

# Mismatched Meshing In Adjacent Shell Elements – A Case Study

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**ABSTRACT:** Finite element models of complex RCC structures might result in mismatched meshing on adjacent elements, especially for shell structure with multiple openings. The recent commercial software offer analysis with mismatched meshing without the classical mesh transitions. The responses of a typical structure for various loading conditions are compared in this article with matched and mismatched meshing by commercially available software. The results indicate that the errors introduced due to analysis with mismatched meshing would be within five percent.

**KEYWORDS:** Finite element method (FEM); Shell Element; Edge Constraint; Mismatched Meshing.

## I. INTRODUCTION

Buildings and structures for complex industrial facilities often contain number of openings/cutouts in floors and walls of different sizes at various positions for facilitating the particular process. Civil structures for such important facilities are generally analyzed by using commercial Finite Element (FE) software in which the floors and walls are modeled employing shell elements. Incorporation of various openings at requisite locations in FE model is necessary to capture the realistic behavior of the structure. Some commercial software such as SAP2000 etc. allows analysis with mismatched meshing on adjacent shell elements.

In the application of the Finite Element Analysis Method, the most time consuming task is usually the creation and modification of the finite element mesh of the system. Not to mention the fact that creation of mesh transitions from coarse mesh to fine mesh can be very tedious. Also matching up node points to create compatible meshes at intersecting planes, such as walls and floors can be quite labor intensive. And even if the mesh generation is automated the mesh transitioning usually produces irregular or skewed elements that may perform poorly. This may have adverse effects on the design, especially in regions of stress concentration, such as in the vicinity of intersecting planes.

In this article, we present a case study, in which the responses of matched and mismatched meshing have been compared for a typical structure with different loading conditions.

## II. ANALYSIS WITH MISMATCHED MESHING

In the classical approach, the change-over from one mesh density to another is addressed by mesh transitions as shown in Fig. 1(a). Some recent commercial software like SAP2000, etc. allow a simpler approach for such analysis by allowing mismatched meshing on adjacent elements. Typical force description is depicted in Fig. 1(b).

In SAP2000, this mismatch is addressed by 'edge constraint' option. This can be assigned to any element (including shell elements), wherein all joints that are on that edge are connected to the adjacent corner joints of the element (SAP Analysis Reference Manual) by 'flexible interpolation constraints'. The displacements at the intermediate joints on an edge of an element are interpolated from the displacements of the corner joints of the element. However, it should be noted that there should be common nodes/joints at regular interval, where *edge constraint* is applied.

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Vol. 6, Issue 9, September 2017

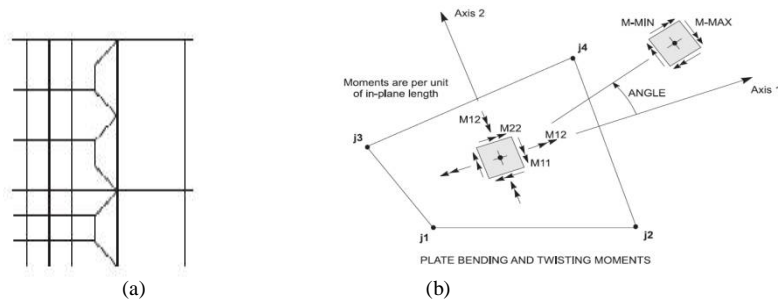


Fig 1 (a) Typical Mesh Transition (b) Forces in Shell Element [SAP200 Manual v16]

### III. METHODOLOGY

In the object-based modeling environment the engineer generates the structural model by creating only a few large area objects that physically define the structural units such as wall panels, columns, beams, floors or ramps. The finite element mesh is not explicitly created by the user, but is automatically generated by assigning meshing parameters to the area objects. These parameters may include variables, such as mesh size, mesh spacing and mesh grading among others. With this capability the engineer can study the effects of mesh refinement by just defining a few control parameters. The new model with the desired level of refinement is thus created with minimal effort.

If the meshes on common edges of adjacent area objects do not match up, automated edge constraints are generated along those edges. These edge constraints enforce displacement compatibility between the mismatched meshes of adjacent objects and eliminate the need for mesh transition elements.

