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Effect of Diaphragm Flexibility on the Seismic Response of RCC Framed Building Considering Diaphragm Discontinuity

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Abstract– *Diaphragms are required to be designed as part of the seismic force-resisting system of every new building as they distribute lateral forces to the vertical elements of lateral force resisting system. Concrete diaphragms consist of different element which plays an important role in resisting lateral loads. Diaphragms acts differently according to the configurations of the building and type of load acting on it. In a RCC framed building, different columns may carry different loads accordingly. In this paper, RCC framed building structures have been analyzed using ETABS software by linear time history analysis by changing flexibility of the floors and simultaneously when plan irregularities are provided. Time history record of El Centro Earthquake has been provided to the software. Responses of all those structures has been plotted and discussed. An attempt is made in this paper to compare the responses of the structures when floor diaphragm flexibility is changed and simultaneously plan irregularities are provided.*

Key Words - Floor *Diaphragm, Stiffness, Earthquake, Flexible Diaphragm, Rigid Diaphragm, Reinforced Concrete, Shear Wall.*

I. INTRODUCTION

A multi-storied framed building can have various types of irregularities and that can affect the normal response of the building. Here we are considering the plan irregularity i.e. diaphragm discontinuity. Diaphragm with abrupt discontinuities or change in stiffness can also affect the normal responses. Along with the diaphragm discontinuity, the variation with flexibility of the slab can be compared to know the variation in responses when discontinuities of same area were placed at different places.

As per IS 1893 (Part 1) 2016, a diaphragm may be classified into following two types,

a. Flexible Floor Diaphragm - As per IS 1893, a floor diaphragm whose maximum lateral displacement measured from the chord of deformed shape at any point of the diaphragm exceeds 1.2 times the average displacement of entire diaphragm is known as Flexible floor Diaphragm.

Rigid Floor Diaphragms - A floor diaphragm whose maximum lateral displacement measured from the chord of deformed shape at any point of the diaphragm does not exceed 1.2 times the average displacement of entire diaphragm is considered to be Rigid Floor diaphragm. Rigid diaphragm distributes the horizontal forces to the vertical resisting elements in direct proportion to the relative rigidities. It is based on the assumption that the diaphragm does not deform itself and will cause each vertical element to deflect the same amount. This may be determined by comparing the computed midpoint in-plane deflection of the diaphragm itself under lateral load with the drift to adjoining vertical elements under tributary lateral load.

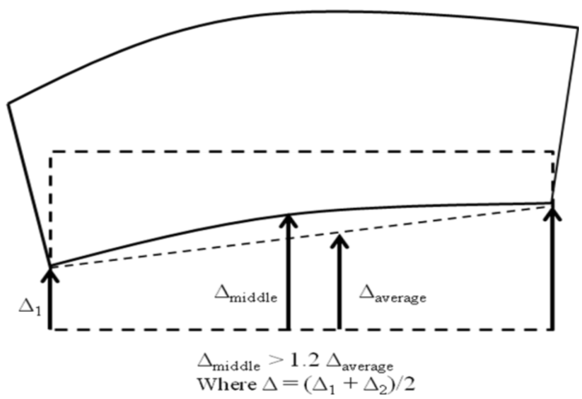


Fig 1 - Flexible Floor Diaphragm

II- OBJECTIVES

1. To compare the effect of diaphragm flexibility of the building on the responses under seismic load.

2. To compare the responses the building structure when the openings are provided at the different places of the plan.
3. To study the effect of diaphragm flexibility on the seismic responses of the building when diaphragm discontinuity is considered.

III- GEOMETRIC DETAILS OF MODEL

For the study, one model was considered. The geometric details have been shown in Table 1. For the analysis, Time history method was used.

Table 1 Geometric Details

No of Storeys	**G + 16**
Storey Height	3 m
Number of Bays	6 bays in both the directions
Beam Size	350 mm x 900 mm
Column Size	350 mm x 1100 mm
Grade of Concrete	M30
Grade of Steel	Fe415
Slab Thickness	110 mm
Seismic zone type	Zone II
Method of analysis	Time History analysis
Ground motion data	Time History record of El Centro Earthquake

IV- MODELING OF FLEXIBLE FLOOR DIAPHRAGM

Computer software ETABS were used to model flexible floor Diaphragm. The software consist of a tool STIFFNESS MODIFIERS which is used to make the slab flexible shown in the figure.

