

STRESS AND DISPLACEMENT ANALYSIS OF DEEP BEAMS WITH WEB OPENINGS

¹Mohammed Mubbashir Ahmed, ²Waseem Sohail, ³Mohammed Khaja Moinuddin

¹P.G. Student Lords Institute of Engineering and Technology, Hyderabad, India

²Asst. Professor Lords Institute of Engineering and Technology, Hyderabad, India

³Asst. Professor Al-Habeeb College of Engineering and Technology, Hyderabad, India

Abstract: Multi story buildings are common in urban region. Day by day they are becoming more slender, generally multi story buildings are of open ground story. Due to parking at ground story the architectural planning will be disturbed in upper story therefore structural engineer has to initiate floating columns from first story, so as to have ground story open for parking. Floating columns have to be supported by transfer girder or reinforced concrete deep beam. The analysis and design of transfer girder or transfer plate should have more concentration as far as displacement and stress analysis are concern. To this particular study simply supported and continuous transfer girder have been considered, transfer girder taken are subjected to huge point load generated from the floating columns. A detail stress and displacement analysis have been done for both the girder by considering the web openings for understanding the behavior of transfer girder or plates and finite element modeling with different element sizes have been done to have a greater accurate evaluation of result using the software SAP 2000. Different types of loadings like Impact load in the form of triangular function time history function, Impact load in the form of trapezoidal time history function and Sinusoidal loading has been considered. Results obtained from this study has shown us greater amount of stresses and displacements with respect to the applied loadings and openings when considered. Finite element modeling has shown us greater accuracy and precise evaluation of results.

Keywords: Reinforced Concrete Deep Beam, Web Openings, Finite Element Modeling, Element Sizes, SAP 2000

1. INTRODUCTION

Reinforced concrete (RC) deep beams are widely used structural elements in building construction. Due to excessive stiffness of the deep beam, for example to distribute the loads of a multi-story structure on the piles below or to avoid relative movement or settlement. A common trouble in these structures is definitely visible cracks in serviceability situations. This has its impact on the sturdiness and on the aesthetics of the structure. According to IS-456 (2000) Clause 29, simply supported beam acts as deep beam when the ratio of its effective span (L) to overall depth (D) is less than 2.0 and that for continuous beam when the ratio is less than 2.5. The effective span is defined as the center to center distance between the supports or 1.15 times the clear span whichever is less. ACI code 318-95 classifies the beam as a deep beam for flexural if the clear span / Overall-depth ratio is less than 1.25 for simply supported beams and 2.5 for continuous beams. In deep beams, the bending stress distribution across any transverse section deviates appreciably from the straight line distribution assumed in elementary beam theory. Consequently a transverse section which is plane before bending does not remain approximately plane after bending. Neutral axis does not lie at the mid depth. Verity of application for Deep beam is found that can be used in situations where other type of beams or structural components cannot be used such as in bridges where long spans are required. Reinforced concrete (RC) deep beams are used for load distribution in a wide range of structures; for example in tall buildings, offshore gravity structures, as transfer girders, pile caps, folded plates, and foundation walls, also shear walls are considered as cantilever deep beam. Deep beams are often located on the perimeter of framed structures where they provide stiffness against horizontal loads. Reinforced concrete (RC) deep beams are commonly used in tall building, particularly at transfer floors, warehouses and other industrial structures. The provision of opening(s) in the web of deep beams is usually required to accommodate essential services such as air-conditioning ducts and electricity cable or to provide accessibility such as doors and windows. The creation of openings due to requirements arises from other disciplines for example; architectural, mechanical and/or a change in the building's function results in a sharp decrease in strength, which may often leads to severe safety hazard. Due to this, a number of studies have been reported in the literature on the behavior and strength of RC deep beams with openings. When such openings are unavoidable, adequate actions should be undertaken to strengthen the beam and reinstate the beam capacity due to the strength losses. Limited studies are covered in the literature on the topic of strengthening options of RC deep beams with openings.

1.1 OBJECTIVES

- 1) To develop deep beams of Reinforced Concrete
- 2) To understand the finite element modelling with different types of area elements and brick elements.
- 3) To understand the influence of web openings in deep beams when subjected to transverse and longitudinal Direction.
- 4) To check the overall performance of deep beams during seismic excitation.
- 5) To understand the floating column's load applied to deep beams.
- 6) To study the behavior of deep beams with respect to stress concentration and displacements, all this objectives will be covered utilizing the software SAP 2000.

2. MODEL DESCRIPTION

An experimental work has been done using Simply supported and continuous beams, sixteen type of models have been considered with different type of loadings and two types of discretization has been performed. Reinforced concrete deep beam of 9m length, 4.5m height and 400mm thickness has been taken, having a make of concrete M20 and rebar taken are HYSD bars of grade 415 N/mm². Six degree of freedom at each nodal point has been provided. Discretization of fine mesh taken is 0.25m x 0.25m size and coarse mesh taken is 0.75m x 0.75m, openings considered are of size 1.5m x 1.5m and are provided in center of the respective model. Eight models of simply supported reinforced concrete deep beam has been taken and eight models of continuous reinforced concrete deep beam, eight models of element type shell and eight models of element type solid has been chosen, all have been modelled using the software SAP 2000.

2.1 FINE MESH DISCRETIZATION

Model 1: Beam modelled as simply supported, having fine discretization of size 0.25m x 0.25m (quadrilateral mesh) Element modelled as thick shell having six degree of freedom at each nodal point.

Model 2: Beam modelled as simply supported, having fine discretization of size 0.25m x 0.25m (quadrilateral mesh) Element modelled as thick solid having six degree of freedom at each nodal point.

