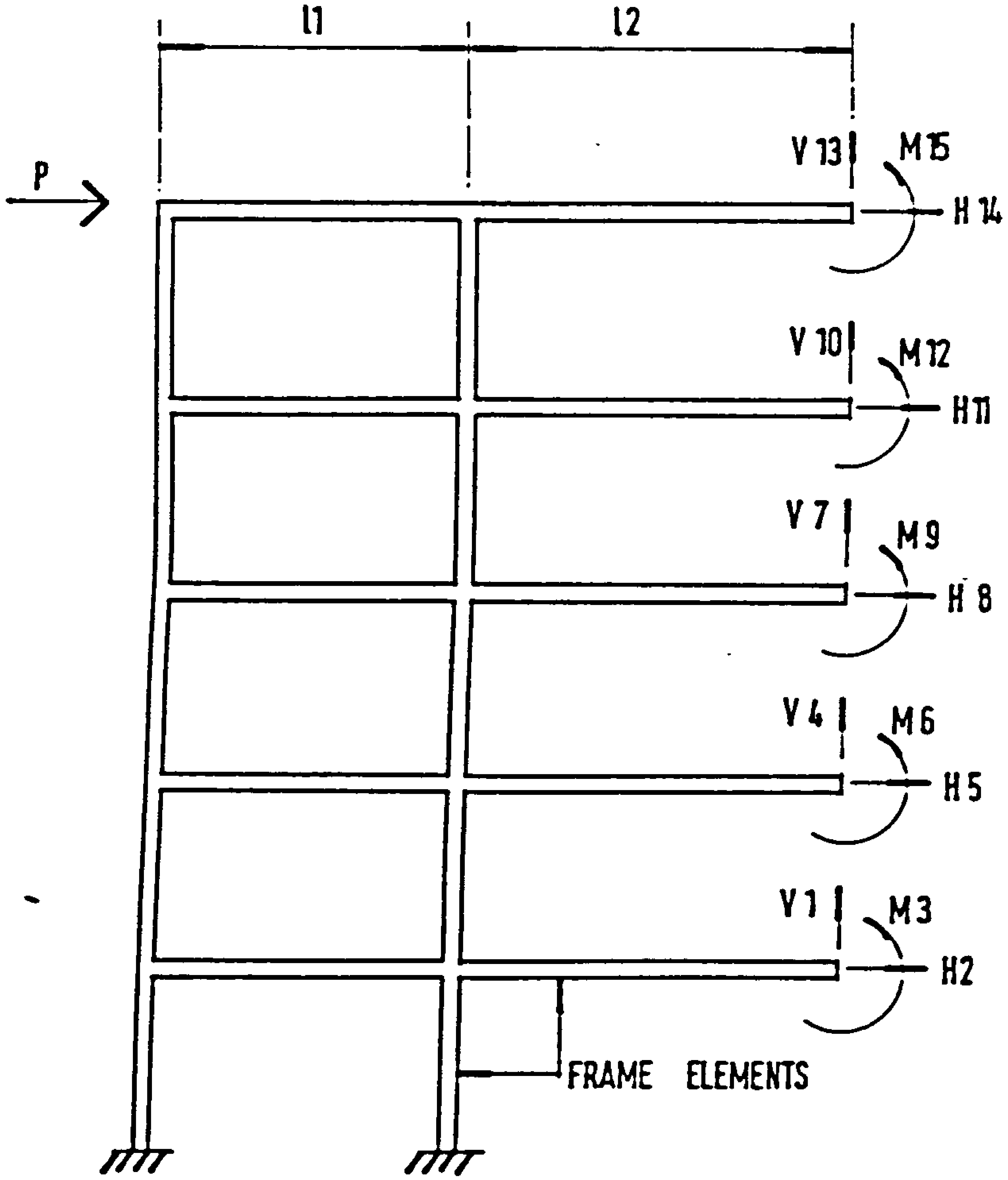
In the proposed method the shear wall and frame are analysed separately. The loading consists of applied loads and interaction forces at the boundary as shown in fig (5.2). Compatibility conditions are applied at the boundary and values of the interaction forces obtained.

This approach allows the coupled shear wall to be analysed using either the finite strip or continuum method and the frame by plane frame method.

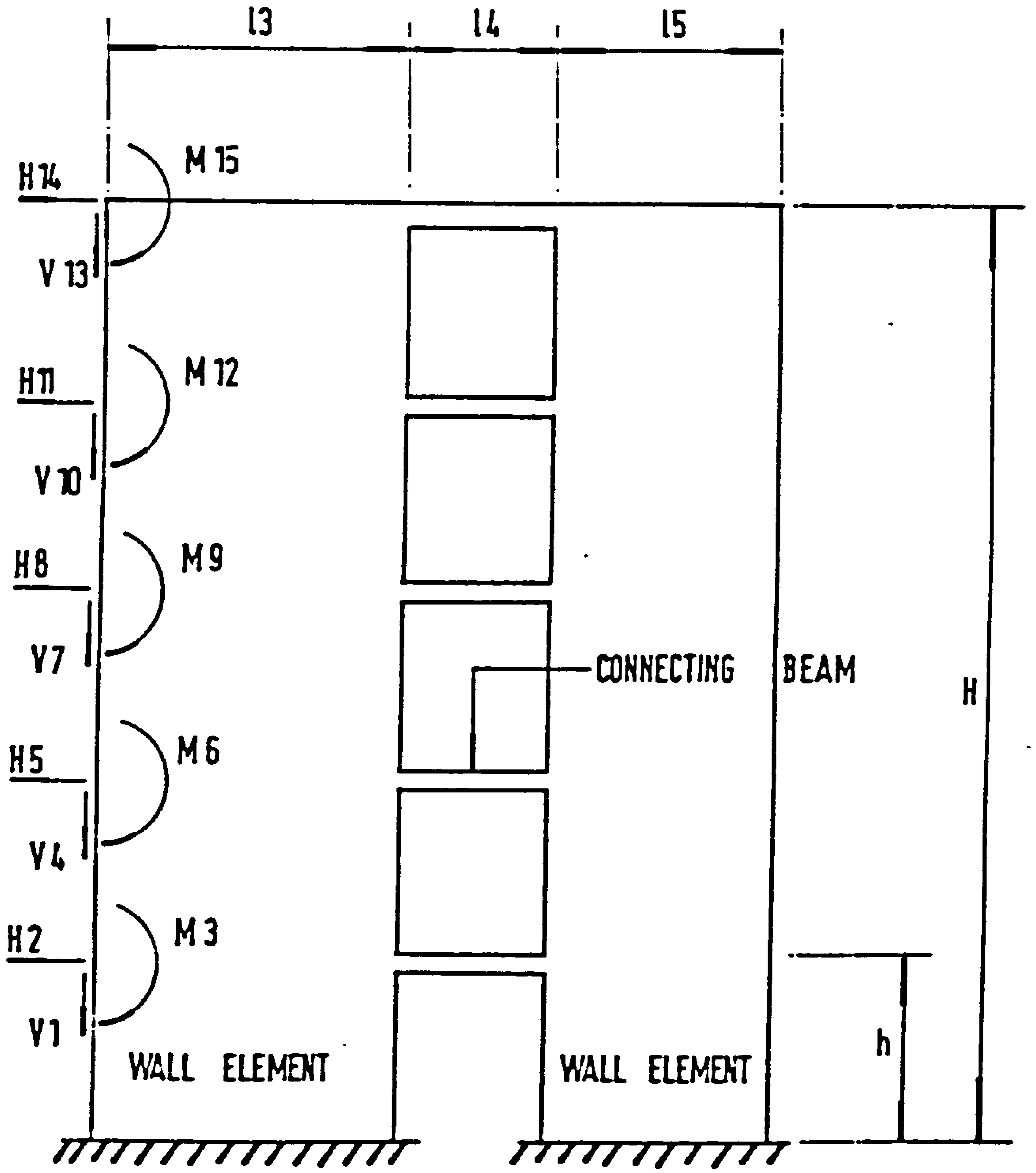
5.2 Basic Concept

The shear wall-frame structure is divided into two substructures, as shown in figs (5.2) & (5.3). To satisfy equilibrium, equal and opposite forces are introduced at the connecting points.

Both substructures can now be considered individually. The loading is considered in two parts:

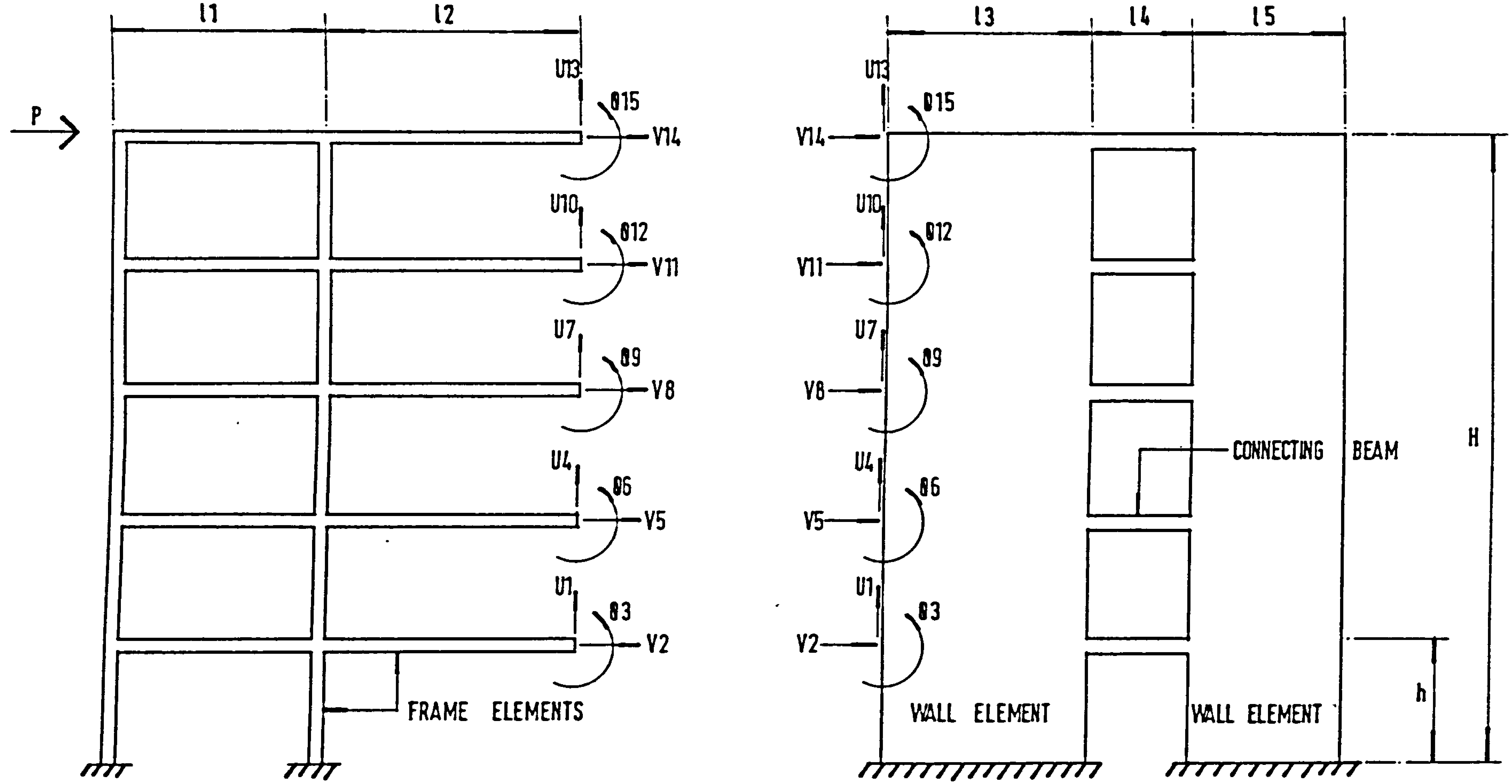


a) FRAMED STRUCTURE



b) COUPLED SHEAR WALL

FIG (5.2) MODULES OF SUBSTRUCTURES
(RESULTANT STRESSES)



a) FRAMED STRUCTURE

b) COUPLED SHEAR WALL

FIG (5.3) MODULES OF SUBSTRUCTURES (BOUNDARY DISPLACEMENT)

a) all applied loads (if any)

b) interaction forces which are unknown

1) Method

Each substructure is now analysed for the following loads

i) externally applied loads

ii) unit value of each non-zero interaction force in turn

For each loading the deflections at all the connecting points are obtained.

2) Assumptions

The analysis is carried out with the usual assumptions:

a) each substructure is perfectly elastic

b) small deformation theory applies

c) Bernoulli-Navier hypothesis holds for strain distribution

The first of these assumptions means that the effect of force H_i is the effect of unit force times H_i. Therefore,

Deflection due to force $H_i = H_i$ * (deflection due to unit load)

At each connecting point the total deflections may be expressed as a combination of :

i) deflection due to applied loads

ii) series of unit load deformation times unknown related interaction forces

3) Solution

The substructures are now recombined to satisfy compatibility conditions. As shown in fig (5.3), the deflections at the connecting points for both substructures must be the same.

Equating the values from both substructures will set up a series of simultaneous equations. Solving these equations by any of the standard methods, the values of the interaction forces can be evaluated. Then a detailed analysis can be carried out of both substructures.

5.3 Theory

5.3.1 General

To reduce the size of the matrix, a condensed matrix may be formed in such a way that the construction of the stiffness matrix is arranged and partitioned in the following manner:

$$\begin{bmatrix} K_{11} & K_{12} \\ K_{21} & K_{22} \end{bmatrix} \begin{bmatrix} U_b \\ U_c \end{bmatrix} = \begin{bmatrix} P_b \\ P_c \end{bmatrix} \qquad (2)$$

where U_b = interior displacment

U_c = boundary displacement at interconnecting points

P_b = external applied load at nodes

P_c = external load at interacting points

Equation (2) may be rewritten as

$$[K_{11}]\ \{U_b\} + [K_{12}]\ \{U_c\} = \{P_b\} \tag{3}$$

$$[K_{21}]\ \{U_b\} + [K_{22}]\ \{U_c\} = \{P_c\} \tag{4}$$

Solving equations (3) & (4), displacement vectors

$\{U_c\}$ & $\{U_b\}$ become

$$\{U_c\} = -[K_{22}]^{-1}\ [K_{21}]\ \{U_b\} + [K_{22}]^{-1}\ \{P_c\} \tag{5}$$

$$\{U_b\} = -[K_{11}]^{-1}\ [K_{12}]\ \{U_c\} + [K_{11}]^{-1}\ \{P_b\} \tag{6}$$

Substituting equation (6) into (5), then the standard condensed equations may be expressed as

$$[\bar{K}]\ \{U_c\} = \{\bar{P}\} \tag{7}$$

where $[\bar{K}]$ = effective stiffness matrix

$\{\bar{P}\}$ = effective load vector

The effective matrix $[\bar{K}]$ and load vector $\{\bar{P}\}$ are given by

$$[\bar{K}] = [K_{22}] - [K_{21}]\ [K_{11}]^{-1}[K_{12}] \tag{8}$$

$$\{\bar{P}\} = \{P_c\} - [K_{21}]\ [K_{11}]^{-1}\ \{P_b\} \tag{9}$$

The condensation procedure, as shown above, is not efficient for digital computation. The reasons are:

a) It involves the inversion of matrices. This may become very cumbersome if the matrices are large.

b) when the analysis of large substructures which are highly redundant, or which consist of many interaction points, the computer storage capacity may become very large. This may cause computational difficulties when the storage exceeds the capacity of the available computer.

To overcome these difficulties, a more efficient method of solving the equations is proposed below.

5.3.2 Proposed Scheme

This scheme combines the methods of stiffness and flexibility. The stiffness method is used to determine the flexibility influence coefficients by applying unit loads at redundant points when the substructures are separated. The latter is used to derive the boundary displacements in terms of the unknown redundant forces and applied loads. Applying the equilibrium conditions at the boundary points, the final redundant forces can be solved by employing the Gauss Elimination method or any suitable solver which produces an accurate solution. The total number of equations is equal to the total number of boundary displacements.

In developing the concepts of this method, it is necessary to familarise the procedure of relating forces and displacements in the structure by using flexibility influence coefficients and to utilise the principle of Maxwell's Reciprocal Theorem to reduce the computer storage.The process of formulating a flexibility matrix can be found in any standard structures text book[14] [51]. The use of the flexibility influence coefficients to evaluate the interaction forces is described below.

5.4 Evaluation of Interaction Forces

a) Basic Concept

This employs the concept of flexibility coefficients which characterises the behaviour of the substructure by specifying a displacement response to applied unit loads.

The flexibility coefficients are obtained by applying an unit load at coordinate 'i' and computing the displacements 'a_{ji}' (j = 1,2, . . .n) at 'n' coordinates. This will produce the ith column of a flexibility matrix. By applying an unit load at all 'n' coordinates in turn a[n x n] flexibility matrix is constructed.

The flexibility matrix is the inverse of the stiffness matrix. Using the usual notation,

$$\{F\} = [K]\ \{d\} \quad (12)$$

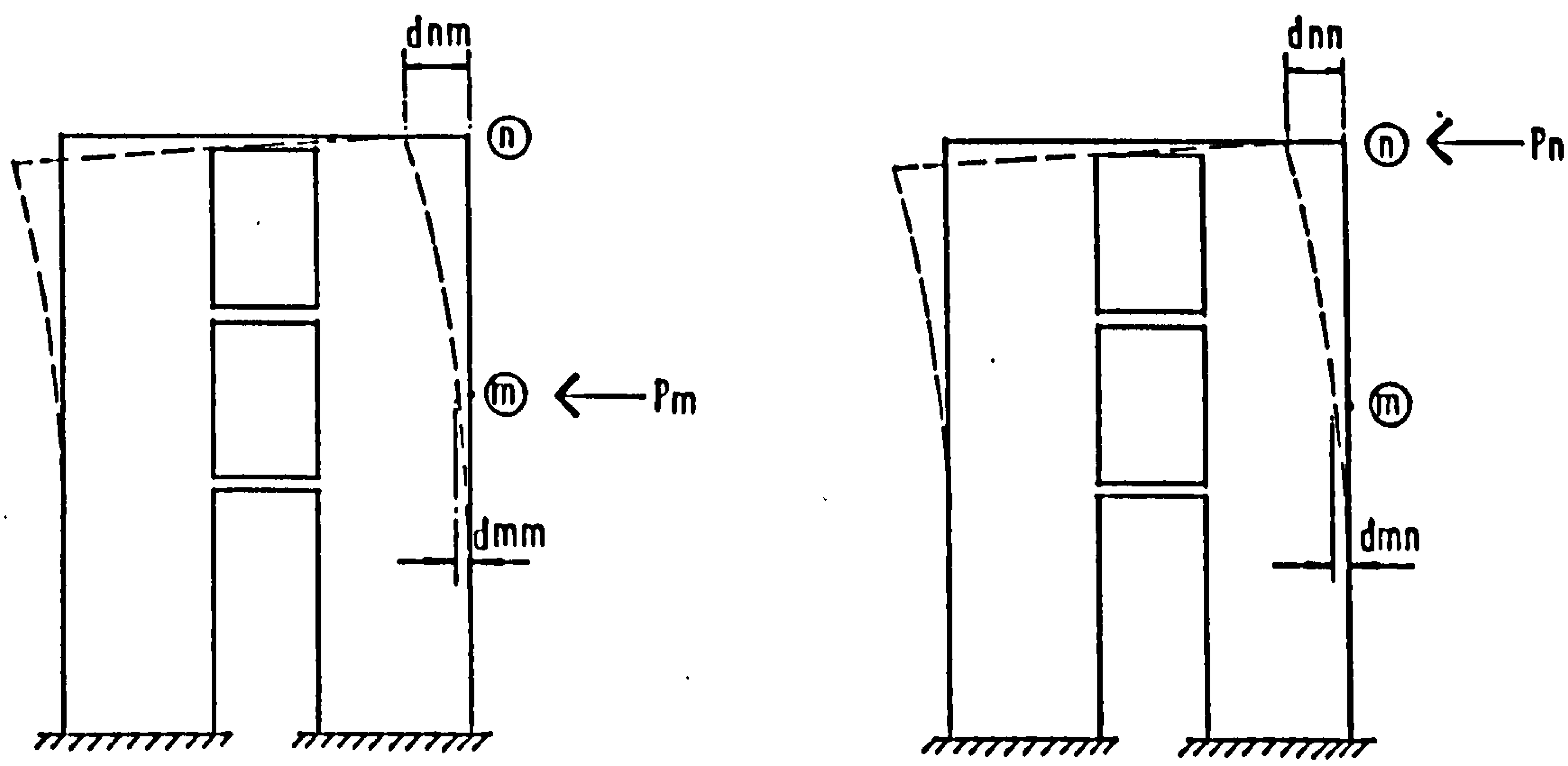
or $$\{d\} = [K]^{-1}\ \{F\}$$

$$= [f]\ \{F\} \quad (13)$$

where [f] = flexibility matrix

As the stiffness matrix is symmetrical, this must also hold for the flexibility matrix. This can also be verified by showing that Maxwell's Reciprocal Theorem will also apply to a coupled shear wall.

b) Application to Coupled Shear Wall



1) Unit Load Applied at Point (m) 2) Unit Load Applied at Point (n)

An element of the flexibility matrix is represented as 'f_{mn}'

When a horizontal load is applied at point 'm' then

$$d_{mm} = f_{mm}\, P_m \tag{14}$$

$$d_{nm} = f_{nm}\, P_m \tag{15}$$

Similarly when a load is applied at point 'n'

$$d_{nn} = f_{nn}\, P_n \tag{16}$$

$$d_{mn} = f_{mn}\, P_n \tag{17}$$

consider the total work done (U_1) by applying P_m first and then P_n

$$U_1 = 1/2\, P_m\, d_{mm} + 1/2\, P_n d_{nn} + P_m\, d_{mn} \tag{18}$$

Similarly by applying P_n first and then P_m

$$U_2 = 1/2\, P_n d_{nn} + 1/2\, P_m\, d_{mm} + P_n\, d_{nm} \tag{19}$$

As the substructures are perfectly elastic, the theory of superposition applies so that

$$U_1 = U_2 \tag{20}$$

Finally,

$$f_{mn} = f_{nm} \tag{21}$$

Equation (21) requires only the upper triangle of the flexibility matrix to be calculated.

5.4.1 Theoretical Approach

Fig (5.1) shows a structure comprised of a coupled shear wall and two bays of a rigid frame with an external applied load acting on the frame. At each interaction joint, there are two displacements and one rotation. The boundary displacements due to redundant forces and external applied load are described below.

5.4.1.1 Coupled Shear Wall (figs (5.2) & (5.3)

i) Redundant Forces

The boundary displacements at interaction points are given by

$$U_i = \sum_{j=1}^{n} f_{ij} \; P_j \tag{22}$$

That in the i^{th} displacement is equal to the sum of the products of the 'f_{ij}' (j = 1,2,. . . .n) in row i and the corresponding force P_j.

Expressing equation (22) in matrix form,

$$\{U_{w1}\} = [f_{w1}]\,\{x\} \tag{23}$$

in which $[f_{w1}]$ is the matrix of flexibility influence coefficients at interaction points due to unit loads applied at redundant points. Since the structure behaves linearly, the boundary displacement $\{U_{w1}\}$ due to actual redundant force $\{x\}$ is equal to $\{x\}$ times $[f_{w1}]$. This means that the vector $\{U_{w1}\}$ only represents the displacements due to redundant forces.

$$[f_{w1}] = \begin{bmatrix} WU_{1,1} & WV_{1,2} & W\theta_{1,3} & WU_{1,4} & & & & & W\theta_{1,n} \\ & WV_{2,2} & W\theta_{2,3} & WU_{2,4} & WV_{2,5} & & & & W\theta_{2,n} \\ & & W\theta_{3,3} & WU_{3,4} & WV_{3,5} & W\theta_{3,6} & & & W\theta_{3,n} \\ & & & & & & & & \\ & & & & & & & & \\ & & & & & & & & \\ & & & & & & & & \\ & & & & & & & WV_{n-1,n-1} & W\theta_{n-1,n} \\ & & & & & & & & W\theta_{n,n} \end{bmatrix} \tag{24}$$

and $\{U_{w1}\}$ is the boundary displacement vector

$$\{U_{w1}\} = \begin{bmatrix} WU_1 \\ WV_2 \\ W\theta_3 \\ \vdots \\ \vdots \\ WU_{n-2} \\ WV_{n-1} \\ W\theta_n \end{bmatrix} \tag{25}$$

where {x} is the magnitude of redundant force vector

$$\{x\} = \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ \vdots \\ \vdots \\ x_{n-1} \\ x_n \end{bmatrix} \tag{26}$$

ii) External Applied Load

When the substructures are completely isolated from each other, the application of external load causes boundary displacements in only that particular substructure. That is to say that the boundary displacements can be calculated from each substructure separately.

Therefore, the coupled shear wall is treated as an independent structure and its boundary displacements $\{U_{w2}\}$ due to external load are obtained directly by solving the stiffness matrix

$$\{U_{w2}\} = \{f_{w2}\} \tag{27}$$

in which $\{f_{w2}\}$ is the vector at interaction points due to the effect of external applied load. The boundary displacement vector $\{U_{w2}\}$ can be shown as

$$\{U_{W2}\} = \begin{bmatrix} WU_1 \\ WV_2 \\ W\theta_3 \\ \vdots \\ \vdots \\ WU_{n-2} \\ WV_{n-1} \\ W\theta_n \end{bmatrix} \tag{28}$$

5.4.1.2 **Frame Structure (Figs (5.2) & (5.3))**

i) Redundant Forces

To generate the flexibility matrix of the frame structure, it is also treated as a completely separate structure. An unit force is applied at each interaction point 'j' and the influence coefficients f_{ij} (i=1,2, . . .n) computed. Due to the linearity of the structure, the boundary displacements can be written as

$$\{U_{f1}\} = [f_{f1}]\ \{x\} \tag{29}$$

in which $[f_{f1}]$ is the matrix of flexibility influence coefficients due to unit loads applied at interaction points and is given by

$$[f_{f1}] = \begin{bmatrix} fu_{1,1} & fv_{1,2} & f\theta_{1,3} & & & & & & f\theta_{1,n} \\ & fv_{2,2} & f\theta_{2,3} & fu_{2,4} & & & & & f\theta_{2,n} \\ & & f\theta_{3,3} & fu_{3,4} & fv_{3,5} & & & & f\theta_{3,n} \\ & & & & & & & & \\ & & & & & & & & \\ & & & & & & & & \\ & & & & & & & & \\ & & & & & & & fv_{n-1,n-1} & f\theta_{n-1,n} \\ & & & & & & & & f\theta_{n,n} \end{bmatrix} \tag{30}$$

and the boundary displacement vector may be expressed as

$$\{U_{f1}\} = \begin{bmatrix} fu_1 \\ fv_2 \\ f\theta_3 \\ \vdots \\ \vdots \\ fu_{n-2} \\ fv_{n-1} \\ f\theta_n \end{bmatrix} \qquad (31)$$

where {x} = magnitude of redundant force vector

ii) External Load (if any)

Since the frame structure is assumed to be an independent stable structure, the external applied load yields corresponding lateral displacements and rotation at each interaction joint. It is simpler to obtain these boundary displacements by standard stiffness method because of the availability of plane frame programs. Thus, the boundary displacement vector is given by

$$\{U_{f2}\} = \begin{bmatrix} fu_1 \\ fv_2 \\ f\theta_3 \\ \vdots \\ \vdots \\ fu_{n-2} \\ fv_{n-1} \\ f\theta_n \end{bmatrix} \qquad (32)$$

5.4.1.3 Solution

Having determined the boundary displacements of each substructure separately due to effects of redundant forces and external applied load, the total boundary displacements of each substructure can be expressed as

a) Coupled Shear Wall

$$\{U_w\} = \{U_{w2}\} - \{U_{w1}\} \tag{33}$$

Substituting equation (23) into equation (33), it becomes

$$\{U_w\} = \{U_{w2}\} - [f_{w1}]\,\{x\} \tag{34}$$

b) Frame Structure

Similarly for frame structure, it is

$$\{U_f\} = \{U_{f2}\} + \{U_{f1}\} \tag{35}$$

Substituting equation (29) into equation (35), it becomes

$$\{U_f\} = \{U_{f2}\} + [f_{f1}]\,\{x\} \tag{36}$$

To achieve the stability of the whole structure, the so-called equilibrium and compatibility conditions should be established at the interaction points for the combination of both substructures together.

Therefore,

$$\{U_w\} = \{U_f\} \tag{37}$$

Substituting equations (34) & (36) into equation (37), it can be expressed as

$$\{U_{w2}\} - [f_{w1}]\,\{x\} = \{U_{f2}\} + [f_{f1}]\,\{x\} \tag{38}$$

Rearranging equation (38), it becomes

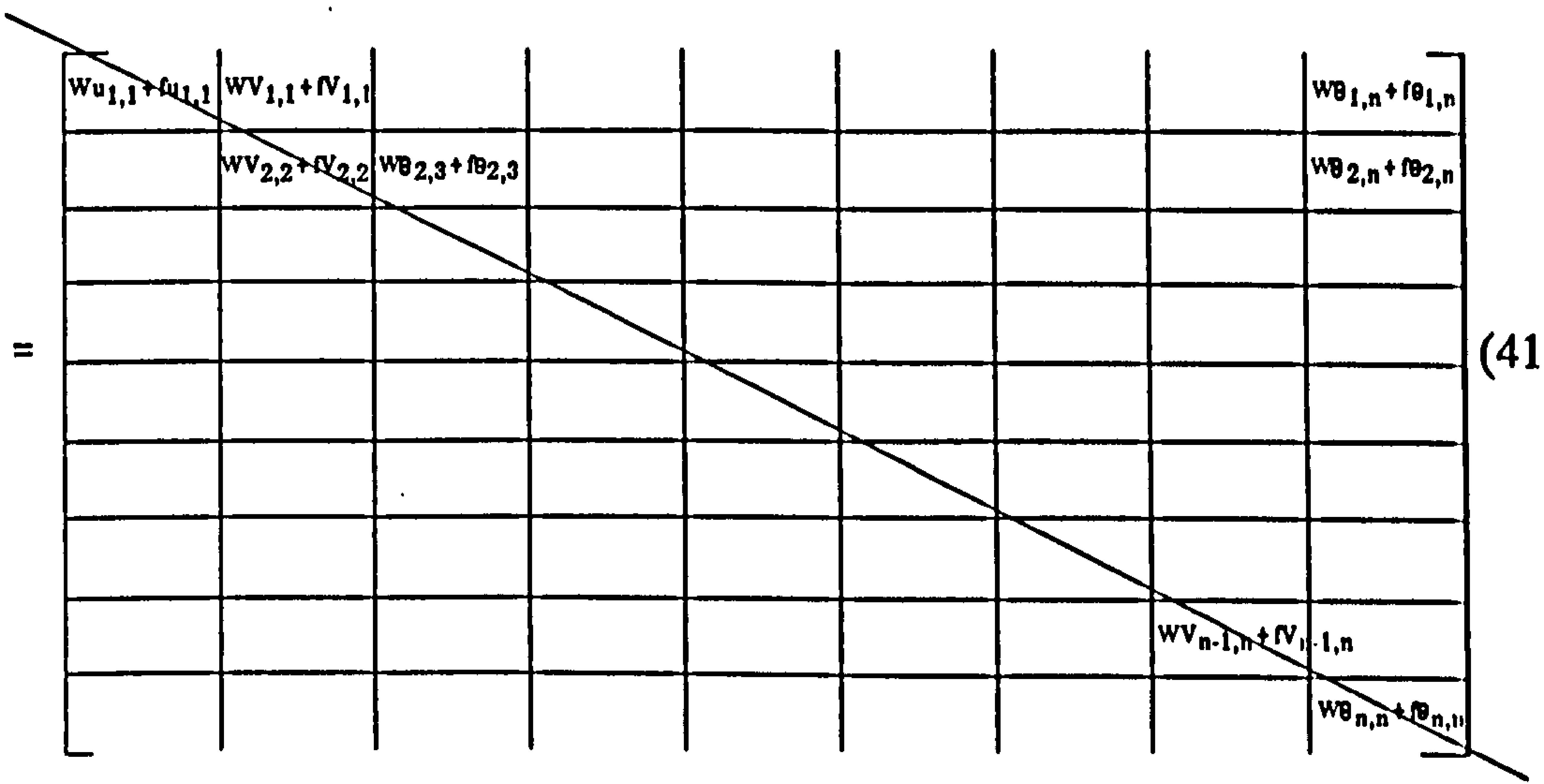
$$\{U_{w2}\} - \{U_{f2}\} = [f_{w1} + f_{f1}]\,\{x\} \tag{39}$$

Finally, it may be written in general form as

$$[\bar{f}]\ \{x\} = \{\bar{U}\} \tag{40}$$

It is very clear that equation (40) is a set of simultaneous equations in term of unknown vector $\{x\}$ in which $[\bar{f}]$ is a combined flexibility influence coefficients between two substructures and is given by

$[\bar{f}]$ =



(41)

and $\{\bar{U}\}$ is the combined boundary displacement vector due to external applied load. It is given by

$$\{\bar{U}\} = \begin{bmatrix} WU_1\text{-}fU_1 \\ WV_2\text{-}fV_2 \\ \vdots \\ \vdots \\ WV_{n-1}\text{-}fV_{n-1} \\ W\theta_n\text{-}f\theta_n \end{bmatrix} \tag{42}$$

Once the interaction forces have been found, the interior forces, stresses and displacements in each member of a substructure can be computed by treating each substructure separately.

5.5 Remarks

The method of analysis, presented in this chapter, divides the structure into substructures. The loading on each substructure consists of applied loads and unknown interaction forces at the connecting points. By considering the compatibility conditions at the connecting points, the values of the interaction forces are calculated. Hence, accurate values can be obtained for the interaction forces. This allows an analysis to be carried out on each substructure.

The shear wall can be analysed using either the continuum method or the finite strip method. The effect of local deformation at the beam-wall junction may also be taken into account. The frame can be analysed using a standard plane frame program.

The advantage of this method is that the computer storage and time is considerably less than for any of the other standard methods. It also directly yields the redundant forces instead of displacements.

In conclusion, it might be pointed out that the method developed here may also be applied to a more complex system of structures. The versatility of the analytical method and low computing time make it ideally suited for application to wall-frame structures. The accuracy and reliability will be compared with those results obtained by either experimental works or other existing approaches and are shown in Chapter six.

CHAPTER SIX

COMPARISON OF ANALYTICAL AND EXPERIMENTAL RESULTS FOR WALL-FRAME STRUCTURES

6.1 Introduction

In Chapter five, the structure analysed was extended from a coupled shear wall to a shear wall and frame structure. The analysis of the structure was carried out in three ways:

a) finite strip element for both wall and frame

b) finite strip for the wall with plane frame for frame

c) continuum method for wall with plane frame for frame

In this chapter the results from the above analyses are compared with previous analytical results and experimental results.

6.2 Comparison with Previous Analysis and Experimental Result

Three shear wall-frame structures previously analysed by various authors are reanalysed using the finite strip and proposed methods.

Six models were tested and the experimental results compared with values analysed by the finite strip and proposed methods.

6.2.1 Previous Analyses

The first wall-frame structure, previously analysed by Oakberg and Weaver[52], is shown in fig (6.1). The wall-frame structure was analysed by

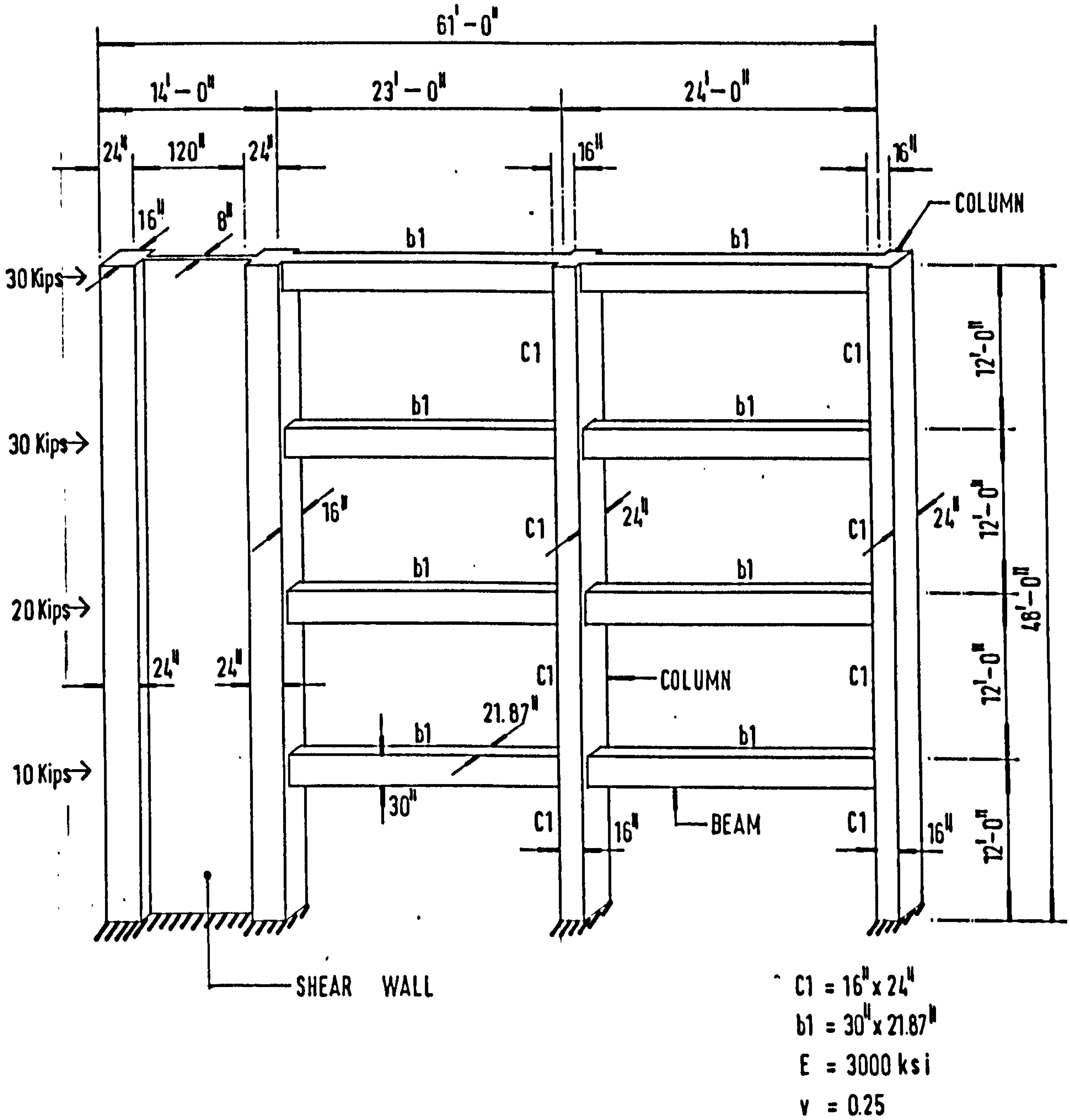


FIG (6.1) WALL - FRAME STRUCTURE ①

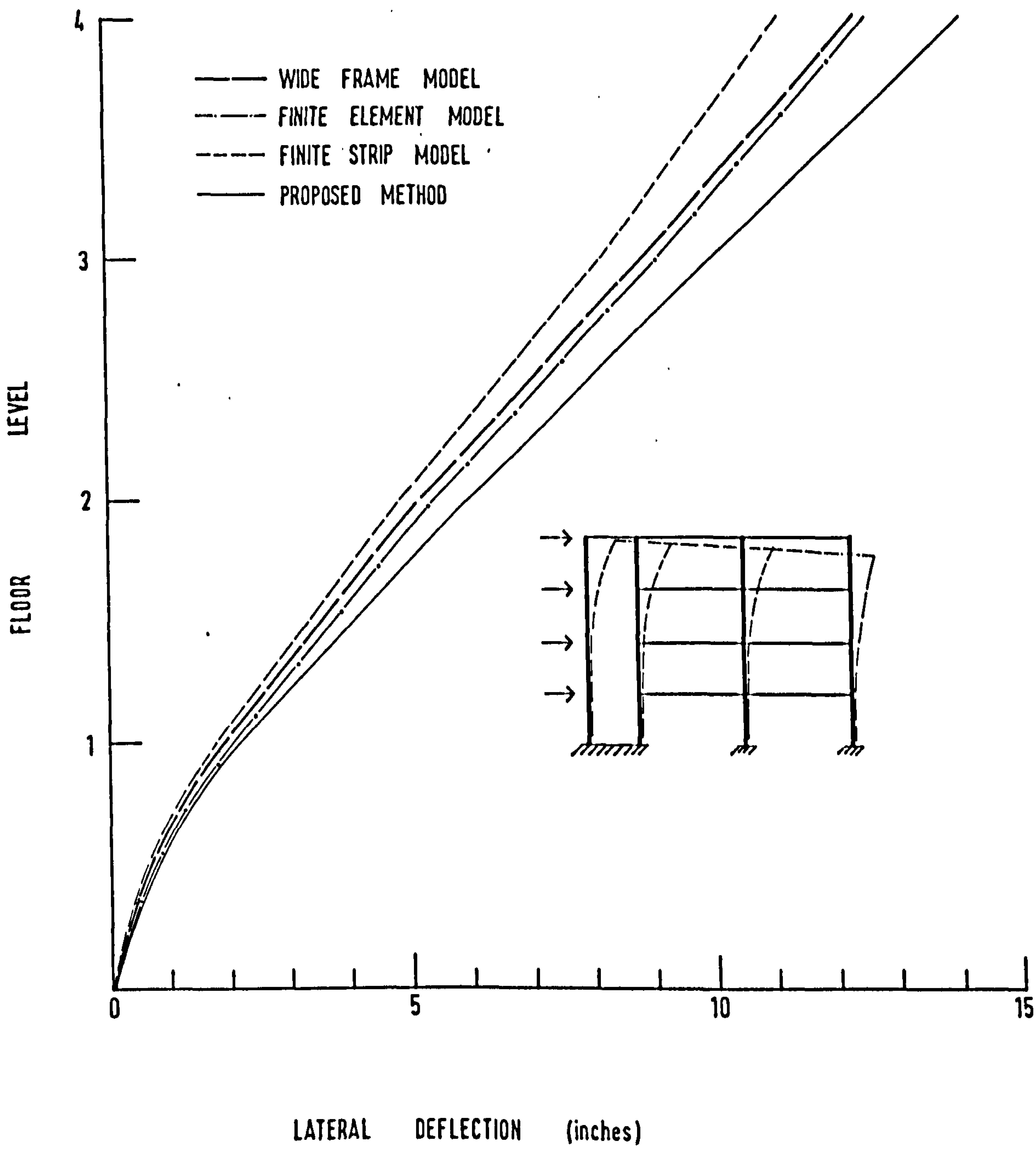


FIG (6.2) DISPLACEMENT AT WALL-BEAM CONNECTION FOR STRUCTURE ①

ACTIONS AT WALL-BEAM CONNECTION POINTS FOR STRUCTURE ①

TABLE 6-1 SHEAR FORCES (kips)				
FLOOR LEVEL	R. G. OAKBERG & WEAVER Jr.		F. S. M.	PROPOSED METHOD
	WIDE FRAME	F. E. M.		
1	6.12	5.25	5.88	4.20
2	7.85	7.13	8.26	6.58
3	7.48	6.83	8.25	6.24
4	5.33	4.98	5.44	4.28

TABLE 6-2 BENDING MOMENT (kip-ft)				
FLOOR LEVEL	R. G. OAKBERG & WEAVER Jr.		F. S. M.	PROPOSED METHOD
	WIDE FRAME	F. E. M.		
1	80.31	65.29	70.3	53.3
2	94.46	82.65	96.9	82.8
3	90.10	79.91	97.7	78.6
4	63.75	58.74	66.6	52.8

TABLE 6-3 ACTIONS IN SHEAR WALL FOR STRUCTURE ①

DESCRIPTION	OAKBERG & WEAVER Jr.		FINITE STRIP METHOD	PROPOSED METHOD
	WIDE FRAME	F. E. M.		
δ(H) (inches * 10^2)	12.38	12.56	11.05	14.64
Mw (kip – ft)	1933.12	1849.11	1811.1	2148.9
Aw (kips)	24.19	26.79	32.9	29.95

NOTE :

δ(H) = MAXIMUM LATERAL DEFLECTION AT THE TOP

Mw = MAXIMUM BENDING MOMENT AT THE BASE

Aw = MAXIMUM AXIAL FORCE IN THE WALL

both the wide column frame and finite element methods. In their analysis a Poisson's ratio value of 0.25 and a modulus of elasticity value of 3000k.s.i. were used. Lateral loads were applied to the shear wall at each floor level. The same loading was used for the analysis using the finite strip and proposed methods.

The lateral deflection of the wall, for all four analyses, is shown in fig (6.2). The interaction forces, at each floor level, are presented in Tables (6.1) to (6.3).

The second shear wall-frame structure analysed is shown in fig (6.3). This ten storey frame with a shear wall at each ends was previously analysed by Oakberg and Weaver[52] using wide column frame and finite element mehtods. The structural properties are the same as in the previous example.

The lateral deflections of the wall for all four analyses are shown in fig (6.4). The proposed method is seen to produce a more flexible structure whilst the finite strip appears conservative. The shear force and bending moment at all connection points are presented in tables (6.4) & (6.5). Very little difference is observed between the various analyses. The maximum value for deflection, shear, bending moment and axial force are given in table (6.6).

The third wall-frame structure is a model of a twenty storey structure previously analysed by Chan & Heidebrecht[12]. The principal dimensions and loading are shown in fig (6.5). The central shear wall is 9" (23cm) thick and connected, via 9" (23cm) floor slabs, to columns at both ends. The

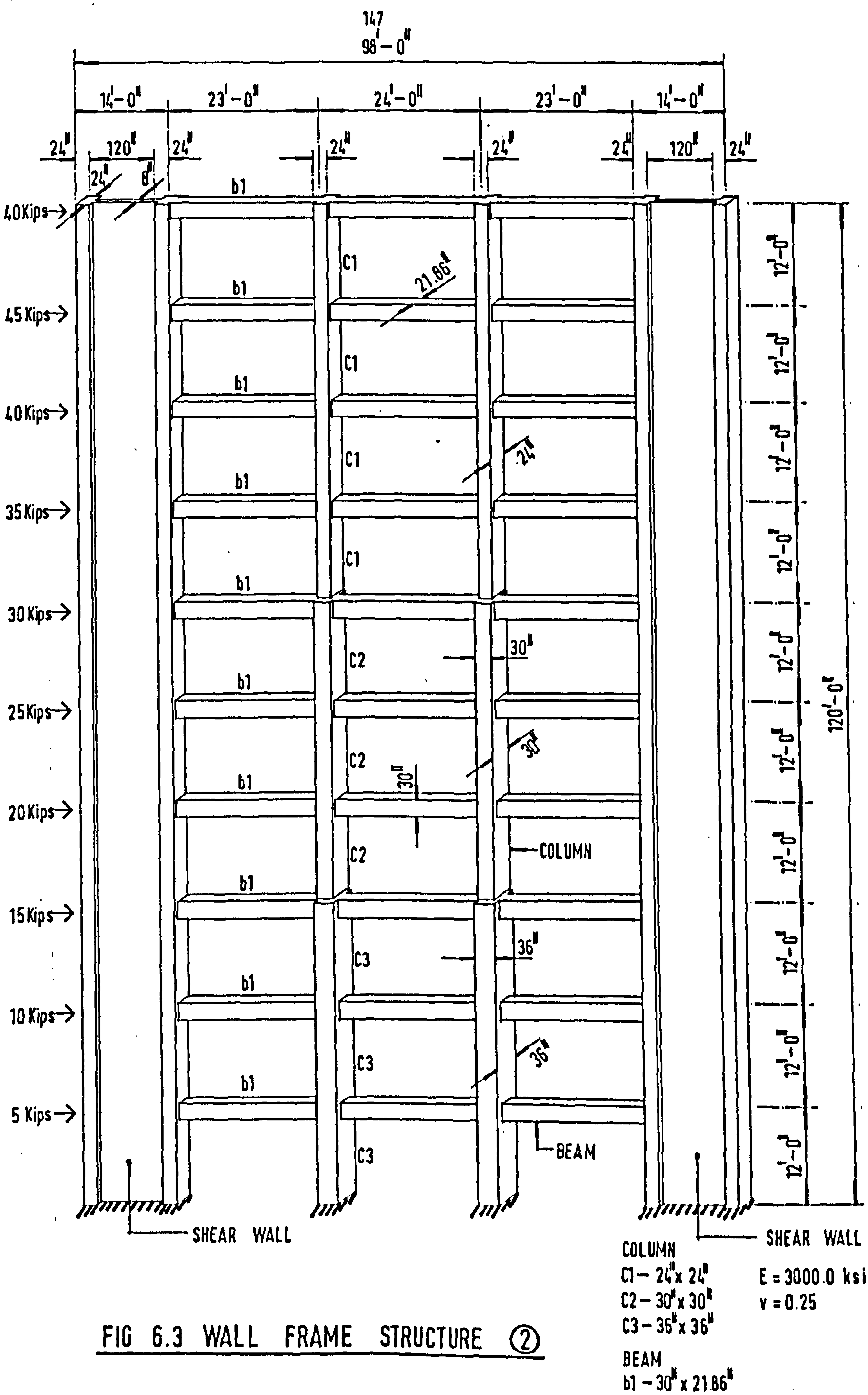


FIG 6.3 WALL FRAME STRUCTURE ②

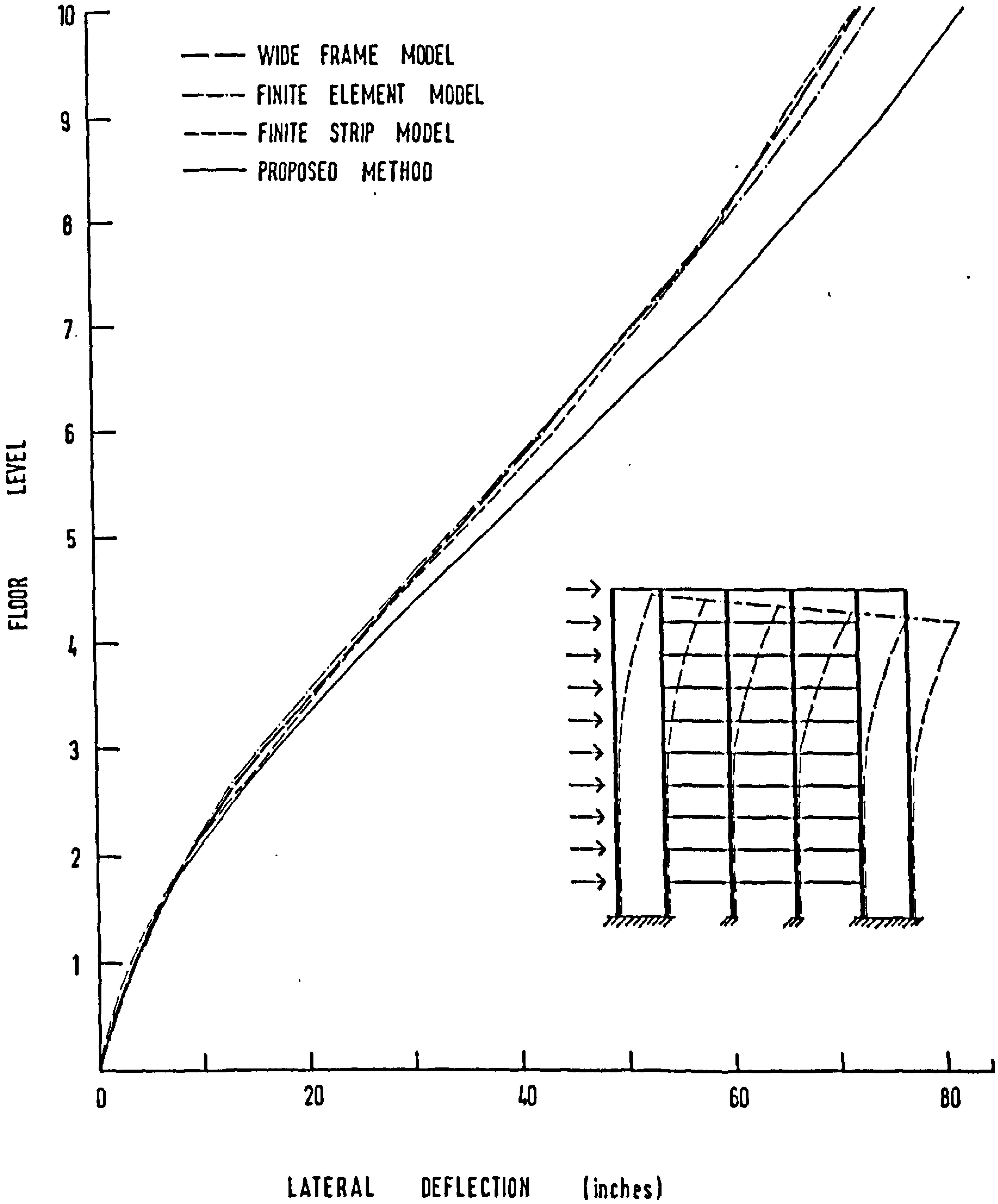


FIG (6.4) DISPLACEMENT AT WALL – BEAM JUNCTION FOR STRUCTURE ②

ACTIONS AT WALL - BEAM CONNECTION POINTS FOR STRUCTURE (2)

TABLE 6-4 SHEAR FORCES (kips)				
FLOOR LEVEL	OAKBERG & WEAVER Jr.		FINITE STRIP METHOD	PROPOSED METHOD
	WIDE FRAME	F. E. M.		
1	-11.07	-10.70	-13.05	-10.48
2	-14.52	-14.59	-13.39	-13.99
3	-15.88	-15.78	-14.97	-15.82
4	-17.43	-17.10	-17.28	-17.02
5	-20.82	-20.04	-19.06	-19.10
6	-22.55	-21.48	-19.65	-20.60
7	-21.96	-20.97	-19.28	-20.00
8	-21.56	-20.20	-18.16	-18.53
9	-18.33	-17.16	-15.55	-15.64
10	-11.67	-11.11	-9.92	-10.20

TABLE 6-5 BENDING MOMENT (kip-ft)				
FLOOR LEVEL	OAKBERG & WEAVER Jr.		FINITE STRIP METHOD	PROPOSED METHOD
	WIDE FRAME	F. E. M.		
1	114.06	132.76	161.17	142.33
2	173.44	168.56	165.25	172.41
3	190.43	183.80	184.83	197.88
4	208.95	199.80	213.33	213.17
5	238.79	223.65	235.25	227.69
6	236.94	234.94	242.58	238.67
7	247.79	228.69	238.00	232.33
8	237.10	216.43	224.17	211.58
9	198.14	181.46	191.92	175.17
10	124.43	117.72	122.42	114.08

TABLE 6 – 6 ACTIONS IN SHEAR WALL FOR STRUCTURE (2)

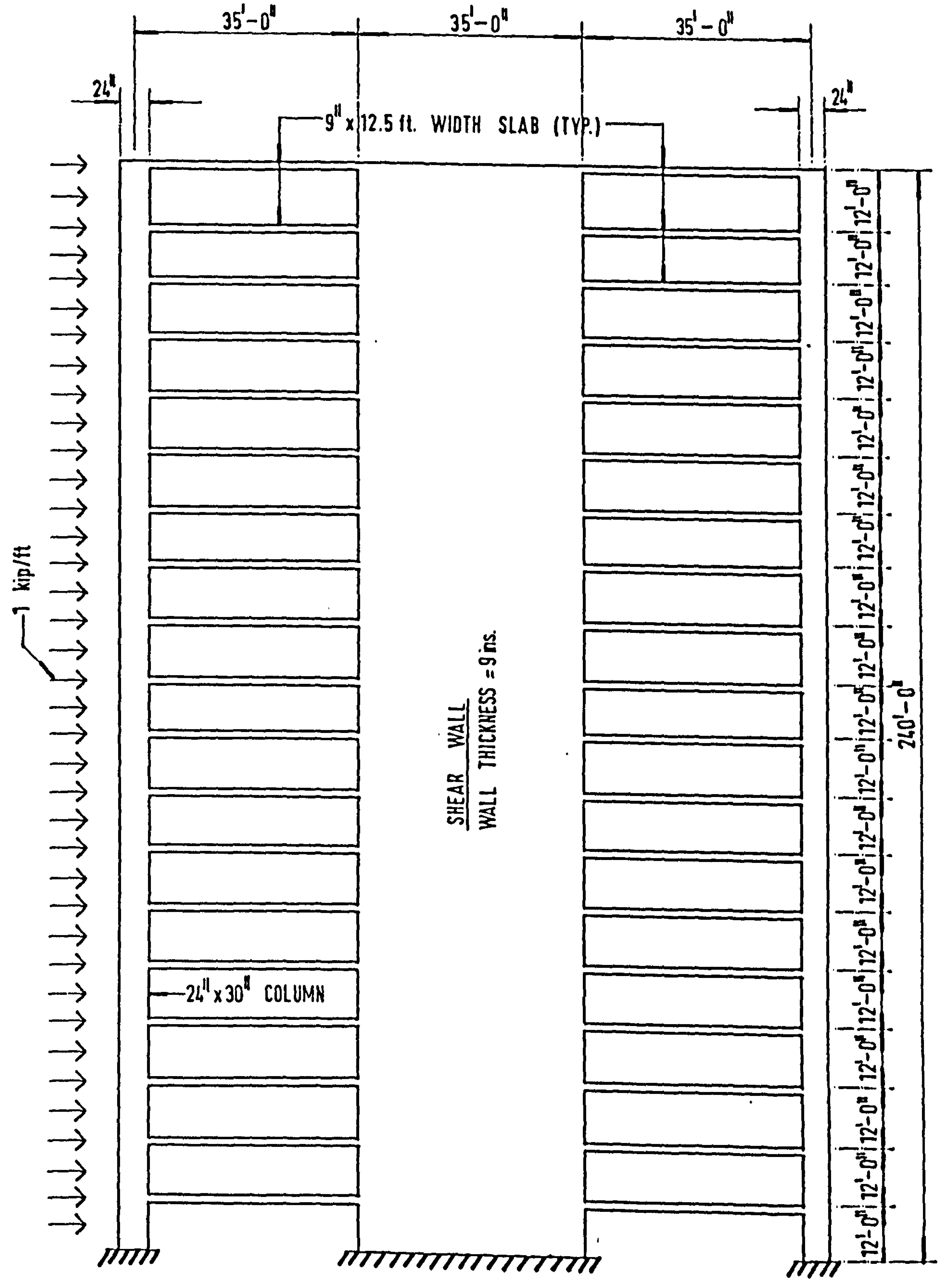
DESCRIPTION	OAKBERG & WEAVER Jr.		FINITE STRIP METHOD	PROPOSED METHOD
	WIDE FRAME	F. E. M.		
δ (H) (inches $* 10^2$)	74.97	73.55	73.2	85.7
Mw (kip – ft)	3946.1	3737.29	3966.1	3845.7
Aw (kips)	168.96	175.82	165.72	166.2

NOTE:

δ (H) = MAXIMUM LATERAL DEFFLECTION AT THE TOP

Mw = MAXIMUM BENDING MOMENT AT THE BASE

Aw = MAXIMUM AXIAL FORCE IN THE WALL



ELASTIC MODULUS = 3×10^6 psi
SHEAR MODULUS = 1.2×10^6 psi

FIG (6.5) WALL – FRAME STRUCTURE ③

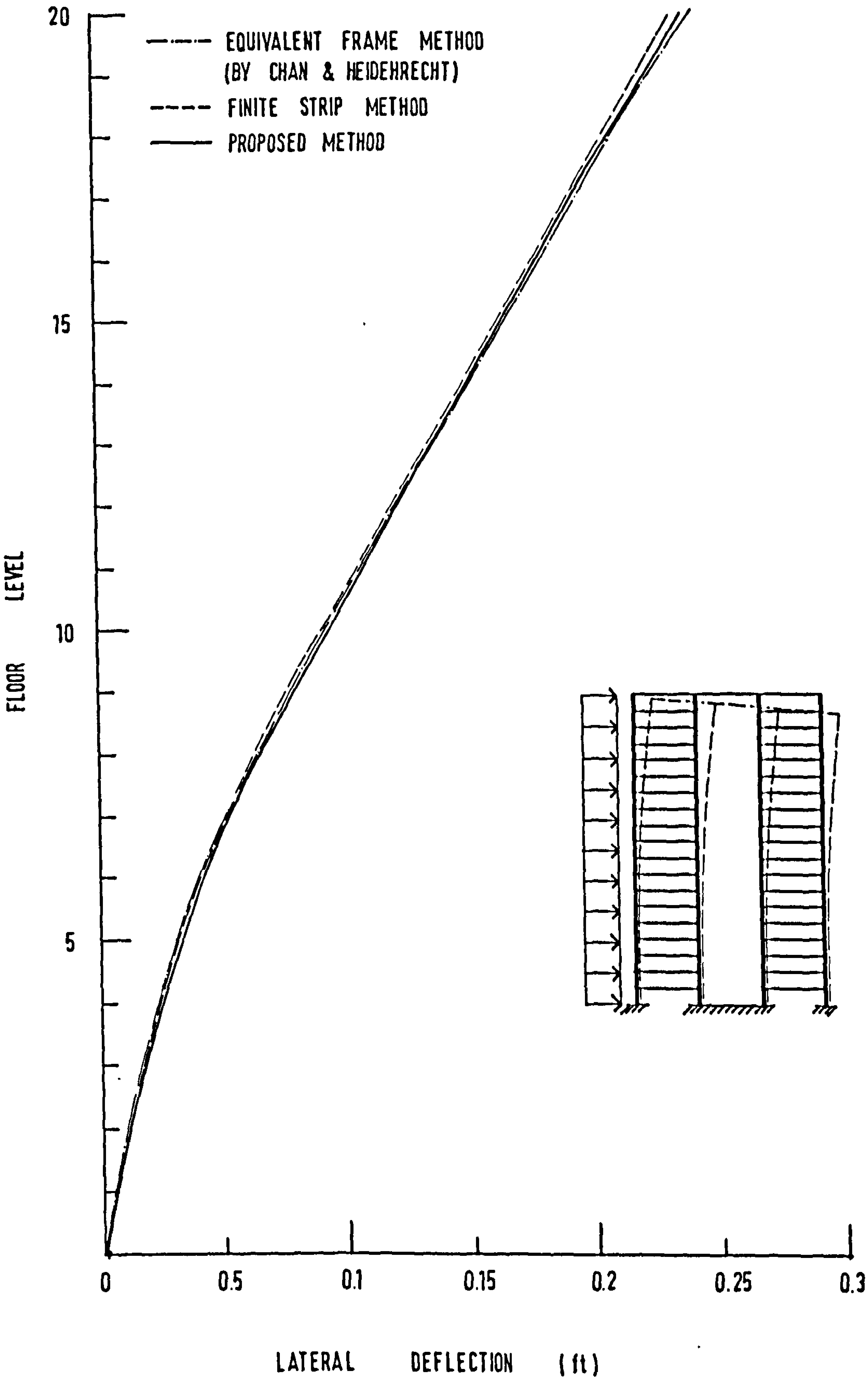


FIG (6.6) DISPLACEMENT FOR WALL-FRAME STRUCTURE ③

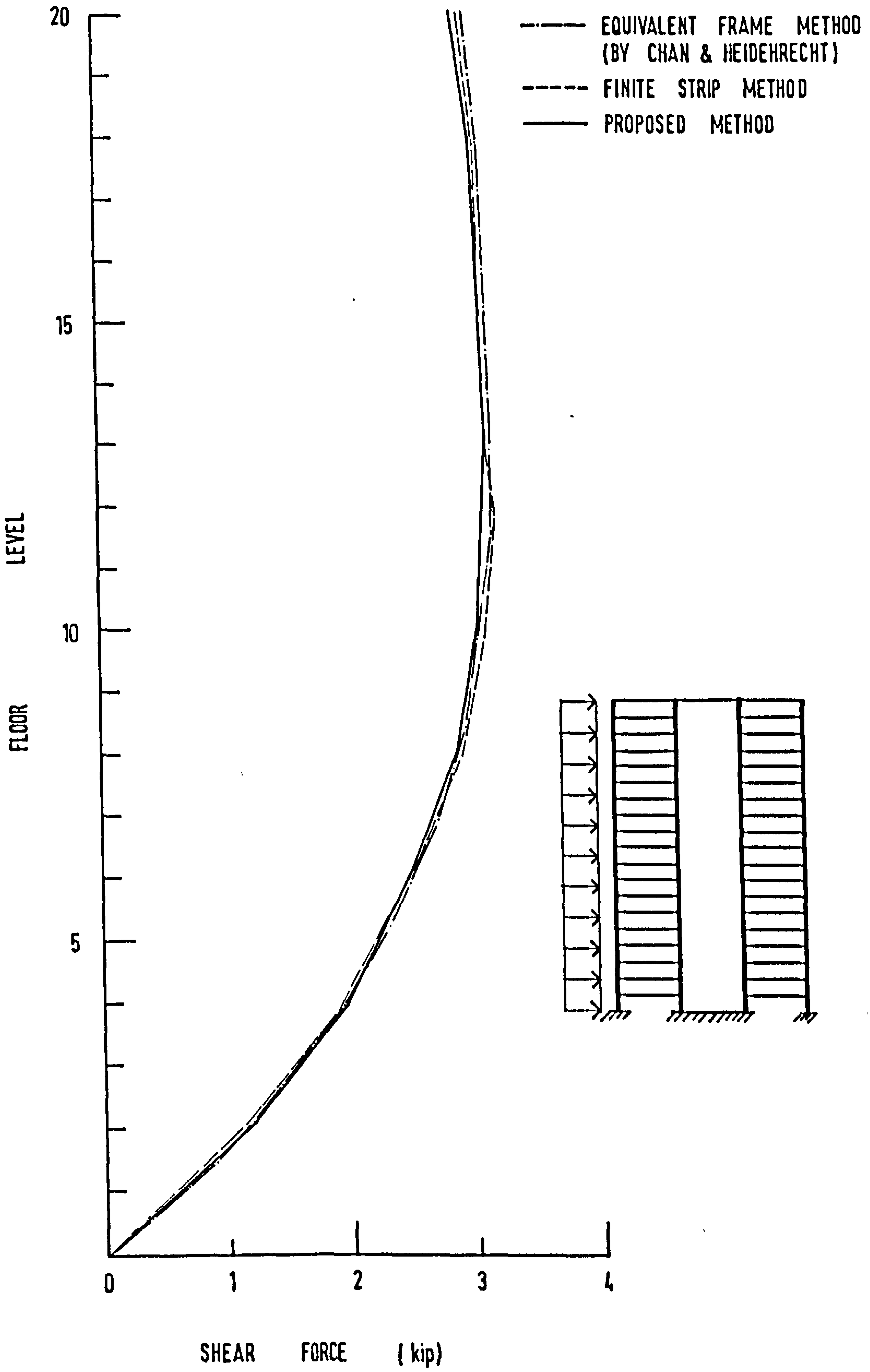


FIG (6.7) SHEAR FORCE IN CONNECTING BEAM FOR STRUCTURE ③

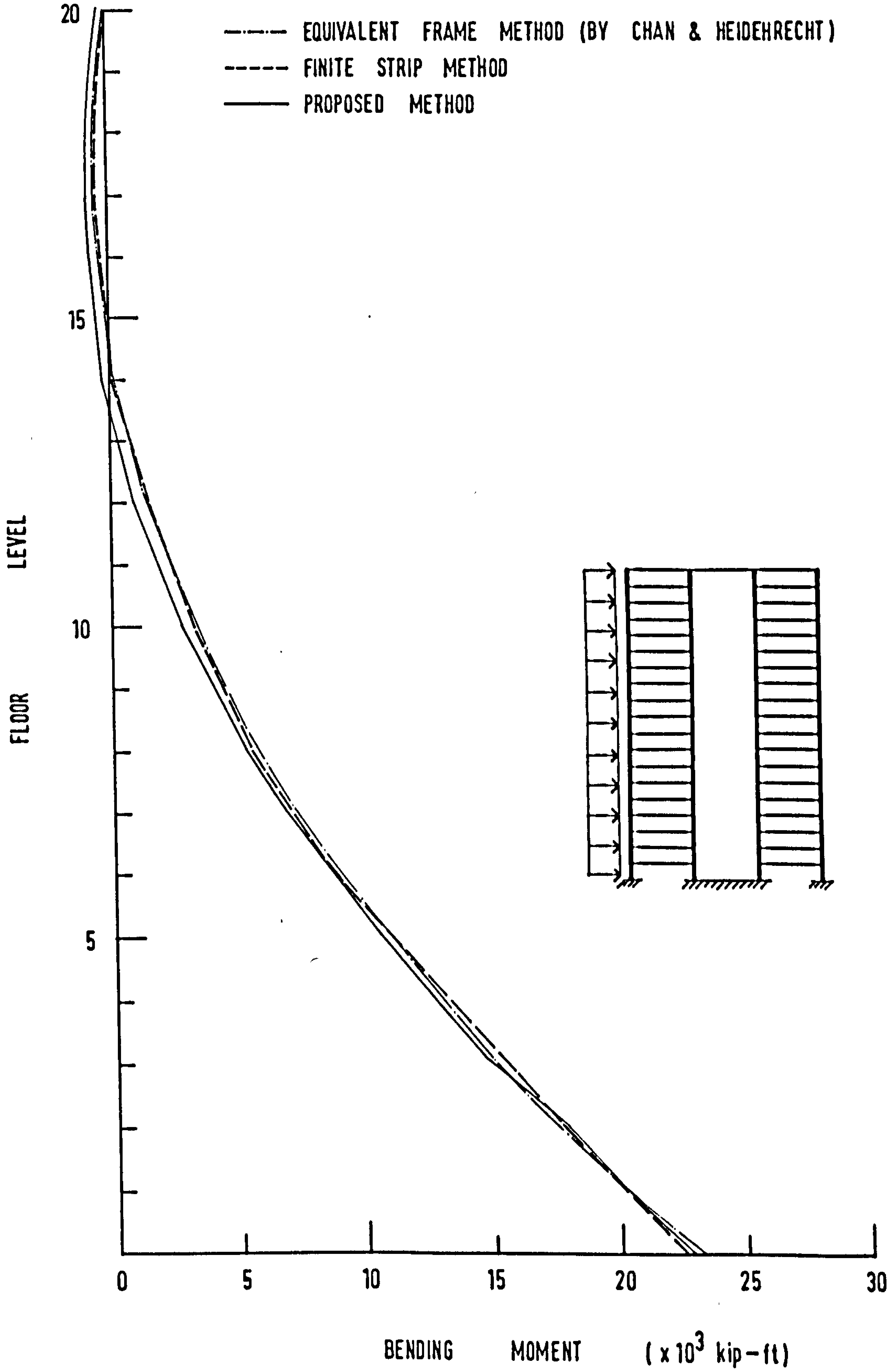


FIG (6.8) BENDING MOMENT IN SHEAR WALL FOR STRUCTURE ③

TABLE 6-7 ACTIONS IN THE STRUCTURE FOR STRUCTURE (3)

DESCRIPTION	EQUIVALENT FRAME METHOD	FINITE STRIP METHOD	PROPOSED METHOD
δ (H) (ft)	0.2464	0.24854	0.237
Mw (base) (kip-ft)	22924	23275	23890
Q(beam) (kip)	3.379	2.95	3.18

NOTE:

δ(H) = MAXIMUM LATERAL DEFLECTION AT THE TOP OF STRUCTURE

Mw(base) = MAXIMUM BENDING MOMENT AT THE BASE OF SHEAR WALL (FOR FINITE STRIP AND PROPOSED METHODS THE MAX. MOMENT IS TAKEN AT THE MID-HEIGHT BETWEEN THE BASE AND 1ST. FLOOR)

Q (beam) = MAXIMUM SHEAR FORCE IN THE CONNECTING BEAM AT WALL—BEAM JUNCTION floor slabs have a clear span of 35ft (10.67m) and an equivalent width of 12.5ft (3.81m). The shear and elastic moduli used were 1.2 x 10^6 p.s.i. (8.3 x 10^3 N/mm^2) and 3.0 x 10^6 p.s.i. (2.07 x 10^4 N/mm^2) respectively. The loading is a lateral uniformly distributed load of 1 kip/ft.