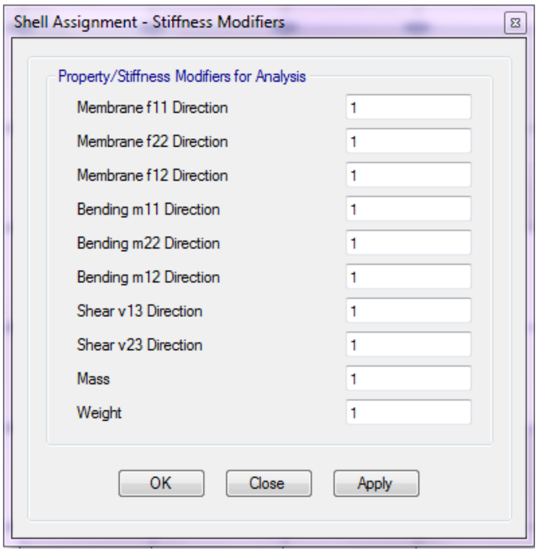


Fig 2 - Stiffness Modifier Tool

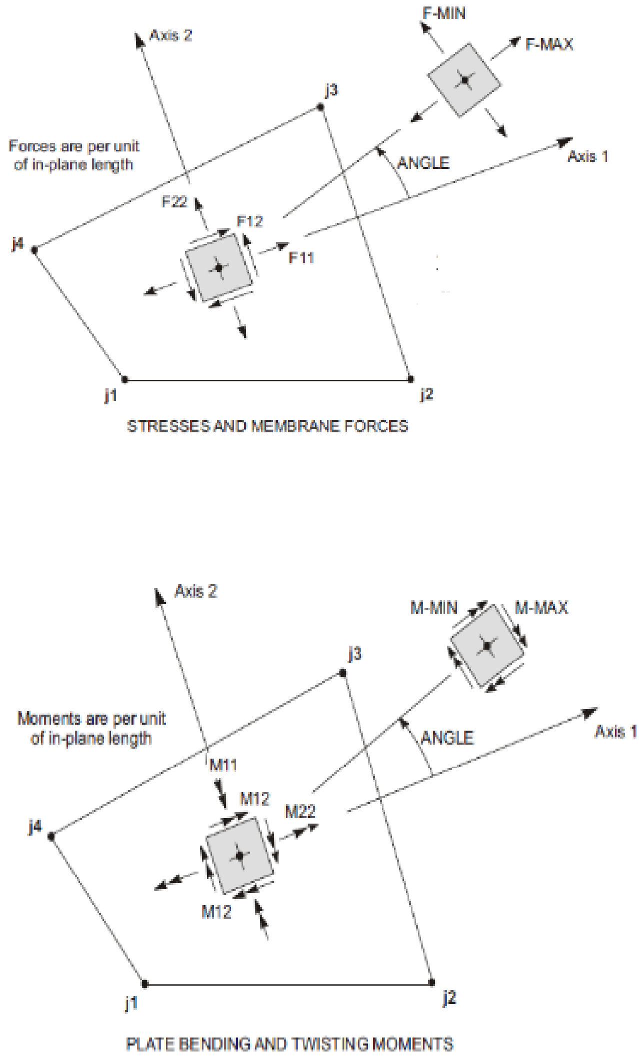
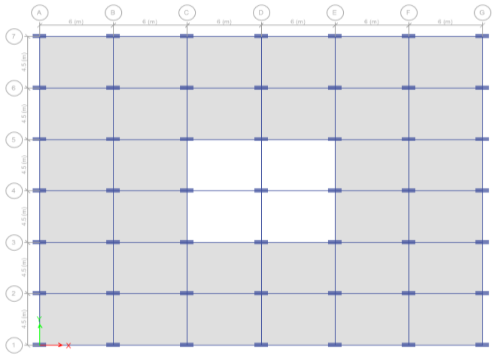


Fig 3 - Shell Element Forces

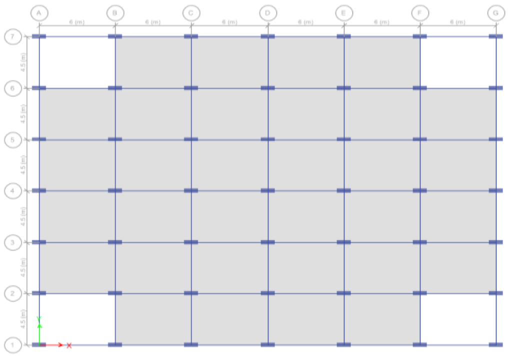
The membrane forces are the in plane forces in respective directions whereas Bending moments are plate bending or twisting moments as shown in the figure. The stiffness of the floors were modified by considering all these parameters. Diaphragms with all these parameters 1 acts as a rigid floor diaphragm. The stiffness of the slab can be reduced by certain percentage out of 1.The analysis is done using linear time history analysis considering ground motion record of El Centro Earthquake.

