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EVALUATION OF ROOF DIAPHRAGM EFFECTS ON SEISMIC BEHAVIOUR OF RC BUILDINGS

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Abstract: Floor and roof systems are designed to carry gravity loads and transfer these loads to supporting beams, columns or walls. Furthermore, they play a key role in distributing earthquake-induced loads to the lateral load resisting systems by diaphragm action. In current practice, horizontal diaphragms are typically assumed to rigid, thus in reinforced concrete buildings the in-plane flexibility of the floor diaphragms is often ignored for simplicity in practical design. This flexibility also increases the lateral load transfer to frames that were not design to carry theses additional lateral loads based on a rigid diaphragm model. If this effect is sizable, it can lead to overloading of structural elements. While a rigid diaphragm model seems reasonable for structures that are nearly square, additional information is needed to determine the minimum aspect ratio for which a flexible diaphragm model should be used in analysis and design of RC structures. This study involves the analysis of influence of diaphragm including their openings on the seismic response of reinforced concrete buildings i.e., 5-story reinforced concrete buildings with plan aspect ratios 1:3 and 1:4 in seismic zone V designed as a Building Frame System according to the Indian Standard Codes. The buildings with semi-rigid diaphragm case exhibits higher displacements, story drifts and larger distribution of lateral loads to middle frames compared to rigid diaphragm models. The overall performances of all the case study buildings were good. The effects of openings in both rigid and semi-rigid cases are negligible.

Keywords: Roof Diaphragms, Pushover Analysis, Floor diaphragm openings, aspect ratio, Pushover Curve, etc.,

I. Introduction

When the buildings are subjected to earthquake loadings, the induced inertia forces are transmitted through floor slabs and resisted by vertical structural components such as shear walls and frames. In this situation, the floor slabs function as diaphragms placed between the vertical load resisting components. In current practice, horizontal diaphragms are typically assumed to be rigid, thus in reinforced concrete buildings the in-plane flexibility of the floor diaphragms is often ignored for simplicity in practical design. However, this assumption is found to create certain discrepancy in lateral load distribution. This discrepancy occurs in the floors systems (horizontal diaphragms) which typically function as deep beams with short spans, and have very high stiffness and strength in comparison with other structural components. Knowledge of the strength and stiffness of the slab and its dynamic properties are essential in determining the overall behavior of a building and the forces which the individual vertical elements are required to resist. When there is a significant difference in story stiffness between two adjoined vertical members, the floor slab connecting the members would sustain high in-plane shear. A diaphragm acts in a manner analogous to a deep beam or girder, where the panels acts as a web, resisting shear, while the diaphragm edge members perform the function of flanges, resisting bending stresses. These edge members are commonly called chords in diaphragm design.

However, the influence of floor diaphragm openings (typically for the purpose of stairways, shafts, and other architectural applications) is never been considered. In order to investigate the influence of diaphragm openings on the seismic response of reinforced concrete buildings, 5-story reinforced concrete building with plan aspect ratios 1:3 and 1:4 are designed as a Building Frame System according to the Indian Standard Codes. The building is assumed to be located in seismic zone V and is analyzed with and without floor openings. The behaviour of the building is investigated under linear dynamic and non-linear static methods.

Analysis was performed by assuming both rigid and semi-rigid (but not completely flexible) behavior. Phenomena such as distribution of lateral load, time period, story shear, story drifts, and relative story displacements for both rigid and semi-rigid diaphragms were examined in this study.

II. Objectives of The Study

The following are the main objectives of the present study:

- To study the effect of roof diaphragm on reinforced concrete building structures.
- To perform linear dynamic and non-linear static pushover analysis for RC frames using ETABS and to study the seismic performance of frames.
- To understand the effects of rigid and semi-rigid floor diaphragms on the seismic performance of 5 story reinforced concrete buildings with aspect ratio 1:3 and 1:4.
- To understand the effects of floor openings placed in symmetric and asymmetric plan locations with respect to the centerline of the building in order to investigate the influence of floor openings in slender plan buildings.

III. Methods of Analysis

Two analysis procedures were conducted for each structure: 1) Linear dynamic, 2) Non-linear static. By capturing the true behavior of reinforced concrete buildings with diaphragm openings, the results of this study will lead to valuable information.

