Structural Analysis Lab

Session 4

"Shear Walls With Openings"

Group 3

Daniel Carroll

James Loney

Brian Keating

Eoghan Russell

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Introduction

The aim of this case study is to examine how the stiffness and behaviour of shear walls change as the openings in them become larger. Methods of modelling the structure will be examined. The effect that various parameters have on the behaviour of shear walls will also be studied.

Buildings need to be able to resist lateral forces caused by wind and earthquake loading. One method of providing lateral stability is to provide shear walls in the building (Macgregor, J G). Shear walls are capable of resisting changes in shape and transferring lateral loads to the ground/foundation (Ching, F D K). Buildings need to have adequate stiffness otherwise lateral loads will cause severe damage to the building and discomfort to the occupants (McCormac, J C). Shear walls have large in plane stiffness. These shear walls need to be able to resist in plane shear forces and bending moments caused by lateral forces.

Shear walls are usually built from reinforced concrete or masonry (Ching, F D K). They are placed in strategic locations in the building to resist all lateral loads (McCormac, J C). It is usually not possible to build shear walls without openings. Openings in shear walls are needed for windows, doors and services (Jack C McCormac, J C).

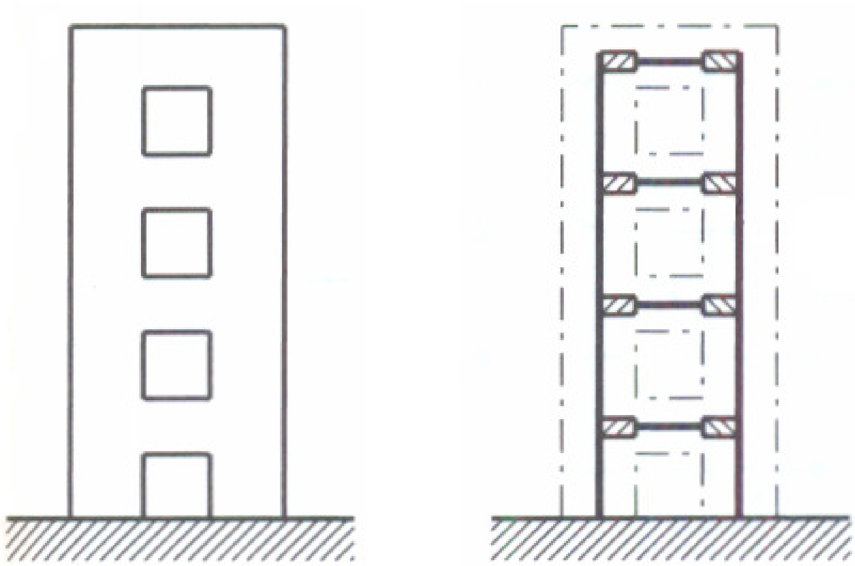
As the openings become larger the behaviour of the structure changes. The stiffness will gradually reduce until a point is reached where the wall behaves like a frame and the stiffness reduces at a higher rate. This is briefly examined using finite element analysis.

Modelling of structure

As mentioned above shear walls need to resist in plane shear forces and bending moments caused by lateral loads. They also have to resist overturning moments due to the lateral loads (Jack C McCormac, J C).

Shear walls can therefore be modelled as deep vertical cantilevers. With a single line of openings in the wall they can be viewed as two vertical cantilevers connected together by lintel beams (Irwin. A D).

A shear wall with a line of openings can also be modelled as a plane frame (Mosley, W H). The walls either side of the openings are modelled as two columns of a frame and the lintel beams between these walls are rigidly jointed members between these two columns.

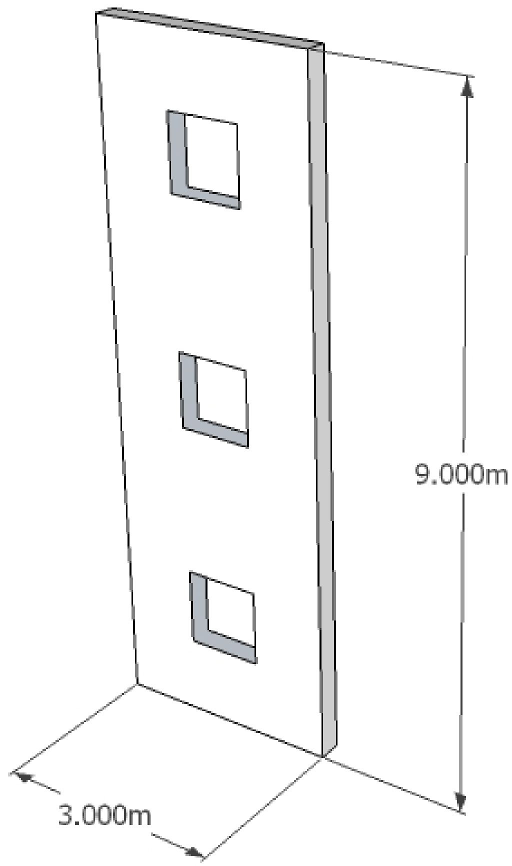


"Stiffness is the load required to cause a unit deflection"

A horizontal point load of 10000N was applied to the top of the structure. The deflection due to this load was determined. The stiffness of the structure was then calculated by dividing the point load by the deflection.