Model 3: Beam modelled as simply supported, having fine discretization of size 0.25m x 0.25m (quadrilateral mesh) Element modelled as thick shell having six degree of freedom at each nodal point and having a square opening at the Center of size 1.5m x 1.5m.

Model 4: Beam modelled as simply supported, having fine discretization of size 0.25m x 0.25m (quadrilateral mesh) Element modelled as thick solid having six degree of freedom at each nodal point and having a square opening at the Center of size 1.5m x 1.5m.

Model 5: Beam modelled as three span continuous with simply supported boundary conditions, having fine discretization of size 0.25m x 0.25m (quadrilateral mesh) Element modelled as thick shell having six degree of freedom at each nodal point, and has additional simply supported restraints at the continuity of the beam.

Model 6: Beam modelled as three span continuous with simply supported boundary conditions, having fine discretization of size 0.25m x 0.25m (quadrilateral mesh) Element modelled as thick solid having six degree of freedom at each nodal point, and has additional simply supported restraints at the continuity of the beam.

Model 7: Beam modelled as three span continuous with simply supported boundary conditions, having fine discretization of size 0.25m x 0.25m (quadrilateral mesh), Element modelled as thick shell having six degree of freedom at each nodal point, having a square opening at the Center of each span of size 1.5m x 1.5m and has additional simply supported restraints at the continuity of the beam.

Model 8: Beam modelled as three span continuous with simply supported boundary conditions, having fine discretization of size 0.25m x 0.25m (quadrilateral mesh), Element modelled as thick solid having six degree of freedom at each nodal point, having a square opening at the Center of each span of size 1.5m x 1.5m and has additional simply supported restraints at the continuity of the beam.

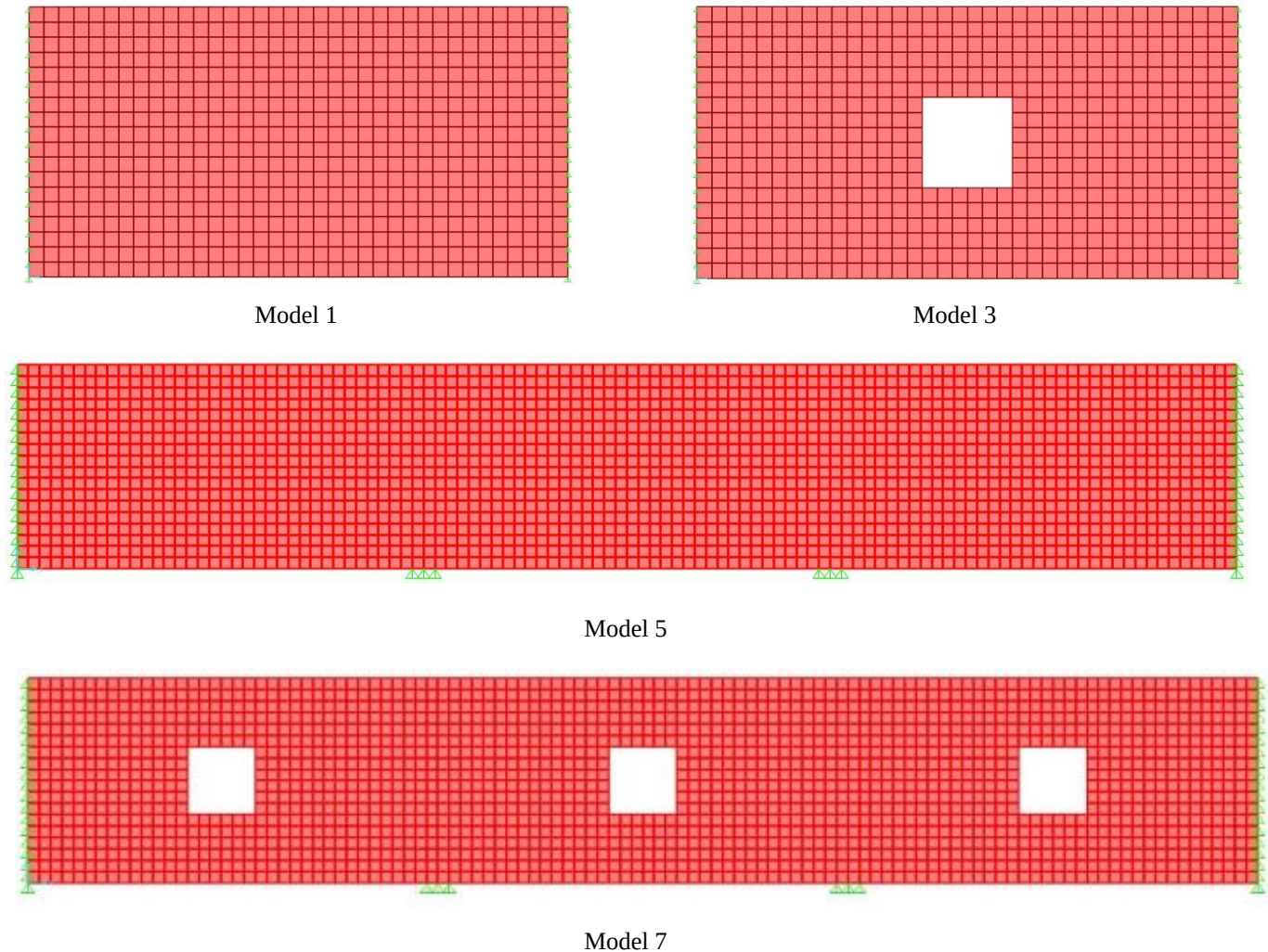


Figure 1: Simply supported and continuous deep beam with and without openings having fine mesh

2.2 COARSE MESH DISCRETIZATION

Model 1: Beam modelled as simply supported, having coarse discretization of size 0.75m x 0.75m (quadrilateral mesh) Element modelled as thick shell having six degree of freedom at each nodal point.