V- BUILDING WITH DIAPHRAGM DISCONTINUITY

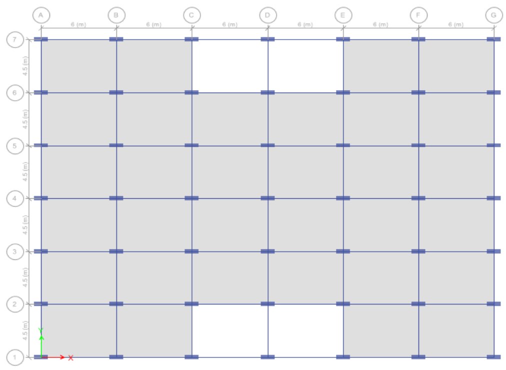
Discontinuity is provided by providing openings to the floors of equal area at different places of the floor.Percentage of Opening provided is 11.11 % .The following patterns were provided and responses were studied.



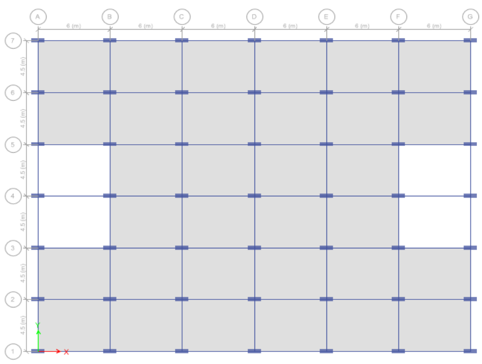
(a) Opening at the Centre



(b) Opening at the Corners



(c) Opening at the Horizontal faces



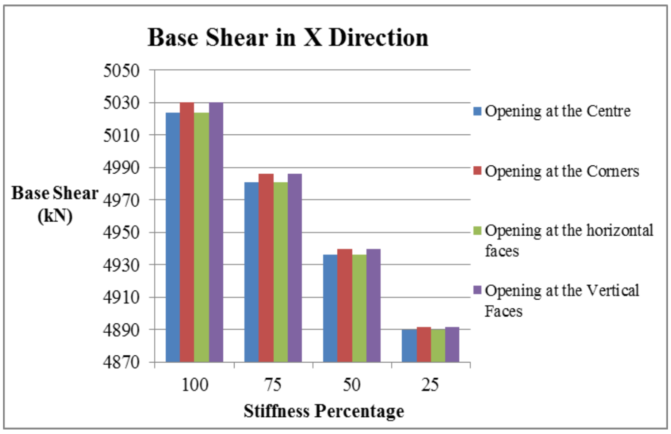
(d) Openings at the Vertical Faces

Fig 4 - Buildings with diaphragm discontinuity

VI- RESULTS AND DISCUSSION

6.1 Base Shear Comparison

When Stiffness of Load resisting system reducing, base shear of the structure is also reducing.



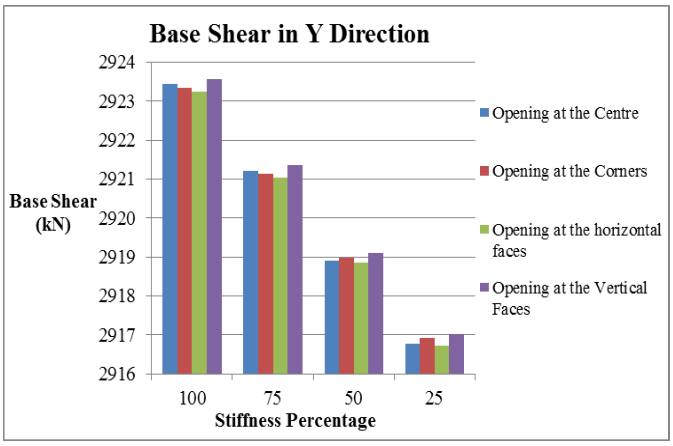


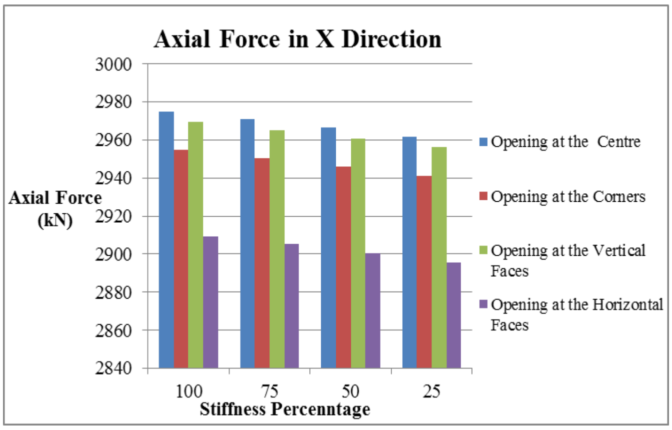
Fig 5 – Base Shear Comparison

In X direction, base shear has reduced with the reduction in stiffness of slab but does not gave considerable difference in while changing the place of opening on the slab. In Ydirection also, the base shear went on reducing with increase in flexibility of the slab with very less difference with the change in the places of the opening.