A point load of 10000N was used instead of 1N as the accuracy of the results using a 1N load would be reduced due to rounding.

For both the theoretical and experimental calculations the following shear wall model was used:



Where, as shown above:

H = 9.0m

L = 3.0m

Also;

Thickness = 0.3m

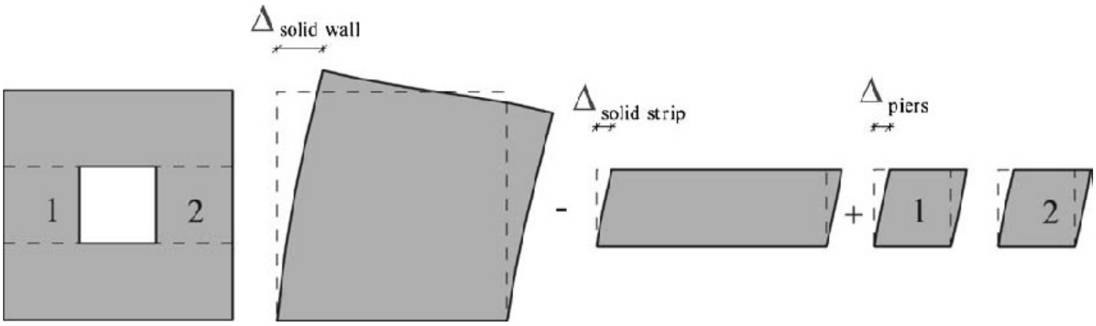
Young's Modulus (E) = 35000N/mm²

Poisson's Ratio (ν) = 0.25

Theoretical Calculations

Having examined several technical papers it was decided to model the chosen structure as two vertical cantilevers connected by lintel beams.

From the technical paper written by Neuenhofer (Neuenhofer, A), a proposed method for calculating the deflections of a shear wall with openings was used. For the purpose of this report we will refer to this method as the Neuenhofer method. This method involves initially examining the shear wall as a whole (as shown below). The displacement of the wall is examined. Using superposition a solid strip is then removed which is equal in height to the opening. The displacement of this strip is determined. The width of the opening is removed from this strip and the remaining displaced piers are then put back into the structure.



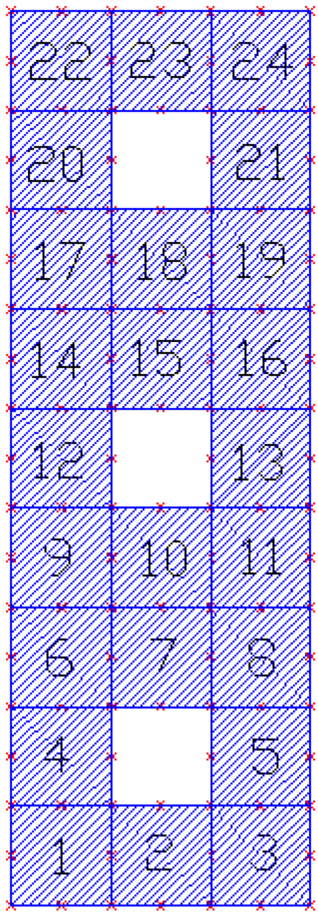
The total deformation is a combination of shear and flexural deformation. For this example Poisson's ratio, ν is taken to be 0.25 and Young's Modulus is taken to be 35,000N/mm^2. Using an excel spreadsheet the deformation and subsequent stiffness was calculated for the varying opening sizes.

This method of analysis however can only be applied for relatively small openings. The massive drop in stiffness at a certain opening size is not taken into account using this method. Using this method the stiffness begins to increase for large openings and therefore this method does not apply for large openings.

Finite Element Analysis

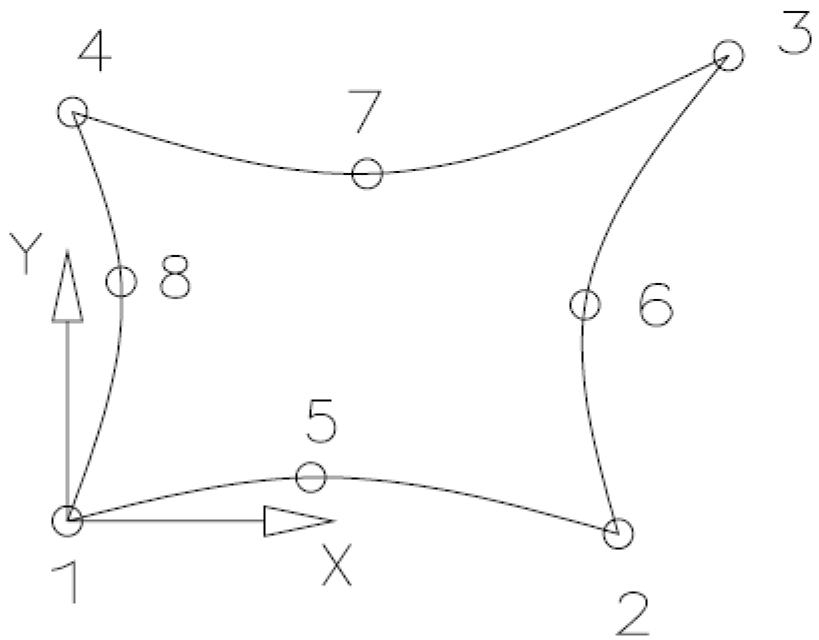
Method Using Z88 Finite Element Analysis Program