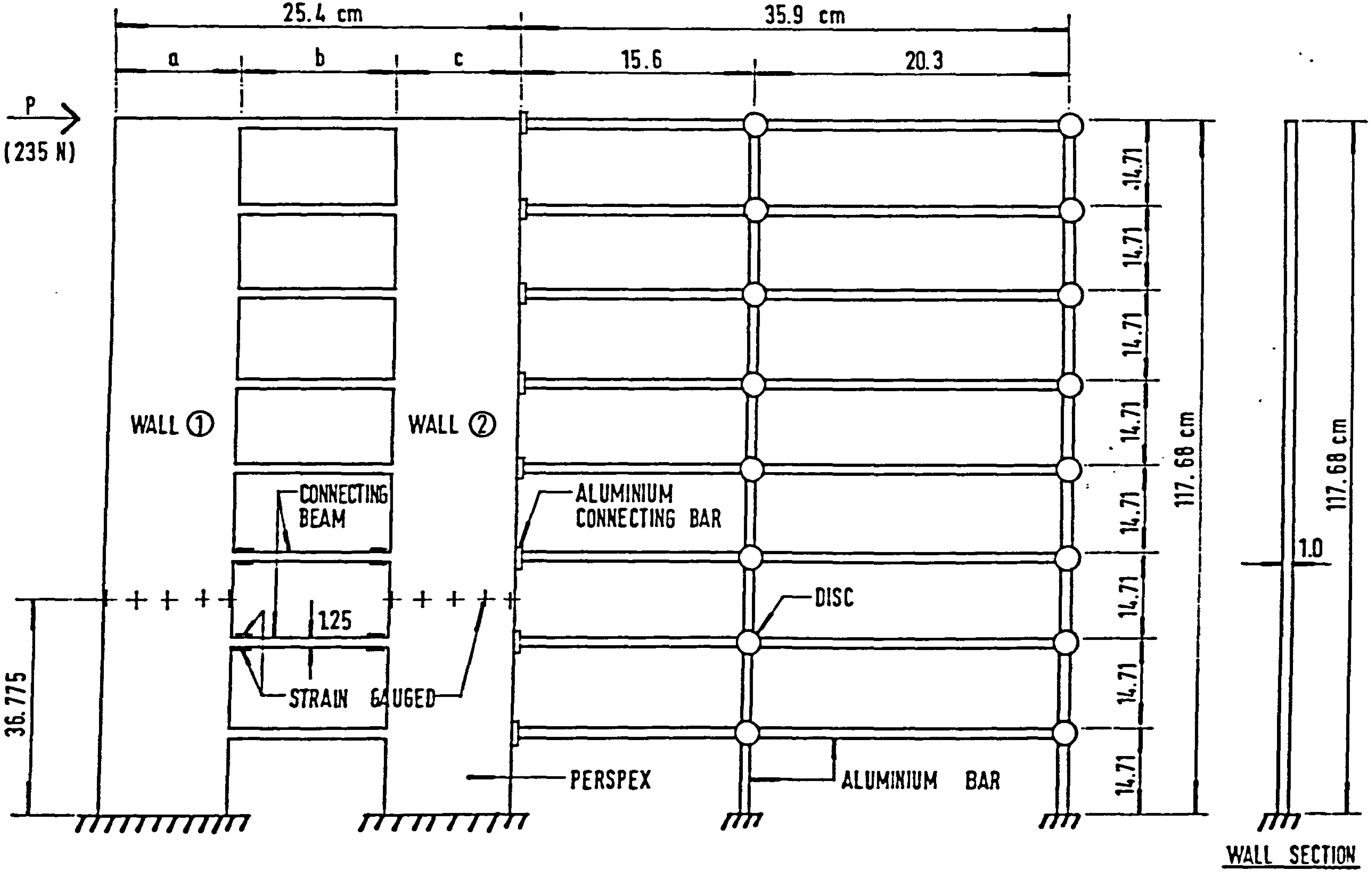
The lateral deflection of the wall-frame structure is shown in fig (6.6) . Both the finite strip and the proposed methods produce similar results to the original equivalent frame method. The variation of the shear force and bending moment are shown in figs (6.7) & (6.8). Again all three analyses produce virtually the same values. The maximum values of tip deflection, shear force and bending moment are presented in table (6.7) for the three analyses. As can be seen there is very small difference in the values obtained by the analyses.

6.2.2 Experimental Results

a) Model Details

Six experimental models were tested and their dimensions are shown in figs (6.9) & (6.10).

The first three models are symmetrical but with different wall widths and connecting beam lengths. Therefore, three ratios of beam length/wall width, 1.34, 0.85 and 0.5 are obtained. The effect of these ratios on the stress distribution can be examined. The fourth model, as shown in fig (6.9), is also of constant thickness but assymmetrical. Models 5 and 6 are symmetrical but the thickness changes from 1.0cm to 0.6cm at a height of

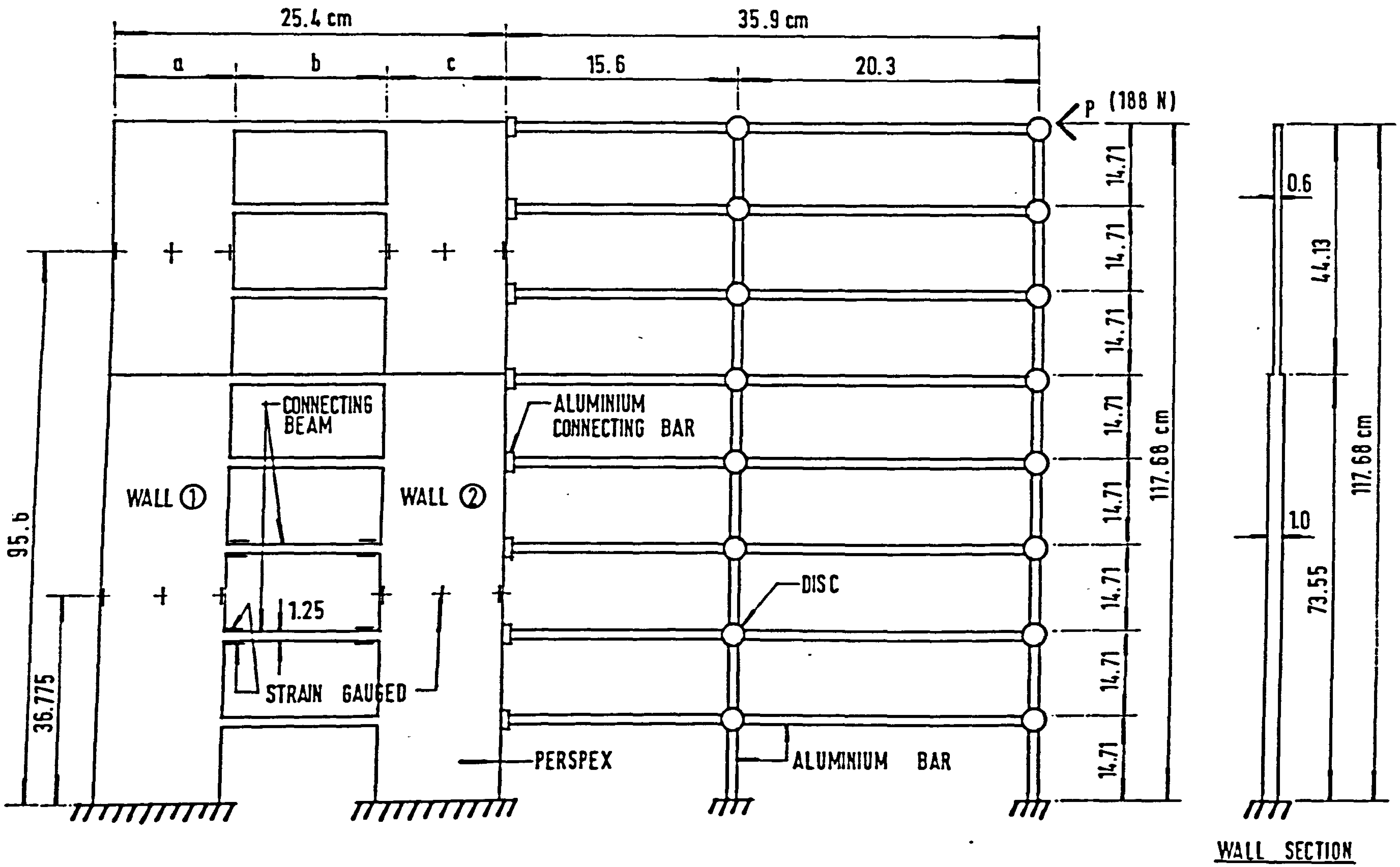


MODEL	DIMENSION		
	a	b	c
1	7.6	10.2	7.6
2	8.9	7.6	8.9
3	10.1	5.2	10.1
4	5.9	5.1	14.4

CONNECTION
1) END MEMBER TO WALL - 2 BOLTS
2) EACH MEMBER TO DISC-2 BOLTS

FIG (6.9) EXPERIMENTAL MODELS ①②③ & ④
(CONSTANT WALL THICKNESS)

MODEL	DIMENSION a	b	c
5	7.6	10.2	7.6
6	10.1	5.2	10.1



CONNECTION

1) END MEMBER TO WALL – 2 BOLTS

2) EACH MEMBER TO DISC – 2 BOLTS

FIG 6.10 EXPERIMENTAL MODELS ⑤ & ⑥
(VARIABLE WALL THICKNESS)

STATIC MODEL

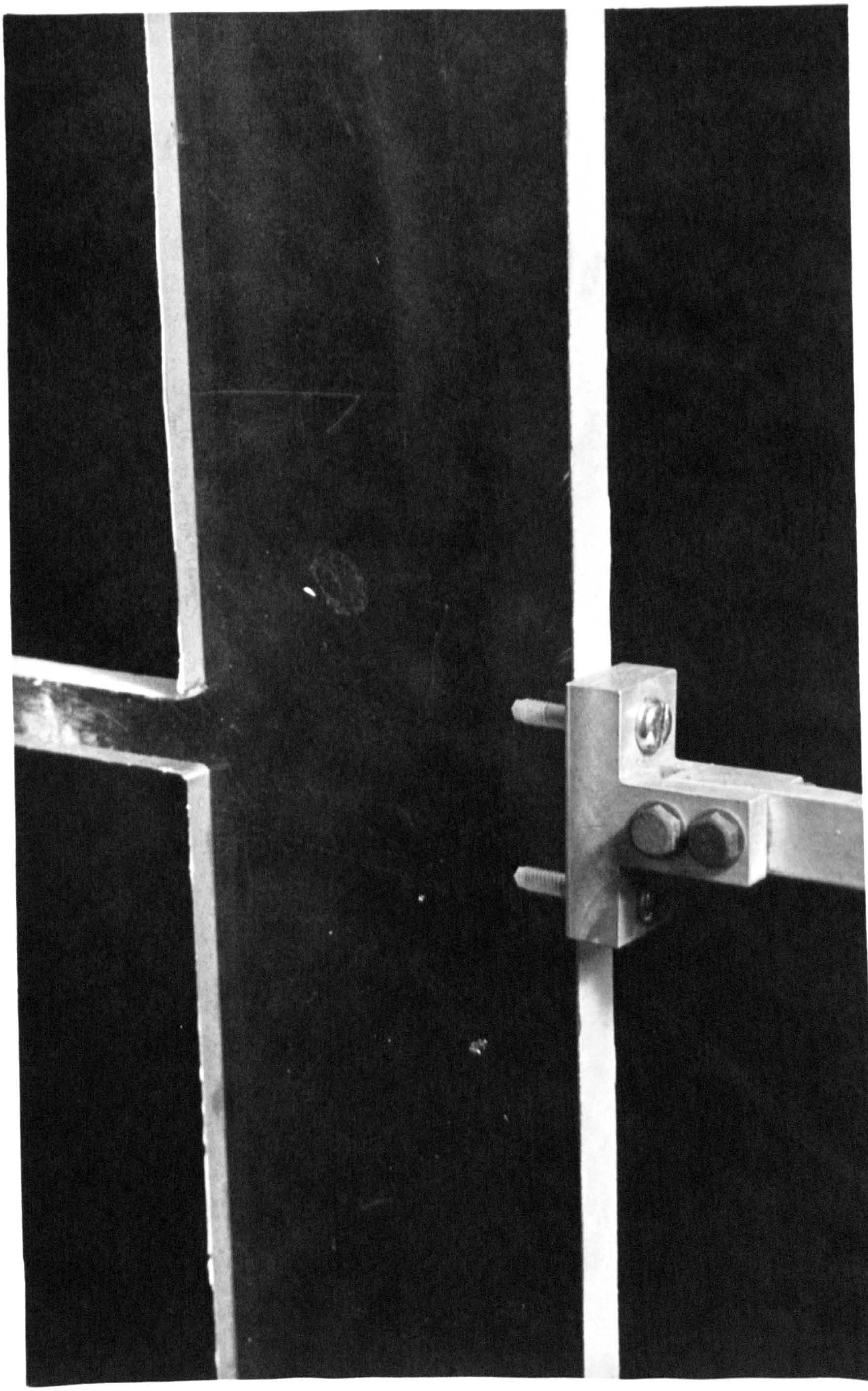


PHOTO (1) WALL - FRAME CONNECTION

STATIC MODEL

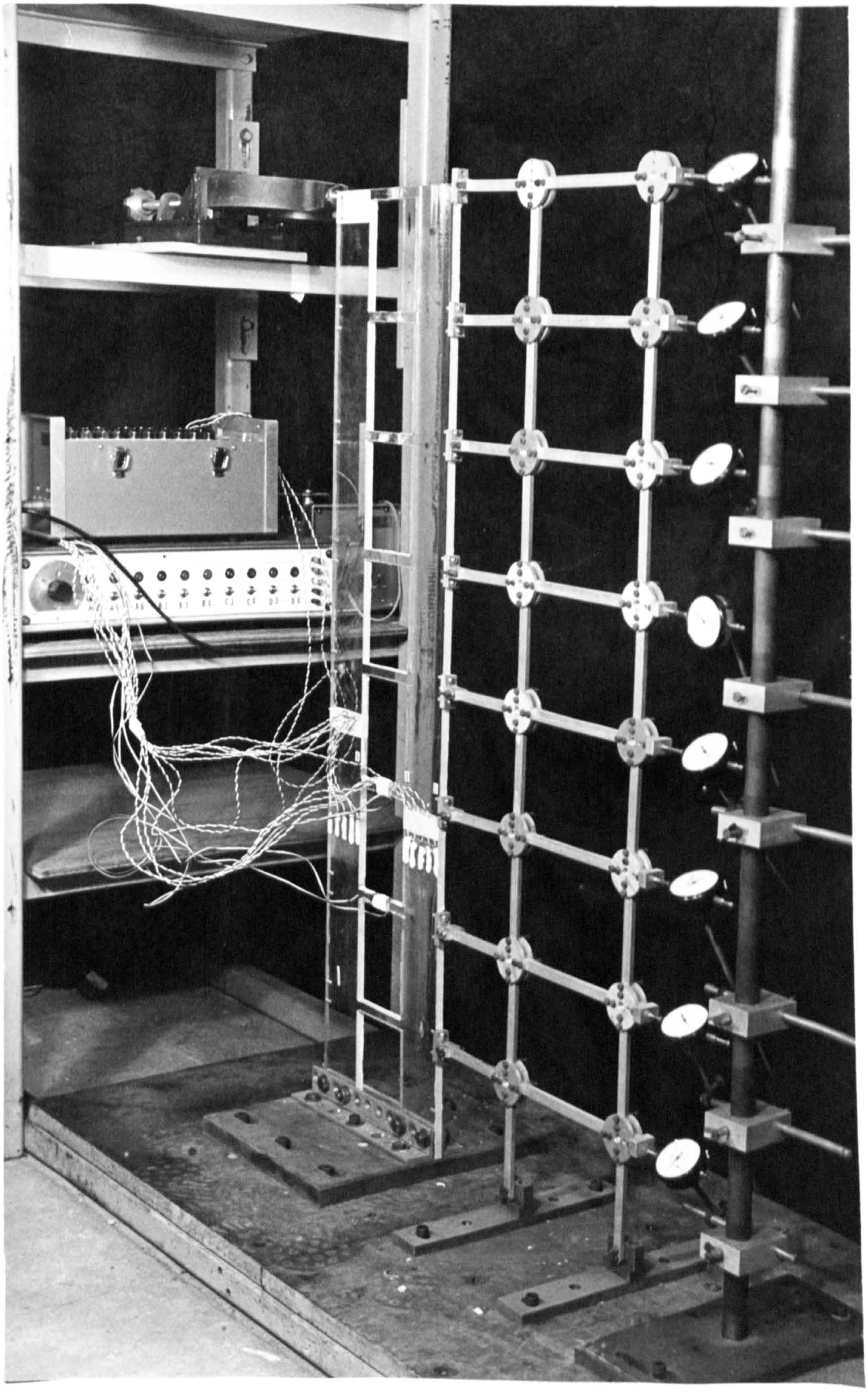


PHOTO (2) WALL - FRAME STRUCTURE
(CONSTANT THICKNESS)

STATIC MODEL

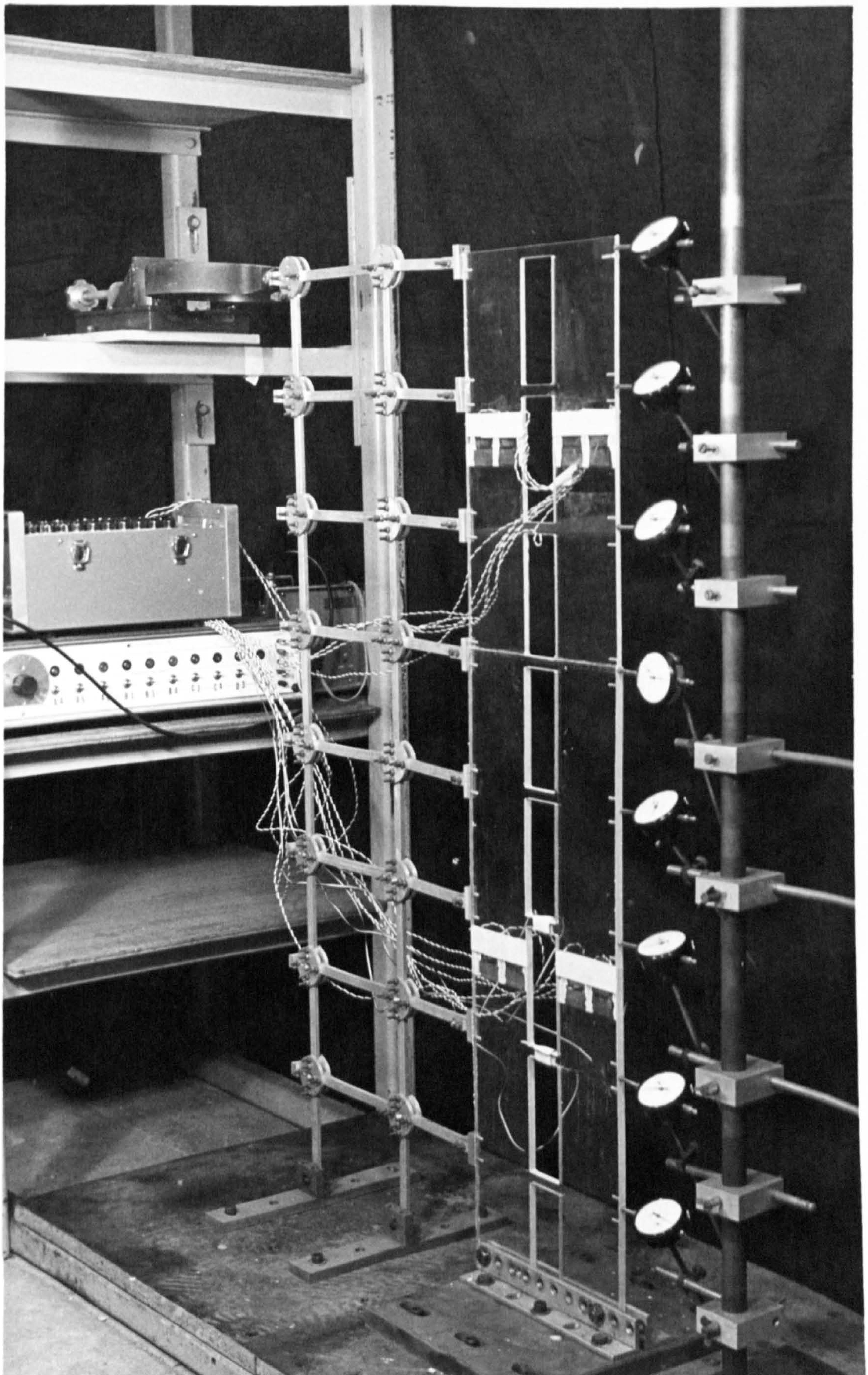


PHOTO (3) WALL - FRAME STRUCTURE
(VARIABLE THICKNESS)

73.55cm above the base. These models were constructed to verify that the proposed methods could accommodate correctly the change in thickness.

b) Model Construction

The coupled shear walls were machined form 1.0cm thick perspex sheeting. As this material has a relatively low modulus of 0.32 x 10^6 N/mm^2, accurate reasonable deflections are obtained at low loads.

The frame was modelled using aluminium flat bar having a modulus of 7.0 x 10^6 N/mm^2. Thus the ratio of the moduli is similar to reinforced concrete related to steel. The flat bars were connected at the joints by means of aluminium discs. At the joint between wall and frame, a 'T' section joint was used. Two bolts were used at these positions to ensure full moment connection. Details of the joints can be seen in photo (1).

Both shear wall and frame were rigidly bolted to the base as can be seen in photos (2) & (3). This ensured that both parts of the model could be considered fully restrained with zero rotation.

The coupled shear wall was strain gauged at a height of 36.7cm from the base. A series of strain gauges were placed across the width of each wall. This allowed the vertical stress distribution, along both walls, to be plotted. Two connecting beams, at levels 29.42cm and 44.13cm were also strain gauged. At both ends of the beams gauges were placed on the top and bottom surfaces. The wires were connected to the measuring equipment so that the strain due to bending moment only was measured.

A series of dial gauges, as shown in photos (2) & (3) were fixed on an independent rod so that lateral deflections of the frame could be measured.

Load was applied to the top of the coupled shear wall via a proving ring.

6.3 Results

The values of lateral deflection, for applied loading of 188 & 235N, are shown in figs (6.11) to (6.16). The experimental results are compared with:

a) finite strip method

b) finite strip combined with plane frame

c) continuum method combined with plane frame

The variations of the vertical stresses in the walls and the moment in the connecting beams are shown for all six models in figs (6.17) to (6.22). Again the experimental results are compared with the finite strip and proposed methods.

The effect of the local wall-beam deformation can be seen in table (6.8). The values of lateral deflection and connecting beam moment are also shown in tables (6.8a) & (6.8b).

6.4 Conclusions

In comparing the results obtained by existing approaches, finite strip and proposed methods, which have been used for static analysis, the