6.2 Column Forces

6.2.1 Column Axial Force

Reduction in the stiffness of the floor leads to reduction in the column axial forces in the stiffer direction.



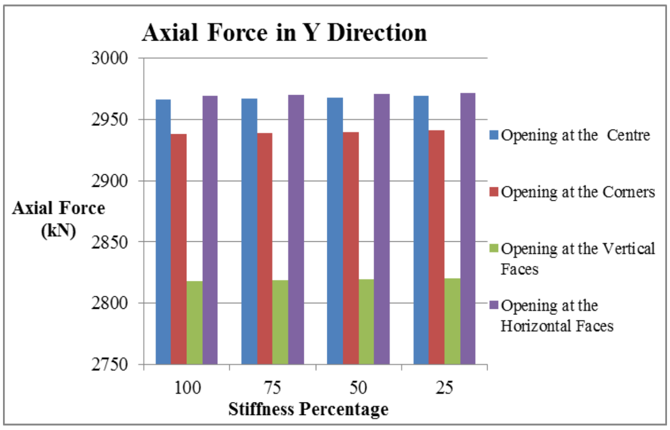
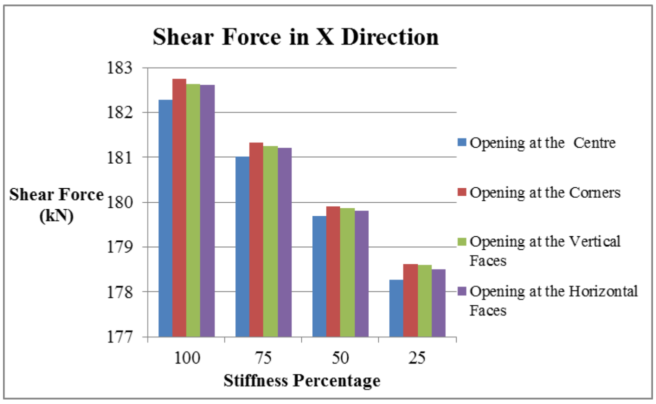


Fig 6 – Column Axial Force comparison for all load cases

Axial Force is reducing as per reducing stiffness in X direction. Opening provided at the centre of the plan produced the largest axial force. In Y direction, axial force increased as per reducing stiffness of the slab and openings when given at the vertical sides produces largest axial force as compared to all other models but model with opening at the horizontal faces has given much smaller value of axial force.

6.2.2 Maximum Column Shear Force Comparison



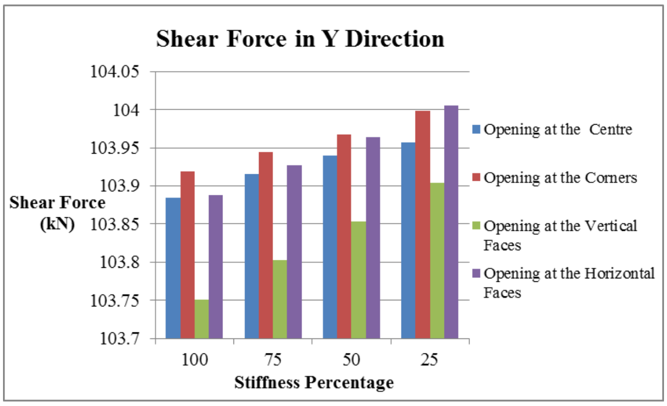
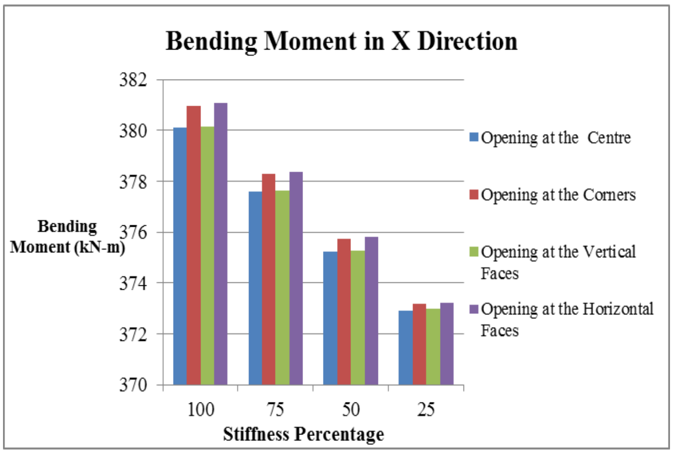


Fig 7 – Column Shear Force comparison for all load cases

In X direction, column shear force goes on reducing while reducing the stiffness of the slab and plan with opening at the centre produces largest shear force. In Y direction, Shear force goes on increasing but plan with opening at the horizontal faces has given much lesser shear force.