The first step in the finite element analysis was to break the structure up into separate super elements as suggested by technical papers on the topic (Kim, H.S. And Lee, D.G.). For the purpose of explaining how the finite element analysis was performed the 1000mm x 1000mm opening case will be explained. The structure was broken up into 24 super elements all of size 1000mm x 1000mm. A series of nodes were created at the corner and mid points of each super element.



The next step was to choose what type of super element to use for the analysis and which type of finite element to break the super elements into. The element chosen for both the super and finite elements was a plane stress element with 8 nodes to match with the amount of nodes on each super element and also as it was recommended by the finite element program as the best choice for our model.

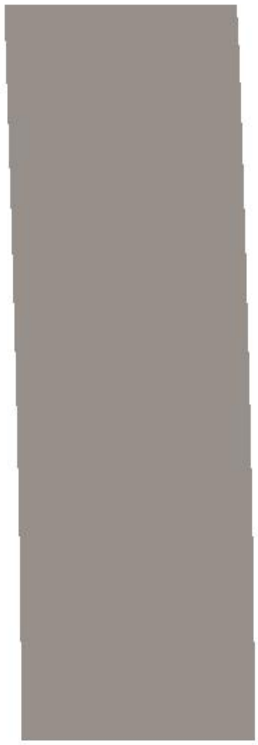
It is called Plane Stress Element No.7 in the finite element analysis program and is very accurate at determining accurate deflections and stresses of a structure. The super elements were then broken up into 100mm interval finite elements.



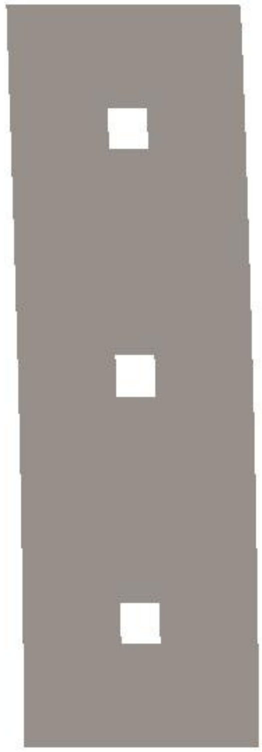
After the model was created for the finite element analysis program the nodes at the base of the wall were restrained to imitate a fixed condition at the base. Also a load of -10000N was applied to the top of the wall. The finite element analysis gave the following results for the horizontal deflection at the top of the shear wall.

CASE TYPE	**DEFLECTION [mm]**
SOLID	0.118
500x500	0.120
700x700	0.124
1000x1000	0.133
2000x2000	0.401