A. EQUIVALENT STATIC ANALYSIS

A realistic assessment of the design forces can be obtained only through a dynamic analysis of the building models. Although this has long been recognized, dynamic analysis is used only infrequently in routine design, because such an analysis is both complicated and time-consuming. A major complication arises from the fact that most structures are designed with the expectation that they would be strained into the inelastic range when subjected to the design earthquake. The design base shear shall first computed as a whole, than be distributed along the height of the buildings based on simple formulas appropriate for buildings with regular distribution of mass and stiffness. The design lateral force obtained at each floor level shall then be distributed to individual lateral load resisting elements depending upon floor diaphragm action. In case of rigid diaphragm action, the total shear in any horizontal plane shall be distributed to the various elements of lateral force resisting system on the basis of relative rigidity.

B. RESPONSE SPECTRUM ANALYSIS

The dynamic analysis of a structure is an essential procedure to design a reliable structure subjected to dynamic loads such as earthquake excitations. The objective of dynamic analysis is to determine the structure‘s response and interpret those theoretical results in order to design the structure. Dynamic response spectrum analysis is one of the methods of dynamic analysis which predicts the structure‘s response using the combination of modal maxima. However, throughout conventional dynamic response spectrum analysis, the possible existence of any uncertainty present in the structure‘s geometric and/or material characteristics is not considered [20]. In the design process, the presence of uncertainty is accounted for by considering a combination of load amplification and strength reduction factors that are obtained by modeling of historic data. However, the impact of presence of uncertainty on a design is not considered in the current deterministic dynamic response spectrum analysis. In the presence of uncertainty in the geometric and/or material properties of the system, an uncertainty analysis must be performed to obtain bounds on the structure‘s response.

C. PUSHOVER ANALYSIS

The pushover analysis of a structure is a static non-linear analysis under permanent vertical loads and gradually increasing lateral loads. The purpose of pushover analysis is to evaluate the expected performance of structural systems by estimating performance of a structural system by estimating its strength and deformation demands in design earthquakes by means of static inelastic analysis, and comparing these demands to available capacities at the performance levels of interest. A plot of the total base shear versus top displacement in a structure is obtained by this analysis that would indicate any premature failure or weakness. The analysis is carried out until failure, thus it enables determination of collapse load and ductility capacity. This type of analysis enables weakness in the structure to be identified. The decision to retrofit can be taken in such studies. The evaluation is

based on an assessment of important performance parameters, including global drift, inter-story drift, inelastic element deformations, deformations between elements, and element connection forces (for elements and connections that cannot sustain inelastic deformations), The inelastic static pushover analysis can be viewed as a method for predicting seismic force and deformation demands, which accounts in an approximate manner for the redistribution of internal forces that no longer can be resisted within the elastic
There are different methods followed for pushover analysis. Basically it has been classified into two ways are:

- **Force Control**

In force control, the structure is subjected to lateral forces and the displacements are calculated. There are so many ways of applying force on the structure. It was broadly classified in to two types. They are a) Fixed Load Distribution and b) Variable Load Distribution. In the Fixed load distribution, the load distribution is determined prior and remains unchanged during the pushover.

- **Displacement Control**

In displacement control, the structure is subjected to a displacement profile and the lateral forces are calculated. In the

1) PUSHOVER CURVE
After assigning all properties of the model, the displacement controlled pushover analysis of the building model is carried out. The models are pushed in monotonic increasing order in a particular direction till the collapse of the structure. The global response of structure at each displacement level is obtained in terms of the base shear, which is presented by pushover curve. Pushover curve is a base shear force versus roof displacement curve, which tells about the shear force developed at the base of the structure at any push level.

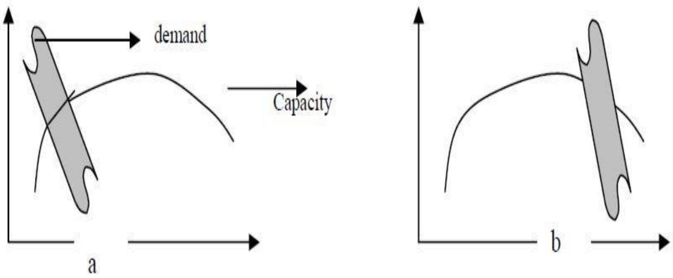

Fig. 3.1 Typical Seismic Demand versus Capacity (a) Safe Design; (b) Unsafe Design

The peak of this curve represents the maximum base shear, i.e. maximum load carrying capacity of the structure; the initial stiffness of the structure is obtained from the tangent at pushover curve at the load level of 10% that of the ultimate load and the maximum roof displacement of structures is taken that deflection beyond which collapse of structure takes place.