6.2.3 Maximum Bending Moment



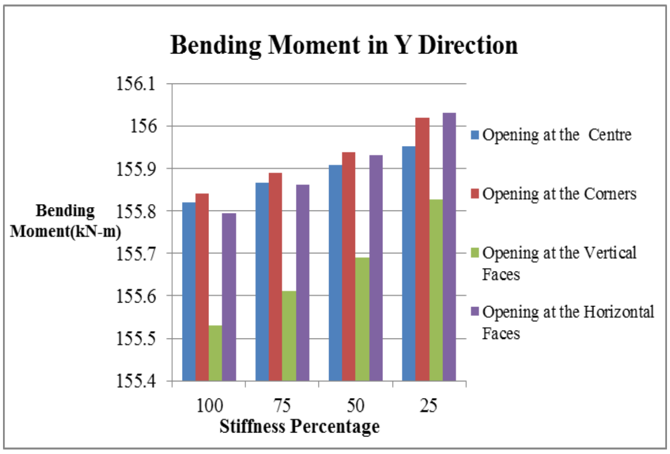


Fig 8 – Column Bending Moment comparison for all load cases

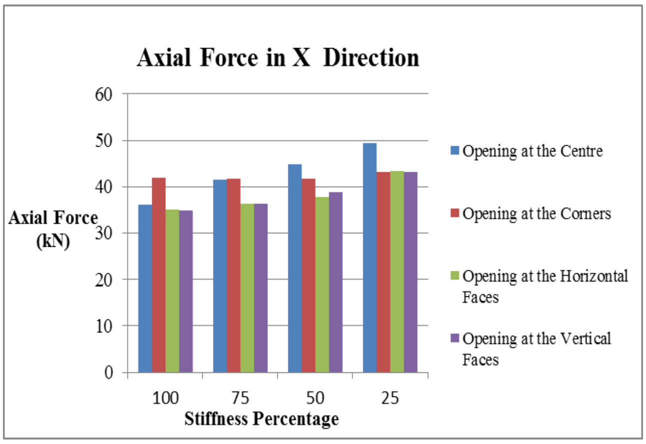
Maximum Bending Moment of Column has decreased with the decrease in stiffness of the floors in X direction.In Y direction, Maximum Bending Moment of Column has increased with the decrease in stiffness of the floors.

6.3 Beam Forces

6.3.1 Beam Axial Forces

As the Stiffness of the floor reduces, beam forces goes on increasing because beams starts carrying forcesin places of Floors. Beams acts as a collectorsin the building structure.

Beam axial force increases with decrease in stiffness of the slab and maximum. Beam axial force is produced by the structure having plan opening at the corners.



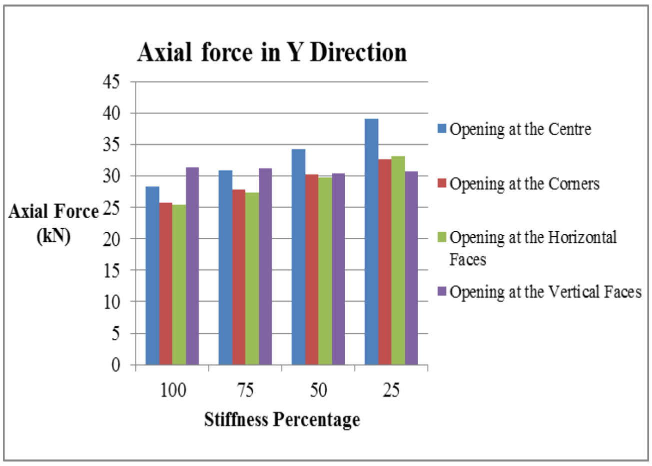
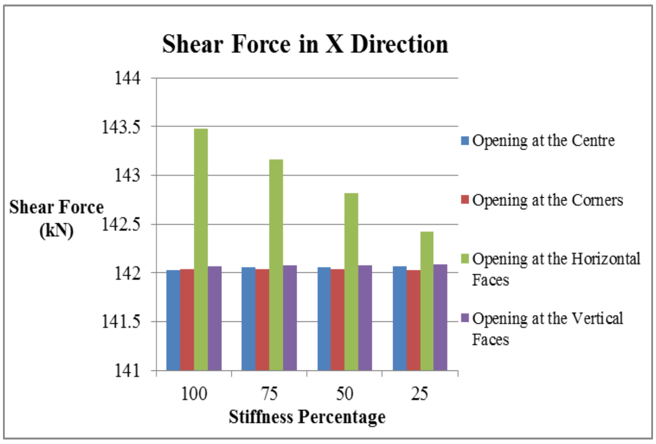


Fig 9 – Beam Axial Force comparison for all load cases

Beam axial force has increased with decrease in stiffness of the slab in both the directions.

