STATIC ANALYSIS OF SHEAR WALLS USING FINITE ELEMENT METHOD

By

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FINAL REPORT

Submitted to the Civil Engineering Program
in Partial Fulfillment of the Requirements
for the Degree
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(Civil Engineering)

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Abdelrahim Musa Mahgoub

CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Civil Engineering Programme
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Approved:

for Prof Dr. Waleed A.Thanoon
Project Supervisor

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK

June 2007

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

ABDELRAHIM MUSA MAHGOUB

ABSTRACT

Shear wall is an important member resisting the lateral forces such as wind and earthquakes forces in the high rise buildings. Different structural models were used for the analysis of shear walls in building. The simplest model for the shear wall is a frame structure using beam/column element. FEM is widely used for analyzing complicated structural systems. The selected structural model must be simple, produce accurate result and be economical. The presence of the opening in shear wall structure further complicated the analysis of this structure and required a special attention. This study covers static structural analysis of solid shear wall as well as shear walls with different opening arrangements. The shear walls were modeled using beam/column and different F.E meshes. The study focuses on the accuracy and effectiveness of different structural models for analyzing shear wall structure. The structural behavior in terms of deformation and stresses distribution are presented and discussed.

ACKNOWLEDGEMENTS

First of all I would like to express my gratitude to the **ALMIGHTY**. Next I would like to express my deepest appreciation to Prof Dr. Waleed Thanoon who led me in doing my final year project. I would like to thank him for the valuable information that he provided to me. In addition I would like to thank him for teaching me the way of conducting research. Beside that I am appreciating his support and kindness throughout the project. Thanks *Prof. Waleed.*

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My Parents and my family
Assoc Prof. Dr. Narayanan Sambu Potty
Mr. Agos "PhD student"
University Technology Petronas

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Shear wall is a wall designed to resist the lateral forces such as wind and earthquake forces. It is the main member to resist the lateral forces in the high rise building. The shear wall may experience shear deformation or bending deformation. Due to that it should be designed carefully to ensure the safety of the high rise building and the ability of the shear wall to withstand the lateral forces. It is important to know the adequate methods to design, model and to analyze the shear wall.

1.2 Problem Statement

There are different methods of modeling and designing the shear walls using finite element method (FEM). These models may be generated using beam/column element, two dimensional element, shell element and solid element. Each model has advantages and disadvantages. In some cases the beam element is more reliable and conservative and in other cases Two-dimensional element or any other element is preferred. To have shear wall which can withstand the lateral forces in high rise building, the most appropriate modeling and analysis methods are required.

Defining the suitable way to model and design the shear walls considering the effect of the opening in the walls and the height of the buildings will help the engineers to do accurate, safe and economic design of the shear walls in a short time.

1.3 Objective of Study

The objectives of this project is to investigate

1. The effectiveness of different structural models for shear wall
2. The effect of different opening arrangement on the stress distribution in the shear wall

1.4 Scope of Study

1. Structural analysis of different shear walls with STAAD.PRO structural software using different element like

(i) Beam/column element

(ii) Shell element

2. Different F.E. Mesh will implemented to analyze the shear wall
3. Different opening size and arrangement will be studied
4. The structural behavior will be investigated in terms of deformation and stress distribution

CHAPTER 2
LITERATURE REVIEW

2.1 Finite Element Method (FEM)

Finite element method models a structure as an assembly of elements or components with various forms of connection between them. Thus, a continuous system such as a plate or shell is modeled as a discrete system with a finite number of elements interconnected at finite number of nodes. The behavior of individual elements is characterized by the element's stiffness or flexibility relation, which all together leads to the system's stiffness or flexibility relation. To establish the element's stiffness or flexibility relation, we can use the mechanics of materials approach for simple one-dimensional bar elements, and the elasticity approach for more complex two- and three-dimensional elements. The analytical and computational development is best effected throughout by means of matrix algebra. There are different types of finite element can be used in the analysis of shear walls. Arnot, K., (2005) suggested that "You should seriously question weather any sort of FE analysis in a low rise building is appropriate and cost effective"

2.2 Factors Affecting the Design of Shear Walls

The deflection of the shear walls is the most important factor that affects the model of the shear walls. Beside that, the distribution of the forces acting on the shear walls should be known especially around the openings in the shear walls. Arnot, K., (2005) mentioned that "if deflection is important to you then you need to get all aspects of your model right, this means:

- Accurate material properties for each member
- Accurate section properties for each member
- A good arrangement of members to idealize the overall physical geometry"

2.3 Beam Element Method

The beam elements are a stick-figure representation of structural members that are much longer in one direction than the other two. The element is represented as a line or curve. The cross sectional information of the beam is required to define the stiffness of the beam element. The beam element generally has two nodes with six degree of freedom in each node. It supports compression, tension, shear and torsion forces. In the design, the orientation of the beam should be defined. These elements are useful in designing, modeling and analyzing beam structures. The beam and wall element method that used in the modeling of the shear wall is very simple method. In addition it will provide accurate results in a short period of time. It can be used in the modeling of shear wall in high rise building as well as low rise building. In the design of shear wall using beam element method, the shear wall will be represented by a single beam. The beam will be exposed to a point load. This type of model is easy to simulate and can be understood. Arnot, K., (2005) said ".......however there is certainly an advantage in that the forces reported for the beam elements are more readily understood and usable than many of the complex contour diagrams that can be displayed for shell models". Li, J., (2003) mentioned that "I strongly recommended to use the simple approach in model 1 (figure1) because it is easy and accurate".

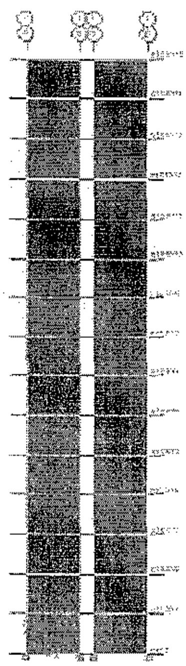


Figure 1 Coupled shear wall

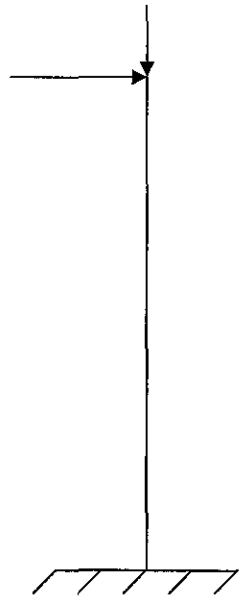


Figure 2 Beam Element

2.4 Two-Dimensional Elements

Two dimensional elements represent the section of the structures or the objects in two dimensions. It can be used in certain cases where the applied load and geometry of the structure are identical in any cross section of the structure. There are different formulations of the two dimensional elements. These formulations are plain stress, plain strain (figure 3) and axisymmetric. The plain stress formulation can be used only if the applied load is assumed to act in a two-dimensional plane. Plain strain is special case of plain stress where the strain in third direction is prevented.

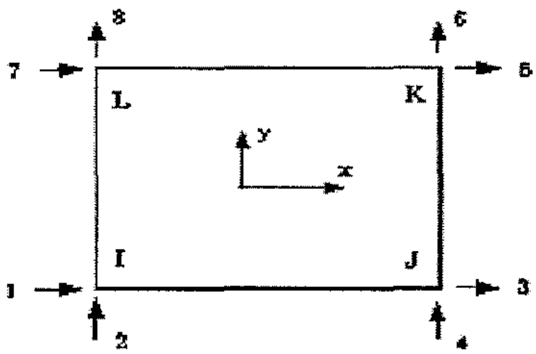


Figure 3 Plane stress-plane strain element

2.5 Shell Elements

Shell element is a surface representation of structures that are much thinner in one direction than the other two. The thickness of the element must be defined before the analysis. The shell elements have six active degrees of freedom per node. The usage of shell element method in the modeling depends on the thickness ratio of the plate to the width or the length of the structure. If the thickness of the structure is too big the behavior of the shell element can not be seen. Also, if the ratio of the thickness of the plate to the length or width is very small, the shell will behave like membranes. Due to that the shell element can not used to model very thin element. Arnot, K., (2005) said " you should not think that the world of shell elements offers a new level of accuracy –in many cases it may better be regarded as a new way to get the same answers, or perhaps worryingly as a new way to make some new mistakes". Maio et al, (2006) mentioned that "the multi layer shell element model can correctly simulate the coupled in-plane/out-plane bending failure for tall walls and the coupled in-plane bending-shear failure for short walls"

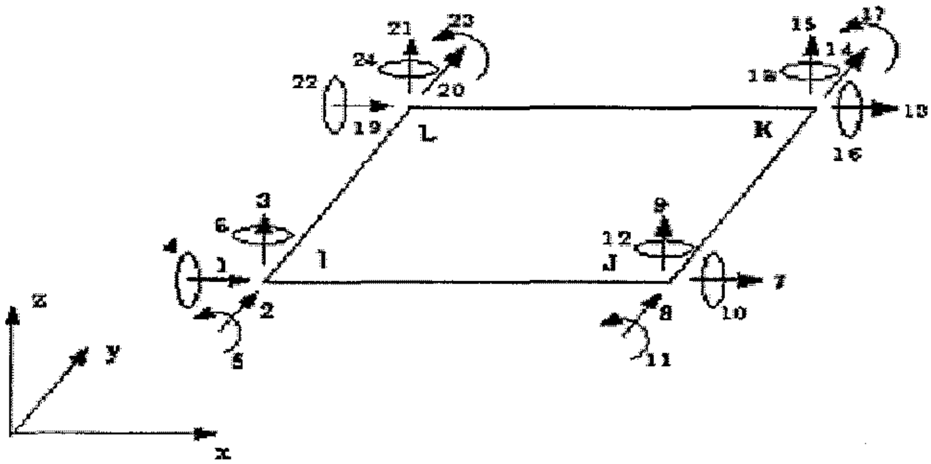


Figure 4 Shell element with six degree of free dom

2.6 Coupled Shear Walls

The coupled shear walls are special case of the shear wall. It is made of coupling beams and wall piers (figure 5). The coupled shear walls are used to provide more openings in the high-rise buildings. The coupled shear wall is connected by beams called tie beams. The behavior of these beams is very important in the coupled shear wall design. In coupled shear wall the dissipation of the input energy can be distributed over the height of the building in the coupling beams rather than concentrating predominantly on the bottom of wall piers where structural damage is not easily repaired (Harries et al. 2000).

2.7 Opening effects

The openings in the shear wall have a great effect in the distribution of the stress on the shear wall. Samih Qaqish & Faiq Daqqaq "the width of the opening has higher effect than the height of opening in transforming the behavior of a shear wall from a single cantilever to a coupled shear wall". Balakaya and Kalkan (2004) said that "high local vertical stress and shear stress concentration were observed around the corners of the opening near the edge of the transverse walls". Balakaya and Kalkan (2004) stated that "the stress flow and crack patterns around the openings of the 3D cases were drastically different than those computed for the 2D cases". Balakaya and Kalkan (2004) say that "... the part of the wall between the openings was deflected more in the 2D models than 3D models".