2) PERFORMANCE POINT
The seismic performance of a building can be evaluated in terms of pushover curve, performance point, displacement ductility, plastic hinge formation etc... This pushover capacity curve is transformed into capacity spectrum by ETABS as per ATC40 and demand or response spectrum is also determined for the structure depending upon the seismic zone, soil conditions and required building performance level. The intersection of demand and capacity spectrum at 5% damping gives the performance point of the structure analyzed

IV. Methodology

Following are the steps followed in the present study to carry out pushover analysis, design and performance study of concrete building
1. Create 3D model of concrete frame building.
2. Assign the corresponding section and loads for the beam and column.
3. Analysis has been carried out for both gravity, wind and earthquake loads.
4. Design has been carried out using ETABS itself, as per IS: 456-2000 provision.
5. Assign default hinge properties at assumed potential points (near beginning and ending of the element)

6. For column PMM hinge property has been assigned and for beam M3 hinge property has been assigned. These points will have pre-defined properties as per ATC-40.
7. Define non-linear/pushover cases, in which first case is force control and second case is displacement control.
8. For displacement control case, earthquake force is used to push the frame laterally upto maximum displacement (4% of building height).
9. Run the static non-linear analysis to get pushover curve.

V. Structural Aspects of Models

A. MATERIAL PROPERTIES

The material properties used for analysis is Reinforced concrete with M25 grade concrete and Fe-415 grade reinforcing steel. The Stress-Strain relationship used is as per I.S.456:2000. The basic material properties used are as follows:

Modulus of elasticity of steel, E_s=210000 MPa
Modulus of elasticity of concrete, E_c= 25000MPa
Characteristic strength of concrete, f_{ck}= 25 MPa
Yield stress for steel, f_y = 415 MPa

B. MATERIAL GEOMETRY

The selected case study buildings have 3:1 and 4:1 plan aspect ratios and are 5 stories in height. The plan dimensions of the 3:1 aspect ratio buildings are 18x54 m and 4:1 aspect ratio buildings have layout with twelve 6m bays, making the overall dimensions 18x72 m as shown in the floor plan in figure 5.1. End shear walls of 8m in length and 250mm in thick are provided in the central bay in the transverse direction. For all buildings the story height is 3.5 m. The thickness of the slab provided is 150mm. Table 5.1 provides the details of column and beam sections considered in the present work.

The gravity loads consisted of dead loads from member self-weight and a uniform 1.5 kN/m^2 partition load and a live load of 4 kN/m^2 at each floor. Design earthquake loads were determined using the Indian standard code IS: 1893-2002 (part 1) for the seismic zone V. The case study buildings were designed according to IS: 456-2000 and IS: 13920-1993. The imposed loads is taken by considering case study buildings as business and office buildings as per IS: 875-1987 (part 2). The wind loads are applied on the buildings as per IS: 875-1987 (part 3) by considering building belongs to a terrain category 3 and for basic wind speed of 50m/s.

C. DIAPHRAGM ASPECT RATIO

The diaphragm aspect ratio of 1:3 and 1:4 were chosen to investigate the applicability of various floor diaphragm type assumptions. The plan dimensions of the 3:1 aspect ratio buildings are 18x54 m and the 4:1 aspect ratio buildings have layout with twelve 6m bays, making the overall dimensions 18x72 m.

D. FLOOR OPENING LOCATION

Several scenarios of diaphragm opening locations are investigated: openings at the building, quarter points, and third points and in the center (more vulnerable to flexural yielding). Also, diaphragm openings locations placed symmetrically and non-symmetrically placed in the building (with respect to the centerline of the building plan as well as diaphragm cross-section) are investigated. Figure 5.4 and 5.5 shows the different opening locations in 1:3 and 1:4 aspect ratio building.

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Aspect ratio	Column section details		Beam section details	
	Storey 1, 2 and 3	Storey 4 and 5	Longitudinal direction	Transverse direction
1:3	650*650 mm	450*450 mm	230*450 mm	230*300 mm
1:4	650*650 mm	450*450 mm	230*450 mm	230*300 mm