Model 2: Beam modelled as simply supported, having coarse discretization of size 0.75m x 0.75m (quadrilateral mesh) Element modelled as thick solid having six degree of freedom at each nodal point.

Model 3: Beam modelled as simply supported, having coarse discretization of size 0.75m x 0.75m (quadrilateral mesh) Element modelled as thick shell having six degree of freedom at each nodal point and having a square opening at the Center of size 1.5m x 1.5m.

Model 4: Beam modelled as simply supported, having coarse discretization of size 0.75m x 0.75m (quadrilateral mesh), Element modelled as thick solid having six degree of freedom at each nodal point and having a square opening at the Center of size 1.5m x 1.5m.

Model 5: Beam modelled as three span continuous with simply supported boundary conditions, having coarse discretization of size 0.75m x 0.75m (quadrilateral mesh) Element modelled as thick shell having six degree of freedom at each nodal point, and has additional simply supported restraints at the continuity of the beam.

Model 6: Beam modelled as three span continuous with simply supported boundary conditions, having coarse discretization of size 0.75m x 0.75m (quadrilateral mesh) Element modelled as thick solid having six degree of freedom at each nodal point, and has additional simply supported restraints at the continuity of the beam.

Model 7: Beam modelled as three span continuous with simply supported boundary conditions, having coarse discretization of size 0.75m x 0.75m (quadrilateral mesh), Element modelled as thick shell having six degree of freedom at each nodal point, having a square opening at the Center of each span of size 1.5m x 1.5m and has additional simply supported restraints at the continuity of the beam.

Model 8: Beam modelled as three span continuous with simply supported boundary conditions, having coarse discretization of size 0.75m x 0.75m (quadrilateral mesh), Element modelled as thick solid having six degree of freedom at each nodal point, having a square opening at the Center of each span of size 1.5m x 1.5m and has additional simply supported restraints at the continuity of the beam.

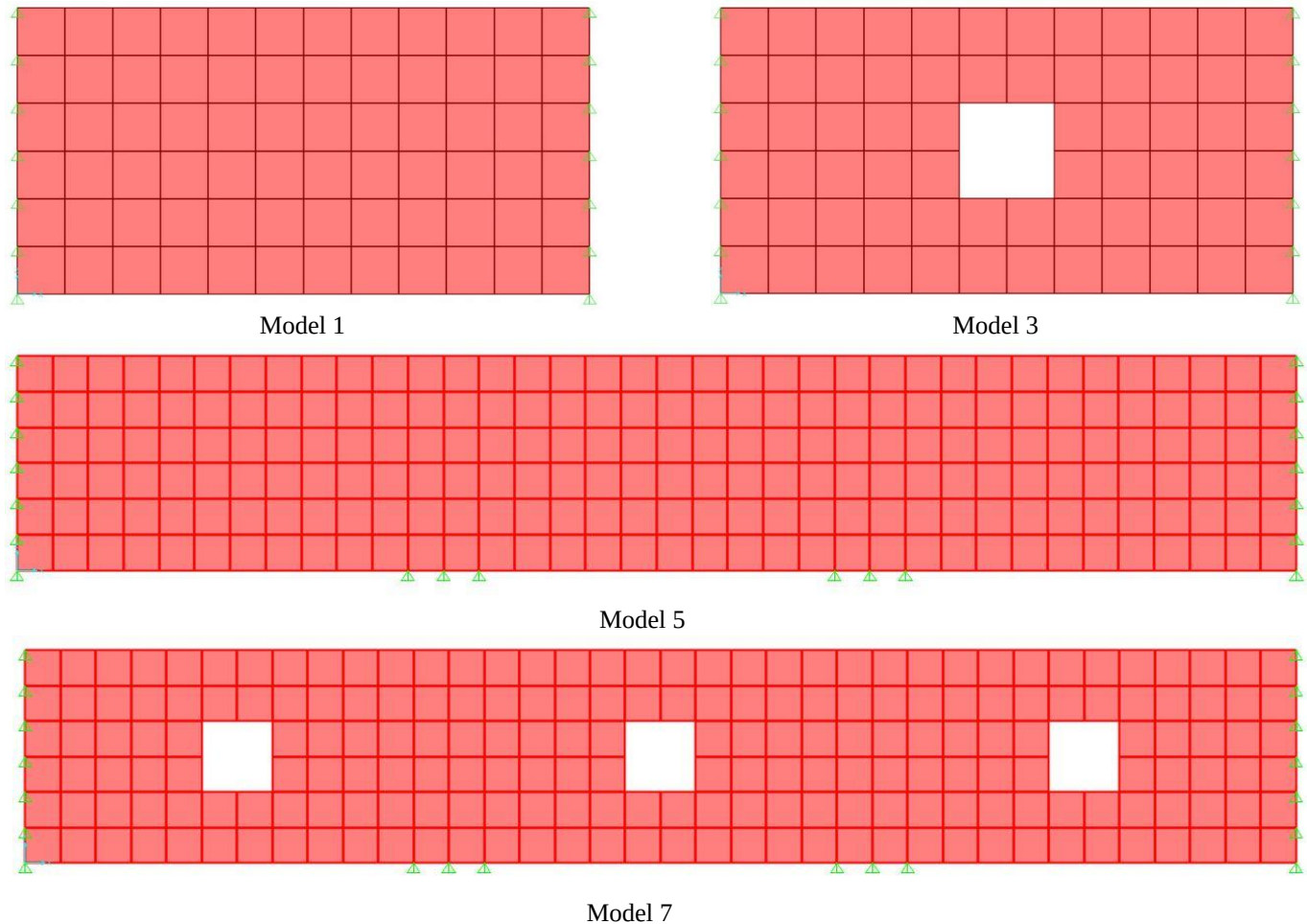


Figure 2: Simply supported and continuous deep beam with and without openings having coarse mesh