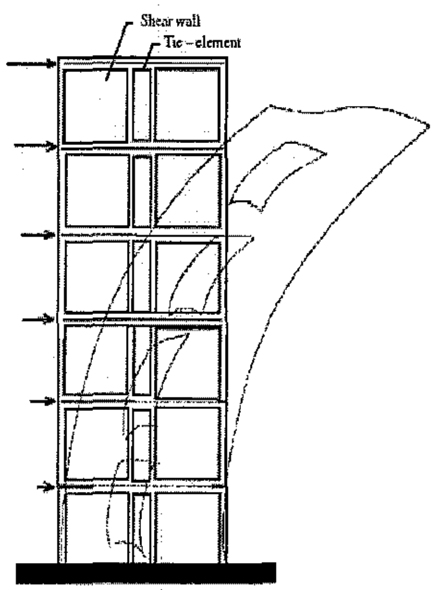


Figure 5 Typical coupled shear wall

2.8 Concluding Remarks

All the previous studies focused either on shell element or beam element for the analysis of shear wall. There are no clear statements about at which situations the shear wall should be analyzed using beam element method and at which situation the shell element should be used. In addition there are limited studies on the effect of the different types of opening on the structural behavior of the shear wall. Further more there are no clear findings about the effect of the openings in the shear wall analysis when it is located in the edge of the wall. Most of the studies focused on analyzing the wall with opening located at the wall centre.

CHAPTER 3
METHODOLOGY

3.1 Process Identification

The overall flow of the project can be divided into the following milestones:

a) Beam Element Modeling

This milestone involves modeling and analyzing the shear walls in low rise and high rise buildings using the beam element method. The shear wall will be modelled as cantilever beam subjected to axial and lateral force. These forces are acting at the highest point of the beam. This is to examine the maximum deflection and to study the behavior of the shear wall when it is modeled using beam element method

b) Two Dimensional Element Modeling

At this stage, the shear walls in the high rise and low rise buildings will be modeled using two dimensional models. In addition, a study of the distribution of the forces in the shear walls will be carried out.

c) Effect of Openings in the Shear Wall Design

At this milestone the effect of the openings in the shear walls design will be studied by introducing the openings in the models of low rise and high rise buildings. The openings can be doors or windows. The openings size varies from small to large size. The size of the opening has great affect on the behavior of the shear wall. The location of the opening is another factor that affects the distribution of the stress on the shear wall.

D) Comparison between Different Models

At the end of the project a comparison between the deflection results of the shear walls in the different types of models will be presented. The comparison is to identify the best way of modeling the shear wall with respect to

- Height of the building
- Location of the opening
- Size of the opening

3.2 Equipments and Software

a) STAAD.PRO 2004

CHAPTER 4
RESULTS AND DISCUSSION

4.1 Modeling

Modeling using beam element has been done using STAAD PRO software. The shear wall has been represented by single cantilever beam. The beam was subjected to axial load and lateral load. The values of lateral load and axial load were 100 KN and 1000 KN respectively. The type of cantilever support was fixed. The cantilever is representing a shear wall for building consists of ten floors. The height of each floor is 3.5m. The total height of the cantilever is 35 meter. The cantilever beam is divided to ten small beams with 11 nodes. The load was applied at the top of the beam in node number 36. The following data were input in the software to design the model

JOINT COORDINATES
DEFINE MATERIAL START
ISOTROPIC CONCRETE
E 2.17185E+007
POISSON 0.17
DENSITY 23.5616
ALPHA 1E-005
DAMP 0.05
END DEFINE MATERIAL
CONSTANTS
MATERIAL CONCRETE MEMB 1 TO 10
MEMBER PROPERTY
1 TO 10 PRIS YD 6 ZD 0.2
SUPPORTS
1 FIXED

1 FIXED

LOAD 1

JOINT LOAD

11 FY -1000

LOAD 2

JOINT LOAD

11 FX 100

LOAD COMBINATION 3

1 1.0 2 1.0

PERFORM ANALYSIS PRINT STATICS CHECK

Figure 6 shows the cantilever model in STAAD.PRO 2004 software

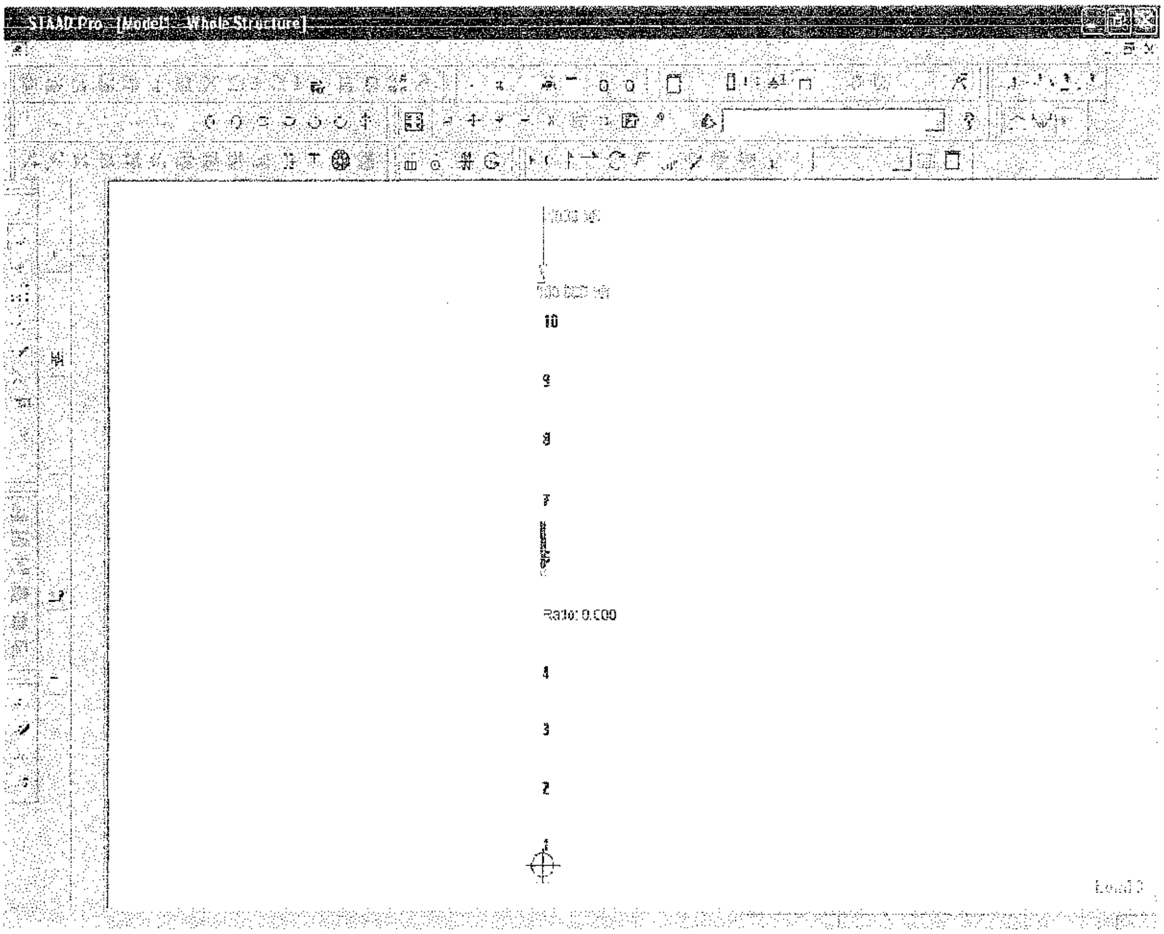
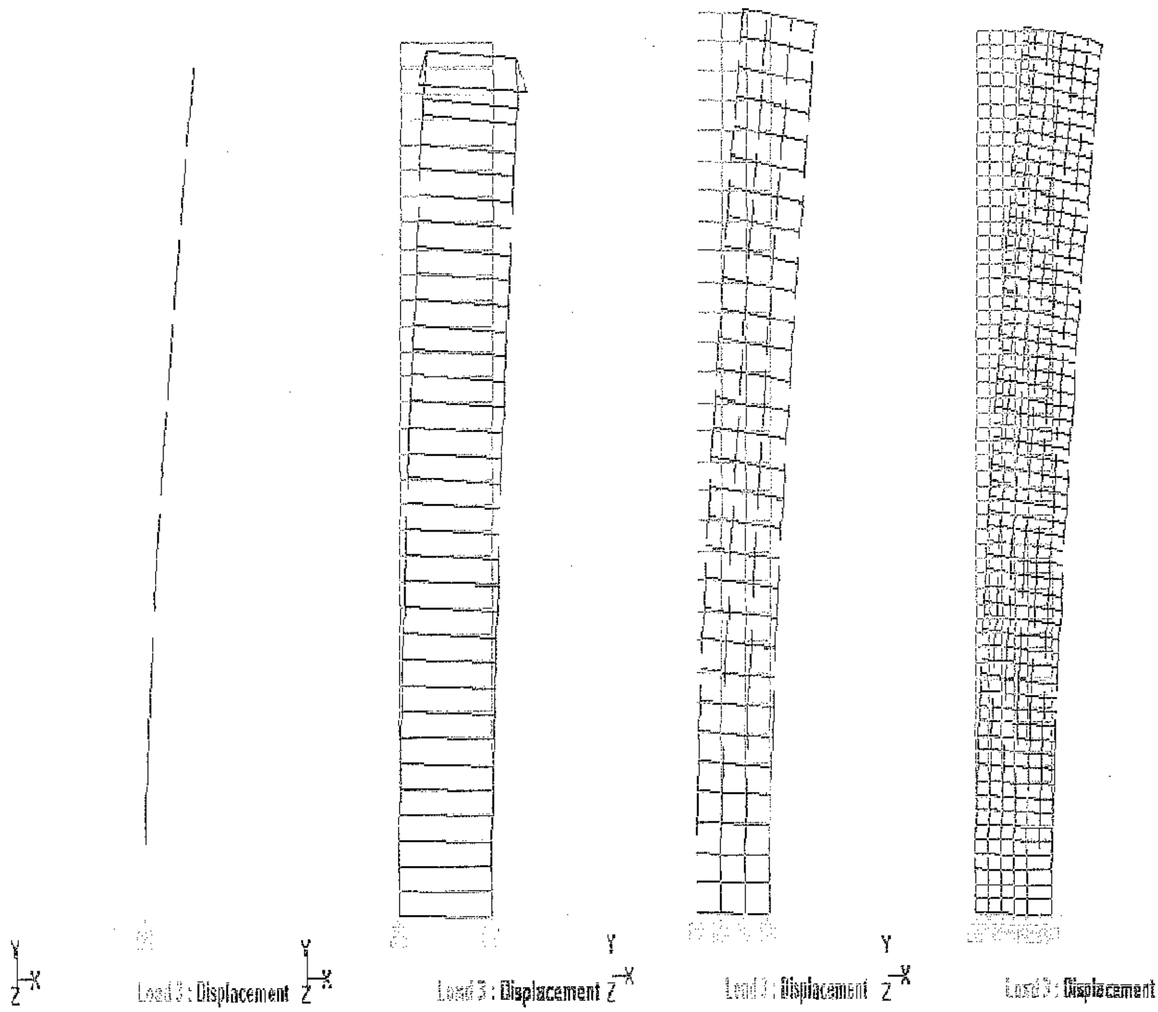


Figure 6 Shear wall model using beam element method.

The software model showed that the value of displacement due to the axial and horizontal load is 31.2 mm at node number 11. Figure 7 is showing the displacement of the beam due to applied load. After analyzing the shear wall using the beam elements a series of finely meshed element has been used to model and analyze the shear wall (Figure 7). These models were exposed to 1000 KN axial force and 100 KN lateral forces. The shell element models have the same properties of the beam element model.