A typical RCC structure with columns, walls, beams and slabs as depicted in Fig. 2 was considered in the study. Fig. 2 and Fig. 3 show the matched and mismatched meshing for the structure modeled as fixed base, while Fig. 6 and Fig.7 show the same for the structure modeled with the raft. The analysis was carried out for different load cases like static, seismic, temperature etc. and the various responses like deflections and forces/stresses in different structural members along the edges with mismatched mesh were compared. SAP2000 was used for the analysis and the 'edge constraint' option was applied for the structure with the mismatched meshing.

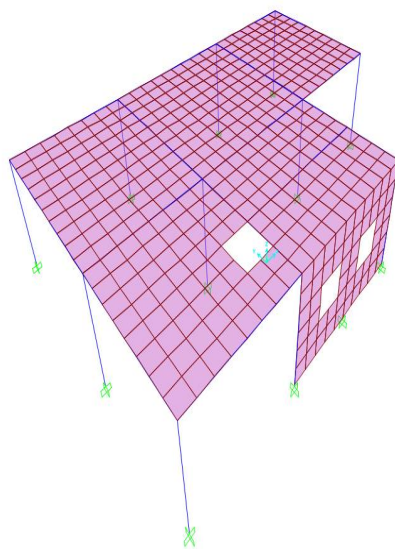


Fig 2: 3D view of Example -1 model

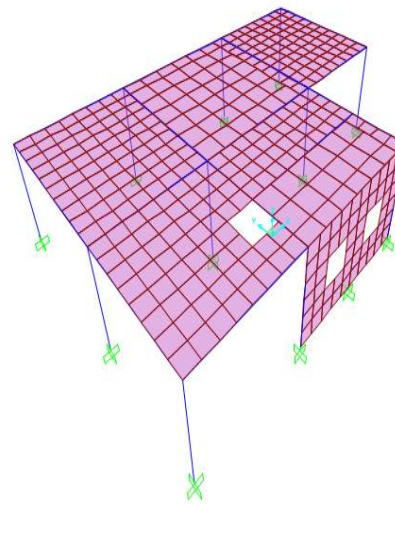


Fig 3: 3D view of Example -2 model

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## IV. EXAMPLE 1: MODEL WITH PROPER MESHING OF SLAB AND RAFT

In this example 250mm thick slab is modeled with beam and column arrangement. Shear wall of 250mm thickness is provided at one side with two openings of 1mx1m each. Shell elements are properly meshed to have all meshing line matching with each other. Deadload, live load, earthquake load and temperature load have been applied as per Table1.

**Table 1: Model details for Example 1 & Example 2**

<b>Material Data:</b>	Weight per unit volume = 25 kN/m <sup>3</sup> Modulus of Elasticity, E = 273864128MPa. Poisson's Ration, $\mu = 0.2$ Coefficient of Thermal Expansion, $\alpha = 5.5E-6/^{\circ}C$
<b>Section Data:</b>	Beam Section = B500x750 , D = 750, B=500 (all dimensions in mm) Column Section = C750x750 , D=750, B=750 (all dimensions in mm) Area section = 250mm , Thickness = 250 mm, Type = Shell-Thick Area section = 300mm , Thickness = 300 mm, Type = Shell-Thick
<b>Loading Data:</b>	Dead Load (DL) = Selfweight factor = -1 Live Load (LL)= Uniform to Shell, intensity of load is shown in Fig 4 Earthquake Load (Spec-x, Spec-y, Spec-Z) – Response Spectrum = Site Specific Response Spectrum applied with 7% Damping. Temperature load (Temp) = load type – Gradient 3-3 = 109.4 °C/m Outside surface Temperature = 52.35°C; Inside surface Temperature = 25°C Temperature Gradient applied to SAP2000 = (52.35-25)/0.25 = 109.4°C/m
<b>Geometry Data:</b>	Grid Spacing A-B = 4m, B-C = 5m & C-D = 4m and 1-2 = 4m & 2-3 = 5 m Z – Direction = 3m Mesh Size = 0.5mx0.5m Opening size = 1mx1m