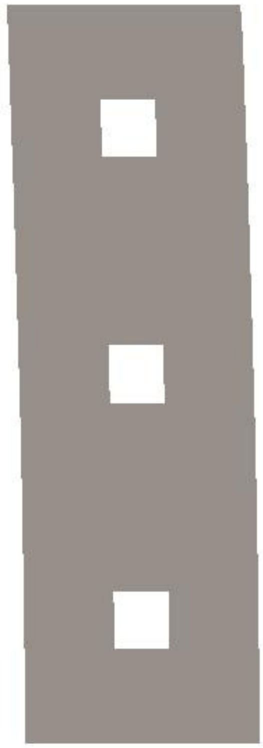
Deflected Shapes of Structure from Z88



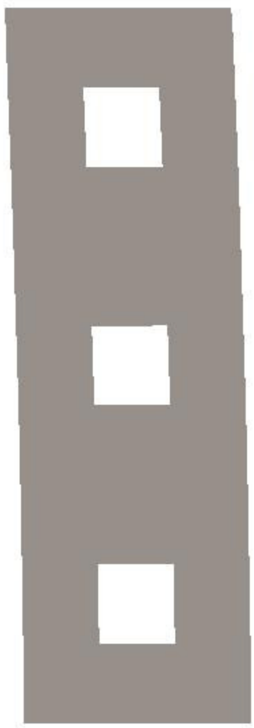
SOLID WALL



500x500mm Openings



700x700mm Openings



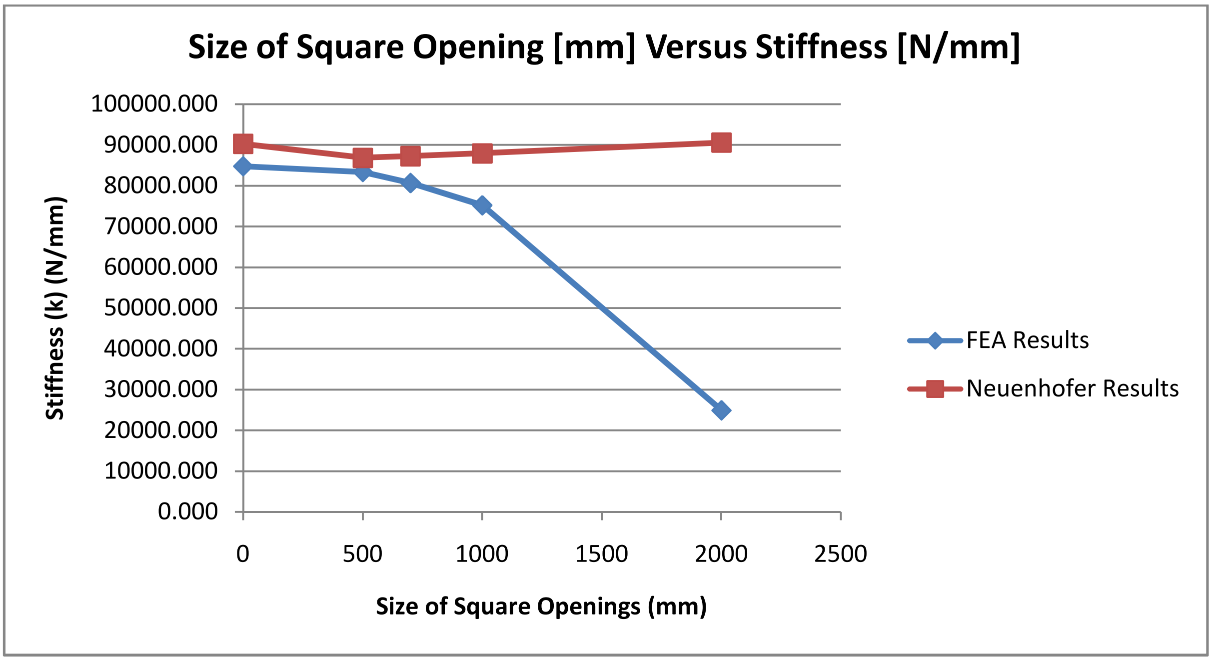
1000x1000mm Openings

2000x2000mm Openings

Results

Finite Element Analysis Results				
CASE TYPE	SQUARE OPENING SIZE [mm]	DEFLECTION [mm]	LOAD [N]	STIFFNESS [N/mm]
SOLID	0	0.118	10000	84745.763
500x500	500	0.120	10000	83333.333
700x700	700	0.124	10000	80645.161
1000x1000	1000	0.133	10000	75187.970
2000x2000	2000	0.401	10000	24923.361

Neuenhofer Method Results				
CASE TYPE	SQUARE OPENING SIZE [MM]	DEFLECTION [MM]	LOAD [n]	STIFFNESS [n/MM]
Solid	0	0.111	10000	90299.161
500x500	500	0.115	10000	86858.334
700x700	700	0.115	10000	87274.504
1000x1000	1000	0.114	10000	87932.960
2000x2000	2000	0.1104	10000	90579.7101



Conclusions

As can be seen from the previous graph of size of square opening vs. stiffness, the finite element results compare well with the theoretical results, but the theoretical results slightly over compensate for the stiffness as stated in the paper. It would appear that the theoretical results only apply to small openings as after the size of the openings increase beyond 700mm (for this shear wall only), the stiffness values from the theoretical calculations do not make sense as they are getting larger as the opening increases. This proves that the formula used to calculate the theoretical stiffness only applies to small openings (<500mm, which only applies for our structure case).

It can also be seen from the deflected shape diagrams that the shear wall can be visually seen behaving like a frame for the 2000 x 2000mm opening case with further confirms this report's findings, that as the openings in a shear wall increase the wall behaves increasingly more like a frame.

It has been concluded that the finite element analysis is a more accurate method for determining the stiffness of a shear wall with openings as it can visually show you how the shear wall behaves with different size openings.

References

Ching, F D K (2001) *Building Construction Illustrated,* New York, John Wiley and Sons

Irwin, A W (1984) "Design of Shear Wall Buildings", CIRIA Report 102, London

Kim, H S and Lee D G (2003) "Analysis of shear walls with openings using super elements" *, Engineering Structures*, Vol. 25, pp 981-991

MacGregor, J G and Wight J K (2005) *Reinforced Concrete Mechanics and Design*, New Jersey, Pearson Prentice Hall

McCormac J C, (2001) *Design of Reinforced Concrete*, New York, John Wiley and Sons

Mosley, W H, Bungey J H and Hulse, R (1999) *Reinforced Concrete Design,* London, MacMillian Press

Neuenhofer, A (2006) "Lateral stiffness of shear walls with openings", *ASCE Journal of Structural Engineers,* vol.132, no. 11, pp 1846-1851