Model 1 (Beam) | Model 2 (1 shell) | Model 3 (9 shells) | Model 4 (36 shells)

Figure 7 Analysis models for a simple wall panel

The quoted number of shells refers to the number of elements used on a floor to floor basis. The lateral deflections for each of these models are given in Table 1.

Table 1 Lateral Deflections for differenr simple Models of wall Panel

Models	Beam	1 Shell	9 Shell	36 Shell
Current study (mm)	31.2	29.6	31.6	31.7
Arnot (2005) (mm)	31.2	29.7	31.0	31.2

The deflection of these models has been compared with the deflection of the same models presented by Arnot, K. (2005). These results showing differences between the results that this project considers and that presented by Arnot, K. (2005). The differences are very small. It ranges from 0 % to 1.6 %. This might be due to some approximations that considered in the current models and in the models that presented by Arnot, K. (2005).

The obtained results showing the following:

1. The beam element method gives the same lateral deflection as the shell element with very small difference
2. The deflection values for the shell elements models vary with the number of the shells. The differences are very small.
3. The differences between the deflection value of the beam model and the shell element model is very small. The beam element model is very simple model. The shell element model is complicated. This complication increase as the number of shell increase
4. The shell element model does not usually lead to better results.

The openings have an effect in the deflection and the stress distribution of the shear wall. The deflection of model number 3 after introducing openings is shown in figure number 8. The deflection of this model is compared with the deflection of model number 3 presented in Arnot, K. (2005). The deflection in this model equal 33.66 mm. The deflection of model number 3 by Arnot, K. (2005) equal 33.6 mm. The difference is 0.01mm.

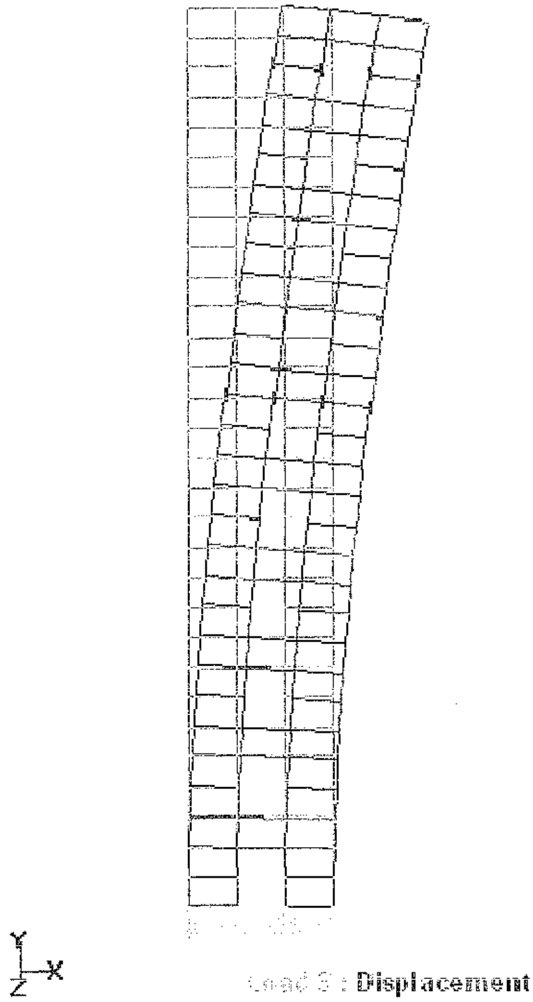


Figure 8 Deflection of model number 3 after introducing openings

The deflection of model 3 has been increased after introducing the opening in the model. The deflection after introducing the opening is 33.66 mm, where it was 31.6 mm before introducing the opening. This is showing the effect of the opening in the shear wall modeling and analysis. The distribution of the stress around the opening is shown in Figure 9.

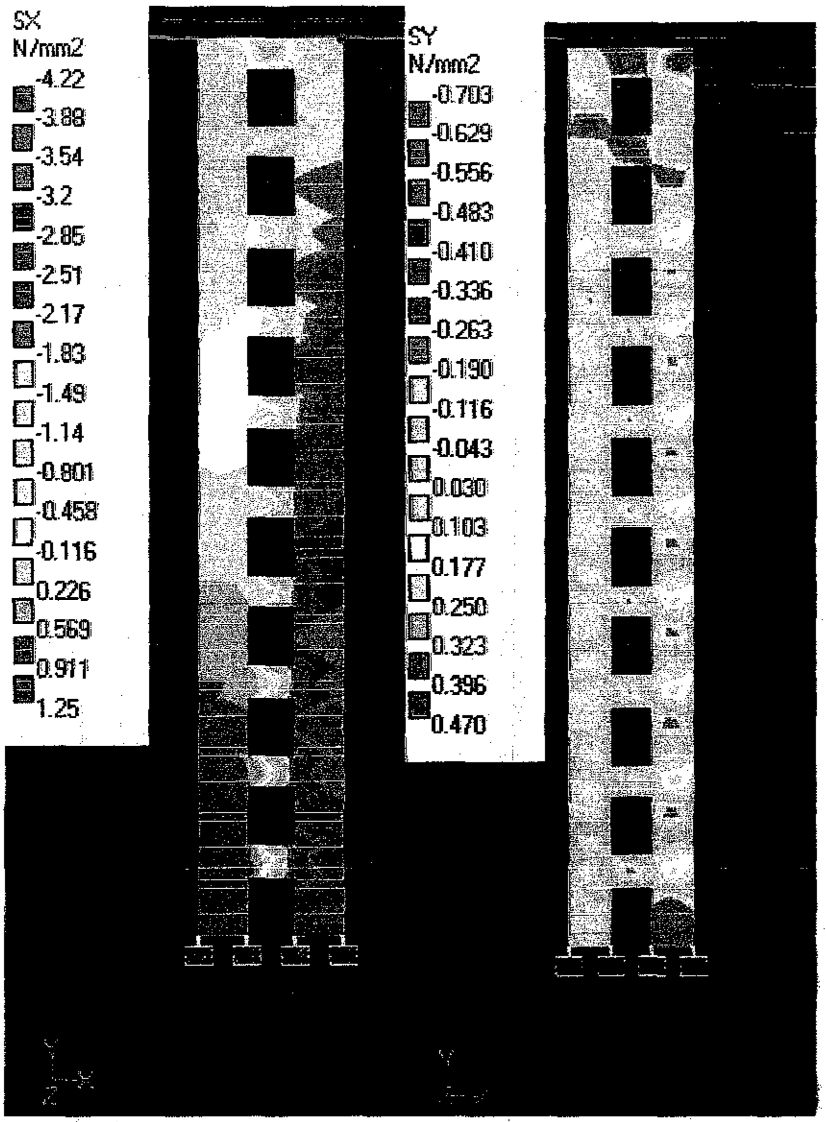
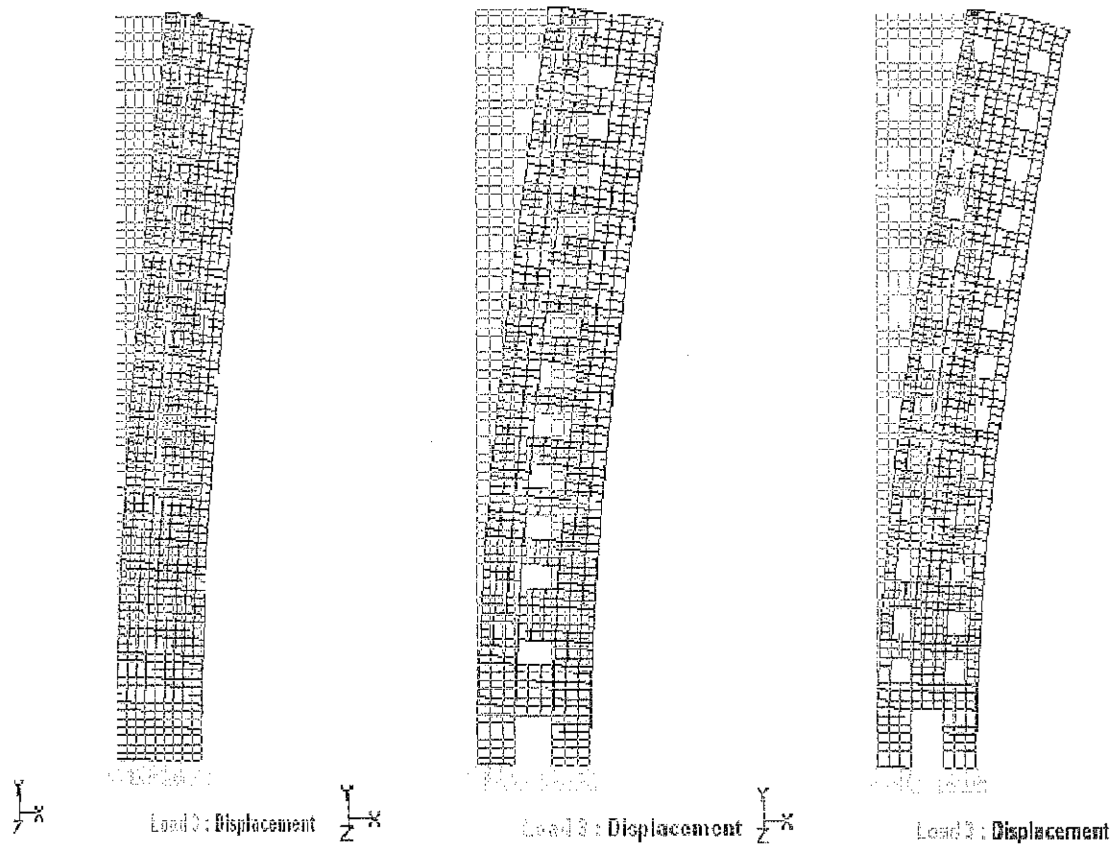


Figure 9 Shear Stress Distribution for model 3 after introducing the openings

This figure compares the stress distribution around the opening in X and Y direction. In X direction, high tension is observed in the right side of the shear wall. In Y direction, slight tension and compression can be observed around the opening.

Different results of deflection are obtained as the location and number of opening change. The effect of two opening in the shear wall can be observed from figure 10. All models have 81 shells, same design properties. The differences are the number size, and the location of the openings. Model B has 26 windows in both sides of the shear wall. Model C has 12 windows in the center of the shear wall. As the number of opening increase the deflection of the shear wall increase. A comparison between the three models is presented in table 3.