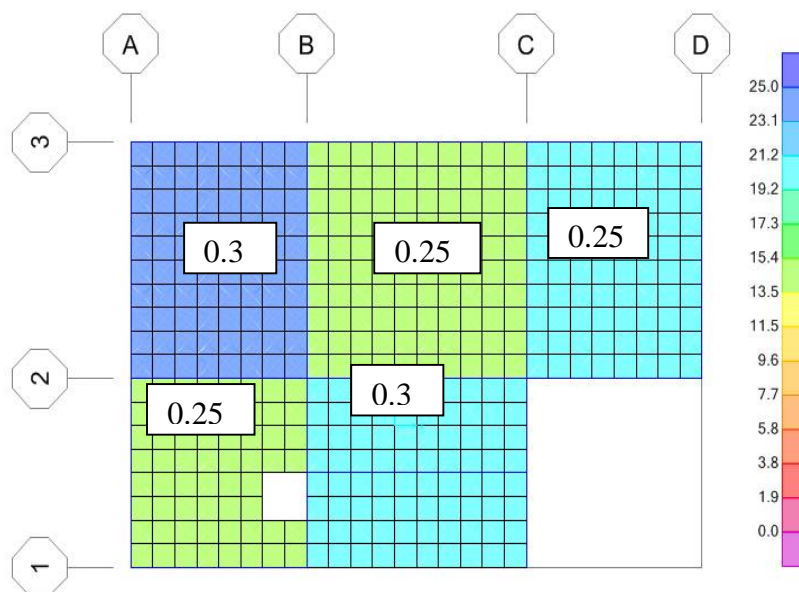


Fig 4: Load Intensity (KN/m<sup>2</sup>) for Load Case: - Live Load (Thickness of slab panel is shown in box)

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## V. EXAMPLE 2: MODEL WITH IMPROPER MESHING OF SLAB AND RAFT WITH EDGE CONSTRAINTS

In this example 250mm thick slab is modeled with beam and column arrangement. Shear wall of 250mm thickness is provided at one side with two openings of 1x1m each. Some shell elements are purposely meshed to have mismatched meshing and have been assigned edge constraints to them to study the effect of edge constraints in analysis results dead load, live load, earthquake load and temperature load have been applied as per Table 1.

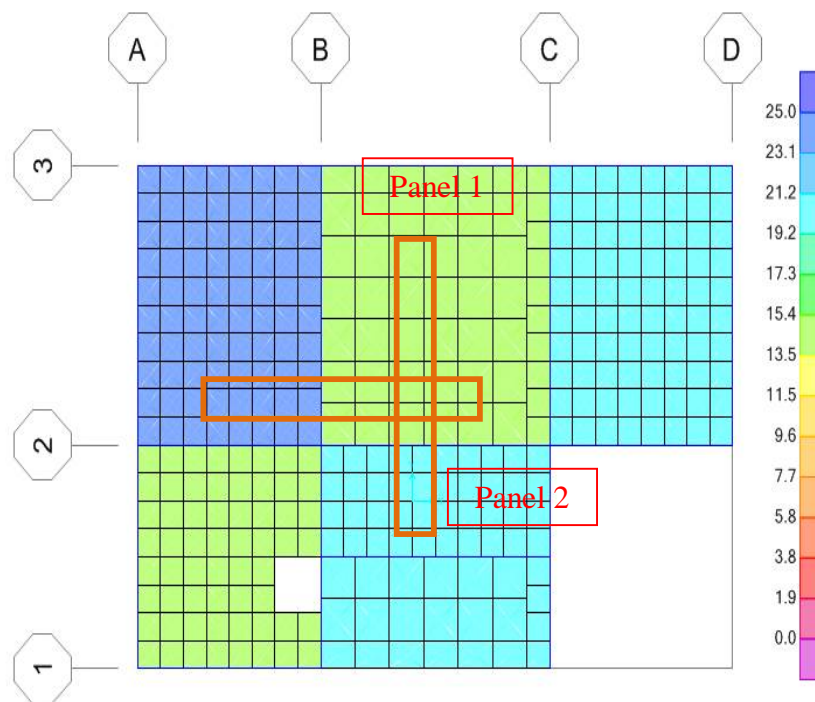


Fig 5: Load intensity for live load case (load intensity contour)