Table 5.1 Section details

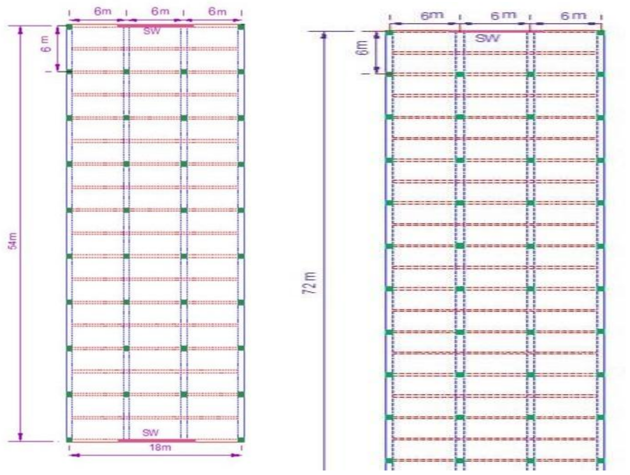

Figure 5.1: Plan of the building with Aspect Ratio 1:3 and 1:4

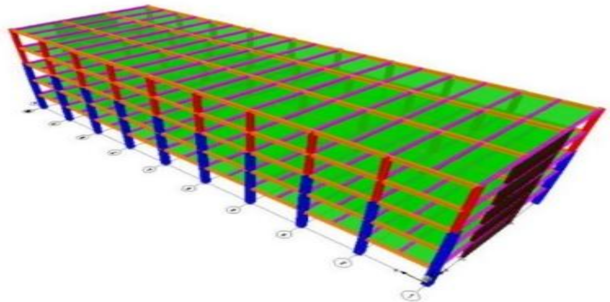
Fig 5.2: 3-D View of the 1:3 Aspect Ratio Building

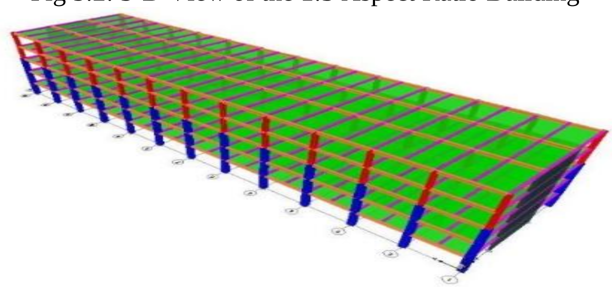
Fig 5.3: 3-D View of the 1:4 Aspect Ratio Building

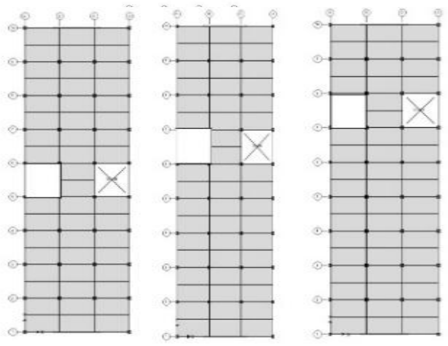

Figure 5.4 Opening Locations in 1:3 Aspect Ratio Building

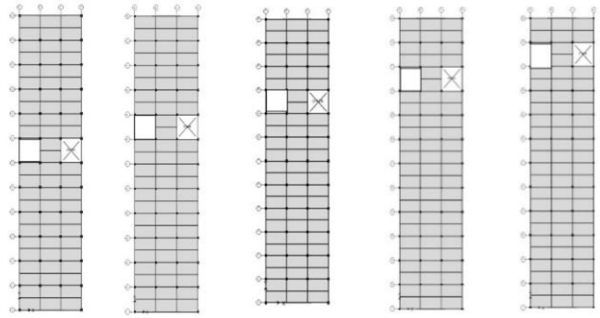

Figure. 5.5 Opening Locations in 1:4 Aspect Ratio Building

VI. Results and Discussion

A. GENERAL

ETABS software is used to compute the response of a five storey buildings for rigid and semi-rigid floor diaphragm conditions. Results from Response Spectrum analysis are observed for the Time period, Story shear, Diaphragm displacement, Story drift and Pier forces to determine the response of building for the rigid and semi-rigid diaphragm models. Results from push over analysis have been used to observe and compare the displacement of the buildings in the performance point and to compare the performance for the rigid and semi-rigid diaphragm buildings for both 1:3 and 1:4 aspect ratios.

B. RESPONSE SPECTRUM ANALYSIS

Results from push over analysis have been used to observe and compare the displacement of the buildings in the performance point and to compare the performance for the rigid and semi-rigid diaphragm buildings for both 1:3 and 1:4 aspect ratios.

1) ANALYSIS OF 1:3 ASPECT RATIO BUILDING

TIME PERIOD: The time required to complete one complete cycle of vibration is called time period. Under free vibration the structure always vibrates in single mode called its fundamental mode and the corresponding time period is called fundamental period of the structure. Figure 6.1, 6.2 and 6.3 shows the time period for the rigid and semi-rigid diaphragm models for the bare frame, time period for bare frame and frame with slab for semi-rigid diaphragm model and time period for bare frame and frame with slab for rigid diaphragm model respectively. Also figure 6.4 and 6.5 shows time period for rigid and semi-rigid diaphragm models for different opening locations.