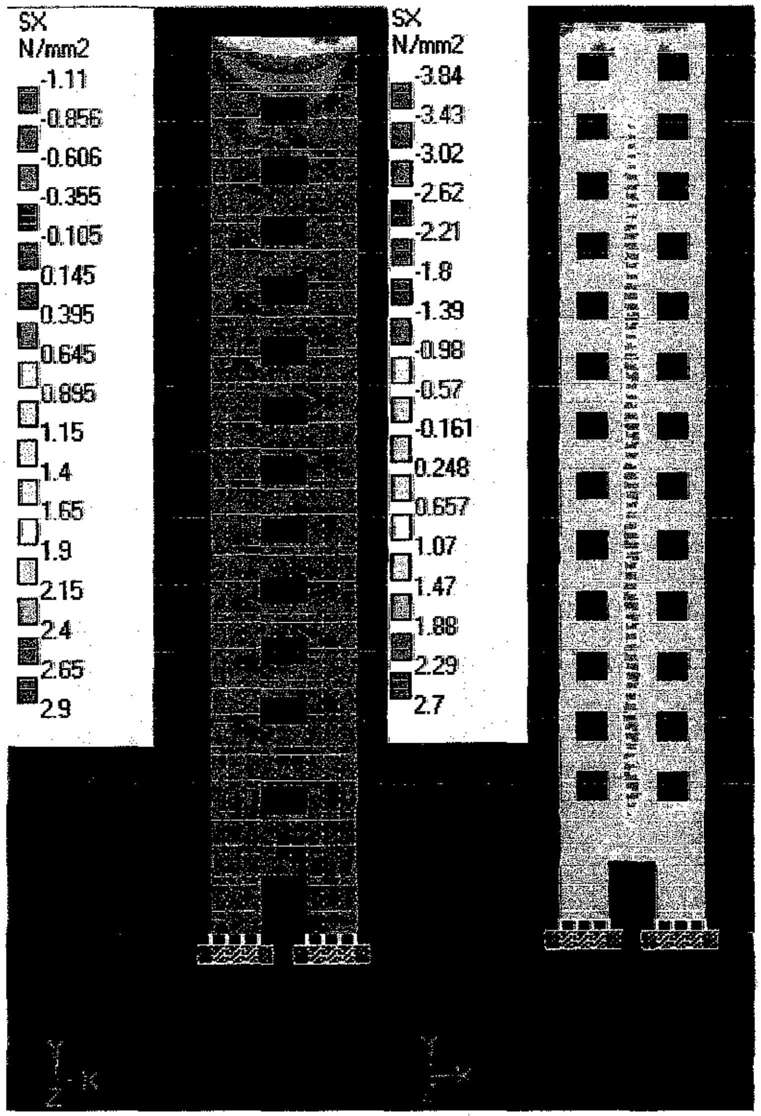
Model A (81 shells) Model B (81 Shells) Model C (81 Shells)

Figure 10 Deflection of 3 Models to Compare The Effect of The Openings

Table 2 Lateral Deflection For Analysis Models With Openings

Model Name	A	B	C
Deflection mm	31.8	33.7	46.8

Model C is showing the highest value of deflection compare to model A and B. This is to prove that the location and the number of the openings have great effect in the displacement of the shear walls. The difference between the deflection of model B and model C is 13.3 mm. this is quit big difference compare to the difference between model B and model A. The stress distribution is varying with respect to the location and the number of the openings as shown in figure 11 and 12.

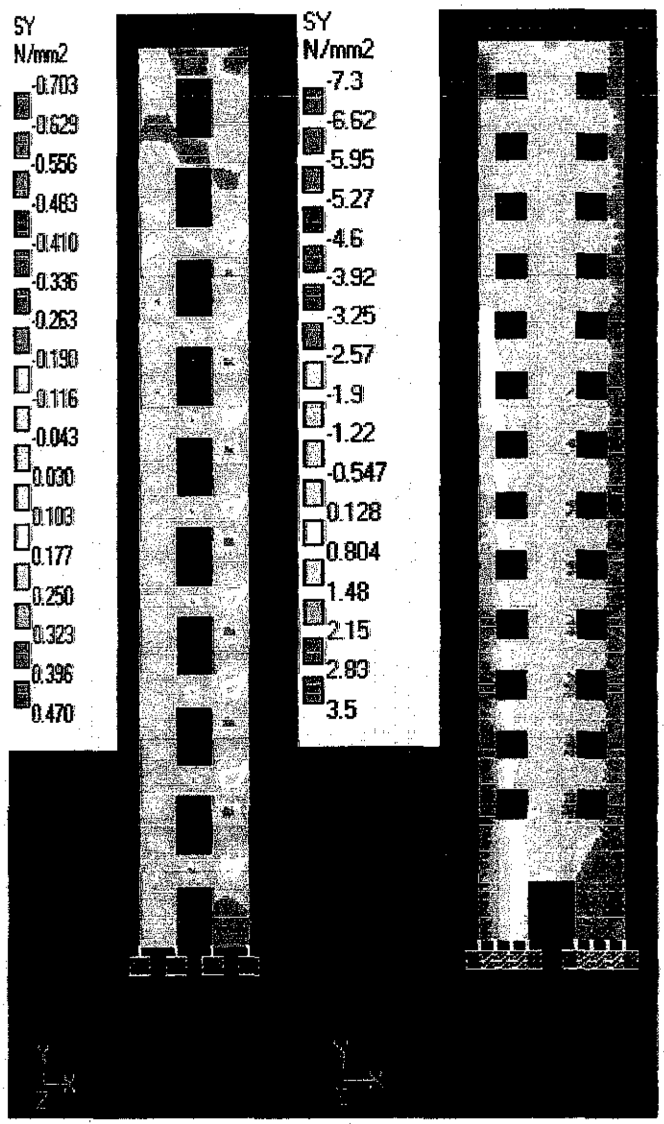


Model A (81 Shells)

Model B (81 Shells)

Figure 11 Shear Stress Distribution in X direction

The stress distribution in the above figure is showing the stress around the opening. There is high tension at the edge of the openings. The tension is increasing with respect to height as in model A. In model B there is no high stress around the opening. The stress is concentrated in the area between the openings.



Model A (*81 Shells*) | Model B (81 Shells)

Figure 12 Shear Stress Distribution in Y direction

A coupled shear wall is designed using STAAD.PRO 2004. The shear wall representing building consists of 20 stories. The height of the shear wall is 56 m. The height of each story is 2.8 meter. The wall is subjected to lateral force of 16.5 KN/m. Openings are introduced in the shear wall. The height of each opening is 2.8 m and the width is 2 meter. The tie beam width is 300 mm and its height is 400 mm. Figure 13 is showing the shear wall model.

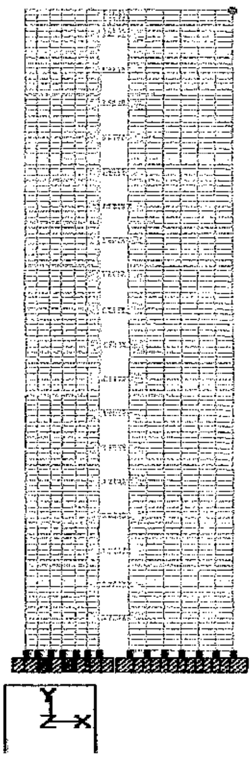
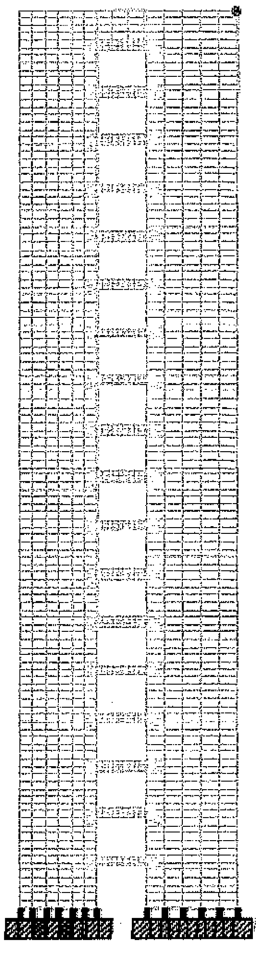


Figure 13 Coupled Shear Wall (CSW)

The analysis of the shear is performed using STAAD.PRO 2004 software. The deflection at the top of the wall is 17.908 mm.

Hand calculation of the deflection of the shear wall has been done. The deflection of the coupled shear wall with single row of opening calculated and provided in appendix B

The calculation was done using Microsoft Excel. This is to help to perform the calculation for different models to check the differences in the result between the software output and the hand calculation. The difference in the deflection values that obtained by the software and the hand calculation is very small. The deflection value obtained by the software is 17.908 mm, were it is 16 mm as indicated in the hand calculation the difference is only 1.908 mm. This difference can be considered as very small difference for 20 stories building. In addition to that the effect of the width of the opening and the thickness of the tie beam has been studied. Figure 14 shows the model of the 20 stories building with wider opening.

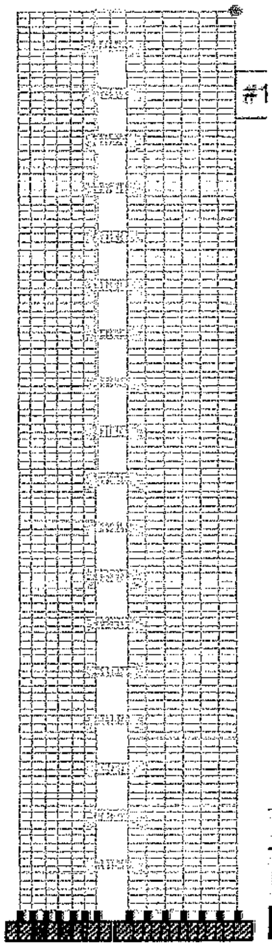


		Horizontal	Vertical	Horizontal	Resultant		Rotational
Node	L/C	X mm	Y mm	Z mm	mm	rX rad	rY rad
1694	1	22.919	-4.617	0.000	22.976	0.000	0.000
1695	1	0.224	-0.251	0.000	0.337	0.000	0.000

Figure 14 Displacement of the shear wall with wider opening size.

The analysis using STAAD.PRO 2004 is showing that the deflection of the building increase from 19.02mm to 22.919mm. This indicates that the increase of the deflection is 3.899 mm due to increase of 1.17 m in the width of the opening. The effect of the increase of the width of the opening in the deflection of the building is not that significant.

The effect of the thickness of the tie beam in the deflection of the building has been studied as shown in figure 15