3. LOAD PARAMETRES

Following loads has been considered are as follows:

1. Dead load + live load
2. Dead load + floating column load
3. Dead load + impact load

Dead load + live load (gravity loading) has been taken as dead load plus live load of (155 KN/M UDL)

Floating column loading has been obtained by modeling a twenty storey structure in ETABS and the highest loading obtained due to live load plus dead load plus floor finishes has been taken.

Three types of impact loading have been taken 1) triangular loading (cosine function) 2) trapezoidal loading (cosine function) 3) cyclic loading (sine function)

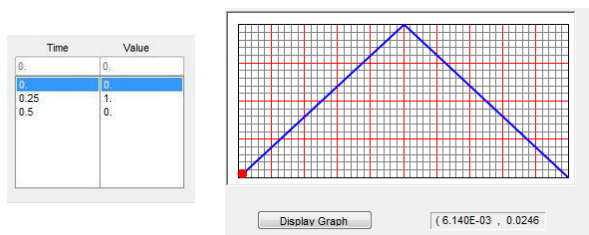


Figure 3: Time and amplitude for triangular loading

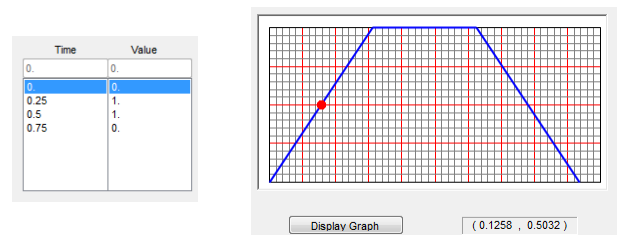


Figure 4: Time and amplitude for trapezoidal loading

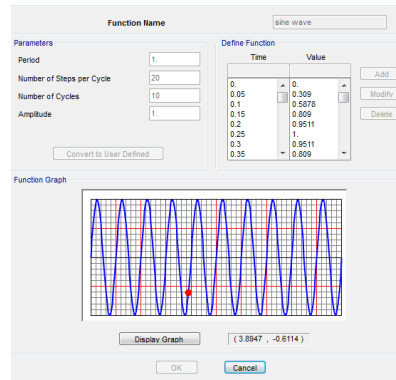


Figure 5: Time and amplitude for cyclic loading

4. ANALYSIS OF DISPLACEMENT AND STRESS

Table 2: Displacement for fine mesh vs coarse Mesh for (DL+ LL) in mm

S.NO	DISP (F M)	DISP (C M)
M-1	0.66	0.241
M-2	0.70	0.252
M-3	0.733	0.256
M-4	0.777	0.267
M-5	1.307	0.316
M-6	1.345	0.364
M-7	1.353	0.325
M-8	1.392	0.336

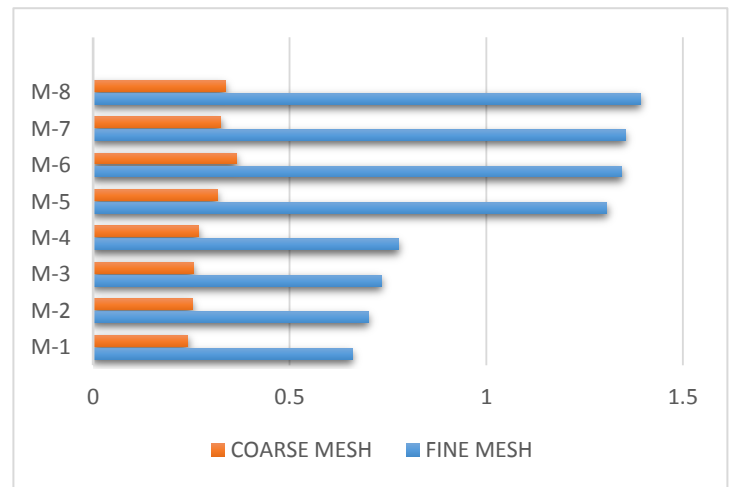
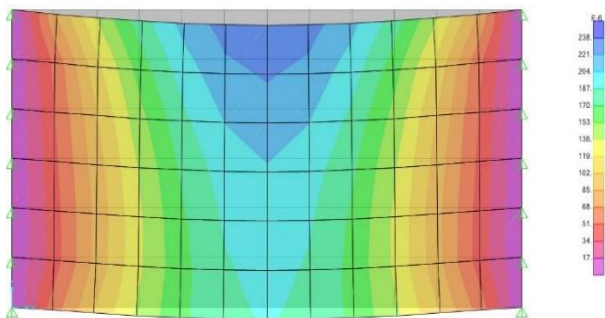


Figure 6: Displacement of fine mesh vs

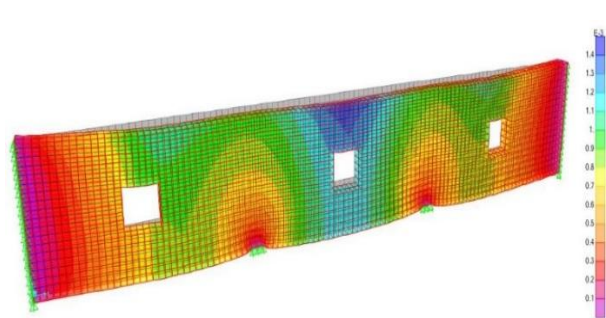
DISP – DISPLACEMENT, F M – FINE MESH,
C M – COARSE MESH

coarse mesh

- Lowest displacement in model 1 coarse mesh (less prone)
- Highest displacement in model 8 fine mesh (danger model)
- Fine mesh is having more accurate displacement.