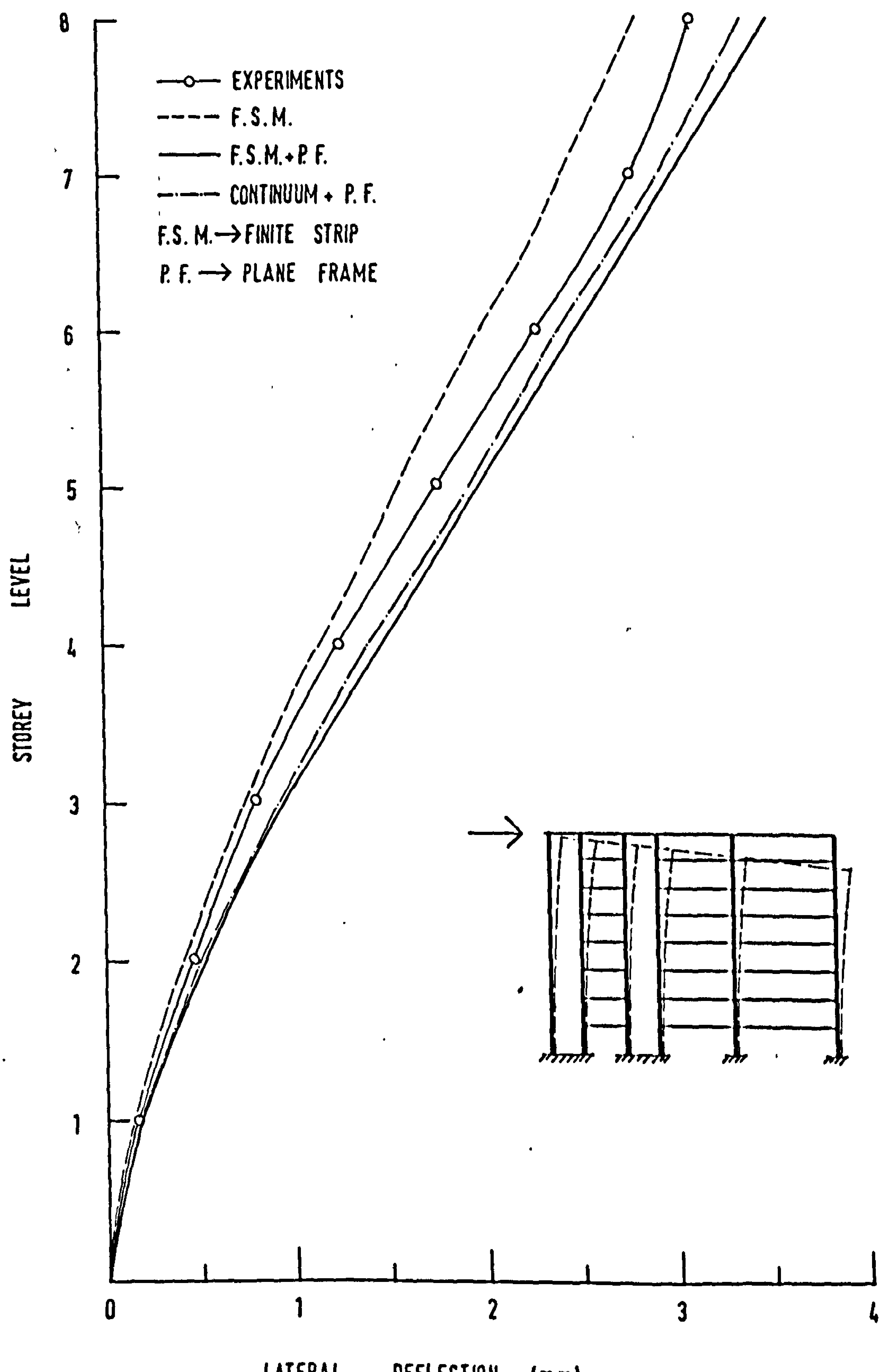


FIG (6-11) DISPLACEMENT FOR EXPERIMENTAL MODEL ①

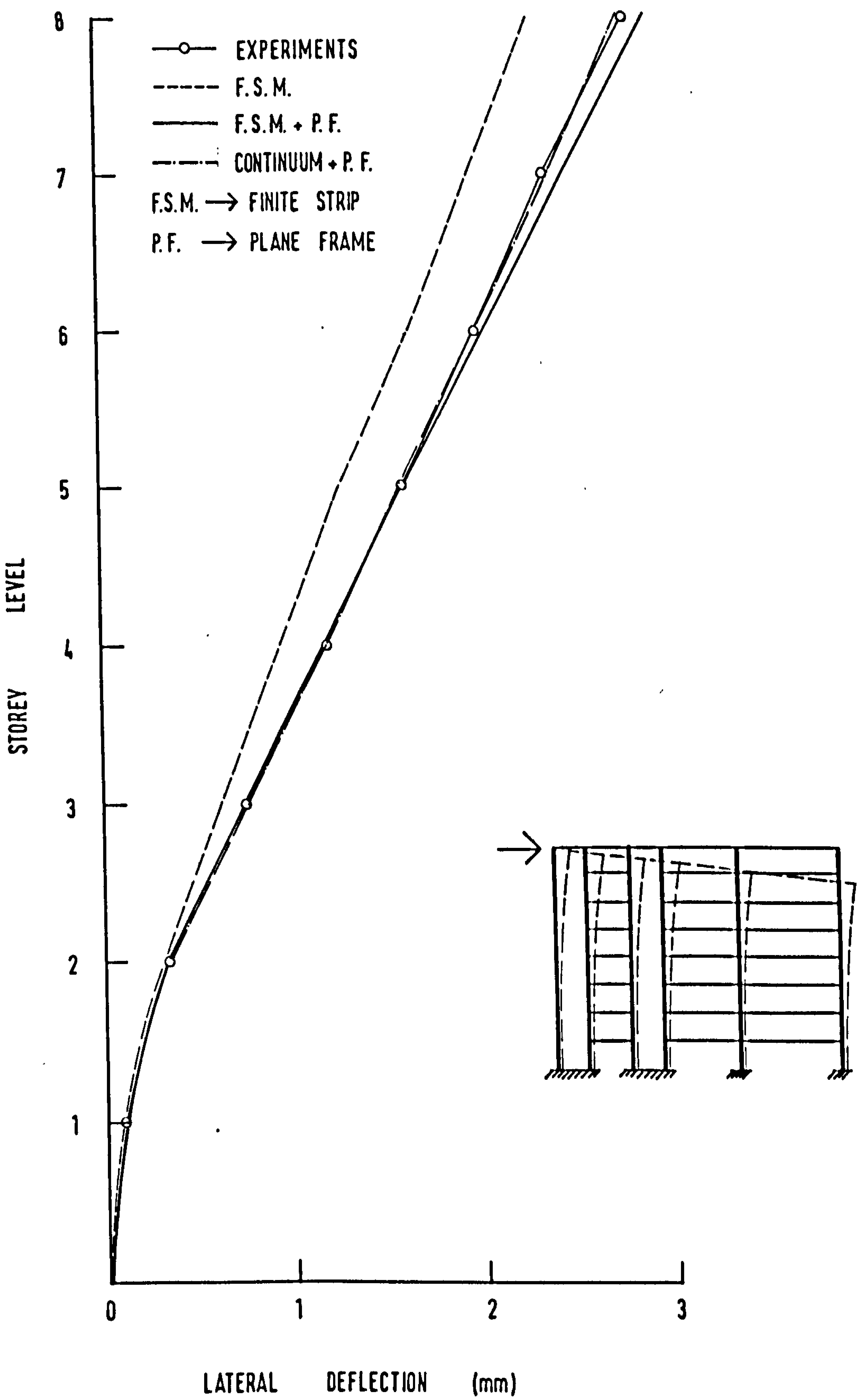


FIG (6–12) DSPLACEMENT FOR EXPERIMENTAL MODEL ②

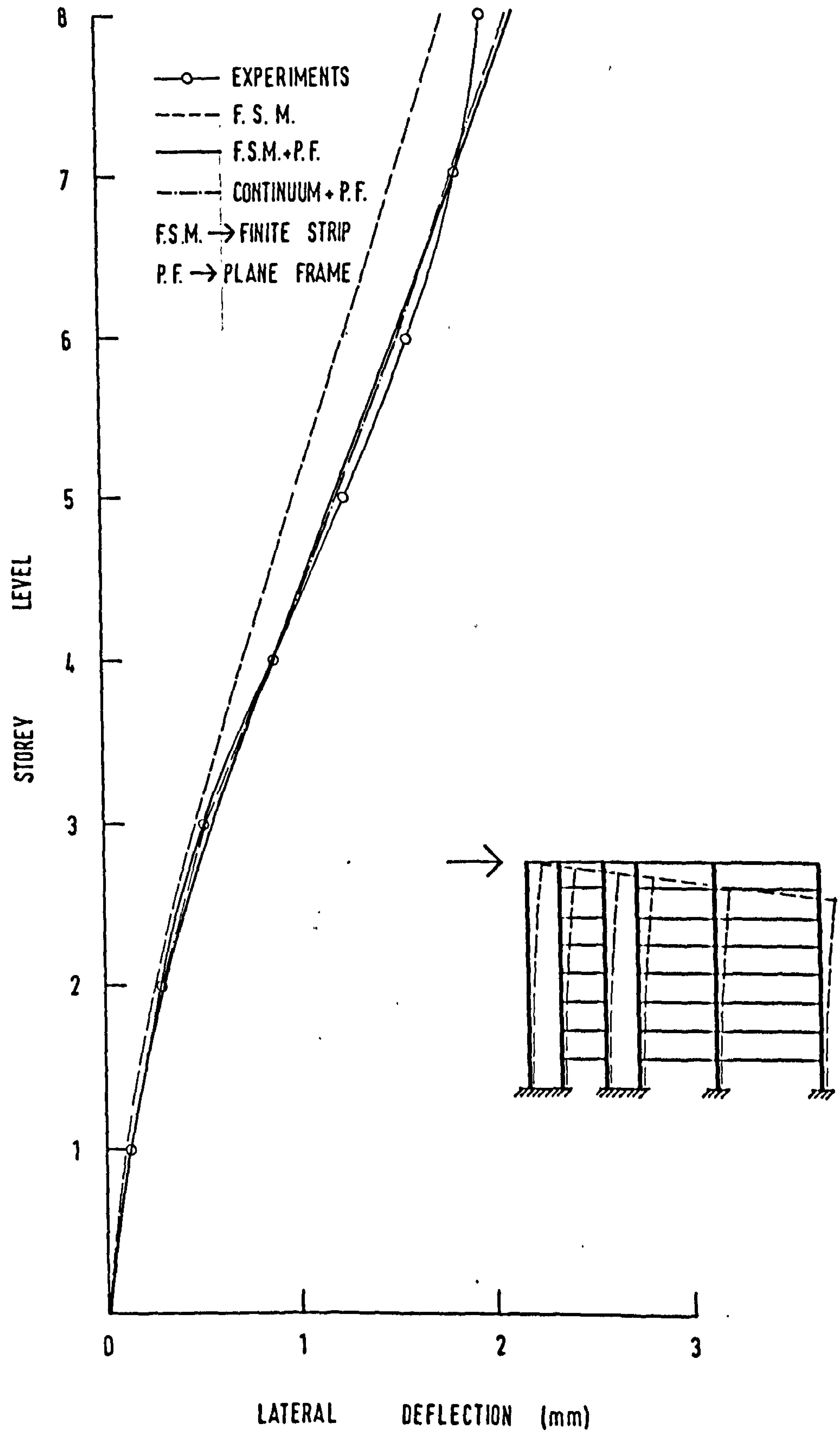


FIG (6-13) DISPLACEMENT FOR EXPERIMENTAL MODEL ③

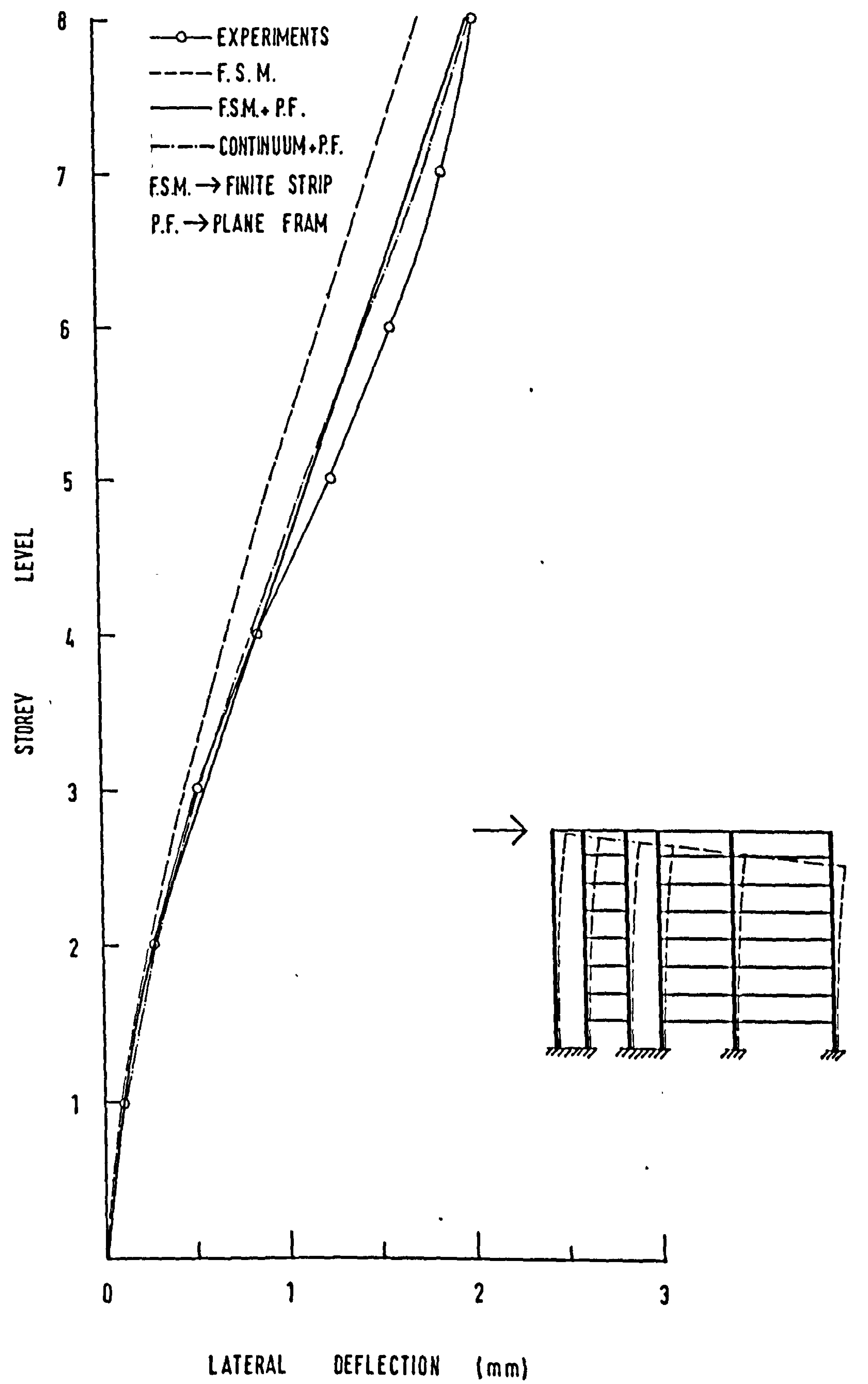


FIG (6-14) DISPLACEMENT FOR EXPERIMENTAL MODEL ④

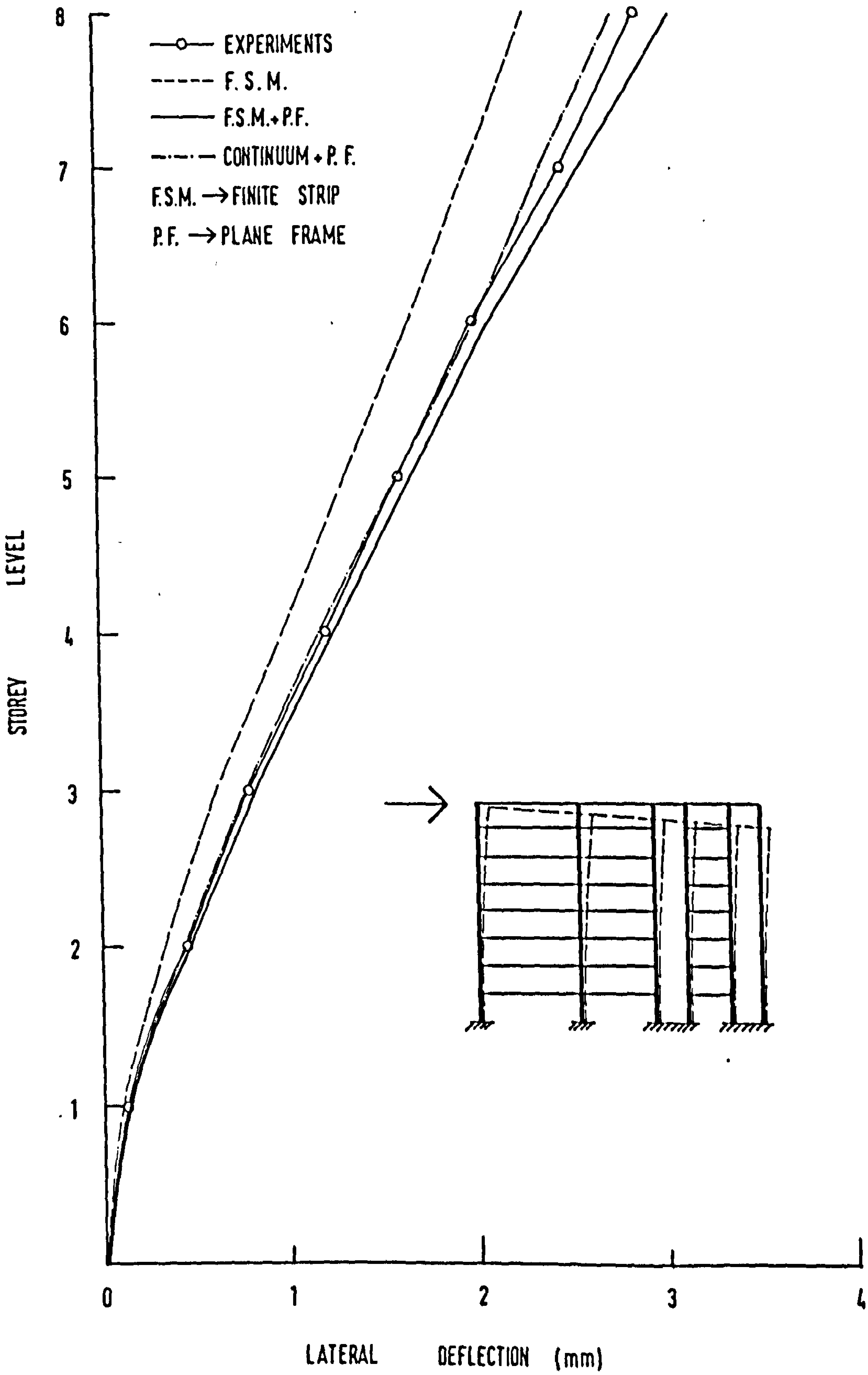


FIG (6-15) DISPLACEMENT FOR EXPERIMENTAL MODEL ⑤

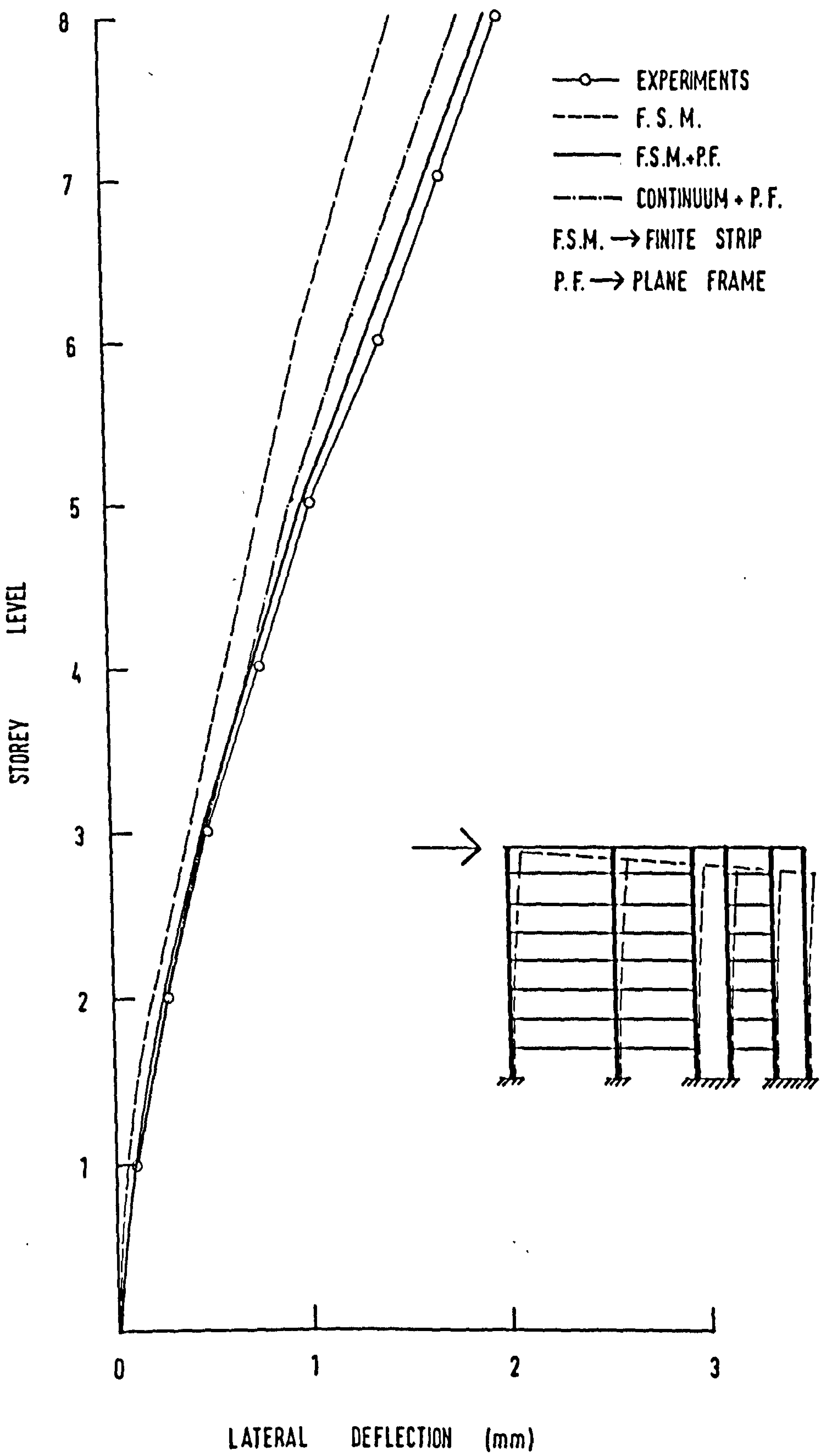


FIG (6-16) DISPLACEMENT FOR EXPERIMENTAL MODEL ⑥

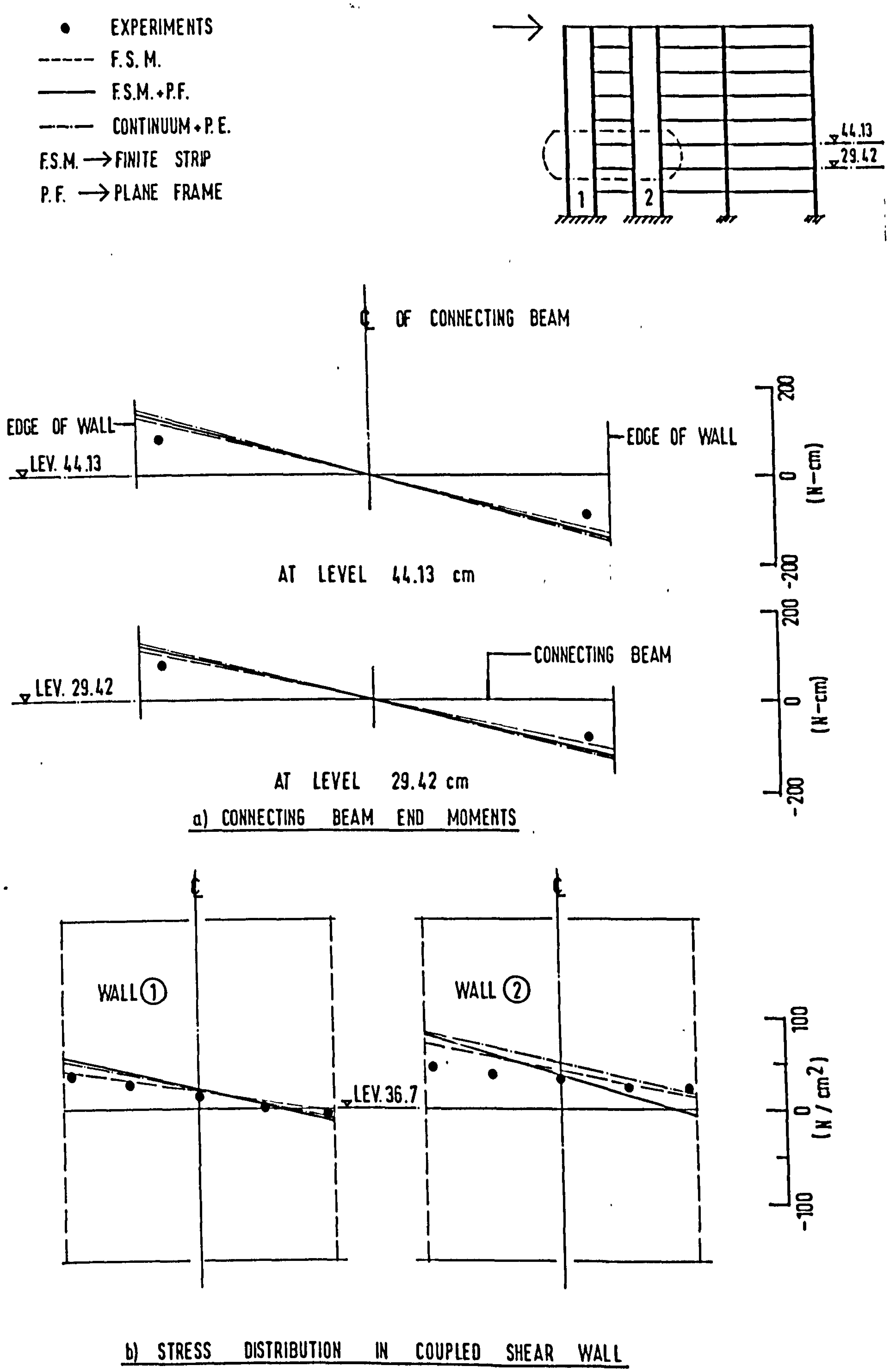


FIG (6-17) STRESS DISTRIBUTION AND BEAM END MOMENT FOR MODEL ①

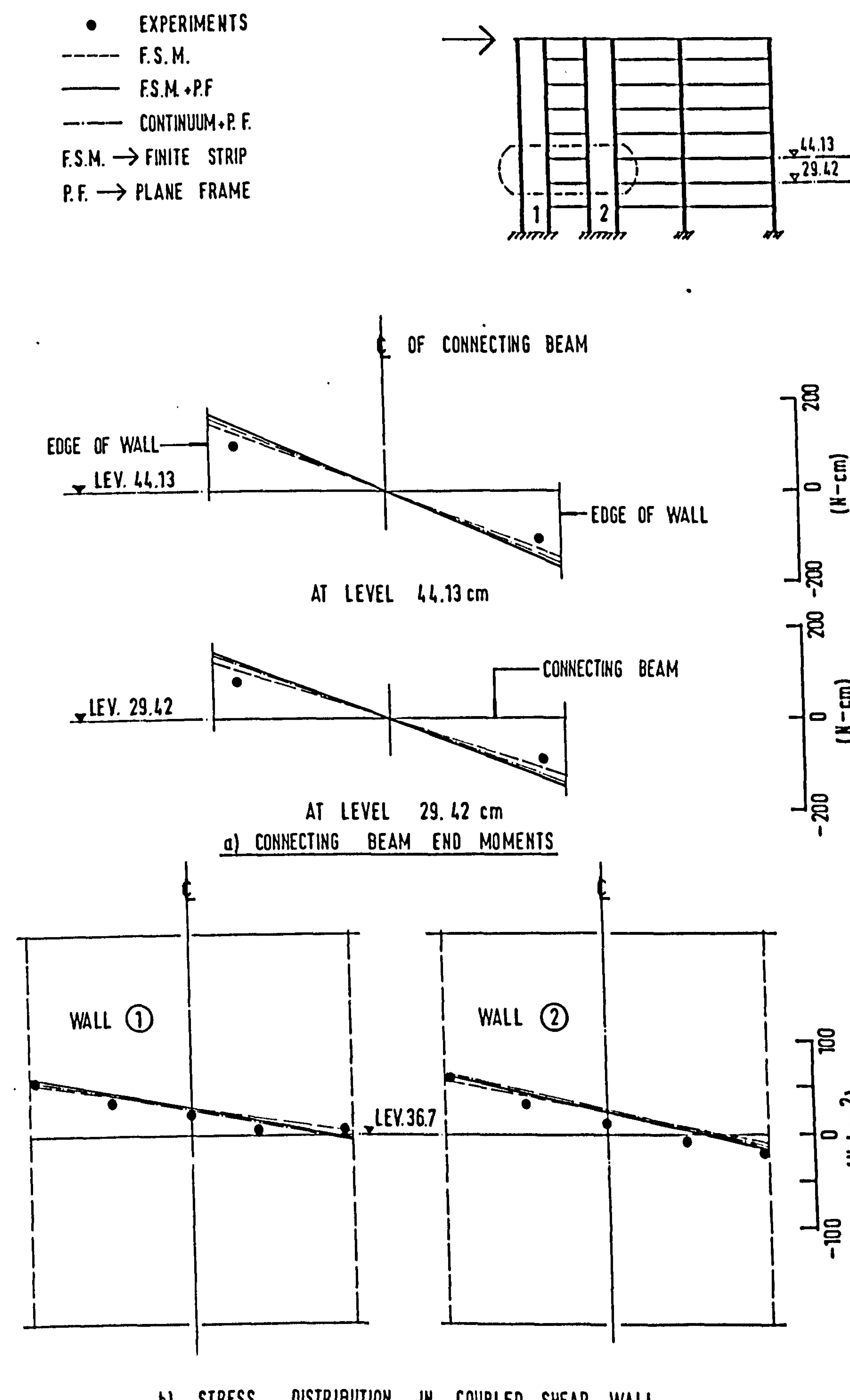


FIG (6-18) STRESS DISTRIBUTION AND BEAM END MOMENT FOR MODEL ②

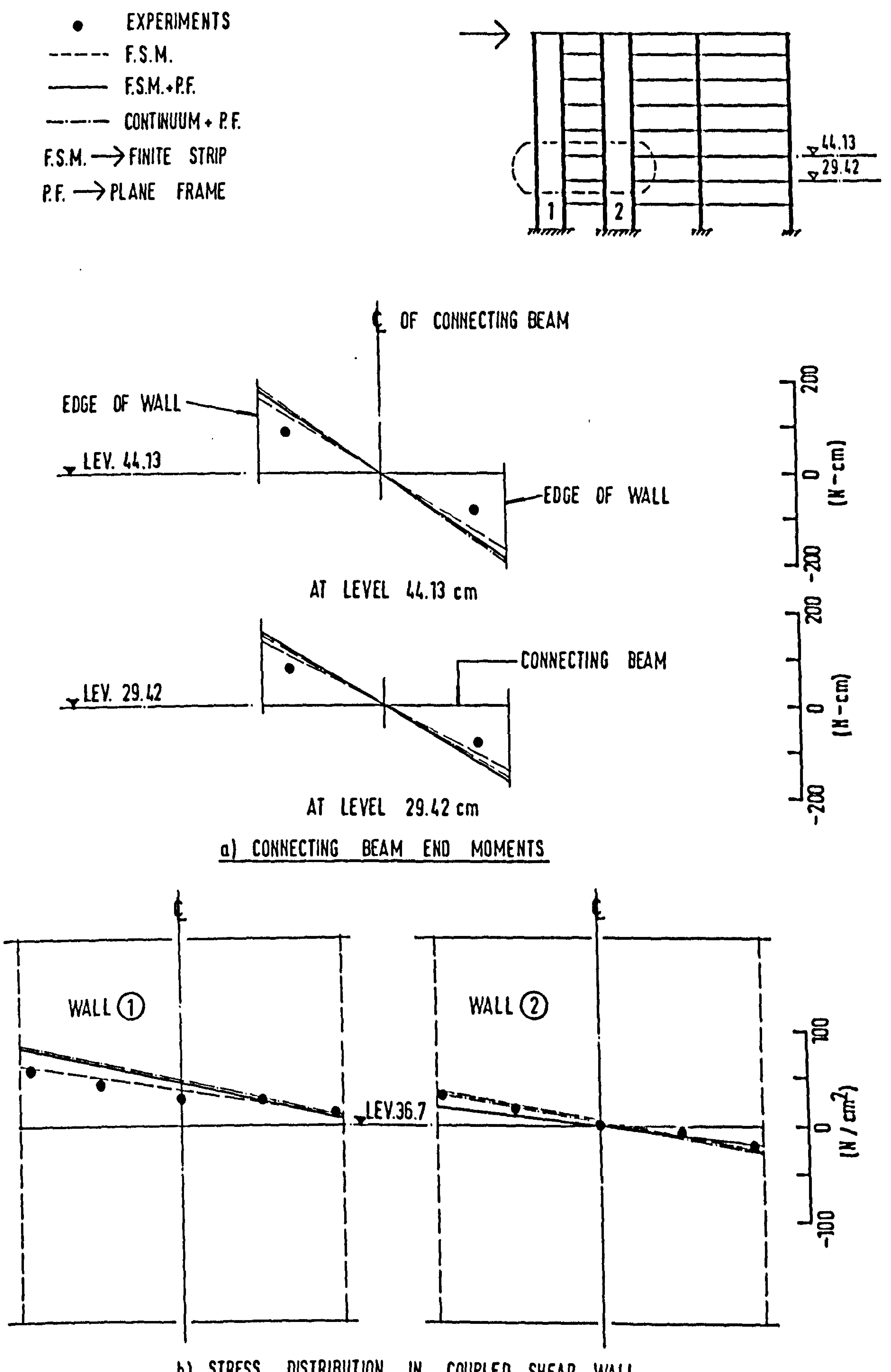


FIG (6-19) STRESS DISTRIBUTION AND BEAM END MOMENT FOR MODEL ③

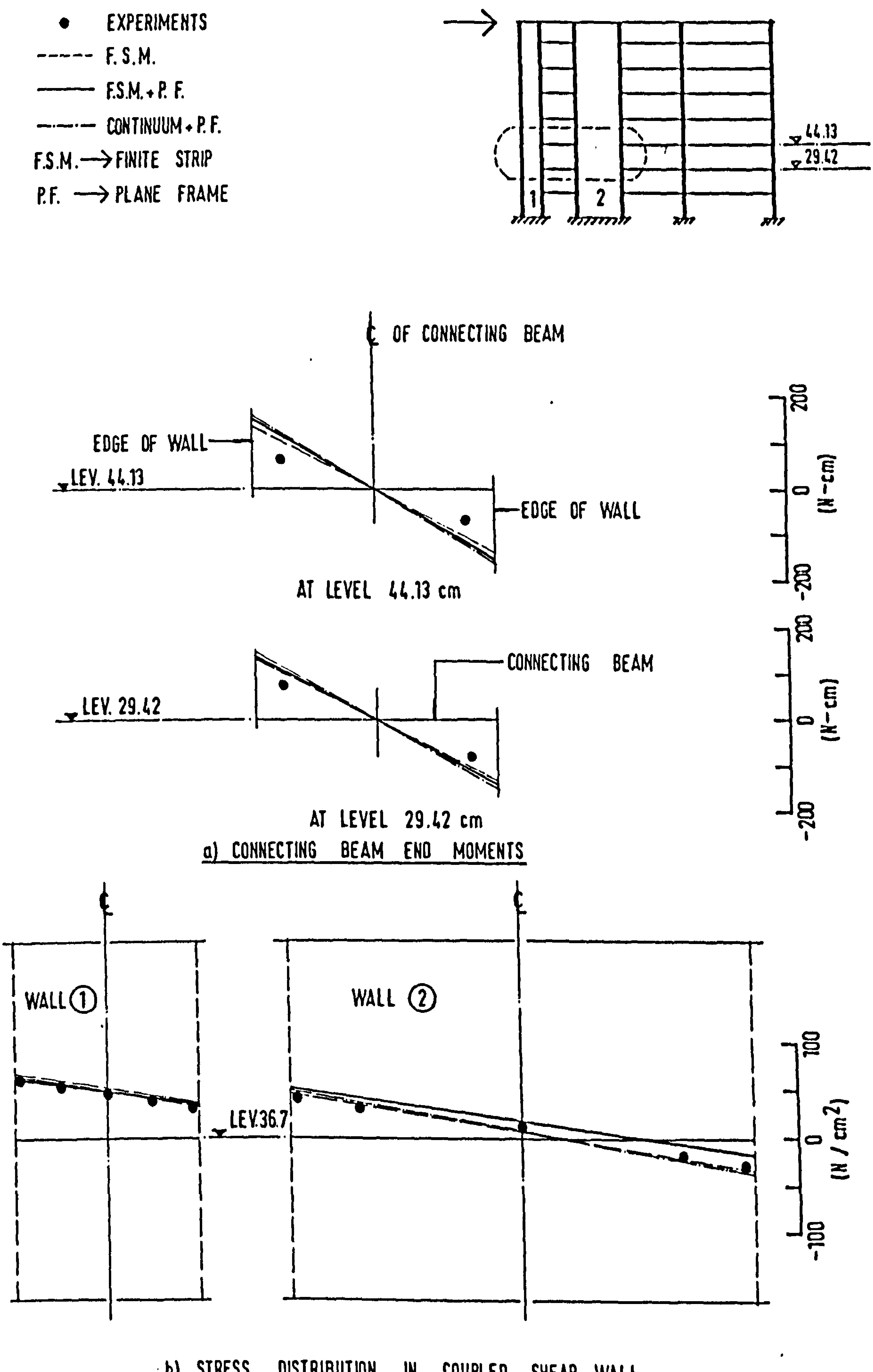


FIG (6-20) STRESS DISTRIBUTION AND BEAM END MOMENT FOR MODEL ④

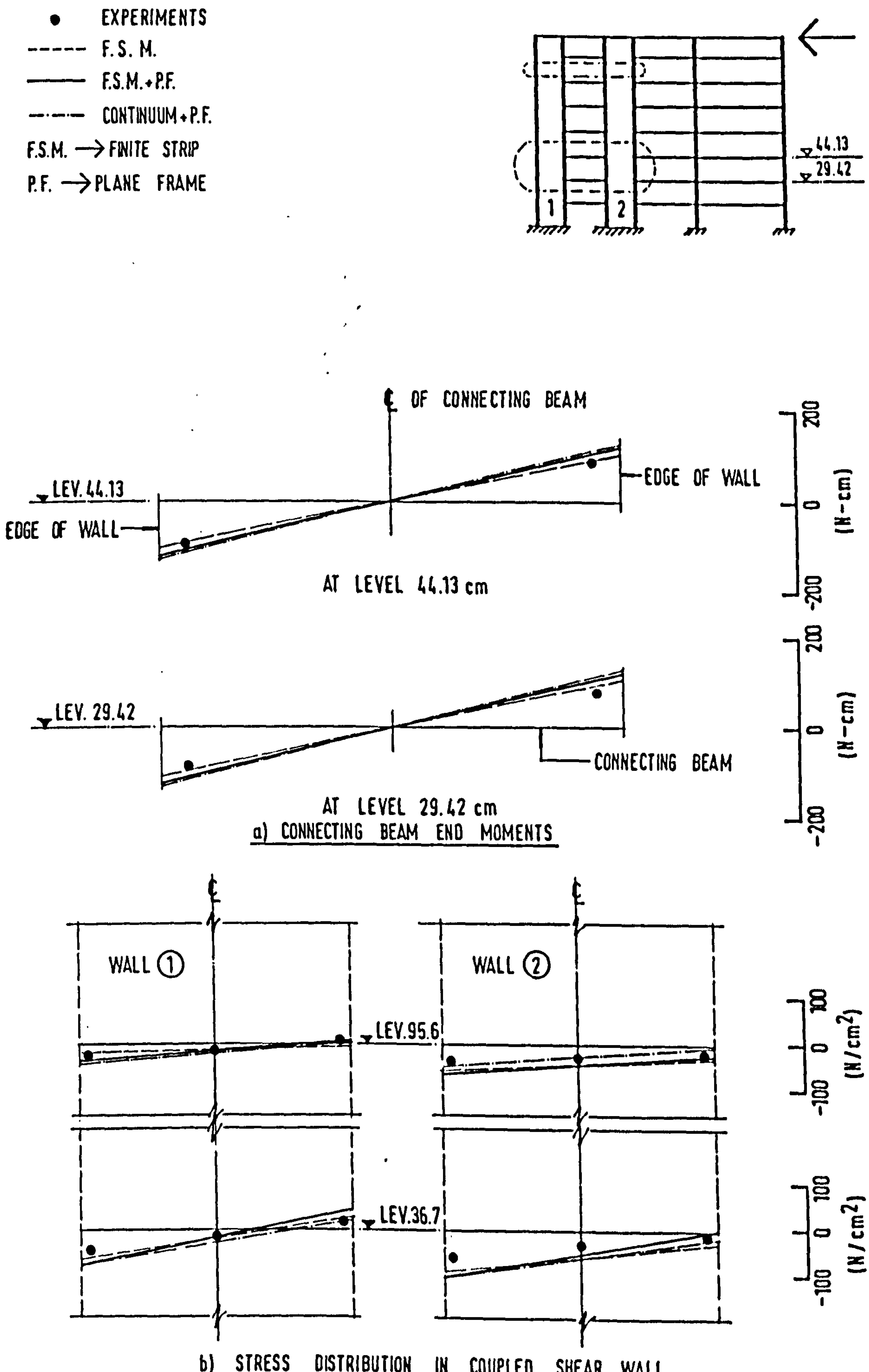


FIG (6-21) STRESS DISTRIBUTION AND BEAM END MOMENT FOR MODEL ⑤

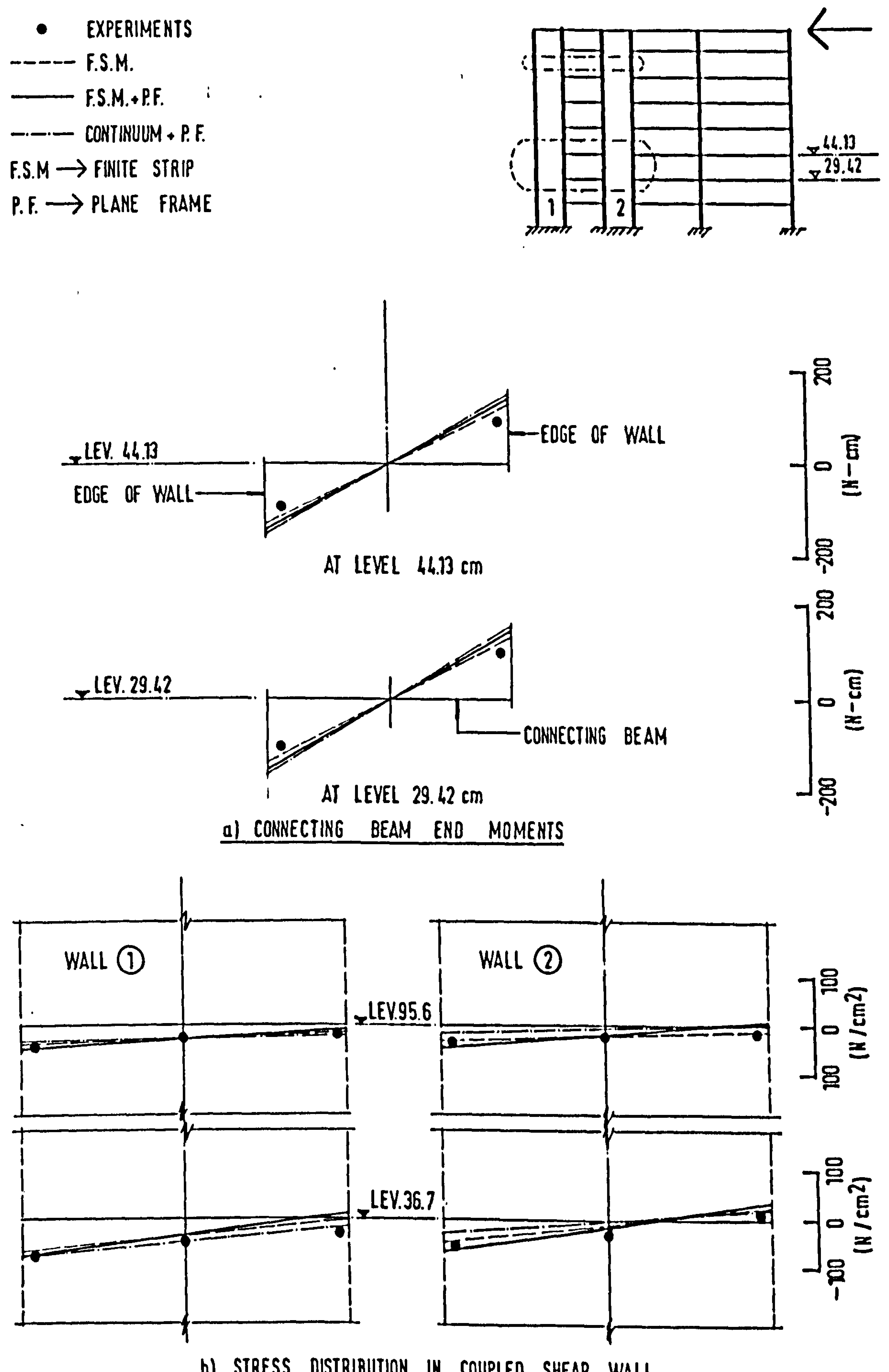


FIG (6-22) STRESS DISTRIBUTION AND BEAM END MOMENT FOR MODEL ⑥

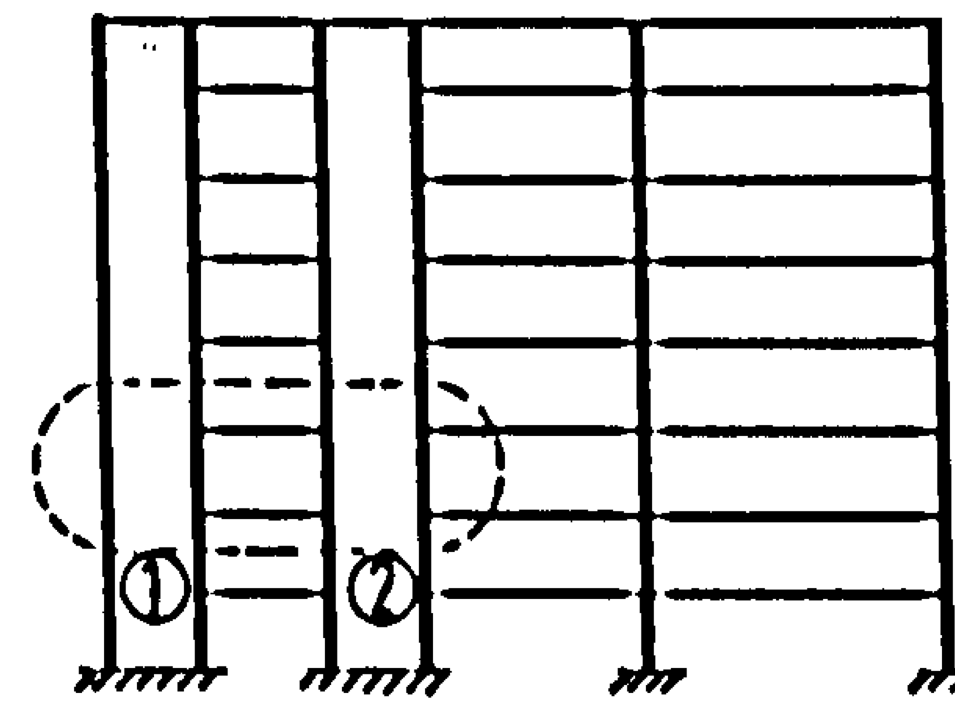
TABLE 6-8a MAXIMIUM DISPLACEMENT AND MOMENT AT CONNECTING BEAMS

	MODEL NO.		EXPERIMENTAL RESULTS	FINITE STRIP		FINITE STRIP + P.F.		CONTINUUM + P.F.	
				A	B	A	B	A	B
MAX. LATERAL DEFLECTION (mm)	1		3.20	2.79	2.88	3.69	3.84	3.34	3.40
	2		2.84	2.29	2.43	2.93	3.11	2.78	2.79
	3		2.00	1.82	1.98	2.21	2.42	2.12	2.15
	4		2.05	1.80	1.90	2.02	2.16	1.92	1.93
	5		2.87	2.29	2.36	3.10	3.20	2.74	2.75
	6		2.04	1.46	1.59	1.87	2.05	1.72	1.74
END MOMENTS OF CONNECTING BEAMS (N-cm)	1	a	80.61	92.90	83.00	116.45	104.66	112.0	111.2
		b	92.82	108.58	97.45	136.74	123.59	130.2	129.3
	2	a	87.45	107.77	95.47	129.10	118.19	125.6	123.8
		b	110.72	126.33	113.43	151.40	137.00	146.6	144.7
	3	a	82.10	111.00	100.95	130.10	119.76	130.7	127.1
		b	98.47	126.00	118.54	148.90	139.38	148.4	144.7
	4	a	70.00	92.22	84.20	103.00	94.65	103.1	100.0
		b	86.00	104.46	98.67	117.90	111.90	118.4	115.4
	5	a	72.20	77.20	69.00	96.3	86.2	98.0	97.2
		b	79.00	91.50	81.70	114.6	103.1	113.7	112.9
	6	a	75.90	93.60	82.90	116.6	107.5	116.4	113.1
		b	83.70	109.10	99.20	136.6	129.5	130.0	127.2

NOTE :

A = WITHOUT LOCAL BEAM — WALL DEFORMATION
B = WITH LOCAL BEAM — WALL DEFORMATION
a = CONNECTING BEAMS AT LEVEL 29.42 cm
b = CONNECTING BEAMS AT LEVEL 44.13 cm
THE END MOMENTS ARE TAKEN AT THE DISTANCE OF 7mm AWAY FROM BEAM ENDS
P.F. = STANDARD PLANE FRAME

TABLE 6-8b MAXIMIUM VERTICAL STRESSES AT WALLS ① & ②



	MODEL NO.	FINITE STRIP		FINITE STRIP + P.F.		CONTINUUM + P.F.	
		A	B	A	B	A	B
WALL ① (N/cm²)	1	43.7	40.9	61.3	58.4	56.2	56.3
	2	52.5	48.8	70.97	67.5	67.6	67.8
	3	61.4	56.9	77.5	73.4	75.8	76.1
	4	66.9	57.4	77.9	67.7	78.7	79.7
	5	-36.4	-34.4	-50.2	-48.2	-45.9	-45.2
	6	-50.2	-46.7	-63.4	-60.1	-59.5	-59.6
WALL ② (N/cm²)	1	72.8	79.3	77.8	86.1	81.1	80.8
	2	55.2	64.9	55.8	67.7	58.8	58.1
	3	30.4	42.5	30.0	44.2	32.3	30.6
	4	48.2	56.3	52.9	62.4	53.4	52.2
	5	-63.0	-67.8	-68.2	-74.4	-60.5	-60.2
	6	-21.2	-38.7	-28.9	-41.2	-25.5	-24.2

NOTE:

A = WITHOUT LOCAL BEAM-WALL DEFORMATION

B = WITH LOCAL BEAM-WALL DEFORMATION

P.F. = STANDARD PLANE FRAME

following conclusions may be drawn:-

As was seen in chapter four, for coupled shear walls only, the finite strip method produces conservative values for the lateral deflections of all the shear wall frame models. The connecting beam moments are overestimated by approximately 25%, but the vertical stress values agree well with the other methods.

These results, once again, show that the finite strip shape function accurately represents the vertical deflection but not the horizontal deflection; and to some extent the rotation also.

Both proposed methods overestimated the lateral displacements and the connecting beam moments but not the vertical stresses. These agree with the values obtained using the other methods.

The overestimation may be due to the values calculated for the inter-connecting points forces. Although all these points are represented as fixed it is the horizontal forces that have the greatest magnitude. As these will predominantly affect the horizontal displacement any error in their values will affect mainly the values of the horizontal displacements. This error will also be dependent upon the relative flexibilities of the wall and frame as can be ssen in fig 6.4 and fig 6.6.

In both the finite strip and continuum methods the lateral displacements modelled are too flexible. However the vertical deflections are accurately modelled as can be seen from a comparison with the values obtained by other methods.

The experimental models produce results similar to the finite strip and continuum models. This suggests that the supposed rigidity of the model was probably not obtained. The critical points to consider in the models are

(a) fixity at the base of the coupled shear wall.

(b) fixity at the joints of the frame.

(c) effective lengths of the frame members connected to the wall.

CHAPTER SEVEN

DYNAMIC BEHAVIOUR

7.1 Introduction

In this Chapter the finite strip method is applied to dynamic analysis[31]. The basic equations of motion are formulated for use in a computer program.

The validity of the theoretical approach is shown by comparing the values of natural frequencies with values obtained experimentally on a shaking table. The comparison is made for shear walls and also shear wall-frame structures.

7.2 Theory

As described in Chapter three, the strain energy of the strip may be expressed as

$$U = \frac{1}{2} \sum_{m=1}^{r} \sum_{n=1}^{r} \delta_m^T K_{mn} \delta_n \qquad (1)$$

in which the stiffness matrix 'Kmn' is given as

$$\left[K_{mn} \right] = \begin{bmatrix} K^p_{mn} & 0 \\ 0 & K^b_{mn} \end{bmatrix} \qquad (2)$$

Similarly the kinetee energy of the mass is given by

$$K = \frac{1}{2} \sum_{m=1}^{r} \sum_{n=1}^{r} \delta_m^T M_{mn} \ddot{\delta}_n \qquad (3)$$

Where the mass matrix M_{mn} is given as

$$\left[M_{mn}\right] = \begin{bmatrix} M^{p}_{mn} & 0 \\ 0 & M^{b}_{mn} \end{bmatrix} \tag{4}$$

in which,

$$M^{p}_{mn} = \int_{V} \rho [N_p]^T [N_p] \; dv \tag{5}$$

$$M^{b}_{mn} = \int_{V} \rho [N_b]^T [N_b] \; dv \tag{6}$$

where 'N$_p$' & 'N$_b$' = Shape functions of in-plane and bending respectively.

'ρ' = Mass density

The potential energy due to the external applied load may be written as

$$V = - \sum_{m=1}^{r} \delta^{T}_{m} F_m \tag{7}$$

Differentiating the total potential energy with respect to nodal line displacement,

$$\delta w = \delta u + \delta k - \delta v \tag{8}$$

To satisfy the equilibrium condition, equation (8) must be equal to zero

$$\delta w = 0 \tag{9}$$

Thus, the above equation in terms of mode shape may be obtained as

$$\sum_{m=1}^{r}\sum_{n=1}^{r} [M_{mn}\ddot{\delta}_m + K_{mn}\delta_m - F_m] = 0 \qquad (10)$$

where $'M_{mn}'$ = consistent mass matrix

$'K_{mn}'$ = stiffness matrix

$'\delta_m'$ = vector of nodal line displacements

$'F_m'$ = external applied load vector

Equation (10) may be written in the usual form for the equation of motion as

$$[M_{mn}]\{\ddot{\delta}_m\} + [K_{mn}]\{\delta_m\} = \{F_m\} \qquad (11)$$

Since the in-plane and bending of the strip are uncoupled, this may be written as

$$\begin{bmatrix} M_p & 0 \\ 0 & M_b \end{bmatrix}\begin{bmatrix} \ddot{\delta}_p \\ \ddot{\delta}_b \end{bmatrix} + \begin{bmatrix} K_p & 0 \\ 0 & K_b \end{bmatrix}\begin{bmatrix} \delta_p \\ \delta_b \end{bmatrix} = \begin{bmatrix} F_p \\ F_b \end{bmatrix} \qquad (12)$$

If the damping effect is included, equation (11) may be rewritten as

$$[M_{mn}]\{\ddot{\delta}_m\} + [C_{mn}]\{\dot{\delta}_m\} + [K_{mn}]\{\delta_m\} = \{F_m\} \qquad (13)$$

where $[C_{mn}]$ is the damping matrix

In order to achieve the compatibility condition at wall-beam or line-beam junctions, the compatibility transformation matrices as described in section(3.7) of chapter three are also applied to mass matrix[15] [16].

7.2.1 Undamped Free Vibration

For undamped free vibration(7) (70), equation (13) becomes

$$[M_{mn}]\{\ddot{\delta}_m\} + [K_{mn}]\{\delta_m\} = 0 \qquad (14)$$

in which $\{\delta\}$ may be expressed as simple harmonic motion

$$\{\delta\} = \{\phi\}\sin(w\ t) \qquad (15)$$

Substituting equations (15) into (14) and rearranging, the standard form of eigenvalue and eigenvector equation is obtained as

$$\Big[[K_{mn}] - W^2{}_m[M_{mn}]\Big]\{\phi_m\} = 0 \qquad (16)$$

For a nontrivial solution,

$$\Big\|[K_{mn}] - W^2{}_m[M_{mn}]\Big\| = 0 \qquad (17)$$

where '$W^2{}_m$' is an eigenvalue diagonal matrix and $\{\phi\ m\}$ is the corresponding eigenvector.

The main characteristics of equation (17) are

i) For 'N' degrees of freedom, the equation has 'N' number of eigenvalues 'W^2'

ii) ' i ' row of 'W2' correspond to ' i ' column of eigenvector $\{\phi\}$

The eigenvalues(17) (44) (62) (63) may be arranged for each mode shape as

$$W^2{}_m = \begin{bmatrix} W^2{}_{1m} & & & & & \\ & W^2{}_{2m} & & & & \\ & & & & & \\ & & & W^2{}_{im} & & \\ & & & & & \\ & & & & & W^2{}_{nm} \end{bmatrix} \qquad (18)$$

Where 'm' & 'n' are series of mode shapes

'r' is the degree of freedom and the corresponding eigenvectors are

$$\phi_m = \begin{bmatrix} \phi_{im1} & & & & & \phi_{im1} \\ & \phi_{2m2} & & & & \\ & & & & & \\ \phi_{im1} & & & \phi_{im4} & & \\ & & & & & \\ \phi_{rm1} & \phi_{rm2} & & \phi_{rm4} & & \phi_{rmn} \end{bmatrix} \tag{19}$$

7.2.2 Dynamic Response

When damping effect and dynamic applied load are present, equation (13) at any time ' t ' may be written as

$$[M]\{\ddot{\delta}\} + [C]\{\dot{\delta}\} + [K]\{\delta\} = \{F(t)\} \tag{20}$$

where $\{\ddot{\delta}\}$ is nodal line acceleration

$\{\dot{\delta}\}$ is nodal line velocity

$\{F(t)\}$ is external applied load at time ' t '

To solve equation (21), Newmark-Wilson Algorithms(49) (71) for step-by step numerical integration may be applied. To demonstrate the use of this method, assume the dynamic eguilibrium at time $t + \Delta t$ is given as

$$[M]\{\ddot{\delta}\}_{t+\Delta t} + [C]\{\dot{\delta}\}_{t+\Delta t} + [K]\{\delta\}_{t+\Delta t} = \{F\}_{t+\Delta t} \tag{21}$$

The set of approximate equations of acceleration velocity and displacement at different intervals of time may be written as

$$\{\ddot{\delta}\}_{t+\tau} = \{\ddot{\delta}\}_t + \frac{1}{\theta}\{\ddot{\delta}\}_{t+\tau} - \{\ddot{\delta}\}_t \tag{22}$$

where 'τ' is the increase in time and generally it is shown as $\tau = \Theta \Delta t$. Using θ=1 in the Wilson-θ method, equation (22) may be rewritten as

$$\{\ddot{\delta}\}_{t+\Delta t} = a_0(\{\delta\}_{t+\Delta t} - \{\delta\}_t) - a_2\{\dot{\delta}\}_t - a_3\{\ddot{\delta}\}_t \quad (23)$$

$$\{\dot{\delta}\}_{t+\Delta t} = \{\dot{\delta}\}_t + a_6\{\ddot{\delta}\}_t + a_7\{\ddot{\delta}\}_{t+\Delta t} \quad (24)$$

$$\{\delta\}_{t+\Delta t} = \{\delta\}_t + \Delta t\{\dot{\delta}\}_t + a_8\{\ddot{\delta}\}_t + a_9\{\ddot{\delta}\}_{t+\Delta t} \quad (25)$$

where the integration constants a_0 to a_9 are dependent on the parameters of θ , β and α used to specify the family of algorithms in Newmark-Wilson Algorithms.

Generally, the displacement vector $\{\delta\}$ at time t + Δt is obtained from the solution of following equation

$$[\bar{K}]\{\delta\}_{t+\Delta t} = \{\bar{F}\}_{t+\Delta t} \quad (24)$$

where $[\bar{K}] = [K] + a_0[M] + a_1[C]$

$$\{\bar{F}\}_{t+\Delta t} = \{F\}_{t+\Delta t} + [M](a_0\{\delta\}_t + a_2\{\dot{\delta}\}_t + a_3\{\ddot{\delta}\}_t)$$
$$+ [C](a_1\{\delta\}_t + a_4\{\dot{\delta}\}_t + a_5\{\ddot{\delta}\}_t)$$

The set of integration constants a_0 to a_9 may be expressed by

$$a_0 = \frac{1}{\alpha \Delta t^2}$$

$$a_1 = \frac{\beta}{\alpha \Delta t}$$

$$a_2 = \frac{1}{\alpha \Delta t}$$

$$a_3 = \frac{1}{2\alpha} - 1$$

$$a_4 = \beta/\alpha - 1$$

$$a_5 = \Delta t/2\ (\beta/\alpha - 2)$$

$$a_6 = \Delta t(1-\beta)$$

$$a_7 = \delta \Delta t$$

$a_8 = \Delta t^2(1/2-\alpha)$

$a_9 = \alpha \Delta t^2$

The accuracy and stability of the methods are controlled by the choice of these parameters namely Θ , β and α. For normal constant and linear acceleration method, they are specified as

i) Constant

$\theta = 1.0$

$\beta = 1/2$

$\alpha = 1/4$

ii) Unconditionally Stable Wilson-Θ method

$\theta \geq 1.37$

$\beta = 1/2$

$\alpha = 1/6$

iii) Linear Acceleration method

$\theta = 1.0$

$\beta = 1/2$

$\alpha = 1/6$

The choice of algorithm depends mainly on the particular requirements of the structural problem that is under investigation.

7.2.3 Structural Damping

In this study, the damping matrix [C] shown in equation (13) is obtained by a simple linear modal superposition method[41]. The essence of method is to perform the coordinate transformation from structural coordinates to normal coordinates and this leads to the corresponding orthogonality of the damping matrix[71]. In general, the orthogonal damping matrix may be expressed as

$$[C] = [M] \sum_{i=0}^{n} a_i \left[[M]^{-1} [K]\right]^i$$

$$= \sum_{i=0}^{n} [C_i] \qquad (27)$$

The damping of an individual mode can be shown to be

$$C_j = \phi_j^T C \phi_j$$

$$= 2\beta_j W_j M_j \qquad (28)$$

Substituting equation (28) into (27), it becomes

$$C_{ji} = \phi_j^T a_i M [M^{-1}K]^i \phi_j$$

$$= a_i W_j^{2i} M_j \qquad (29)$$

Thus, the damping associated with only mode ' $_j$ ' is given by

$$C_j = \sum_{i=0}^{n} C_{ji}$$

$$= \sum_{i=0}^{n} a_i W_j^{2i} M_j$$

$$= 2\beta_j W_j M_j \qquad (30)$$

Solving equation (30) for β_j, it becomes

$$\beta_j = \frac{1}{2w_j} \sum_{i=0}^{n} a_i W_j^{2i} \qquad (31)$$

where β_j = linear viscous damping factor

W_j = the undamped natural frequency of vibration in mode 'j'

Equation (31) is used to evaluate the constants 'ai' for any specified number of modes.

The real damping mechanism governing the dynamic behaviour of the building is very complex and difficult to establish[9] [42]. Therefore, only Rayleigh damping is used here. This is given by

$$[C] = a_0[M] + a_1[K] \qquad (32)$$

where 'a_0' & 'a_1' are arbitrary constants related to the damping ratio.

For the first and second modes, the constants a_0 & a_1 can be obtained from

$$\begin{bmatrix} \beta_0 \\ \beta_1 \end{bmatrix} = \frac{1}{2} \begin{bmatrix} 1/W_0 & W_0 \\ 1/W_1 & W_1 \end{bmatrix} \begin{bmatrix} a_0 \\ a_1 \end{bmatrix} \qquad (33)$$

where W_0 & W_1 are the 1st and 2nd modes of undamped natural frequency respectively.

The modal damping in other modes may be evaluated from

$$\beta_j = \frac{1}{2}(a_0/W_j + a_1 W_j) \qquad (34)$$

7.2.4 Comparison with Previous Examples

Five previous examples which were studied by Cheung & Kasemset[27] are presented here to demonstrate the accuracy of the present developed program for the free vibration analysis of a cantilever shear wall, coupled shear walls and wall-frame structures. The geometric and structural data of the structures are detailed in figs (7.1) to (7.5)

From the results shown in table (7.1), it can be seen that the natural frequencies obtained by the present program are in good agreement with those investigated by Cheung & Kasemset.

7.3 Experimental Investigation

In order to further validate the accuracy of the method, twelve experimental tests on eight storey coupled shear wall models and then shear wall-frame models were carried out. The tests were conducted on a small scale shaking table (photo 4). The method and procedure employed in the tests are described below. The obtained natural frequencies of each model are compared with theoretical results.

a) Experimental Setting

The twelve experimental models representing the coupled shear walls and wall-frame structures employed for the static tests in chapter four were used for the dynamic tests. The experiments were carried out on 1.2x1.2x0.025 m thick aluminum shaking table which was floating on a film of oil. The oil was continuously supplied by a tank located at a height of approximately 4m from the ground and was recirculated by a small electric pump.

The experimental models were bolted onto the aluminum shaking table which was driven by an electric vibrator. The generator and amplifier are used to operate the vibrator.

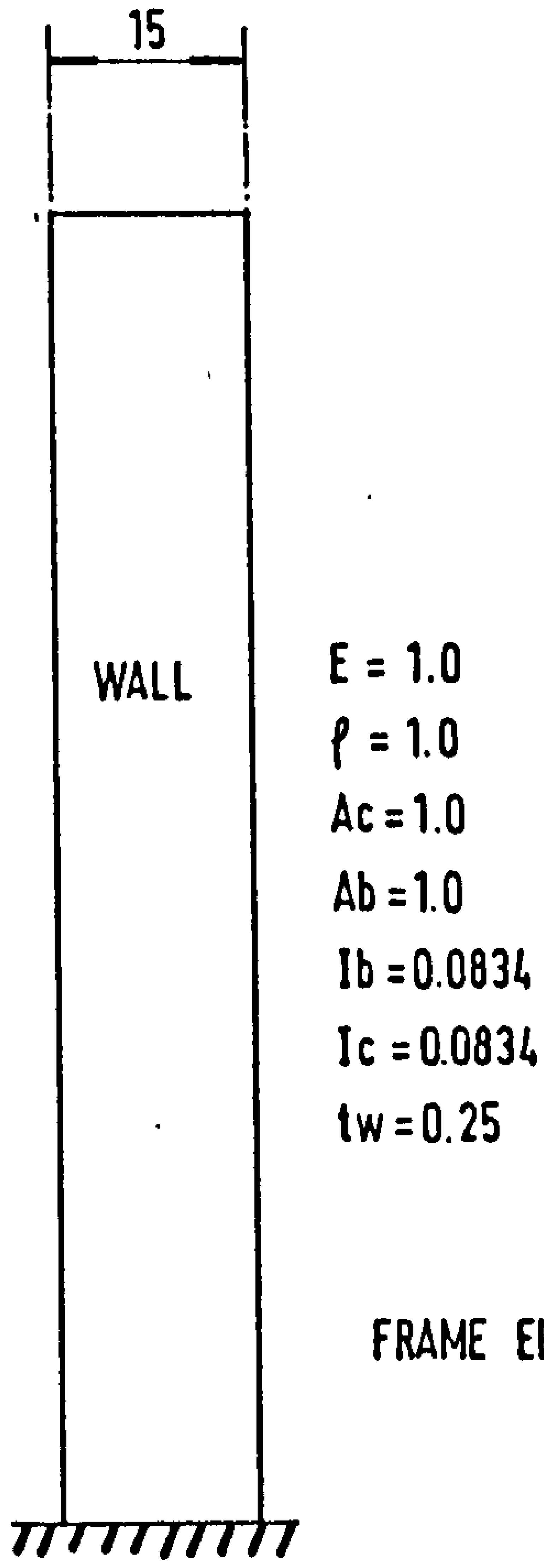


FIG (7.1) SHEAR WALL ①

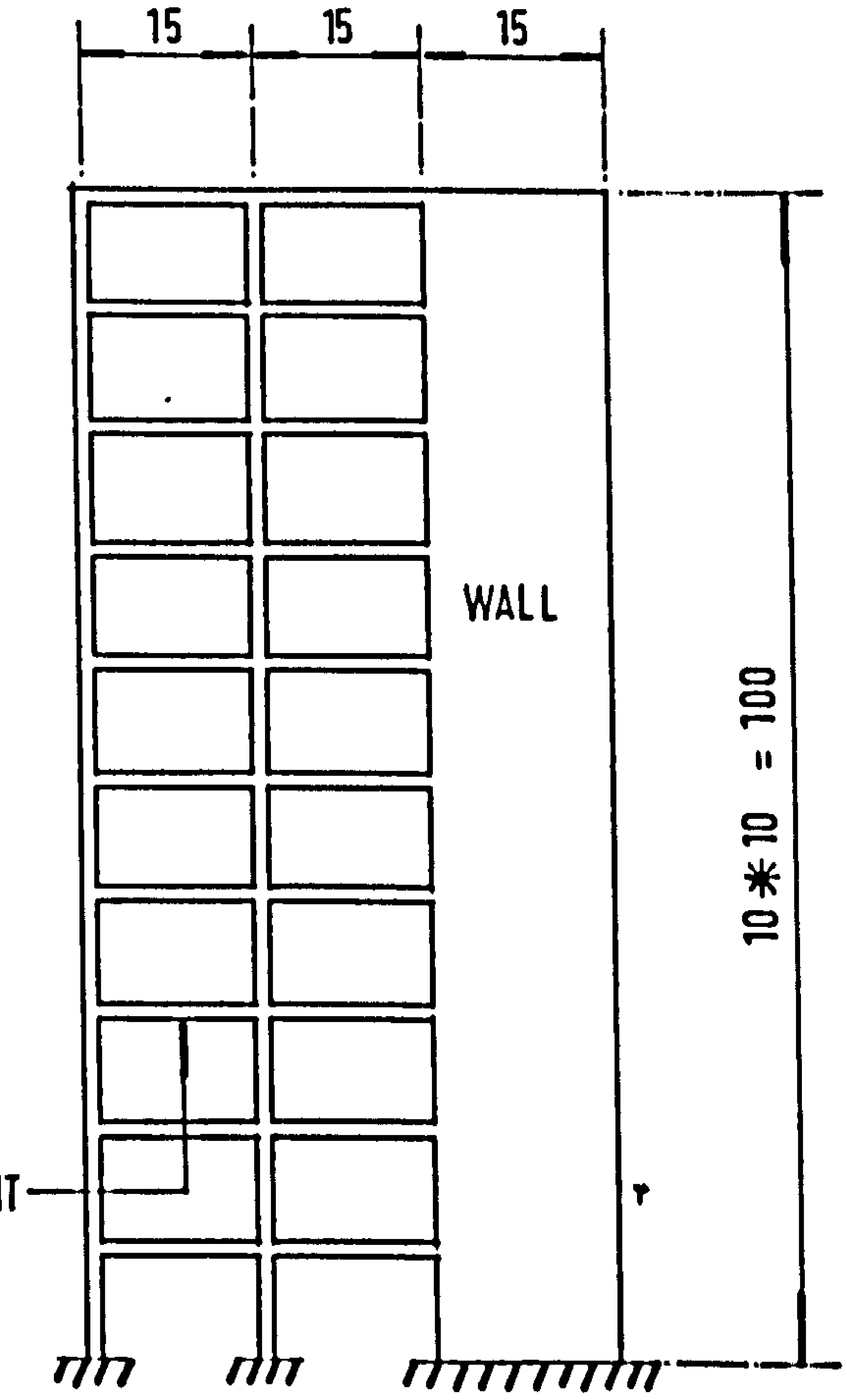


FIG (7-3) WALL - FRAME ③

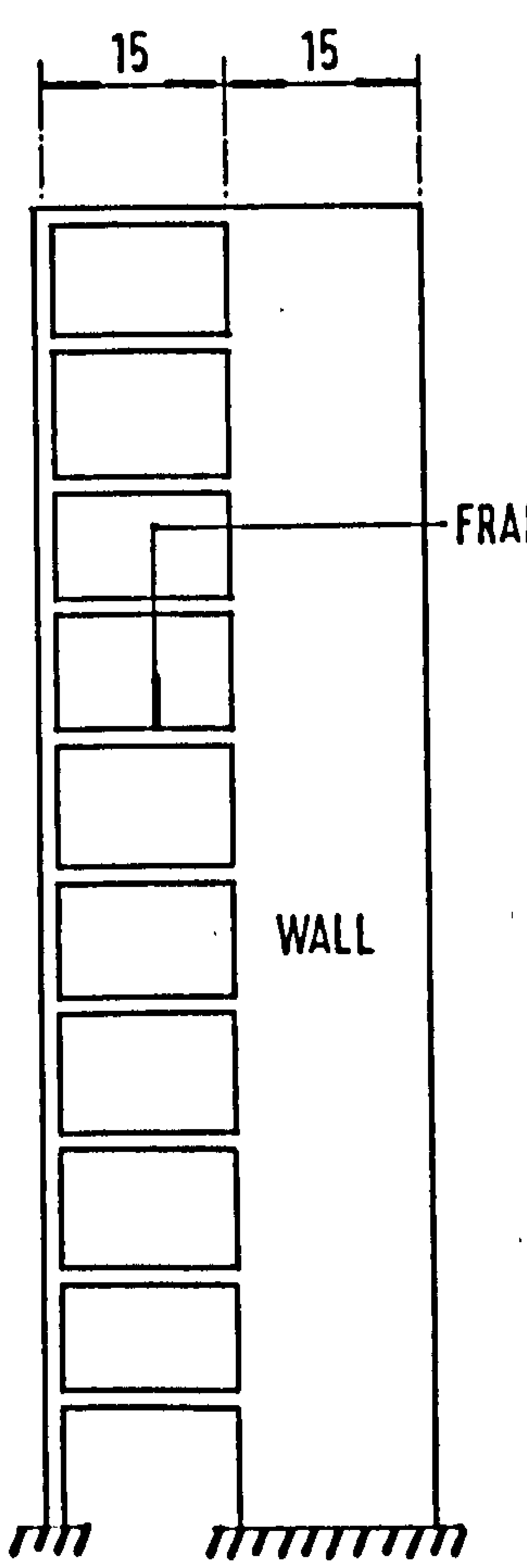


FIG (7.2) WALL-FRAME ②

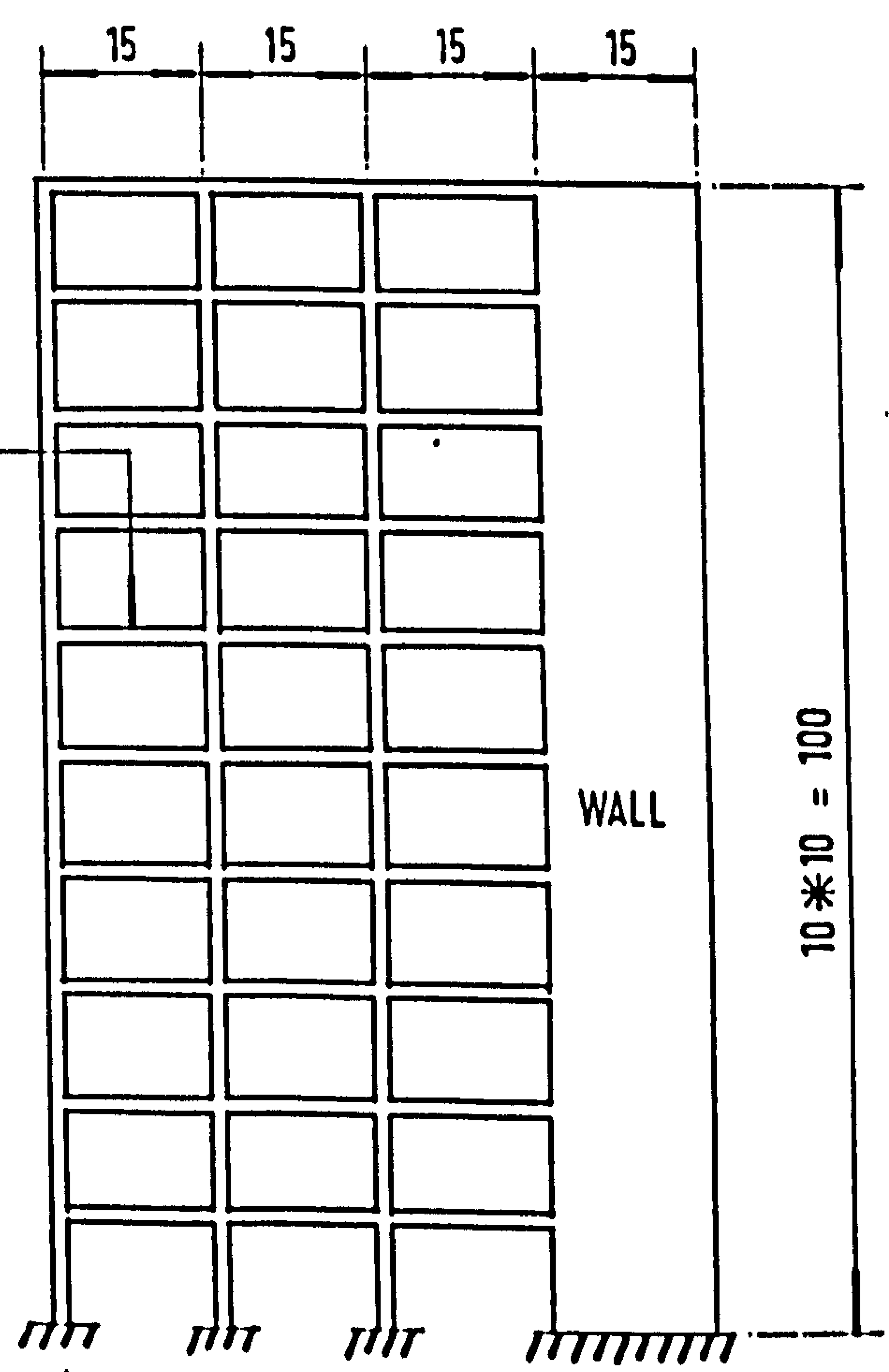


FIG (7-4) WALL - FRAME ④

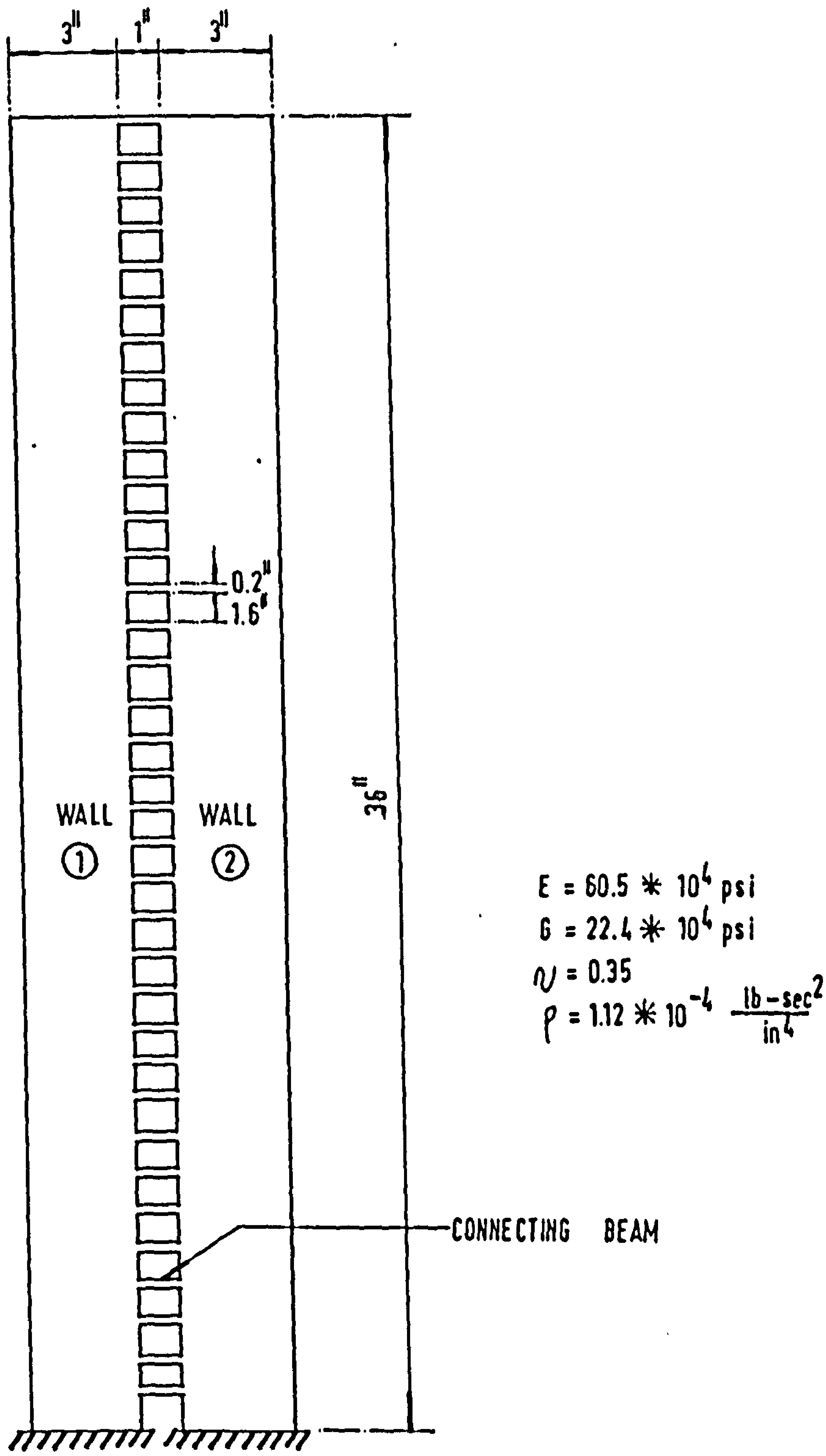
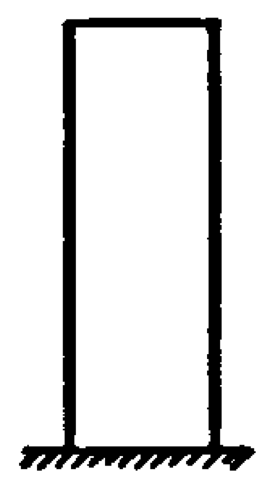
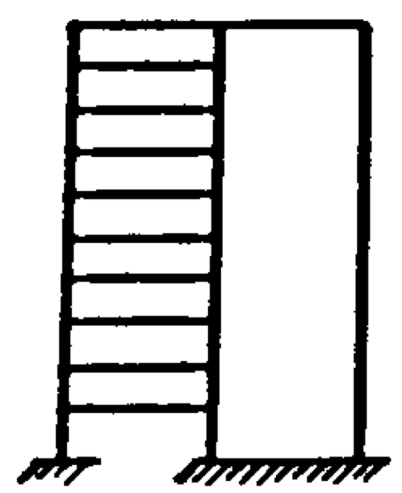
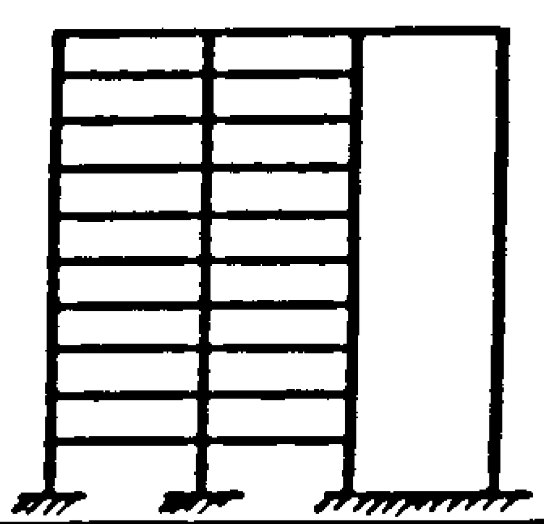
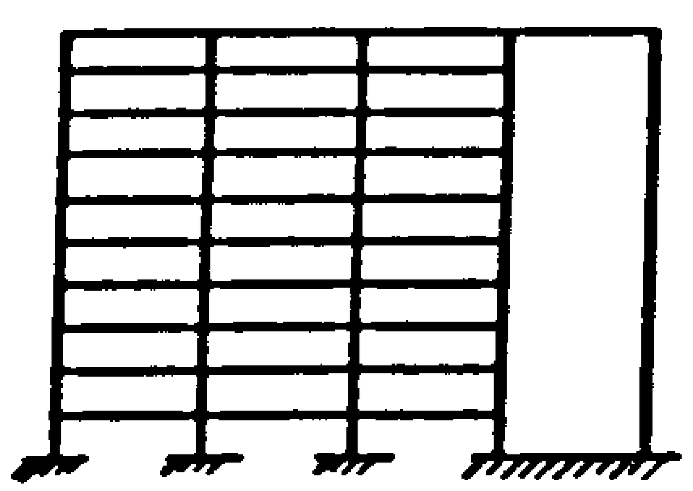
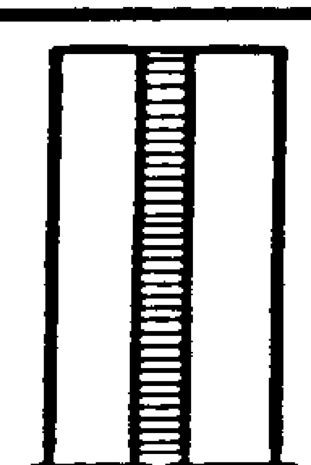


FIG (7-5) COUPLED SHEAR WALL ⑤

TABLE = 7 — 1	PROGRAM DEVELOPED BY CHEUNG & KASEMSET				PRESENT DEVELOPED PROGRAM			
STRUCTURES	NATURAL FREQUENCIES (HZ)				NATURAL FREQUENCIES (HZ)			
	MODE 1	2	3	4	MODE 1	2	3	4
① 	1.53	8.89	15.76	22.96	1.53	8.92	15.82	22.94
② 	1.49	7.18	12.75	15.36	1.49	7.18	12.75	15.36
③ 	1.38	6.23	10.93	13.90	1.38	6.23	10.93	13.90
④ 	1.30	5.63	10.34	12.19	1.30	5.63	10.34	12.20
⑤ 	53.0	227.0			53.0	227.0		

DYNAMIC MODEL

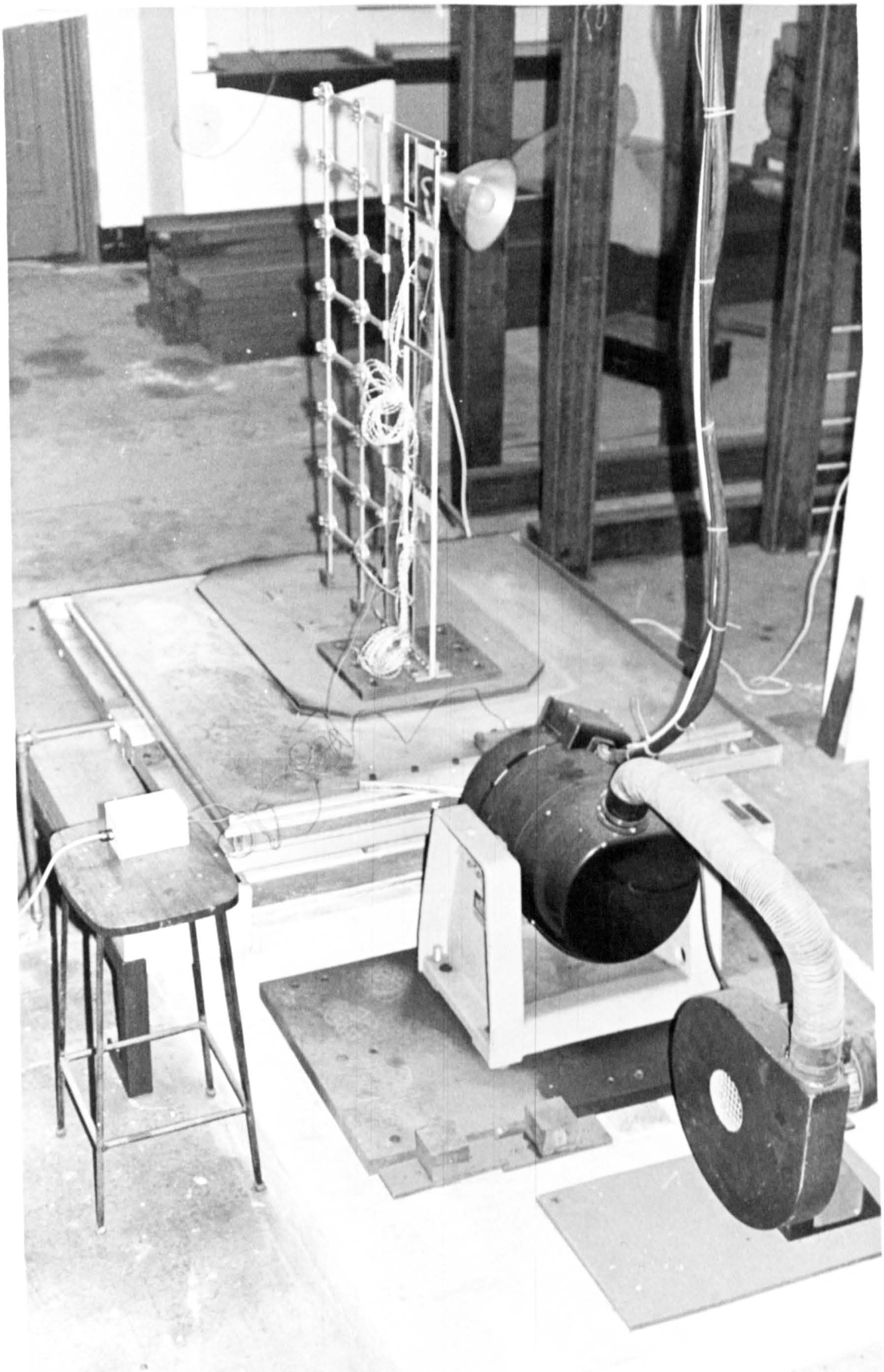


PHOTO (4) EXPERIMENT SET UP

The base of each experimental model was bolted to the same steel plate as used for the static tests. The steel base plate was then bolted to the aluminum table to transfer the vibration effects to the models. Two electronic accelerometers were used to monitor the response of the table and the model (photos 5, 6, & 7)

A steady-state harmonic excitation is employed in these experiments to evaluate natural frequencies of the models.

b) Test Procedure

During the tests, the signals of the response from electronic accelerometers were fed to the measuring units for recording. The procedure of operating the tests and measuring the natural frequencies are described below:

i) The vibration table was set on and the oil was pumped to the base of shaking table.

ii) The base acceleration was set first and then initial reading was recorded.

iii) The accelerating at the top of the model was recorded at each increment of frequency.

iv) The forcing frequency was increased in steps of 1 Hz and the procedure was repeated until the peak amplitude was obtained.