6.3.2 Shear Force Comparison



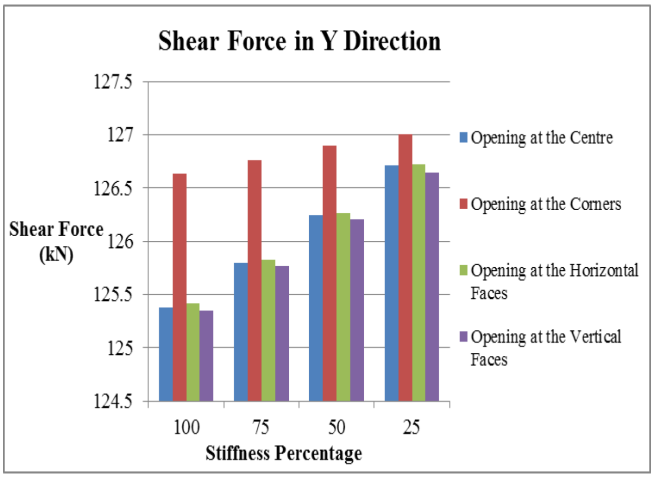
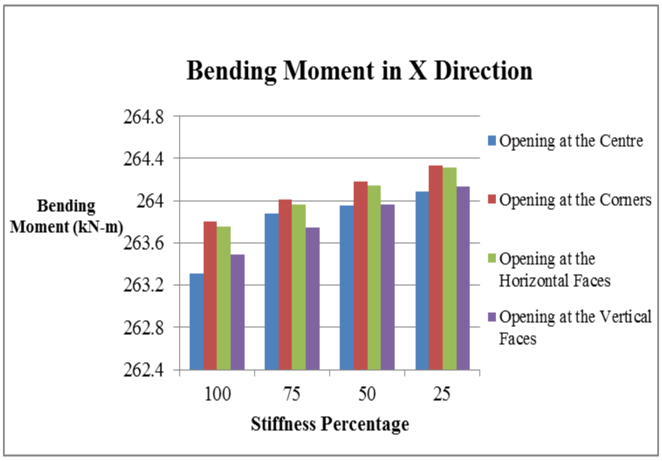


Fig 10 – Beam Shear Force comparison for all load cases

Shear Force in X direction is decreasing with decrease in stiffness of the slab whereas it is increasing as per reducing stiffness of floors.

6.3.3 Maximum Bending Moment Comparison



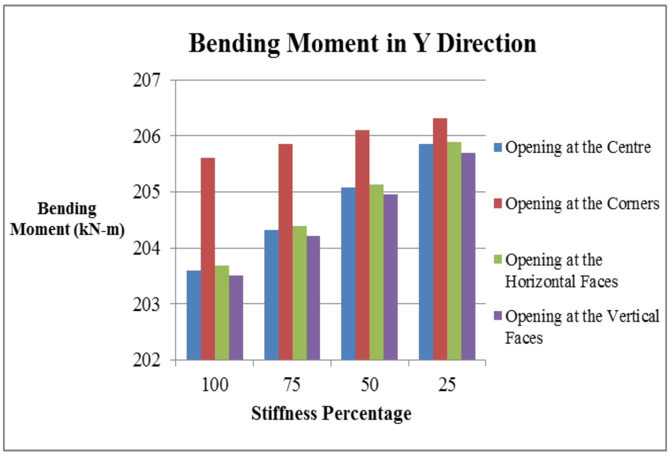


Fig 11 – Beam Bending Moment comparison for all load cases

Bending moment is increasing with the reduction in stiffness of thr floors in both the directions. Structure with plan opening at the centre gives much less Bending moment in X direction. Slab opening when provided at the corners gives maximum response of Bending Moment.