Edge constraint can assign a specific mesh to area elements (Red box marking area) under Assign>Area>Generate Edge Constraints. In typical finite element analysis, shell elements are connected to other elements at corner points only. When an element does not frame into the corner point of a shell element, but instead frames into the edge of the shell element, no connection exists between the element and the shell element. SAP2000 is able to perform the analysis in this fashion. However, SAP2000 also has the capability of using an auto edge constraint. The SAP2000 auto edge constraint feature allows user to specify that elements framing into the edge of a shell element be connected to the shell element. SAP2000 internally takes care of connection between the elements by constraining points lying along an edge of the shell element to move with that edge of the element.



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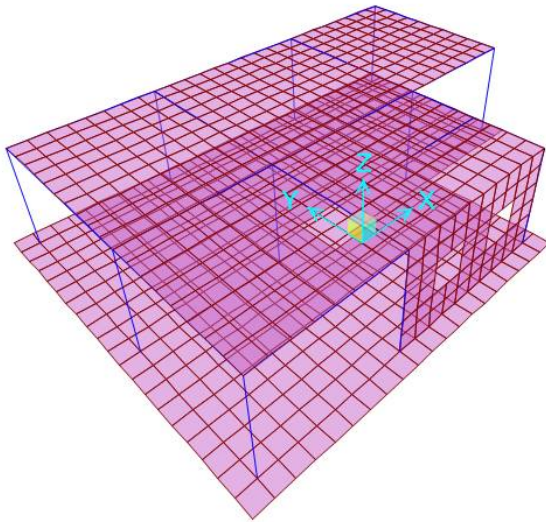


Fig 6: 3D View of Example 3 Model

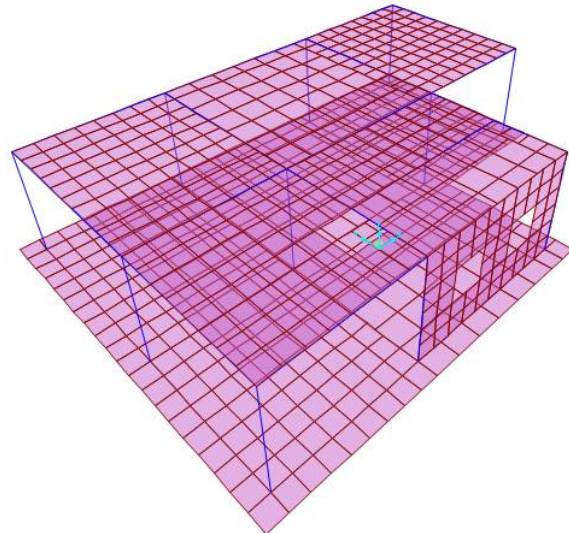


Fig 7: 3D View of Example 4 Model

## VI. EXAMPLE 3: MODEL WITH PROPER MESHING OF SLAB, RAFT, AND WALL

All material and geometric property is similar as example 1 above, the only difference being the raft is modeled and spring constant is applied as per Table 2.

**Table 2: Spring Constant details for Example 3 & Example 4**

Thickness of raft plate element	Total area of raft	$K_x$ (kN/m)	$K_y$ (kN/m)	$K_z$ (kN/m)
500 mm	124 m <sup>2</sup>	2.96 e+6	2.96 e+6	3.50 e+6

## VII. EXAMPLE 4: MODEL WITH IMPROPER MESHING OF SLAB, RAFT, AND WALL WITH EDGE CONSTRAINT

All material and geometric property is similar as example 2 above the only difference being the raft is modeled and spring constant is applied as per Table 2.