DYNAMIC MODEL

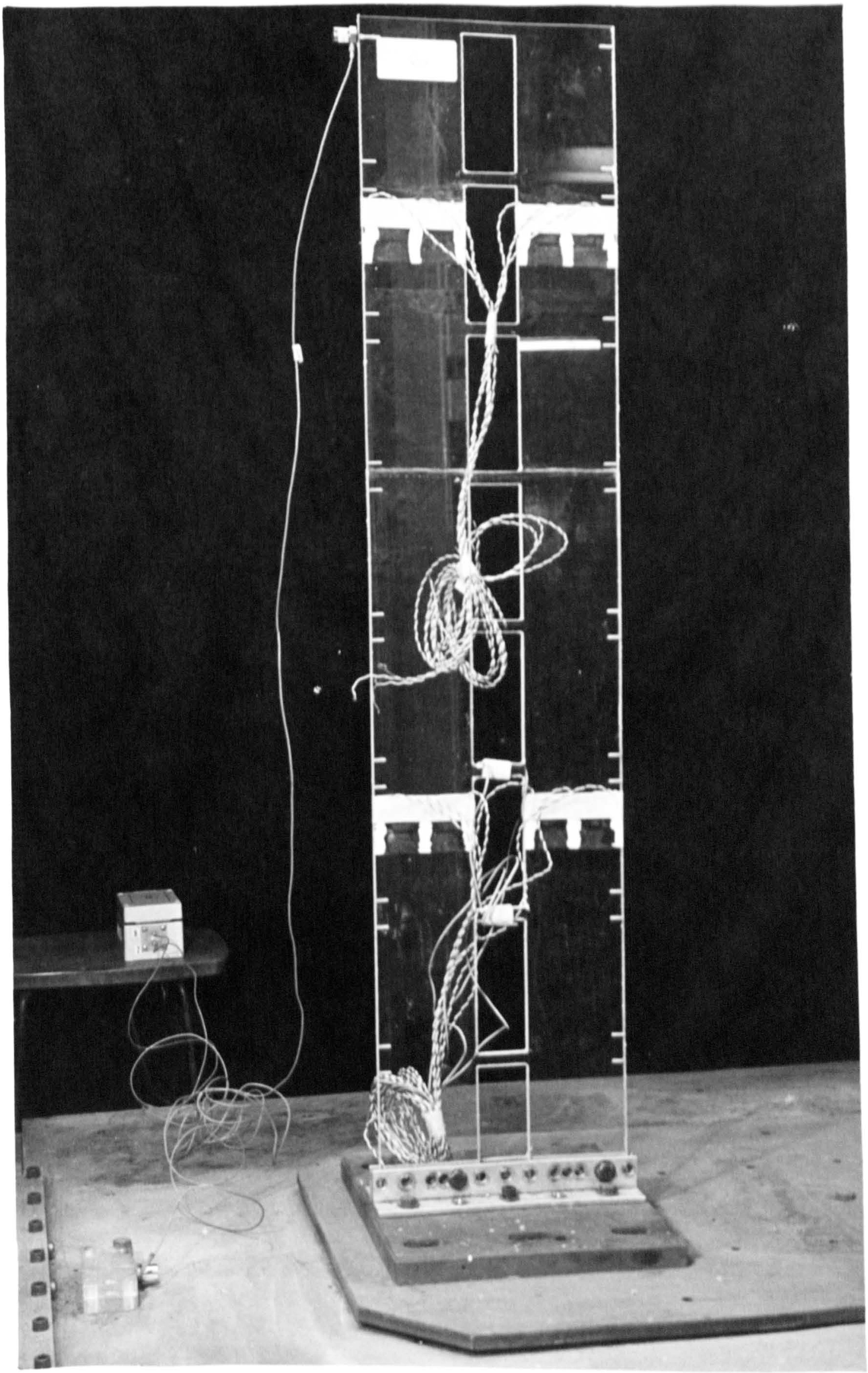


PHOTO (5) COUPLED SHEAR WALL

DYNAMIC MODEL

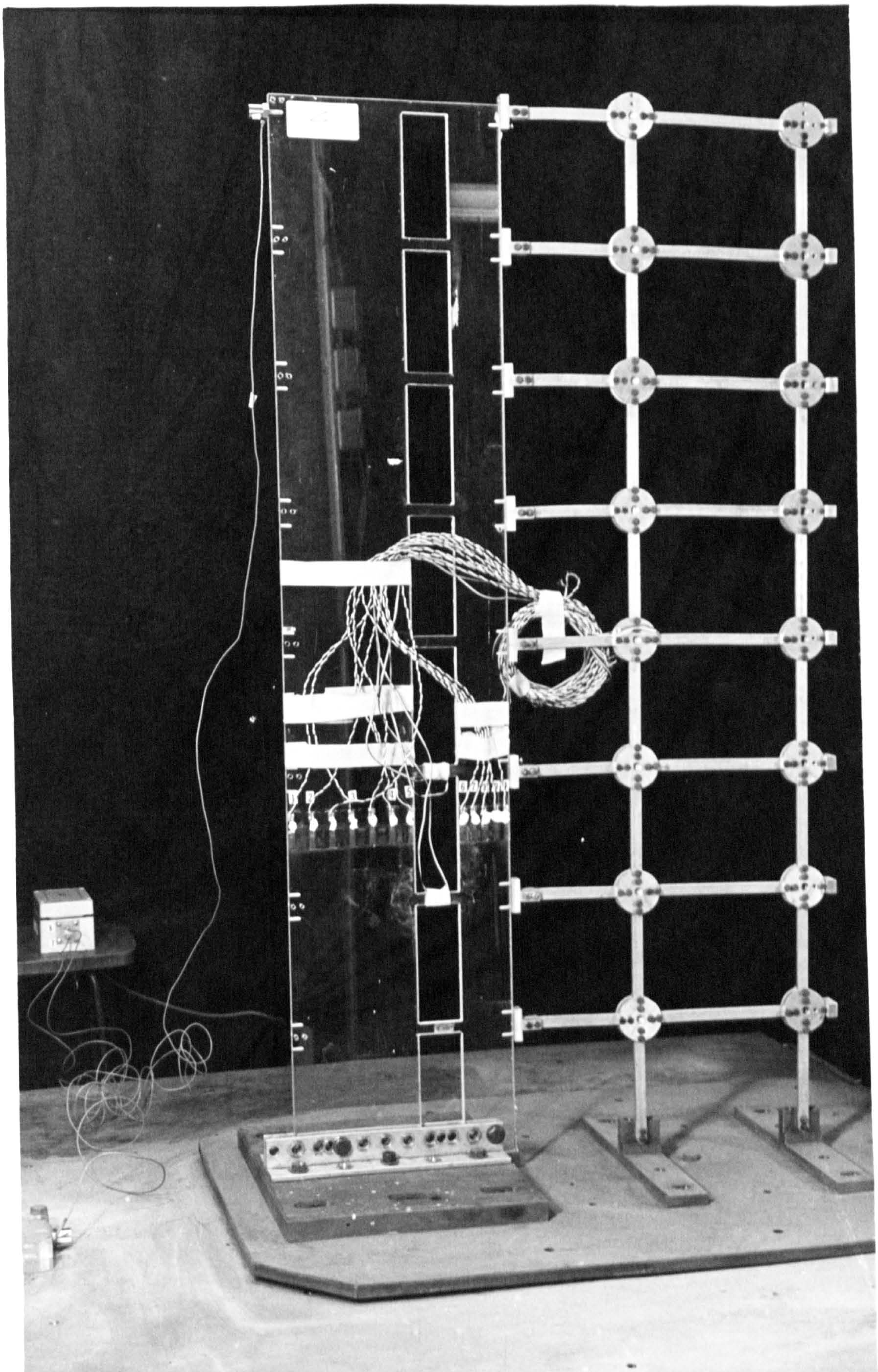


PHOTO (6) WALL - FRAME STRUCTURE
(CONSTANT THICKNESS)

DYNAMIC MODEL

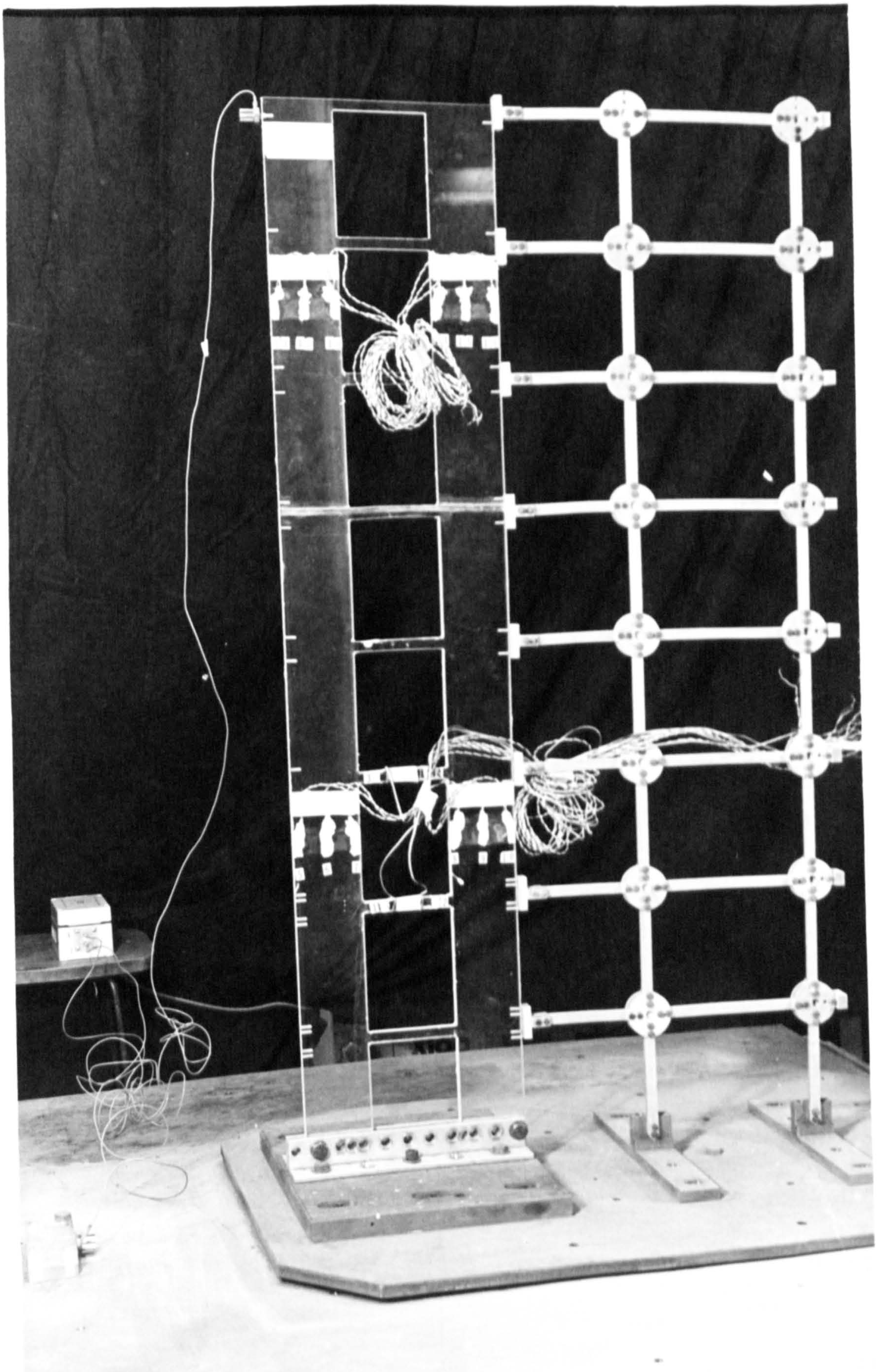
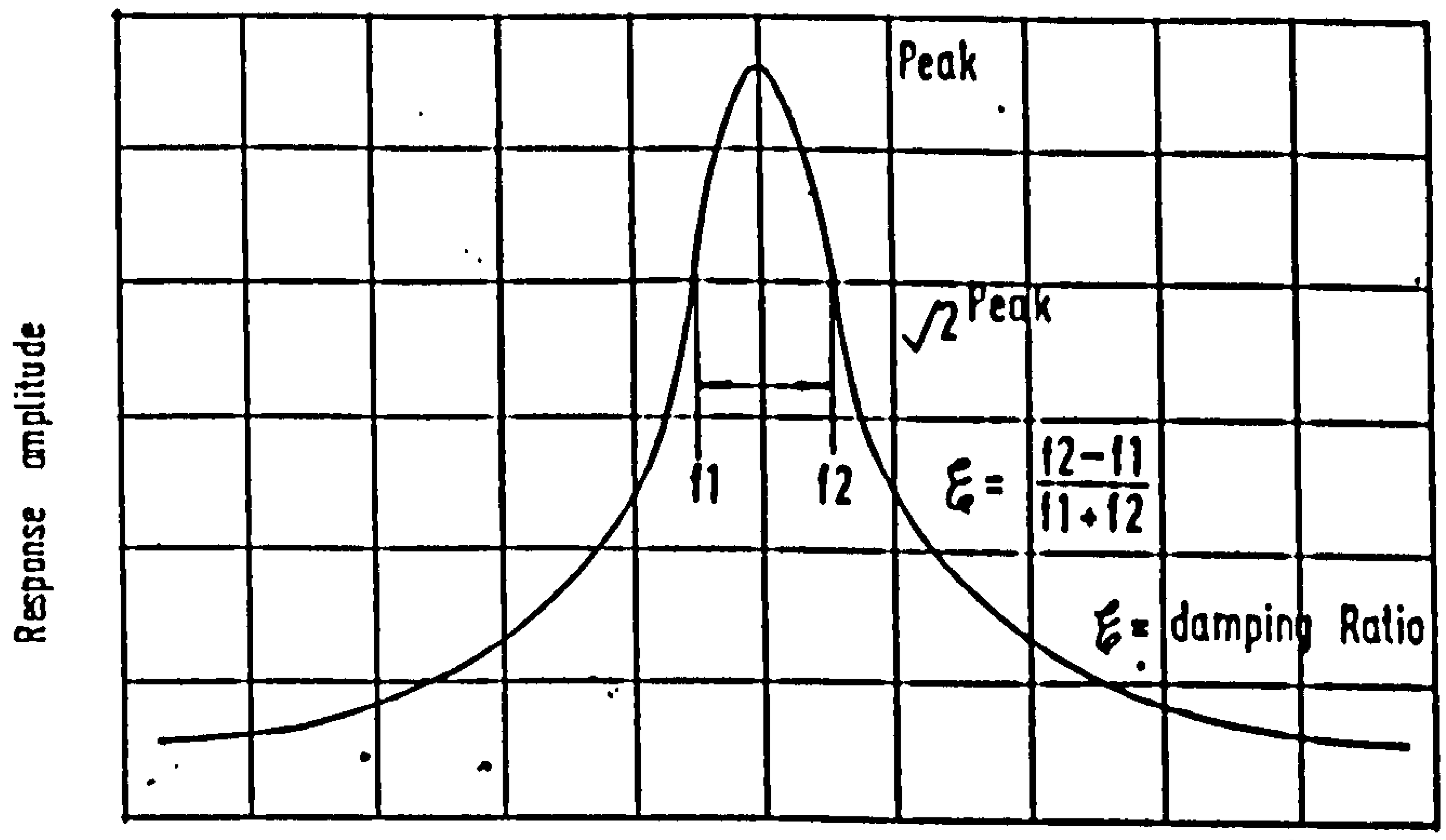


PHOTO (7) WALL - FRAME STRUCTURE
(VARIABLE THICKNESS)



Experimental frequency response curve

c) Determination of Dynamic Modulus

The dynamic modulus of the shear wall models was evaluated by testing a solid wall cantilever. This cantilever was machined from the same material as all the other models. The model was vibrated on the shaking table through the ranges 4 to 31 Hz and 130 to 180 Hz and the first and second modes found.

The theoretical values of the modes of a cantilever are given by the standard equation.

$$W = C^2 \left(\frac{EI}{PA}\right)^{1/2}$$

$$\text{where } C^2 = \left(\frac{1.875}{l}\right)^2$$

7.3.1 Comparison of Experimental and Theoretical Results (figs (7.6) to(7.8))

For each model, the first two natural frequencies were obtained. The results from the experimental models are compared with the theoretical

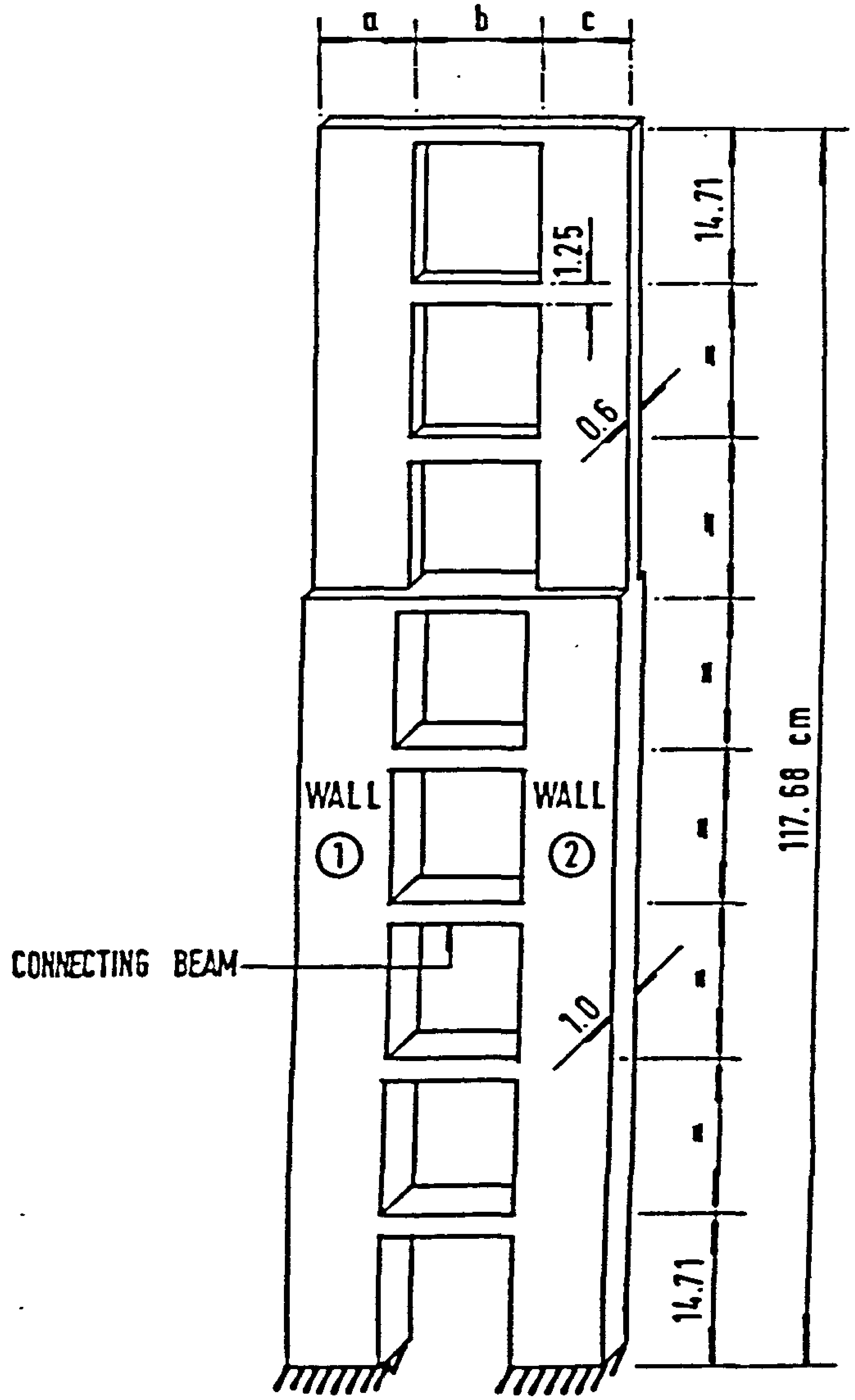


FIG (7.6) COUPLED SHEAR WALL MODELS ⑤ & ⑥

MODEL	DIMENSION		
	a	b	c
1	7.6	10.2	7.6
2	8.9	7.6	8.9
3	10.1	5.2	10.1
4	5.9	5.1	14.4
5	7.6	10.2	7.6
6	10.1	5.2	10.1

$E = 3.2 * 10^6$ N/cm^2
POISSON RATIO = 0.2

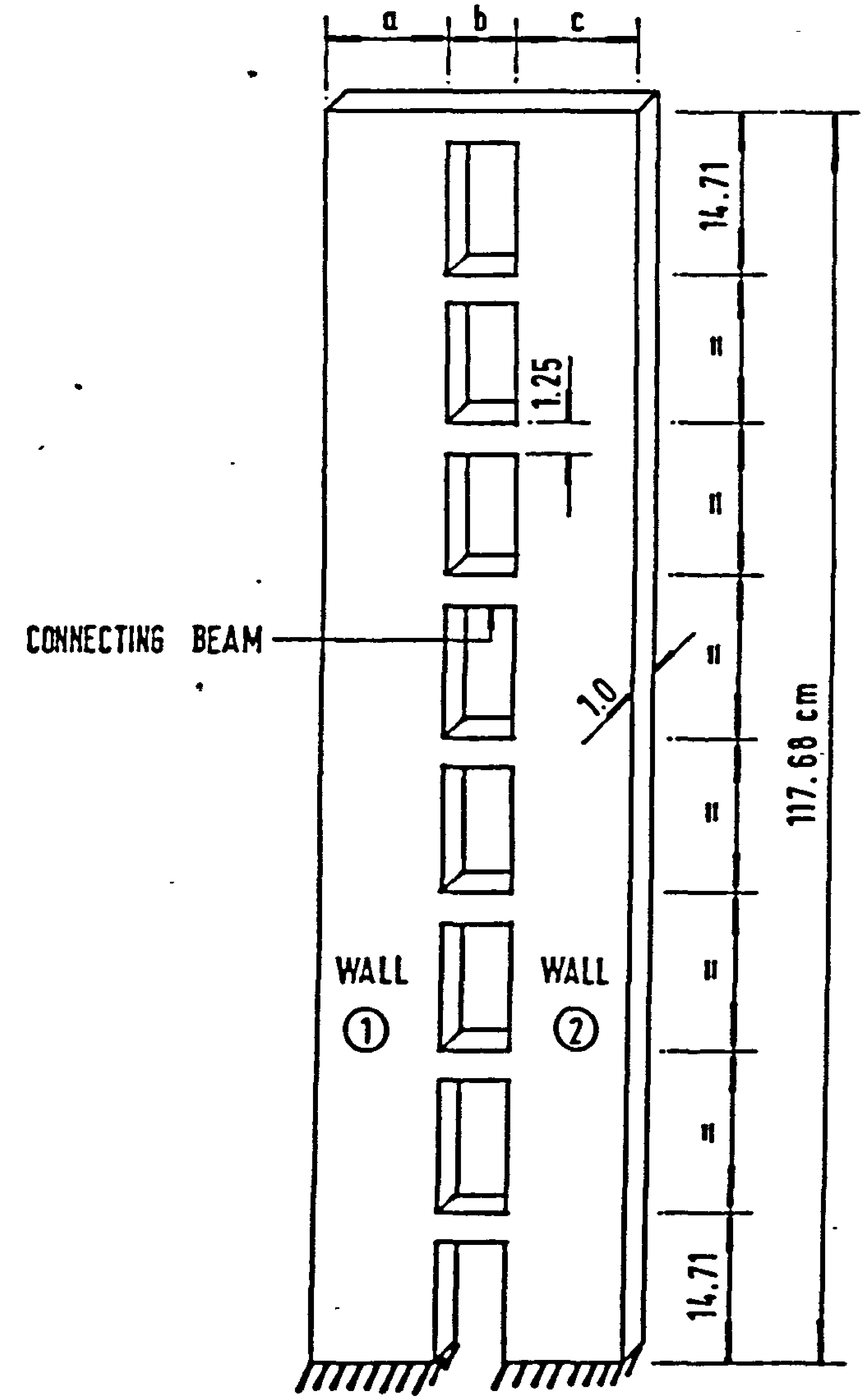
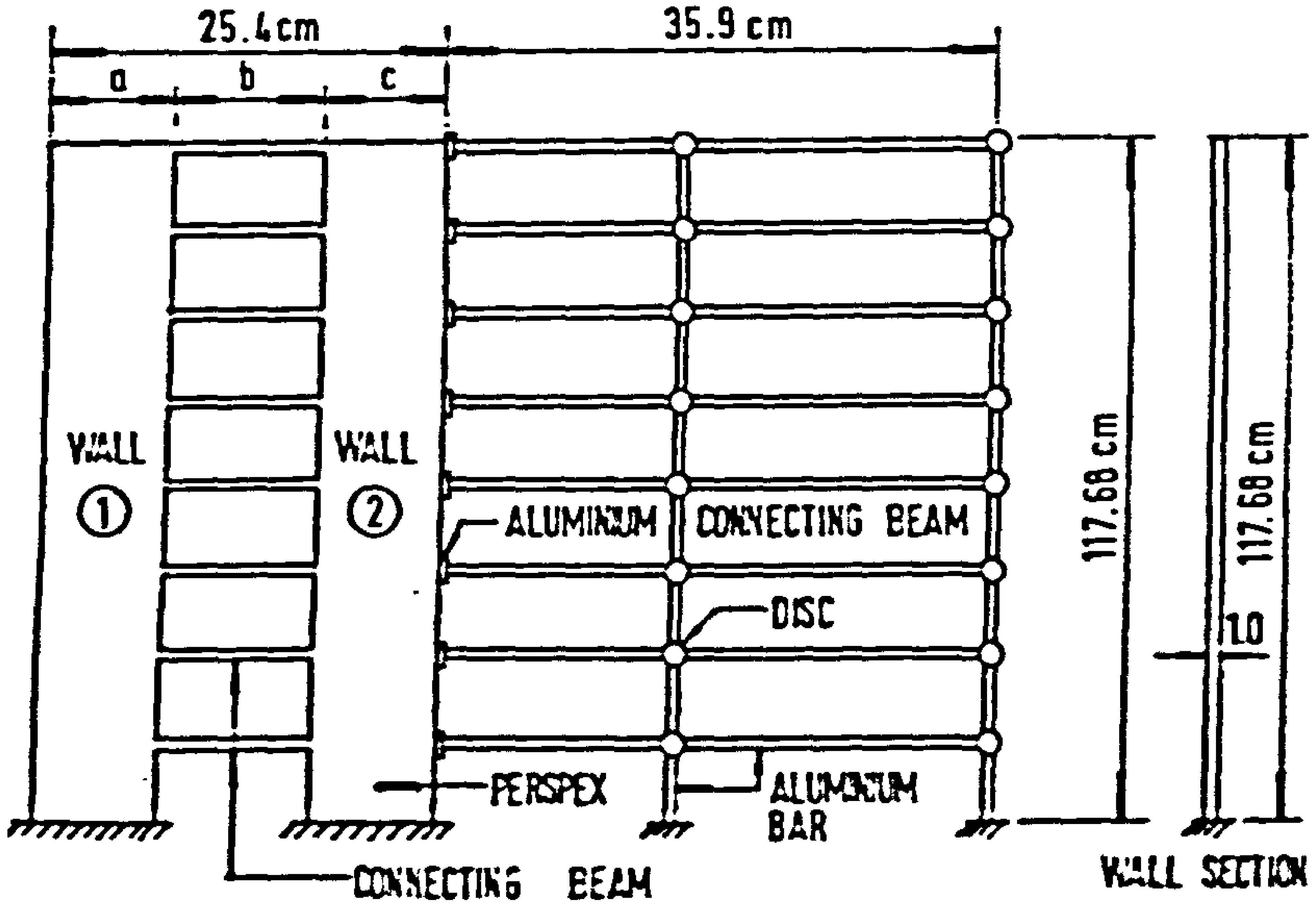


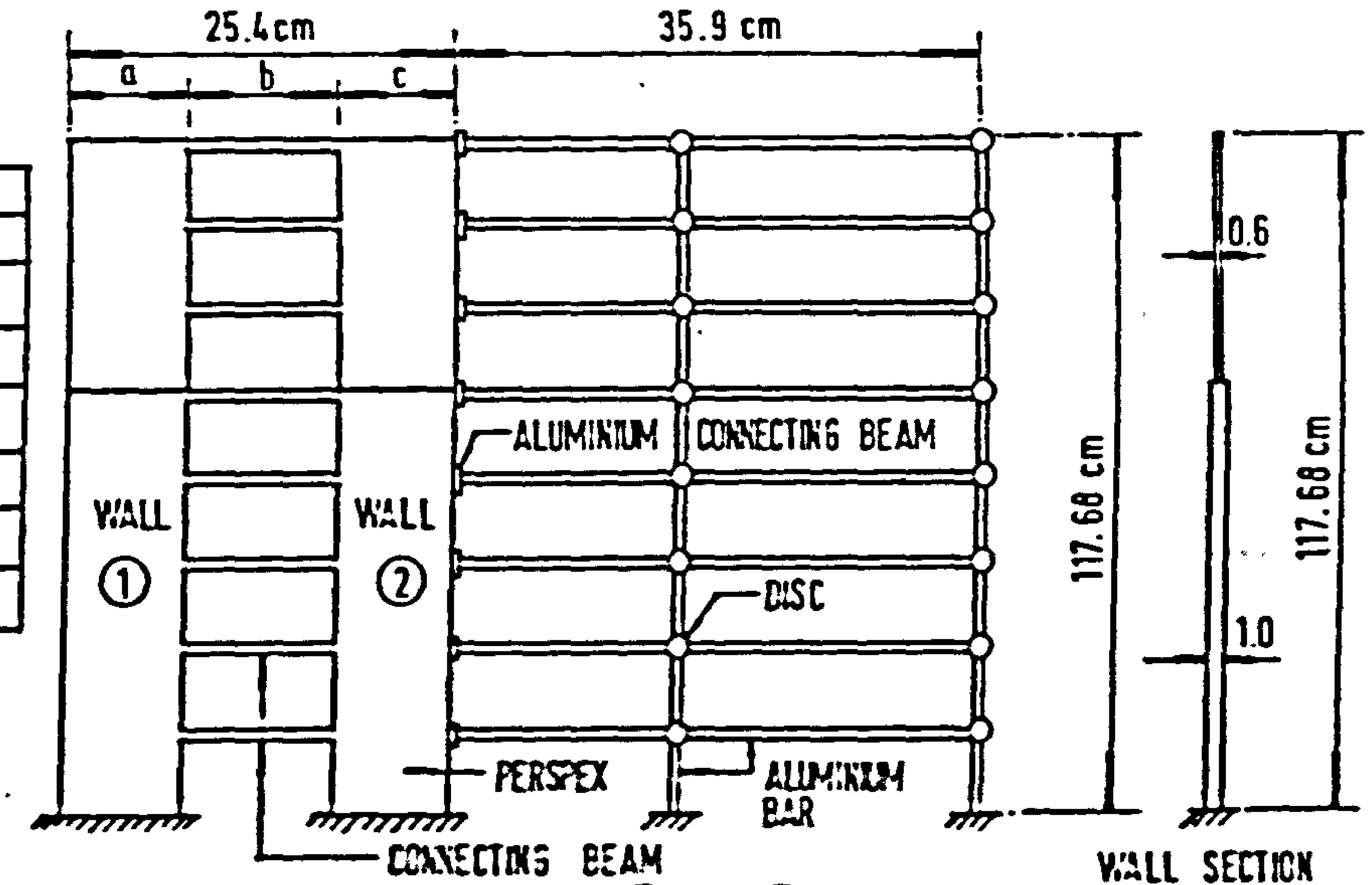
FIG (7.7) COUPLED SHEAR WALL MODELS ① ② ③ & ④



EXPERIMENTAL MODELS ⑦⑧⑨ & ⑩
(CONSTANT THICKNESS)

MODEL	DIMENSION a	DIMENSION b	DIMENSION c
7	7.6	10.2	7.6
8	8.9	7.6	8.9
9	10.1	5.2	10.1
10	5.9	5.1	14.4
11	7.6	10.2	7.6
12	10.1	5.2	10.1

CONNECTION
1) END MEMBER TO WALL - 2 BOLTS
2) EACH MEMBER TO DISC - 2 BOLTS



EXPERIMENTAL MODELS ⑪ & ⑫
(VARIABLE THICKNESS)

FIG (7.8) EXPERIMENTAL WALL - FRAME MODELS

TABLE = 7-2 COUPLED SHEAR WALL MODELS		NATURAL FREQUENCY (HZ)	
		1ST. MODE	2ND. MODE
MODEL 1	T2	29.5	126.5
	T1	25.0	107.2
	EXP	26.0	132.0
MODEL 2	T2	35.6	151.5
	T1	30.2	128.4
	EXP	30.0	160.0
MODEL 3	T2	43.6	182.4
	T1	36.5	153.1
	EXP	33.0	184.0
MODEL 4	T2	45.7	202.6
	T1	38.3	170.5
	EXP	34.0	203.0
MODEL 5	T2	34.4	129.1
	T1	29.2	109.4
	EXP	29.0	128.0
MODEL 6	T2	51.9	187.9
	T1	44.0	159.3
	EXP	36.0	181.0

NOTE:

T2 – THEORETICAL VALUES WITH DYNAMIC MODULUS OF 0.45×10^{10} N/m^2

T1 – THEORETICAL VALUES WITH STATIC MODULUS OF 0.32×10^{10} N/m^2

EXP – EXPERIMENTAL VALUES

TABLE = 7-3 WALL-FRAME MODELS		NATURAL FREQUENCY (HZ)	
		1ST. MODE	2ND. MODE
BY LITTLER	T2	35.5	121
	EXP	38.5	133
MODEL 7	T1	43.0	146.1
	T2	45.7	158.2
BY LITTLER	T2	39.0	135
	EXP	41.0	147
MODEL 8	T1	46.5	160.3
	T2	49.9	175.8
BY LITTLER	T2	44.4	155
	EXP	45.0	168
MODEL 9	T1	50.5	175.6
	T2	54.9	195.3
MODEL 10	EXP	61.0	167.0
	T1	52.1	187.1
	T2	56.8	209.5
MODEL 11	EXP	50.0	128.0
	T1	47.6	151.0
	T2	50.6	163.2
MODEL 12	EXP	61.0	158.0
	T1	56.5	181.1
	T2	61.6	200.7

NOTE:

T2 – THEORETICAL VALUES WITH DYNAMIC MODULUS OF 0.45×10^{10} N/m^2

T1 – THEORETICAL VALUES WITH STATIC MODULUS OF 0.32×10^{10} N/m^2

EXP – EXPERIMENTAL VALUES

$HZ = \frac{W}{2\pi}$ (f = HZ = NATURAL FREQUENCY IN CYCLES/SEC)

ω = ANGULAR FREQUENCY (RAD/SEC)

TABLE = 7-4 COUPLED SHEAR WALL MODELS WITH EQUIVALENT PROPERTIES		NATURAL FREQUENCY (HZ)	
		1ST. MODE	2ND. MODE
MODEL 1	T2	23.5	100.2
	T1	20.0	84.5
	EXP	26.0	132.0
MODEL 2	T2	30.6	128.9
	T1	25.8	108.8
	EXP	30.0	160.0
MODEL 3	T2	39.5	164.3
	T1	33.4	138.5
	EXP	33.0	184.0
MODEL 4	T2	41.3	181.5
	T1	34.8	153.0
	EXP	32.0	202.0
MODEL 5	T2	27.2	102.1
	T1	22.9	86.1
	EXP	30.0	128.0
MODEL 6	T2	46.7	168.0
	T1	39.4	141.7
	EXP	36.0	177.0

NOTE:

T2 — THEORETICAL VALUES WITH DYNAMIC MODULUS OF $0.45 \times 10^{10} N/m^2$

T1 — THEORETICAL VALUES WITH STATIC MODULUS OF $0.32 \times 10^{10} N/m^2$

EXP — EXPERIMENTAL VALUES

TABLE = 7-5 WALL-FRAME MODELS WITH EQUIVALENT PROPERTIES		NATURAL FREQUENCY (HZ)	
		1ST. MODE	2ND. MODE
MODEL 7	T2	38.9	130.4
	T1	36.5	117.5
	EXP	38.5	133.0
MODEL 8	T2	44.8	155.3
	T1	41.6	140.3
	EXP	41.0	147.0
MODEL 9	T2	51.5	181.6
	T1	47.2	162.9
	EXP	45.0	168.0
MODEL 10	T2	53.1	193.8
	T1	48.7	172.6
	EXP	61.0	168.0
MODEL 11	T2	43.2	133.5
	T1	40.5	120.4
	EXP	50.0	128.0
MODEL 12	T2	57.4	184.7
	T1	52.6	165.9
	EXP	61.0	158.0

NOTE:

T2 — THEORETICAL VALUES WITH DYNAMIC MODULUS OF $0.45 \times 10^{10} N/m^2$

T1 — THEORETICAL VALUES WITH STATIC MODULUS OF $0.32 \times 10^{10} N/m^2$

EXP — EXPERIMENTAL VALUES

TABLE = 7-6 COUPLED SHEAR WALL MODELS WITH LOCAL WALL DEFORMATION AT BEAM-WALL JUNCTIONS		NATURAL FREQUENCY (HZ)	
		1ST. MODE	2ND. MODE
MODEL 1	T2	28.0	122.9
	T1	23.6	103.6
	EXP	26.0	132.0
MODEL 2	T2	32.4	145.8
	T1	28.2	123.0
	EXP	30.0	160.0
MODEL 3	T2	40.6	172.4
	T1	34.2	145.4
	EXP	33.0	184.0
MODEL 4	T2	43.3	194.4
	T1	36.5	164.0
	EXP	38.0	202.0
MODEL 5	T2	32.7	125.5
	T1	27.6	105.8
	EXP	30.0	128.0
MODEL 6	T2	48	177.3
	T1	40.5	150.0
	EXP	36.0	177.0

NOTE:

T2 — THEORETICAL VALUES WITH DYNAMIC MODULUS OF 0.45×10^{10} N/m^2

T1 — THEORETICAL VALUES WITH STATIC MODULUS OF 0.32×10^{10} N/m^2

EXP — EXPERIMENTAL VALUES

TABLE = 7-7 WALL-FRAME MODELS WITH LOCAL WALL DEFORMATION AT BEAM-WALL JUNCTIONS		NATURAL FREQUENCY (HZ)	
		1ST. MODE	2ND. MODE
MODEL 7	T2	45.0	156.1
	T1	42.4	144.3
	EXP	38.5	133.0
MODEL 8	T2	48.6	172.1
	T1	45.3	157.1
	EXP	41.0	147.0
MODEL 9	T2	52.5	188.2
	T1	48.4	169.8
	EXP	45.0	168.0
MODEL 10	T2	55.0	204
	T1	50.6	182.5
	EXP	61.0	168.0
MODEL 11	T2	49.9	161.3
	T1	47.0	149.4
	EXP	50.0	128.0
MODEL 12	T2	58.8	194.0
	T1	54.2	175.2
	EXP	61.0	158.0

NOTE:

T2 — THEORETICAL VALUES WITH DYNAMIC MODULUS OF 0.45×10^{10} N/m^2

T1 — THEORETICAL VALUES WITH STATIC MODULUS OF 0.32×10^{10} N/m^2

EXP — EXPERIMENTAL VALUES

results, analysed by the finite strip method, in tables (7.2) & (7.3).

It can be seen in table (7.2) for the coupled shear wall that the theoretical prediction based on the static modulus seems to give a poor agreement for the 2nd mode of the natural frequency. The reason for this may be due to the material properties of the perspex models varying during the vibration. Once the dynamic modulus was introduced, the results for the 2nd mode of natural frequency have noticeably improved.

Again, it can be seen in table (7.3) that for wall-frame combinations, the theoretical natural frequencies obtained with the static modulus of the aluminum are in good agreement with experimental predictions.

The modulus of the perspex, however, had to be altered in evaluating the second mode to obtain better results.

The natural frequencies analysed by equivalent medium method are given in tables (7.4) & (7.5) for both coupled shear wall and wall-frame models. The results obtained shown close agreement with the experimental results.

The twelve models were reanalysed by the finite strip allowing for local wall-beam junction deformations. The results are shown in tables (7.6) & (7.7). In this case, the results for the wall-frame models for the 1st mode are noticeably improved, but it provides slightly higher values for the 2nd mode.

7.4 Conclusions

Comparing the experimental and theoretical results, the following conclusions can be made:

1) In order to obtain accurate values for the 2nd mode of the natural frequency, the dynamic modulus of the perspex should be used.

2) From the comparison of the results given in table (7.2) for wall models, it can be seen that the natural frequencies obtained by experimental results are in good agreement. Generally the experimental results were slightly lower values for all the wall models for the 1st mode and higher values for the 2nd mode.

3) Again, it can be seen that in table (7.3) for wall-frame models, the experimental and theoretical results are also in good agreement. The results obtained by the finite strip method gives slightly lower value for the 1st mode and higher for the 2nd mode.

4) It may be concluded that the finite strip method gives accurate results for the natural frequencies of coupled shear walls and wall-frame structures.

CHAPTER EIGHT

COMPUTER PROGRAMS

8.1 Introduction

The programs developed in this thesis are for the analysis of a wall-frame structure which has elastic properties. The computer programs are described below:

1) Finite strip representation for both wall and coupled shear wall with frame is given in program A. Its flow chart is shown in fig (8.1). Generally, the use of five to six terms for the mode shapes is sufficient to yield a reasonable answer. To improve the speed of the calculations and storage efficiency, attention should be paid to the nodal numbering as the bandwidth of the overall stiffness matrix is determined from the nodal number difference between two nodal lines. This program may be used for both static and dynamic conditions.

2) Finite strip is used to represent the shear wall or coupled shear wall and plane frame for frame elements. The program is developed in such a way that it can be used for individual and combined structural systems as shown in flow chart B. With little modifications, it may be applicable to shear wall with space frame structure.

The program contains two parts. Part one is developed for shear walls and coupled shear walls with a number of wall elements. The second part is for the analysis of a frame structure. In a wall-frame structure, these two parts are combined together to determine their interaction forces and then distributes the forces to each system separately. In flow chart B, it can be seen that the program possesses more flexibility for analysing high rise buildings with any form of structural system which could occur in practice.

3) In program C, the continuum method is used to model the coupled shear wall and a plane frame for frame elements. Deformation equations for coupled shear walls under different load cases are preset in the program. Details of the derivation of these equations are given in Chapter two . As shown in flow chart C, it can be seen that the steps are rather simple and the method of forming the flexibility matrix is dependent on the preset equations.

The program is divided into two parts, the second part being the same as program B.

These three programs are written in Fortran and a listing of the programs is given in Appendix (B). Comparison of these three programs is presented in table (8.1) for reference.

8.2 FLOW CHARTS: THREE FLOW CHARTS ARE DESCRIBED BELOW

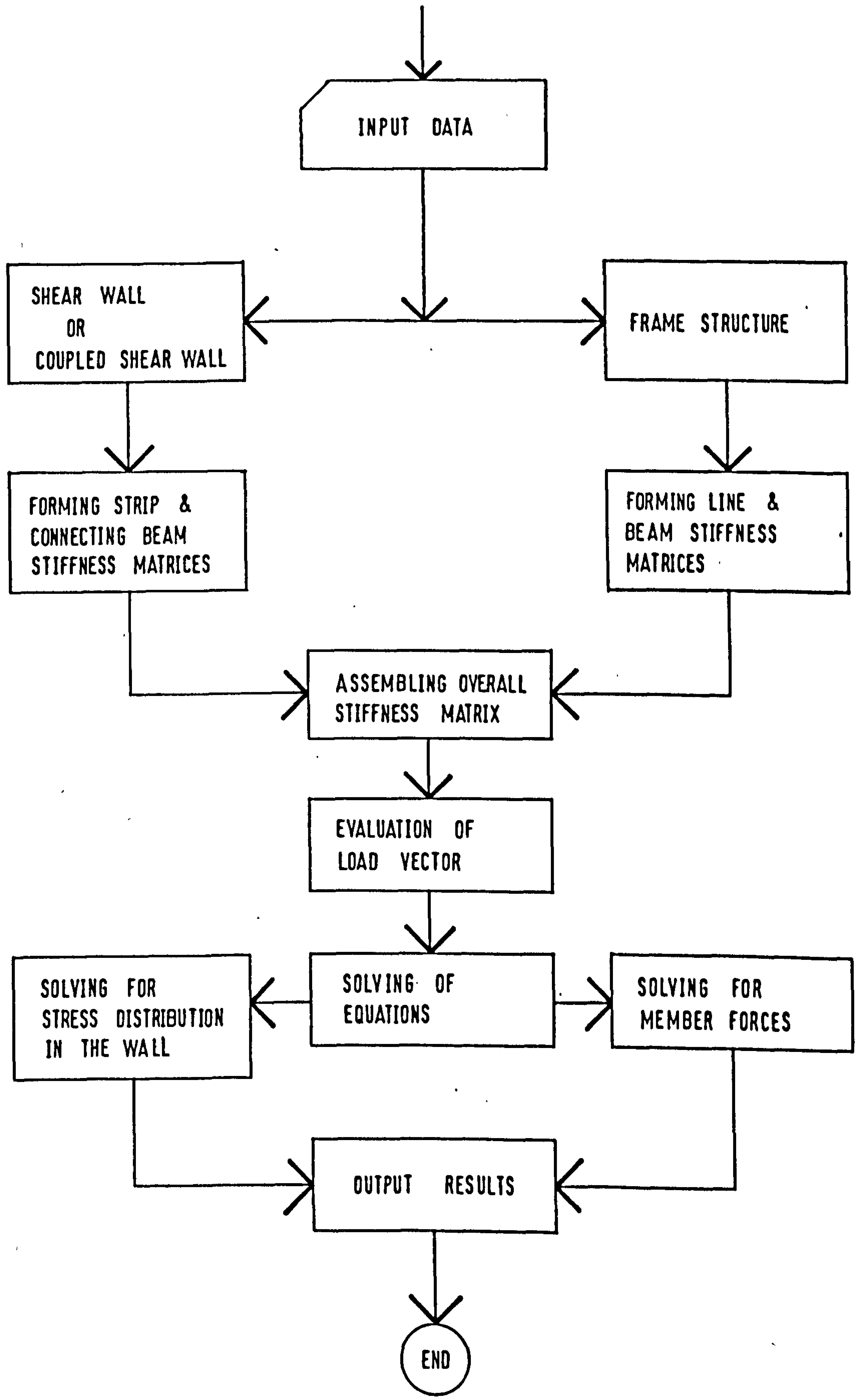


FIG.(8·1) = FLOW CHART 'A' — FINITE STRIP FOR WALL-FRAME STRUCTURE

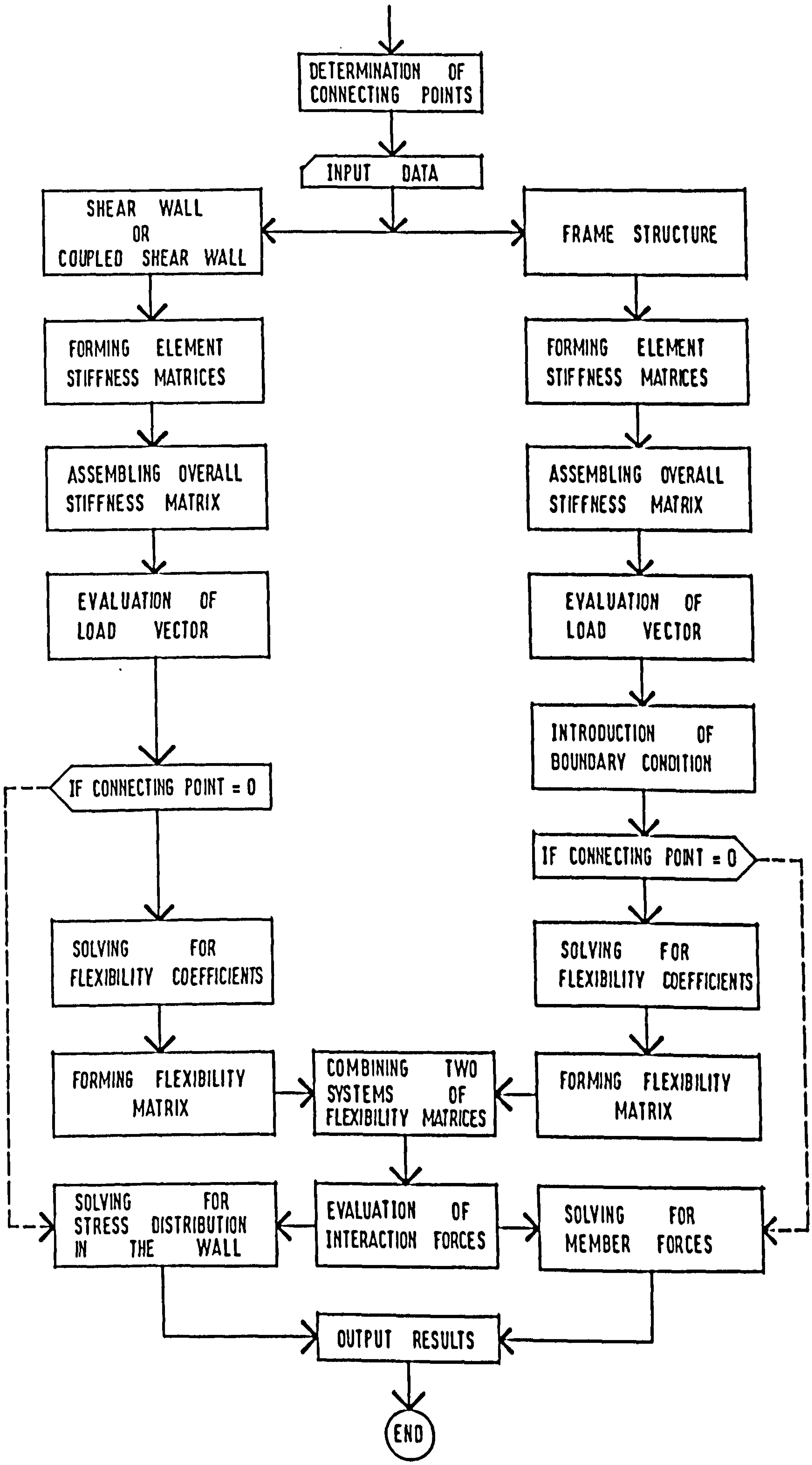


FIG (8.2) = FLOW CHART 'B' – FINITE STRIP COMBINED WITH PLANE FRAME

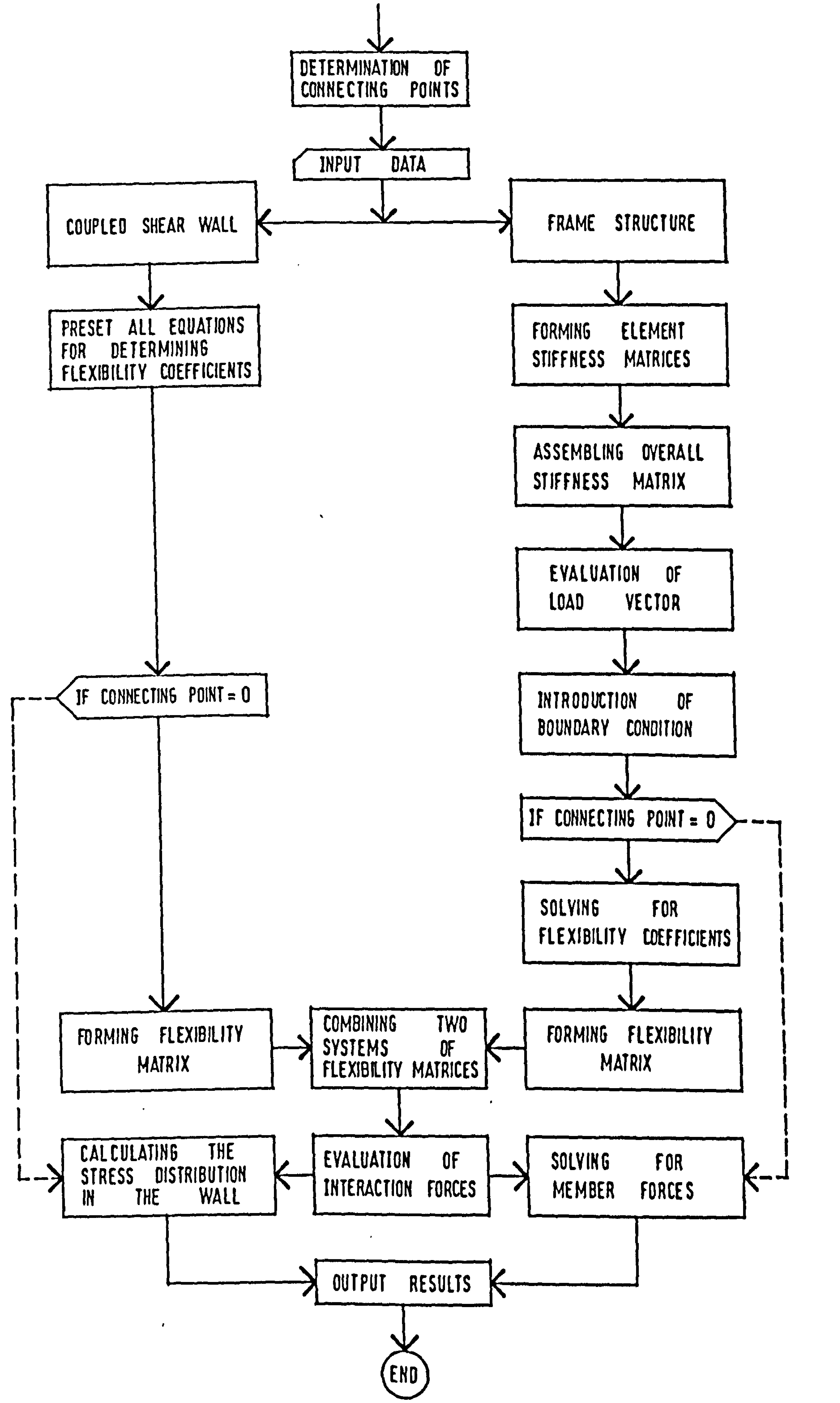


FIG (8.3) = FLOW CHART 'C' – CONTINUUM METHOD COMBINED WITH PLANE FRAME

Table 8.1 Comparisons of the Programs A,B & C

Program 'A' (F.S.M)	Program 'B' (F.S.M + P.F)	Program 'C' (Continuum + P.F)
1) Structural systems		
i) The procedure for formulating the stiffness matrices for wall, beam and line elements are the same.	Two different systems for formulating the stiffness matrices are used.	The derivation of stiffness matrices is only applicable to the frame structure.
ii) Forming the flexibility matrices are not necessary.	The flexibility coefficeints at connecting points are obtained from solving each substructure separately.	The flexibility coefficients for coupled shear wall are computed directly from preset equations . This leads to shorter time.
iii) Boundary conditions are pre set.	Boundary conditions are required for frame structure.	Boundary conditions are required for frame structure.
iv) No singularity occurs in the structural stiffness matrix.	Singularity of stiffness matrix is possible.	Singularity of stiffness matrix is possible.
2) Input Data		
Only one set of input data is necessary.	It involves two sets of separate input data.	It involves two sets of separate input data.

3) Bandwidth		
The bandwidth depends on the difference in nodal line numbering and generally, it is relatively small bandwidth.	It is dependent on the nodal line numbering in finite strip as well as the numbering scheme adopted for the nodes in the frame structure. Its bandwidth is determined from the largest difference between any two nodes in an elements. Sometimes, due to poor arrangement, this might lead to uneconomical computation.	It is only dependent on the numbering system in the frame structure.
4) Interaction points		
i) Determination of the position of interaction points is unnecessary.	Proper choice of interaction points is important for distributing the proportion of forces among the two systems.	Proper choice of interaction points is important for distributing the proportion of forces among the two systems.
ii) The forces at the connecting points are obtained after a solution is derived for the whole structure.	The required interaction forces are decided before analysing the complete structure. It gives more flexible to obtain the desired forces in any substrucutre and avoid unnecessary computing time.	The required interaction forces are decided before analysing the complete structure. It gives more flexible to obtain the desired forces in any substrucutre and avoid unnecessary computing time.

5) Computation Time and Storage The size of storage and computing time are mostly dependent on the number of mode shapes required and nodal line numbering.	It depends on the proper choice of the position of interaction points as well as the number of interaction points.	It depends on the proper choice of the position of interaction points as well as the number of interaction points.
6) Remarks The displacement shape functions are used to represent the behaviour of wall and frame structures. The accuracy and reliability of the structure is greatly dependent on these functions which must be able to give the complete displacement shape of the structure under investigation. Thus, for complex types of structure, these functions might only yield very approximate answers.	Only the coupled shear wall is modelled by the shape functions. Generally, the beam eigenfunction produces a reasonale profile for this type of structure.	No shape functions are required. Its flexibility coefficients for coupled shear wall are obtained directly from the preset equations

8.3 Remarks

1) In program A, the procedure for formulating the wall, beam and frame stiffness matrices is identical. The assembly of the total element stiffness matrices is performed by adding each element stiffness matrix according to its nodal line numbering. The edge of the first strip is added to edge 1 of second strip and so on. Thus, in general, the bandwidth of its resulting overall matrix is rather small. For example, in two dimensional structure which contains the displacement parameters U & V and rotaion Θ, its matrix becomes 3* (number of nodal lines) by 3* (the difference between two nodal lines).

2) Two different structural systems are used in programs B & C. The method of formulating the element stiffness matrices are carried out separately. The conventional plane frame method which is inclusive of shear deformation in the elements is used to analyse the frame structure. These two methods permit more flexibility to combine with any other form of complex frame structure.

3) In program C, the procedure of formulating the wall stiffness matrices is avoided. The flexibility coefficients at connecting points are obtained directly from the preset equations. This method leads to a shorter computing time and is more suitable to apply to those coupled shear walls whose flexibility coefficients are available in preset equations.

CHAPTER NINE

CONCLUSIONS AND RECOMMENDATION

9.1 Conclusions

Three general computer programs, based on the different approaches, have been written to support the accuracy of the proposed method. Their reliability is determined by comparing the results obtained with numerical examples, which were analysed by other existing approaches, and also experimental models. From the comparisons shown in Chapters four and six, it can be seen that the proposed method meets the requirements of versatility and economy in computing time.

The following conclusions may be drawn from this study:

1) For coupled shear walls alone, both finite strip and continuum methods produce virtually the same results. The maximum lateral deflection as derived by the finite strip method is generally an underestimate of about 10%. This may be seen from the comparative results given in Chapter four. Similar results were also found for wall-frame structures in Chapter six. The reason for this is that the assumed shape function is based on basic bending theory. An improvement is shown when local wall deformation at wall-beam junction is included in the analysis. This shows that the addition of local wall-beam junction deformation is significant for coupled shear walls.

2) It can be seen in Chapter three that economy of computer

storage and solution time for the finite strip method is ensured by presetting the boundary conditions which reduce the two dimensional unknown functions to one unknown function. The structures are idealised in such a way so as to reduce the number of nodes compared to the finite element method. This idealisation leads to a smaller bandwidth and hence reduced storage requirements.

3) Two different approaches for analysing the coupled shear walls by the finite strip method are introduced. In the first approach, the connecting beams are idealised as a continuum medium and can therefore be represented by strip elements. Though this approach can be easily implemented and involves less computing time, it has the disadvantage of being less versatile. When the connecting beams are of unequal depth and non-uniformly spaced throughout the height of the coupled shear wall, it should not be used.

On the other hand, the second approach is more flexible. The stiffness matrix of each individual beam is derived. The matrices, for each beam, are then combined to produce the matrix for a single equivalent beam using the appropriate shape function. Compatibility conditions are then applied to the deformations of this equivalent beam and the attached shear walls. It can be concluded that the second approach is more realistic and should preferably be used for the analysis even if its computing time is slightly longer.

4) Of the three programs, program C which combines continuum

and plane frame methods will produce the shortest computing time. The process of formulating the stiffness matrix of the coupled shear wall is unnecessary. This program is particularly useful for analysing coupled shear walls when the connecting beams are of equal size and the storey height is uniform throughout the whole building.

5) To verify the proposed method, different numerical examples with a variety of wall and frame dimensions and positions, as shown in figs (6.1) to (6.8), were analysed. The values of deflection and stress resultants are compared with the finite element and other existing methods. This comparison is shown in Chapter six and from these results, it can be seen that interaction forces at wall-frame connecting points and maximum lateral deflection, bending moment and axial forces in the walls obtained by the proposed method show good agreements with the other existing approaches.

6) The theoretical behaviour of experimental models has been analysed by the finite strip method. From the comparison, it seems that the greatest discrepancy is at the connecting beams which have slightly higher end moments than the experimental results. The values of the vertical wall stresses are in good agreement. Also, it can be seen that the values for the end moments of the connecting beams may be improved by including the effect of local wall deformation at wall-beam junctions even when the connecting beams are short.

7) From items 1 and 6, it can be concluded that the most

accurate results may be obtained when the effects of local wall deformation at wall-beam junctions of a coupled shear wall is included in the analysis. From the above discussion, it can be concluded that the proposed method has been shown to yield accurate results and close agreement with other existing approaches in any circumstances. Thus, it is ideally suitable for modelling wall-frame structures for high rise buildings.

9.2 Recommendations for Future Works

In this study, the proposed method has been developed to model any combination of coupled shear wall and frame structures. Its versatility and short computing time make it suitable for a future parameter study. In the present investigation, it was assumed that the structure behaves linearly and the concept of small displacements is applicable. This opens up three possible paths for future research work on this method. There are given below:

1) The coupled shear walls can be analysed by either the finite strip or continuum method. In the finite strip, its accuracy and reliability is solely dependent on the assumed shape function which has to be able to predict the complete displacement shapes of the structure. As stated in item 1 of section 9.1, the function used in the present study tends to be more favourable to structure deformed in bending. Therefore, another more versatile shape function suitable for any shape of complex wall-frame structures is worth looking for.

2) Owing to the presence of high in-plane rigidity floor slab at each floor

level, it is generally assumed that the displacement of the structure at each level undergoes only a rigid body displacement. Thus, another possibility is to consider the behaviour of the structure when the floor slab rigidity is reduced by floor openings.

3) The third recommendation for future work is to consider geometric nonlinear behaviour or large displacement analysis to examine the reliability of the present study.

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APPENDIX (A)

Computer Programs

Input Data Notation

Structure Data

Title	Title
NSJ	1 = Static Problem 0 = none
NFR	1 = Free Frequency 0 = none
NRE	1 = Forced Response 0 = none
LH	1 = Lower Order (u & v mly) 2 = High Order (u, v & Θ)
NSP	1 = Beam Eigenfunction 2 = Polynomial Function
NODL	Number of nodal lines
Nspan	Number of nodal spans
MOT	Number of mode shapes
NDF	Degree of freedom
NBA	Bandwidth
Nwall	Number of strips.
Nbeam	Number of strips for connecting beams
NCOL	Number of line elements
A(I)	Each strip height
B(I)	Each strip span

NBPT	Number of height types
NYY(I)	Number of beam position
HTT(I)	Each beam height

Structural Properties

Wall Strips

E1	Sectional modulus
PX	Poisson Ratio in X-direction
PY	Poisson Ratio in Y-direction
Fmass	Mass density

Beam Strips

E2	Sectional modulus
PX2	Poisson Ratio in X-direction
Fmass2	Mass density

Line Elements

E3	Sectional modulus
PX3	Poisson Ratio in X-direction
Fmass3	Mass density

Load Data

Lcase	Number of load cases
NPTL	Number of point load lines
NUDL	Number of uniform load line
NPT	Number of point loads in each line
PLD(I)	Load position
NUUM	1 = Load at X-direction 2 = Load at Y-direction 3 = Moment
LTYPE	1 = Point load 2 = Uniform load

Computed Results

Displacement

NDISPL	1 = Displacement 0 = none
NOD	Number of output lines
NE(I)	Output line number
NYP(I)	Output position

Stresses

NwallQ	Number of output walls
NBeamQ	Number of output beams
NCOLQ	Number of output line elements
NP	Number of output position in Y-direction.