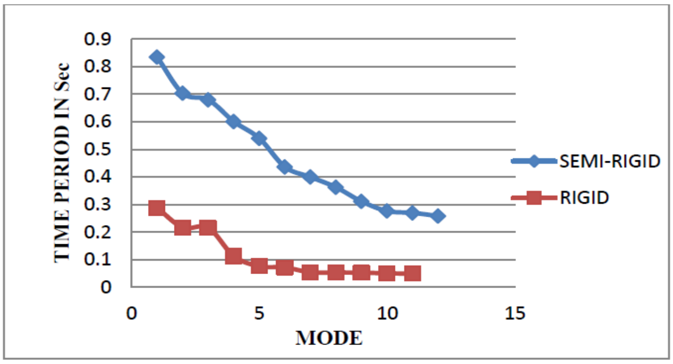

Figure 6.1 Time Period for Bare Frame Models

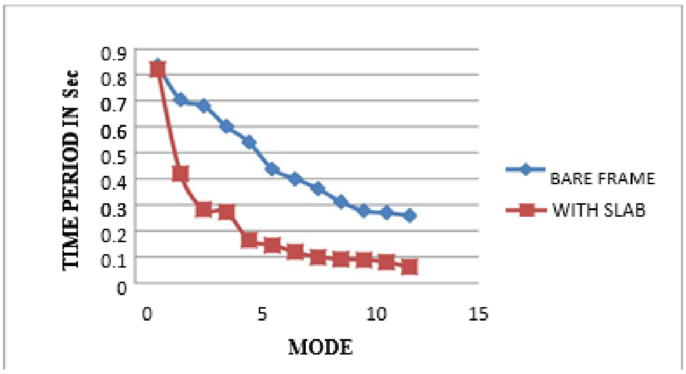

Figure 6.2 Time Period for Semi-Rigid Models

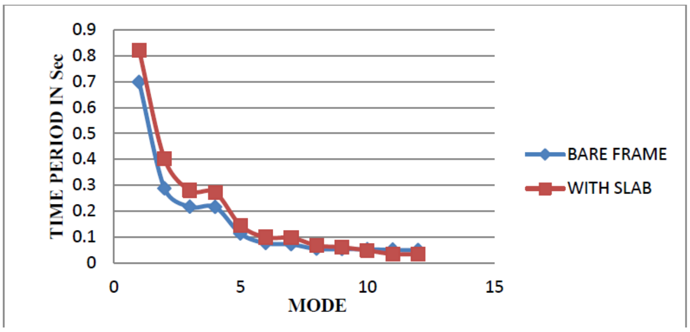

Figure 6.3 Time Period for Rigid Models

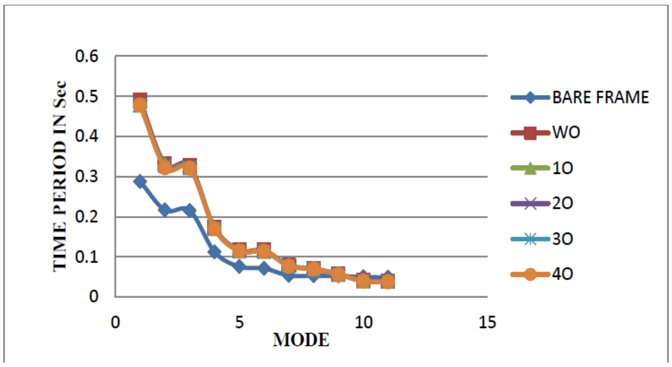

Figure 6.4 Time Period for Rigid Model for Different Openings

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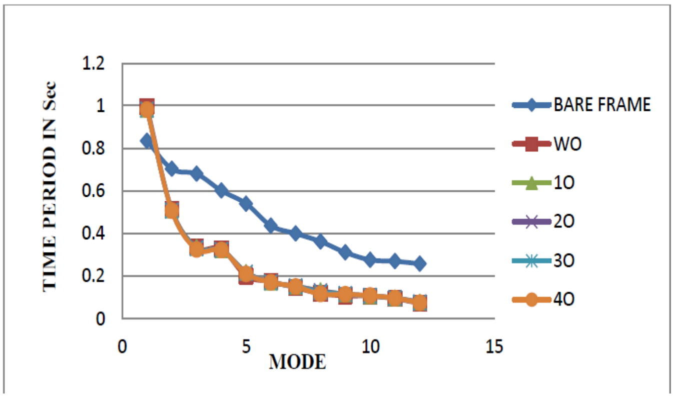