## VIII. RESULTS AND DISCUSSIONS

The vertical deflection patterns for the different load cases for the beam along the edge with mismatched mesh are presented in Fig. 8(a) and Fig. 8(b) for matched and mismatched meshing respectively. It may be noted that the deflection of the beam is quite similar in either case.

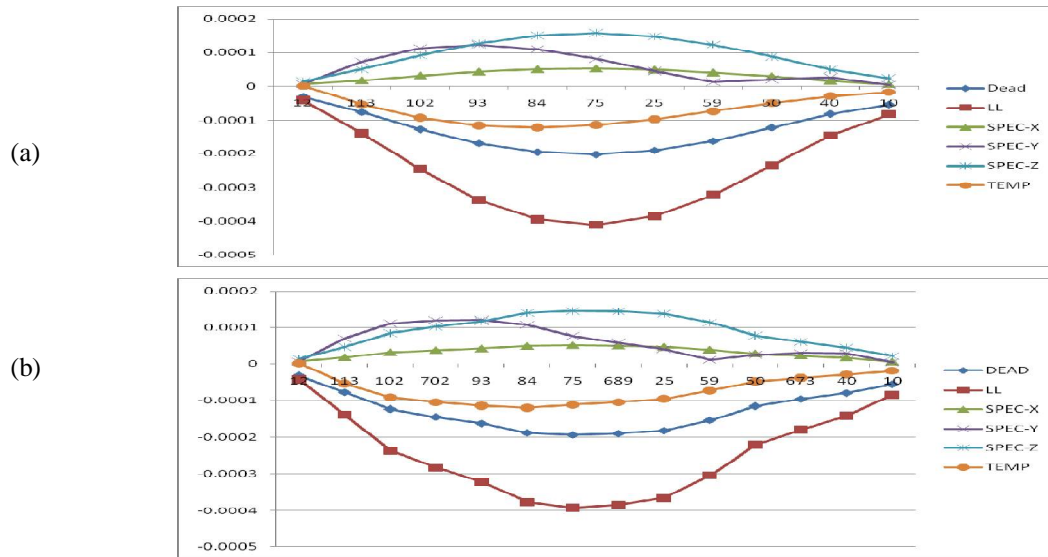


Fig 8 Deflection Pattern for Different Load Cases for Beam along Mismatched Edge (a) Matched Meshing (b) Mismatched Meshing with edge constraints

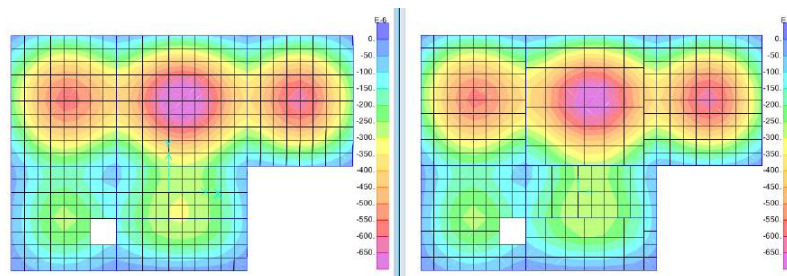


Fig 9 Joint Deflection (in m) Contour for Slab Panels without Raft model: Live Load Case (a) Matched Meshing (b) Mismatched Meshing with edge constraints

Fig. 9 depicts the joint deflection contour for the slab panels for the live (gravity) load case for the model without raft. It is observed that the deflection pattern in both the matched mesh model and the mismatched mesh (with edge constraint) model yields similar patterns.

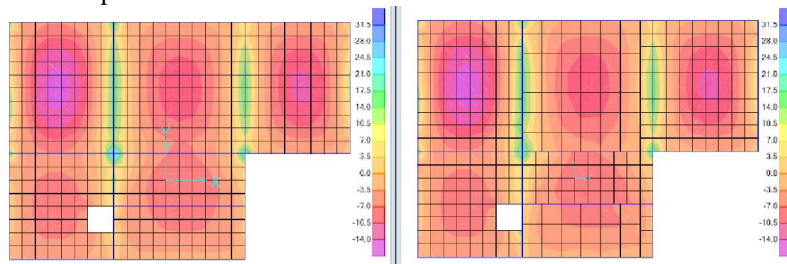


Fig 10 Force M11 Pattern Contour (in kN-m/m) for Slab Panels without Raft model: Live Load Case (a) Matched Meshing (b) Mismatched Meshing with edge constraints

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Predominant forces for the wall panel are M11 and F11. Fig. 10 depicts the M11 pattern contour for the slab panels for the live (gravity) load case for the model without raft. It is observed that the moment developed in the slab for both the matched mesh model and the mismatched mesh (with edge constraint) model displays very similar patterns.