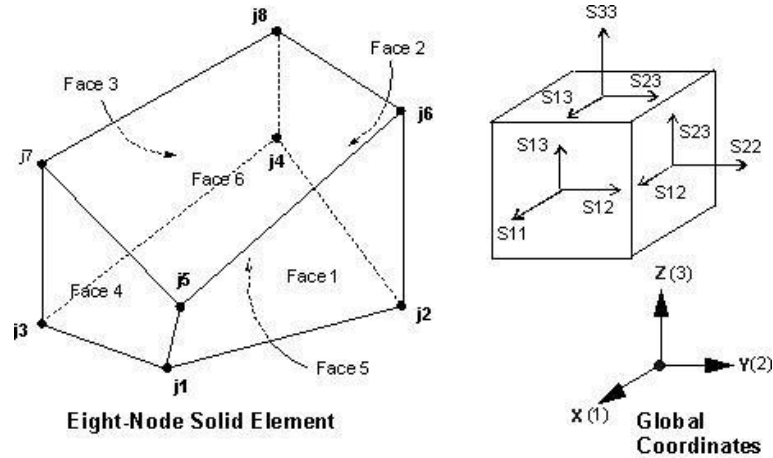
Model 1 simply supported deep beam coarse mesh



Model 8 continuous deep beam fine mesh

Figure 7: Models showing lowest and highest displacement

4.1 ELEMENT STRESS NOMENCLATURE



Solid Element Stresses

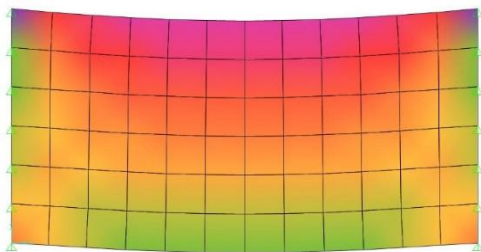
Figure 8: element stresses for a solid element

Table 3: Shell stresses for fine mesh and coarse mesh shell element in N/MM square

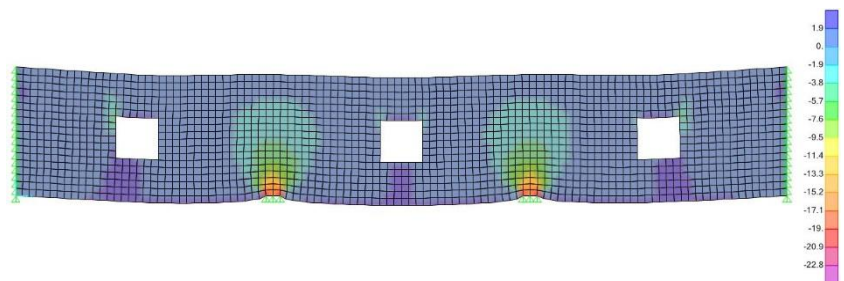
S.no	S11	S22	S12
M-1	7.769	1.664	2.143
M- 3	7.748	4.294	2.394
M- 5	21.711	23.681	10.831
M- 7	21.244	23.847	10.749

S.no	S11	S22	S12
M-1	1.645	0.556	0.737
M-3	1.636	0.919	0.723
M- 5	2.253	3.062	1.343
M- 7	2.159	3.028	1.32

*Highest stress value 23.847 in s22 has been shown in M - 7 for fine mesh
*Lowest stress value 0.556 in s22 has been shown in M-1 for coarse mesh
*The comparison between fine and coarse mesh give us that the fine mesh has more accuracy and define results than the coarser one hence finer the mesh better the accuracy



Model 1 simply supported deep beam coarse mesh



Model 7 continuous deep beam with openings fine mesh

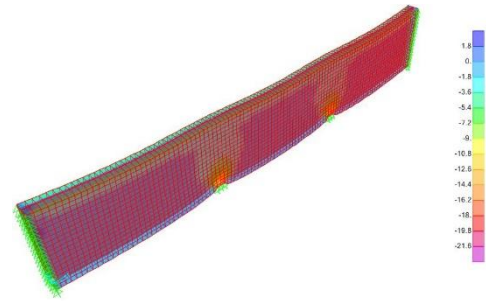
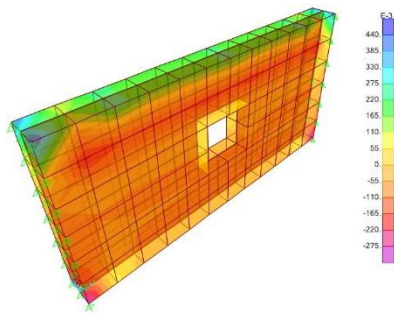
Figure 9: Models showing lowest and highest stress values

Table 4: Solid Stresses for fine mesh and coarse mesh for solid element in N/MM square

S.no.	S11	S22	S33	S13
M-2	8.047	2.097	4.406	3.31
M-4	8.027	2.093	4.405	3.291
M-6	20.21	8.465	22.393	8.53
M-8	19.716	8.404	22.59	8.477

S.no.	S11	S22	S33	S13
M-2	1.698	0.409	1.08	0.762
M-4	1.689	0.407	1.076	0.749
M-6	2.801	1.373	4.364	1.86
M-8	1.961	0.971	2.904	1.039

Highest stress value 22.393 in s33 has been shown in M- 6 for fine mesh, lowest stress value 0.407 in s22 has been shown in M-4 for coarse mesh Gradual increase in stresses have been followed from model 2 to model 6, model 8 with has shown less stresses when compared to model 6.