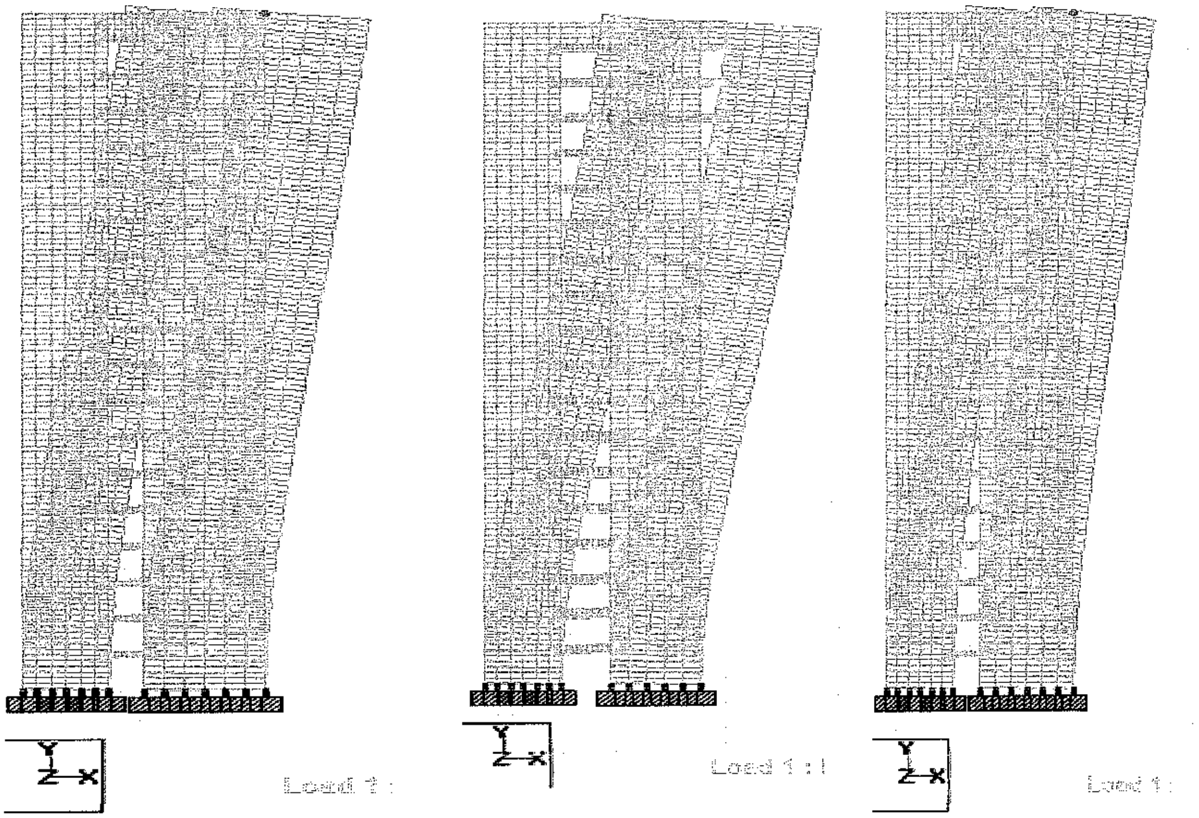
		Horizontal	Vertical	Horizontal	Resultant		Rotational
Node	L/C	X mm	Y mm	Z mm	mm	rX rad	rY rad
1694	1	13.423	-4.459	0.000	13.502	0.000	0.000
1695	1	0.152	-0.084	0.000	0.174	0.000	0.000

Figure 15 Displacement of the couple shear wall with thicker tie beam.

The deflection of the 20 stories building has been reduced from 17.908mm to 13.423mm. The reduction in the deflection equal 4.5 mm for increasing the thickness of the tie beam by 0.2 m. this is showing the great effect of the thickness of the tie beam in deflection of the tall building.

In addition to the analysis using STAAD.PRO 2004 software, hand calculation of the deflection of the building with wider opening size and the building with thicker tie beam has been done. The deflection values were compared with the values that obtained by the software.

Comparison between shear wall, shear wall with wider opening and shear wall with thicker tie beam is shown in figure 16



Normal CSW | CSW with wider opening | CSW with thicker beam

Figure 16 Comparison between the deflection of different CSW models

Table 3 is showing that the difference between the hand calculation and the software output is very small. The hand calculation of the deflection is attached in Appendix B and C.

Table 3 Comparison between the deflection of different CSW models

Coupled shear wall				
Deflection (mm)	Model	Normal	With wider opening	With thicker tie beam
	STAAD.PRO	17.897	22.919	13.423
	Hand calculation	15.9	21.4	13.5
	Deviation %	11	6.6	0.57

Numbers and locations of the opening has great effect in the deflection of the coupled shear wall. The deflection of the coupled shear wall after introducing two columns of opening has been compared with the deflection of the coupled shear wall wit one columns of opening as in figure 17 and table 4

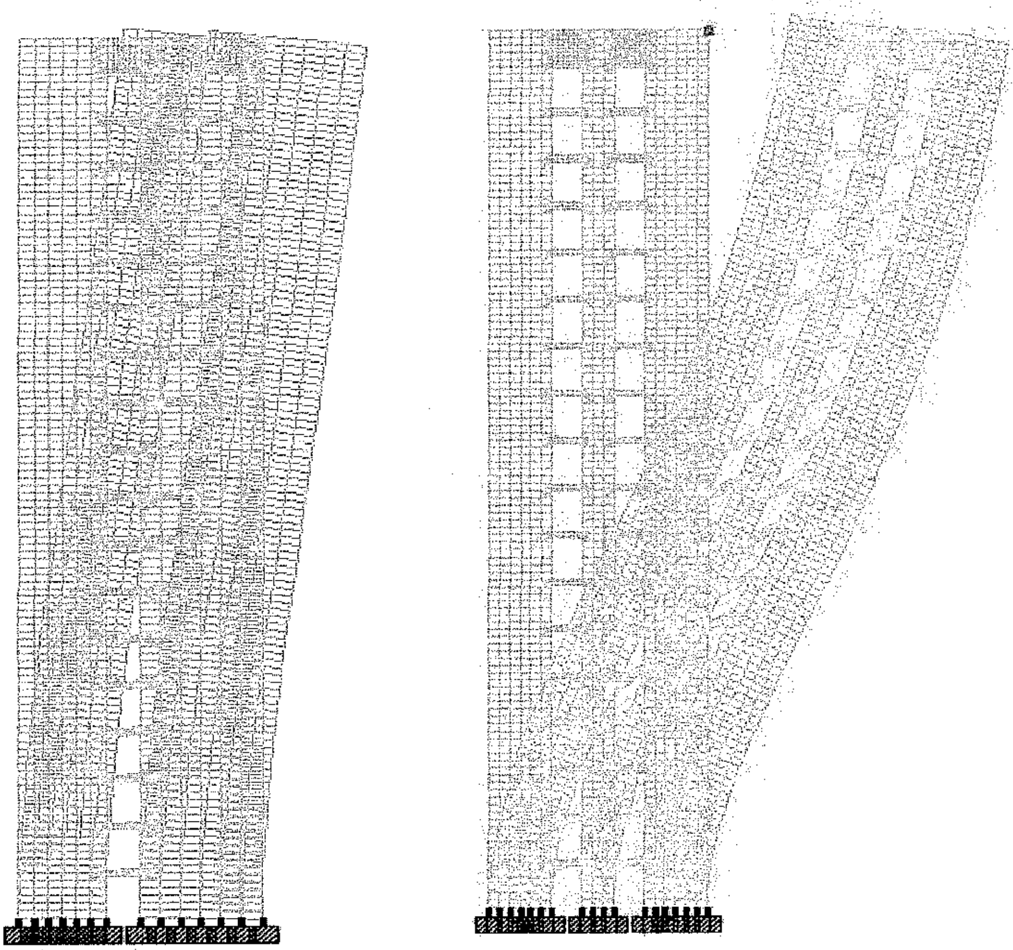


Figure 17 Comparison between CSW with different number of openings

Table 4 Comparison of deflection of CSW with different number of openings

Coupled shear wall			
Deflection (mm)	Model	with single row of opening	with two rows of opening
	STAAD PRO 2004	17.897	57.963
	Hand calculation	15.9	66.3

Figure 17 and table 4 shows that the deflection of the coupled shear wall increased by 40.1 mm after two rows of opening were introduced. This is to confirm the great effect of the opening in the deflection of the shear wall. The number of the opening can be increased with the usage of couple shear wall. Using couple shear wall to introduce more opening is better than build one big wall to introduce many openings. The lateral case will be more complex in the design and it will be more expensive in terms of the cost compare to the couple shear wall. The hand calculation of the deflection of the couple shear wall was done. The difference between the hand calculation result and the software result is very small. This is might be due to the approximation of some of the values of some factors that were extracted from some figures. The scale of the figures is not precise which might lead to the differences in the result between the software and the hand calculation. The hand calculation of the deflection of the shear wall is quit tedious and complex. Usages of Microsoft excel sheet helps in the hand calculation, but some of the values should be entered according to different dimension of the wall. Due to that, it is not easy to use the excel sheet with varying dimension of the walls.

The bending moment and axial force has been calculated using excel sheet. The axial force and the bending moment are varying with the height of the floor as shown in figure 18 and 19.

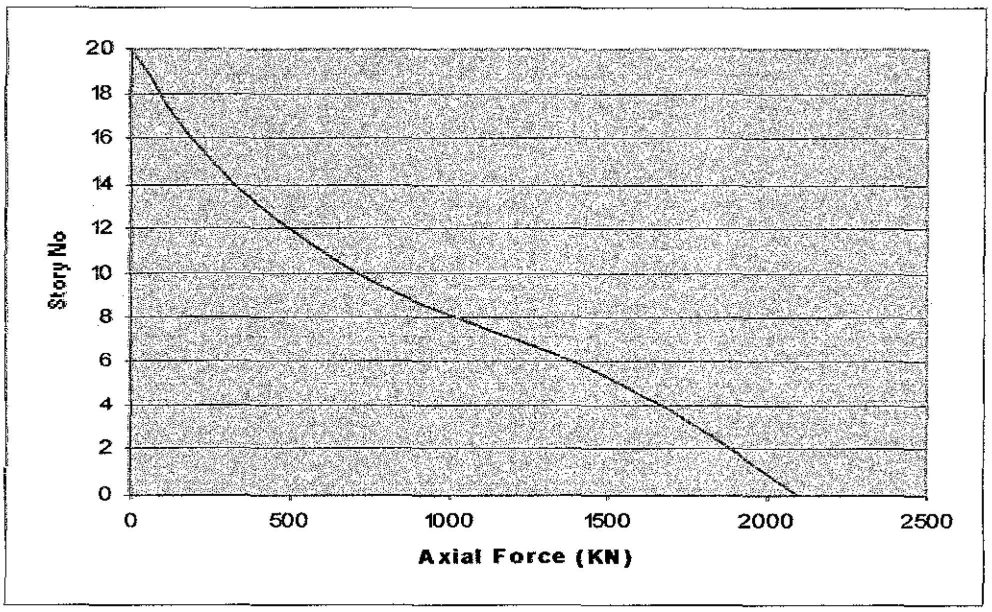


Figure 18 Variation of axial force in column with respect to floor number

The axial force reduces the wind moment in the walls. The axial force value increases as the height of the building decrease. It reaches its maximum value at the base of building.

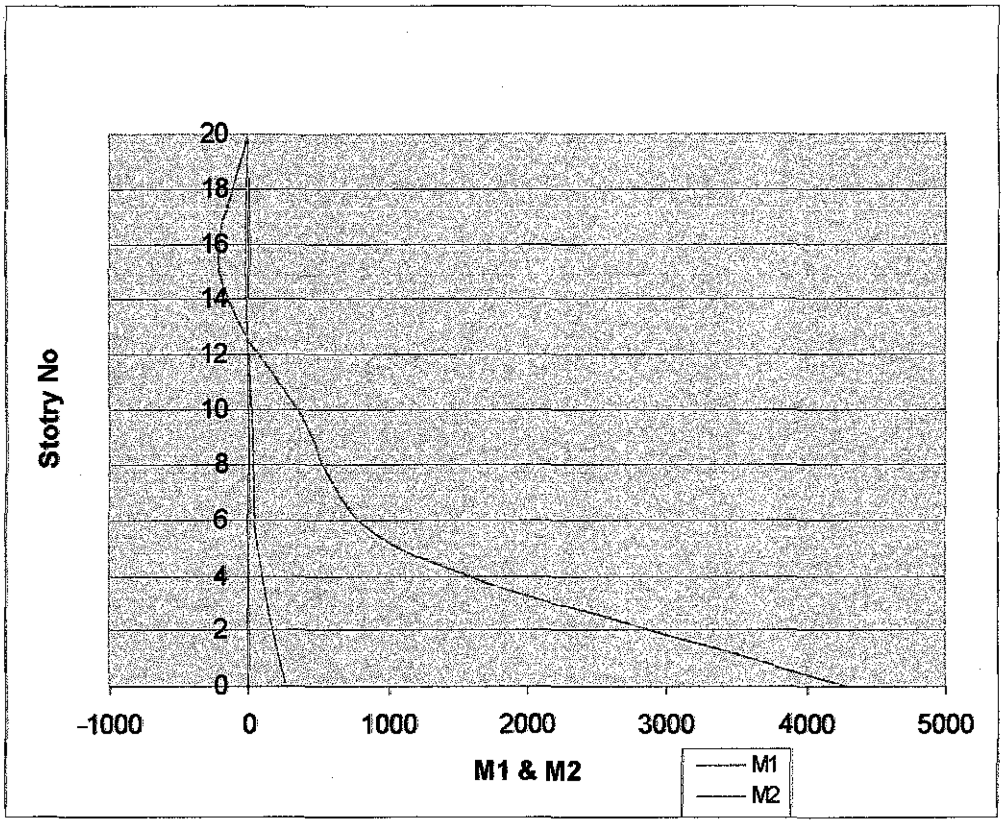


Figure 19 variation of bending moment in column with respect to floor number

At top stories (12-20), negative moment takes place in the walls due to the receptivity moment induced by the connecting beams. In the lower levels, the amount of deformation of the connecting beams is reduced and the relative influence of the resisting axial force is diminished. The proportion of the wind lateral force moment that is resisted by axial forces diminished towards the base.