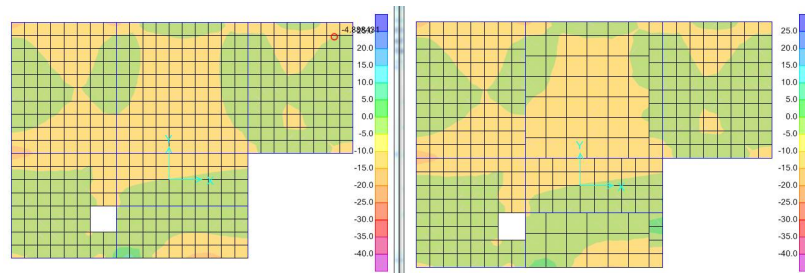


Fig 11 Force F11 Pattern Contour (in kN/m) for Slab Panels without Raft model: Live Load Case  
(a) Matched Meshing (b) Mismatched Meshing with edge constraints

Fig. 11 depicts the F11 pattern contour for the slab panels for the live (gravity) load case for the model without raft. It is noted that for both the matched mesh model and the mismatched mesh (with edge constraint) model, the forces in the slab panels are quite close.

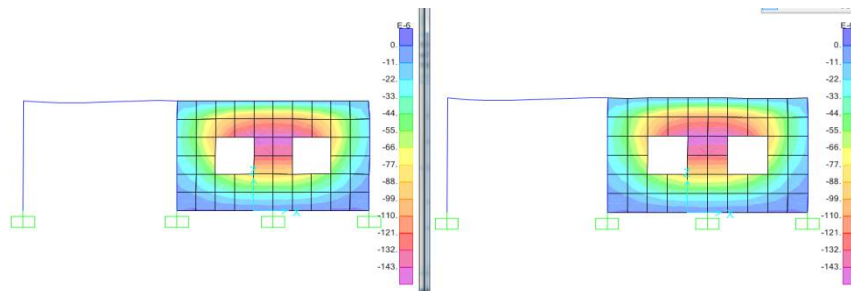


Fig 12 Joint Deflection (in m) Contour for Wall Panels without Raft model: Temperature Load Case  
(a) Matched Meshing (b) Mismatched Meshing with edge constraints

Fig. 12 depicts the joint deflection contour for the wall panels for the temperature load case for the model without raft. It is observed that the deflection pattern in both the matched mesh model and the mismatched mesh (with edge constraint) model yields similar patterns.

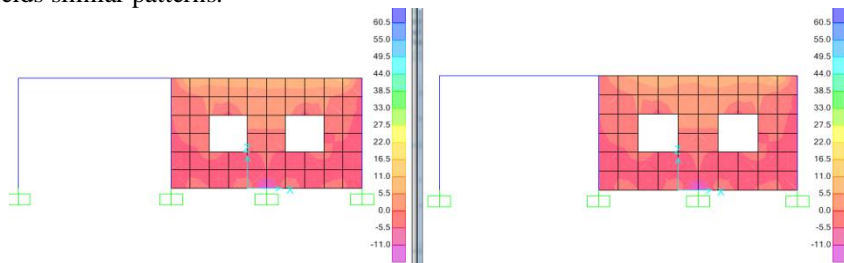


Fig 13 Force M22 Pattern Contour (in kN-m/m) for Wall Panels without Raft model: Temperature Load Case  
(a) Matched Meshing (b) Mismatched Meshing with edge constraints

Predominant forces for the wall panel are M22 and F22. Fig. 13 depicts the M22 pattern contour for the same wall panels for the temperature load case for the model without raft. It is observed that the moment developed in the wall for both the matched mesh model and the mismatched mesh (with edge constraint) model displays very similar patterns.