Npout	Number of output in X-direction
XDP	Output distance in X-direction

Interaction Points

NCL	Number of connecting points at lefthand side
NCR	Number of connecting points at righthand side
NI(1)	Nodal line number at lefthand side
NI(2)	Nodal line number at righthand side
YCP	Connecting point position
JCP	Connecting point number
NXH	1 = Unit load in X-direction 0 = none
NYV	1 = Unit load in Y-direction 0 = none
NMO	1 = Unit moment 0 = none

Frame Structure

V	Max. number of members
NK	Max. number of joints
NV	Max. number of joint difference
M	Number of members
NJ	Number of joints
NR	Number of restraints

NRJ	Number of restrained joints
E	Sectional modulus
X(I)	Distance in X-direction
Y(I)	Distance in Y-direction
IZ(I)	Moment of inertia
AX(I)	Sectional Area
SF(I)	Shear shape factor
RVL(I)	1 = Modified effective length 0 = Original length
RL(I)	Restrained direction
NLJ	Number of loaded joints
NLM	Number of loaded members
A(3*I-2)	Load at X-direction
A(3*I-1)	Load at Y-direction
A(3*I)	Monemt
NTOL	Number of load types

APPENDIX (B)

Computer Program Listings

Three Computer program listings are given in this thesis:

a) Program A - Finite Strip for Both Wall and Frame

b) Program B - Finite Strip Combined with Plane Frame

c) Program C - Continuum Combined with Plane Frame

Program A - Finite Strip for Both Wall and Frame

```
      parameter (memory = 50000)
      dimension a(memory)


      ldyn = 1


      mxbnd = 50
      mxdof = 300
      mxitr = 20
c
c    input expected max band width, max dof and max trial eigen vectors
c         if you have no idea input as zero(0)
      read (5,*)maxbnd,maxdof,maxitr
      if (maxbnd.le.0) maxbnd=mxbnd
      if (maxdof.le.0) maxdof=mxdof
      if (maxitr.le.0) maxitr=mxitr
      ksize = maxbnd*maxdof
      msize = 1
      idissz = maxdof
      iusize = 1
      if (ldyn.ge.1) then
          msize = ksize
          iusize = maxdof * maxitr
          idissz = 1
      endif
      ivsize = iusize
      iwsize = iusize
c....for static problems
      ipld = 1
      ipdis = ipld + maxdof
      ipg   = ipdis+ idissz
      ipsdl = ipg + ksize
      nnsdl = 80*80
      lstat = ipsdl + nnsdl
      if (lstat.gt.memory) then
          write (6,2001)
2001  format(///,'    warning : there could be memory problem ',/,
     1    '    recheck that the results, if come, are ok!',/,
     2    '    retry increasing memory in the first statement',//)
      endif
c... additional memory required for dynamic problems
      ipgm = ipsdl
      ipsdl= ipgm + msize
      ipu  = ipsdl
      ipv  = ipu + iusize
      ipw  = ipv + ivsize
      ldymc = ipw + iwsize
      if (ldymc.gt.memory) then
          write (6,2002)
2002  format(///,'    warning : there could be memory problem ',/,
     1    '    recheck that the results, if come, are ok!',/,
     2    '    retry increasing memory in the first statement',/,
     3    '    alternatively ',/,
     4    '    try to reduce the bandwidth ie. maxbnd and/or ',/,
     4  '  try to reduce the no. of trial eigen vectors(maxitr) ',/,
     4  '  try to reduce the max. dof (maxdof) ',/)
      endif
      call strip(a(ipld),a(ipg),a(ipgm),a(ipdis),
     1       a(ipu),a(ipv),a(ipw),maxdof,a(ipsdl) )
      stop
      end
      subroutine strip(ld,g,gm,dis,u,v,w,maxdof,sdl)
```



```
C     USE POLYN FUNCTION,SIN FUNCTION,LOWER ORDER, HIGH ORDER AND DYN.
      CHARACTER *8 PROGRM, TODAY, CURTIM
      PARAMETER (PROGRM ='STRIP   ')
      CHARACTER*80 TITLE
      DIMENSION SD1(80,80)
      DIMENSION JJ(30),JK(30),
     1          B(30),A(30),THK(30),HT(30),HPLD(30),SF1(30),
     2          NTY(30),NYP(30),PLD1(30),SF2(30),Y1(3),Y2(3),
     3          PLD2(30),PLD3(30),ZI2(30),HTT(10,30),
     4          AA1(30),AY1(30),ZI1(30),AA2(30),NYY(30),NLY(30),
     5          NE(30),XDP(10),E1(10),E2(10),NSH(30)
         DIMENSION LD(1),G(1),GM(1),DIS(1),ALD(1)
         DIMENSION u(maxdof,1),v(maxdof,1),w(maxdof,1)
      DATA KK/3/
C     INPUT STRUCTURE DATA
C     LH=1 FOR LOW ORDER ,LH=2 FOR HIGH ORDER
C     NSP=1 FOR SINE FUNCTION ,NSP=2 FOR POLYN. FUNCTION
C     NCT=1 LE TO LE,NCT=2 ST TO ST,NCT=3 LE TO ST,NCT=4 ST TO LE
C        CALL  DATE(TODAY)
C        CALL TIME(CURTIM)
C        WRITE (50,88999) PROGRM, TODAY, CURTIM
C        WRITE (6,88999) PROGRM, TODAY, CURTIM
88999    FORMAT( 10(/), 25X,'PROGRAM  USED IS :',A8,
     1          4(/),20X,'DATE :',A10,'   TIME  ',A10,10(/) )
C      TSET  = TIMER(0.0)
      WRITE(6,500)
      DO 9910 I=1,2
      READ(5,'(A80)') TITLE
9910  WRITE(6,'(A80)')TITLE
C *** STRUCTURE DATA ***
      READ(5,*) NST,NFR,NRE,LH,NSP
      READ(5,*) NODL,NSPAN,MOT,NDF,NBA,NWALL,NBEAM,NCOL
      WRITE(6,510)
      WRITE(6,520)
      WRITE(6,530) NST,NFR,NRE,LH,NSP,NDF,NBA,MOT,NODL,NSPAN,NWALL,
     1          NBEAM,NCOL
         LL=NDF*MOT
         NN=NCOL*LL
         NL=NBA*MOT
C  DEFINE THE ADDRESSES OF THE DIAGONAL ELEMENTS OF L & G
      DO 10 I=1,NL
         J=I*(I+1)/2
         LD(I)=J
10       LD(I)=J
         K1=NL*(NL+1)/2
         NNNL = NN-NL
      DO 9920 I=1,NNNL
         K=NL+I
9920     LD(K)=K1+I*NL
      IF(NST .EQ. 1) NSTFR=1
      IF(NFR .EQ. 1) NSTFR=2
C ...............
      WRITE(6,532)
      READ(5,*) (A(J),J=1,NCOL),(B(J),J=1,NSPAN)
      WRITE(6,810)(A(J),J=1,NCOL),(B(J),J=1,NSPAN)
810   FORMAT(10F12.2)
C ...............
      READ(5,'(A80)') TITLE
      READ(5,*) NSPT
      DO 14 J=1,NSPT
      READ(5,*) NYY(J),(HTT(J,L),L=1,NYY(J))
14    CONTINUE
      DO 20 K=1,KK
```

```
      GO TO (2,4,6),K
C ...............
C *** WALL DATA ***
 2    IF(NWALL .EQ. 0) GO TO 20
      READ(5,'(A80)') TITLE
      WRITE(6,'(A80)')TITLE
      WRITE(6,540)
      WRITE(6,560)
      DO 30 N=1,NWALL
         write (6,*)'  wall no. ',n
      READ(5,*) I,JJ(I),JK(I),NSEG
      WRITE(6,820) I,JJ(I),JK(I),NSEG
      READ(5,*) E1(I),PX1,PY1,FMASS
      WRITE(6,550) E1(I),PX1,PY1,FMASS
 820  FORMAT(4I5)
      READ(5,*) (THK(J),HT(J),J=1,NSEG)
      WRITE(6,810)(THK(J),HT(J),J=1,NSEG)
      CALL SHXY(NST,NFR,LH,NSP,MOT,NDF,G,LD,A,B,JJ,JK,E1,PX1,PY1,
     1          NSEG,THK,HT,I,FMASS,1,K,NL,NN,sd1)
        IF (nstfr.EQ.2) THEN
                CALL SHXY(NST,NFR,LH,NSP,MOT,NDF,GM,LD,A,B,JJ,JK,
     1                 E1,PX1,PY1,NSEG,THK,HT,I,FMASS,2,K,NL,NN,sd1)
        ENDIF
 30     CONTINUE
      GO TO 20
C ...............
C *** BEAM SPAN DATA ***
 4    IF(NBEAM .EQ. 0) GO TO 20
      READ(5,'(A80)') TITLE
      WRITE(6,'(A80)')TITLE
      WRITE(6,570)
      WRITE(6,590)
      READ(5,*) NSEG
      READ(5,*) (SF1(J),AA1(J),AY1(J),ZI1(J),J=1,NSEG)
      WRITE(6,810)(SF1(J),AA1(J),AY1(J),ZI1(J),J=1,NSEG)
      WRITE(6,592)
      DO 50 N=1,NBEAM
         write (6,*)'  beam no. ',n
      READ(5,*) I,JJ(I),JK(I),NP,NBPT,LSLOPE,NCT
      WRITE(6,830)I,JJ(I),JK(I),NP,NBPT,LSLOPE,NCT
C *** NSH IS  FOR LOCAL WALL-BEAM JUNCTION DEFORMATION ********
      READ(5,*) E2(I),PX2,FMASS,NSH(I)
      IF(NSH(I) .NE. 0) READ(5,*) WBC
      WRITE(6,580) E2(I),PX2,FMASS,NSH(I)
 830  FORMAT(7I5)
      READ(5,*) (NTY(J),J=1,NP)
      WRITE(6,840)(NTY(J),J=1,NP)
 840  FORMAT(20I5)
      IF(LSLOPE .NE. 0) READ(5,*) (XCY(J),Y1(J),Y2(J),J=1,LSLOPE)
      IF(LSLOPE .NE. 0) WRITE(6,850)(XCY(J),Y1(J),Y2(J),J=1,LSLOPE)
 850  FORMAT(I5,8F8.4)
      CALL SHXY(NST,NFR,LH,NSP,MOT,NDF,G,LD,A,B,JJ,JK,E2,PX2,NBPT,
     1     NCT,NP,NTY,SF1,AA1,AY1,ZI1,I,MOT,FMASS,1,K,NL,LSLOPE,Y1,Y2,
     2     XCY,NN,NSH,WBC,sd1)
         if (nstfr.eq.2) then
      CALL SHXY(NST,NFR,LH,NSP,MOT,NDF,Gm,LD,A,B,JJ,JK,E2,PX2,NBPT,
     1     NCT,NP,NTY,SF1,AA1,AY1,ZI1,I,MOT,FMASS,2,K,NL,LSLOPE,Y1,Y2,
     2     XCY,NN,NSH,WBC,sd1)
         endif
 50      continue
      GO TO 20
C ...............
C *** LINK ELEMENT DATA ***
```



```
 6    IF(NCOL .EQ. 0) GO TO 20
      READ(5,'(A80)') TITLE
      WRITE(6,'(A80)')TITLE
      WRITE(6,600)
      READ(5,*) E3,PX3,FMASS,NTPP
      WRITE(6,610) E3,PX3,FMASS,NTPP
      WRITE(6,620)
      READ(5,*) (SF2(J),AA2(J),ZI2(J),J=1,NTPP)
      WRITE(6,810)(SF2(J),AA2(J),ZI2(J),J=1,NTPP)
      DO 70 N=1,NCOL
         write (6,*)'  column no. ',n
      READ(5,*) I,JJ(I),NSEG
      WRITE(6,860)I,JJ(I),NSEG
 860  FORMAT(3I5)
      READ(5,*) (NTY(J),J=1,NSEG)
      WRITE(6,840)(NTY(J),J=1,NSEG)
      READ(5,*) (HT(J),J=1,NSEG)
      WRITE(6,810)(HT(J),J=1,NSEG)
      CALL SLXY(NST,NFR,LH,NSP,MOT,NDF,G,LD,A,JJ,JK,E3,PX3,NSEG,HT,
     1        NTY,SF2,AA2,ZI2,I,FMASS,1,K,NL,NN,sd1)
       if (nstfr.eq.2) then
          CALL SLXY(NST,NFR,LH,NSP,MOT,NDF,Gm,LD,A,JJ,JK,E3,PX3,
     2    NSEG,HT,NTY,SF2,AA2,ZI2,I,FMASS,2,K,NL,NN,sd1)
         endif
 70   CONTINUE
 20   CONTINUE
         III=1
C ...............
      IF(NST .EQ. 1) THEN
C ...............
C *** LOADING DATA ***
      READ(5,'(A80)') TITLE
      WRITE(6,'(A80)')TITLE
      READ(5,*) LCASE
      WRITE(6,630) LCASE
      DO 200 LC=1,LCASE
         NN=NCOL*NDF*MOT
         NL=NBA*MOT
      DO 210 J=1,NN
         DIS(J)=0.0
 210     ALD(J)=0.0
      READ(5,*) NPTL,NCOL
      WRITE(6,640)
      WRITE(6,650) NPTL,NCOL
      IF(NPTL .EQ. 0) GO TO 60
      READ(5,'(A80)') TITLE
      WRITE(6,'(A80)')TITLE
      WRITE(6,660)
      DO 90 I=1,NPTL
      READ(5,*) LE,NPT,NCVM,LTYPE
      WRITE(6,670)LE,NPT,NCVM,LTYPE
      WRITE(6,680)
      DO 92 J=1,NPT
         FLD1(J)=0.0
         FLD2(J)=0.0
 92      FLD3(J)=0.0
      IF(NCVM .EQ. 1) READ(5,*) (FLD1(J),J=1,NPT)
      IF(NCVM .EQ. 2) READ(5,*) (FLD1(1),FLD2(J),J=1,NPT)
      IF(NCVM .EQ. 3) READ(5,*) (FLD1(J),FLD2(J),FLD3(J),J=1,NPT)
      IF(NCVM .EQ. 1) WRITE(6,810)(FLD1(J),J=1,NPT)
      IF(NCVM .EQ. 2) WRITE(6,810)(FLD1(1),FLD2(J),J=1,NPT)
      IF(NCVM .EQ. 3) WRITE(6,810)(FLD1(J),FLD2(J),FLD3(J),J=1,NPT)
      READ(5,*) (XFLD(J),J=1,NPT)
```

```
      WRITE(6,810)(HPLD(J),J=1,NPT)
 90   CALL ALOAD(NSP,DIS,LE,NPT,LTYPE,A,PLD1,PLD2,PLD3,HPLD,NDF,MOT)
 80   IF(NUDL .EQ. 0) GO TO 100
      READ(5,'(A80)') TTITLE
      WRITE(6,'(A80)')TTITLE
      WRITE(6,690)
      DO 110 I=1,NUDL
      READ(5,*) LE,NUVM,NLSEG,LTYPE
      WRITE(6,700)LE,NUVM,NLSEG,LTYPE
      WRITE(6,680)
         NPT=NLSEG
      DO 112 J=1,NPT
         PLD1(J)=0.0
         PLD2(J)=0.0
 112     PLD3(J)=0.0
      IF(NUVM .EQ. 1) READ(5,*) (PLD1(J),J=1,NPT)
      IF(NUVM .EQ. 2) READ(5,*) (PLD1(1),PLD2(J),J=1,NPT)
      IF(NUVM .EQ. 3) READ(5,*) (PLD1(J),PLD2(J),PLD3(J),J=1,NPT)
      IF(NUVM .EQ. 1) WRITE(6,810)(PLD1(J),J=1,NPT)
      IF(NUVM .EQ. 2) WRITE(6,810)(PLD1(1),PLD2(J),J=1,NPT)
      IF(NUVM .EQ. 3) WRITE(6,810)(PLD1(J),PLD2(J),PLD3(J),J=1,NPT)
      READ(5,*) (HPLD(J),J=1,NPT+1)
      WRITE(6,810)(HPLD(J),J=1,NPT+1)
 110  CALL ALOAD(NSP,DIS,LE,NPT,LTYPE,A,PLD1,PLD2,PLD3,HPLD,
     1            NDF,MOT)
 100  CONTINUE
         WRITE (6,75001)(G(I),I=1,25)
75001    FORMAT(5G18.8)
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C        REPLACE OLD SOLVE BY NEW SOLVE
         IRED = 1
         IF (LC.GT.1) IRED = 0
         NRHS = 1
         CALL NEWSLV(G,LD,DIS,NN,NRHS,IRED)
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C ...............
C *** COMPUTING DISPLACEMENT ***
      READ(5,'(A80)') TTITLE
      WRITE(6,'(A80)')TTITLE
      READ(5,*) NDISPL,NCO
      IF(NDISPL .EQ. 0) GO TO 152
      DO 150 I=1,NCO
 150  READ(5,*) NE(I),NTP(I),(HT(J),J=1,NTP(I))
      CALL DISP(LH,NSP,NDF,MOT,DIS,NTP,HT,LC,A,NE,NCO)
C ...............
C *** COMPUTING STRESSES ***
 152  READ(5,'(A80)') TTITLE
      WRITE(6,'(A80)')TTITLE
      READ(5,*) NWALLQ,NCOLQ,NBEAMQ
      DO 200 K=1,KK
      GO TO (160,170,160),K
 160  IF(K .EQ. 1) NWC=NWALLQ
      IF(K .EQ. 3) NWC=NCOLQ
      IF(NWC .EQ. 0) GO TO 200
      IF(K .EQ. 1) WRITE(6,710)
      IF(K .EQ. 3) WRITE(6,730)
      READ(5,'(A80)') TTITLE
      DO 180 N=1,NWC
      IF(K .EQ. 1) THEN
      READ(5,*) I,NP,(THK(J),HT(J),J=1,NP),NPOCT,(NOP(J),J=1,NPOCT)
      CALL DSW(LH,NSP,MOT,NDF,JJ,KK,B,A,THK,E1,PX1,PY1,NP,HT,I,DIS,
     1         NPOCT,NOP)
      ELSE
```



```
      READ(5,*) I,NP,(NTY(J),HT(J),J=1,NP)
      CALL DBL(LH,NSP,MOT,NDF,NTY,JJ,A,E3,PX3,ZI2,AA2,SF2,NP,HT,I,DIS)
      ENDIF
 180  CONTINUE
      GO TO 200
 170  IF(NBEAMQ .EQ. 0) GO TO 200
      IF(K .EQ. 2) WRITE(6,720)
      READ(5,'(A80)') TTITLE
      DO 190 N=1,NBEAMQ
      READ(5,*) I,J1,J2,NP,NBPT,NCT,(NTY(J),J=1,NP)
      CALL DBB(LH,NSP,MOT,NP,NTY,HTT,NBPT,J1,J2,B,A,AA1,AY1,ZI1,SF1,
     1         E2,PX2,I,DIS,NCT,NDF,NSH,WBC)
 190  CONTINUE
 200  CONTINUE
C ...............
      ELSE
      IF(NFR .EQ. 1 ) THEN
      READ(5,'(A80)') TITLE
      WRITE(6,'(A80)')TITLE
      READ(5,*) M,NRQD
      WRITE(6,870) M,NRQD
      ENDIF
         TOLVEC=0.0001
         GES=0.0
         IRENT=0
         IPOCT=6
         NOI=30
         NN=NCOL*NDF*MOT
         NL=NBA*MOT
      IF(NFR.EQ.1) CALL EIGEN(G,GM,LD,NL,NN,M,NRQD,TOLVEC,GES,IRENT,
     1            u,v,w,IPOCT,NOI)
      ENDIF
 500  FORMAT( 'ANALYSIS OF STRUCTURE BY FINITE STRIP METHOD'/44('*'))
 510  FORMAT(/ 'STRUCTURE DATA')
 520  FORMAT(/ 2X,'NST',2X,'NFR',2X,'NRE',3X,'LH',2X,'NSP',2X,'NDF',
     1        2X,'NBA',2X,'MOT',2X,'NCOL',2X,'NSPAN',2X,'NWALL',2X,
     1        'NBEAM',2X,'NCOL')
 530  FORMAT(8I5,I6,3I7,I6)
 532  FORMAT(/ 'HEIGHT/WIDTH :-')
 540  FORMAT(/ 12X,'E1',9X,'PX1',9X,'PY1',7X,'FMASS')
 550  FORMAT(F14.2,3F12.4)
 560  FORMAT(/ 'NOS.,JJ,IK,NSEG/THICKNESS,HEIGHT :-')
 570  FORMAT(/ 12X,'E2',9X,'PX2',7X,'FMASS',9X,'NSEG')
 580  FORMAT(F14.4,2F12.4,I13)
 590  FORMAT(/'SF1,AA1,AY1,ZI1 :-')
 592  FORMAT(/'NOS.,JJ,IK,NO.OF TYPE,NBPT,ISLOPE,NCT/TYPE MEMBER :-')
 600  FORMAT(/ 12X,'E3',9X,'PX3',7X,'FMASS')
 610  FORMAT(F14.4,2F12.4,I10)
 620  FORMAT(/ 'NOS.,JJ,IK,NSEG/SF2,AA2,ZI2/TYPE,HEIGHT :-')
 630  FORMAT(/ 'NOS. OF LOADCASES:',I5)
 640  FORMAT(/ 2X,'NPTL',2X,'NCOL')
 650  FORMAT(2I6)
 660  FORMAT(/ 3X,'LE',3X,'NPT',3X,'NT',3X,'LTYPE')
 670  FORMAT(I5,I6,I5,I8)
 680  FORMAT(/ 'PLD1,PLD2,PLD3,HPLD')
 690  FORMAT(/ 3X,'LE',3X,'NT',3X,'NLSEG',3X,'LTYPE')
 700  FORMAT(2I5,2I8)
 710  FORMAT(/ 'POINT',2X,'NOS.',2X,'MODE'/)
 720  FORMAT(/ 'POINT',2X,'NOS.',2X,'MODE',22X,'DMC1(X,Y,S)',38X,
     1        'DMC2(X,Y,S)'/)
 730  FORMAT(/ 'POINT',2X,'LINE',2X,'MODE',5X,'X-FORCES',5X,
     1        'Y-FORCES',5X,'Z-MOMENT'/)
 870  FORMAT('M:',I5,'  NRQD:',I5)
```

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```
C        TNOW = TIMER(TSET)
C        WRITE (6,99995) TNOW
C        WRITE(50,99995) TNOW
99995    FORMAT(///,T30,'TOTAL CPU TIME :',G12.4,' MILLI. SEC.',//)
      STOP
      END
      FUNCTION TIMER(TBEG)
      CALL MTIME(T)
      TIMER = T-TBEG
      RETURN
      END
      SUBROUTINE SHXY(NST,NFR,LH,NSP,MOT,NDF,G,LD,A,B,JJ,JK,E1,PX1,
     1               PY1,NSEG,THK,HT,N,FMASS,NSTFR,KK,NL,NN,sd1)
C     DIMENSION SD1(80,80)
      DIMENSION SD1(80,80)
      DIMENSION DDB(4,3,3),D(3,3),DD1(6,6),A(1),B(1),
     1          YY(7),BB(7),BT1(6,6),BK(6,6),BR(6,6),HT(1),THK(1),
     2          JJ(1),JK(1),G(1),LD(1),DDL(4,3,3),E1(1)
C     YY(1) DENOTES YM*YN
C     YY(2) DENOTES YM*YNDD
C     YY(3) DENOTES YMD*YND
C     YY(4) DENOTES YMDD*YNDD
C     YY(5) DENOTES YMDD*YN
C     YY(6) DENOTES YMD*YN
C     YY(7) DENOTES YM*YND

        L=2*NDF*MOT
        L1=MOT*NDF
      DO 12 I=1,L
      DO 12 J=1,L
 12     SD1(I,J)=0.0
      DO 10 K=1,4
      DO 10 I=1,NDF
      DO 10 J=1,NDF
 10     DDL(K,I,J)=0.0
      DO 20 I=1,6
      DO 20 J=1,6
        DD1(I,J)=0.0
        BT1(I,J)=0.0
        BK(I,J)=0.0
 20     BR(I,J)=0.0
        A1=A(JJ(N))
        B1=B(N)
        EE=E1(N)
      DO 30 I=1,7
 30     BB(I)=B1**I/(FLOAT(I))
        DE=EE/(1.0-PX1*PY1)
        D(1,1)=DE
        D(1,2)=PX1*DE
        D(2,2)=D(1,1)
        D(3,3)=EE/(2.0+2.0*PX1)
        BT1(1,1)=-1.0/B1
        BT1(5,5)=3.0/B1**2
        BT1(6,6)=1.0/B1**2
        BT1(1,4)=-BT1(1,1)
        BT1(2,1)=1.0
        BT1(3,2)=1.0
        BT1(4,3)=1.0
        BT1(5,2)=-BT1(5,5)
        BT1(5,3)=-2.0/B1
        BT1(5,6)=BT1(1,1)
        BT1(6,2)=2.0/B1**3
        BT1(6,3)=BT1(6,6)
```



```
        BT1(6,5)=-BT1(6,2)
      DO 40 MO=1,MOT
      DO 40 NO=MO,MOT
      DO 14 K=1,4
      DO 14 I=1,NDF
      DO 14 J=1,NDF
 14     DDB(K,I,J)=0.0
      DO 42 M=2,NSEG
        AK=HT(M)
        AL=HT(M-1)
      IF(NSTFR .EQ. 2) GO TO 44
      IF(NSP .EQ. 1) THEN
      CALL SHY1(YY,MO,NO,A1,AL,AK)
        G1=D(1,1)*YY(1)
        G2=D(3,3)*YY(3)
        G3=D(1,2)*YY(5)
        G4=D(3,3)*YY(3)
        G5=D(3,3)*YY(3)
        G6=D(1,2)*YY(2)
        G7=D(3,3)*YY(3)
        G8=D(2,2)*YY(4)
        G9=D(3,3)*YY(3)
      ELSE
      CALL SHY2(YY,MO,NO,A1,AL,AK)
        G1=D(1,1)*YY(1)
        G2=D(3,3)*YY(3)
        G3=D(1,2)*YY(6)
        G4=D(3,3)*YY(7)
        G5=D(3,3)*YY(3)
        G6=D(1,2)*YY(7)
        G7=D(3,3)*YY(6)
        G8=D(2,2)*YY(3)
        G9=D(3,3)*YY(1)
      ENDIF
      IF(LH .EQ. 1) THEN
        D1=1.0/B1
        D2=B1/3.0
        D3=B1/6.0
        DDL(1,1,1)=G1*D1+G2*D2
        DDL(1,2,1)=(G3+G4)*(-0.5)
        DDL(1,1,2)=(G6+G7)*(-0.5)
        DDL(1,2,2)=G8*D2+G9*D1
        DDL(2,1,1)=DDL(1,1,1)
        DDL(2,2,1)=-DDL(1,2,1)
        DDL(2,1,2)=-DDL(1,1,2)
        DDL(2,2,2)=DDL(1,2,2)
        DDL(3,1,1)=-G1*D1+G5*D3
        DDL(3,2,1)=(-G3+G4)*(-0.5)
        DDL(3,1,2)=(G6-G7)*(-0.5)
        DDL(3,2,2)=G8*D3-G9*D1
        DDL(4,1,1)=DDL(3,1,1)
        DDL(4,2,1)=-DDL(3,2,1)
        DDL(4,1,2)=-DDL(3,1,2)
        DDL(4,2,2)=DDL(3,2,2)
      ELSE
        BK(1,1)=B1*G1+BB(3)*G2
        BK(2,2)=B1*G2
        BK(3,3)=B1*G3
        BK(4,4)=BB(3)*G3+B1*G9
        BK(5,5)=BB(5)*G3+4.0*BB(3)*G9
        BK(6,6)=BB(7)*G3+9.0*BB(5)*G9
        BK(1,2)=BB(2)*G2
        BK(3,4)=BB(2)*G3
```

```
      BK(3,5)=BB(3)*G8
      BK(3,6)=BB(4)*G8
      BK(4,5)=BB(4)*G8+B1**2*G9
      BK(4,6)=BB(5)*G8+B1**3*G9
      BK(5,6)=BB(6)*G8+6.0*BB(4)*G9
   DO 60 I=1,6
   DO 60 J=1,6
60    BK(J,I)=BK(I,J)
      BK(1,3)=B1*G6
      BK(1,4)=BB(2)*(G6+G7)
      BK(1,5)=BB(3)*(G6+2.0*G7)
      BK(1,6)=BB(4)*(G6+3.0*G7)
      BK(2,4)=B1*G7
      BK(2,5)=B1*BK(2,4)
      BK(2,6)=B1*BK(2,5)
      BK(3,1)=B1*G3
      BK(4,1)=BB(2)*(G3+G4)
      BK(5,1)=BB(3)*(G3+2.0*G4)
      BK(6,1)=BB(4)*(G3+3.0*G4)
      BK(4,2)=B1*G4
      BK(5,2)=B1*BK(4,2)
      BK(6,2)=B1*BK(5,2)
   ENDIF
   GO TO 46
44 IF(NSP .EQ. 1) CALL SHY1(YY,MO,NO,A1,AL,AK)
   IF(NSP .EQ. 2) CALL SHY2(YY,MO,NO,A1,AL,AK)
   IF(LH .EQ. 1) THEN
      SMM=B1/6.0*FMASS
      SM1=SMM*YY(1)
   IF(NSP .EQ. 1) SM2=SMM*YY(3)
   IF(NSP .EQ. 2) SM2=SMM*YY(1)
   DO 50 I=1,2
      DDL(I,1,1)=2.0*SM1
      DDL(I,2,2)=2.0*SM2
      DDL(I+2,1,1)=SM1
50    DDL(I+2,2,2)=SM2
   ELSE
      SM1=FMASS*YY(1)
   IF(NSP .EQ. 1) SM2=FMASS*YY(3)
   IF(NSP .EQ. 2) SM2=SM1
      BK(1,1)=BB(3)*SM1
      BK(2,2)=B1*SM1
      BK(3,3)=B1*SM2
      BK(4,4)=BB(3)*SM2
      BK(5,5)=BB(5)*SM2
      BK(6,6)=BB(7)*SM2
      BK(2,1)=BB(2)*SM1
      BK(4,3)=BB(2)*SM2
      BK(5,3)=BK(4,4)
      BK(5,4)=BB(4)*SM2
      BK(6,3)=BK(5,4)
      BK(6,4)=BK(5,5)
      BK(6,5)=BB(6)*SM2
   DO 52 I=1,6
   DO 52 J=I,6
52    BK(I,J)=BK(J,I)
   ENDIF
46 IF(LH .EQ. 1) GO TO 48
   CALL [illegible](DD1,BT1,6,6,6,6)
   CALL [illegible](DD1,BK,BB,6,6,6,6,6,6)
   CALL [illegible](BB,BT1,DD1,6,6,6,6,6,6)
   DO 70 I=1,3
   DO 70 J=1,3
```



```
      DDB(1,I,J)=DDB(1,I,J)+DD1(I,J)*THK(M)
      DDB(2,I,J)=DDB(2,I,J)+DD1(I+3,J+3)*THK(M)
      DDB(3,I,J)=DDB(3,I,J)+DD1(I,J+3)*THK(M)
70    DDB(4,I,J)=DDB(4,I,J)+DD1(I+3,J)*THK(M)
   GO TO 42
48 DO 80 K=1,4
   DO 80 I=1,2
   DO 80 J=1,2
80    DDB(K,I,J)=DDB(K,I,J)+DDL(K,I,J)*THK(M)
42 CONTINUE
      L2=(MO-1)*NDF
      L3=(NO-1)*NDF
   DO 43 I=1,NDF
   DO 43 J=1,NDF
      I1=L2+I
      I2=L3+J
      I3=L1+I
      I4=L1+J
      SD1(I1,I2)=SD1(I1,I2)+DDB(1,I,J)
      SD1(L1+I1,L1+I2)=SD1(L1+I1,L1+I2)+DDB(2,I,J)
      SD1(I1,L1+I2)=SD1(I1,L1+I2)+DDB(3,I,J)
      SD1(L1+I1,I2)=SD1(L1+I1,I2)+DDB(4,I,J)
43 CONTINUE
   IF(MO .NE. NO) THEN
   DO 45 I=1,NDF
   DO 45 J=1,NDF
      I1=L2+I
      I2=L3+J
      SD1(I2,I1+L1)=SD1(I1,L1+I2)
   IF(I .EQ. 1 .AND. J .EQ. 2) SD1(I2,I1+L1)=-SD1(I2,I1+L1)
   IF(I .EQ. 2 .AND. J .EQ. 1) SD1(I2,I1+L1)=-SD1(I2,I1+L1)
   IF(I .EQ. 2 .AND. J .EQ. 3) SD1(I2,I1+L1)=-SD1(I2,I1+L1)
   IF(I .EQ. 3 .AND. J .EQ. 2) SD1(I2,I1+L1)=-SD1(I2,I1+L1)
45 CONTINUE
   ENDIF
40 CONTINUE
   CALL ASSEM(G,LD,SD1,JJ,JK,NDF,MOT,KK,N,NL,NN)
   RETURN
   END
   SUBROUTINE SLKY(NST,NFR,LH,NSP,MOT,NDF,G,LD,A,JJ,JK,E3,PX3,NSEG,
  1                KT,NTY,SF2,AA2,ZZ2,N,FMASS,NSTFR,KK,NL,NN,sd1)
   DIMENSION SD1(80,80)
   DIMENSION YY(7),DD1(6,6),A(1),AA2(1),ZZ2(1),NTY(1),KT(1),
  1          DDB(4,3,3),SF2(1),G(1),LD(1),JJ(1),JK(1)
      L=2*NDF*MOT
      L1=NDF*MOT
   DO 2 I=1,L
   DO 2 J=1,L
2     SD1(I,J)=0.0
      A1=A(JJ(N))
      GS=E3/(2.0*(1.0+PX3))
   DO 20 MO=1,MOT
   DO 20 NO=MO,MOT
   DO 10 K=1,4
   DO 10 I=1,NDF
   DO 10 J=1,NDF
10    DDB(K,I,J)=0.0
      K1=(MO-1)*NDF
      K2=(NO-1)*NDF
   DO 22 M=2,NSEG
      K=NTY(M)
      AK=KT(M)
      AL=KT(M-1)
```

```
      IF(NSP .EQ. 1) CALL SHY1(YY,MO,NO,A1,AL,AK)
      IF(NSP .EQ. 2) CALL SHY2(YY,MO,NO,A1,AL,AK)
      DO 34 I=1,NDF
      DO 34 J=1,NDF
 34      DD1(I,J)=0.0
      IF(NSTFR .EQ. 2) GO TO 40
      IF(LH .EQ. 2) THEN
      IF(NSP .EQ. 1) THEN
         DILI=AA2(K)*GS/SF2(K)*YY(3)
         DILA=E3*ZI2(K)*YY(4)
         DILB=E3*AA2(K)*YY(4)
      ELSE
         DILI=AA2(K)*GS/SF2(K)*YY(3)
         DILA=E3*ZI2(K)*YY(4)
         DILB=E3*AA2(K)*YY(3)
      ENDIF
         DD1(1,1)=DILI
         DD1(2,2)=DILB
         DD1(3,3)=DILI+DILA
         DD1(3,1)=-DILI
         DD1(1,3)=DD1(3,1)
      ELSE
      IF(NSP .EQ. 1) THEN
         DD1(1,1)=E3*ZI2(K)*YY(4)
         DD1(2,2)=E3*AA2(K)*YY(4)
      ELSE
         DD1(1,1)=E3*ZI2(K)*YY(4)
         DD1(2,2)=E3*AA2(K)*YY(3)
      ENDIF
      ENDIF
      GO TO 24
 40      ELI=FMASS*AA2(K)*YY(1)
         GLI=FMASS*ZI2(K)*YY(3)
      IF(NSP .EQ. 1) FLI=FMASS*AA2(K)*YY(3)
      IF(NSP .EQ. 2) FLI=FMASS*AA2(K)*YY(1)
         DD1(1,1)=ELI
         DD1(2,2)=FLI
      IF(LH .EQ. 2) DD1(3,3)=GLI
 24   DO 22 I=1,NCF
      DO 22 J=1,NCF
 22      DDB(1,I,J)=DDB(1,I,J)+DD1(I,J)
      DO 23 I=1,NCF
      DO 23 J=1,NCF
         L2=(MO-1)*NCF
         L3=(NO-1)*NCF
         I1=L2+I
         I2=L3+J
         SD1(I1,I2)=SD1(I1,I2)+DDB(1,I,J)
 23   CONTINUE
      CALL ASSEM(G,ED,SD1,JJ,JK,NCF,MOT,KK,N,NC,NN)
      RETURN
      END
      SUBROUTINE SHHY(NST,NSFR,LH,NSP,MOT,NCF,G,ED,A,B,JJ,JK,E2,PX2,
     1                NBPT,HTT,NP,NTY,SF1,AA1,AY1,ZI1,N,NCT,FMASS,
     2                NSTFR,KK,NC,LSLOPE,Y1,Y2,NLY,NN,NSH,WBC,A41)
      DIMENSION SD1(83,83)
      DIMENSION DDB(4,3,3),BK(6,6),DD1(6,6),BR(6,6),BT1(6,6),TT(3),
     1          A(1),B(1),AA1(1),AY1(1),JJ(1),JK(1),G(1),
     2          ZI1(1),NTY(1),SF1(1),E2(1),
     3          Y1(3),Y2(3),R(6,6),T(6,6),HTT(13,1),NLY(1),DDD(6,6),
     4          DDL(4,3,3),ED(12),NSH(1)
         L=2*NCF*MOT
         L1=NCF*NCT
```



```
      DO 12 I=1,L
      DO 12 J=1,L
 12      SD1(I,J)=0.0
      DO 14 I=1,6
      DO 14 J=1,6
         BT1(I,J)=0.0
         BR(I,J)=0.0
 14      DD1(I,J)=0.0
      DO 16 I=1,6
      DO 16 J=1,6
         BK(I,J)=0.0
         R(I,J)=0.0
 16      T(I,J)=0.0
         A1=A(JJ(N))
         DD=0.00
      IF(NSH(N) .EQ. 1) DD=WBC
         B1=B(N)+DD
         EE=E2(N)
         GS=EE/(2.0*(1.0+PX2))
      DO 30 MO=1,MOT
      DO 30 NO=MO,MOT
      DO 20 L=1,4
      DO 20 I=1,NDF
      DO 20 J=1,NDF
         DDL(L,I,J)=0.0
 20      DDB(L,I,J)=0.0
      IF(LSLOPE .NE. 0) KKM=2
      IF(LSLOPE .EQ. 0) KKM=1
      DO 22 KKL=1,KKM
      IF(KKL .EQ. 1) NPLL=NP
      IF(KKL .EQ. 2) NPLL=LSLOPE+1
      DO 22 M=2,NPLL
      IF(KKL .EQ. 1) K=NTY(M)
      IF(KKL .EQ. 2) K=NLY(M-1)
         Y=HTT(NBPT,M)
         PYY=12.0*EE*ZI1(K)*SF1(K)/(GS*AY1(K)*B1**2)
      IF(NSTFR .EQ. 2) GO TO 32
         YK1=B1**3*(1.0+PYY)
         YK2=2.0-PYY
         YK3=4.0+PYY
         BK(1,1)=EE*AA1(K)/B1
         BK(2,2)=12.0*EE*ZI1(K)/YK1
         BK(3,2)=6.0*EE*ZI1(K)*B1/YK1
         BK(3,3)=YK3*EE*ZI1(K)*B1**2/YK1
         BK(4,4)=BK(1,1)
         BK(5,5)=BK(2,2)
         BK(6,6)=BK(3,3)
         BK(4,1)=-BK(1,1)
         BK(5,2)=-BK(2,2)
         BK(5,3)=-BK(3,2)
         BK(6,2)=BK(3,2)
         BK(6,3)=YK2*EE*ZI1(K)*B1**2/YK1
         BK(6,5)=-BK(6,2)
      GO TO 34
 32      P1=PYY
         P2=PYY**2
         AM=FMASS*AA1(K)*B1
         AM1=1.0/3.0*AM
         AM2=AM/(1.0+PYY)**2
         R2=ZI1(K)/AY1(K)
         AM3=AM2/B1**2*R2
         BK(1,1)=AM1
         BK(2,2)=(13.0/35.0+7.0/10.0*P1+1.0/3.0*P2)*AM2+6.0/5.0*AM3
```

```
      BK(3,2)=((11.0/210.0+11.0/120.0*P1+1.0/240.0*P2)*B1)*AM2
    1         +((1.0/10.0-1.0/2.0*P1)*B1)*AM3
      BK(3,3)=((1.0/105.0+1.0/60.0*P1+1.0/120.0*P2)*B1**2)*AM2
    1         +((2.0/15.0+1.0/6.0*P1+1.0/3.0*P2)*B1**2)*AM3
      BK(4,1)=AM1*0.5
      BK(4,4)=BK(1,1)
      BK(5,2)=(9.0/70.0+3.0/10.0*P1+1.0/6.0*P2)*AM2-6.0/5.0*AM3
      BK(5,3)=((13.0/420.0+3.0/40.0*P1+1.0/24.0*P2)*B1)*AM2
    1         +((-1.0/10.0+1.0/2.0*P1)*B1)*AM3
      BK(5,5)=(13.0/35.0+7.0/10.0*P1+1.0/3.0*P2)*AM2+6.0/5.0*AM3
      BK(6,2)=-((13.0/420.0+3.0/40.0*P1+1.0/24.0*P2)*B1)*AM2
    1         +((1.0/10.0-1.0/2.0*P1)*B1)*AM3
      BK(6,3)=-((1.0/140.0+1.0/60.0*P1+1.0/120.0*P2)*B1**2)*AM2
    1         +((-1.0/30.0-1.0/6.0*P1+1.0/6.0*P2)*B1**2)*AM3
      BK(6,5)=-((11.0/210.0+11.0/120.0*P1+1.0/24.0*P2)*B1)*AM2
    1         +((-1.0/10.0+1.0/2.0*P1)*B1)*AM3
      BK(6,6)=((1.0/105.0+1.0/60.0*P1+1.0/120.0*P2)*B1**2)*AM2
    1         +((2.0/15.0+1.0/6.0*P1+1.0/3.0*P2)*B1**2)*AM3
 34   DO 40 I=1,6
      DO 40 J=I,6
 40     BK(I,J)=BK(J,I)
      IF(KKL .EQ. 2) THEN
        H1=Y1(M-1)
        H2=Y2(M-1)
        Y=Y1(M-1)
      CALL TRANF(R,B,H1,H2,N)
      CALL TMP(T,R,6,6,6,6)
      CALL TMPT(BK,T,DD1,6,6,6,6,6,6)
      CALL TMPT(T,DD1,BK,6,6,6,6,6,6)
      ELSE
      GO TO 38
      ENDIF
 38   DO 50 K=1,2
      IF(K .EQ. 1) MN=MO
      IF(K .EQ. 2) MN=NO
      IF(NSP .EQ. 1) THEN
      CALL SHAPEA(Y,YM,MN,A1)
         CM=YM(1)
         VM=YM(2)
         CD=YM(2)
      ELSE
      CALL SHAPEB(Y,YM,MN,A1)
         CM=YM(1)
         VM=YM(1)
         CD=YM(2)
      ENDIF
      IF(LK .EQ. 1) THEN
         BT1(1,1)=CM
         BT1(2,2)=VM
         BT1(3,1)=-CD
         BT1(4,3)=CM
         BT1(5,4)=VM
         BT1(6,3)=-CD
      ELSE
         J=0
      DO 63 I=1,2
         BT1(1+J,1+J)=CM
         BT1(2+J,2+J)=VM
 63        J=NDF
      GO TO (2,4,6,8),NCT
 2       BT1(3,3)=-CD
         BT1(6,6)=-CD
      GO TO 100
```



```
 4       BT1(3,1)=-UD
         BT1(6,4)=-UD
      GO TO 100
 6       BT1(3,3)=-UD
         BT1(6,4)=-UD
      GO TO 100
 8       BT1(3,1)=-UD
         BT1(6,6)=-UD
      ENDIF
 100     LL=2*NDF
      IF(K .EQ. 1) THEN
      CALL TMP(DD1,BT1,6,LL,6,6)
      CALL TMPT(DD1,BK,BR,LL,6,6,6,6,6)
      ELSE
      CALL TMPT(BR,BT1,DD2,LL,6,LL,6,6,6)
      ENDIF
 50   CONTINUE
      DO 22 I=1,NDF
      DO 22 J=1,NDF
         DDB(1,I,J)=DDB(1,I,J)+DD2(I,J)
         DDB(2,I,J)=DDB(2,I,J)+DD2(I+NDF,J+NDF)
         DDB(3,I,J)=DDB(3,I,J)+DD2(I,J+NDF)
 22      DDB(4,I,J)=DDB(4,I,J)+DD2(I+NDF,J)
         L2=(MO-1)*NDF
         L3=(NO-1)*NDF
      DO 33 I=1,NDF
      DO 33 J=1,NDF
         I1=L2+I
         I2=L3+J
         I3=L1+I
         I4=L1+J
         SD1(I1,I2)=SD1(I1,I2)+DDB(1,I,J)
         SD1(L1+I1,L1+I2)=SD1(L1+I1,L1+I2)+DDB(2,I,J)
         SD1(I1,L1+I2)=SD1(I1,L1+I2)+DDB(3,I,J)
         SD1(L1+I1,I2)=SD1(L1+I1,I2)+DDB(4,I,J)
 33   CONTINUE
      IF(MO .NE. NO) THEN
      DO 45 I=1,NDF
      DO 45 J=1,NDF
        I1=L2+I
        I2=L3+J
        SD1(I2,I1+L1)=SD1(I1,L1+I2)
      IF(I .EQ. 1 .AND. J .EQ. 2) SD1(I2,I1+L1)=-SD1(I2,I1+L1)
      IF(I .EQ. 2 .AND. J .EQ. 1) SD1(I2,I1+L1)=-SD1(I2,I1+L1)
      IF(I .EQ. 2 .AND. J .EQ. 3) SD1(I2,I1+L1)=-SD1(I2,I1+L1)
      IF(I .EQ. 3 .AND. J .EQ. 2) SD1(I2,I1+L1)=-SD1(I2,I1+L1)
 45   CONTINUE
      ENDIF
 30   CONTINUE
      CALL ASSEM(G,ID,SD1,JJ,JK,NCF,NCT,KK,N,NC,NN)
      RETURN
      END
      SUBROUTINE ASSEM(G,ID,SD1,JJ,JK,NCF,NCT,KK,N,NB,NN)
      DIMENSION  SD1(80,80)
      DIMENSION  G(1),JJ(1),JK(1),ID(1)
C     REARRANGEMENT OF MEMBER STIFFNESS MATRIX
        ND=NCF*NCT
        NRJ=(JJ(N)-1)*ND
        NRK=(JK(N)-1)*ND
      DO 10 L=1,ND
        IP=NRJ+L
      DO 12 K=1,ND
        IQ=NRJ+K
```

```
         IF (IC.LT.IR) GO TO 12
         JDIA = LD(IC)
         IPOS  = JDIA-IC+IR
         SKIRIC = G(IPOS)
         G(IPOS) = SKIRIC + SD1(L,K)
         WRITE (69,75001)L,K,IR,IC,JDIA,IPOS,G(IPOS)
75001    FORMAT(/,'LOOP12  L,K,IR,IC,JDIA,IPOS=',4I5,2I8,G15.8)
 12   CONTINUE
      IF(KK .EQ. 3) GO TO 10
      DO 30 K =1,ND
         IC=NNK+K
         IF (IC.LT.IR) GO TO 30
         JDIA = LD(IC)
         IPOS  = JDIA-IC+IR
         SKIRIC = G(IPOS)
         G(IPOS) = SKIRIC + SD1(L,K+ND)
         WRITE (69,75002)L,K+ND,IR,IC,JDIA,IPOS ,G(IPOS)
75002    FORMAT(/,'LOOP30  L,K,IR,IC,JDIA,IPOS=',4I5,2I8,G15.8)
 30   CONTINUE
      IF(IC .GT. NB) NB=IC
 10   CONTINUE
      IF(KK .EQ. 3) GO TO 50
      DO 40 L=1,ND
      DO 40 K=1,ND
         IR=NNK+L
         IC=NNK+K
         IF (IC.LT.IR) GO TO 40
         JDIA = LD(IC)
         IPOS  = JDIA-IC+IR
         SKIRIC = G(IPOS)
         G(IPOS) = SKIRIC + SD1(ND+L,ND+K)
         WRITE (69,75003)ND+L,ND+K,IR,IC,JDIA,IPOS,G(IPOS)
75003    FORMAT(/,'LOOP40  L,K,IR,IC,JDIA,IPOS=',4I5,2I8,G15.8)
 40   CONTINUE
 50   RETURN
      END
      SUBROUTINE ALOAD(NSP,ALD,LE,NPT,LTYPE,A,PLD1,PLD2,PLD3,
     1              EPLD,NDF,MOT)
      DIMENSION ALD(1),PLD1(1),PLD2(1),PLD3(1),EPLD(1),YM(3),
     1              A(1),YT(2,2),T(8,2),APF(3),Z(2)
         A1=A(LE)
      DO 10 MO=1,MOT
      DO 2 I=1,3
 2       APF(I)=0.0
         K1=(LE-1)*NDF*MOT+(MO-1)*NDF
      IF(LTYPE .EQ. 1) THEN
      DO 12 I=1,NPT
         Y=EPLD(I)
      IF(NSP .EQ. 1) CALL SHAPEA(Y,YM,MO,A1)
      IF(NSP .EQ. 2) CALL SHAPEB(Y,YM,MO,A1)
         APF(1)=APF(1)+YM(1)*PLD1(I)
      IF(NSP .EQ. 1) APF(2)=APF(2)+YM(2)*PLD2(I)
      IF(NSP .EQ. 2) APF(2)=APF(2)+YM(1)*PLD2(I)
         APF(3)=APF(3)+YM(2)*PLD3(I)
 12   CONTINUE
      ELSE
      DO 14 I=1,NPT
         ROOT3=SQRT(3.0)
         XA=EPLD(I+1)
         XB=EPLD(I)
         H=(XA-XB)/FLOAT(10)
         P=H/(2.0*ROOT3)
      DO 20 J=1,10
```



```
         Z(1)=XB+(FLOAT(J)-0.5)*H-P
         Z(2)=Z(1)+P*2.0
      DO 30 K=1,2
         Y=Z(K)
      IF(NSP .EQ. 1) CALL SHAPEA(Y,YM,MO,A1)
      IF(NSP .EQ. 2) CALL SHAPEB(Y,YM,MO,A1)
         YT(K,1)=YM(1)
 30      YT(K,2)=YM(2)
         T(MO,1)=T(MO,1)+YT(1,1)+YT(2,1)
      IF(NSP .EQ. 1) T(MO,2)=T(MO,2)+YT(1,2)+YT(2,2)
 20   IF(NSP .EQ. 2) T(MO,2)=T(MO,2)+YT(1,1)+YT(2,1)
      DO 40 L=1,2
 40      T(MO,L)=T(MO,L)*H/2.0
         APF(1)=APF(1)+T(MO,1)*PLD1(I)
         APF(2)=APF(2)+T(MO,2)*PLD2(I)
         APF(3)=APF(3)+T(MO,2)*PLD3(I)
 14   CONTINUE
      ENDIF
      DO 10 J=1,NDF
 10      ALD(K1+J)=ALD(K1+J)+APF(J)
C1100 FORMAT(6F8.2)
      RETURN
      END
      SUBROUTINE DISP(LH,NSP,NDF,MOT,DIS,NYP,HT,LC,A,NE,NOD)
      DIMENSION  DS(3),YM(3),DIS(1),NYP(1),HT(1),A(1),NE(1)
C     COMPUTE DISPLACEMENT AT SPECIFIED POINTS
      WRITE(6,10)
      WRITE(6,20) LC
      WRITE(6,30)
      DO 66 NL=1,NOD
         A1=A(NE(NL))
      WRITE(6,60) NE(NL)
 60   FORMAT(/ 'NODAL LINE:' ,I2/ 12('.'))
      WRITE(6,70)
      DO 66 M=1,NYP(NL)
      WRITE(6,80)
 80   FORMAT(/)
      DO 90 J=1,NDF
 90      DS(J)=0.0
         NY=1
      DO 50 MO=1,MOT
         K=NDF*(MO-1)+NDF*(NE(NL)-1)*MOT
         Y=HT(M)
      IF(NSP .EQ. 1) CALL SHAPEA (Y,YM,MO,A1)
      IF(NSP .EQ. 2) CALL SHAPEB (Y,YM,MO,A1)
C     EVALUATE DISPLACEMENT FOR IN-PLANE
         DS(1)=DS(1)+DIS(K+1)*YM(1)
      IF(LH .EQ. 2)  DS(3)=DS(3)+DIS(K+3)*YM(2)
      IF(NSP .EQ. 1) DS(2)=DS(2)+DIS(K+2)*YM(2)
      IF(NSP .EQ. 2) DS(2)=DS(2)+DIS(K+2)*YM(1)
      WRITE(6,100) Y,MO,(DS(J),J=1,NDF)
 50   CONTINUE
 66   CONTINUE
 10   FORMAT(////45X,'COMPUTED OUTPUT RESULTS:'/45X,23('*'))
 20   FORMAT(/   'LOAD CASES:',I5)
 30   FORMAT( //   'DISPLACEMENT AND ROTATION :' /   25('*'))
 70   FORMAT( / 7X,'POINTS',3X,'SERIES', 5X,'X-AXIS',5X,'Y-AXIS',5X,
     1   'Z-ROTN')
100   FORMAT(F13.2,I9 ,3F11.6)
      RETURN
      END
      SUBROUTINE DSM(LH,NSP,MOT,NDF,II,JK,B,A,THK,E1,PX1,PY1,NP,NT,
     1                 N,DIS,NPOUT,NDP)
```

```
C     IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION  D(3,3),DB1(6,6),JJ(1),JK(1),THK(1),A(1),XDP(10),
     1           YM(3),HT(1),PS(6,1),FS(6,1),FSNW(6,10),B(1),DIS(1),
     1           E1(1)
         EE=E1(N)
      DO 2 I=1,3
      DO 2 J=1,2*NDF
 2       DB1(I,J)=0.0
         DE=EE/(1.0-PX1*PY1)
         D(1,1)=DE
         D(1,2)=PX1*DE
         D(2,1)=D(1,2)
         D(2,2)=DE
         D(3,3)=EE/(2.0+2.0*PX1)
         A1=A(JJ(N))
         BL=B(N)
      DO 14 M=1,NP
      WRITE(6,300)
 300  FORMAT(/)
      DO 12 I=1,10
      DO 12 J=1,3
 12      FSNW(J,I)=0.0
         NM=1
      DO 10 N1=1,MOT
      DO 10 MO=NM,N1
         L1=NDF*(MO-1)
         NNJ=(JJ(N)-1)*NDF*MOT+L1
         NNK=(JK(N)-1)*NDF*MOT+L1
         Y=HT(M)
C     CALL SHAPEA(Y,YM,MO,A1)
      IF(NSP .EQ. 1) CALL SHAPEA(Y,YM,MO,A1)
      IF(NSP .EQ. 2) CALL SHAPEB(Y,YM,MO,A1)
      IF(NSP .EQ. 1) THEN
         D1=D(1,1)*YM(1)
         D2=D(1,2)*YM(3)
         D3=D(2,1)*YM(1)
         D4=D(2,2)*YM(3)
         D5=D(3,3)*YM(2)
      ELSE
         D1=D(1,1)*YM(1)
         D2=D(1,2)*YM(2)
         D3=D(2,1)*YM(1)
         D4=D(2,2)*YM(2)
         D5=D(3,3)*YM(2)
      ENDIF
      DO 23 L=1,NDF
 23      PS(L,1)=DIS(NNJ+L)
      DO 22 L=1,NDF
 22      PS(NDF+L,1)=DIS(NNK+L)
      DO 40 K=1,NPOUT
         X=XDP(K)
      IF(LM .EQ. 1) THEN
         X1D=-1.0/BL
         X11=(1.0-X/BL)
         X12=X/BL
         DB1(1,1)=X1D*D1
         DB1(1,2)=X11*D2
         DB1(1,3)=-X1D*D1
         DB1(1,4)=X12*D2
         DB1(2,1)=X1D*D3
         DB1(2,2)=X11*D4
         DB1(2,3)=-X1D*D3
         DB1(2,4)=X12*D4
```



```
         DB1(3,1)=X11*D5
         DB1(3,2)=X1D*D5
         DB1(3,3)=X12*D5
         DB1(3,4)=-X1D*D5
      ELSE
         B1=-1.0/BL
         B2=1.0-X/BL
         B3=1.0-3.0*X**2/BL**2+2.0*X**3/BL**3
         B4=-6.0*X/BL**2+6.0*X**2/BL**3
         B5=X-2.0*X**2/BL+X**3/BL**2
         B6=1.0-4.0*X/BL+3.0*X**2/BL**2
         B7=1.0/BL
         B8=X/BL
         B9=3.0*X**2/BL**2-2.0*X**3/BL**3
         B10=6.0*X/BL**2-6.0*X**2/BL**3
         B11=X**3/BL**2-X**2/BL
         B12=3.0*X**2/BL**2-2.0*X/BL
         DB1(1,1)=B1*D1
         DB1(1,2)=B3*D2
         DB1(1,3)=B5*D2
         DB1(1,4)=B7*D1
         DB1(1,5)=B9*D2
         DB1(1,6)=B11*D2
         DB1(2,1)=B1*D3
         DB1(2,2)=B3*D4
         DB1(2,3)=B5*D4
         DB1(2,4)=B7*D3
         DB1(2,5)=B9*D4
         DB1(2,6)=B11*D4
         DB1(3,1)=B2*D5
         DB1(3,2)=B4*D5
         DB1(3,3)=B6*D5
         DB1(3,4)=B8*D5
         DB1(3,5)=B10*D5
         DB1(3,6)=B12*D5
      ENDIF
         LL=2*NDF
      CALL TMPT(DB1,PS,FS,3,LL,1,6,6 ,1)
      DO 40 J=1,3
 40      FSNW(J,K)=FSNW(J,K)+FS(J,1)
 10      NM=MO+1
      WRITE(6,100) Y,N,MOT
      WRITE(6,*) 'OUTPUT POINTS, X AND Y STRESSES, SHEAR STRESS'
      DO 112 K=1,NPOUT
 112  WRITE(6,120) XDP(K),(FSNW(J,K),J=1,3)
 100  FORMAT(F10.4,2I5)
 120  FORMAT(F10.4,3F20.6)
 14   CONTINUE
      RETURN
      END
      SUBROUTINE DSL(LM,NSP,MOT,NDF,NTY,JJ,A,E3,PX3,ZZ2,AA2,SF2,NP,HT,
     1              N,DIS)
      DIMENSION DB1(6,6),YM(3),NTY(1),JJ(1),ZZ2(1),PS(6,1),A(1),
     1          AA2(1),HT(1),FSN(6,2),FS(6,1),DIS(1),SF2(1)
      DO 10 I=1,NDF
      DO 10 J=1,NDF
 10      DB1(I,J)=0.0
         A1=A(JJ(N))
         GS=E3/(2.0*(1.0+PX3))
      DO 20 M=1,NP
         Y=HT(M)
      WRITE(6,300)
 300  FORMAT(/)
```

```
      DO 22 J=1,NDF
22       FSN(J,1)=0.0
         NM=1
      DO 20 N1=1,MOT
      DO 20 MO=NM,N1
         L=NDF*(MO-1)
         NNJ=(JJ(N)-1)*NDF*MOT+L
      DO 30 J=1,NDF
30       PS(J,1)=DIS(NNJ+J)
         K=NTY(M)
         D1=AA2(K)*GS/SF2(K)
         D2=E3*AA2(K)
         D3=E3*ZI2(K)
      IF(NSP .EQ. 1) CALL SHAPEA(Y,YM,MO,A1)
      IF(NSP .EQ. 2) CALL SHAPEB(Y,YM,MO,A1)
      IF(NSP .EQ. 1) DB1(2,2)=D2*YM(3)
      IF(NSP .EQ. 2) DB1(2,2)=D2*YM(2)
      IF(LH .EQ. 1) THEN
         DB1(1,1)=D1*YM(3)
      ELSE
         DB1(1,1)=D1*YM(2)
         DB1(3,3)=D3*YM(3)
         DB1(1,3)=-D1*YM(2)
      ENDIF
         LL=NDF
      CALL TMPT(DB1,PS,FS,LL,LL,1,6,6,1)
      DO 40 J=1,NDF
40       FSN(J,1)=FSN(J,1)+FS(J,1)
      WRITE(6,100) Y,JJ(N),MO,(FSN(J,1),J=1,NDF)
20       NM=MO+1
100   FORMAT(F10.4,2I5,3F18.4)
      RETURN
      END
      SUBROUTINE DBB(LH,NSP,MOT,NP,NTY,HTT,NBPT,J1,J2,B,A,AA1,AY1,
     1              ZI1,SF1,E2,PX2,N,DIS,NCT,NDF,NSH,WBC)
      DIMENSION BK(6,6),DD1(6,6),BT1(6,6),YM(3),SF1(1),
     1          A(1),B(1),AA1(1),AY1(1),ZI1(1),DIS(1),
     2          NTY(1),PB(6,1),FB(6,1),FSN(6,2),HTT(10,1),E2(1),
     3          NSH(1)
      DO 10 I=1,6
      DO 10 J=1,6
         BT1(I,J)=0.0
10       DD1(I,J)=0.0
      DO 12 I=1,6
      DO 12 J=1,2*NCF
12       BT1(I,J)=0.0
         A1=A(J1)
         DD=0.0
      IF(NSH(N) .EQ. 1) DD=WBC
         B1=B(N)+DD
         EE=E2(N)
         GS=EE/(2.0*(1.0+PX2))
      DO 28 M=2,NP
      WRITE(6,300)
300   FORMAT(/)
         Y=HTT(NBPT,M)
         K=NTY(M)
      DO 32 J=1,6
32       FSN(J,1)=0.0
         NM=1
      DO 30 N1=1,MOT
      DO 30 MO=NM,N1
         PYY=12.0*EE*ZI1(K)*SF1(K)/(GS*AY1(K)*B1**2)
```



```
         PP=1.0/(1.0+PYY)
         BK(1,1)=EE*AA1(K)/B1
         BK(2,2)=12.0*EE*ZI1(K)/B1**3*PP
         BK(3,2)=6.0*EE*ZI1(K)/B1**2*PP
         BK(3,3)=EE*ZI1(K)/B1*(3.0*PP+1.0)
         BK(4,4)=BK(1,1)
         BK(5,5)=BK(2,2)
         BK(6,6)=BK(3,3)
         BK(4,1)=-BK(1,1)
         BK(5,2)=-BK(2,2)
         BK(5,3)=-BK(3,2)
         BK(6,2)=BK(3,2)
         BK(6,3)=EE*ZI1(K)/B1*(3.0*PP-1.0)
         BK(6,5)=-BK(6,2)
      DO 40 I=1,6
      DO 40 J=I,6
40       BK(I,J)=BK(J,I)
      IF(NSP .EQ. 1) THEN
      CALL SHAPEA(Y,YM,MO,A1)
         UM=YM(1)
         VM=YM(2)
         UD=YM(2)
      ELSE
      CALL SHAPEB(Y,YM,MO,A1)
         UM=YM(1)
         VM=YM(1)
         UD=YM(2)
      ENDIF
      IF(LH .EQ. 1) THEN
         BT1(1,1)=UM
         BT1(2,2)=VM
         BT1(3,1)=-UD
         BT1(4,3)=UM
         BT1(5,4)=VM
         BT1(6,3)=-UD
      ELSE
         J=0
      DO 60 I=1,2
         BT1(1+J,1+J)=UM
         BT1(2+J,2+J)=VM
60          J=NCF
      GO TO (2,4,6,8),NCT
2        BT1(3,3)=-UD
         BT1(6,6)=-UD
      GO TO 100
4        BT1(3,1)=-UD
         BT1(6,4)=-UD
      GO TO 100
6        BT1(3,3)=-UD
         BT1(6,4)=-UD
      GO TO 100
8        BT1(3,1)=-UD
         BT1(6,6)=-UD
      ENDIF
100      LL=2*NCF
      CALL TMPT(BK,BT1,DD1,6,6,LL,6,6,6)
         L=NCF*(MO-1)
         NNJ=(J1-1)*NCF*MOT+L
         NNK=(J2-1)*NCF*MOT+L
      DO 110 J=1,NCF
         PB(J,1)=DIS(NNJ+J)
110      PB(J+NCF,1)=DIS(NNK+J)
      CALL TMPT(DD1,PB,FB,6,LL,1,6,6,1)
```

```
      DO 34 J=1,6
 34      FSN(J,1)=FSN(J,1)+FB(J,1)
      WRITE(6,200) Y,N,MO,(FSN(J,1),J=1,6)
 30      NM=MO+1
 28      CONTINUE
 200  FORMAT(F10.4,2I5,6F17.4)
      RETURN
      END
      SUBROUTINE EIGEN(G,GM,LD,NL,N,M,NRQD,TOLVEC,GES,IRENT,
     1                u,v,w,IPOUT,NOI)
      DIMENSION G(1),LD(1),GM(1)
      REAL U(300,1),V(300,1),W(300,1),BD(20),ERR(20)
         NA=LD(N)
         NK=NA
         WRITE (6,6701)(LD(I),I=1,N)
 6701    FORMAT('   ARRAY  LD :',/,(10I5))
         WRITE (50,5001) NA,NK,LD(N)
         WRITE (6,5001) NA,NK,LD(N)
 5001    FORMAT('   NA, NK,  LD(N) =',3I10)
         WRITE (69,69100) (G(I),I=1,NA)
 69100   FORMAT(/,'     STIF. MATRIX ',/,(6E15.6))
         WRITE (69,69105) (GM(I),I=1,NA)
 69105   FORMAT(/,'     MASS. MATRIX ',/,(6E15.6))
      CALL SIVIB2(GM,LD,G,LD,BD,ERR,U,V,W,NA,NK,N,M,NRQD,NOI,TOLVEC,
     1            IRENT,GES,IPOUT)
      RETURN
      END
      SUBROUTINE SIVIB2(G,GD,L,LD,BD,ERR,U,V,W,NA,NK,N,M,NRQD,NOI,
     1                  TOLVEC,IRENT,GES,IPOUT)
      REAL L(1),G(1),U(300,1),V(300,1),W(300,1),BD(1),ERR(1),CD(50)
      INTEGER LD(1),GD(1)
      CALL REDUCE(L,LD,NK,N,IPOUT)
      IF(N.LT.0)GOTO 121
         LET=0
         LOCK=1
         INT=1
      IF(IRENT.EQ.2)CALL PREMLT(W,U,L,LD,NK,M,N,1,IRENT)
      CALL RANDOM(U,N,M,IRENT,GES)
      CALL CRTHOG(U,N,M,1)
 50   CALL BACSUB(U,V,L,LD,NK,N,M,LOCK)
      CALL PREMLT(V,W,G,GD,NA,N,M,LOCK,0)
      CALL FORSUB(W,V,L,LD,NK,N,M,LOCK)
      CALL DECPLE(U,V,W,BD,N,M,LOCK,TOLVEC)
      CALL RANDOM(V,N,M,IRENT,GES)
      CALL CRTHOG(V,N,M,LOCK)
      CALL ERROR(U,V,BD,ERR,N,M,NRQD,LOCK,TOLVEC,LET)

C ___ MONITOR PRINT INSTRUCTIONS

      WRITE(IPOUT,21)INT
 21   FORMAT(/,1X,'AFTER ',I4,' ITERATIONS')
      DO 28 J=1,M
 28      CD(J)=SQRT(1.0/(BD(J)))/(2.0*3.1416)
      WRITE(IPOUT,22)(CD(I),I=1,M-1)
 27   FORMAT(1X,'VECTOR ERRS:',6F15.6)
      WRITE(IPOUT,27)(ERR(I),I=1,M-1)
 22   FORMAT(1X,'EIGENVALUES:',6F15.6)
      DO 23 I=1,N
      DO 23 J=LOCK,M
 23      U(I,J)=W(I,J)
      IF(LET.EQ.1)GOTO 19
      IF(NOI LT.INT)GOTO 11
         INT=INT+1
```



```
      GOTO 50
C ___ MONITOR PRINT INSTRUCTIONS
 10   WRITE(IPOUT,100)
 100  FORMAT(/,1X,'CONVERGENCE OBTAINED ')
      GOTO 120
 11   WRITE(IPOUT,101)
 101  FORMAT(/,1X,'CONVERGENCE NOT OBTAINED')
 120  CALL BACSUB(U,W,L,LD,NK,N,M,1)
      DO 121 J=1,M
         EL=0.0
      DO 122 I=1,N
 122  IF(ABS(W(I,J)).GT.EL)EL=ABS(W(I,J))
         EL=1.0/EL
      DO 123 I=1,N
 123     W(I,J)=W(I,J)*EL
 121  CONTINUE
         WRITE (IPOUT,991)(I,I=1,M-1)
 991     FORMAT (/,T10,'EIGEN VECTORS',/,
     1   4X,8I15)
         DO 990 I = 1, N
 990  WRITE(IPOUT,26) (U(I,J),J=1,M-1)
 26   FORMAT(11X,8F15.6)
      RETURN
      END
      SUBROUTINE REDUCE(L,LD,NK,N,IPOUT)
      REAL L(1)
      INTEGER LD(1),Q
         XCM=1.0
         L(1)=SQRT(L(1))
      DO 132 I=2,N
         Q=LD(I)-I
         M1=1+LD(I-1)-Q
      DO 200 J=M1,I
         NN=0
         EL=L(J+Q)
      IF(J .EQ. 1) GO TO 2
         KK=LD(J)-J
         NN=1+LD(J-1)-KK
         NN=MAX0(NN,M1)
      IF(NN .EQ. J) GO TO 2
      DO 3 K=NN,J-1
 3       EL=EL-L(Q+K)*L(KK+K)
 2       L(J+Q)=EL/L(LD(J))
 200  CONTINUE
      IF(EL) 5,5,50
 50      XC=1.0/L(I+Q)
      IF(XC .GT. XCM) GO TO 130
         XCM=XC
         JCM=I
 130     L(LD(I))=SQRT(EL)
 132  CONTINUE
C *** MONITOR PRINTING
         ICM=INT(ALOG10(XCM))+1
      WRITE(IPOUT,10) ICM,JCM
 10   FORMAT(/ 20X,'ACCURACY LOSS',I4,' DECIMAL AT PIVOT ',I4)
      GO TO 6
 5    WRITE(IPOUT,11) I
 11   FORMAT(/ 20X,'REDUCTION FAILURE PIVOT',I4,'  NOT POSITIVE')
         N=-N
 6    RETURN
      END
      SUBROUTINE RANDOM(U,N,M,IRENT,GES)
      REAL U(300,1)
```

```
      K=1
      IF(IRENT.NE.0)K=M
         IRENT=1
      DO 1 I=1,N
      DO 1 J=K,M
      IF(GES.EQ.0.0)GES=0.31415926
         Y=GES*GES
2        Y=Y*10.0
      IF(Y.LT.1.0)GOTO 2
         Y=Y-NINT(Y)
         U(I,J)=Y
1        GES=Y
      RETURN
      END
      SUBROUTINE ORTHOG(W,N,M,LOCK)
      REAL W(300,1)
      DO 1 I=LOCK,M
      DO 1 J=1,I
         EL=0.0
      DO 4 K=1,N
4        EL=EL+W(K,J)*W(K,I)
      IF(I.EQ.J)GOTO 5
      DO 6 K=1,N
6        W(K,I)=W(K,I)-EL*W(K,J)
      GOTO 1
5        D=1.0/SQRT(EL)
      DO 3 K=1,N
         W(K,I)=D*W(K,I)
3     CONTINUE
1     CONTINUE
      RETURN
      END
      SUBROUTINE DECPLE(U,V,W,BD,N,M,LOCK,TOLVEC)
      REAL U(300,1),V(300,1),W(300,1),BD(1)
C     THIS SECTION CALCULATE THE EIGENVALUES
      DO 1 J=LOCK,M
         EL=0.0
      DO 2 I=1,N
2        EL=EL+U(I,J)*V(I,J)
1        BD(J)=EL
      DO 3 J=LOCK+1,M
         I=J
4        K=I-1
      IF(ABS(BD(K)).GT.ABS(BD(I)))GOTO 3
         EL=BD(I)
         BD(I)=BD(K)
         BD(K)=EL
      DO 5 II=1,N
         EL=U(II,I)
         EL1=V(II,I)
         U(II,I)=U(II,K)
         U(II,K)=EL
         V(II,I)=V(II,K)
         V(II,K)=EL1
5     CONTINUE
         I=I-1
      IF((I-1).GT.LOCK)GOTO 4
3     CONTINUE
      DO 6 I=1,N
      DO 6 J=LOCK,M
6        W(I,J)=V(I,J)
      DO 7 I=LOCK,M
      IF(I.EQ.1)GOTO 7
```