The beam element can be used in the modeling and analysis of the shear wall with opening. Figure 20 is showing beam element model and shell element model for shear wall. the height of the wall is 56 m. the width of wall 1 is 2 m and wall 1 is 2 m. the coupling beam has the properties of a rectangular section 200mm width and 1100 mm deep for the shell element model and 2 m deep for the beam element model. Vertical load of 1000 KN and horizontal load of 50 KN were applied at the top of the model.

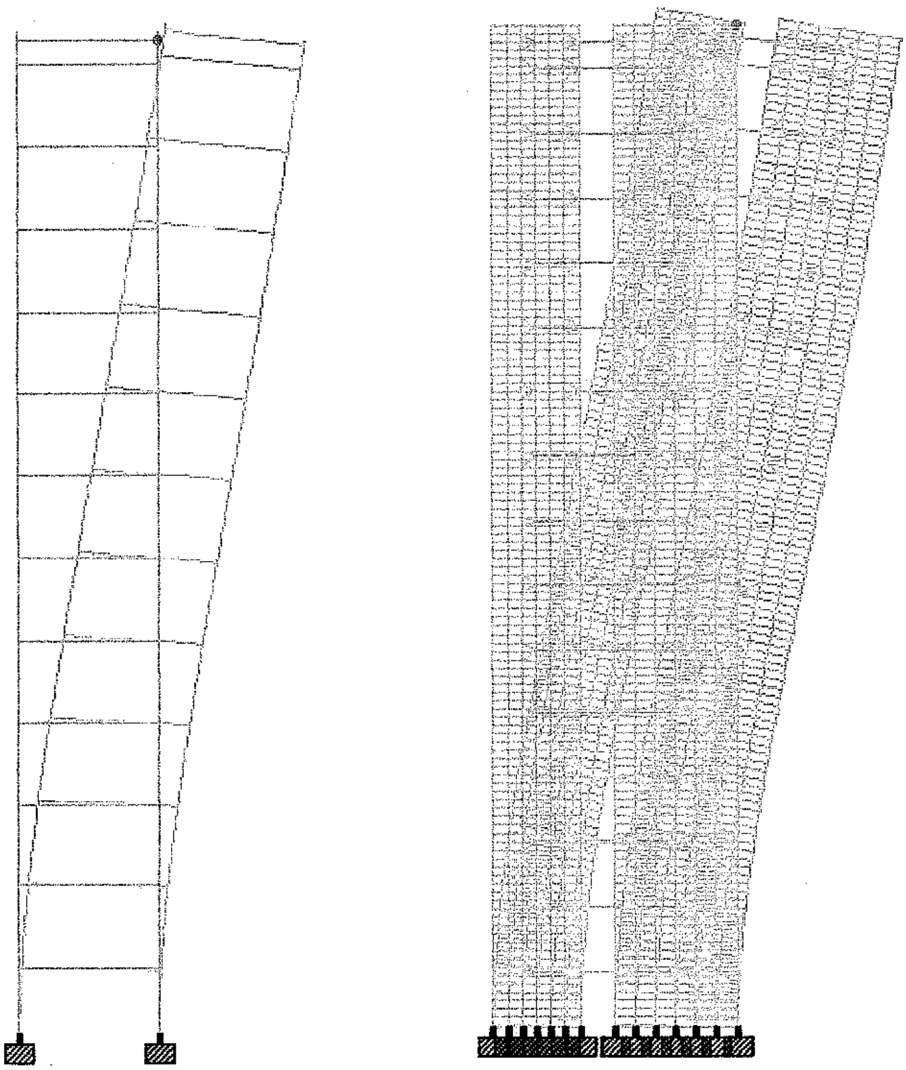
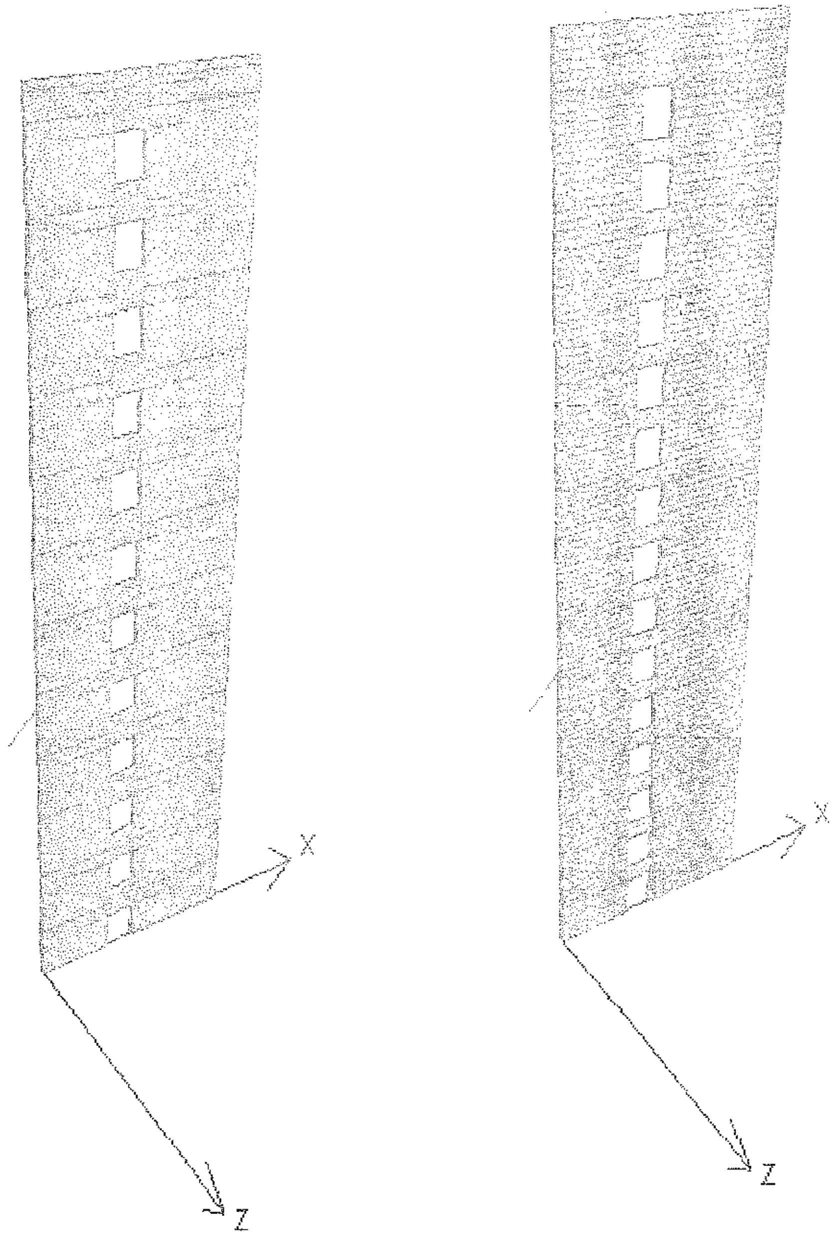


Figure 20 Comparison of deflection in models of CSW using beam and shell elements

Figure 21 shows 3D rendered view of beam element and shell element. The deflection of the shear wall using the beam element model is 25.671mm. When shell element method is used, the deflection of the wall becomes 28.544. This is mean that the shell element method give higher value of deflection compares to the beam element method. In the shell element model the connecting beams were modeled using beam element method Table 5 show the result and the difference between the value of the deflection using beam element and shell element method.



Beam Element Model　　　　　Shell Element Model

Figure 21　3D rendered view of beam and shell elements

Table 5　Comparison of deflection of shear wall models using beam and shell elements

Model Name	Beam element	Shell element
Deflection (mm)	25.671	28.544

The difference between the two results is 2.873 mm for the 20 story building. This deference is considered as very small difference. Modeling of the shear wall using shell element is very complicated and required a lot of work compared to the beam element method. Beam element method is very simple method compared to the shell element method and does not require a lot of consideration during the analysis using STAAD.Pro software. The analysis of the shear wall can be done easily and faster using the beam element method.

4.2 Calculation

The deflection of he cantilever has peen calculated using the following formula

$$\Delta = \frac{PL^3}{3EI}$$

Where

Δ : *displacement* (m)

P: applied force (KN)

L: length of the cantilever (m)

E: Young's Modulus (KN/m^2)

I: moment of inertia (m^4)

At this example we consider the wall height is 35 m (10 story at 3.5m), 5.045m long and 200mm thick. An axial load of 1000 KN and lateral load of 100 KN are applied at the top of the wall.

I= $bh^3/12$

I= 0.2 X $5.045^3/12$

I=2.14 m^4

P= 100 KN

L= 35 m^3

E= 21.72 X 106 KN/m^2

$$\Delta = \frac{100 \times 35^3}{3 \times 21.72 \times 10^6 \times 2.14}$$

$\Delta = 30.75$ mm

The difference between the calculated value of displacement and the value obtained by STAAD.PRO software = 31.18- 30.75 = 0.43 mm.

This difference may be due to the values of the density and poison ratio which is not considered in the calculation, but it considered in the analysis by the software.

CHAPTER 5

CONCLUSION

The modeling and analysis method of the shear walls is very important especially in high rise building. The following conclusions are made

1. There are different ways of modeling the shear walls. Beam element and shell element method are presented in this report.
2. The deflection of the shear wall is varying from one model to another. The variation is small. The difference between the deflection that obtained by using beam element method and the minimum delectation obtained by using shell element is 1.6 mm for the ten story building.
3. The beam element model is a simple model compared to the shell element model which can be considered as a complex model.
4. As more number of shells being used the model become more complicated and there is no significant difference in terms of displacement of the shear wall.
5. As the size of the shear wall increase the analysis of the wall using shell element method will be more tedious and complex.
6. The beam element as presented in this report shows very good result compare to the shell element. The difference between the deflection of the shear wall obtained by beam element method and shell element method is 2.87 mm. the shell element is not a better option of modeling the shear wall compare to beam element which is simpler and easier.
7. Tie beam which connects the shear walls plays an important role in the deflection of the shear wall. By increasing the thickness of the tie beam the deflection of the shear wall is decreased.