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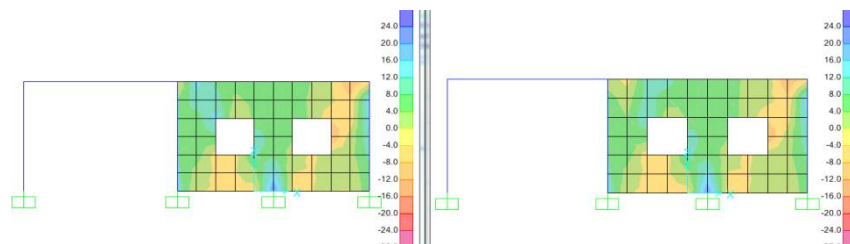


Fig 14 Force F22 Pattern Contour (in kN/m) for Wall Panels without Raft model: Temperature Load Case  
(a) Matched Meshing (b) Mismatched Meshing with edge constraints

Fig. 14 depicts the F22 pattern contour for the wall for the temperature load case for the model without raft. It is noted that for both the matched mesh model and the mismatched mesh (with edge constraint) model, the forces in the slab panels are quite close.

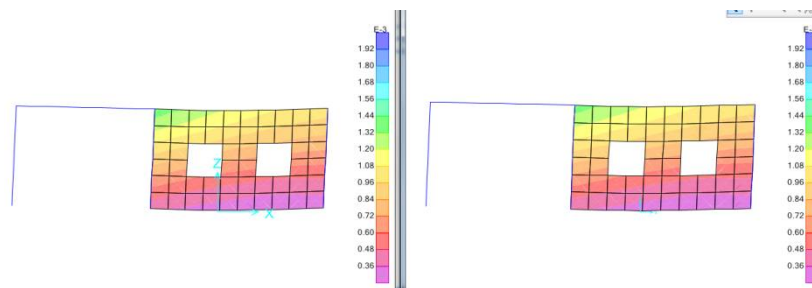


Fig 15 Joint Deflection (in m) Contour for Wall Panels with Raft model: EQ-X Load Case  
(a) Matched Meshing (b) Mismatched Meshing with edge constraints

Fig. 15 depicts the joint deflection contour for the wall panels for the seismic load case (EQ-X) for the model with raft. It is observed that there is little variation in the deflection pattern for the matched mesh model and the mismatched mesh model (with edge constraint).

Fig. 16 depicts the F22 pattern contour for the wall for the seismic load case (EQ-X) for the model without raft. It is noted that for both the matched mesh model and the mismatched mesh (with edge constraint), the forces in the wall panels are quite close.

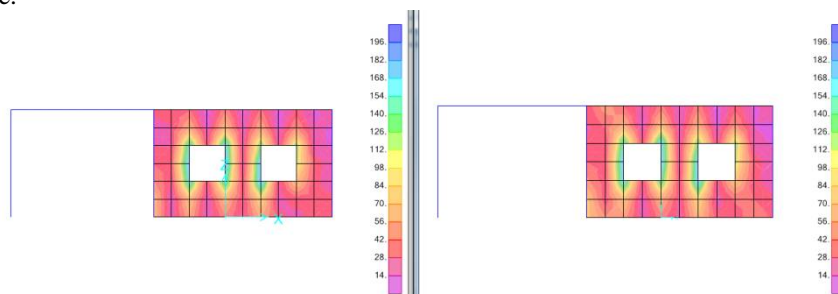


Fig 16 Force F22 Pattern Contour (in KN/m) for Wall Panels with Raft model: EQ-X load Case  
(a) Matched Meshing (b) Mismatched Meshing with edge constraints

Thus, from the comparison of the deflection pattern and stress contours, it may be generally concluded that though there are minor variations, that the responses are well captured along the mismatched edges and also around the opening with the mismatched meshing when using the edge constraint option.