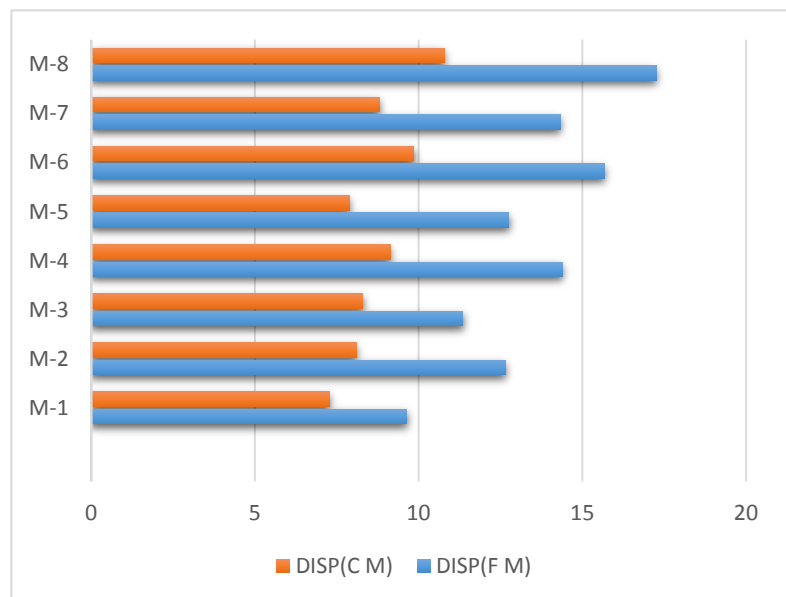
Model-4 simply supported deep beam with opening coarse mesh

Model-6 continuous deep beam fine mesh

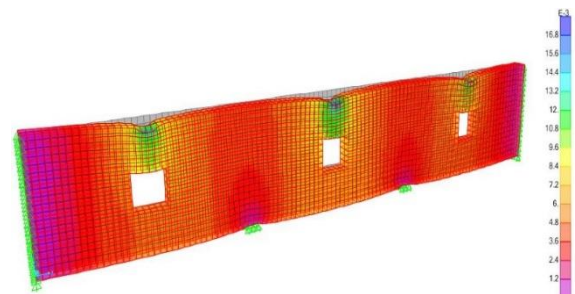
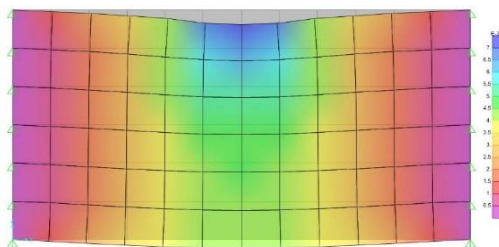
Figure 10: Models showing lowest and highest stress values

Table 5: Displacement for fine mesh vs coarse mesh (DL+FLOATING COLUMN LOAD) in mm

S.no	DISP (F M)	DISP (C M)
M-1	9.646	7.289
M-2	12.649	8.098
M-3	11.359	8.303
M-4	14.39	9.137
M-5	12.76	7.894
M-6	15.672	9.863
M-7	14.337	8.812
M-8	17.255	10.782



Highest displacement has been shown in M-8 fine mesh, Figure 11: Displacement of fine mesh vs coarse mesh.
Lowest displacement in M-1 coarse mesh.



Model-1 simply supported deep beam coarse mesh

Model-8 continuous deep beam with openings fine mesh

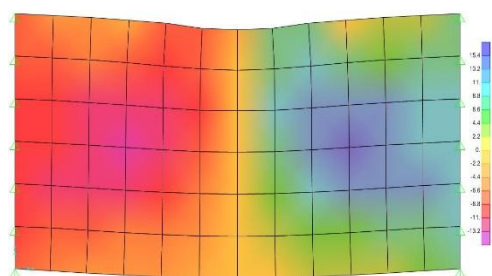
Figure 11: Models showing lowest and highest displacement.

Table 6: Shell stresses for fine mesh and coarse mesh shell element for (DL+FLOATING COLUMN LOAD) in N/MM square

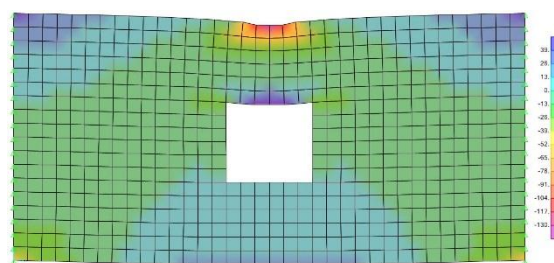
S.no	S11	S22	S12
M-1	114.381	120.177	39.194
M-3	135.592	120.477	41.396
M-5	129.924	127.962	59.758
M-7	135.281	128.634	59.454

S.no	S11	S22	S12
M-1	41.297	40.206	14.161
M-3	49.779	45.402	21.06
M-5	42.673	44.391	21.54
M-7	48.272	44.628	21.704

*highest stress value 135.592 in s11 has been shown in M-3 of fine mesh.
 *lowest stress value 14.161 in s12 has been shown in M-1 of coarse mesh.
 *simply supported beam when subjected to opening has shown more stress value than continuous beam in s11 category.