Wang S K, (1997) "Stiffness, Stability and fundamental period of coupled shear walls Variable thickness" *Proceeding Institute of Civil Engineers Structures and Buildings,* vol. 122, pp 334-338

Appendix 1

Formulae used (A. Neuenhofer method)

$$\Delta_{total} = \Delta_{flex} + \Delta_{shear} = \frac{P \times H^3}{3 \times E \times I} + \alpha \times \frac{P \times H}{G \times A}$$

$$\Delta_{total} = \Delta_{flex} + \Delta_{shear} = \frac{P}{E \times b}\left[4 \times \left(\frac{H}{L}\right)^3 + 3 \times \left(\frac{H}{L}\right)\right]$$

$$\Delta_{solid\ wall} = 4 \times \left(\frac{H}{L}\right)^3 + 3 \times \left(\frac{H}{L}\right)$$

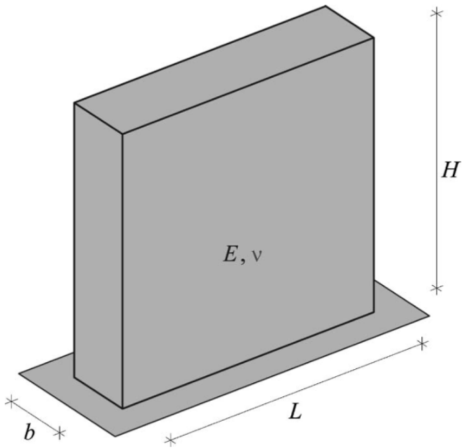
$$\Delta_{solid\ strip} = \left(\frac{H}{L}\right)^3 + 3 \times \left(\frac{H}{L}\right)$$

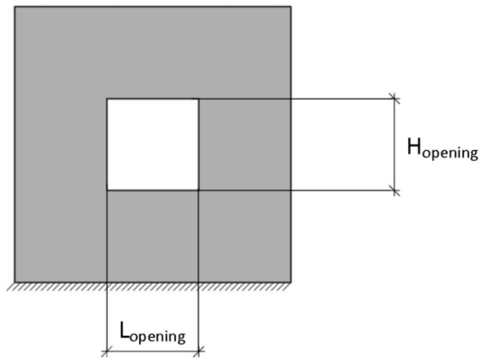
$$\Delta_{pier} = \left(\frac{H_{opening}}{L_{opening}}\right)^3 + 3 \times \left(\frac{H_{opening}}{L_{opening}}\right)$$

$$\Delta_{piers} = \frac{1}{\left(\frac{1}{\Delta_{pier}} + \frac{1}{\Delta_{pier}}\right)}$$

$$\Delta_{wall} = \Delta_{solid\ wall} - \Delta_{solid\ strip} + \Delta_{piers}$$

$$k = \frac{P}{\Delta_{wall}}$$





Where:

Δ_{total}= $total\ displacement,$

Δ_{flex}= $displacement\ due\ to\ flexure,$

Δ_{shear}= $displacement\ due\ to\ shear,$

$\Delta_{solid\ wall}$= $displacement\ of\ solid\ shear\ wall,$

$\Delta_{solid\ strip}$= $displacement\ of\ solid\ strip\ of\ shear\ wall,$

Δ_{pier}= $Displacement\ of\ pier,$

Δ_{piers}= $\sum displacement\ of\ piers,$

Δ_{wall}= $total\ displacement\ of\ shear\ wall,$

$k = stiffness,$

$P = applied\ point\ load,$

$H = height\ of\ shear\ wall,$

$L = lenght\ \ of\ shear\ wall$

$b = depth\ of\ shear\ wall,$

$H_{opening} = height\ of\ opening,$

$L_{opening} = lenght\ of\ opening,$

$E = young's\ modulus,$

$I = second\ moment\ of\ area,$

$G = shear\ modulus = \frac{E}{2(1+v)}$

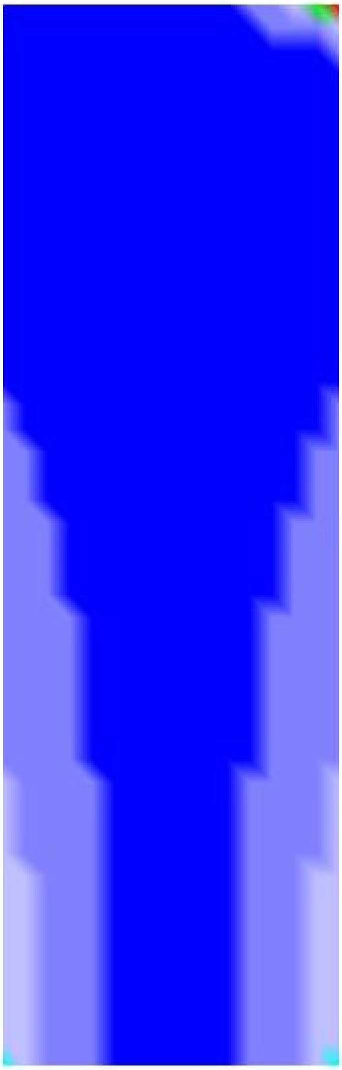
Where $v = poisson's\ \ ratio$

Appendix 2

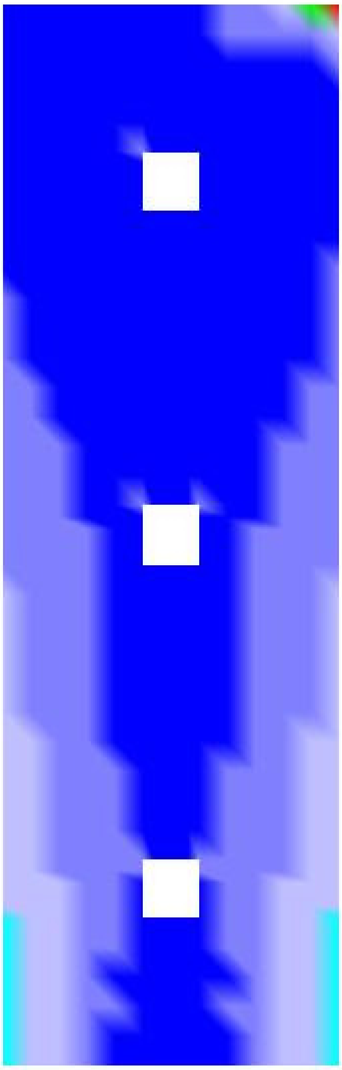
Finite Element Stress Analysis Screen Shots

Stress Magnitude Legend;

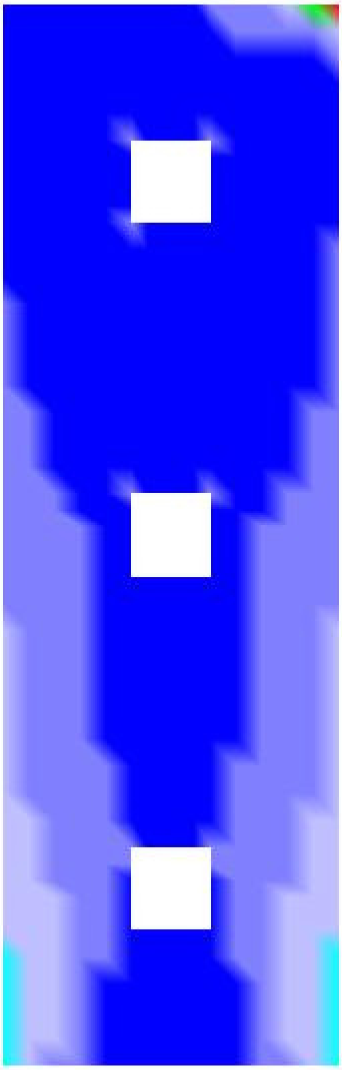
RED > ORANGE > YELLOW > WHITE > LIGHT BLUE > BLUE



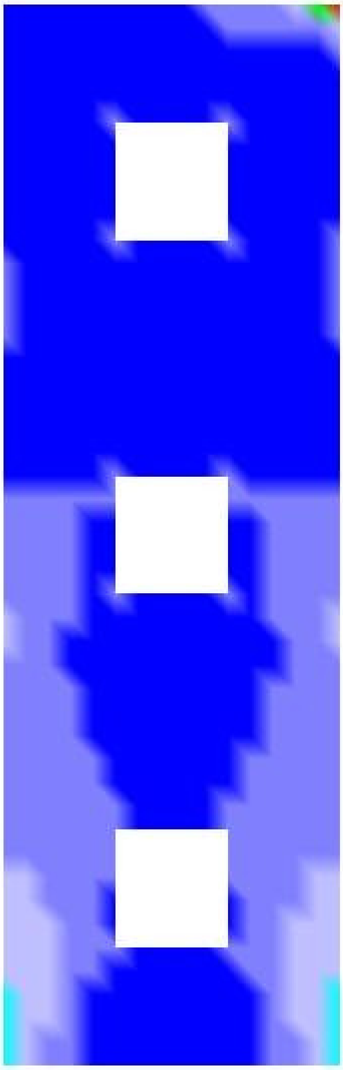
Solid Wall



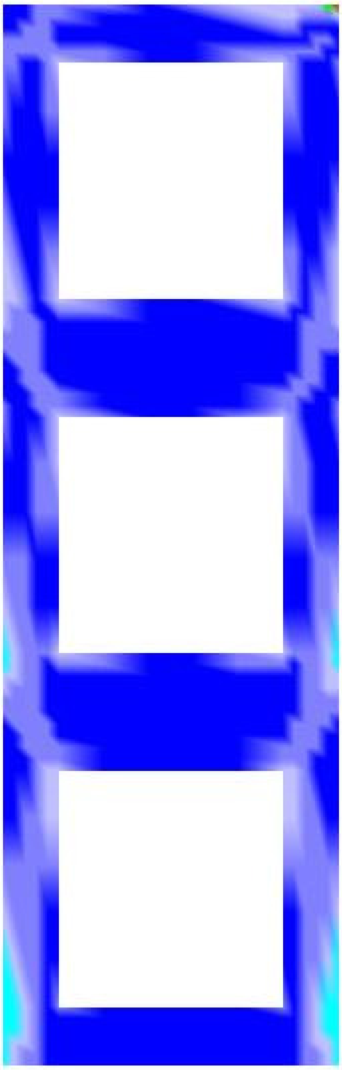
500x500mm Openings



700x700mm Openings



1000x1000mm Openings



2000x2000mm Openings

Finite Element Analysis Input Data:

For the 1000 x 1000mm Opening Case Only – Input Data;

2 106 24 212 1 0 0 0 0 0 (2D, 106 Nodes, 24 Super Elements, 212 DOF, 1 Material Type, 0...)

1	2	0	0	(Node 1, 2DOF, X=0, Y=0)
2	2	500	0	
3	2	1000	0	
4	2	1500	0	
5	2	2000	0	
6	2	2500	0	
7	2	3000	0	
8	2	0	500	
9	2	1000	500	
10	2	2000	500	
11	2	3000	500	
12	2	0	1000	
13	2	500	1000	
14	2	1000	1000	
15	2	1500	1000	
16	2	2000	1000	
17	2	2500	1000	
18	2	3000	1000	
19	2	0	1500	
20	2	1000	1500	
21	2	2000	1500	
22	2	3000	1500	
23	2	0	2000	
24	2	500	2000	
25	2	1000	2000	
26	2	1500	2000	
27	2	2000	2000	

28	2	2500	2000
29	2	3000	2000
30	2	0	2500
31	2	1000	2500
32	2	2000	2500
33	2	3000	2500
34	2	0	3000
35	2	500	3000
36	2	1000	3000
37	2	1500	3000
38	2	2000	3000
39	2	2500	3000
40	2	3000	3000
41	2	0	3500
42	2	1000	3500
43	2	2000	3500
44	2	3000	3500
45	2	0	4000
46	2	500	4000
47	2	1000	4000
48	2	1500	4000
49	2	2000	4000
50	2	2500	4000
51	2	3000	4000
52	2	0	4500
53	2	1000	4500
54	2	2000	4500
55	2	3000	4500
56	2	0	5000
57	2	500	5000

58	2	1000	5000
59	2	1500	5000
60	2	2000	5000
61	2	2500	5000
62	2	3000	5000
63	2	0	5500
64	2	1000	5500
65	2	2000	5500
66	2	3000	5500
67	2	0	6000
68	2	500	6000
69	2	1000	6000
70	2	1500	6000
71	2	2000	6000
72	2	2500	6000
73	2	3000	6000
74	2	0	6500
75	2	1000	6500
76	2	2000	6500
77	2	3000	6500
78	2	0	7000
79	2	500	7000
80	2	1000	7000
81	2	1500	7000
82	2	2000	7000
83	2	2500	7000
84	2	3000	7000
85	2	0	7500
86	2	1000	7500
87	2	2000	7500

88	2	3000	7500
89	2	0	8000
90	2	500	8000
91	2	1000	8000
92	2	1500	8000
93	2	2000	8000
94	2	2500	8000
95	2	3000	8000
96	2	0	8500
97	2	1000	8500
98	2	2000	8500
99	2	3000	8500
100	2	0	9000
101	2	500	9000
102	2	1000	9000
103	2	1500	9000
104	2	2000	9000
105	2	2500	9000
106	2	3000	9000

1 7 (Super Element 1, Type 7 Super Element)

1 3 14 12 2 9 13 8 (Occurs at Nodes 1-3-14-12-2-9-13-8)

2 7

3 5 16 14 4 10 15 9

3 7

5 7 18 16 6 11 17 10

4 7

12 14 25 23 13 20 24 19

5 7

16 18 29 27 17 22 28 21

6 7

23 25 36 34 24 31 35 30

7 7

25 27 38 36 26 32 37 31

8 7

27 29 40 38 28 33 39 32

9 7

34 36 47 45 35 42 46 41

10 7

36 38 49 47 37 43 48 42

11 7

38 40 51 49 39 44 50 43

12 7

45 47 58 56 46 53 57 52

13 7

49 51 62 60 50 55 61 54

14 7

56 58 69 67 57 64 68 63

15 7

58 60 71 69 59 65 70 64

16 7

60 62 73 71 61 66 72 65

17 7

67 69 80 78 68 75 79 74

18 7

69 71 82 80 70 76 81 75

19 7

71 73 84 82 72 77 83 76

20 7

78 80 91 89 79 86 90 85

21 7

82 84 95 93 83 88 94 87

22 7

89 91 102 100 90 97 101 96

23 7

91 93 104 102 92 98 103 97

24 7

93 95 106 104 94 99 105 98

1 24 35000 0.25 2 300 (SE1, to SE24, E=35000N/mm², ν=0.25, Integration Order=2, thickness=300mm)

1 7 (SE1, Divide into Finite Element Type 7)