6.4 Time Period Comparison

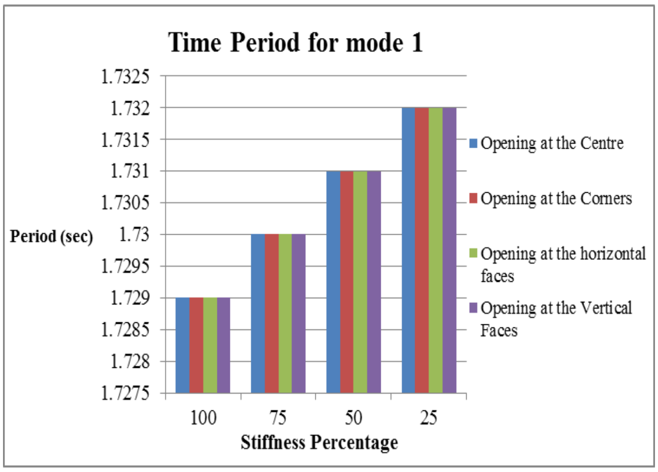


Fig 12 – Time Period Comparison for all Load Cases

Time period does does not show any variation with the placing of openings in different places. But as per decreasing stiffness, time period has increased.

6.5 Maximum Storey Displacement

6.5.1 For Plan with opening at the centre

In X Direction

Storey	Storey Displacement(mm) for Stiffness Percentage			
	100%	75%	50%	25%
Story16	23.883	23.827	23.771	23.712
Story15	23.39	23.321	23.258	23.192
Story14	22.709	22.642	22.568	22.497
Story13	21.788	21.722	21.65	21.572
Story12	20.631	20.567	20.498	20.422
Story11	19.273	19.201	19.125	19.053
Story10	17.738	17.672	17.6	17.522
Story9	16.055	15.987	15.913	15.839
Story8	14.263	14.203	14.139	14.07
Story7	12.405	12.348	12.288	12.225
Story6	10.495	10.445	10.392	10.337
Story5	8.561	8.518	8.476	8.432
Story4	6.62	6.588	6.554	6.519
Story3	4.682	4.658	4.632	4.606
Story2	2.777	2.761	2.745	2.728
Story1	1.036	1.03	1.024	1.018
Base	0	0	0	0

In Y Direction

Storey	Storey Displacement(mm) for Stiffness Percentage			
	100%	75%	50%	25%
Story16	25.609	25.643	25.681	25.724
Story15	25.295	25.326	25.359	25.396
Story14	24.848	24.88	24.915	24.954
Story13	24.247	24.281	24.317	24.357
Story12	23.504	23.539	23.577	23.618
Story11	22.608	22.644	22.682	22.724
Story10	21.516	21.551	21.589	21.63
Story9	20.179	20.212	20.247	20.286
Story8	18.587	18.618	18.653	18.692
Story7	16.771	16.799	16.83	16.864
Story6	14.766	14.788	14.814	14.843
Story5	12.583	12.602	12.622	12.644
Story4	10.216	10.231	10.248	10.267
Story3	7.692	7.704	7.717	7.732
Story2	5.052	5.06	5.068	5.077
Story1	2.351	2.354	2.358	2.362
Base	0	0	0	0

6.5.2 For Plan with opening at the Corners

In X direction

Storey	Storey Displacement(mm) for Stiffness Percentage			
	100%	75%	50%	25%
Story16	23.9	23.837	23.774	23.716
Story15	23.398	23.328	23.265	23.199
Story14	22.718	22.65	22.575	22.505
Story13	21.798	21.731	21.658	21.58
Story12	20.641	20.576	20.506	20.43
Story11	19.285	19.211	19.133	19.061
Story10	17.75	17.682	17.608	17.529
Story9	16.068	15.997	15.922	15.846
Story8	14.275	14.212	14.146	14.076
Story7	12.416	12.357	12.295	12.23
Story6	10.506	10.454	10.399	10.341
Story5	8.57	8.526	8.481	8.436
Story4	6.627	6.594	6.558	6.522
Story3	4.688	4.662	4.636	4.608
Story2	2.781	2.765	2.747	2.73
Story1	1.037	1.031	1.025	1.018
Base	0	0	0	0

Storey	Storey Displacement(mm) for Stiffness Percentage			
	100%	75%	50%	25%
Story16	25.611	25.644	25.679	25.721
Story15	25.296	25.327	25.361	25.398
Story14	24.85	24.882	24.917	24.955
Story13	24.251	24.284	24.319	24.359
Story12	23.509	23.543	23.58	23.622
Story11	22.614	22.649	22.687	22.731
Story10	21.523	21.557	21.594	21.637
Story9	20.186	20.218	20.253	20.294
Story8	18.594	18.625	18.659	18.7
Story7	16.777	16.805	16.836	16.871
Story6	14.772	14.794	14.82	14.85
Story5	12.589	12.607	12.627	12.651
Story4	10.221	10.236	10.253	10.273
Story3	7.696	7.708	7.721	7.736
Story2	5.055	5.062	5.07	5.079
Story1	2.352	2.355	2.359	2.364
Base	0	0	0	0