Model-3 simply supported deep beam coarse mesh



Model-1 simply supported deep beam with opening fine mesh

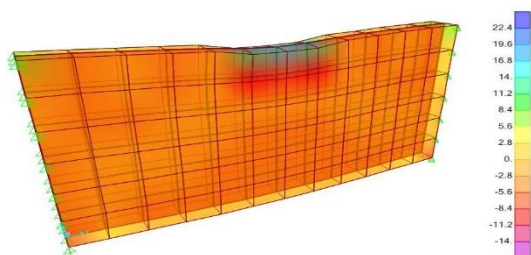
Figure 12: Models showing lowest and highest stress values

Table 6: Shell stresses for fine mesh and coarse mesh solid element for (DL+FLOATING COLUMN LOAD) in N/MM square

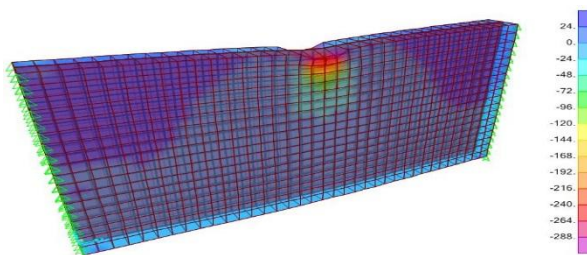
S.no	S11	S22	S33	S13
M-2	150.866	95.865	304.669	109.162
M-4	171.887	96.345	304.147	111.733
M-6	151.509	95.814	304.667	109.256
M-8	171.752	96.362	304.237	112.075

S.no	S11	S22	S33	S13
M-2	44.312	21.197	73.826	23.849
M-4	52.845	22.239	74.254	27.526
M-6	60.53	23.452	86.405	38.216
M-8	57.939	22.932	86.182	38.264

*highest stress value 304.669 in s33 has been shown in M-2 of fine mesh.
 *lowest stress value 21.197 in s22 has been shown in M-2 of coarse mesh.
 *beam without openings has shown more stress value when compared with beam with opening.



Model-2 simply supported deep beam coarse mesh



Model-4 simply supported deep beam fine mesh

Figure 13: Models showing lowest and highest stress values

Table 7: Displacement for fine mesh vs coarse mesh (DL+ IMPACT LOAD 1) (TRIANGULAR LOADING) in mm.

S.no	DISP(F M)		DISP(C M)	
	U1	U2	U1	U2
M- 1	0.858	55.114	0.552	56.031
M-2	1.141	25.226	0.642	23.322
M-3	0.864	56.187	0.553	57.148
M-4	1.144	26.864	0.644	24.61
M-5	1.132	66.175	0.885	66.99
M-6	1.332	57.209	0.995	52.377
M-7	1.165	66.494	0.93	67.349
M-8	1.357	57.377	1.041	52.657

U1-ACCELERATION IN X DIRECTION

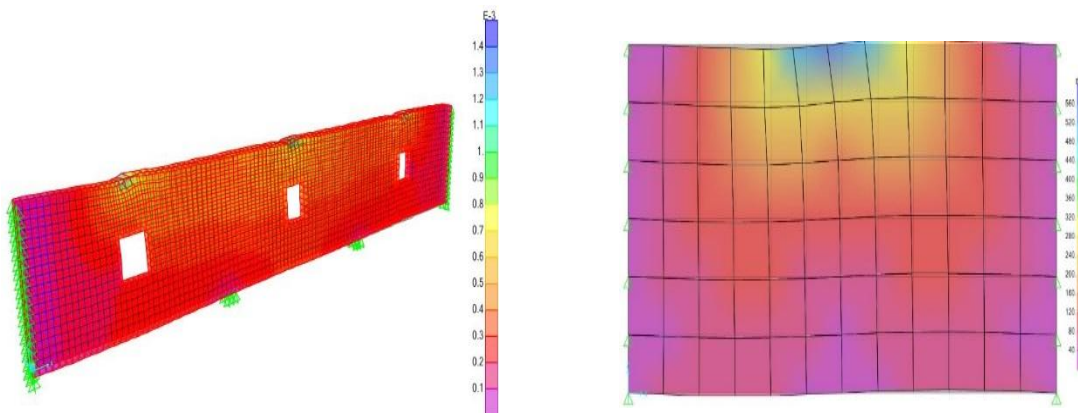
U2-ACCELERATION IN Y DIRECTION

*highest displacement 1.357 is obtained with respect to U1 in Model 8 in fine mesh.

*lowest displacement 0.552 is obtained with respect to U1 in Model 1 in coarse mesh.