8. The opening has a great effect in the deflection of the shear wall. The deflection of the shear walls increase by introducing the openings. The number and the location of the opening have significant effect in the displacement of the shear wall. The width of the opening has minor effect in the deflection of the shear wall compare to the height of the opening. The distribution of the stress is also varying with respect to the location and the number of the openings. The axial force and the bending moment distribution are varying with respect to the height of the floor as presented in this report.

9. Hand calculation of the deflection of the couple shear wall is tedious and complicated due to the extraction of some of the factors values from some graphs and the scale of the graphs is not that clear which may result in inaccurate values.

REFRENCES

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9. www.feaservice.com
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APPENDIX A
STAAD PRO OUTPUT FILE

```
**************************************************
*                                                *
*        STAAD.Pro                               *
*        Version  2004    Bld 1001.INDIA         *
*        Proprietary Program of                  *
*        Research Engineers,  Intl.              *
*        Date=    APR 11, 2007                   *
*        Time=    18:58:44                       *
*                                                *
*   USER ID: Snow Panther [LZ0]                  *
**************************************************
```

INPUT FILE: beam1.STD

```
 1. STAAD SPACE
 2. START JOB INFORMATION
 3. ENGINEER DATE 09-APR-07
 4. END JOB INFORMATION
 5. INPUT WIDTH 79
 6. UNIT METER KN
 7. JOINT COORDINATES
 8. 1 4 0 0; 2 4 1 0; 3 4 2 0; 4 4 3 0; 5 4 4 0; 6 4 5 0; 7 4 6 0; 8 4 7 0
 9. 9 4 8 0; 10 4 9 0; 11 4 10 0; 12 4 11 0; 13 4 12 0; 14 4 13 0
10. 15 4 14 0; 16 4 15 0; 17 4 16 0; 18 4 17 0; 19 4 18 0; 20 4 19 0
11. 21 4 20 0; 22 4 21 0; 23 4 22 0; 24 4 23 0; 25 4 24 0; 26 4 25 0
12. 27 4 26 0; 28 4 27 0; 29 4 28 0; 30 4 29 0; 31 4 30 0; 32 4 31 0
13. 33 4 32 0; 34 4 33 0; 35 4 34 0; 36 4 35 0
14. MEMBER INCIDENCES
```

15. 1 1 2; 2 2 3; 3 3 4; 4 4 5; 5 5 6; 6 6 7; 7 7 8; 8 8 9; 9 9 10

16. 10 10 11; 11 11 12; 12 12 13; 13 13 14; 14 14 15; 15 15 16; 16 16 17

17. 17 17 18; 18 18 19; 19 19 20; 20 20 21; 21 21 22; 22 22 23; 23 23 24

18. 24 24 25; 25 25 26; 26 26 27; 27 27 28; 28 28 29; 29 29 30; 30 30 31

19. 31 31 32; 32 32 33; 33 33 34; 34 34 35; 35 35 36

20. DEFINE MATERIAL START

21. ISOTROPIC CONCRETE

22. E 2.17185E+007

23. POISSON 0.17

24. DENSITY 23.5616

25. ALPHA 1E-005

26. DAMP 0.05

27. END DEFINE MATERIAL

28. CONSTANTS

29. MATERIAL CONCRETE MEMB 1 TO 35

30. MEMBER PROPERTY

31. 1 TO 35 PRIS YD 5.045 ZD 0.2

32. SUPPORTS

33. 1 FIXED

34. LOAD 1

35. JOINT LOAD

36. 36 FX 100

37. LOAD 2

38. JOINT LOAD

39. 36 FY -1000

40. LOAD COMBINATION 3

STAAD SPACE -- PAGE NO. 2

41. 1 1.0 2 1.0

42. PERFORM ANALYSIS PRINT STATICS CHECK

P R O B L E M   S T A T I S T I C S

NUMBER OF JOINTS/MEMBER+ELEMENTS/SUPPORTS = 36/ 35/ 1

ORIGINAL/FINAL BAND-WIDTH= 1/ 1/ 12 DOF

TOTAL PRIMARY LOAD CASES = 2, TOTAL DEGREES OF FREEDOM = 210

SIZE OF STIFFNESS MATRIX = 3 DOUBLE KILO-WORDS

REQRD/AVAIL. DISK SPACE = 12.1/ 6478.4 MB, EXMEM = 459.3 MB

STAAD SPACE -- PAGE NO. 3

STATIC LOAD/REACTION/EQUILIBRIUM SUMMARY FOR CASE NO. 1

***TOTAL APPLIED LOAD (KN METE) SUMMARY (LOADING 1)

SUMMATION FORCE-X = 100.00

SUMMATION FORCE-Y = 0.00

SUMMATION FORCE-Z = 0.00

SUMMATION OF MOMENTS AROUND THE ORIGIN-

MX= 0.00 MY= 0.00 MZ= -3500.00

***TOTAL REACTION LOAD(KN METE) SUMMARY (LOADING 1)

SUMMATION FORCE-X = -100.00

SUMMATION FORCE-Y = 0.00

SUMMATION FORCE-Z = 0.00

SUMMATION OF MOMENTS AROUND THE ORIGIN-

MX= 0.00 MY= 0.00 MZ= 3500.00

MAXIMUM DISPLACEMENTS (CM /RADIANS) (LOADING 1)

MAXIMUMS AT NODE

X = 3.11880E+00 36

Y = 0.00000E+00 0

Z = 0.00000E+00 0

RX= 0.00000E+00 0

RY= 0.00000E+00 0

RZ= -1.31778E-03 36

STATIC LOAD/REACTION/EQUILIBRIUM SUMMARY FOR CASE NO. 2

***TOTAL APPLIED LOAD (KN METE) SUMMARY (LOADING 2)

SUMMATION FORCE-X = 0.00

SUMMATION FORCE-Y = -1000.00

SUMMATION FORCE-Z = 0.00

SUMMATION OF MOMENTS AROUND THE ORIGIN-

MX= 0.00 MY= 0.00 MZ= -4000.00

***TOTAL REACTION LOAD(KN METE) SUMMARY (LOADING 2)

SUMMATION FORCE-X = 0.00

SUMMATION FORCE-Y = 1000.00

SUMMATION FORCE-Z = 0.00

SUMMATION OF MOMENTS AROUND THE ORIGIN-

```
MX=        0.00  MY=         0.00  MZ=      4000.00

STAAD SPACE                              -- PAGE NO.    4


MAXIMUM DISPLACEMENTS ( CM  /RADIANS) (LOADING      2)
      MAXIMUMS    AT NODE
  X =  0.00000E+00      0
  Y = -1.59715E-01     36
  Z =  0.00000E+00      0
  RX=  0.00000E+00      0
  RY=  0.00000E+00      0
  RZ=  0.00000E+00      0



************ END OF DATA FROM INTERNAL STORAGE ************


43. FINISH


      *********** END OF THE STAAD.Pro RUN ***********

       **** DATE= APR 11,2007   TIME= 18:58:46 ****

    ************************************************************
    *  For questions on STAAD.Pro,                              *
    *  Please contact : Research Engineers Ltd.                 *
    *  E2/4,Block GP, Sector-V,Salt Lake, KOLKATA - 700 091     *
    *  India : TEL:(033)2357-3575      FAX:(033)2357-3467       *
    *  email : support@calcutta.reiusa.com                      *
    *  US    : Ph-(714) 974-2500, Fax-(714) 921-0683            *
    ************************************************************
```

APPENDIX B

CALCULATION OF THE DEFLECTION OF THE CSW WITH WIDER OPENING

applied load (w)=	16.5		
ab=	5		
bc=	3.17		
cd=	5.84		
th	0.3		
th beam=	0.6		
b=	3.17	(window width)	
A1=	1.5		
A2=	1.752		
At=	3.252		
total H=	56		
I1=	3.125		
I2=	4.9794176		
It=	8.1044176		
L	8.59		
I beam=	0.0054		
r=	0.15		
h window	2.4		
G=	E/(2(1+r))	2*(1+r)=	2.3
	G=E/2.3		

Ic=Ib/(1+r)
r=(12EIbλ/B*B*G*A)

GA= 1.2 (rectangular section)

r= 0.098876494

Ic= 0.004914

effective length of the beam = actual length + have beam depth= 3.47

Determine the structural Parameter K, α and KαH using the charts

$$K^2 = 1 + \frac{AI}{A_1 A_2 L^2}$$

K^2= 1.1359
K= 1.0658

$$\alpha^2 = \frac{12\, IcL^2}{b^3 hI}$$

α^2 = 0.0053542

α= 0.07317

$K\sigma H$= 4.367
Z/H= 0 at base level

From figure of variation of wall moment factors K1 and K2

K1= 0.36
K2= 0.64

Total Base Moment= 0.5*applied force*total height = 25872 KN.m

portion of base moment due to individual cantilever action is
K1*total base moment= 9313.9 KN.m

Moment of wall1, M1= 3591 KN.m

Moment of wall2, M2= 5723 KN.m

Portion of base moment due to composite cantilever action is
K2*Total Base Moment = 16558 KN.m

Composite Section

X1=ab/2 = 2.5 m
X2=ab+bc+(cd/2) = 11.09 m

X'=(A1X1+A2X2)/At = 7.128 m

moment of inertia about the composite centroide Ig = I1+I2+(A1*A2/A)*L*L

Ig= 67.73391539

σa= porsition due to cantilever + porsition due to composite action
σa= (M1*X1/I1)+(M2*X'/Ig)
σa= 4.62 N/mm2
σb= - (M1*X1/I1)+((K2*total base moment)*(X'-bc)/Ig)
σb= -2.35 N/mm2
σc=(M2*(cd/2)/I2)+((K2*total base moment)*(X'-(ab+bc))/Ig)
σc= 3.101 N/mm2
σd= - (M2*(cd/2)/I2)+((K2*total base moment)*(X'-(ab+bc))/Ig)
σd= -5.038 N/mm2

If the walls were un copled the base moment:

M1=I1*total base moment/It
M1= 9976 KN.m
M2=I2*total base moment/It
M2= 15896 KN.m

Then:

$\sigma a=-\sigma b=M1*X1/I1$

$\sigma a=-\sigma b=$	7.981	N/mm2
$\sigma c=-\sigma d=$	9.322	N/mm2

so the coupling action reduces the stress by

A=	42.167%
B=	70.518%
C=	66.733%
D=	45.952%

Finding the maximum Shear and Moment in Beams

$K\alpha H=$ 4.367

at F2 max z/h = 0.36 — using figure of (variation of shear flow factor F2)

F2= 0.42

q=wHF2/(K^2*L)

q= 39.77

Qmax= q*h = 95.5 KN.m

Maximum Lateral Deflection

YH=w*H^4*F3/(8EI) — F3 is function of K and $K\alpha H$ at top Z/H = 1.0

$K\alpha H=$ 4.367

K=1.10

E= 3.60E+07

from figure of (variation of top deflection factor F3)