5 E 5 E (Divide SE into 5 equally in X, 5 equally in Y)

2 7

5 E 5 E

3 7

5 E 5 E

4 7

5 E 5 E

5 7

5 E 5 E

6 7

5 E 5 E

7 7

5 E 5 E

8 7

5 E 5 E

9 7

5 E 5 E

10 7

5 E 5 E

11 7

5 E 5 E

12 7

5 E 5 E

13 7

5 E 5 E

14 7

5 E 5 E

15 7

5 E 5 E

16 7

5 E 5 E

17 7

5 E 5 E

18 7

5 E 5 E

19 7

5 E 5 E

20 7

5 E 5 E

21 7

5 E 5 E

22 7

5 E 5 E

23 7

5 E 5 E

24 7

5 E 5 E

For the opening Case's only - Restraint and loading conditions Input Data;

63				(63 Restraint and Loading Conditions)
1	1	2	0	(Node 1, X-Displacement=1, Restraint=2, Displacement=0)
12	1	2	0	
18	1	2	0	
29	1	2	0	
35	1	2	0	
46	1	2	0	
52	1	2	0	
63	1	2	0	
69	1	2	0	
80	1	2	0	
86	1	2	0	
97	1	2	0	
103	1	2	0	
114	1	2	0	
120	1	2	0	
131	1	2	0	
137	1	2	0	
148	1	2	0	
154	1	2	0	
165	1	2	0	
171	1	2	0	
182	1	2	0	
188	1	2	0	
199	1	2	0	
205	1	2	0	
216	1	2	0	
222	1	2	0	
233	1	2	0	

239	1	2	0	
250	1	2	0	
256	1	2	0	
1	2	2	0	(Node 1, Y-Displacement=1, Restraint=2, Displacement=0)
12	2	2	0	
18	2	2	0	
29	2	2	0	
35	2	2	0	
46	2	2	0	
52	2	2	0	
63	2	2	0	
69	2	2	0	
80	2	2	0	
86	2	2	0	
97	2	2	0	
103	2	2	0	
114	2	2	0	
120	2	2	0	
131	2	2	0	
137	2	2	0	
148	2	2	0	
154	2	2	0	
165	2	2	0	
171	2	2	0	
182	2	2	0	
188	2	2	0	
199	2	2	0	
205	2	2	0	
216	2	2	0	
222	2	2	0	

233	2	2	0	
239	2	2	0	
250	2	2	0	
256	2	2	0	
1978	1	1	-10000	(Node 1978, X-Displacement=1, Load=1, Load=-10000)

Solid Wall Input Data;

2 8 1 16 1 0 0 0 0 0				(2D, 8 Nodes, 1 Super Element, 16 DOF, 1, 0...)
1	2	0	0	(Node 1, 2 DOF, X=0, Y=0)
2	2	1500	0	
3	2	3000	0	
4	2	0	4500	
5	2	3000	4500	
6	2	0	9000	
7	2	1500	9000	
8	2	3000	9000	
1 7				(SE1, Type 7 Super Element)
1 3 8 6 2 5 7 4				(Occurs at Nodes 1-3-8-6-2-5-7-4)
1 1 35000 0.25 2 300				(SE1, to SE1, E=35000N/mm², v=0.25, Integration Order=2, thickness=300mm)
1 7				(SE1, Divide into Finite Element Type 7)
15 E 45 E				(Divide SE into 15 equally in X, 45 equally in Y)

Solid wall – Restraints and Loading Input data;

63				(63 Restraint and Loading Conditions)
1	1	2	0	(Node 1, X-Displacement=1, Restraint=2, Displacement=0)
1	2	2	0	
92	1	2	0	
92	2	2	0	
138	1	2	0	
138	2	2	0	
229	1	2	0	
229	2	2	0	

275	1	2	0
275	2	2	0
366	1	2	0
366	2	2	0
412	1	2	0
412	2	2	0
503	1	2	0
503	2	2	0
549	1	2	0
549	2	2	0
640	1	2	0
640	2	2	0
686	1	2	0
686	2	2	0
777	1	2	0
777	2	2	0
823	1	2	0
823	2	2	0
914	1	2	0
914	2	2	0
960	1	2	0
960	2	2	0
1051	1	2	0
1051	2	2	0
1097	1	2	0
1097	2	2	0
1188	1	2	0
1188	2	2	0
1234	1	2	0
1234	2	2	0

1325	1	2	0
1325	2	2	0
1371	1	2	0
1371	2	2	0
1462	1	2	0
1462	2	2	0
1508	1	2	0
1508	2	2	0
1599	1	2	0
1599	2	2	0
1645	1	2	0
1645	2	2	0
1736	1	2	0
1736	2	2	0
1782	1	2	0
1782	2	2	0
1873	1	2	0
1873	2	2	0
1919	1	2	0
1919	2	2	0
2010	1	2	0
2010	2	2	0
2056	1	2	0
2056	2	2	0
2146	1	1	-10000 (Node 2146, X-Displacement=1, Load=1, Load=-10000)