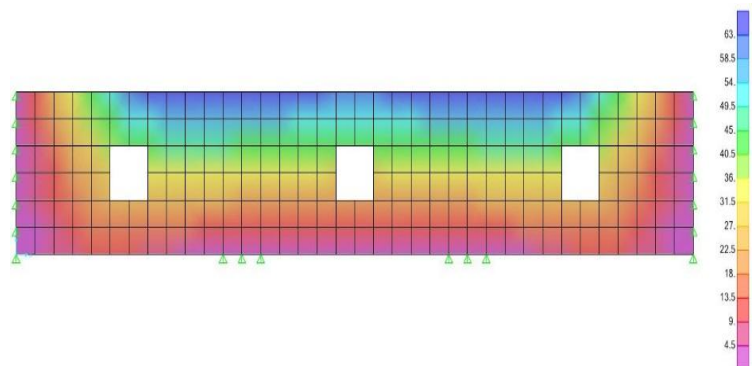
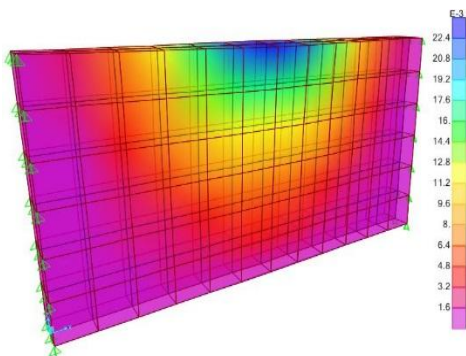
*highest displacement 67.349 is obtained with respect to U2 in Model 7 in coarse mesh.

*lowest displacement 23.322 is obtained with respect to U2 in Model 2 in coarse mesh.



Model 1 simply supported deep beam coarse mesh

Model 8 continuous deep beam with openings fine mesh



Model 2 simply supported deep beam coarse mesh

Model 7 continuous deep beam with openings coarse mesh

Figure 14: Models showing lowest and highest displacement

Table 8: Displacement for fine mesh vs coarse mesh (DL+ IMPACT LOAD 2) (TRAPEZOIDAL LOADING) in mm.

S.no	DISP(F M)		DISP(C M)	
	U1	U2	U1	U2
M-1	0.89	65.331	0.553	64.464
M-2	1.239	32.995	0.646	29.999
M-3	0.897	66.441	0.556	67.63
M-4	1.244	34.929	0.648	31.934
M-5	1.265	77.563	0.924	77.948
M-6	1.537	67.51	1.05	62.522
M-7	1.316	77.902	0.973	78.242
M-8	1.578	67.675	1.101	62.81

*highest displacement 1.578 is obtained with respect to U1 in Model 8 in fine mesh.

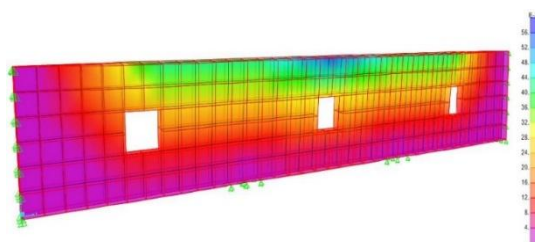
*lowest displacement 0.553 is obtained with respect to U1 in Model 1 in coarse mesh.

*highest displacement 77.948 is obtained with respect to U2 in Model 7 in coarse mesh.

*lowest displacement 29.999 is obtained with respect to U2 in Model 2 in coarse mesh.

Table 8: Displacement for fine mesh vs coarse mesh (DL+ IMPACT LOAD 3) (CYCLIC LOADING) in mm.

S.no	DISP (F M)		DISP (C M)	
	U1	U2	U1	U2
M-1	0.846	132.263	0.563	106.31
M-2	1.219	116.319	0.638	75.762
M-3	0.851	103.236	0.564	139.197
M-4	1.22	156.904	0.639	91.382
M-5	1.203	166.237	0.667	171.489
M-6	1.262	473.517	1.043	305.425
M-7	1.142	151.587	0.764	116.454
M-8	1.516	298.867	0.95	516.789



Model 8 continuous deep beam with openings coarse mesh
 Figure 15: Model showing highest displacement with respect to U2

*highest displacement 1.516 is obtained with respect to U1 in Model 8 in fine mesh.

*lowest displacement 0.563 is obtained with respect to U1 in Model 1 in coarse mesh.

*highest displacement 516.789 is obtained with respect to U2 in Model 8 in coarse mesh.

*lowest displacement 75.762 is obtained with respect to U2 in Model 2 in coarse mesh.

*SOME FIGURES HAVE NOT BEEN PROVIDED DUE TO SPACE ISSUES.

5 CONCLUSIONS

- Transfer girder modelling subjected to discretization has given a greater accuracy, and varied results this concludes that FINITE ELEMENT MODELLING TECHNIQUE is a must for the analysis and designing of a transfer girder.
- Continuous transfer girder has shown the highest amount of stress concentration and displacement, considering gravity loading and floating column loading, thus it should be abstained from designing where ever possibility occurs.
- Transfer girder modelled as solid has shown a greater impact of stress concentration and displacement as the floating column loading and gravity loading applied on the girder has affected in a 3 point way same follows for restraints too.
- Transfer girder subjected to openings has shown more stress concentration at the periphery and around the opening.
- The maximum value of displacement with respect to gravity loading obtained is 1.392 mm.
- The highest value of displacement with respect to floating column loading obtained is 17.255 mm.
- Uniform stress concentration has been seen in number of models irrespective of discretization.
- As per our keen observation it has been concluded that displacement at mid span has been more effective rather than at the supports.
- Impact loading has shown a greater impact of displacement on the transfer girder if the acceleration is in the y direction (U2).
- Acceleration in x direction (U1) has yield very less displacement.
- Trapezoidal loading has given higher impact when compared with triangular loading as acceleration here is constant for an amount of time period (0.25 – 0.5).
- The highest displacement occurred due to sinusoidal loading (sine wave) is 516.789 mm, with respect to coarse discretization, it states that results obtained through the effect of sinusoidal loading are irrespective of discretization.

- Cyclic loading or sinusoidal loading has been proved the most effective loading compared among the three impact loading.
- SAP 2000 has given a great user friendly interface to carry out all the analysis efficiently and for the study of a particular member this software has a better approach and dedicated options to follow.

6 REFERENCE

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