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**Table 3: Result comparisons of slab panels**

Sr. No	Forces (load Case - Live Load)		Panel 1 (refer Fig. 5)			Panel 2 (refer Fig. 5)		
			Match Meshing	Match Meshing wt edge const.	% Error	Match Meshing	Match Meshing wt edge const.	% Error
1	M11	Max	20.94	21.01	0.33%	21.1	20.53	-2.70%
2		Min	-14.85	-14.88	0.20%	-9.57	-9.47	-1.04%
3	F11	Max	0.29	0.3	3.45%	4.81	4.98	3.53%
4		Min	-8.88	-8.68	-2.25%	-9.7	-9.38	-3.30%

The force description for referring the Tables 3 to 5 had been depicted in Fig. 1 (b). The results for the forces in the typical slab panels 1 & 2 for the gravity load case are presented in Table 3. The range of errors are generally within 4% for the model with edge constraint.

**Table 4 Result comparisons of slab panels**

Sr. No	Forces (load Case - Temperature Load)		Panel 1 (refer Fig. 5)			Panel 2 (refer Fig. 5)		
			Match Meshing	Match Meshing wt edge const.	% Error	Match Meshing	Match Meshing wt edge const.	% Error
1	M22	Max	40.92	40.722	0.48%	41.33	41.9	1.38%
2		Min	13.29	13.58	2.18%	14.66	15.1	3.00%
3	F22	Max	-1.62	-1.64	1.23%	0.24	0.235	-2.08%
4		Min	-86.4	-87.61	1.40%	-86.73	-87.51	0.90%

The results for the forces in the typical slab panels 1 & 2 for the temperature load case are displayed in Table 4. The range of errors are generally within 3% for the model with edge constraint.

**Table 5 Result comparisons of slab panels**

Sr. No	Forces (load Case - EQ-X Load)		Panel 1 (refer Fig. 5)			Panel 2 (refer Fig. 5)		
			Match Meshing	Match Meshing wt edge const.	% Error	Match Meshing	Match Meshing wt edge const.	% Error
1	M11	Max	22.4	22.22	-0.80%	29.79	29.55	-0.81%
2		Min	1.44	1.44	0.00%	1.51	1.45	-3.97%
3	F11	Max	55.65	55.51	-0.25%	79.47	80.11	0.81%
4		Min	1.95	2.03	4.10%	4.56	4.44	-2.63%

The results for the forces in the typical slab panels 1 & 2 for the seismic load case are shown in Table 5. The range of errors are generally within 4% for the model with edge constraint.

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From the comparison presented in the tables it is concluded that with the edge constraint option, the analysis results, like the deflections and stresses obtained with mismatched meshing fall within 5% of those obtained from matched meshing.

## IX. CONCLUSIONS

In this article the responses of a typical RCC structure with beam and shell elements (including openings) were studied with matched and mismatched meshing for different loading conditions like gravity, seismic and thermal loads. The responses including the deflection pattern of beams along the edge with mismatched mesh, deflection contour for the slab panels, and forces/stresses in the slab panels were compared. From the tabular and visual comparison, it is observed that with '*edge constraint*' option in SAP2000, the results from the mismatched meshing are within five percent of those from matched meshing. Though there are slight differences, the contours in either case match quite well. It may be concluded that within the limitations of this study, the analysis options with mismatched meshing in recent commercial software, for example, '*edge constraint*' option in SAP2000, offer simpler modeling with errors within five percent.

Further investigations need to be conducted towards ascertaining the error margins for runs with *edge constraint* option in SAP2000 where (i) the slab and / or wall panels are more flexible; (ii) the load intensity are higher; (iii) concentrated load along / near the mismatched edge; (iv) multiple openings in slab / wall panels (v) complex geometry; (vi) other loads like projectile impact, water jet, blast, etc. These studies would help practicing designers to develop confidence while applying the innovative modeling options in the modern FE software.

## REFERENCES

- [1] Bathe K. J. (1996), Finite Element Procedures, Prentice Hall, Upper Saddle River, New Jersey, USA.
- [2] CSI Analysis Reference Manual, SAP 2000, Version 16, Computers and Structures, INC.