```
      DO 7 J=LOCK,I-1
         EL=0.0
      DO 9 K=1,N
9        EL=EL+U(K,I)*V(K,J)
         EL=-2.0*EL
         Q=BD(I)-BD(J)
      IF(ABS(Q/BD(J)).GT.TOLVEC)GOTO 10
      IF(ABS(EL/BD(J)).GT.TOLVEC)GOTO 10
         EL=0.0
      GOTO 7
10       ELL=SQRT(Q*Q+4.0*EL*EL)
      IF(Q.LT.0.0)ELL=-ELL
         EL=EL/(Q+ELL)
      DO 13 K=1,N
         W(K,I)=W(K,I)-EL*V(K,J)
13       W(K,J)=W(K,J)+EL*V(K,I)
7     CONTINUE
      RETURN
      END
      SUBROUTINE ERROR(U,W,BD,ERR,N,M,NRQD,LOCK,TOLVEC,LET)
      REAL U(300,1),W(300,1),BD(1),ERR(1)
      DO 2 J=LOCK,M
         ER=0.0
      IF(BD(J)) 6,6,60
60    DO 1 I=1,N
         EL=U(I,J)-W(I,J)
1        ER=ER+EL*EL
      GOTO 2
6     DO 8 I=1,N
         EL=U(I,J)+W(I,J)
8        ER=ER+EL*EL
2        ERR(J)=SQRT(ER/N)
5     IF(TOLVEC-ERR(LOCK))4,3,3
3        ERR(LOCK)=-ERR(LOCK)
         LOCK=LOCK+1
      IF(NRQD .GE. LOCK) GOTO 5
         LET=1
4     RETURN
      END
      SUBROUTINE FORSUB(U,V,L,LD,NK,N,M,LOCK)
      REAL L(1),U(300,1),V(300,1)
      INTEGER LD(1),Q
      DO 12 K=LOCK,M
12       V(1,K)=U(1,K)/L(1)
      DO 13 I=2,N
         Q=LD(I)-I
         M1=1+LD(I-1)-Q
      DO 13 K=LOCK,M
         EL=0.0
      IF(M1.EQ.I)GOTO 13
      DO 14 J=M1,I-1
14       EL=EL+L(J+Q)*V(J,K)
13       V(I,K)=(U(I,K)-EL)/L(LD(I))
      RETURN
      END
      SUBROUTINE [illegible](U,V,L,LD,NA,N,M,LOCK,IRENT)
      REAL L(1),U(300,1),V(300,1),LK
      INTEGER LD(1),Q
      DO 1 I=1,N
         LK=L(LD(I))
      DO 1 K=LOCK,M
1        V(I,K)=U(I,K)*LK
      DO 4 I=2,N
```

```
      Q=LD(I)-I
      M1=1+LD(I-1)-Q
      DO 4 K=LOCK,M
      IF(M1.EQ.I)GOTO 4
      IF(IRENT.EQ.2)GOTO 6
      DO 5 J=M1,I-1
5        V(I,K)=V(I,K)+L(J+Q)*U(J,K)
6     CONTINUE
      DO 4 J=M1,I-1
         V(J,K)=V(J,K)+L(J+Q)*U(I,K)
4     CONTINUE
      RETURN
      END
      SUBROUTINE BACSUB(U,V,L,LD,NK,N,M,LOCK)
      REAL L(1),U(300,1),V(300,1)
      INTEGER LD(1),Q
      DO 20 K=LOCK,M
      DO 20 I=1,N
20       V(I,K)=U(I,K)/L(LD(I))
      DO 21 IT=2,N
         I=N+2-IT
         Q=LD(I)-I
         M1=1+LD(I-1)-Q
      IF(M1.EQ.I)GOTO 21
      DO 21 J=M1,I-1
      DO 21 K=LOCK,M
         V(J,K)=V(J,K)-L(J+Q)*V(I,K)/L(LD(J))
21    CONTINUE
      RETURN
      END
      SUBROUTINE TRANF(R,B,H1,H2,N)
      DIMENSION R(6,6),B(30)
         B1=B(N)
      DO 10 I=1,6
      DO 10 J=1,6
10       R(I,J)=0.0
         YL=H2-H1
         AL=SQRT(B1**2+YL**2)
         CX=B1/AL
         CY=YL/AL
         K=0
      DO 20 I=1,2
         R(K+1,K+1)=CX
         R(K+2,K+2)=CX
         R(K+3,K+3)=1.0
         R(K+1,K+2)=CY
         R(K+2,K+1)=-CY
20       K=3
      RETURN
      END
      SUBROUTINE TMP (TR,TB,L1,L2,LR,LA)
      DIMENSION TR(LA,LR), TB(LR,LA)
C     TRANSPOSE MATRIX
      DO 13 I=1,L1
      DO 13 J=1,L2
         TR(J,I)=TB(I,J)
13    CONTINUE
      RETURN
      END
      SUBROUTINE TMPT (FD,SF,DF,LL,LM,LN,L,M,N)
      DIMENSION FD(L,M),SF(M,N), DF(L,N)
C     STANDARD MATRIX MULTIPLICATION
      DO 13 J=1,LN
```



```
      DO 10 I=1,LL
         DF(I,J)=0.0
      DO 10 K=1,LM
         DF(I,J)=DF(I,J) +FD(I,K)*SF(K,J)
10    CONTINUE
      RETURN
      END
      SUBROUTINE SHAPEA (Y, YM, MO, A)
      DIMENSION YM(3)
C     Y - DIRECTION SHAPE FUNCTION
C     INITIALISE Y-DIRECTION TO ZERO
      DO 10 I=1,3
         YM(I)=0.0
10    CONTINUE
         UT=(2.0*FLOAT(MO)-1.0)*3.1416/2.0
      IF (MO .EQ. 1)  UM=1.87509918
      IF (MO .EQ. 2)  UM=4.69403989
      IF (MO .EQ. 3)  UM=7.85475922
      IF (MO .EQ. 4)  UM=10.99553970
      IF (MO .EQ. 5)  UM=14.13716980
      IF (MO .GE. 6)  UM=UT
         TM=(SIN(UM) + SINH(UM))/(COS(UM) + COSH(UM))
         TKY=UM*Y/A
         S=SIN(TKY)
         C=COS(TKY)
         SH=SINH(TKY)
         CH=COSH(TKY)
         T=UM/A
         TT=T*T
         TTT=TT*T
         YM(1)=(S-SH - TM*(C - CH))
         YM(2)=(T*C-T*CH - TM*(-T*S - T*SH))
         YM(3)=(-TT*S-TT*SH - TM*(-TT*C - TT*CH))
      RETURN
      END
      SUBROUTINE SHAPEB (Y, YM, MO, A)
      DIMENSION YM(3)
C     Y - DIRECTION SHAPE FUNCTION
C     INITIALISE Y-DIRECTION TO ZERO
         ZBYB=Y/A
      DO 100 M=1,MO
      DO 10 I=1,3
         YM(I)=0.0
10    CONTINUE
      IF(ABS(ZBYB) .LT. 0.1E-6 ) GO TO 100
         ZBYEN=1.0
         MINUS1=-1
      DO 50 N=1,M
         ZBYEN = ZBYEN * ZBYB
         MINUS1=-MINUS1
         FACTOR = FLOAT(M)/FLOAT(N+1)
      DO 45 K=1,N
45       FACTOR = FACTOR*(M-N+K)*(M+K)/K/K
         PRIM = MINUS1*ZBYEN*FACTOR
         PRIMD= PRIM/ZBYB*FLOAT(N)/A
         PRIMDD=PRIMD/ZBYB*FLOAT(N-1)/A
         YM(1)=YM(1)+PRIM
         YM(2)=YM(2)+PRIMD
         YM(3)=YM(3)+PRIMDD
50    CONTINUE
100   CONTINUE
1000  RETURN
      END
```

```
      SUBROUTINE SHY1(YY, MO, NO, A, AL, AK)
      DIMENSION YY(7),SUM(7),YYL(2,7),YYM(2,2,3),YM(3),Z(2)
         DATA  II/20/
C     INITIALISE TO ZERO
      DO 10 I=1,7
         SUM(I)=0.0
 10   CONTINUE
         ROOT3=SQRT(3.0)
         A1=AL
         B=AK
         H=(B-A1)/FLOAT(II)
         P=H/(2.0*ROOT3)
      DO 20 J=1,II
         Z(1)= A1+(FLOAT(J)-0.5)*H - P
         Z(2)=Z(1) +P*2.0
      DO 50 K=1,2
         Y=Z(K)
      DO 52 I=1,2
      IF(I .EQ. 1) MN=MO
      IF(I .EQ. 2) MN=NO
      CALL SHAPEA (Y, YM, MN, A)
      DO 52 M=1,3
         YYM(K,I,M)=YM(M)
 52   CONTINUE
         YYL(K,1)=YYM(K,1,1)*YYM(K,2,1)
         YYL(K,2)=YYM(K,1,1)*YYM(K,2,3)
         YYL(K,3)=YYM(K,1,2)*YYM(K,2,2)
         YYL(K,4)=YYM(K,1,3)*YYM(K,2,3)
         YYL(K,5)=YYM(K,1,3)*YYM(K,2,1)
         YYL(K,6)=YYM(K,1,2)*YYM(K,2,1)
         YYL(K,7)=YYM(K,1,1)*YYM(K,2,2)
 50   CONTINUE
      DO 20 I=1,7
         SUM(I)=SUM(I)+YYL(1,I)+YYL(2,I)
 20   CONTINUE
      DO 56 I=1,7
         YY(I)=SUM(I)*H/2.0
 56   CONTINUE
      RETURN
      END
      SUBROUTINE SHY2(YY, MO, NO, A, AL, AK)
      DIMENSION YY(7),SUM(7),YYL(2,7),YYM(2,2,3),YM(3),Z(2)
         DATA  II/20/
C     INITIALISE TO ZERO
      DO 10 I=1,7
         SUM(I)=0.0
 10   CONTINUE
         ROOT3=SQRT(3.0)
         A1=AL
         B=AK
         H=(B-A1)/FLOAT(II)
         P=H/(2.0*ROOT3)
      DO 20 J=1,II
         Z(1)= A1+(FLOAT(J)-0.5)*H - P
         Z(2)=Z(1) +P*2.0
      DO 50 K=1,2
         Y=Z(K)
      DO 52 I=1,2
      IF(I .EQ. 1) MN=MO
      IF(I .EQ. 2) MN=NO
      CALL SHAPEB (Y, YM, MN, A)
      DO 52 M=1,3
         YYM(K,I,M)=YM(M)
```



```
 52   CONTINUE
         YYL(K,1)=YYM(K,1,1)*YYM(K,2,1)
         YYL(K,2)=YYM(K,1,1)*YYM(K,2,3)
         YYL(K,3)=YYM(K,1,2)*YYM(K,2,2)
         YYL(K,4)=YYM(K,1,3)*YYM(K,2,3)
         YYL(K,5)=YYM(K,1,3)*YYM(K,2,1)
         YYL(K,6)=YYM(K,1,2)*YYM(K,2,1)
         YYL(K,7)=YYM(K,1,1)*YYM(K,2,2)
 50   CONTINUE
      DO 20 I=1,7
         SUM(I)=SUM(I)+YYL(1,I)+YYL(2,I)
 20   CONTINUE
      DO 56 I=1,7
         YY(I)=SUM(I)*H/2.0
 56   CONTINUE
      RETURN
      END
         SUBROUTINE NEWSLV(G,LD,DIS,NN,M,IRED)
C     G:STIF. MATRIX,  DIS:LOAD/DISPL. VECTOR  LD:DIA. ADDRESSES
C     NN:NO. OF DOF      NA:SIZE OF ARRAY G       IPOUT:PRINT CHANNEL
C     IRED = 0 FOR NO DECOMPOSITION, NE 0 FOR DECOMPOSITION
         DIMENSION G(1), DIS(NN,1), LD(1)
         IPOUT = 6
         IF (NN.LE.0) THEN
           WRITE(6,6001) NN
6001     FORMAT(///,T10,'ERROR STOP IN NEWSLV,  NN = 0?')
         STOP
         ENDIF
         NA = LD(NN)
         IF (IRED.GT.0) CALL REDUCE (G,LD, NA,NN, IPOUT)
         CALL FORSUB(DIS,DIS,G,LD,NA,NN,M,1)
         CALL BACSUB(DIS,DIS,G,LD,NA,NN,M,1)
         RETURN
         END
```

Program B - Finite Strip Combined with Plane Frame

```
      COMMON/PROPF/IPC(40),PXH(40),PYV(40),PMO(40),XF( 80, 80),FF( 80)
      COMMON/POOPW/XW( 80, 80),FW( 80),XP( 80)
      DIMENSION NL(40),YPC(40),SK(300,50),DIS(300),HDEF(40),DIPLO(40),
     1    ROT(40),JJ1(30),BL(30),AH(30),E1(10),AA1(30),AY1(30),JK1(30),
     1    ZI1(30),SF1(30),ZI2(30),AA2(30),SF2(30),HTT(10,30),NI(2),
     1    SMT(300,50,2)
      CHARACTER*80 TITLE
      CHARACTER *8 PROGRM, TODAY, CURTIM
      PARAMETER (PROGRM ='PSTRIP')
C *** INPUT OF WALL DATA
        CALL  DATE(TODAY)
        CALL  TIME(CURTIM)
        WRITE (6,88999) PROGRM, TODAY, CURTIM
88999   FORMAT( 10(/), 25X,'PROGRAM  USED IS :',A8,
     1            4(/),20X,'DATE :',A10,'   TIME   ',A10,10(/) )
       TSET  = TIMER(0.0)
C ****INPUT OF CONNECTING POINTS DATA
      READ(5,*) NLC,NRC
      WRITE(6,500) NLC,NRC
        NCP=NLC+NRC
        NPC=3*NCP
C *** WALL INPUT DATA *****
      READ(5,'(A80)') TITLE
      WRITE(6,'(A80)') TITLE
      READ(5,*) NCSW
      WRITE(6,512) NCSW
      DO 12 IW=1,NCSW
      READ(5,*) NCLL,NI(1),NCRR,NI(2)
      WRITE(6,520) NCLL
      WRITE(6,530) NCRR
        NCPP=NCLL+NCRR
      DO 16 I=1,NCP
        PXH(I)=0.0
        PYV(I)=0.0
   16   PMO(I)=0.0
      IF(NCLL .EQ. 0) GOTO 22
      DO 17 I=1,NCLL
      READ(5,*) PXH(I),PYV(I),PMO(I),NL(I),YPC(I)
      WRITE(6,540) PXH(I),PYV(I),PMO(I),NL(I),YPC(I)
   17 CONTINUE
   22 IF(NCRR .EQ. 0) GOTO 18
      DO 23 J=1,NCRR
        I=J+NCLL
      READ(5,*) PXH(I),PYV(I),PMO(I),NL(I),YPC(I)
      WRITE(6,540) PXH(I),PYV(I),PMO(I),NL(I),YPC(I)
   23 CONTINUE
C *** CALCULATION OF XW MATRIX
   18 IF(IW .GT. 1) GO TO 26
      DO 27 I=1,NPC
      DO 27 J=1,NPC
   27   XW(I,J)=0.0
   26 CALL STF(SK,NN,NBW,JJ1,JK1,AY,BL,E1,PX1,PY1,E2,PX2,AA1,AY1,ZI1,
     1     SF1,E3,PX3,ZI2,AA2,SF2,HTT,NCLL,LH,MOT,NDF,NSA)
      DO 19 I=1,NN
      DO 19 J=1,NBW
   19   SMT(I,J,IW)=SK(I,J)
      DO 28 NPTL=1,3
      DO 28 N=1,NCP
      IF(PXH(N) .EQ. 0) GOTO 28
      IF(PYV(N) .EQ .0) GOTO 28
      IF(PMO(N) .EQ. 0) GOTO 28
        XI=YPC(N)
      IF(NL(N) .EQ. -1) NSID=NI(1)
```



```
      IF(NL(N) .EQ.  1) NSID=NI(2)
      IF(NPTL .EQ. 1) P=PXH(N)
      IF(NPTL .EQ. 2) P=PYV(N)
      IF(NPTL .EQ. 3) P=PMO(N)
        NUDL=0
      DO 29 II=1,NN
   29   DIS(II)=0.0
        XI=YPC(N)
        NUDL=0
      CALL ALOAD(DIS,P,XI,NPTL,NUDL,MOT,NSID,NDF,AH,NODL)
      DO 36 I=1,NN
      DO 36 J=1,NBW
   36   SK(I,J)=SMT(I,J,IW)
      CALL SOLVE(SK,DIS,NN,NBW,300,50)
      CALL DISP(LH,MOT,DIS,NCLL,NCRR,YPC,NI,HDEF,DIPLO,ROT,NDF,AH,NCP)
      DO 32 M=N,NCP
        I1=3-NPTL
        N1=3*N-I1
        M1=3*M-2
      IF(NCSW .GT. 1) THEN
      IF(IW .EQ. 1 .AND. NLC .NE. 0) THEN
        N1=N1+3*NLC
        M1=M1+3*NLC
      ENDIF
      ENDIF
      IF(NPTL .EQ. 2 .AND. N1 .GT. M1) GO TO 34
      IF(NPTL .EQ. 3 .AND. N1 .GT. M1) GO TO 38
        XW(N1,M1)= XW(N1,M1)+HDEF(M)
   34   XW(N1,M1+1)=XW(N1,M1+1)+DIPLO(M)
   38   XW(N1,M1+2)=XW(N1,M1+2)+ROT(M)
   32 CONTINUE
   28 CONTINUE
C *** CALCULATION OF FW MATRIX
      READ(5,'(A80)') TITLE
      WRITE(6,'(A80)') TITLE
      IF(IW .GT. 1) GO TO 47
      DO 48 J=1,NPC
   48   FW(J)=0.0
   47 DO 52 II=1,NN
   52   DIS(II)=0.0
      READ (5,*) NFW
      WRITE(6,550) NFW
      IF(NFW .EQ. 0) GOTO 53
      DO 63 J=1,NFW
      READ(5,*) P,XI,NPTL,NUDL,NSID
      WRITE(6,562) P,XI,NPTL,NUDL,NSID
   63 CALL ALOAD(DIS,P,XI,NPTL,NUDL,MOT,NSID,NDF,AH,NODL)
      DO 50 I1=1,NN
      DO 50 J1=1,NBW
   50   SK(I1,J1)=SMT(I1,J1,IW)
      CALL SOLVE(SK,DIS,NN,NBW,300,50)
      CALL DISP(LH,MOT,DIS,NCLL,NCRR,YPC,NI,HDEF,DIPLO,ROT,NDF,AH,NCP)
        N=1
      IF(NCSW .GT. 1) THEN
      IF(IW .EQ. 1 .AND. NLC .NE. 0) THEN
        N=N+NLC
        NP=NCRR
      ENDIF
      ENDIF
      DO 49 M=N,NCP
        FW(3*M-2)=FW(3*M-2)+HDEF(M-N+1)
        FW(3*M-1)=FW(3*M-1)+DIPLO(M-N+1)
        FW(3*M)=FW(3*M)+ROT(M-N+1)
```

```
   49 CONTINUE
   53 CONTINUE
   12 CONTINUE
C *** END OF WALL DATA ***
C *** FRAME DATA *********
C *** XF ANF FF MATRICES SET UP
      DO 60 I=1,NPC
         FF(I)=0.0
      DO 60 J=1,NPC
   60    XF(I,J)=0.0
      READ(5,'(A80)') TITLE
      WRITE(6,'(A80)') TITLE
      READ(5,*) NFC
      WRITE(6,550) NFC
      DO 66 I=1,NCP
         PXH(I)=0.0
         PYV(I)=0.0
   66    PMO(I)=0.0
      DO 70 IFF=1,NFC
      READ(5,*) NCL,NCR,NNT
      WRITE(6,610) NCL,NCR,NNT
      IF(NNT .EQ. 1) THEN
      IF(NCL .EQ. 0) GO TO 76
C *** CONNECTION TO LEFTHAND SIDE OF WALL *****
         NCC=NCL
      DO 72 I=1,NCC
      READ(5,*) PXH(I),PYV(I),PMO(I),IPC(I),YPC(I)
   72 WRITE(6,620) PXH(I),PYV(I),PMO(I),IPC(I),YPC(I)
      CALL FRAME( NCC,0,NPC)
   76 IF(NCR .EQ. 0) GO TO 70
C *** CONNECTION TO RIGHTHAND SIDE OF WALL *****
         NCC=NCR
      DO 75 J=1,NCC
         I=J+NLC
      READ(5,*) PXH(I),PYV(I),PMO(I),IPC(I),YPC(I)
   75 WRITE(6,620) PXH(I),PYV(I),PMO(I),IPC(I),YPC(I)
      CALL FRAME( NCC,NLC,NPC)
      ELSE
         NCC=NCL+NCR
      DO 74 I=1,NCC
      READ(5,*) PXH(I),PYV(I),PMO(I),IPC(I),YPC(I)
   74 WRITE(6,620) PXH(I),PYV(I),PMO(I),IPC(I),YPC(I)
      CALL FRAME( NCC,0,NPC)
      ENDIF
   70 CONTINUE
C *** END OF FRAME DATA ***
C *** SOLUTION OF EQUATIONS
      CALL SOLV(NPC)
C *** CALCULATION OF ACTUAL FORCES
      IF(NLC .EQ. 0) GOTO 65
      WRITE(6,700)
      WRITE(6,710)
      WRITE(6,720)
      DO 69 I=1,NLC
         K=IPC(I)
         PXH(I)=PXH(I)*XP(3*I-2)
         PYV(I)=PYV(I)*XP(3*I-1)
         PMO(I)=PMO(I)*XP(3*I)
   69 WRITE(6,730)K,PXH(I),PYV(I),PMO(I)
   65 IF(NRC .EQ. 0) GOTO 71
         LL=NLC
      WRITE(6,740)
      WRITE(6,710)
```



```
      WRITE(6,720)
      DO 73 I=1,NRC
         N=I+LL
         K=IPC(N)
         PXH(N)=PXH(N)*XP(3*N-2)
         PYV(N)=PYV(N)*XP(3*N-1)
         PMO(N)=PMO(N)*XP(3*N)
   73 WRITE(6,730)K,PXH(N),PYV(N),PMO(N)
   71 CONTINUE
C**** COMPUTE WALL STRESSES
      READ(5,'(A80)') TITLE
      WRITE(6,'(A80)')TITLE
      READ(5,*) NCSW
      WRITE(6,550) NCSW
      READ(5,*) NWALL,NCOL,NBEAM,NFW
      WRITE(6,732) NWALL,NCOL,NBEAM,NFW
      DO 162 II=1,NN
  162    DIS(II)=0.0
      DO 154 IW=1,NCSW
      READ(5,*) NIW
      WRITE(6,550) NIW
      IF(NFW .EQ. 0) GO TO 124
      DO 125 II=1,NFW
      READ(5,*) P,XI,NPTL,NCDL,NSID
      WRITE(6,750) P,XI,NPTL,NCDL,NSID
  125 CALL ALOAD(DIS,P,XI,NPTL,NUDL,MOT,NSID,NDF,AH,NCDL)
  124 READ(5,*) NCLL,NI(1),NCRR,NI(2)
      DO 122 K=1,2
      GO TO (126,128),K
  126 IF(NCLL .EQ. 0) GO TO 122
         NSID=NI(K)
         NLR=NCLL
      GO TO 132
  128 IF(NCRR .EQ. 0) GO TO 122
         NSID=NI(K)
         NLR=NCRR
  132 DO 120 M=1,NLR
         I=M
      IF(NCLL .NE. 0 .AND. K .EQ. 2) I=I+NCLL
         XI=YPC(I)
      DO 120 J=1,3
      GO TO (130,140,150), J
  130    P=-PXH(I)
         NPTL=1
      GO TO 120
  140    P=-PYV(I)
         NPTL=2
      GO TO 120
  150    P=-PMO(I)
         NPTL=3
  120 CALL ALOAD(DIS,P,XI,NPTL,NCDL,MOT,NSID,NDF,AH,NCDL)
  122 CONTINUE
      DO 170 I1=1,NN
      DO 170 J1=1,NFW
  170    SK(I1,J1)=SKT(I1,J1,NIW)
      CALL SOLVE(SK,DIS,NN,NBW,300,50)
      CALL STRESS(LE,DIS,JJ1,JK1,AH,XL,E1,PX1,PY1,E2,PX2,AA1,AY1,ZZ1,
     1            SF1,E3,PX3,ZZ2,AA2,SF2,NTT,NWALL,NCOL,NBEAM,NDF,MOT)
C *** COMPUTING DISPLACEMENT ***
      READ(5,'(A80)') TITLE
      WRITE(6,'(A80)')TITLE
      READ(5,*) NDISPL
      WRITE(6,550) NDISPL
```

```
      IF(NDISPL .EQ. 0) GO TO 154
      WRITE(6,770)
      CALL DISP(LH,MOT,DIS,NCLL,NCRR,YPC,NI,HDEF,DIPLO,ROT,NDF,AH,NCP)
      DO 156 M=1,NCP
         FW(3*M-2)=HDEF(M)
         FW(3*M-1)=DIPLO(M)
         FW(3*M)=ROT(M)
      WRITE(6,780) FW(3*M-2),FW(3*M-1),FW(3*M)
  156 CONTINUE
  154 CONTINUE
  512 FORMAT(1X,I10)
  520 FORMAT(1H0,5X,33HNO. OF L.H.S.CONNECTION POINTS = ,I4)
  530 FORMAT(1H0,5X,33HNO. OF R.H.S.CONNECTION POINTS = ,I4)
  500 FORMAT(1X,2I10)
  510 FORMAT(1X,F10.4,2I10)
  540 FORMAT(1X,3F10.4,I10,F10.4)
  550 FORMAT(1X,I10)
  560 FORMAT(1X,2F10.4,3I10)
  562 FORMAT(1X,2F10.4,3I10)
  610 FORMAT(1X,3I10)
  620 FORMAT(1X,3F10.4,I10,F10.4)
  700 FORMAT(///,1X,14HLEFT HAND SIDE)
  710 FORMAT(4X,10HCONNECTING,4X,10HHORIZONTAL,4X,8HVERTICAL)
  720 FORMAT(6X,5HPOINT,9X,5HFORCE,9X,5HFORCE,6X,6HMOMENT)
  730 FORMAT(1X,I10,3F10.4)
  740 FORMAT(///,1X,15HRIGHT HAND SIDE)
  732 FORMAT(1X,4I10)
  750 FORMAT(1X,2F10.4,3I10)
  752 FORMAT(1X,3I10)
  760 FORMAT(1X,I10)
  770 FORMAT( /)
  780 FORMAT(3F20.10)
        TNOW = TIMER(TSET)
        WRITE (6,99995) TNOW
99995   FORMAT(///,T30,'TOTAL CPU TIME :',G12.4,' MILLI. SEC.',//)
      STOP
      END


        FUNCTION TIMER(TBEG)
        CALL MTIME(T)
        TIMER = T-TBEG
        RETURN
        END

      SUBROUTINE SOLV (NPC)
      COMMON/PROPT/XPC(40),FXX(40),FYY(40),FMO(40),XF( 80, 80),FF( 80)
      COMMON/POCPW/XW( 80, 80),FW( 80),XP( 80)
      DIMENSION  S( 80, 80),FFF( 80),XXP( 80,1),
     1           XWXXP( 80,1),XFXXP( 80,1)
      DO 120 I=1,NPC
         XFXXP(I,1)=0.0
  120    XWXXP(I,1)=0.0
      DO 1 I=1,NPC
        FFF(I)=FW(I)-FF(I)
      DO 1 J=1,NPC
         S(I,J)=XF(I,J)+XW(I,J)
    1 CONTINUE
      DO 4 I=1,NPC
      DO 4 J=1,NPC
         II=J-I+1
          S(I,II)= S(I,J)
```



```
    4 CONTINUE
      CALL SOLVE( S,FFF,NPC,NPC,120,120)
      DO 10 I=1,NPC
         XXP(I,1)=FFF(I)
   10    XP(I)=FFF(I)
      CALL TMPT (XW,XXP,XWXXP,NPC,NPC,1,120,120,1)
      WRITE(6,*)'XWXXP'
      DO 100 I=1,NPC
  100    XWXXP(I,1)=FW(I)-XWXXP(I,1)
      WRITE(6,1000) (XWXXP(I,1),I=1,NPC)
 1000 FORMAT(3F15.8)
      CALL TMPT (XF,XXP,XFXXP,NPC,NPC,1,120,120,1)
      WRITE(6,*)'XFXXP'
      DO 110 I=1,NPC
  110    XFXXP(I,1)=FF(I)+XFXXP(I,1)
      WRITE(6,1000) (XFXXP(I,1),I=1,NPC)
      RETURN
      END


      SUBROUTINE STP(SK,NN,NL,JJ1,JK1,AH,BL,E1,PX1,PY1,E2,PX2,AA1,AY1,
     1         ZI1,SF1,E3,PX3,ZI2,AA2,SF2,HTT,NODL,LH,MOT,NDF,NBA)
      CHARACTER*80 TITLE
      DATA KK/3/
      DIMENSION SK(300,50),JJ1(30),JK1(30),
     1         BL(30),AH(30),THK(30),HT(30),SF1(30),
     2         NTY(30),SF2(30),ZI2(30),HTT(10,30),E2(10),
     3         AA1(30),AY1(30),ZI1(30),AA2(30),NYY(30),E1(10)
C     INPUT STRUCTURE DATA
C     LH=1 FOR LOW ORDER ,LH=2 FOR HIGH ORDER
C     NSP=1 FOR SINE FUNCTION ,NSP=2 FOR POLYN. FUNCTION
C     NCT=1 LE TO LE,NCT=2 ST TO ST,NCT=3 LE TO ST,NCT=4 ST TO LE
      WRITE(6,500)
      DO 10 I=1,2
      READ(5,'(A80)') TITLE
   10 WRITE(6,'(A80)')TITLE
C *** STRUCTURE DATA ***
      READ(5,*) LH
      READ(5,*) NCOL,NSPAN,MOT,NDF,NBA,NWALL,NBEAM,NCOL
      WRITE(6,510)
      WRITE(6,520)
      WRITE(6,530) LH,NDF,NBA,MOT,NCOL,NSPAN,NWALL,NBEAM,NCOL
         LL=NDF*MOT
         NN=NCOL*LL
         NL=NBA*MOT
      DO 12 I=1,NN
      DO 12 J=1,NL
   12    SK(I,J)=0.0
C ...............
      WRITE(6,532)
      READ(5,*) (AH(J),J=1,NCOL),(BL(J),J=1,NSPAN)
      WRITE(6,810)(AH(J),J=1,NCOL),(BL(J),J=1,NSPAN)
  810 FORMAT(10F12.2)
C ...............
      READ(5,'(A80)') TITLE
      READ(5,*) NRPT
      DO 14 J=1,NRPT
      READ(5,*) NYY(J),(HTT(J,L),L=1,NYY(J))
   14 CONTINUE
      DO 20 K=1,KK
      GO TO (2,4,6),K
C ...............
```

```
C *** WALL DATA ***
 2     IF(NWALL .EQ. 0) GO TO 20
       READ(5,'(A80)') TITLE
       WRITE(6,'(A80)')TITLE
       WRITE(6,560)
       DO 30 N=1,NWALL
       READ(5,*) I,JJ1(I),JK1(I),NSEG
       WRITE(6,820) I,JJ1(I),JK1(I),NSEG
       READ(5,*) E1(I),PX1,PY1
       WRITE(6,550) E1(I),PX1,PY1
 820   FORMAT(4I5)
       READ(5,*) (THK(J),HT(J),J=1,NSEG)
       WRITE(6,810)(THK(J),HT(J),J=1,NSEG)
 30    CALL SHXY(LH,MOT,NDF,SK,AH,BL,JJ1,JK1,E1,PX1,PY1,
      1          NSEG,THK,HT,I,K,NL,NN)
       GO TO 20
C ...............
C *** BEAM SPAN DATA ***
 4     IF(NBEAM .EQ. 0) GO TO 20
       READ(5,'(A80)') TITLE
       WRITE(6,'(A80)')TITLE
       READ(5,*) NSEG
       WRITE(6,590)
       READ(5,*) (SF1(J),AA1(J),AY1(J),ZI1(J),J=1,NSEG)
       WRITE(6,810)(SF1(J),AA1(J),AY1(J),ZI1(J),J=1,NSEG)
       WRITE(6,592)
       DO 50 N=1,NBEAM
       READ(5,*) I,JJ1(I),JK1(I),NP,NBPT,NCT
       WRITE(6,830)I,JJ1(I),JK1(I),NP,NBPT,NCT
       READ(5,*) E2(I),PX2
       WRITE(6,580) E2(I),PX2
 830   FORMAT(7I5)
       READ(5,*) (NTY(J),J=1,NP)
       WRITE(6,840)(NTY(J),J=1,NP)
 840   FORMAT(20I5)
 50    CALL SBXY(LH,MOT,NDF,SK,AH,BL,JJ1,JK1,E2,PX2,NBPT,
      1   HTT,NP,NTY,SF1,AA1,AY1,ZI1,I,NCT,K,NL,NN)
       GO TO 20
C ...............
C *** LINE ELEMENT DATA ***
 6     IF(NCOL .EQ. 0) GO TO 23
       READ(5,'(A80)') TITLE
       WRITE(6,'(A80)')TITLE
       WRITE(6,600)
       READ(5,*) E3,PX3,NTPP
       WRITE(6,610) E3,PX3,NTPP
       WRITE(6,620)
       READ(5,*) (SF2(J),AA2(J),ZI2(J),J=1,NTPP)
       WRITE(6,810)(SF2(J),AA2(J),ZI2(J),J=1,NTPP)
       DO 70 N=1,NCOL
       READ(5,*) I,JJ1(I),NSEG
       WRITE(6,860)I,JJ1(I),NSEG
 860   FORMAT(3I5)
       READ(5,*) (NTY(J),J=1,NSEG)
       WRITE(6,840)(NTY(J),J=1,NSEG)
       READ(5,*) (HT(J),J=1,NSEG)
       WRITE(6,810)(HT(J),J=1,NSEG)
 70    CALL SCXY(LH,MOT,NDF,SK,AH,JJ1,JK1,E3,PX3,NSEG,HT,
      1          NTY,SF2,AA2,ZI2,I,K,NL,NN)
 23    CONTINUE
         III=1
C ...............
C      CALL DECINC(NN,NL,SK,III)
```



```
 500   FORMAT( 'ANALYSIS OF STRUCTURE BY FINITE STRIP METHOD'/44('*'))
 510   FORMAT(/ 'STRUCTURE DATA')
 520   FORMAT(/ 3X,'LH',2X,'NDF',2X,'NBA',2X,'MOT',2X,'NODL',2X,'NSPAN',
      1         2X,'NWALL',2X,'NBEAM',2X,'NCOL')
 530   FORMAT(4I5,I6,3I7,I6)
 532   FORMAT(/ 'HEIGHT/WIDTH :-')
 550   FORMAT(F14.4,2F12.4)
 560   FORMAT(/ 'NOS.,JJ1,JK1,NSEG/E1,PX1,PY1/THICKNESS,HEIGHT :-')
 580   FORMAT(F14.4,F12.4)
 590   FORMAT(/'SF1,AA1,AY1,ZI1 :-')
 592   FORMAT(/'NOS.,JJ1,JK1,NO.OF TYPE,NBPT,NCT/E2,PX2/TYPE MEMBER :-')
 600   FORMAT(/ 12X,'E3',9X,'PX3')
 610   FORMAT(F14.4,2F12.4)
 620   FORMAT(/ 'NOS.,JJ1,JK1,NSEG/SF2,AA2,ZI2/TYPE,HEIGHT :-')
       RETURN
       END


       SUBROUTINE STRESS(LH,DIS,JJ1,JK1,AH,BL,E1,PX1,PY1,E2,PX2,AA1,AY1,
      1          ZI1,SF1,E3,PX3,ZI2,AA2,SF2,HTT,NWALL,NCOL,NBEAM,NDF,MOT)
       DIMENSION JJ1(30),JK1(30),BL(30),AH(30),THK(30),E1(10),HT(30),
      1          DIS(300),NTY(30),ZI2(30),AA2(30),SF2(30),HTT(10,30),
      1          AA1(30),AY1(30),ZI1(30),SF1(30),XDP(10),E2(10)
       CHARACTER*80 TITLE
C *** COMPUTING STRESSES ***
         KK=3
       DO 10 K=1,KK
       GO TO (20,30,20),K
 20    IF(K .EQ. 1) NWC=NWALL
       IF(K .EQ. 3) NWC=NCOL
       IF(NWC .EQ. 0) GO TO 10
       IF(K .EQ. 1) WRITE(6,710)
       IF(K .EQ. 3) WRITE(6,730)
       READ(5,'(A80)') TITLE
       DO 50 N=1,NWC
       IF(K .EQ. 1) THEN
       READ(5,*) I,NP,(THK(J),HT(J),J=1,NP),NPOUT,(XDP(J),J=1,NPOUT)
       CALL DSW(LH,MOT,NDF,JJ1,JK1,BL,AH,THK,E1,PX1,PY1,NP,HT,I,DIS,
      1          NPOUT,XDP)
       ELSE
       GO TO 40
       ENDIF
 50    CONTINUE
 40    GO TO 10
 30    IF(NBEAM .EQ. 0) GO TO 10
       IF(K .EQ. 2) WRITE(6,720)
       READ(5,'(A80)') TITLE
       DO 60 N=1,NBEAM
       READ(5,*) I,J1,J2,NP,NBPT,NCT,(NTY(J),J=1,NP)
       CALL DBB(LH,MOT,NP,NTY,HTT,NBPT,J1,J2,BL,AH,AA1,AY1,ZI1,SF1,
      1          E2,PX2,I,DIS,NCT,NDF)
 60    CONTINUE
 10    CONTINUE
 710   FORMAT(/ 'POINT',2X,'NOS.',2X,'NODE'/)
 720   FORMAT(/ 'POINT',2X,'NOS.',2X,'NODE',22X,'END1(X,Y,S)',38X,
      1         'END2(X,Y,S)'/)
 730   FORMAT(/ 'POINT',2X,'LINE',5X,'NODE',5X,'X-FORCES',5X,
      1         'Y-FORCES',5X,'Z-MOMENT'/)
       RETURN
       END
```

```
      SUBROUTINE SHXY(LH,MOT,NDF,SK,AH,BL,JJ1,JK1,E1,PX1,
     1                PY1,NSEG,THK,HT,N,KK,NL,NN)
      DIMENSION DDB(4,3,3),D(3,3),DD1(6,6),AH(30),BL(30),SD1(80,80),
     1          YY(7),BB(7),BT1(6,6),BK(6,6),BR(6,6),HT(30),THK(30),
     2          JJ1(30),JK1(30),SK(300,50),DDL(4,3,3),E1(10)
C     YY(1) DENOTES YM*YN
C     YY(2) DENOTES YM*YNDD
C     YY(3) DENOTES YMD*YND
C     YY(4) DENOTES YMDD*YNDD
C     YY(5) DENOTES YMDD*YN
C     YY(6) DENOTES YMD*YN
C     YY(7) DENOTES YM*YND

         L=2*NDF*MOT
         L1=MOT*NDF
      DO 12 I=1,L
      DO 12 J=1,L
12       SD1(I,J)=0.0
      DO 10 K=1,4
      DO 10 I=1,NDF
      DO 10 J=1,NDF
10       DDL(K,I,J)=0.0
      DO 20 I=1,6
      DO 20 J=1,6
         DD1(I,J)=0.0
         BT1(I,J)=0.0
         BK(I,J)=0.0
20       BR(I,J)=0.0
         A1=AH(JJ1(N))
         B1=BL(N)
         EE=E1(N)
      DO 30 I=1,7
30       BB(I)=B1**I/(FLOAT(I))
         DE=EE/(1.0-PX1*PY1)
         D(1,1)=DE
         D(1,2)=PX1*DE
         D(2,2)=D(1,1)
         D(3,3)=EE/(2.0+2.0*PX1)
         BT1(1,1)=-1.0/B1
         BT1(5,5)=3.0/B1**2
         BT1(6,6)=1.0/B1**2
         BT1(1,4)=-BT1(1,1)
         BT1(2,1)=1.0
         BT1(3,2)=1.0
         BT1(4,3)=1.0
         BT1(5,2)=-BT1(5,5)
         BT1(5,3)=-2.0/B1
         BT1(5,6)=BT1(1,1)
         BT1(6,2)=2.0/B1**3
         BT1(6,3)=BT1(6,6)
         BT1(6,5)=-BT1(6,2)
      DO 40 MO=1,MOT
      DO 40 NO=MO,MOT
      DO 14 K=1,4
      DO 14 I=1,NDF
      DO 14 J=1,NDF
14       DDB(K,I,J)=0.0
      DO 42 N=2,NSEG
         AK=HT(N)
         AJ=HT(N-1)
      CALL SHY1(YY,MO,NO,A1,AJ,AK)
         G1=D(1,1)*YY(1)
         G2=D(3,3)*YY(3)
```



```
         G3=D(1,2)*YY(5)
         G4=D(3,3)*YY(3)
         G5=D(3,3)*YY(3)
         G6=D(1,2)*YY(2)
         G7=D(3,3)*YY(3)
         G8=D(2,2)*YY(4)
         G9=D(3,3)*YY(3)
       IF(LH .EQ. 1) THEN
         D1=1.0/B1
         D2=B1/3.0
         D3=B1/6.0
         DDL(1,1,1)=G1*D1+G2*D2
         DDL(1,2,1)=(G3+G4)*(-0.5)
         DDL(1,1,2)=(G6+G7)*(-0.5)
         DDL(1,2,2)=G8*D2+G9*D1
         DDL(2,1,1)=DDL(1,1,1)
         DDL(2,2,1)=-DDL(1,2,1)
         DDL(2,1,2)=-DDL(1,1,2)
         DDL(2,2,2)=DDL(1,2,2)
         DDL(3,1,1)=-G1*D1+G5*D3
         DDL(3,2,1)=(-G3+G4)*(-0.5)
         DDL(3,1,2)=(G6-G7)*(-0.5)
         DDL(3,2,2)=G8*D3-G9*D1
         DDL(4,1,1)=DDL(3,1,1)
         DDL(4,2,1)=-DDL(3,2,1)
         DDL(4,1,2)=-DDL(3,1,2)
         DDL(4,2,2)=DDL(3,2,2)
       ELSE
         BK(1,1)=B1*G1+BB(3)*G2
         BK(2,2)=B1*G2
         BK(3,3)=B1*G8
         BK(4,4)=BB(3)*G8+B1*G9
         BK(5,5)=BB(5)*G8+4.0*BB(3)*G9
         BK(6,6)=BB(7)*G8+9.0*BB(5)*G9
         BK(1,2)=BB(2)*G2
         BK(3,4)=BB(2)*G8
         BK(3,5)=BB(3)*G8
         BK(3,6)=BB(4)*G8
         BK(4,5)=BB(4)*G8+B1**2*G9
         BK(4,6)=BB(5)*G8+B1**3*G9
         BK(5,6)=BB(6)*G8+6.0*BB(4)*G9
       DO 60 I=1,6
       DO 60 J=1,6
60       BK(J,I)=BK(I,J)
         BK(1,3)=B1*G6
         BK(1,4)=BB(2)*(G6+G7)
         BK(1,5)=BB(3)*(G6+2.0*G7)
         BK(1,6)=BB(4)*(G6+3.0*G7)
         BK(2,4)=B1*G7
         BK(2,5)=B1*BK(2,4)
         BK(2,6)=B1*BK(2,5)
         BK(3,1)=B1*G3
         BK(4,1)=BB(2)*(G3+G4)
         BK(5,1)=BB(3)*(G3+2.0*G4)
         BK(6,1)=BB(4)*(G3+3.0*G4)
         BK(4,2)=B1*G4
         BK(5,2)=B1*BK(4,2)
         BK(6,2)=B1*BK(5,2)
       ENDIF
       IF(LH .EQ. 1) GO TO 48
       CALL TMP(DD1,BT1,0,6,6,6)
       CALL TMPT(DD1,BK,BR,6,6,6,6,6,6)
       CALL TMPT(BR,BT1,DD1,6,6,6,6,6,6)
```

```
      DO 70 I=1,3
      DO 70 J=1,3
         DDB(1,I,J)=DDB(1,I,J)+DD1(I,J)*THK(M)
         DDB(2,I,J)=DDB(2,I,J)+DD1(I+3,J+3)*THK(M)
         DDB(3,I,J)=DDB(3,I,J)+DD1(I,J+3)*THK(M)
 70      DDB(4,I,J)=DDB(4,I,J)+DD1(I+3,J)*THK(M)
      GO TO 42
 48   DO 80 K=1,4
      DO 80 I=1,2
      DO 80 J=1,2
 80      DDB(K,I,J)=DDB(K,I,J)+DDL(K,I,J)*THK(M)
 42   CONTINUE
         L2=(MO-1)*NDF
         L3=(NO-1)*NDF
      DO 43 I=1,NDF
      DO 43 J=1,NDF
         I1=L2+I
         I2=L3+J
         I3=L1+I
         I4=L1+J
         SD1(I1,I2)=SD1(I1,I2)+DDB(1,I,J)
         SD1(L1+I1,L1+I2)=SD1(L1+I1,L1+I2)+DDB(2,I,J)
         SD1(I1,L1+I2)=SD1(I1,L1+I2)+DDB(3,I,J)
         SD1(L1+I1,I2)=SD1(L1+I1,I2)+DDB(4,I,J)
 43   CONTINUE
      IF(MO .NE. NO) THEN
      DO 45 I=1,NDF
      DO 45 J=1,NDF
         I1=L2+I
         I2=L3+J
         SD1(I2,I1+L1)=SD1(I1,L1+I2)
      IF(I .EQ. 1 .AND. J .EQ. 2) SD1(I2,I1+L1)=-SD1(I2,I1+L1)
      IF(I .EQ. 2 .AND. J .EQ. 1) SD1(I2,I1+L1)=-SD1(I2,I1+L1)
      IF(I .EQ. 2 .AND. J .EQ. 3) SD1(I2,I1+L1)=-SD1(I2,I1+L1)
      IF(I .EQ. 3 .AND. J .EQ. 2) SD1(I2,I1+L1)=-SD1(I2,I1+L1)
 45   CONTINUE
      ENDIF
 40   CONTINUE
      CALL ASSEM(SK,SD1,JJ1,JK1,NDF,MCT,KK,N,NL,NN)
      RETURN
      END

      SUBROUTINE SLXY(LH,MCT,NDF,SK,AH,JJ1,JK1,E3,PX3,NSEG,
     1                HT,NTY,SF2,AA2,ZI2,N,KK,NL,NN)
      DIMENSION YY(7),DD1(6,6),AH(30),AA2(30),ZI2(30),NTY(30),HT(30),
     1          DDB(4,3,3),SD1(80,80),SF2(30),SK(300,50),
     2          JJ1(30),JK1(30)
         L=2*NDF*MCT
         L1=NDF*MCT
      DO 2 I=1,L
      DO 2 J=1,L
 2       SD1(I,J)=0.0
         A1=AH(JJ1(N))
         GS=E3/(2.0*(1.0+PX3))
      DO 20 MO=1,MCT
      DO 20 NO=MO,MCT
      DO 10 K=1,4
      DO 10 I=1,NDF
      DO 10 J=1,NDF
 10      DDB(K,I,J)=0.0
         K1=(MO-1)*NDF
         K2=(NO-1)*NDF
```



```
      DO 22 M=2,NSEG
         K=NTY(M)
         AK=HT(M)
         AL=HT(M-1)
      CALL SHY1(YY,MO,NO,A1,AL,AK)
      DO 34 I=1,NDF
      DO 34 J=1,NDF
 34      DD1(I,J)=0.0
      IF(LH .EQ. 2) THEN
         DILI=AA2(K)*GS/SF2(K)*YY(3)
         DILA=E3*ZI2(K)*YY(4)
         DILB=E3*AA2(K)*YY(4)
         DD1(1,1)=DILI
         DD1(2,2)=DILB
         DD1(3,3)=DILI+DILA
         DD1(3,1)=-DILI
         DD1(1,3)=DD1(3,1)
      ELSE
         DD1(1,1)=E3*ZI2(K)*YY(4)
         DD1(2,2)=E3*AA2(K)*YY(4)
      ENDIF
      DO 22 I=1,NDF
      DO 22 J=1,NDF
 22      DDB(1,I,J)=DDB(1,I,J)+DD1(I,J)
      DO 20 I=1,NDF
      DO 20 J=1,NDF
         L2=(MO-1)*NDF
         L3=(NO-1)*NDF
         I1=L2+I
         I2=L3+J
         SD1(I1,I2)=SD1(I1,I2)+DDB(1,I,J)
 20   CONTINUE
      CALL ASSEM(SK,SD1,JJ1,JK1,NDF,MCT,KK,N,NL,NN)
      RETURN
      END

      SUBROUTINE SBXY(LH,MCT,NDF,SK,AH,BL,JJ1,JK1,E2,PX2,
     1                NBPT,HTT,NP,NTY,SF1,AA1,AY1,ZI1,N,NCT,
     2                KK,NL,NN)
      DIMENSION DDB(4,3,3),BK(6,6),DD1(6,6),BR(6,6),BT1(6,6),YM(3),
     1          AH(30),BL(30),AA1(30),AY1(30),JJ1(30),JK1(30),SK(300,50),
     2          ZI1(30),HT(30),NTY(30),SD1(80,80),SF1(30),E2(10),
     3          HTT(10,30),DD2(6,6),
     4          DDL(4,3,3)
         L=2*NDF*MCT
         L1=NDF*MCT
      DO 12 I=1,L
      DO 12 J=1,L
 12      SD1(I,J)=0.0
      DO 14 I=1,6
      DO 14 J=1,6
         BT1(I,J)=0.0
         BR(I,J)=0.0
 14      DD1(I,J)=0.0
      DO 16 I=1,6
      DO 16 J=1,6
 16      BK(I,J)=0.0
         A1=AH(JJ1(N))
         B1=BL(N)+0.00
         EE=E2(N)
         GS=EE/(2.0*(1.0+PX2))
```

```
      DO 30 MO=1,MOT
      DO 30 NO=MO,MOT
      DO 20 L=1,4
      DO 20 I=1,NDF
      DO 20 J=1,NDF
         DDL(L,I,J)=0.0
 20      DDB(L,I,J)=0.0
      DO 22 M=2,NP
         K=NTY(M)
         Y=HTT(NBPT,M)
         PYY=12.0*EE*ZI1(K)*SF1(K)/(GS*AY1(K)*B1**2)
         PP=1.0/(1.0+PYY)
         BK(1,1)=EE*AA1(K)/B1
         BK(2,2)=12.0*EE*ZI1(K)/B1**3*PP
         BK(3,2)=6.0*EE*ZI1(K)/B1**2*PP
         BK(3,3)=EE*ZI1(K)/B1*(3.0*PP+1.0)
         BK(4,4)=BK(1,1)
         BK(5,5)=BK(2,2)
         BK(6,6)=BK(3,3)
         BK(4,1)=-BK(1,1)
         BK(5,2)=-BK(2,2)
         BK(5,3)=-BK(3,2)
         BK(6,2)=BK(3,2)
         BK(6,3)=EE*ZI1(K)/B1*(3.0*PP-1.0)
         BK(6,5)=-BK(6,2)
      DO 40 I=1,6
      DO 40 J=I,6
 40      BK(I,J)=BK(J,I)
      DO 50 K=1,2
      IF(K .EQ. 1) MN=MO
      IF(K .EQ. 2) MN=NO
      CALL SHAPEA(Y,YM,MN,A1)
         UM=YM(1)
         VM=YM(2)
         UD=YM(2)
      IF(LH .EQ. 1) THEN
         BT1(1,1)=UM
         BT1(2,2)=VM
         BT1(3,1)=-UD
         BT1(4,3)=UM
         BT1(5,4)=VM
         BT1(6,3)=-UD
      ELSE
         J=0
      DO 60 I=1,2
         BT1(1+J,1+J)=UM
         BT1(2+J,2+J)=VM
 60         J=NDF
      GO TO (2,4,6,8),NCT
 2       BT1(3,3)=-UD
         BT1(6,6)=-UD
      GO TO 100
 4       BT1(3,1)=-UD
         BT1(6,4)=-UD
      GO TO 100
 6       BT1(3,3)=-UD
         BT1(6,4)=-UD
      GO TO 100
 8       BT1(3,1)=-UD
         BT1(6,6)=-UD
      ENDIF
 100     LL=2*NDF
      IF(K .EQ. 1) THEN
```



```
      CALL TMP(DD1,BT1,6,LL,6,6)
      CALL TMPT(DD1,BK,BR,LL,6,6,6,6,6)
      ELSE
      CALL TMPT(BR,BT1,DD2,LL,6,LL,6,6,6)
      ENDIF
 50   CONTINUE
      DO 22 I=1,NDF
      DO 22 J=1,NDF
         DDB(1,I,J)=DDB(1,I,J)+DD2(I,J)
         DDB(2,I,J)=DDB(2,I,J)+DD2(I+NDF,J+NDF)
         DDB(3,I,J)=DDB(3,I,J)+DD2(I,J+NDF)
 22      DDB(4,I,J)=DDB(4,I,J)+DD2(I+NDF,J)
         L2=(MO-1)*NDF
         L3=(NO-1)*NDF
      DO 43 I=1,NDF
      DO 43 J=1,NDF
         I1=L2+I
         I2=L3+J
         I3=L1+I
         I4=L1+J
         SD1(I1,I2)=SD1(I1,I2)+DDB(1,I,J)
         SD1(L1+I1,L1+I2)=SD1(L1+I1,L1+I2)+DDB(2,I,J)
         SD1(I1,L1+I2)=SD1(I1,L1+I2)+DDB(3,I,J)
         SD1(L1+I1,I2)=SD1(L1+I1,I2)+DDB(4,I,J)
 43   CONTINUE
      IF(MO .NE. NO) THEN
      DO 45 I=1,NDF
      DO 45 J=1,NDF
         I1=L2+I
         I2=L3+J
         SD1(I2,I1+L1)=SD1(I1,L1+I2)
      IF(I .EQ. 1 .AND. J .EQ. 2) SD1(I2,I1+L1)=-SD1(I2,I1+L1)
      IF(I .EQ. 2 .AND. J .EQ. 1) SD1(I2,I1+L1)=-SD1(I2,I1+L1)
      IF(I .EQ. 2 .AND. J .EQ. 3) SD1(I2,I1+L1)=-SD1(I2,I1+L1)
      IF(I .EQ. 3 .AND. J .EQ. 2) SD1(I2,I1+L1)=-SD1(I2,I1+L1)
 45   CONTINUE
      ENDIF
 30   CONTINUE
      CALL ASSEM(SK,SD1,JJ1,JK1,NDF,MOT,KK,N,NL,NN)
      RETURN
      END


      SUBROUTINE ASSEM(SK,SD1,JJ1,JK1,NDF,MOT,KK,N,NB,NN)
      DIMENSION  SD1(80,80),JJ1(30),JK1(30),SK(300,50)
C     REARRANGEMENT OF MEMBER STIFFNESS MATRIX
         ND=NDF*MCT
         NNJ=(JJ1(N)-1)*ND
         NNK=(JK1(N)-1)*ND
      DO 10 L=1,ND
      DO 12 K=L,ND
         IR=NNJ+L
         IC=NNJ+K-IR+1
 12      SK(IR,IC)=SK(IR,IC) + SD1(L,K)
      IF(KK .EQ. 3) GO TO 10
      DO 30 I1=1,ND
         IC=NNK+I1-IR+1
 30      SK(IR,IC)=SK(IR,IC) + SD1(L,I1+ND)
      IF(IC .GT. NB) NB=IC
 10   CONTINUE
      IF(KK .EQ. 3) GO TO 50
      DO 40 L=1,ND
      DO 40 K=L,ND
```

```
         IR=NNK+L
         IC=NNK+K-IR+1
 40      SK(IR,IC)=SK(IR,IC) + SD1(ND+L,ND+K)
 50   RETURN
      END


      SUBROUTINE ALOAD(DIS,PP,Y,NP,NU,MOT,NSID,NDF,AH,NODL)
      DIMENSION DIS(300),YM(3),AH(30),YT(2,2),T(8,2),APF(3),Z(2)
      DATA  NT/10/
C     WRITE(6,111) PP,Y,NP,NU,MOT,NSID,NDF,AH(1),NODL
         LE=NSID
         A1=AH(LE)
      DO 10 MO=1,MOT
      DO 2 I=1,3
 2       APF(I)=0.0
         K1=(LE-1)*NDF*MOT+(MO-1)*NDF
      IF(NP .NE. 0) THEN
         CALL SHAPEA(Y,YM,MO,A1)
      IF(NP .EQ. 1) APF(1)=APF(1)+YM(1)*PP
      IF(NP .EQ. 2) APF(2)=APF(2)+YM(2)*PP
      IF(NP .EQ. 3) APF(3)=APF(3)+YM(2)*PP
      ELSE
         ROOT3=SQRT(3.0)
         HA=A1
         HB=0.0
         H=(HA-HB)/FLOAT(NT)
         P=H/(2.0*ROOT3)
      DO 20 J=1,NT
         Z(1)=HB+(FLOAT(J)-0.5)*H-P
         Z(2)=Z(1)+P*2.0
      DO 30 K=1,2
         Y=Z(K)
         CALL SHAPEA(Y,YM,MO,A1)
         YT(K,1)=YM(1)
 30      YT(K,2)=YM(2)
         T(MO,1)=T(MO,1)+YT(1,1)+YT(2,1)
 20      T(MO,2)=T(MO,2)+YT(1,2)+YT(2,2)
      DO 40 L=1,2
 40      T(MO,L)=T(MO,L)*H/2.0
      IF(NU .EQ. 1) APF(1)=APF(1)+T(MO,1)*PP
      IF(NU .EQ. 2) APF(2)=APF(2)+T(MO,2)*PP
      IF(NU .EQ. 3) APF(3)=APF(3)+T(MO,2)*PP
      ENDIF
      DO 10 J=1,NDF
 10      DIS(K1+J)=DIS(K1+J)+APF(J)
      RETURN
      END


      SUBROUTINE SOLVE  ( SK,DIS,N,MS,NX,MX)
C     GAUSS ELIMINATION METHOD
      DIMENSION SK(NX,MX),DIS(NX),D( 80)
         N1=N-1
      IF(ABS(SK(N, 1)) .LE. 0.0000000001) THEN
         SK(N,1)=10.0**30
      ELSE
         GO TO 310
      ENDIF
 310  DO 100 K=1,N1
         C=SK(K,1)
         K1=K+1
      IF(ABS(C) - 0.0000000001) 1,1,3
```



```
 1    WRITE(6,2) K
 2    FORMAT('**** SINGULARITY IN ROW ',I5)
      GO TO 300
C     DIVIDE ROW BY DIAGONAL COEFFICIENT
 3       NI=K1+MS-2
         L=MIN(NI,N)
      DO 11 J=2,MS
 11      D(J)=SK(K,J)
      DO 4 J=K1,L
         K2=J-K+1
 4       SK(K,K2)=SK(K,K2)/C
         DIS(K)=DIS(K)/C
C     ELIMINATE UNKNOWN X(K) FROM ROW I
      DO 10 I=K1, L
         K2=I-K1+2
         C=D(K2)
      DO 5 J=I,L
         K2=J-I+1
         K3=J-K+1
 5       SK(I,K2 )=SK(I,K2 ) - C*SK(K, K3 )
 10      DIS(I)=DIS(I)-C*DIS(K)
 100  CONTINUE
C     COMPUTE UNKNOWN
      IF(ABS(SK(N, 1))- 0.0000000001) 1,1,101
 101     DIS(N)=DIS(N)/SK(N,1)
C     BACKSUBSTITUTION TO COMPUTE UNKNOWN
      DO 200 I=1,N1
         K=N-I
         K1=K+1
         NI=K1 + MS - 2
         L=MIN(NI, N)
      DO 200 J=K1,L
         K2= J-K+1
 200     DIS(K)=DIS(K)-SK(K,K2 )*DIS(J)
 300  RETURN
      END


      SUBROUTINE DISP(LH,MOT,DIS,NCL,NCR,YPC,NI,HDEF,DIPLO,ROT,NDF,AH,
     1                NCP)
      DIMENSION DS(3),YM(3),DIS(300),NYP(30),HT(30),AH(30),NI(2),NNP(2),
     1          HDEF(40),DIPLO(40),ROT(40),YPC(40)
C     COMPUTE DISPLACEMENT AT SPECIFIED POINTS
      DO 40 I=1,NCP
         HDEF(I)=0.0
         DIPLO(I)=0.0
 40      ROT(I)=0.0
         NNP(1)=NCL
         NNP(2)=NCR
      DO 20 KK=1,2
      IF(NI(KK) .EQ. 0) GO TO 20
      IF(NI(KK) .NE. 0) NX=NI(KK)
      DO 20 MM=1,NNP(KK)
            M=MM
      IF(KK .EQ. 2) M=MM+NCL
         A1=AH(NX)
      DO 90 J=1,NDF
 90      DS(J)=0.0
         N=1
      DO 30 MO=1,MOT
         K=NDF*(MO-1)+NDF*(NX-1)*MOT
         Y=YPC(M)
      CALL SHAPEA (Y,YM,MO,A1)
```

```
      MT=MO
         DS(1)=DS(1)+DIS(K+1)*YM(1)
         DS(2)=DS(2)+DIS(K+2)*YM(2)
 50   IF(LH .EQ. 2)  DS(3)=DS(3)+DIS(K+3)*YM(2)
         HDEF(M)=DS(1)
         DIPLO(M)=DS(2)
         ROT(M)=DS(3)
 20   CONTINUE
 10   FORMAT(////45X,'COMPUTED OUTPUT RESULTS:'/45X,23('*'))
 30   FORMAT( //   'DISPLACEMENT AND ROTATION :' /   25('*'))
 70   FORMAT( / 7X,'POINTS',2X,'SERIES', 9X,'X-AXIS',9X,'Y-AXIS',9X,
     1   'Z-ROTN')
 100  FORMAT(F15.2,I8 ,3F15.12)
      RETURN
      END


      SUBROUTINE DBW(LH,MOT,NDF,JJ1,JK1,BL,AH,THK,E1,PX1,PY1,NP,HT,
     1              N,DIS,NPOCT,XDP)
      DIMENSION  D(3,3),DB1(6,6),JJ1(30),JK1(30),THK(30),AH(30),XDP(10),
     1           YM(3),HT(30),PS(6,1),FS(6,1),FSNW(6,10),BL(30),DIS(300),
     1           E1(10)
      WRITE(6,*)' WALL'
         EE=E1(N)
      DO 2 I=1,3
      DO 2 J=1,2*NDF
 2       DB1(I,J)=0.0
         DE=EE/(1.0-PX1*PY1)
         D(1,1)=DE
         D(1,2)=PX1*DE
         D(2,1)=D(1,2)
         D(2,2)=DE
         D(3,3)=EE/(2.0+2.0*PX1)
         A1=AH(JJ1(N))
         B1=BL(N)
      DO 14 M=1,NP
      WRITE(6,300)
 300  FORMAT(/)
      DO 12 I=1,10
      DO 12 J=1,3
 12      FSNW(J,I)=0.0
         NM=1
      DO 10 N1=1,MOT
      DO 10 MO=NM,N1
         L1=NDF*(MO-1)
         NNJ=(JJ1(N)-1)*NDF*MOT+L1
         NNK=(JK1(N)-1)*NDF*MOT+L1
         Y=HT(M)
      CALL SHAPEA(Y,YM,MO,A1)
         D1=D(1,1)*YM(1)
         D2=D(1,2)*YM(3)
         D3=D(2,1)*YM(1)
         D4=D(2,2)*YM(3)
         D5=D(3,3)*YM(2)
      DO 20 L=1,NDF
 20      PS(L,1)=DIS(NNJ+L)
      DO 22 L=1,2
 22      PS(NDF+L,1)=DIS(NNK+L)
      DO 40 K=1,NPOCT
         X=XDP(K)
      IF(LH .EQ. 1) THEN
         X1D=-1.0/B1
```