6.5.3 For Plan with opening at the Horizontal Faces

In X direction

Storey	Storey Displacement(mm) for Stiffness Percentage			
	100%	75%	50%	25%
Story16	23.882	23.826	23.771	23.716
Story15	23.392	23.323	23.263	23.198
Story14	22.711	22.644	22.571	22.504
Story13	21.79	21.724	21.653	21.577
Story12	20.632	20.569	20.501	20.427
Story11	19.274	19.202	19.128	19.058
Story10	17.739	17.673	17.602	17.526
Story9	16.056	15.988	15.915	15.843
Story8	14.264	14.204	14.14	14.073
Story7	12.405	12.349	12.289	12.227
Story6	10.496	10.446	10.393	10.339
Story5	8.561	8.518	8.476	8.434
Story4	6.62	6.588	6.554	6.52
Story3	4.682	4.658	4.633	4.607
Story2	2.777	2.761	2.745	2.729
Story1	1.037	1.031	1.024	1.018
Base	0	0	0	0

In Y direction

Storey	Storey Displacement(mm) for Stiffness Percentage			
	100%	75%	50%	25%
Story16	25.724	25.682	25.645	25.612
Story15	25.396	25.36	25.327	25.297
Story14	24.954	24.916	24.882	24.85
Story13	24.357	24.318	24.283	24.25
Story12	23.618	23.578	23.542	23.508
Story11	22.724	22.684	22.647	22.613
Story10	21.63	21.59	21.554	21.52
Story9	20.286	20.249	20.215	20.184
Story8	18.692	18.655	18.622	18.592
Story7	16.864	16.832	16.803	16.775
Story6	14.843	14.816	14.791	14.77
Story5	12.644	12.623	12.604	12.587
Story4	10.267	10.249	10.234	10.219
Story3	7.731	7.718	7.706	7.695
Story2	5.077	5.068	5.061	5.054
Story1	2.362	2.358	2.355	2.352
Base	0	0	0	0

6.5.4 For Plan with opening at the Horizontal Faces

In X Direction

Storey	Storey Displacement(mm) for Stiffness Percentage			
	100%	75%	50%	25%
Story16	23.893	23.832	23.774	23.711
Story15	23.397	23.326	23.262	23.195
Story14	22.716	22.647	22.572	22.499
Story13	21.797	21.729	21.655	21.575
Story12	20.64	20.575	20.503	20.426
Story11	19.283	19.209	19.131	19.057
Story10	17.749	17.68	17.606	17.526
Story9	16.067	15.996	15.92	15.843
Story8	14.274	14.212	14.144	14.073
Story7	12.416	12.357	12.294	12.227
Story6	10.506	10.453	10.397	10.339
Story5	8.57	8.525	8.48	8.434
Story4	6.627	6.593	6.558	6.52
Story3	4.687	4.662	4.635	4.607
Story2	2.781	2.764	2.747	2.729
Story1	1.037	1.031	1.025	1.018
Base	0	0	0	0

In Y Direction

Storey	Storey Displacement(mm) for Stiffness Percentage			
	100%	75%	50%	25%
Story16	25.608	25.639	25.721	25.721
Story15	25.295	25.326	25.398	25.398
Story14	24.849	24.881	24.955	24.955
Story13	24.248	24.282	24.359	24.359
Story12	23.506	23.541	23.622	23.622
Story11	22.611	22.647	22.731	22.731
Story10	21.519	21.554	21.638	21.638
Story9	20.182	20.216	20.295	20.295
Story8	18.59	18.622	18.701	18.701
Story7	16.773	16.803	16.872	16.872
Story6	14.769	14.792	14.851	14.851
Story5	12.585	12.605	12.652	12.652
Story4	10.218	10.234	10.274	10.274
Story3	7.694	7.706	7.737	7.737
Story2	5.053	5.061	5.08	5.08
Story1	2.351	2.355	2.364	2.364
Base	0	0	0	0

There is no any considerable difference found in the storey drift .

7.0 Concluding Remarks

On studying the above literatures, we have reached to the following conclusions,

1. Floor Diaphragm Flexibility affects Base Shear of the Building, Column Forces, Beam Forces but doesn't show considerable difference in Time Period and Storey Drift.

2. Orientation of the openings in the building plan changes the responses of the structure under seismic load.

3. The Flexibility of the slabs plays vital role in reducing Base Shear, Column Axial Forces.

4. Base shear and Column axial force has been reduced as per increasing flexibility of the floors when THA is applied in X direction but reduction has been found when THA is applied in Y Direction.

5. Opening at the faces of the floors in shorter side gives comparatively larger Base Shear but Column forces where found higher when openings were in longer side.

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