F3= 0.33

Ytop= 2.14E-02 m

if there is no coupling beam F3=1

Ytop= 6.47E-02 m

APPENDIX C

CALCULATION OF THE DEFLECTION OF THE CSW WITH THICKER TIE BEAM

applied load (w)=	16.5		
ab=	5		
bc=	2		
cd=	7		
th	0.3		
th beam=	0.6		
b=	2	(window width)	
A1=	1.5		
A2=	2.1		
At=	3.6		
total H=	56		
I1=	3.125		
I2=	8.575		
It=	11.7		
L	8		
I beam=	0.0054		
r=	0.15		
h window	2.4		
G=	E/(2(1+r))	2*(1+r)=	2.3
	G=E/2.3		

Ic=Ib/(1+r)
r=(12EIbλ/B*B*G*A)

GA= 1.2 (rectangular section)

r= 0.2484

Ic= 0.004326

effective length of the beam = actual length + have beam depth= 2.3

Determine the structural Parameter K, α and KαH using the charts

$$K^2 = 1 + \frac{AI}{A_1 A_2 L^2}$$

K^2= 1.2089
K= 1.0995

$$\alpha^2 = \frac{12\ IcL^2}{b^3 hI}$$

α^2 = 0.0097235

α= 0.09861

KσH= 6.072
Z/H= 0 at base level

From figure of variation of wall moment factors K1 and K2

K1= 0.25
K2= 0.75

Total Base Moment= 0.5*applied force*total height = 25872 KN.m

portion of base moment due to individual cantilever action is
K1*total base moment= 6468 KN.m

Moment of wall1, M1= 1728 KN.m

Moment of wall2, M2= 4740 KN.m

Portion of base moment due to composite cantilever action is
K2*Total Base Moment = 19404 KN.m

Composite Section

X1=ab/2 = 2.5 m
X2=ab+bc+(cd/2) = 10.5 m

X'=(A1X1+A2X2)/At = 7.167 m

moment of inertia about the composite centroide Ig = I1+I2+(A1*A2/A)*L*L

Ig= 67.7

σa= porsition due to cantilever + porsition due to composite action
σa= (M1*X1/I1)+(M2*X'/Ig)
σa= 3.44 N/mm2
σb= - (M1*X1/I1)+((K2*total base moment)*(X'-bc)/Ig)
σb= -0.76 N/mm2
σc=(M2*(cd/2)/I2)+((K2*total base moment)*(X'-(ab+bc))/Ig)
σc= 1.983 N/mm2
σd= - (M2*(cd/2)/I2)+((K2*total base moment)*(X'-(ab+bc))/Ig)
σd= -3.893 N/mm2

If the walls were un copled the base moment:

M1=I1*total base moment/It
M1= 6910 KN.m
M2=I2*total base moment/It
M2= 18962 KN.m

Then:

$\sigma a=-\sigma b=M1*X1/I1$

$\sigma a=-\sigma b=$	5.528 N/mm2
$\sigma c=-\sigma d=$	7.739 N/mm2

so the coupling action reduces the stress by

A=	37.843%
B=	86.233%
C=	74.383%
D=	49.694%

Finding the maximum Shear and Moment in Beams

$K\alpha H=$	6.072	
at F2 max z/h = 0.3		using figure of (variation of shear flow factor F2)
F2=	0.53	
q=wHF2/(K^2*L)		
q=	50.64	
Qmax= q*h =	121.5 KN.m	

Maximum Lateral Deflection

YH=w*H^4*F3/(8EI)

F3 is function of K and $K\alpha H$ at top Z/H = 1.0

$K\alpha H=$ 6.072

K=1.10

E= 3.60E+07

from figure of (variation of top deflection factor F3)

F3=	0.28
Ytop=	1.35E-02 m

if there is no coupling beam F3=1

Ytop= 4.82E-02 m

APPENDIX D

CALCULATION OF THE DEFLECTION OF SYMETRICAL CSW

applied load (w)=		8.25	
ab=		4	
bc=		1	
cd=		2	
beam width		0.3	
th beam=		0.4	
b=		1	(window width)
A1=		1.2	
A2=		0.6	
At=		1.8	
total H=		56	
I1=		1.6	
I2=		0.1	
It=		1.7	
L		4	
I beam=		0.0016	
r=		0.15	
h window		2.6	
G=	E/(2(1+r))		2*(1+r)= 2.3
	G=E/2.3		

Ic=Ib/(1+r)
r=(12EIbλ/B*B*G*A)

GA=	1.2	(rectangular section)
r=	0.4416	
Ic=	0.001110	

effective length of the beam = actual length + have beam depth= 1.2

Determine the structural Parameter K, α and KαH using the charts

$$K^2 = 1 + \frac{AI}{A_1 A_2 L^2}$$

K^2= 1.2656
K= 1.1250

$$\alpha^2 = \frac{12\, IcL^2}{b^3 hI}$$

α^2 = 0.0279004

α= 0.16703

KαH= 10.523
Z/H= 0 at base level

From figure of variation of wall moment factors K1 and K2

K1= 0.2
K2= 0.8

Total Base Moment= 0.5*applied force*total height = 12936 KN.m

portion of base moment due to individual cantilever action is
K1*total base moment= 2587.2 KN.m

Moment of wall1, M1= 2435 KN.m

Moment of wall2, M2= 152 KN.m

Portion of base moment due to composite cantilever action is
K2*Total Base Moment = 10349 KN.m

Composite Section

X1=ab/2 = 2 m
X2=ab+bc+(cd/2) = 6 m

X'=(A1X1+A2X2)/At = 3.333 m

moment of inertia about the composite centroide Ig = I1+I2+(A1*A2/A)*L*L

Ig= 8.1

σa= porsition due to cantilever + porsition due to composite action
σa= (M1*X1/I1)+(M2*X'/Ig)
σa= 7.30 N/mm2
σb= - (M1*X1/I1)+((K2*total base moment)*(X'-bc)/Ig)
σb= -3.90 N/mm2
σc=(M2*(cd/2)/I2)+((K2*total base moment)*(X'-(ab+bc))/Ig)
σc= -0.608 N/mm2
σd= - (M2*(cd/2)/I2)+((K2*total base moment)*(X'-(ab+bc))/Ig)
σd= -6.207 N/mm2

If the walls were un copled the base moment:

M1=I1*total base moment/It
M1= 12175 KN.m
M2=I2*total base moment/It
M2= 761 KN.m

Then:
σa=-σb=M1*X1/I1
σa=-σb= 15.219 N/mm2
σc=-σd= 7.609 N/mm2

so the coupling action reduces the stress by
A= 52.016%
B= 74.403%
C= 107.984%
D= 18.436%

Finding the maximum Shear and Moment in Beams

KαH= 10.523
at F2 max z/h = 0.18 using figure of (variation of shear flow factor F2)
F2= 0.65
q=wHF2/(K^2*L)
q= 59.32

Qmax= q*h = 154.2 KN.m

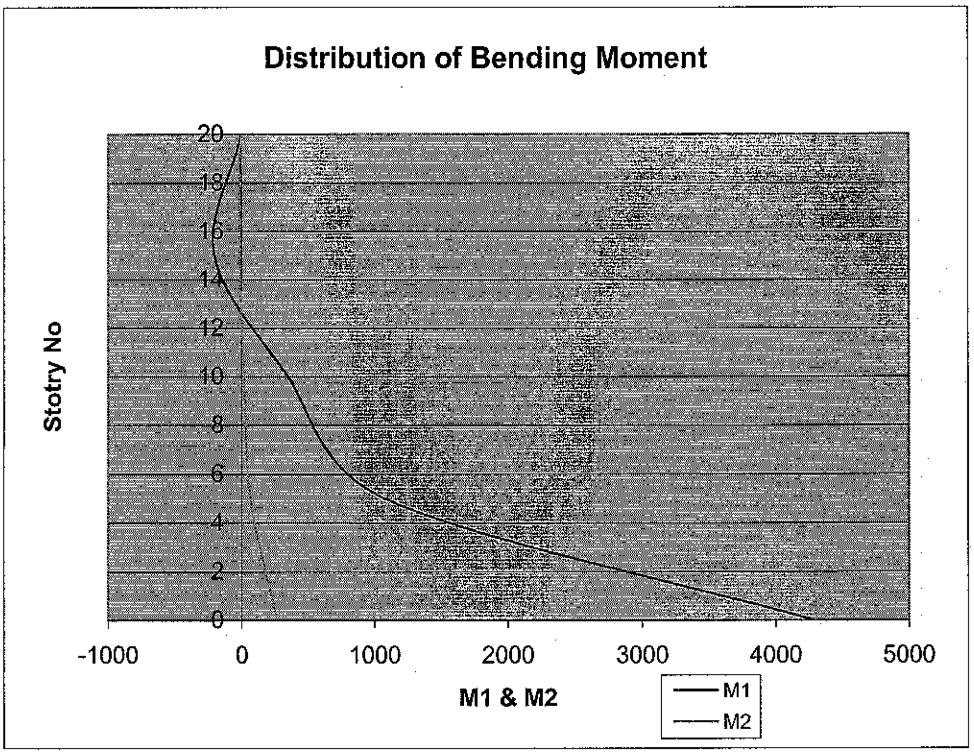
Maximum Lateral Deflection

YH=w*H^4*F3/(8EI) F3 is function of K and KαH
at top Z/H = 1.0
KαH= 10.523
K=1.10
E= 3.60E+07
from figure of (variation of top deflection factor F3)
F3= 0.2
Ytop= 6.63E-02 m

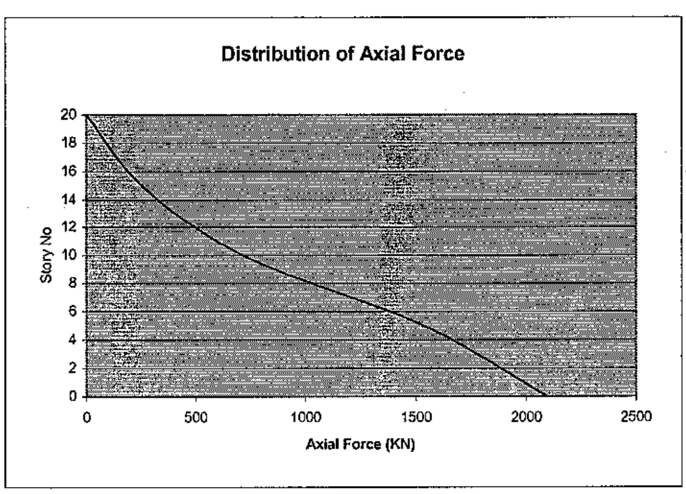
if there is no coupling beam F3=1
Ytop= 3.31E-01 m

I1/It= 0.941176471
I2/It= 0.058823529
wH^2/2= 12936

Z	Z/H	(1-z/H)^2	floor	N=wh^2F1/	N*L	M1	M2
0	0	1	0	2095.354	8381.416	4286.665	267.9189
14	0.25	0.5625	5	1533.186	6132.743	1076.476	67.28034
28	0.5	0.25	10	715.4867	2861.947	350.1674	21.88565
42	0.75	0.0625	15	255.531	1022.124	-201.058	-12.5662
56	1	0	20	0	0	0	0



Distribution of Bending Moment
Stotry No
M1 & M2
M1
M2
-1000
0
1000
2000
3000
4000
5000
0
2
4
6
8
10
12
14
16
18
20



Distribution of Axial Force
Story No
Axial Force (KN)
0
500
1000
1500
2000
2500
0
2
4
6
8
10
12
14
16
18
20