```
         X11=(1.0-X/B1)
         X12=X/B1
         DB1(1,1)=X1D*D1
         DB1(1,2)=X11*D2
         DB1(1,3)=-X1D*D1
         DB1(1,4)=X12*D2
         DB1(2,1)=X1D*D3
         DB1(2,2)=X11*D4
         DB1(2,3)=-X1D*D3
         DB1(2,4)=X12*D4
         DB1(3,1)=X11*D5
         DB1(3,2)=X1D*D5
         DB1(3,3)=X12*D5
         DB1(3,4)=-X1D*D5
      ELSE
         B1A=-1.0/B1
         B2=1.0-X/B1
         B3=1.0-3.0*X**2/B1**2+2.0*X**3/B1**3
         B4=-6.0*X/B1**2+6.0*X**2/B1**3
         B5=X-2.0*X**2/B1+X**3/B1**2
         B6=1.0-4.0*X/B1+3.0*X**2/B1**2
         B7=1.0/B1
         B8=X/B1
         B9=3.0*X**2/B1**2-2.0*X**3/B1**3
         B10=6.0*X/B1**2-6.0*X**2/B1**3
         B11=X**3/B1**2-X**2/B1
         B12=3.0*X**2/B1**2-2.0*X/B1
         DB1(1,1)=B1A*D1
         DB1(1,2)=B3*D2
         DB1(1,3)=B5*D2
         DB1(1,4)=B7*D1
         DB1(1,5)=B9*D2
         DB1(1,6)=B11*D2
         DB1(2,1)=B1A*D3
         DB1(2,2)=B3*D4
         DB1(2,3)=B5*D4
         DB1(2,4)=B7*D3
         DB1(2,5)=B9*D4
         DB1(2,6)=B11*D4
         DB1(3,1)=B2*D5
         DB1(3,2)=B4*D5
         DB1(3,3)=B6*D5
         DB1(3,4)=B8*D5
         DB1(3,5)=B10*D5
         DB1(3,6)=B12*D5
      ENDIF
         LL=2*NDF
      CALL TMPT(DB1,PS,FS,3,LL,1,6,6 ,1)
      DO 40 J=1,3
 40      FSNW(J,K)=FSNW(J,K)+FS(J,1)
 10      NM=MO+1
      WRITE(6,100) Y,N,MOT
      WRITE(6,*) 'OUTPUT POINTS, X AND Y STRESSES, SHEAR STRESS'
      DO 112 K=1,NPOCT
 112  WRITE(6,120) XDP(K),(FSNW(J,K),J=1,3)
 14   CONTINUE
 100  FORMAT(F10.4,2I5)
 120  FORMAT(F10.4,3F20.6)
      RETURN
      END

      SUBROUTINE DBB(LH,MOT,NP,KTY,KTT,XBPT,J1,J2,BL,AH,AA1,AT1,
     1              Z11,SF1,E2,PX2,X,DIS,NDT,XDF)
```

```
      DIMENSION BK(6,6),DD1(6,6),BT1(6,6),YM(3),SF1(30),E2(10),
     1          AH(30),BL(30),AA1(30),AY1(30),ZI1(30),DIS(300),
     2          NTY(30),PB(6,1),FB(6,1),FSN(6,2),HTT(10,30)
      WRITE(6,*)' BEAM'
      DO 10 I=1,6
      DO 10 J=1,6
         BT1(I,J)=0.0
 10      DD1(I,J)=0.0
      DO 12 I=1,6
      DO 12 J=1,2*NDF
 12      BT1(I,J)=0.0
         A1=AH(J1)
         B1=BL(N)+0.00
         EE=E2(N)
         GS=EE/(2.0*(1.0+PX2))
      DO 28 M=2,NP
      WRITE(6,300)
 300  FORMAT(/)
         Y=HTT(NBPT,M)
         K=NTY(M)
      DO 32 J=1,6
 32      FSN(J,1)=0.0
         NM=1
      DO 30 N1=1,MOT
      DO 30 MO=NM,N1
         PYY=12.0*EE*ZI1(K)*SF1(K)/(GS*AY1(K)*B1**2)
         PP=1.0/(1.0+PYY)
         BK(1,1)=EE*AA1(K)/B1
         BK(2,2)=12.0*EE*ZI1(K)/B1**3*PP
         BK(3,2)=6.0*EE*ZI1(K)/B1**2*PP
         BK(3,3)=EE*ZI1(K)/B1*(3.0*PP+1.0)
         BK(4,4)=BK(1,1)
         BK(5,5)=BK(2,2)
         BK(6,6)=BK(3,3)
         BK(4,1)=-BK(1,1)
         BK(5,2)=-BK(2,2)
         BK(5,3)=-BK(3,2)
         BK(6,2)=BK(3,2)
         BK(6,3)=EE*ZI1(K)/B1*(3.0*PP-1.0)
         BK(6,5)=-BK(6,2)
      DO 40 I=1,6
      DO 40 J=I,6
 40      BK(I,J)=BK(J,I)
      CALL SHAPEA(Y,YM,MO,A1)
         CM=YM(1)
         VM=YM(2)
         CD=YM(2)
      IF(LM .EQ. 1) THEN
         BT1(1,1)=CM
         BT1(2,2)=VM
         BT1(3,1)=-CD
         BT1(4,3)=CM
         BT1(5,4)=VM
         BT1(6,3)=-CD
      ELSE
         J=0
      DO 60 I=1,2
         BT1(1+J,1+J)=CM
         BT1(2+J,2+J)=VM
 60      J=NCT
      GO TO (2,4,6,8),NCT
 2       BT1(3,3)=-CD
         BT1(6,6)=-CD
```



```
      GO TO 100
 4       BT1(3,1)=-UD
         BT1(6,4)=-UD
      GO TO 100
 6       BT1(3,3)=-UD
         BT1(6,4)=-UD
      GO TO 100
 8       BT1(3,1)=-UD
         BT1(6,6)=-UD
      ENDIF
 100     LL=2*NDF
      CALL TMPT(BK,BT1,DD1,6,6,LL,6,6,6)
         L=NDF*(MO-1)
         NNJ=(J1-1)*NDF*MOT+L
         NNK=(J2-1)*NDF*MOT+L
      DO 110 J=1,NDF
         PB(J,1)=DIS(NNJ+J)
 110     PB(J+NDF,1)=DIS(NNK+J)
      CALL TMPT(DD1,PB,FB,6,LL,1,6,6,1)
      DO 34 J=1,6
 34      FSN(J,1)=FSN(J,1)+FB(J,1)
      WRITE(6,200) Y,N,MO,(FSN(J,1),J=1,6)
 30      NM=MO+1
 28      CONTINUE
 200  FORMAT(F8.3,2I5,6F15.4)
      RETURN
      END


      SUBROUTINE TMP (TR,TB,L1,L2,LR,LA)
      DIMENSION TR(LA,LR), TB(LR,LA)
C     TRANSPOSE MATRIX
      DO 10 I=1,L1
      DO 10 J=1,L2
         TR(J,I)=TB(I,J)
 10   CONTINUE
      RETURN
      END


      SUBROUTINE TMPT (FD,SF,DF,LL,LM,LN,L,M,N)
      DIMENSION FD(L,M),SF(M,N), DF(L,N)
C     STANDARD MATRIX MULTIPLICATION
      DO 10 J=1,LN
      DO 10 I=1,LL
         DF(I,J)=0.0
      DO 10 K=1,LM
         DF(I,J)=DF(I,J) +FD(I,K)*SF(K,J)
 10   CONTINUE
      RETURN
      END


      SUBROUTINE SHAPEA (Y, YM, MO, A)
      DIMENSION YM(3)
C     Y - DIRECTION SHAPE FUNCTION
C     INITIALISE Y-DIRECTION TO ZERO
      DO 10 I=1,3
         YM(I)=0.0
 10   CONTINUE
         UT=(2.0*FLOAT(MO)-1.0)*3.1416/2.0
```

```
      IF (MO .EQ. 1)  UM=1.87509918
      IF (MO .EQ. 2)  UM=4.69403989
      IF (MO .EQ. 3)  UM=7.85475922
      IF (MO .EQ. 4)  UM=10.99553970
      IF (MO .EQ. 5)  UM=14.13716980
      IF (MO .GE. 6)  UM=UT
         TM=(SIN(UM) + SINH(UM))/(COS(UM) + COSH(UM))
         TKY=UM*Y/A
         S=SIN(TKY)
         C=COS(TKY)
         SH=SINH(TKY)
         CH=COSH(TKY)
         T=UM/A
         TT=T*T
         TTT=TT*T
         YM(1)=(S-SH - TM*(C - CH))
         YM(2)=(T*C-T*CH - TM*(-T*S - T*SH))
         YM(3)=(-TT*S-TT*SH - TM*(-TT*C - TT*CH))
      RETURN
      END

      SUBROUTINE SHY1(YY, MO, NO, A, AL, AK)
      DIMENSION YY(7),SUM(7),YYL(2,7),YYM(2,2,3),YM(3),Z(2)
         DATA  II/20/
C     INITIALISE TO ZERO
      DO 10 I=1,7
         SUM(I)=0.0
 10   CONTINUE
         ROOT3=SQRT(3.0)
         A1=AL
         B=AK
         H=(B-A1)/FLOAT(II)
         P=H/(2.0*ROOT3)
      DO 20 J=1,II
         Z(1)= A1+(FLOAT(J)-0.5)*H - P
         Z(2)=Z(1) +P*2.0
      DO 50 K=1,2
         Y=Z(K)
      DO 52 I=1,2
      IF(I .EQ. 1) MN=MO
      IF(I .EQ. 2) MN=NO
      CALL SHAPEA (Y, YM, MN, A)
      DO 52 M=1,3
         YYM(K,I,M)=YM(M)
 52   CONTINUE
         YYL(K,1)=YYM(K,1,1)*YYM(K,2,1)
         YYL(K,2)=YYM(K,1,1)*YYM(K,2,3)
         YYL(K,3)=YYM(K,1,2)*YYM(K,2,2)
         YYL(K,4)=YYM(K,1,3)*YYM(K,2,3)
         YYL(K,5)=YYM(K,1,3)*YYM(K,2,1)
         YYL(K,6)=YYM(K,1,2)*YYM(K,2,1)
         YYL(K,7)=YYM(K,1,1)*YYM(K,2,2)
 50   CONTINUE
      DO 20 I=1,7
         SUM(I)=SUM(I)+YYL(1,I)+YYL(2,I)
 20   CONTINUE
      DO 56 I=1,7
         YY(I)=SUM(I)*H/2.0
 56   CONTINUE
      RETURN
      END
```



```
      SUBROUTINE FRAME(NCC,LL,NPC)
      COMMON/PROPF/IPC(40),PXH(40),PYV(40),PMO(40),XF( 80, 80),FF( 80)
      INTEGER RL,CRL,COL,ROW,UBW,V
      REAL L,IZ
      COMMON V,NK,NV,JU,M3,N3
      COMMON L(170),IZ(170),AX(170),AML(170,6),R(170,9),X(170),Y(170),LM
     1       L(170),JJ(170),JK(170)
      COMMON RL(510),CRL(510),A(510),AE(510),D(510),AR(510),DJ(510),
     1       AC(510)
      COMMON S(510,21)
      DIMENSION SMR(6,6),AMD(6),AMSS(6),SM(6,6),SMD(6,6),ARRAY(10),
     1          SF(170),MRVL(170)
      READ(5,*) V,NK,NV
         N3=NK*3
         JU=(NV+1)*3
         M3=V*3
 201  CONTINUE
      WRITE(6,500)
      DO 2 J=1,5
      READ(5,'(A80)') TITLE
      WRITE(6,'(A80)') TITLE
    2 CONTINUE
         NLS=3*NCC+1
         NCD=NLS-1
      READ(5,*) M,NJ,NR,NRJ,E,PX
      DO 3 I=1,6
      DO 3 J=1,6
         SMR(I,J)=0.0
         SM(I,J)=0.0
    3    SMD(I,J)=0.0
      DO 4 I=1,N3
         RL(I)=0.0
      DO 4 J=1,JU
    4    S(I,J)=0.0
         NDJ=3
      WRITE(6,510)
      WRITE(6,520)
         N=NDJ*NJ-NR
      WRITE(6,530)M,NJ,NR,NRJ,E,PX
      WRITE(6,540)
      WRITE(6,550)
      DO15K=1,M
      READ(5,*) I,JJ(I),JK(I),X(I),Y(I),IZ(I),AX(I),SF(I),MRVL(I)
         L(I)=SQRT(X(I)**2+Y(I)**2)
         CX=X(I)/L(I)
         CY=Y(I)/L(I)
      WRITE(6,560)I,JJ(I),JK(I),X(I),Y(I),L(I),IZ(I),AX(I),SF(I),
     1              MRVL(I)
         R(I,3)=0.0
         R(I,6)=0.0
         R(I,7)=0.0
         R(I,8)=0.0
         R(I,1)=CX
         R(I,5)=CX
         R(I,9)=1.0
         R(I,2)=CY
 15      R(I,4)=-CY
      WRITE(6,570)
      WRITE(6,580)
      DO 16 J=1,NRJ
      READ(5,*) K,RL(3*K-2),RL(3*K-1),RL(3*K)
 16   WRITE(6,590) K,RL(3*K-2),RL(3*K-1),RL(3*K)
         CRL(1)=RL(1)
```

```
      NNR=N+NR
      DO 19 K=2,NNR
 19      CRL(K)=CRL(K-1)+RL(K)
         I=0
         UBW=0
         ITEST=0
 219     I=I+1
      IF(I-M) 20,20,266
 20      J1=3*JJ(I)-2
         J2=3*JJ(I)-1
         J3=3*JJ(I)
         K1=3*JK(I)-2
         K2=3*JK(I)-1
         K3=3*JK(I)
C *** CHANGE TO SHEAR DEFORMATION *******
      IF(MRVL(I) .NE. 0) L(I)=L(I)+0.5*SQRT(IZ(I)*12.0/AX(I))
         GS=E/(2.0*(1.0+PX))
         PYY=12.0*E*IZ(I)*SF(I)/(GS*AX(I)*L(I)**2)
         YK1=L(I)**3*(1.0+PYY)
         YK2=2.0-PYY
         YK3=4.0+PYY
         SM(1,1)=E*AX(I)/L(I)
         SM(2,2)=12.0*E*IZ(I)/YK1
         SM(3,2)=6.0*E*IZ(I)*L(I)/YK1
         SM(3,3)=YK3*E*IZ(I)*L(I)**2/YK1
         SM(4,4)=SM(1,1)
         SM(5,5)=SM(2,2)
         SM(6,6)=SM(3,3)
         SM(4,1)=-SM(1,1)
         SM(5,2)=-SM(2,2)
         SM(5,3)=-SM(3,2)
         SM(6,2)=SM(3,2)
         SM(6,3)=YK2*E*IZ(I)*L(I)**2/YK1
         SM(6,5)=-SM(6,2)
      DO 5 IM1=1,6
      DO 5 JM1=IM1,6
 5       SM(IM1,JM1)=SM(JM1,IM1)
         NDD=2*NDJ
         NDDD=NDD/3
      DO 21 K=1,NDDD
      DO 21 J=1,NDD
         KT=3*K
         KU=KT-1
         KV=KT-2
         SMR(J,KV)=SM(J,KV)*R(I,1)+SM(J,KU)*R(I,4)+SM(J,KT)*R(I,7)
         SMR(J,KU)=SM(J,KV)*R(I,2)+SM(J,KU)*R(I,5)+SM(J,KT)*R(I,8)
 21      SMR(J,KT)=SM(J,KV)*R(I,3)+SM(J,KU)*R(I,6)+SM(J,KT)*R(I,9)
      IF(ITEST .EQ. 1) GOTO 101
      DO 22 J=1,NDDD
      DO 22 K=1,NDD
         JT=3*J
         JU=JT-1
         JV=JT-2
         SMD(JV,K)=R(I,1)*SMR(JV,K)+R(I,4)*SMR(JU,K)+R(I,7)*SMR(JT,K)
         SMD(JU,K)=R(I,2)*SMR(JV,K)+R(I,5)*SMR(JU,K)+R(I,8)*SMR(JT,K)
 22      SMD(JT,K)=R(I,3)*SMR(JV,K)+R(I,6)*SMR(JU,K)+R(I,9)*SMR(JT,K)
      IF(RL(J1)) 35,23,35
 23      ROW=J1-CRL(J1)
         S(ROW,1)=S(ROW,1)+SMD(1,1)
      IF(RL(J2)) 25,24,25
 24      S(ROW,2)=S(ROW,2)+SMD(1,2)
 25   IF(RL(J3)) 27,26,27
 26      COL=J3-CRL(J3)-ROW+1
```



```
         S(ROW,COL)=S(ROW,COL)+SMD(1,3)
 27   IF(RL(K1)) 29,28,29
 28      COL=K1-CRL(K1)-ROW+1
         S(ROW,COL)=SMD(1,4)
 29   IF(RL(K2)) 31,30,31
 30      COL=K2-CRL(K2)-ROW+1
         S(ROW,COL)=SMD(1,5)
 31   IF(RL(K3)) 33,32,33
 32      COL=K3-CRL(K3)-ROW+1
         S(ROW,COL)=SMD(1,6)
 33   IF(COL-UBW) 35,35,34
 34      UBW=COL
 35   IF(RL(J2)) 47,36,47
 36      ROW=J2-CRL(J2)
         S(ROW,1)=S(ROW,1)+SMD(2,2)
 37   IF(RL(J3)) 39,38,39
 38      S(ROW,2)=S(ROW,2)+SMD(2,3)
 39   IF(RL(K1)) 41,40,41
 40      COL=K1-CRL(K1)-ROW+1
         S(ROW,COL)=SMD(2,4)
 41   IF(RL(K2)) 43,42,43
 42      COL=K2-CRL(K2)-ROW+1
         S(ROW,COL)=SMD(2,5)
 43   IF(RL(K3)) 45,44,45
 44      COL=K3-CRL(K3)-ROW+1
         S(ROW,COL)=SMD(2,6)
 45   IF(COL-UBW) 47,47,46
 46      UBW=COL
 47   IF(RL(J3)) 56,48,56
 48      ROW=J3-CRL(J3)
         S(ROW,1)=S(ROW,1)+SMD(3,3)
      IF(RL(K1)) 50,49,50
 49      COL=K1-CRL(K1)-ROW+1
         S(ROW,COL)=SMD(3,4)
 50   IF(RL(K2)) 52,51,52
 51      COL=K2-CRL(K2)-ROW+1
         S(ROW,COL)=SMD(3,5)
 52   IF(RL(K3)) 54,53,54
 53      COL=K3-CRL(K3)-ROW+1
         S(ROW,COL)=SMD(3,6)
 54   IF(COL-UBW) 56,56,55
 55      UBW=COL
 56   IF(RL(K1)) 61,57,61
 57      ROW=K1-CRL(K1)
         S(ROW,1)=S(ROW,1)+SMD(4,4)
      IF(RL(K2)) 59,58,59
 58      S(ROW,2)=S(ROW,2)+SMD(4,5)
 59   IF(RL(K3)) 61,60,61
 60      COL=K3-CRL(K3)-ROW+1
         S(ROW,COL)=S(ROW,COL)+SMD(4,6)
 61   IF(RL(K2)) 64,62,64
 62      ROW=K2-CRL(K2)
         S(ROW,1)=S(ROW,1)+SMD(5,5)
      IF(RL(K3)) 64,63,64
 63      S(ROW,2)=S(ROW,2)+SMD(5,6)
 64   IF(RL(K3)) 66,65,66
 65      ROW=K3-CRL(K3)
         S(ROW,1)=S(ROW,1)+SMD(6,6)
 66   GOTO 219
 266     III=1
      CALL RESEND(N,UBW,S,III)
 67      LN=0
         LP=0
```

```
      WRITE(6,600)
 267     LN=LN+1
         LE=LN+LL
  69  DO 70 I=1,V
         LML(I)=0
      DO 70 J=1,6
         AMSS(J)=0.0
         AMD(J)=0.0
  70     AML(I,J)=0.0
      DO 71 I=1,N3
         DJ(I)=0.0
         D(I)=0.0
         AC(I)=0.0
         A(I)=0.0
         AE(I)=0.0
  71     AR(I)=0.0
      IF(LN .GT. NCD) GOTO 72
      IF(LN .GT. NCC) GOTO 1128
      IF(PXH(LE) .EQ. 0.0) GOTO 267
         K=IPC(LE)
         A(3*K-2)=+1.0
      WRITE(6,610) K
      GOTO 88
1128     NOV=2*NCC
      IF(LN .GT. NOV) GOTO 1130
         NOVI=LE-NCC
      IF(PYV(NOVI) .EQ. 0.0) GOTO 267
         K=IPC(NOVI)
         A(3*K-1)=+1.0
      WRITE(6,620) K
      GOTO 88
1130     NOWI=LE-NOV
      IF(PMO(NOWI) .EQ. 0.0) GOTO 267
         K=IPC(NOWI)
         A(3*K)=+1.0
      WRITE(6,630) K
      GOTO 88
  72     LM=LN-NCD
      WRITE(6,640) LM
      READ(5,650)(ARRAY(I),I=1,10)
      WRITE(6,660)(ARRAY(I),I=1,10)
      READ(5,*) NLJ,NLM
      WRITE(6,670)NLJ
      WRITE(6,680)NLM
      IF(NLJ) 76,80,76
  76  WRITE(6,690)
      WRITE(6,700)
      DO 79 J=1,NLJ
      READ(5,*) K,A(3*K-2),A(3*K-1),A(3*K)
  79  WRITE(6,710)K,A(3*K-2),A(3*K-1),A(3*K)
  80  IF(NLM) 81,88,81
  81  READ(5,*) III
      IF(III) 386,281,386
 281  WRITE(6,720)
      WRITE(6,730)
      WRITE(6,740)
 284  DO 85 J=1,NLM
      READ(5,*) I,AML(I,1),AML(I,2),AML(I,3),AML(I,4),AML(I,5),
     1         AML(I,6)
      WRITE(6,750)I,AML(I,1),AML(I,2),AML(I,3),AML(I,4),AML(I,5),
     1         AML(I,6)
  85  LML(I)=1
      GOTO 811
```



```
 386  CALL LOAD(L,AML,LML,NLM)
 811  IF(III-1) 127,285,285
 285  DO 87 I=1,M
      IF(LML(I)-1) 87,86,87
  86     INA=3*JJ(I)-2
         AE(INA)=AE(INA)-R(I,1)*AML(I,1)-R(I,4)*AML(I,2)-R(I,7)*AML(I,3)
         INB=INA+1
         AE(INB)=AE(INB)-R(I,2)*AML(I,1)-R(I,5)*AML(I,2)-R(I,8)*AML(I,3)
         INC=INA+2
         AE(INC)=AE(INC)-R(I,3)*AML(I,1)-R(I,6)*AML(I,2)-R(I,9)*AML(I,3)
         IND=3*JK(I)-2
         AE(IND)=AE(IND)-R(I,1)*AML(I,4)-R(I,4)*AML(I,5)-R(I,7)*AML(I,6)
         INE=IND+1
         AE(INE)=AE(INE)-R(I,2)*AML(I,4)-R(I,5)*AML(I,5)-R(I,8)*AML(I,6)
         INF=IND+2
         AE(INF)=AE(INF)-R(I,3)*AML(I,4)-R(I,6)*AML(I,5)-R(I,9)*AML(I,6)
  87  CONTINUE
  88  DO 91 J=1,NNR
      IF(RL(J))90,89,90
  89     K=J-CRL(J)
      GOTO 91
  90     K=N+CRL(J)
  91     AC(K)=A(J)+AE(J)
      WRITE(6,760)
      WRITE(6,770)
      CALL SLVBND(N,UBW,S,AC,D)
         J=N+1
      DO 96 JEJ=1,NNR
         JE=NNR-JEJ+1
      IF(RL(JE))95,94,95
  94  J=J-1
         DJ(JE)=D(J)
      GOTO 96
  95     DJ(JE)=0.0
  96  CONTINUE
      IF(LM.GT.0) GO TO 973
      IF(LN.GT.NCC) GOTO 974
      DO 970 JE=1,NCC
         JT=JE+LL
         LT=LE
         JEE=IPC(JT)
         JET=3*JEE
         JX=3*JT-2
         LX=3*LT-2
      IF(LX.GT.JX) GOTO 980
         XF(LX,JX)=DJ(JET-2)
 980  IF(LX.GT.JX+1) GOTO 981
         XF(LX,JX+1)=DJ(JET-1)
 981  IF(LX.GT.JX+2) GOTO 970
         XF(LX,JX+2)=DJ(JET)
 970  WRITE(6,780) JEE,DJ(JET-2),DJ(JET-1),DJ(JET)
      GOTO 1126
 974  IF(LN.GT.NOV) GOTO 976
      DO 977 JE=1,NCC
         JT=JE+LL
         LT=LE-NCC
         JEE=IPC(JT)
         JET=3*JEE
         JX=3*JT-2
         LX=3*LT-1
      IF(LX.GT.JX) GOTO 982
         XF(LX,JX)=DJ(JET-2)
 982  IF(LX.GT.JX+1) GOTO 983
```

```
      XF(LX,JX+1)=DJ(JET-1)
  983 IF(LX.GT.JX+2) GOTO 977
      XF(LX,JX+2)=+DJ(JET)
  977 WRITE(6,780)JEE,DJ(JET-2),DJ(JET-1),DJ(JET)
      GOTO 1126
  976 DO 979 JE=1,NCC
        JT=JE+LL
        LT=LE-2*NCC
        JEE=IPC(JT)
        JET=3*JEE
        JX=3*JT-2
        LX=3*LT
      IF(LX.GT.JX) GOTO 984
        XF(LX,JX)=DJ(JET-2)
  984 IF(LX.GT.JX+1) GOTO 985
        XF(LX,JX+1)=DJ(JET-1)
  985 IF(LX.GT.JX+2) GOTO 979
        XF(LX,JX+2)=DJ(JET)
  979 WRITE(6,780)JEE,DJ(JET-2),DJ(JET-1),DJ(JET)
      GOTO 1126
  973 CONTINUE
      DO 972 JE=1,NCC
        JT=JE+LL
        JEE=IPC(JT)
        JET=3*JEE
        JT=JT+2*LL
        FF(3*JT-2)=DJ(JET-2)
        FF(3*JT-1)=DJ(JET-1)
        FF(3*JT)=+DJ(JET)
  972 WRITE(6,780) JEE,DJ(JET-2),DJ(JET-1),DJ(JET)
      GOTO 1126
 1135 CONTINUE
        NJS=3*NJ
      DO 97 JE=3,NJS,3
        JEE=JE/3
   97 WRITE(6,790)JEE,DJ(JE-2),DJ(JE-1),DJ(JE)
      WRITE(6,800)
      WRITE(6,810)
      WRITE(6,820)
        ITEST=1
        I=0
  200   I=I+1
      IF(I-M)20,20,117
  101 DO 102 J=1,6
  102 AMD(J)=SMR(J,1)*DJ(J1)+SMR(J,2)*DJ(J2)+SMR(J,3)*DJ(J3)+SMR(J,4)*DJ
     1     (K1)+SMR(J,5)*DJ(K2)+SMR(J,6)*DJ(K3)
      WRITE(6,830) I
      DO 104 J=1,6
  104   AMSS(J)=AML(I,J)+AMD(J)
      WRITE(6,840)(AMSS(J),J=1,6)
      IF(RL(J1)-1)106,105,106
  105   AR(J1)=AR(J1)+R(I,1)*AMD(1)+R(I,4)*AMD(2)+R(I,7)*AMD(3)
  106 IF(RL(J2)-1)108,107,108
  107   AR(J2)=AR(J2)+R(I,2)*AMD(1)+R(I,5)*AMD(2)+R(I,8)*AMD(3)
  108 IF(RL(J3)-1)110,109,110
  109   AR(J3)=AR(J3)+R(I,3)*AMD(1)+R(I,6)*AMD(2)+R(I,9)*AMD(3)
  110 IF(RL(K1)-1)112,111,112
  111   AR(K1)=AR(K1)+R(I,1)*AMD(4)+R(I,4)*AMD(5)+R(I,7)*AMD(6)
  112 IF(RL(K2)-1)114,113,114
  113   AR(K2)=AR(K2)+R(I,2)*AMD(4)+R(I,5)*AMD(5)+R(I,8)*AMD(6)
  114 IF(RL(K3)-1)200,115,200
  115   AR(K3)=AR(K3)+R(I,3)*AMD(4)+R(I,6)*AMD(5)+R(I,9)*AMD(6)
  116 GOTO 200
```



```
  117 WRITE(6,850)
      WRITE(6,860)
      DO 121 K=1,NNR
      IF(RL(K)-1)121,120,121
  120   AR(K)=AR(K)-A(K)-AE(K)
  121 CONTINUE
      DO 126 KE=3,NJS,3
      IF(RL(KE-2)-1)122,124,122
  122 IF(RL(KE-1)-1)123,124,123
  123 IF(RL(KE)-1)126,124,126
  124   KEE=KE/3
      WRITE(6,870)KEE,AR(KE-2),AR(KE-1),AR(KE)
  126 CONTINUE
 1126 CONTINUE
      IF(LN-NLS)267,129,129
  127 WRITE(6,882)
  129 DO 801 I=1,NOW
  801 WRITE(6,884) (XF(I,K),K=1,NOW)
  130 WRITE(6,886)V,NK,NV
  500 FORMAT(////,1H1,1X,25HANALYSIS OF A PLANE FRAME)
  510 FORMAT(////,1H ,10HFRAME DATA)
  520 FORMAT(1H0,3X,7HMEMBERS,10X,6HJOINTS,7X,10HRESTRAINTS,6X,
     1      10HJNTS RESTR,10X,1HE,10X,2HPX)
  530 FORMAT(1H ,I8,3I15,F22.3,F12.3)
  540 FORMAT(////,1H ,18HMEMBER INFORMATION)
  550 FORMAT(///,1H ,3X,6HMEMBER,2X,10HJOINT NOS.,12X,1HX,13X,1HY,11X,6H
     1LENGTH,7X,2HIZ,7X,4HAREA,7X,2HSF,7X,4HMRVL)
  560 FORMAT(I7,2I6,5X,F13.3,F14.3,F15.3,F11.3,F10.3,F9.2,F10.2)
  570 FORMAT(////,1H ,16HJOINT RESTRAINTS)
  580 FORMAT(1H0,4X,5HJOINT,10X,7HRESTR-X,8X,7HRESTR-Y,8X,7HRESTR-M)
  590 FORMAT(1H ,I8,3I15)
  600 FORMAT(1H1,39HUNIT LOADS APPLIED AT CONNECTING JOINTS)
  610 FORMAT(////,1H ,30HUNIT HORIZONTAL LOAD AT JOINT ,I6)
  620 FORMAT(////,1H ,28HUNIT VERTICAL LOAD AT JOINT ,I6)
  630 FORMAT(////,1H ,26HUNIT MOMENT LOAD AT JOINT ,I6)
  640 FORMAT(1H1,11HLOADING NO.,I2)
  650 FORMAT(10A8)
  660 FORMAT(10A8)
  670 FORMAT(//,1H ,20HNO. OF LOADED JOINTS,I5)
  680 FORMAT(//,1H ,20HNO.OF LOADED MEMBERS,I4)
  690 FORMAT(////,1H ,25HACTIONS APPLIED AT JOINTS)
  700 FORMAT(/,1H ,4X,5HJOINT,14X,2HFX,18X,2HFY,16X,6HMOMENT)
  710 FORMAT(1H ,I8,3F20.3)
  720 FORMAT(////,1H ,28HFIXED END FORCES AND MOMENTS)
  730 FORMAT(//,1H ,3X,6HMEMBER,22X,5HEND-1,49X,5HEND-2,/)
  740 FORMAT(18X,'FX',12X,'FY',13X,'MOMENT',18X,'FX',12X,'FY',13X,
     1'MOMENT')
  750 FORMAT(1H ,I8,3F15.3,6X,3F15.3)
  760 FORMAT(////,1H ,19HJOINT DISPLACEMENTS)
  770 FORMAT(1H0,4X,5HJOINT,8X,11HX-DIRECTION,9X,11HY-DIRECTION,8X,13HRO
     1TATION-RADS)
  780 FORMAT(1H ,I8,3F20.8)
  790 FORMAT(1H ,I8,3F20.8)
  800 FORMAT(////,1H ,18HMEMBER END ACTIONS)
  810 FORMAT(1H0,3X,6HMEMBER,13X,5HEND-1,45X,5HEND-2)
  820 FORMAT(17X,5HAXIAL,10X,5HSHEAR,10X,6HMOMENT,14X,5HAXIAL,10X,
     1      5HSHEAR,10X,6HMOMENT)
  830 FORMAT(1H ,I8)
  840 FORMAT(1H+,8X,3F15.3,F20.3,2F15.3)
  850 FORMAT(////,1H ,17HSUPPORT REACTIONS/)
  860 FORMAT(1H ,4X,5HJOINT,14X,2HFX,18X,2HFY,16X,6HMOMENT)
  870 FORMAT(1H ,I8,3F20.3)
  882 FORMAT(1H0,15HPROCEDURE FAILS)
```

```
  884 FORMAT(1X,6F17.9)
  886 FORMAT(////14HMAXM. MEMBERS=,I6,4X,13HMAXM. JOINTS=,I6,4X,
     1              18HMAXM. JOINT DIFF.=,I6)
      RETURN
      END


      SUBROUTINE LOAD(L,AML,LML,NLM)
      REAL L
      DIMENSION L(170),AML(170,6),LML(170)
      WRITE(6,286)
  286 FORMAT(////,1H ,12HMEMBER LOADS)
      WRITE(6,724)
  724 FORMAT(////,1H ,5X,6HMEMBER,5X,4HLOAD,15X,5HTOTAL)
      WRITE(6,725)
  725 FORMAT(1H ,7X,2HNO,7X,4HTYPE,15X,4HLOAD,14X,1HA,14X,1HC)
  289 DO 800 J=1,NLM
      READ(5,*) I,NTOL
      DO 701 N=1,NTOL
      READ(5,*) LT,W,A,C
      ST=L(I)
      B=L(I)-A
      GOTO(730,731,732,733,734),LT
  730 WRITE(6,830)I
      DI=(W*B*(ST**2-B**2))/(6.0*ST)
      DJ=(W*A*(ST**2-A**2))/(6.0*ST)
      GOTO 700
  731 WRITE(6,831)I
      DI=(W*B*(4.0*A*(B+ST)-C**2))/(24.0*ST)
      DJ=(W*A*(4.0*B*(A+ST)-C**2))/(24.0*ST)
      GOTO 700
  732 WRITE(6,832)I
      AL=A/ST
      BL=B/ST
      CL=C/ST
      DI=W*ST**2*(270.0*(BL-BL**3)-CL**2*(45.0*BL+2.0*CL))/1620.0
      DJ=W*ST**2*(270.0*(AL-AL**3)-CL**2*(45.0*AL-2.0*CL))/1620.0
      GOTO 700
  733 WRITE(6,833)I
      AL=A/ST
      BL=B/ST
      CL=C/ST
      DI=(W*ST**2)*(270.0*(BL-BL**3)-CL**2*(45.0*BL-2.0*CL))/1620.0
      DJ=(W*ST**2)*(270.0*(AL-AL**3)-CL**2*(45.0*AL+2.0*CL))/1620.0
  700 FI=(2.0*DJ-4.0*DI)/ST
      FJ=(4.0*DJ-2.0*DI)/ST
      RI=(FI+FJ-W*B)/ST
      RJ=(-FI-FJ-W*A)/ST
      EI=0.0
      EJ=0.0
      GOTO 750
  734 WRITE(6,834)I
      EI=-(W*B)/ST
      EJ=-(W*A)/ST
      FI=0.0
      FJ=0.0
      RI=0.0
      RJ=0.0
  750 AML(I,1)=AML(I,1)+EI
      AML(I,2)=AML(I,2)+RI
      AML(I,3)=AML(I,3)+FI
      AML(I,4)=AML(I,4)+EJ
      AML(I,5)=AML(I,5)+RJ
```



```
      AML(I,6)=AML(I,6)+FJ
      WRITE(6,726)W,A,C
  726 FORMAT(1H+,28X,3F15.3)
  701 CONTINUE
  800 LML(I)=1
  830 FORMAT(1H ,I8,6X,8HCONC    )
  831 FORMAT(1H ,I8,6X,8HUNIFORM )
  832 FORMAT(1H ,I8,6X,8HTRIANG R)
  833 FORMAT(1H ,I8,6X,8HTRIANG L)
  834 FORMAT(1H ,I8,6X,8HAXIAL   )
      RETURN
      END

      SUBROUTINE DECBND(N,UBW,A,III)
      INTEGER P,Q,UBW
      DIMENSION A(510,21)
      DO 509 I=1,N
         P=N-I+1
      IF(UBW-P)500,501,501
  500    P=UBW
  501 DO 509 J=1,P
         Q=UBW-J
      IF((I-1)-Q)502,503,503
  502    Q=I-1
  503    SUM=A(I,J)
      IF(Q)532,532,531
  531 DO 530 K=1,Q
         IK=I-K
         JK=J+K
      IF(IK)530,530,504
  504    SUM=SUM-A(IK,1+K)*A(IK,JK)
  530 CONTINUE
  532 IF(J-1)505,506,505
  505    A(I,J)=SUM*TEMP
      GOTO 509
  506 IF(SUM)507,507,508
  507    III=0
      RETURN
  508    TEMP=1.0/SQRT(SUM)
         A(I,J)=TEMP
  509 CONTINUE
      RETURN
      END


      SUBROUTINE SLVBND(N,UBW,U,B,X)
      INTEGER UBW
      DIMENSION U(510,21),B(510),X(510)
      DO 513 I=1,N
         J=I-UBW+1
      IF((I+1)-UBW)510,510,511
  510    J=1
  511    SUM=B(I)
         IM=I-1
      IF(J-IM)550,550,513
  550 DO 551 K=J,IM
         IKP=I-K+1
      IF(IKP)551,551,512
  512    SUM=SUM-U(K,IKP)*X(K)
  551 CONTINUE
  513    X(I)=SUM*U(I,1)
      DO 517 II=1,N
         I=N-II+1
```

```
      J=I+UBW-1
      IF(J-N)515,515,514
  514    J=N
  515    SUM=X(I)
         IP=I+1
      IF(IP-J)552,552,517
  552 DO 553 K=IP,J
         KIP=K-I+1
      IF(KIP)553,553,516
  516    SUM=SUM-U(I,KIP)*X(K)
  553 CONTINUE
  517    X(I)=SUM*U(I,1)
      RETURN
      END
```

Program C - Continuum Combined with Plane Frame

```
      COMMON/PROPW/A1,A2,ZI1,ZI2,C1,C4,CC1,CC4,COSH,SINH,ALPHA,BETA,EW
      COMMON/CONW/BERA,BENR,BENE,BEGA,BEGR,FL,EK1,EK4,H,GAMMA,ENETA
      COMMON/PROPF/IPC(40),PXH(40),PYV(40),PMO(40),XF(120,120),FF(120)
      COMMON/POOPW/XW(120,120),FW(120),XP(120)
      COMMON/PROCP/NLT(40),APL(40),AXI(40),YPC(40),C2,C3
      COMMON/PROPD/DFW(120),DXW(120,120)
      DIMENSION NL(40)
      CHARACTER *8 PROGRM, TODAY, CURTIM
      PARAMETER (PROGRM ='PFSWA')
C INPUT OF WALL DATA
         CALL  DATE(TODAY)
         CALL TIME(CURTIM)
         WRITE (6,88999) PROGRM, TODAY, CURTIM
88999    FORMAT( 10(/), 25X,'PROGRAM  USED IS :',A8,
     1              4(/),20X,'DATE :',A10,'   TIME  ',A10,10(/) )
       TSET  = TIMER(0.0)
      READ(5,*) D1,D2,DCB,B,CBL,FH,H,EW,PW
      ZI1=35.30
      ZI2=35.30
      A1=6.08
      A2=6.08
      FL=CBL+(D1+D2)/2.0
      CBA=CBL+DCB
      EG=0.75*(1+PW)
      ZIP=((B*DCB**3)/12.0)/(1+EG*((2*DCB/CBA)**2))
      C1=D1/2
      C2=D1-C1
      C3=D2/2
      C4=D2-C3
C OVERALL WALL CONSTANTS CALCULATED
      ALPHA=SQRT((((FL**2)/(ZI1+ZI2))+(1.0/A1)+(1.0/A2))*12*ZIP/(FH*(CBL
     1**3)))
      BETA=(12.0*ZIP*FL)/((ZI1+ZI2)*FH*(CBL**3))
      GAMMA=12.0*ZIP/(A2*FH*(CBL**3))
      ENETA=12.0*ZIP/(A1*FH*(CBL**3))
      BEMA=(BETA*FL)/(ALPHA**2)
      BERA=1.0-BEMA
      BENE=ENETA-(BETA*C1)
      BEGA=GAMMA-(BETA*C4)
      BENR=((ENETA*FL)/(ALPHA**2))+(C1*BERA)
      BEGR=((GAMMA*FL)/(ALPHA**2))+(C4*BERA)
      SINH=(EXP(ALPHA*H)-EXP(-ALPHA*H))/2.0
      COSH=(EXP(ALPHA*H)+EXP(-ALPHA*H))/2.0
      EK1=(1.0/(A1*EW))-((FL*C1)/((ZI1+ZI2)*EW))
      EK4=(-1.0/(A2*EW))+((FL*C4)/((ZI1+ZI2)*EW))
      CC1=C1/((ZI1+ZI2)*EW)
      CC4=-C4/((ZI1+ZI2)*EW)
      WRITE(6,2)
    2 FORMAT(///,10X,21HSHEAR WALL DIMENSIONS)
      WRITE(6,3)
    3 FORMAT(1H ,10X,21H*********************)
      WRITE(6,4)A1
      WRITE(6,5)ZI1
      WRITE(6,6)A2
      WRITE(6,7)ZI2
      WRITE(6,8)CBL
      WRITE(6,9)ZIP
      WRITE(6,10)H
      WRITE(6,11)FH
      WRITE(6,12) EW
```



```
    4 FORMAT(1H0,24X,20HAREA OF LEFT WALL = ,F9.3)
    5 FORMAT(1H0,7X,37HSECOND MOMENT OF AREA OF LEFT WALL = ,F17.3)
    6 FORMAT(1H0,23X,21HAREA OF RIGHT WALL = ,F9.3)
    7 FORMAT(1H0,6X,38HSECOND MOMENT OF AREA OF RIGHT WALL = ,F17.3)
    8 FORMAT(1H0,16X,28HLENGTH OF CONNECTING BEAM = ,F9.3)
    9 FORMAT(1H0,12X,32HSECOND MOMENT OF AREA OF BEAM = ,F9.3)
   10 FORMAT(1H0,27X,17HOVERALL HEIGHT = ,F9.3)
   11 FORMAT(1H0,29X,15HFLOOR HEIGHT = ,F9.3)
   12 FORMAT(1H0,20X,24HMODULUS OF ELASTICITY = ,F17.3)
C INPUT OF CONNECTING POINTS DATA
      READ(5,*) NCL,NCR
      WRITE(6,14) NCL
   14 FORMAT(1H0,5X,33HNO. OF L.H.S.CONNECTION POINTS = ,I4)
      WRITE(6,15) NCR
   15 FORMAT(1H0,5X,33HNO. OF R.H.S.CONNECTION POINTS = ,I4)
      NCP=NCL+NCR
      DO16I=1,NCP
      PXH(I)=0.0
      PYV(I)=0.0
   16 PMO(I)=0.0
      IF(NCL.EQ.0) GOTO22
      DO17I=1,NCL
      READ(5,*) YCP,NXH,NYV,NMO,ICP
      WRITE(6,19) YCP,NXH,NYV,NMO,ICP
      YPC(I)=YCP
      IPC(I)=ICP
      NL(I)=-1
      IF(NXH.EQ.0) GOTO20
      PXH(I)=1000.0
   20 IF(NYV.EQ.0) GOTO21
      PYV(I)=1000.0
   21 IF(NMO.EQ.0) GOTO17
      PMO(I)=1000.0
   17 CONTINUE
   19 FORMAT(1X,F10.4,4I6)
   22 IF(NCR.EQ.0) GOTO26
      DO23I=1,NCR
      READ(5,*) YCP,NXH,NYV,NMO,ICP
      WRITE(6,19) YCP,NXH,NYV,NMO,ICP
      YPC(I+NCL)=YCP
      IPC(I+NCL)=ICP
      NL(I+NCL)=1
      IF(NXH.EQ.0) GOTO24
      PXH(I+NCL)=1000.0
   24 IF(NYV.EQ.0) GOTO25
      PYV(I+NCL)=1000.0
   25 IF(NMO.EQ.0) GOTO23
      PMO(I+NCL)=1000.0
   23 CONTINUE
   26 CONTINUE
C CALCULATION OF XW MATRIX
      NPC=3*NCP
      DO27I=1,NPC
      DO27J=1,NPC
   27 XW(I,J)=0.0
      DO28N=1,NCP
      IF(PXH(N).EQ.0) GOTO28
       P=PXH(N)
      XI=YPC(N)
      IF(N.GT.NCL) GOTO31
```

```
      WRITE(6,30) IPC(N)
   30 FORMAT(1H0,4X,40HHORIZONTAL FORCE L.H.S.CONNECTING POINT ,I3)
      GOTO33
   31 NN=N-NCL
      WRITE(6,32) IPC(N)
   32 FORMAT(1H0,4X,40HHORIZONTAL FORCE R.H.S.CONNECTING POINT ,I3)
   33 DO34M=1,NCP
      X=YPC(M)
      IF(N.GT.M)GOTO34
      CALL DEH(X,XI,P,HDEF,ROT,DIPLO,DIPRO)
      N1=3*N-2
      M1=3*M-2
      XW(N1,M1)=HDEF
      IF(NL(M).EQ.1)GOTO35
      XW(N1,M1+1)=DIPLO
      GOTO36
   35 XW(N1,M1+1)=DIPRO
   36 XW(N1,M1+2)=ROT
   34 CONTINUE
   28 CONTINUE
      DO37N=1,NCP
      IF(PTV(N).EQ.0) GOTO37
      P=PTV(N)
      XI=YPC(N)
      IF(N.GT.NCL) GOTO42
      DO38M=1,NCP
      X=YPC(M)
      IF(N.GT.M)GOTO38
      CALL DEVL(X,XI,P,HDEF,ROT,DIPLO,DIPRO)
      N1=3*N-1
      M1=3*M-2
      IF(N1.GT.M1)GOTO39
      XW(N1,M1)=HDEF
   39 IF(NL(M).EQ.1) GOTO40
      XW(N1,M1+1)=DIPLO
      GOTO29
   40 XW(N1,M1+1)=DIPRO
   29 XW(N1,M1+2)=ROT
   38 CONTINUE
      GOTO37
   42 DO41M=1,NCP
      X=YPC(M)
      IF(N.GT.M)GOTO41
      CALL DEVR(X,XI,P,HDEF,ROT,DIPLO,DIPRO)
      N1=3*N-1
      M1=3*M-2
      IF(N1.GT.M1)GOTO44
      XW(N1,M1)=HDEF
   44 IF(NL(M).EQ.1) GOTO43
      XW(N1,M1+1)=DIPLO
      GOTO74
   43 XW(N1,M1+1)=DIPRO
   74 XW(N1,M1+2)=ROT
   41 CONTINUE
   37 CONTINUE
      DO45N=1,NCP
      IF(PTH(N).EQ.0) GOTO45
      P=PTH(N)
      XI=YPC(N)
      DO46M=N,NCP
```



```
      X=YPC(M)
      IF(N.GT.M)GOTO46
      CALL DEM(X,XI,P,HDEF,ROT,DIPLO,DIPRO)
      N1=3*N
      M1=3*M-2
      IF(N1.GT.M1)GOTO77
      XW(N1,M1)=HDEF
   75 IF(NL(M).EQ.1)GOTO76
      XW(N1,M1+1)=DIPLO
      GOTO77
   76 XW(N1,M1+1)=DIPRO
   77 XW(N1,M1+2)=ROT
   46 CONTINUE
   45 CONTINUE
      DO1000I=1,NPC
 1000 WRITE(6,1001) (XW(I,J),J=1,NPC)
 1001 FORMAT(1X,6F17.9)
C CALCULATION OF FW MATRIX
      DO48J=1,NPC
   48 FW(J)=0.0
      READ (5,*) NFW
      WRITE(6,1004) NFW
 1004 FORMAT(1H ,18HNO FORCES ON WALL=,I4)
      IF(NFW.EQ.0) GOTO 47
      DO59I=1,NFW
      READ(5,*) NLT(I),APL(I),AXI(I)
      WRITE(6,1005) NLT(I),APL(I),AXI(I)
 1005 FORMAT(1H ,4HTYPE,I4,5HFORCE,F8.3,8HLOCATION,F8.3)
      P=APL(I)
      XI=AXI(I)
      NTL=NLT(I)
      DO50M=1,NCP
      X=YPC(M)
      GOTO(51,52,53,54,55,56),NTL
   51 CALL DEH(X,XI,P,HDEF,ROT,DIPLO,DIPRO)
      GOTO57
   52 CALL DEVL(X,XI,P,HDEF,ROT,DIPLO,DIPRO)
      GOTO57
   53 CALL DEVR(X,XI,P,HDEF,ROT,DIPLO,DIPRO)
      GOTO 57
   54 CALL DEM(X,XI,P,HDEF,ROT,DIPLO,DIPRO)
      GOTO 57
   55 CALL UDL(X,P,HDEF,ROT,DIPLO,DIPRO)
      GOTO 57
   56 CALL TDL(X,P,HDEF,ROT,DIPLO,DIPRO)
   57 FW(3*M-2)=FW(3*M-2)+HDEF
      IF(NL(M).EQ.1) GO TO 58
      FW(3*M-1)=FW(3*M-1)+DIPLO
      GOTO 50
   58 FW(3*M-1)=FW(3*M-1)+DIPRO
   50 FW(3*M)=FW(3*M)+ROT
   59 CONTINUE
   47 CONTINUE
      DO120I=1,NPC
      DFW(I)=FW(I)
      DO120J=I,NPC
      DXW(I,J)=XW(I,J)
  120 DXW(J,I)=XW(I,J)
      WRITE(6,3002)
 3002 FORMAT(10HDXW MATRIX)
```

```
      DO3001I=1,NPC
 3001 WRITE(6,3000)(DXW(I,J),J=1,NPC)
 3000 FORMAT(1X,6F17.9)
C XF ANF FF MATRICES SET UP
      NPC=3*(NCL+NCR)
      DO60I=1,NPC
      FF(I)=0.0
      DO60J=1,NPC
   60 XF(I,J)=0.0
      IF(NCL.EQ.0)GOTO 61
C LEFT HAND FRAME
      LL=0
      CALL FRAME(NCL,LL)
   61 IF(NCR.EQ.0)GOTO62
C RIGHT HAND FRAME
      LL=NCL
      CALL FRAME(NCR,LL)
   62 CONTINUE
C     DO1002I=1,NPC
C1002 WRITE(6,1001)(XF(I,J),J=1,NPC)
C     DO1003I=1,NPC
C1003 WRITE(6,1001)FF(I)

C MODIFICATIOM OF MATRICES FOR PINNED CONNECTIONS
      NPM=0
      DO80I=1,NCP
      IF(PXH(I).NE.0.0)GOTO81
      NPM=NPM+1
      NPP=NPC-NPM+1
      I2=3*I-2-NPM
      I3=3*I-NPM
      DO82J=1,I2
      DO82K=I3,NPP
      XF(J,K-1)=XF(J,K)
   82 XW(J,K-1)=XW(J,K)
      DO83J=I3,NPP
      DO83K=J,NPP
      FF(J-1)=FF(J)
      FW(J-1)=FW(J)
      XF(J-1,K-1)=XF(J,K)
   83 XW(J-1,K-1)=XW(J,K)
   81 IF(PYV(I).NE.0.0)GOTO84
      NPM=NPM+1
      NPP=NPC-NPM+1
      I2=3*I-1-NPM
      I3=3*I+1-NPM
      DO86J=1,I2
      DO86K=I3,NPP
      XF(J,K-1)=XF(J,K)
   86 XW(J,K-1)=XW(J,K)
      DO88J=I3,NPP
      DO88K=J,NPP
      FF(J-1)=FF(J)
      FW(J-1)=FW(J)
      XF(J-1,K-1)=XF(J,K)
   88 XW(J-1,K-1)=XW(J,K)
   84 IF(PMO(I).NE.0.0)GOTO80
      NPM=NPM+1
      I2=3*I-NPM
      I3=3*I+2-NPM
```



```
      NPP=NPC-NPM+1
      IF(I3.GT.NPP)GOTO80
      DO92J=1,I2
      DO92K=I3,NPP
      XF(J,K-1)=XF(J,K)
   92 XW(J,K-1)=XW(J,K)
      DO94J=I3,NPP
      DO94K=J,NPP
      FF(J-1)=FF(J)
      FW(J-1)=FW(J)
      XF(J-1,K-1)=XF(J,K)
   94 XW(J-1,K-1)=XW(J,K)
   80 CONTINUE
      NPD=NPC-NPM
C     WRITE(6,2004)
C2004 FORMAT(1H ,17HMODIFIED MATRICES)
C     DO2001I=1,NPD
C2001 WRITE(6,1001)(XF(I,J),J=1,NPD)
C     DO2002I=1,NPD
C2002 WRITE(6,1001)(XW(I,J),J=1,NPD)
C     DO2003I=1,NPD
C2003 WRITE(6,1001)FF(I)
C SOLUTION OF EQUTIONS
      CALL SOLV(NPD)
C     DO63I=1,NPD
C  63 WRITE(6,64) XP(I)
C  64 FORMAT(1X,F10.5)
CMODIFY XP MATRIX TO OBTAIN FORCES AT CONNECTIONS
      DO100I=1,NCP
      IF(PXH(I).NE.0.0)GOTO102
      I3=3*I-2
      I4=I3+1
      NPD=NPD+1
      DO104J=I4,NPD
      JE=NPD-J+I4
  104 XP(JE)=XP(JE-1)
      XP(I3)=0.0
  102 IF(PYV(I).NE.0.0)GOTO106
      I3=3*I-1
      I4=I3+1
      NPD=NPD+1
      DO108J=I4,NPD
      JE=NPD-J+I4
  108 XP(JE)=XP(JE-1)
      XP(I3)=0.0
  106 IF(PMO(I).NE.0.0)GOTO100
      I3=3*I
      I4=I3+1
      NPD=NPD+1
      DO110J=I4,NPD
      JE=NPD-J+I4
  110 XP(JE)=XP(JE-1)
      XP(I3)=0.0
  100 CONTINUE
C CALCULATION OF ACTUAL FORCES
      IF(NCL.EQ.0) GOTO 65
      WRITE(6,66)
      WRITE(6,67)
      WRITE(6,68)
   66 FORMAT(///,1X,14HLEFT HAND SIDE)
```

```
   67 FORMAT(4X,10HCONNECTING,4X,10HHORIZONTAL,4X,8HVERTICAL)
   68 FORMAT(6X,5HPOINT,9X,5HFORCE,9X,5HFORCE,6X,6HMOMENT)
      DO69I=1,NCL
      K=IPC(I)
      PXH(I)=PXH(I)*XP(3*I-2)
      PYV(I)=PYV(I)*XP(3*I-1)
      PMO(I)=PMO(I)*XP(3*I)
   69 WRITE(6,70)K,PXH(I),PYV(I),PMO(I)
   70 FORMAT(1X,I8,F18.6,2F14.6)
   65 IF(NCR.EQ.0) GOTO71
      LL=NCL
      WRITE(6,72)
      WRITE(6,67)
      WRITE(6,68)
   72 FORMAT(///,1X,15HRIGHT HAND SIDE)
      DO73I=1,NCR
      N=I+LL
      K=IPC(N)
      PXH(N)=PXH(N)*XP(3*N-2)
      PYV(N)=PYV(N)*XP(3*N-1)
      PMO(N)=PMO(N)*XP(3*N)
   73 WRITE(6,70)K,PXH(N),PYV(N),PMO(N)
   71 CONTINUE
      CALL FORW(NCP,NCL,NFW)
      CALL FORB(NCP,NCL,NFW,FH,CBL)
      CALL DEFW(NCP,NCL)
        TNOW = TIMER(TSET)
        WRITE (6,99995) TNOW
99995   FORMAT(///,T30,'TOTAL CPU TIME :',G12.4,' MILLI. SEC.',//)
      STOP
      END
        FUNCTION TIMER(TBEG)
        CALL MTIME(T)
        TIMER = T-TBEG
        RETURN
        END
      SUBROUTINE DEH(X,XI,P,HDEF,ROT,DIPLO,DIPRO)
      COMMON/PROPW/A1,A2,ZI1,ZI2,C1,C4,CC1,CC4,COSH,SINH,ALPHA,BETA,EW
      COMMON/CONW/BERA,BENR,BENE,BEGA,BEGR,FL,EK1,EK4,H,GAMMA,ENETA
      SINHXI=(EXP(ALPHA*XI)-EXP(-ALPHA*XI))/2.0
      COSHXI=(EXP(ALPHA*XI)+EXP(-ALPHA*XI))/2.0
      SEC=(EXP(ALPHA*(H-XI))+EXP(-ALPHA*(H-XI)))/2.0
      SES=(EXP(ALPHA*(H-XI))-EXP(-ALPHA*(H-XI)))/2.0
      SINHX=(EXP(ALPHA*(H-X))-EXP(-ALPHA*(H-X)))/2.0
      COSHX=(EXP(ALPHA*(H-X))+EXP(-ALPHA*(H-X)))/2.0
      DEH1=3*(XI**2)*X-(XI**3)
      DEH2=XI
      DEH3=(1-COSHXI)*SINHX-SINH+SES
      DEH4=0.0
      ROT1=XI**2
      ROT2=0.0
      ROT3=(1-COSHXI)*COSHX
      DEV1=(1-COSHXI)*COSHX
      DEV2=0.0
      DEV3=XI**2
      IF(X.GT.XI)GOTO1
      SECH=(EXP(ALPHA*(XI-X))-EXP(-ALPHA*(XI-X)))/2.0
      TANH=(EXP(ALPHA*(XI-X))+EXP(-ALPHA*(XI-X)))/2.0
      DEH1=DEH1+((XI-X)**3)
      DEH2=DEH2-(XI-X)
```



```
      DEH4=SECH*COSH
      ROT1=ROT1-((XI-X)**2)
      ROT2=(1-TANH)*COSH
      DEV2=(1-TANH)*COSH
      DEV3=DEV3-((XI-X)**2)
    1 TDEH1=BERA*DEH1/6.0
      TDEH2=DEH2*BETA*FL/(ALPHA**4)
      TDEH3=(DEH3+DEH4)*BETA*FL/(COSH*(ALPHA**5))
      TROT1=ROT1*BERA/2.0
      TROT2=(ROT2-ROT3)*BETA*FL/(COSH*(ALPHA**4))
      TDEV1=(DEV1-DEV2)*BETA/(COSH*(ALPHA**4))
      TDEV2=DEV3*BETA/((ALPHA**2)*2)
      HDEF=P*(TDEH1+TDEH2+TDEH3)/(EW*(ZI1+ZI2))
      ROT=-P*(TROT1+TROT2)/(EW*(ZI1+ZI2))
      DIPLO=EK1*P*(TDEV1+TDEV2)+(CC1*P*DEV3/2.0)
      DIPRO=EK4*P*(TDEV1+TDEV2)+(CC4*P*DEV3/2.0)
C     WRITE(6,2) X,XI,HDEF,ROT,DIPLO,DIPRO
C   2 FORMAT(1X,6F17.9)
      RETURN
      END
      SUBROUTINE DEVL(X,XI,P,HDEF,ROT,DIPLO,DIPRO)
      COMMON/PROPW/A1,A2,ZI1,ZI2,C1,C4,CC1,CC4,COSH,SINH,ALPHA,BETA,EW
      COMMON/CONW/BERA,BENR,BENE,BEGA,BEGR,FL,EK1,EK4,H,GAMMA,ENETA
      SINHXI=(EXP(ALPHA*XI)-EXP(-ALPHA*XI))/2.0
      COSHXI=(EXP(ALPHA*XI)+EXP(-ALPHA*XI))/2.0
      SEC=(EXP(ALPHA*(H-XI))+EXP(-ALPHA*(H-XI)))/2.0
      SES=(EXP(ALPHA*(H-XI))-EXP(-ALPHA*(H-XI)))/2.0
      SINHX=(EXP(ALPHA*(H-X))-EXP(-ALPHA*(H-X)))/2.0
      COSHX=(EXP(ALPHA*(H-X))+EXP(-ALPHA*(H-X)))/2.0
      DEH1=(XI**2)-(2*X*XI)
      DEH2=COSH
      DEH3=SINHX*SINHXI+SEC
      ROT1=XI
      ROT2=COSHX*SINHXI
      ROT3=0.0
      DEV1=XI
      DEV2=COSHX*SINHXI
      DEV3=0.0
      IF(X.GT.XI) GOTO1
      SECH=(EXP(ALPHA*(XI-X))-EXP(-ALPHA*(XI-X)))/2.0
      TANH=(EXP(ALPHA*(XI-X))+EXP(-ALPHA*(XI-X)))/2.0
      DEH1=DEH1-(XI-X)**2
      DEH2=DEH2*TANH
      ROT1=ROT1-(XI-X)
      ROT3=COSH*SECH
      DEV1=DEV1-(XI-X)
      DEV3=COSH*SECH
    1 TDEH1=-BENR*DEH1/2.0
      TDEH2=(DEH3-DEH2)*FL*BENE/(COSH*ALPHA**4)
      TROT1=BENR*ROT1
      TROT2=BENE*FL*(ROT3-ROT2)/(COSH*ALPHA**3)
      TDEV1=-BENE*DEV1/(ALPHA**2)
      TDEV2=BENE*(DEV2-DEV3)/(COSH*ALPHA**3)
      HDEF=P*(TDEH1+TDEH2)/(EW*(ZI1+ZI2))
      ROT=-P*(TROT1+TROT2)/(EW*(ZI1+ZI2))
      DIPLO=P*EK1*(TDEV1+TDEV2)+P*DEV1*((1.0/(A1*EW))+C1*CC1)
      DIPRO=P*EK4*(TDEV1+TDEV2)+P*C1*CC4*DEV1
C     WRITE(6,2) X,XI,HDEF,ROT,DIPLO,DIPRO
C   2 FORMAT(1X,6F17.9)
      RETURN
```

```
      END
      SUBROUTINE DEVR(X,XI,P,HDEF,ROT,DIPLO,DIPRO)
      COMMON/PROPW/A1,A2,ZI1,ZI2,C1,C4,CC1,CC4,COSH,SINH,ALPHA,BETA,EW
      COMMON/CONW/BERA,BENR,BENE,BEGA,BEGR,FL,EK1,EK4,H,GAMMA,ENETA
      SINHXI=(EXP(ALPHA*XI)-EXP(-ALPHA*XI))/2.0
      COSHXI=(EXP(ALPHA*XI)+EXP(-ALPHA*XI))/2.0
      SEC=(EXP(ALPHA*(H-XI))+EXP(-ALPHA*(H-XI)))/2.0
      SES=(EXP(ALPHA*(H-XI))-EXP(-ALPHA*(H-XI)))/2.0
      SINHX=(EXP(ALPHA*(H-X))-EXP(-ALPHA*(H-X)))/2.0
      COSHX=(EXP(ALPHA*(H-X))+EXP(-ALPHA*(H-X)))/2.0
      DEH1=(XI**2)-(2*X*XI)
      DEH2=SINHX*SINHXI+SEC
      DEH3=COSH
      ROT1=XI
      ROT2=COSHX*SINHXI
      ROT3=0.0
      DEV1=XI
      DEV2=0.0
      DEV3=COSHX*SINHXI
      IF(X.GT.XI) GOTO1
      SECH=(EXP(ALPHA*(XI-X))-EXP(-ALPHA*(XI-X)))/2.0
      TANH=(EXP(ALPHA*(XI-X))+EXP(-ALPHA*(XI-X)))/2.0
      DEH1=DEH1-((XI-X)**2)
      DEH3=DEH3*TANH
      ROT1=ROT1-(XI-X)
      ROT3=COSH*SECH
      DEV1=DEV1-(XI-X)
      DEV2=COSH*SECH
    1 TDEH1=BEGR*DEH1/2.0
      TDEH2=(DEH3-DEH2)*BEGA*FL/(COSH*ALPHA**4)
      TROT1=-BEGR*ROT1
      TROT2=(ROT2-ROT3)*BEGA*FL/(COSH*ALPHA**3)
      TDEV1=BEGA*DEV1/(ALPHA**2)
      TDEV2=BEGA*(DEV2-DEV3)/(COSH*ALPHA**3)
      HDEF=P*(TDEH1+TDEH2)/(EW*(ZI1+ZI2))
      ROT=-P*(TROT1+TROT2)/(EW*(ZI1+ZI2))
      DIPLO=P*EK1*(TDEV1+TDEV2)-P*C4*CC1*DEV1
      DIPRO=P*EK4*(TDEV1+TDEV2)+P*DEV1*((1.0/(A2*EW))-C4*CC4)
C     WRITE(6,2) X,XI,HDEF,ROT,DIPLO,DIPRO
C   2 FORMAT(1X,6F17.9)
      RETURN
      END
      SUBROUTINE DEM(X,XI,P,HDEF,ROT,DIPLO,DIPRO)
      COMMON/PROPW/A1,A2,ZI1,ZI2,C1,C4,CC1,CC4,COSH,SINH,ALPHA,BETA,EW
      COMMON/CONW/BERA,BENR,BENE,BEGA,BEGR,FL,EK1,EK4,H,GAMMA,ENETA
      SINHXI=(EXP(ALPHA*XI)-EXP(-ALPHA*XI))/2.0
      COSHXI=(EXP(ALPHA*XI)+EXP(-ALPHA*XI))/2.0
      SEC=(EXP(ALPHA*(H-XI))+EXP(-ALPHA*(H-XI)))/2.0
      SES=(EXP(ALPHA*(H-XI))-EXP(-ALPHA*(H-XI)))/2.0
      SINHX=(EXP(ALPHA*(H-X))-EXP(-ALPHA*(H-X)))/2.0
      COSHX=(EXP(ALPHA*(H-X))+EXP(-ALPHA*(H-X)))/2.0
      DEH1=(XI**2)-2*XI*X
      DEH2=COSH
      DEH3=SEC+SINHX*SINHXI
      ROT1=XI
      ROT2=COSHX*SINHXI
      ROT3=0.0
      DEV1=XI
      DEV2=COSHX*SINHXI
      DEV3=0.0
```



```
      IF(X.GT.XI) GOTO1
      SECH=(EXP(ALPHA*(XI-X))-EXP(-ALPHA*(XI-X)))/2.0
      TANH=(EXP(ALPHA*(XI-X))+EXP(-ALPHA*(XI-X)))/2.0
      DEH1=DEH1-(XI-X)**2
      DEH2=COSH*TANH
      ROT1=ROT1-(XI-X)
      ROT3=COSH*SECH
      DEV1=DEV1-(XI-X)
      DEV3=COSH*SECH
    1 TDEH1=BERA*DEH1/2.0
      TDEH2=BETA*FL*(DEH3-DEH2)/(COSH*ALPHA**4)
      TROT1=-BERA*ROT1
      TROT2=BETA*FL*(ROT3-ROT2)/(COSH*ALPHA**3)
      TDEV1=DEV1*BETA/(ALPHA**2)
      TDEV2=BETA*(DEV2-DEV3)/(COSH*ALPHA**3)
      HDEF=P*(TDEH1+TDEH2)/(EW*(ZI1+ZI2))
      ROT=-P*(TROT1+TROT2)/(EW*(ZI1+ZI2))
      DIPLO=P*EK1*(TDEV2-TDEV1)-(P*DEV1*CC1)
      DIPRO=P*EK4*(TDEV2-TDEV1)-(P*CC4*DEV1)
C     WRITE(6,2) X,XI,HDEF,ROT,DIPLO,DIPRO
C   2 FORMAT(1X,6F17.9)
      RETURN
      END
      SUBROUTINE UDL(X,P,HDEF;ROT,DIPLO,DIPRO)
      COMMON/PROPW/A1,A2,ZI1,ZI2,C1,C4,CC1,CC4,COSH,SINH,ALPHA,BETA,EW
      COMMON/CONW/BERA,BENR,BENE,BEGA,BEGR,FL,EK1,EK4,H,GAMMA,ENETA
      SINHX=(EXP(ALPHA*(H-X))-EXP(-ALPHA*(H-X)))/2.0
      COSHX=(EXP(ALPHA*(H-X))+EXP(-ALPHA*(H-X)))/2.0
      SECHX=(EXP(ALPHA*X)-EXP(-ALPHA*X))/2.0
      TANHX=(EXP(ALPHA*X)+EXP(-ALPHA*X))/2.0
      DEH1=((H*X**2)/2)-((X**3)/3)+((X**4)/(4*H))
      DEH2=(H*X)-(X**2/2)
      DEH3=SINHX-SINH
      DEH4=(1-TANHX)/(ALPHA*H)
      ROT1=(H*X)-(X**2)+(X**3/H)
      ROT2=COSHX
      ROT3=SECHX
      ROT4=H-X
      DEV1=ROT1
      DEV2=ROT4
      DEV3=SECHX
      DEV4=COSHX
      TDEH1=BERA*DEH1/2.0
      TDEH2=BEMA*DEH2/(ALPHA**2*H)
      TDEH3=(DEH3-DEH4)*BEMA/(COSH*ALPHA**3)
      TROT1=BERA*ROT1/2.0
      TROT2=ROT2*BEMA/(COSH*ALPHA**2)
      TROT3=ROT3*BEMA/(H*COSH*ALPHA**3)
      TROT4=ROT4*BEMA/(H*ALPHA**2)
      TDEV1=DEV1*BETA/(2*ALPHA**2)
      TDEV2=DEV2*BETA/(H*ALPHA**4)
      TDEV3=DEV3*BETA/(H*COSH*ALPHA**5)
      TDEV4=DEV4*BETA/(COSH*ALPHA**4)
      HDEF=P*(TDEH1+TDEH2+TDEH3)/(EW*(ZI1+ZI2))
      ROT=-P*(TROT1-TROT2+TROT3+TROT4)/(EW*(ZI1+ZI2))
      DIPLO=EK1*P*(TDEV1-TDEV2+TDEV3+TDEV4)+(CC1*P*DEV1/2)
      DIPRO=EK4*P*(TDEV1-TDEV2+TDEV3+TDEV4)+(CC4*P*DEV1/2)
      RETURN
      END
      SUBROUTINE TDL(X,P,HDEF,ROT,DIPLO,DIPRO)
```

```
      COMMON/PROPW/A1,A2,ZI1,ZI2,C1,C4,CC1,CC4,COSH,SINH,ALPHA,BETA,EW
      COMMON/CONW/BERA,BENR,BENE,BEGA,BEGR,FL,EK1,EK4,H,GAMMA,ENETA
      SINHX=(EXP(ALPHA*(H-X))-EXP(-ALPHA*(H-X)))/2.0
      COSHX=(EXP(ALPHA*(H-X))+EXP(-ALPHA*(H-X)))/2.0
      SECHX=(EXP(ALPHA*X)-EXP(-ALPHA*X))/2.0
      TANHX=(EXP(ALPHA*X)+EXP(-ALPHA*X))/2.0
      DEH1=((2*H*X**3)/6)-(X**3/6)+(X**5/(60*H**2))
      DEH2=(SINHX/(ALPHA*COSH))+X
      DEH3=DEH2+(1/COSH)
      DEH4=((X**3)/6)-(TANHX/(COSH*ALPHA**2))
      ROT1=(2*H*X/3)-(X**2/2)+(X**4/(12*H**2))
      ROT2=1-(COSHX/COSH)
      ROT3=(X**2/2)-(SECHX/(ALPHA*COSH))
      DEV1=ROT2
      DEV2=ROT3
      DEV3=ROT1
      TDEH1=BERA*DEH1
      TDEH2=BEMA*DEH2/(ALPHA**2)
      TDEH3=2*BEMA*DEH3/((H**2)*(ALPHA**4))
      TDEH4=2*BEMA*DEH4/((H**2)*(ALPHA**4))
      TROT1=BERA*ROT1
      TROT2=ROT2*(BEMA/(ALPHA**2))
      TROT3=2*ROT2*(BEMA/((H**2)*(ALPHA**4)))
      TROT4=2*BEMA*ROT3*((H**2)*(ALPHA**2))
      TDEV1=DEV1*BETA/(ALPHA**4)
      TDEV2=(DEV1*2*BETA)/((H**2)*(ALPHA**6))
      TDEV3=(2*BETA*DEV2)/((H**2)*(ALPHA**4))
      TDEV4=DEV3*BETA/(ALPHA**2)
      HDEF=P*(TDEH1+TDEH2-TDEH3-TDEH4)/(EW*(ZI1+ZI2))
      ROT=-P*(TROT1+TROT2-TROT3-TROT4)/(EW*(ZI1+ZI2))
      DIPLO=EK1*P*(-TDEV1+TDEV2+TDEV3+TDEV4)+(CC1*P*DEV3)
      DIPRO=EK4*P*(-TDEV1+TDEV2+TDEV3+TDEV4)+(CC4*P*DEV3)
      RETURN
      END
      SUBROUTINE DEVRO(X,XI,P,HDEF,ROT,DIPLO,DIPRO)
      COMMON/PROPW/A1,A2,ZI1,ZI2,C1,C4,CC1,CC4,COSH,SINH,ALPHA,BETA,EW
      COMMON/CONW/BERA,BENR,BENE,BEGA,BEGR,FL,EK1,EK4,H,GAMMA,ENETA
      SINHXI=(EXP(ALPHA*XI)-EXP(-ALPHA*XI))/2.0
      COSHXI=(EXP(ALPHA*XI)+EXP(-ALPHA*XI))/2.0
      SEC=(EXP(ALPHA*(H-XI))+EXP(-ALPHA*(H-XI)))/2.0
      SES=(EXP(ALPHA*(H-XI))-EXP(-ALPHA*(H-XI)))/2.0
      SINHX=(EXP(ALPHA*(H-X))-EXP(-ALPHA*(H-X)))/2.0
      COSHX=(EXP(ALPHA*(H-X))+EXP(-ALPHA*(H-X)))/2.0
      DEH1=(XI**2)-(2*XI*X)
      DEH2=SEC+(SINHXI*SINHX)
      DEH3=COSH
      ROT1=XI
      ROT2=SINHXI*COSHX
      ROT3=0.0
      DEV1=XI
      DEV2=0.0
      DEV3=COSHXI*SINHXI
      IF(X.GT.XI) GOTO1
      SECH=(EXP(ALPHA*(XI-X))-EXP(-ALPHA*(XI-X)))/2.0
      TANH=(EXP(ALPHA*(XI-X))+EXP(-ALPHA*(XI-X)))/2.0
      DEH1=DEH1-((XI-X)**2)
      DEH3=DEH3*TANH
      ROT1=ROT1-(XI-X)
      ROT3=COSH*SECH
      DEV1=DEV1-(XI-X)
```



```
      DEV2=COSH*SECH
    1 TDEH1=DEH1*GAMMA*FL/(2*ALPHA**2)
      TDEH2=(DEH3-DEH2)*GAMMA*FL/(COSHH*ALPHA**4)
      TROT1=-ROT1*GAMMA*FL/(ALPHA**2)
      TROT2=(ROT2-ROT3)*GAMMA*FL/(COSH*ALPHA**3)
      TDEV1=DEV1*GAMMA/(ALPHA**2)
      TDEV2=(DEV2-DEV3)*GAMMA/(COSH*ALPHA**3)
      HDEF=P*(TDEH1+TDEH2)/(EW*(ZI1+ZI2))
      ROT=-P*(TROT1+TRORT2)/(EW*(ZI1+ZI2))
      DIPLO=P*EK1*(TDEV1+TDEV2)
      DIPRO=P*EK4*(TDEV1+TDEV2)+P*DEV1/(A2*EW)
C     WRITE(6,2) X,XI,HDEF,ROT,DIPLO,DIPRO
C   2 FORMAT(1X,6F17.9)
      RETURN
      END
      SUBROUTINE DEVLO(X,XI,P,HDEF,ROT,DIPLO,DIPRO)
      COMMON/PROPW/A1,A2,ZI1,ZI2,C1,C4,CC1,CC4,COSH,SINH,ALPHA,BETA,EW
      COMMON/CONW/BERA,BENR,BENE,BEGA,BEGR,FL,EK1,EK4,H,GAMMA,ENETA
      SINHXI=(EXP(ALPHA*XI)-EXP(-ALPHA*XI))/2.0
      COSHXI=(EXP(ALPHA*XI)+EXP(-ALPHA*XI))/2.0
      SEC=(EXP(ALPHA*(H-XI))+EXP(-ALPHA*(H-XI)))/2.0
      SES=(EXP(ALPHA*(H-XI))-EXP(-ALPHA*(H-XI)))/2.0
      SINHX=(EXP(ALPHA*(H-X))-EXP(-ALHA*(H-X)))/2.0
      COSHX=(EXP(ALPHA*(H-X))+EXP(-ALPHA*(H-X)))/2.0
      DEH1=(XI**2)-(2*X*XI)
      DEH2=COSH
      DEH3=SEC
      DEH4=SINHX*SINHXI
      ROT1=XI
      ROT2=COSHX*SINHXI
      ROT3=0.0
      DEV1=XI
      DEV2=SINHXI*COSHX
      DEV3=0.0
      IF(X.GT.XI) GOTO1
      SECH=(EXP(ALPHA*(XI-X))-EXP(-ALPHA*(XI-X)))/2.0
      TANH=(EXP(ALPHA*(XI-X))+EXP(-ALPHA*(XI-X)))/2.0
      DEH1=DEH1-(XI-X)**2
      DEH2=COSH*TANH
      ROT1=ROT1-(XI-X)
      ROT3=COSH*SECH
      DEV1=DEV1-(XI-X)
      DEV3=COSH*SECH
    1 TDEH1=-DEH1*ENETA*FL/(2*ALPHA**2)
      TDEH2=(DEH3+DEH4-DEH2)*FL*ENETA/(COSH*ALPHA**4)
      TROT1=ROT1*ENETA*FL/(ALPHA**2)
      TROT2=(ROT3-ROT2)*ENETA*FL/(COSH*ALPHA**3)
      TDEV1=-DEV1*ENETA/(ALPHA**2)
      TDEV2=(DEV2-DEV3)*ENETA/(COSH*ALPHA**3)
      HDEF=P*(TDEH1+TDEH2)/(EW*(ZI1+ZI2))
      ROT=-P*(TROT1+TROT2)/(EW*(ZI1+ZI2))
      DIPLO=P*EK1*(TDEV1+TDEV2)+P*DEV1/(A1*EW)
      DIPRO=P*EK4*(TDEV1+TDEV2)
C     WRITE(6,2) X,XI,HDEF.ROT,DIPLO,DIPRO
C   2 FORMAT(1X,6F17.9)
      RETURN
      END
      SUBROUTINE SOLV(NPC)
      COMMON/PROPF/IPC(40),PXH(40),PTV(40),PMO(40),XF(120,120),FF(120)
      COMMON/POCPW/XW(120,120),FW(120),XP(120)
```

```
      DIMENSION S(120,120)
      DO1I=1,NPC
      FF(I)=FW(I)-FF(I)
      DO1J=I,NPC
      XF(I,J)=XF(I,J)+XW(I,J)
    1 CONTINUE
C SET UP S MATRIX
      S(1,1)=SQRT(XF(1,1))
      DO2J=2,NPC
      S(1,J)=XF(1,J)/S(1,1)
    2 CONTINUE
      DO3I=2,NPC
      DO3J=I,NPC
      SUM=0.0
      L=I-1
      IF(J.NE.I) GOTO 5
      DO4M=1,L
    4 SUM=SUM+S(M,I)**2
      S(I,I)=SQRT(XF(I,I)-SUM)
      GOTO3
    5 CONTINUE
      DO6M=1,L
    6 SUM=SUM+S(M,I)*S(M,J)
      S(I,J)=(XF(I,J)-SUM)/S(I,I)
    3 CONTINUE
      FW(1)=FF(1)/S(1,1)
      DO8I=2,NPC
      SUM=0.0
      L=I-1
      DO9M=1,L
    9 SUM=SUM+S(M,I)*FW(M)
      FW(I)=(FF(I)-SUM)/S(I,I)
    8 CONTINUE
      XP(NPC)=FW(NPC)/S(NPC,NPC)
      NCC=NPC-1
      DO10J=1,NCC
      I=NPC-J
      SUM=0.0
      L=I+1
      DO11M=L,NPC
   11 SUM=SUM+S(I,M)*XP(M)
   10 XP(I)=(FW(I)-SUM)/S(I,I)
      RETURN
      END
      SUBROUTINE FRAME(NCC,LL)
      COMMON/PROPF/IPC(40),PXH(40),PYV(40),PMO(40),XF(120,120),FF(120)
      INTEGER EL,CRL,COL,ROW,UBW,V
      REAL L,IZ
      COMMON V,NK,NV,JC,M3,N3
      COMMON L(170),IZ(170),AX(170),AML(170,6),R(170,9),X(170),Y(170),LM
     1L(170),JJ(170),JK(170)
      COMMON EL(510),CRL(510),A(510),AE(510),D(510),AR(510),DJ(510),AC(5
     110)
      COMMON S(510,21)
      DIMENSION SMR(6,6),AMD(6),AMSS(6),SM(6,6),SMD(6,6),ARRAY(10)
      READ(5,*) V,NK,NV
      M3=NK*3
      JC=(NV+1)*3
      N3=V*3
  231 CONTINUE
```



```
      WRITE(6,1)
    1 FORMAT(////,1H1,1X,25HANALYSIS OF A PLANE FRAME)
      DO501J=1,5
      READ(5,400)(ARRAY(I),I=1,10)
      WRITE(50,400)(ARRAY(I),I=1,10)
  400 FORMAT(10A8)
      WRITE(6,500)(ARRAY(I),I=1,10)
  500 FORMAT(1H0,10A8)
  501 CONTINUE
      NLS=3*NCC+1
      NCD=NLS-1
      READ(5,*) M,NJ,NR,NRJ,E
      DO203I=1,6
      DO203J=1,6
      SMR(I,J)=0.0
      SM(I,J)=0.0
  203 SMD(I,J)=0.0
      DO204I=1,N3
      RL(I)=0.0
      DO204J=1,JU
  204 S(I,J)=0.0
      NDJ=3
      WRITE(6,4)
    4 FORMAT(////,1H ,10HFRAME DATA)
      WRITE(6,5)
    5 FORMAT(1H0,3X,7HMEMBERS,10X,6HJOINTS,7X,10HRESTRAINTS,6X,10HJNTS R
     1ESTR,18X,1HE)
      N=NDJ*NJ-NR
      WRITE(6,6)M,NJ,NR,NRJ,E
    6 FORMAT(1H ,I8,3I15,F30.3)
      WRITE(6,10)
   10 FORMAT(////,1H ,18HMEMBER INFORMATION)
      WRITE(6,11)
   11 FORMAT(///,1H ,3X,6HMEMBER,2X,10HJOINT NOS.,12X,1HX,13X,1HY,11X,6H
     1LENGTH,14X,2HIZ,13X,4HAREA)
      DO15K=1,M
   13 READ(5,*) I,JJ(I),JK(I),X(I),Y(I),IZ(I),AX(I)
      L(I)=SQRT(X(I)**2+Y(I)**2)
      CX=X(I)/L(I)
      CY=Y(I)/L(I)
      WRITE(6,14)I,JJ(I),JK(I),X(I),Y(I),L(I),IZ(I),AX(I)
   14 FORMAT(1H ,I7,2I6,5X,F13.3,F14.3,F15.3,F18.3,F16.3)
      R(I,3)=0.0
      R(I,6)=0.0
      R(I,7)=0.0
      R(I,8)=0.0
      R(I,1)=CX
      R(I,5)=CX
      R(I,9)=1.0
      R(I,2)=CY
   15 R(I,4)=-CY
      WRITE(6,16)
   16 FORMAT(////,1H ,16HJOINT RESTRAINTS)
      WRITE(6,17)
   17 FORMAT(1H0,4X,5HJOINT,10X,7HRESTR-X,8X,7HRESTR-Y,8X,7HRESTR-M)
      DO18J=1,NRJ
      READ(5,*) K,RL(3*K-2),RL(3*K-1),RL(3*K)
   18 WRITE(6,1118)K,RL(3*K-2),RL(3*K-1),RL(3*K)
 1118 FORMAT(1H ,I8,3I15)
      CRL(1)=RL(1)
```

```
      NNR=N+NR
      DO19K=2,NNR
   19 CRL(K)=CRL(K-1)+RL(K)
      I=0
      UBW=0
      ITEST=0
  219 I=I+1
      IF(I-M)20,20,266
   20 J1=3*JJ(I)-2
      J2=3*JJ(I)-1
      J3=3*JJ(I)
      K1=3*JK(I)-2
      K2=3*JK(I)-1
      K3=3*JK(I)
      AI=4.0*E*IZ(I)/L(I)
      AJ=4.0*E*IZ(I)/L(I)
      BIJ=2.0*E*IZ(I)/L(I)
      CI=(AI+BIJ)/L(I)
      CJ=(AJ+BIJ)/L(I)
      DIJ=(CI+CJ)/L(I)
      SCM1A=(E*AX(I))/L(I)
      SM(1,1)=SCM1A
      SM(4,4)=SCM1A
      SM(1,4)=-SCM1A
      SM(4,1)=-SCM1A
      SM(2,2)=DIJ
      SM(2,3)=CI
      SM(2,5)=-DIJ
      SM(2,6)=CJ
      SM(3,2)=CI
      SM(3,3)=AI
      SM(3,5)=-CI
      SM(3,6)=BIJ
      SM(5,2)=-DIJ
      SM(5,3)=-CI
      SM(5,5)=DIJ
      SM(5,6)=-CJ
      SM(6,2)=CJ
      SM(6,3)=BIJ
      SM(6,5)=-CJ
      SM(6,6)=AJ
      NDD=2*NDJ
      NDDD=NDD/3
      DO21K=1,NDDD
      DO21J=1,NDD
      KT=3*K
      KU=KT-1
      KV=KT-2
      SMR(J,KV)=SM(J,KV)*R(I,1)+SM(J,KU)*R(I,4)+SM(J,KT)*R(I,7)
      SMR(J,KU)=SM(J,KV)*R(I,2)+SM(J,KU)*R(I,5)+SM(J,KT)*R(I,8)
   21 SMR(J,KT)=SM(J,KV)*R(I,3)+SM(J,KU)*R(I,6)+SM(J,KT)*R(I,9)
      IF(ITEST.EQ.1)GOTO101
      DO22J=1,NDDD
      DO22K=1,NDD
      JT=3*J
      JW=JT-1
      JV=JT-2
      SMM(JV,K)=R(I,1)*SMR(JV,K)+R(I,4)*SMR(JW,K)+R(I,7)*SMR(JT,K)
      SMM(JW,K)=R(I,2)*SMR(JV,K)+R(I,5)*SMR(JW,K)+R(I,8)*SMR(JT,K)
   22 SMM(JT,K)=R(I,3)*SMR(JV,K)+R(I,6)*SMR(JW,K)+R(I,9)*SMR(JT,K)
```



```
      IF(RL(J1))35,23,35
   23 ROW=J1-CRL(J1)
      S(ROW,1)=S(ROW,1)+SMD(1,1)
      IF(RL(J2))25,24,25
   24 S(ROW,2)=S(ROW,2)+SMD(1,2)
   25 IF(RL(J3))27,26,27
   26 COL=J3-CRL(J3)-ROW+1
      S(ROW,COL)=S(ROW,COL)+SMD(1,3)
   27 IF(RL(K1))29,28,29
   28 COL=K1-CRL(K1)-ROW+1
      S(ROW,COL)=SMD(1,4)
   29 IF(RL(K2))31,30,31
   30 COL=K2-CRL(K2)-ROW+1
      S(ROW,COL)=SMD(1,5)
   31 IF(RL(K3))33,32,33
   32 COL=K3-CRL(K3)-ROW+1
      S(ROW,COL)=SMD(1,6)
   33 IF(COL-UBW)35,35,34
   34 UBW=COL
   35 IF(RL(J2))47,36,47
   36 ROW=J2-CRL(J2)
      S(ROW,1)=S(ROW,1)+SMD(2,2)
   37 IF(RL(J3))39,38,39
   38 S(ROW,2)=S(ROW,2)+SMD(2,3)
   39 IF(RL(K1))41,40,41
   40 COL=K1-CRL(K1)-ROW+1
      S(ROW,COL)=SMD(2,4)
   41 IF(RL(K2))43,42,43
   42 COL=K2-CRL(K2)-ROW+1
      S(ROW,COL)=SMD(2,5)
   43 IF(RL(K3))45,44,45
   44 COL=K3-CRL(K3)-ROW+1
      S(ROW,COL)=SMD(2,6)
   45 IF(COL-UBW)47,47,46
   46 UBW=COL
   47 IF(RL(J3))56,48,56
   48 ROW=J3-CRL(J3)
      S(ROW,1)=S(ROW,1)+SMD(3,3)
      IF(RL(K1))50,49,50
   49 COL=K1-CRL(K1)-ROW+1
      S(ROW,COL)=SMD(3,4)
   50 IF(RL(K2))52,51,52
   51 COL=K2-CRL(K2)-ROW+1
      S(ROW,COL)=SMD(3,5)
   52 IF(RL(K3))54,53,54
   53 COL=K3-CRL(K3)-ROW+1
      S(ROW,COL)=SMD(3,6)
   54 IF(COL-UBW)56,56,55
   55 UBW=COL
   56 IF(RL(K1))61,57,61
   57 ROW=K1-CRL(K1)
      S(ROW,1)=S(ROW,1)+SMD(4,4)
      IF(RL(K2))59,58,59
   58 S(ROW,2)=S(ROW,2)+SMD(4,5)
   59 IF(RL(K3))61,60,61
   60 COL=K3-CRL(K3)-ROW+1
      S(ROW,COL)=S(ROW,COL)+SMD(4,6)
   61 IF(RL(K2))64,62,64
   62 ROW=K2-CRL(K2)
      S(ROW,1)=S(ROW,1)+SMD(5,5)
```

```
      IF(RL(K3))64,63,64
   63 S(ROW,2)=S(ROW,2)+SMD(5,6)
   64 IF(RL(K3))66,65,66
   65 ROW=K3-CRL(K3)
      S(ROW,1)=S(ROW,1)+SMD(6,6)
   66 GOTO219
  266 III=1
      CALL DECBND(N,UBW,S,III)
   67 LN=0
      LM=0
      WRITE(6,2268)
 2268 FORMAT(1H1,39HUNIT LOADS APPLIED AT CONNECTING JOINTS)
  267 LN=LN+1
      LE=LN+LL
   69 DO70I=1,V
      LML(I)=0
      DO70J=1,6
      AMSS(J)=0.0
      AMD(J)=0.0
   70 AML(I,J)=0.0
      DO71I=1,N3
      DJ(I)=0.0
      D(I)=0.0
      AC(I)=0.0
      A(I)=0.0
      AE(I)=0.0
   71 AR(I)=0.0
      IF(LN.GT.NCD) GOTO72
      IF(LN.GT.NCC) GOTO1128
      IF(PXH(LE).EQ.0.0)GOTO267
      K=IPC(LE)
      A(3*K-2)=1000.00
      WRITE(6,1129) K
 1129 FORMAT(////,1H ,30HUNIT HORIZONTAL LOAD AT JOINT ,I6)
      GOTO88
 1128 NOV=2*NCC
      IF(LN.GT.NOV) GOTO1130
      NOVI=LE-NCC
      IF(PYV(NOVI).EQ.0.0) GOTO267
      K=IPC(NOVI)
      A(3*K-1)=1000.00
      WRITE(6,1131) K
 1131 FORMAT(////,1H ,28HUNIT VERTICAL LOAD AT JOINT ,I6)
      GOTO88
 1130 NOWI=LE-NOV
      IF(PMO(NOWI).EQ.0.0) GOTO267
      K=IPC(NOWI)
      A(3*K)=1000.00
      WRITE(6,1132) K
 1132 FORMAT(////,1H ,26HUNIT MOMENT LOAD AT JOINT ,I6)
      GOTO88
   72 LM=LN-NCD
      WRITE(6,73) LM
   73 FORMAT(1H1,11HLOADING NO.,I2)
      READ(5,401)(ARRAY(I),I=1,10)
  401 FORMAT(10A8)
      WRITE(6,502)(ARRAY(I),I=1,10)
  502 FORMAT(1H0,10A8)
      READ(5,*) NLJ,NLM
      WRITE(6,74)NLJ
```



```
   74 FORMAT(//,1H ,20HNO. OF LOADED JOINTS,I5)
      WRITE(6,75)NLM
   75 FORMAT(//,1H ,20HNO.OF LOADED MEMBERS,I4)
      IF(NLJ)76,80,76
   76 WRITE(6,77)
   77 FORMAT(////,1H ,25HACTIONS APPLIED AT JOINTS)
      WRITE(6,78)
   78 FORMAT(/,1H ,4X,5HJOINT,14X,2HFX,18X,2HFY,16X,6HMOMENT)
      DO79J=1,NLJ
      READ(5,*) K,A(3*K-2),A(3*K-1),A(3*K)
   79 WRITE(6,1179)K,A(3*K-2),A(3*K-1),A(3*K)
 1179 FORMAT(1H ,I8,3F20.3)
   80 IF(NLM)81,88,81
   81 READ(5,*) IFL
      IF(IFL)386,281,386
  281 WRITE(6,82)
   82 FORMAT(////,1H ,28HFIXED END FORCES AND MOMENTS)
      WRITE(6,83)
   83 FORMAT(//,1H ,3X,6HMEMBER,22X,5HEND-1,49X,5HEND-2,/)
      WRITE(6,283)
  283 FORMAT(1H ,18X,2HFX,12X,2HFY,13X,6HMOMENT,18X,2HFX,12X,2HFY,13X,6H
     1MOMENT)
  284 DO85J=1,NLM
      READ(5,*) I,AML(I,1),AML(I,2),AML(I,3),AML(I,4),AML(I,5),AML(I,6
     1)
      WRITE(6,84)I,AML(I,1),AML(I,2),AML(I,3),AML(I,4),AML(I,5),AML(I,6)
   84 FORMAT(1H ,I8,3F15.3,6X,3F15.3)
   85 LML(I)=1
      GOTO810
  386 CALL LOAD(L,AML,LML,NLM)
  810 IF(III-1)127,285,285
  285 DO87I=1,M
      IF(LML(I)-1)87,86,87
   86 INA=3*JJ(I)-2
      AE(INA)=AE(INA)-R(I,1)*AML(I,1)-R(I,4)*AML(I,2)-R(I,7)*AML(I,3)
      INB=INA+1
      AE(INB)=AE(INB)-R(I,2)*AML(I,1)-R(I,5)*AML(I,2)-R(I,8)*AML(I,3)
      INC=INA+2
      AE(INC)=AE(INC)-R(I,3)*AML(I,1)-R(I,6)*AML(I,2)-R(I,9)*AML(I,3)
      IND=3*JK(I)-2
      AE(IND)=AE(IND)-R(I,1)*AML(I,4)-R(I,4)*AML(I,5)-R(I,7)*AML(I,6)
      INE=IND+1
      AE(INE)=AE(INE)-R(I,2)*AML(I,4)-R(I,5)*AML(I,5)-R(I,8)*AML(I,6)
      INF=IND+2
      AE(INF)=AE(INF)-R(I,3)*AML(I,4)-R(I,6)*AML(I,5)-R(I,9)*AML(I,6)
   87 CONTINUE
   88 DO91J=1,NNR
      IF(RL(J))90,89,90
   89 K=J-CRL(J)
      GOTO91
   90 K=N+CRL(J)
   91 AC(K)=A(J)+AE(J)
      WRITE(6,92)
   92 FORMAT(////,1H ,19HJOINT DISPLACEMENTS)
      WRITE(6,93)
   93 FORMAT(1H0,4X,5HJOINT,8X,11HX-DIRECTION,9X,11HY-DIRECTION,8X,13HRO
     1TATION-RADS)
      CALL SLVBND(N,UBW,S,AC,D)
      J=N+1
      DO96JLJ=1,NNR
```

```
      JE=NNR-JEJ+1
      IF(RL(JE))95,94,95
   94 J=J-1
      DJ(JE)=D(J)
      GOTO96
   95 DJ(JE)=0.0
   96 CONTINUE
      IF(LM.GT.0)GO TO 973
      IF(LN.GT.NCC)GOTO974
      DO970JE=1,NCC
      JT=JE+LL
      JEE=IPC(JT)
      JET=3*JEE
      LT=LE
      JX=3*JT-2
      LX=3*LT-2
      IF(LX.GT.JX)GOTO980
      XF(LX,JX)=DJ(JET-2)
  980 IF(LX.GT.JX+1)GOTO981
      XF(LX,JX+1)=DJ(JET-1)
  981 IF(LX.GT.JX+2)GOTO970
      XF(LX,JX+2)=DJ(JET)
  970 WRITE(6,971) JEE,DJ(JET-2),DJ(JET-1),DJ(JET)
      GOTO1126
  974 IF(LN.GT.NOV) GOTO976
      DO977JE=1,NCC
      JT=JE+LL
      LT=LE-NCC
      JEE=IPC(JT)
      JET=3*JEE
      JX=3*JT-2
      LX=3*LT-1
      IF(LX.GT.JX)GOTO982
      XF(LX,JX)=DJ(JET-2)
  982 IF(LX.GT.JX+1)GOTO983
      XF(LX,JX+1)=DJ(JET-1)
  983 IF(LX.GT.JX+2)GOTO977
      XF(LX,JX+2)=DJ(JET)
  977 WRITE(6,971)JEE,DJ(JET-2),DJ(JET-1),DJ(JET)
      GOTO1126
  976 DO979JE=1,NCC
      LT=LE-2*NCC
      JT=JE+LL
      JEE=IPC(JT)
      JET=3*JEE
      JX=3*JT-2
      LX=3*LT
      IF(LX.GT.JX)GOTO984
      XF(LX,JX)=DJ(JET-2)
  984 IF(LX.GT.JX+1)GOTO985
      XF(LX,JX+1)=DJ(JET-1)
  985 IF(LX.GT.JX+2)GOTO979
      XF(LX,JX+2)=DJ(JET)
  979 WRITE(6,971)JEE,DJ(JET-2),DJ(JET-1),DJ(JET)
  971 FORMAT(1H ,I8,3F20.8)
      GOTO1126
  973 CONTINUE
      DO972JE=1,NCC
      JT=JE+LL
      JEE=IPC(JT)
```



```
      JET=3*JEE
      JT=JT+2*LL
      FF(3*JT-2)=DJ(JET-2)
      FF(3*JT-1)=DJ(JET-1)
      FF(3*JT)=DJ(JET)
  972 WRITE(6,971) JEE,DJ(JET-2),DJ(JET-1),DJ(JET)
      GOTO1126
 1135 CONTINUE
      NJS=3*NJ
      DO97JE=3,NJS,3
      JEE=JE/3
   97 WRITE(6,1197)JEE,DJ(JE-2),DJ(JE-1),DJ(JE)
 1197 FORMAT(1H ,I8,3F20.8)
      WRITE(6,98)
   98 FORMAT(////,1H ,18HMEMBER END ACTIONS)
      WRITE(6,99)
   99 FORMAT(1H0,3X,6HMEMBER,13X,5HEND-1,45X,5HEND-2)
      WRITE(6,300)
  300 FORMAT(1H ,17X,5HAXIAL,10X,5HSHEAR,10X,6HMOMENT,14X,5HAXIAL,10X,5H
     1SHEAR,10X,6HMOMENT)
      ITEST=1
      I=0
  200 I=I+1
      IF(I-M)20,20,117
  101 DO102J=1,6
  102 AMD(J)=SMR(J,1)*DJ(J1)+SMR(J,2)*DJ(J2)+SMR(J,3)*DJ(J3)+SMR(J,4)*DJ
     1(K1)+SMR(J,5)*DJ(K2)+SMR(J,6)*DJ(K3)
      WRITE(6,103)I
  103 FORMAT(1H ,I8)
      DO104J=1,6
  104 AMSS(J)=AML(I,J)+AMD(J)
      WRITE(6,1104)(AMSS(J),J=1,6)
 1104 FORMAT(1H+,8X,3F15.3,F20.3,2F15.3)
      IF(RL(J1)-1)106,105,106
  105 AR(J1)=AR(J1)+R(I,1)*AMD(1)+R(I,4)*AMD(2)+R(I,7)*AMD(3)
  106 IF(RL(J2)-1)108,107,108
  107 AR(J2)=AR(J2)+R(I,2)*AMD(1)+R(I,5)*AMD(2)+R(I,8)*AMD(3)
  108 IF(RL(J3)-1)110,109,110
  109 AR(J3)=AR(J3)+R(I,3)*AMD(1)+R(I,6)*AMD(2)+R(I,9)*AMD(3)
  110 IF(RL(K1)-1)112,111,112
  111 AR(K1)=AR(K1)+R(I,1)*AMD(4)+R(I,4)*AMD(5)+R(I,7)*AMD(6)
  112 IF(RL(K2)-1)114,113,114
  113 AR(K2)=AR(K2)+R(I,2)*AMD(4)+R(I,5)*AMD(5)+R(I,8)*AMD(6)
  114 IF(RL(K3)-1)200,115,200
  115 AR(K3)=AR(K3)+R(I,3)*AMD(4)+R(I,6)*AMD(5)+R(I,9)*AMD(6)
  116 GOTO200
  117 WRITE(6,118)
  118 FORMAT(////,1H ,17HSUPPORT REACTIONS/)
      WRITE(6,119)
  119 FORMAT(1H ,4X,5HJOINT,14X,2HFX,18X,2HFY,16X,6HMOMENT)
      DO121K=1,NNR
      IF(RL(K)-1)121,120,121
  120 AR(K)=AR(K)-A(K)-AE(K)
  121 CONTINUE
      DO126KE=3,NJS,3
      IF(RL(KE-2)-1)122,124,122
  122 IF(RL(KE-1)-1)123,124,123
  123 IF(RL(KE)-1)126,124,126
  124 KEE=KE/3
      WRITE(6,125)KEE,AR(KE-2),AR(KE-1),AR(KE)
```

```
  125 FORMAT(1H ,I8,3F20.3)
  126 CONTINUE
 1126 CONTINUE
      IF(LN-NLS)267,129,129
  127 WRITE(6,128)
  128 FORMAT(1H0,15HPROCEDURE FAILS)
  129 DO800I=1,NOW
  800 WRITE(6,801) (XF(I,K),K=1,NOW)
  801 FORMAT(1X,6F17.9)
  130 WRITE(6,600)V,NK,NV
  600 FORMAT(////,1H ,14HMAXM. MEMBERS=,I6,4X,13HMAXM. JOINTS=,I6,4X,18H
     1MAXM. JOINT DIFF.=,I6)
      RETURN
      END
      SUBROUTINE DECBND(N,UBW,A,III)
      INTEGER P,Q,UBW
      DIMENSION A(510,21)
      DO509I=1,N
      P=N-I+1
      IF(UBW-P)500,501,501
  500 P=UBW
  501 DO509J=1,P
      Q=UBW-J
      IF((I-1)-Q)502,503,503
  502 Q=I-1
  503 SUM=A(I,J)
      IF(Q)532,532,531
  531 DO530K=1,Q
      IK=I-K
      JK=J+K
      IF(IK)530,530,504
  504 SUM=SUM-A(IK,1+K)*A(IK,JK)
  530 CONTINUE
  532 IF(J-1)505,506,505
  505 A(I,J)=SUM*TEMP
      GOTO509
  506 IF(SUM)507,507,508
  507 III=0
      RETURN
  508 TEMP=1.0/SQRT(SUM)
      A(I,J)=TEMP
  509 CONTINUE
      RETURN
      END
      SUBROUTINE LOAD(L,AML,LML,NLM)
      REAL L
      DIMENSION L(170),AML(170,6),LML(170)
      WRITE(6,286)
  286 FORMAT(////,1H ,12HMEMBER LOADS)
      WRITE(6,724)
  724 FORMAT(////,1H ,5X,6HMEMBER,5X,4HLOAD,15X,5HTOTAL)
      WRITE(6,725)
  725 FORMAT(1H ,7X,2HNO,7X,4HTYPE,15X,4HLOAD,14X,1HA,14X,1HC)
  289 DO800J=1,NLM
      READ(5,*) I,NTOL
      DO701N=1,NTOL
      READ(5,*) LT,W,A,C
      ST=L(I)
      B=L(I)-A
      GOTO(730,731,732,733,734),LT
```



```
  730 WRITE(6,830)I
      DI=(W*B*(ST**2-B**2))/(6.0*ST)
      DJ=(W*A*(ST**2-A**2))/(6.0*ST)
      GOTO700
  731 WRITE(6,831)I
      DI=(W*B*(4.0*A*(B+ST)-C**2))/(24.0*ST)
      DJ=(W*A*(4.0*B*(A+ST)-C**2))/(24.0*ST)
      GOTO700
  732 WRITE(6,832)I
      AL=A/ST
      BL=B/ST
      CL=C/ST
      DI=W*ST**2*(270.0*(BL-BL**3)-CL**2*(45.0*BL+2.0*CL))/1620.0
      DJ=W*ST**2*(270.0*(AL-AL**3)-CL**2*(45.0*AL-2.0*CL))/1620.0
      GOTO700
  733 WRITE(6,833)I
      AL=A/ST
      BL=B/ST
      CL=C/ST
      DI=(W*ST**2)*(270.0*(BL-BL**3)-CL**2*(45.0*BL-2.0*CL))/1620.0
      DJ=(W*ST**2)*(270.0*(AL-AL**3)-CL**2*(45.0*AL+2.0*CL))/1620.0
  700 FI=(2.0*DJ-4.0*DI)/ST
      FJ=(4.0*DJ-2.0*DI)/ST
      RI=(FI+FJ-W*B)/ST
      RJ=(-FI-FJ-W*A)/ST
      HI=0.0
      HJ=0.0
      GOTO750
  734 WRITE(6,834)I
      HI=-(W*B)/ST
      HJ=-(W*A)/ST
      FI=0.0
      FJ=0.0
      RI=0.0
      RJ=0.0
  750 AML(I,1)=AML(I,1)+HI
      AML(I,2)=AML(I,2)+RI
      AML(I,3)=AML(I,3)+FI
      AML(I,4)=AML(I,4)+HJ
      AML(I,5)=AML(I,5)+RJ
      AML(I,6)=AML(I,6)+FJ
      WRITE(6,726)W,A,C
  726 FORMAT(1H+,28X,3F15.3)
  701 CONTINUE
  800 LML(I)=1
  830 FORMAT(1H ,I8,6X,8HCONC    )
  831 FORMAT(1H ,I8,6X,8HUNIFORM )
  832 FORMAT(1H ,I8,6X,8HTRIANG R)
  833 FORMAT(1H ,I8,6X,8HTRIANG L)
  834 FORMAT(1H ,I8,6X,8HAXIAL   )
      RETURN
      END
      SUBROUTINE SLVBND(N,UBW,U,B,X)
      INTEGER UBW
      DIMENSION U(510,21),B(510),X(510)
      DO513I=1,N
      J=I-UBW+1
      IF((I+1)-UBW)510,510,511
  510 J=1
  511 SUM=B(I)
```

```
      IM=I-1
      IF(J-IM)550,550,513
  550 DO551K=J,IM
      IKP=I-K+1
      IF(IKP)551,551,512
  512 SUM=SUM-U(K,IKP)*X(K)
  551 CONTINUE
  513 X(I)=SUM*U(I,1)
      DO517II=1,N
      I=N-II+1
      J=I+UBW-1
      IF(J-N)515,515,514
  514 J=N
  515 SUM=X(I)
      IP=I+1
      IF(IP-J)552,552,517
  552 DO553K=IP,J
      KIP=K-I+1
      IF(KIP)553,553,516
  516 SUM=SUM-U(I,KIP)*X(K)
  553 CONTINUE
  517 X(I)=SUM*U(I,1)
      RETURN
      END
      SUBROUTINE FORW(NCP,NCL,NFW)
      COMMON/PROPW/A1,A2,ZI1,ZI2,C1,C4,CC1,CC4,COSH,SINH,ALPHA,BETA,EW
      COMMON/CONW/BERA,BENR,BENE,BEGA,BEGR,FL,EK1,EK4,H,GAMMA,ENETA
      COMMON/PROPF/IPC(40),PXH(40),PYV(40),PMO(40),XF(120,120),FF(120)
      COMMON/PROCP/NLT(40),APL(40),AXI(40),YPC(40),C2,C3
      DIMENSION FORT(40),FORM(40),XT(40)
      READ(5,*)NFORL,NFORR
      NFORT=NFORL+NFORR
      IF(NFORT.EQ.0)GOTO18
C READ IN REQUIRED LOCATION POINTS
C LEFT HAND WALL
      DO2I=1,NFORL
    2 READ(5,*) XT(I)
C RIGHT HAND WALL
      DO3I=1,NFORR
      J=I+NFORL
    3 READ(5,*)XT(J)
C FORCE VALUES INITIALISED TO ZERO
      DO4I=1,NFORT
      FORT(I)=0.0
    4 FORM(I)=0.0
C FORCES FOUND AT EACH LOCATION
C CONNECTION POINT FORCES
      DO5I=1,NFORT
      X=XT(I)
      SINHX=(EXP(ALPHA*(H-X))-EXP(-ALPHA*(H-X)))/2.0
      COSHX=(EXP(ALPHA*(H-X))+EXP(-ALPHA*(H-X)))/2.0
      DO6J=1,NCP
      XI=YPC(J)
      SINHXI=(EXP(ALPHA*XI)-EXP(-ALPHA*XI))/2.0
      COSHXI=(EXP(ALPHA*XI)+EXP(-ALPHA*XI))/2.0
      SECH=(EXP(ALPHA*(H-XI))+EXP(-ALPHA*(H-XI)))/2.0
      SINH=(EXP(ALPHA*(H-XI))-EXP(-ALPHA*(H-XI)))/2.0
      TANH=(EXP(ALPHA*(XI-X))+EXP(-ALPHA*(XI-X)))/2.0
      SECH=(EXP(ALPHA*(XI-X))-EXP(-ALPHA*(XI-X)))/2.0
      P=-PXH(J)
```



```
      IF(P.EQ.0.0)GOTO 7
      AL1=-BETA*(1-COSHXI)*SINHX/(COSH*ALPHA**3)
      AL2=0.0
      AL3=0.0
      AM1=0.0
      IF(X.GT.XI) GOTO 8
      AL2=-BETA*SECH/(ALPHA**3)
      AL3=BETA*(XI-X)/(ALPHA**2)
      AM1=(XI-X)
    8 FORT1=P*(AL1+AL2+AL3)
      FORM1=(FORT1*FL)-(P*AM1)
      IF(I.GT.NFORL)GOTO9
      FORT(I)=FORT(I)+FORT1
      FORM(I)=FORM(I)+(FORM1*ZI1/(ZI1+ZI2))
      GOTO7
    9 FORT(I)=FORT(I)-FORT1
      FORM(I)=FORM(I)+(FORM1*ZI2/(ZI1+ZI2))
    7 P=-PYV(J)
      IF(P.EQ.0.0)GOTO10
      IF(J.GT.NCL) GOTO11
      AL1=-BENE*SINHX*SINHXI/(COSH*ALPHA**2)
      AL2=0.0
      AM1=0.0
      AM2=0.0
      IF(X.GT.XI) GOTO 12
      AL2=-BENE*(1-TANH)/(ALPHA**2)
      AM1=-C1
      AM2=1.0
   12 FORT1=P*(AL1+AL2)
      FORM1=(FORT1*FL)+(P*AM1)
      IF(I.GT.NFORL) GOTO 13
      FORT(I)=FORT(I)+FORT1+(P*AM2)
      FORM(I)=FORM(I)+(FORM1*ZI1/(ZI1+ZI2))
      GOTO10
   13 FORT(I)=FORT(I)-FORT1
      FORM(I)=FORM(I)+(FORM1*ZI2/(ZI1+ZI2))
      GOTO 10
   11 AL1=BEGA*SINHX*SINHXI/(COSH*ALPHA**2)
      AL2=0.0
      AM1=0.0
      AM2=0.0
      IF(X.GT.XI)GOTO14
      AL2=BEGA*(1-TANH)/(ALPHA**2)
      AM1=C4
      AM2=1.0
   14 FORT1=P*(AL1+AL2)
      FORM1=(FORT1*FL)+(P*AM1)
      IF(I.GT.NFORL) GOTO 15
      FORT(I)=FORT(I)+FORT1
      FORM(I)=FORM(I)+(FORM1*ZI1/(ZI1+ZI2))
      GOTO10
   15 FORT(I)=FORT(I)+(P*AM2)-FORT1
      FORM(I)=FORM(I)+(FORM1*ZI2/(ZI1+ZI2))
   10 P=-PMO(J)
      IF(P.EQ.0.0)GOTO6
      AL1=-BETA*SINHX*SINHXI/(COSH*(ALPHA**2))
      AL2=0.0
      AL3=0.0
      AM1=0.0
      IF(X.GT.XI)GOTO16
```

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      AL2=-BETA*(1-TANH)/(ALPHA**2)
      AM1=1.0
   16 FORT1=P*(AL1+AL2)
      FORM1=(FORT1*FL)+(P*AM1)
      IF(I.GT.NFORL)GOTO17
      FORT(I)=FORT(I)+FORT1
      FORM(I)=FORM(I)+(FORM1*ZI1/(ZI1+ZI2))
      GOTO6
   17 FORT(I)=FORT(I)-FORT1
      FORM(I)=FORM(I)+(FORM1*ZI2/(ZI1+ZI2))
    6 CONTINUE
    5 CONTINUE
   18 IF(NFW.EQ.0)GOTO33
C FORCES DUE TO APPLIED LOADS
      DO19I=1,NFORT
      X=XT(I)
      SINHX=(EXP(ALPHA*(H-X))-EXP(-ALPHA*(H-X)))/2.0
      COSHX=(EXP(ALPHA*(H-X))+EXP(-ALPHA*(H-X)))/2.0
      DO20J=1,NFW
      XI=AXI(J)
      SINHXI=(EXP(ALPHA*XI)-EXP(-ALPHA*XI))/2.0
      COSHXI=(EXP(ALPHA*XI)+EXP(-ALPHA*XI))/2.0
      SEC=(EXP(ALPHA*(H-XI))+EXP(-ALPHA*(H-XI)))/2.0
      SES=(EXP(ALPHA*(H-XI))-EXP(-ALPHA*(H-XI)))/2.0
      TANH=(EXP(ALPHA*(XI-X))+EXP(-ALPHA*(XI-X)))/2.0
      SECH=(EXP(ALPHA*(XI-X))-EXP(-ALPHA*(XI-X)))/2.0
      AM2=0.0
      AM3=0.0
      NTL=NLT(J)
      P=APL(J)
      GOTO(21,22,23,24,25,26)NTL
   21 AL1=-BETA*(1-COSHXI)*SINHX/(COSH*ALPHA**3)
      AL2=0.0
      AL3=0.0
      AM1=0.0
      IF(X.GT.XI)GOTO27
      AL2=-BETA*SECH/(ALPHA**3)
      AL3=BETA*(XI-X)/(ALPHA**2)
      AM1=(XI-X)
   27 FORT1=P*(AL1+AL2+AL3)
      FORM1=(FORT1*FL)-(P*AM1)
      IF(I.GT.NFORL)GOTO 28
      GOTO29
   22 AL1=-BENE*SINHX*SINHXI/(COSH*ALPHA**2)
      AL2=0.0
      AM1=0.0
      IF(X.GT.XI)GOTO30
      AL2=-BENE*(1-TANH)/(ALPHA**2)
      AM1=-C1
      AM2=1.0
   30 FORT1=P*(AL1+AL2)
      FORM1=(FORT1*FL)+(P*AM1)
      IF(I.GT.NFORL)GOTO28
      GOTO29
   23 AL1=BEGA*SINHX*SINHXI/(COSH*ALPHA**2)
      AL2=0.0
      AM1=0.0
      IF(X.GT.XI)GOTO31
      AL2=BEGA*(1-TANH)/(ALPHA**2)
      AM1=C4
```



```
      AM3=1.0
   31 FORT1=P*(AL1+AL2)
      FORM1=(FORT1*FL)+(P*AM1)
      IF(I.GT.NFORL)GOTO28
      GOTO29
   24 AL1=-BETA*SINHX*SINHXI/(COSH*ALPHA**2)
      AL2=0.0
      AM1=0.0
      IF(X.GT.XI)GOTO32
      AL2=-BETA*(1-TANH)/(ALPHA**2)
      AM1=1.0
   32 FORT1=P*(AL1+AL2)
      FORM1=(FORT1*FL)+(P*AM1)
      IF(I.GT.NFORL)GOTO28
      GOTO29
   25 TANHX=(EXP(ALPHA*X)+EXP(-ALPHA*X))/2.0
      AL1=-BETA*SINHX/(COSH*ALPHA**3)
      AL2=BETA*(COSH-TANHX)/(H*COSH*ALPHA**4)
      AM1=((H-X)**2)/(2*H)
      AL3=AM1*BETA/(ALPHA**2)
      FORT1=P*(AL1+AL2+AL3)
      FORM1=(FORT1*FL)-(P*AM1)
      IF(I.GT.NFORL)GOTO28
      GOTO29
   26 TANHX=(EXP(ALPHA*X)+EXP(-ALPHA*X))/2.0
      AL1=-BETA*SINHX/(COSH*ALPHA**3)
      AL2=2*BETA*SINHX/((H**2)*COSH*ALPHA**5)
      AL4=2*BETA*(X*COSH-TANHX)/((H**2)*COSH*ALPHA**4)
      AM1=((2*H)-(3*X)+((X**3)/(H**2)))/3.0
      AL3=AM1*BETA/(ALPHA**2)
      FORT1=P*(AL1+AL2+AL3+AL4)
      FORM1=(FORT1*FL)-(P*AM1)
      IF(I.GT.NFORL)GOTO28
   29 FORT(I)=FORT(I)+FORT1+(P*AM2)
      FORM(I)=FORM(I)+(FORM1*ZI1/(ZI1+ZI2))
      GOTO20
   28 FORT(I)=FORT(I)-FORT1+(P*AM3)
      FORM(I)=FORM(I)+(FORM1*ZI2/(ZI1+ZI2))
   20 CONTINUE
   19 CONTINUE
   33 IF(NFORL.EQ.0)GOTO38
      WRITE(6,34)
   34 FORMAT(1H ,14HLEFT HAND WALL)
      WRITE(6,35)
   35 FORMAT(1H ,12X,8HLOCATION,12X,5HFORCE,12X,6HMOMENT)
      DO36I=1,NFORL
   36 WRITE(6,37) XT(I),FORT(I),FORM(I)
   37 FORMAT(3X,3F16.3)
   38 IF(NFORR.EQ.0)GOTO42
      WRITE(6,39)
   39 FORMAT(1H ,15HRIGHT HAND WALL)
      WRITE(6,35)
      DO41I=1,NFORR
      J=I+NFORL
   41 WRITE(6,37)XT(J),FORT(J),FORM(J)
C STRESSES NOW CALCULATED
   42 IF(NFORL.EQ.0)GOTO47
      WRITE(6,34)
      WRITE(6,43)
      WRITE(6,44)
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43 FORMAT(1H ,25X,8HSTRESSES)
44 FORMAT(1H ,4HLEFT,16X,6HCENTRE,16X,5HRIGHT)
   DO45I=1,NFORL
   STR1=FORT(I)/A1
   STR2=FORM(I)*C1/ZI1
   STR3=FORM(I)*C2/ZI1
   ST1=STR1-STR2
   ST2=STR1-(STR2/2.0)
   ST3=STR1
   ST4=STR1+(STR3/2.0)
   ST5=STR1+STR3
45 WRITE(6,46) ST1,ST2,ST3,ST4,ST5
46 FORMAT(5F10.5)
47 IF(NFORR.EQ.0)GOTO49
   WRITE(6,39)
   WRITE(6,43)
   WRITE(6,44)
   DO48I=1,NFORR
   J=I+NFORL
   STR1=FORT(J)/A2
   STR2=FORM(J)*C3/ZI2
   STR3=FORM(J)*C4/ZI2
   ST1=STR1-STR2
   ST2=STR1-(STR2/2.0)
   ST3=STR1
   ST4=STR1+(STR3/2.0)
   ST5=STR1+STR3
48 WRITE(6,46) ST1,ST2,ST3,ST4,ST5
49 RETURN
   END
   SUBROUTINE FORB(NCP,NCL,NFW,FH,CBL)
   COMMON/PROPW/A1,A2,ZI1,ZI2,C1,C4,CC1,CC4,COSH,SINH,ALPHA,BETA,EW
   COMMON/CONW/BERA,BENR,BENE,BEGA,BEGR,FL,EK1,EK4,H,GAMMA,ENETA
   COMMON/PROPF/IPC(40),PXH(40),PYV(40),PMO(40),XF(120,120),FF(120)
   COMMON/PROCP/NLT(40),APL(40),AXI(40),YPC(40),C2,C3
   DIMENSION FOCB(20),XB(20)
   READ(5,*) NFORB
   DO2I=1,NFORB
 2 READ(5,*) XB(I)
   DO4I=1,NFORB
 4 FOCB(I)=0.0
C SHEAR FORCE FOUND AT EACH LOACATION
C EFFECT OF CONNECTING POINT FORCES
   DO6I=1,NFORB
   X=XB(I)
   SINHX=(EXP(ALPHA*(H-X))-EXP(-ALPHA*(H-X)))/2.0
   COSHX=(EXP(ALPHA*(H-X))+EXP(-ALPHA*(H-X)))/2.0
   DO8J=1,NCP
   XI=YPC(J)
   SINHXI=(EXP(ALPHA*XI)-EXP(-ALPHA*XI))/2.0
   COSHXI=(EXP(ALPHA*XI)+EXP(-ALPHA*XI))/2.0
   SEC=(EXP(ALPHA*(H-XI))+EXP(-ALPHA*(H-XI)))/2.0
   SES=(EXP(ALPHA*(H-XI))-EXP(-ALPHA*(H-XI)))/2.0
   TANP=(EXP(ALPHA*(XI-X))+EXP(-ALPHA*(XI-X)))/2.0
   SECP=(EXP(ALPHA*(XI-X))-EXP(-ALPHA*(XI-X)))/2.0
   P=-PXH(J)
   IF(P.EQ.0.0) GO TO 7
   AL1=-BETA*FH*(1-COSHXI)*COSHX/(COSP*(ALPHA**2))
   AL2=0.0
   IF(X.GT.XI) GOTO 9
```



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   AL2=BETA*FH*(1-TANH)/(ALPHA**2)
 9 FORB1=P*(AL1+AL2)
   FOCB(I)=FOCB(I)+FORB1
 7 P=-PYV(J)
   IF(P.EQ.0.0)GOTO10

   IF(J.GT.NCL) GOTO 11
   AL1=-BENE*FH*SINHXI*COSHX/(ALPHA*COSH)
   AL2=0.0
   IF(X.GT.XI)GOTO12
   AL2=BENE*FH*SECH/ALPHA
12 FORB1=P*(AL1+AL2)
   FOCB(I)=FOCB(I)+FORB1
   GO TO 10
11 AL1=BEGA*FH*SINHXI*COSHX/(COSH*ALPHA)
   AL2=0.0
   IF(X.GT.XI)GOTO 13
   AL2=-BEGA*FH*SECH/ALPHA
13 FORB1=P*(AL1+AL2)
   FOCB(I)=FOCB(I)+FORB1
10 P=-PMO(J)
   IF(P.EQ.0.0) GOTO 8
   AL1=-BETA*FH*SINHXI*COSHX/(COSH*ALPHA)
   AL2=0.0
   IF(X.GT.XI)GOTO 14
   AL2=BETA*FH*SECH/ALPHA
14 FORB1=P*(AL1+AL2)
   FOCB(I)=FOCB(I)+FORB1
 8 CONTINUE
 6 CONTINUE
   IF(NFW.EQ.0)GOTO 36
   DO16I=1,NFORB
   X=XB(I)
   SINHX=(EXP(ALPHA*(H-X))-EXP(-ALPHA*(H-X)))/2.0
   COSHX=(EXP(ALPHA*(H-X))+EXP(-ALPHA*(H-X)))/2.0
   DO18J=1,NFW
   XI=AXI(J)
   SINHXI=(EXP(ALPHA*XI)-EXP(-ALPHA*XI))/2.0
   COSHXI=(EXP(ALPHA*XI)+EXP(-ALPHA*XI))/2.0
   TANH=(EXP(ALPHA*(XI-X))+EXP(-ALPHA*(XI-X)))/2.0
   SECH=(EXP(ALPHA*(XI-X))-EXP(-ALPHA*(XI-X)))/2.0
   NTL=NLT(J)
   P=APL(J)
   GOTO(21,22,23,24,25,26)NTL
21 AL1=-BETA*FH*(1-COSHXI)*COSHX/(COSH*(ALPHA**2))
   AL2=0.0
   IF(X.GT.XI)GOTO27
   AL2=BETA*FH*(1-TANH)/(ALPHA**2)
27 FORB1=P*(AL1+AL2)
   GOTO28
22 AL1=-BENE*FH*SINHXI*COSHX/(ALPHA*COSH)
   AL2=0.0
   IF(X.GT.XI) GOTO30
   AL2=BENE*FH*SECH/ALPHA
30 FORB1=P*(AL1+AL2)
   GOTO28
23 AL1=BEGA*FH*SINHXI*COSHX/(COSH*ALPHA)
   AL2=0.0
   IF(X.GT.XI) GOTO32
   AL2=-BEGA*FH*SECH/ALPHA
```

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 32 FORB1=P*(AL1+AL2)
    GOTO28
 24 AL1=-BETA*FH*(1-COSHXI)*COSHX/(COSH*(ALPHA**2))
    AL2=0.0
    IF(X.GT.XI) GOTO34
    AL2=BETA*FH*(1-TANH)/(ALPHA**2)
 34 FORB1=P*(AL1+AL2)
    GOTO28
 25 AL1=-BETA*FH*COSHX/(COSH*(ALPHA**2))
    AL2=BETA*FH*(1-(X/H))/(ALPHA**2)
    SECHX=(EXP(ALPHA*X)-EXP(ALPHA*X))/2.0
    AL3=-BETA*FH*SECHX/(H*COSH*(ALPHA**3))
    FORB1=P*(AL1+AL2+AL3)
    GOTO28
 26 SECHX=(EXP(ALPHA*X)-EXP(-ALPHA*X))/2.0
    AL1=BETA*FH*COSHX/(COSH*(ALPHA**2))
    AL1=AL1*((2/(H**2*ALPHA**2))-1.0)
    AL2=(FH-ALPHA*FH*SECHX/COSH)
    AL2=-2.0*BETA*AL2/(H**2*ALPHA**4)
    AL3=((FH*X**2)+(FH**3/12))/(H**2)
    AL3=-(AL3-FH)*BETA/(ALPHA**2)
    FORB1=P*(AL1+AL2+AL3)
 28 FOCB(I)=FOCB(I)+FORB1
 18 CONTINUE
 16 CONTINUE
 36 WRITE(6,38)
 38 FORMAT(1H ,27HFORCES AND MOMENTS IN BEAMS)
    DO40I=1,NFORB
    FORM=FOCB(I)*CBL/2.0
 40 WRITE(6,42) XB(I),FOCB(I),FORM
 42 FORMAT(3F10.3)
    RETURN
    END
    SUBROUTINE DEFW(NCP,NCL)
    COMMON/PROPF/IPC(40),PXH(40),PYV(40),PMO(40),XF(120,120),FF(120)
    COMMON/PROPD/DFW(120),DXW(120,120)
    DIMENSION XD(120),DX(120)
    DO1I=1,NCP
    XD(3*I-2)=-PXH(I)
    XD(3*I-1)=-PYV(I)
  1 XD(3*I)=-PMO(I)
    NPC=3*NCP
    DO2I=1,NPC
    DX(I)=0.0
    DO3J=1,NPC
  3 DX(I)=DX(I)+DXW(I,J)*XD(J)/1000.0
  2 DX(I)=DX(I)+DFW(I)
C PRINT OUT OF DISPLACEMENTS AT CONNECTING POINTS
    IF(NCL.EQ.0)GOTO10
    WRITE(6,4)
    WRITE(6,5)
    WRITE(6,6)
    DO8I=1,NCL
  8 WRITE(6,11) I,DX(3*I-2),DX(3*I-1),DX(3*I)
 10 NCR=NCP-NCL
    IF(NCR.EQ.0) GOTO12
    WRITE(6,14)
    WRITE(6,5)
    WRITE(6,6)
    DO16I=1,NCR
```



```
    J=I+NCL
 16 WRITE(6,11) I,DX(3*J-2),DX(3*J-1),DX(3*J)
  4 FORMAT(1H1,14HLEFT HAND WALL)
 11 FORMAT(9X,I6,3(F12.4))
  5 FORMAT(1H ,8X,10HCONNECTING,18X,11HDEFLECTIONS)
  6 FORMAT(1H ,12X,5HPOINT,4X,5HHORIZ,4X,4HVERT,4X,3HROT)
 14 FORMAT(1H1,15HRIGHT HAND WALL)
 12 RETURN
    END
```