Figure 6.5 Time Period for Semi-Rigid Model for Different Openings

STORY SHEAR: The total design lateral force at the base of a structure is the base shear. The calculated base shear is then distributed to each Storey relative to its mass and stiffness. This distributed base shear at each level is known as Storey shears. Table 6.1 and 6.2 shows the distribution of story shear to the different stories in case of semi-rigid and rigid diaphragm models respectively.

Story	1	2	3	4	5
Bare Frame	2473.27	2323.27	1918.35	1382.27	649.31
WO	6505.77	6197.97	5387.82	4092.96	2202.24
1O	6195.24	5909.79	5142.92	3882.75	2059.01
2O	6195.24	5909.35	5142.2	3883.35	2060.56
3O	6195.24	5907.66	5139.47	3884.61	2065.05
4O	6195.24	5903.6	5133.07	3884.99	2071.82

Table 6.1: Storey shear distribution for semi-rigid models in kN

Story	**Bare Frame**	**WO**	**1O**	**2O**	**3O**	**4O**
5	611.09	2250.77	2127.35	2127.44	2127.71	2128.13
4	1397.79	4045.22	3841.78	3841.83	3841.98	3842.23
3	1943.47	5265.67	5008.18	5008.2	5008.26	5008.36
2	2313.09	6105.07	5811.74	5811.73	5811.74	5811.75
1	2473.28	6505.78	6195.24	6195.24	6195.24	6195.24

Table 6.2 Story Shear Distribution for Rigid models in kN

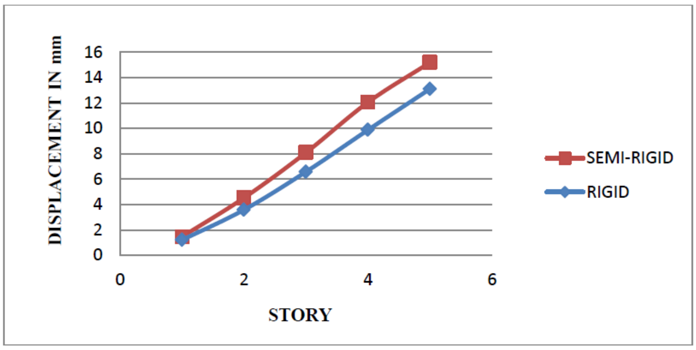

Figure 6.6 Diaphragm Displacements in Model with Slab

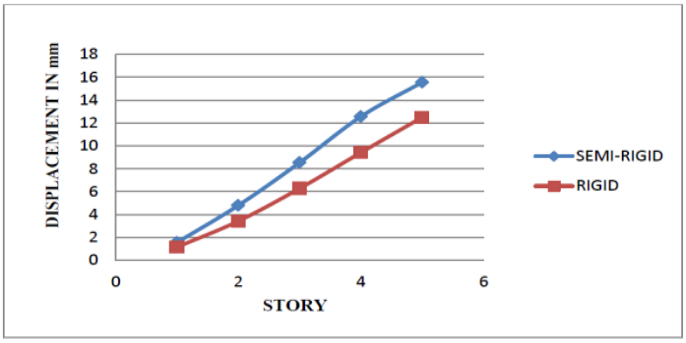

Figure 6.7 Diaphragm Displacements in Model with opening at 1

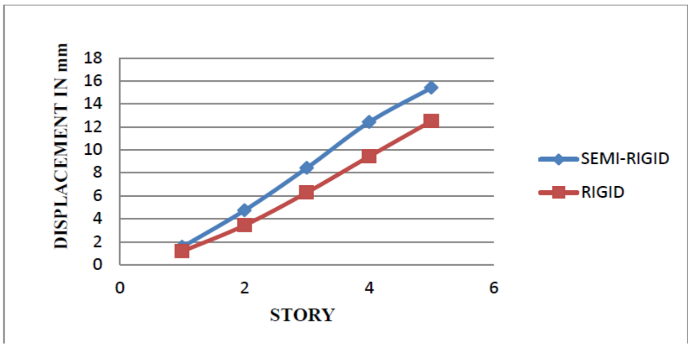

Figure 6.8 Diaphragm Displacements in Model with Opening at 2

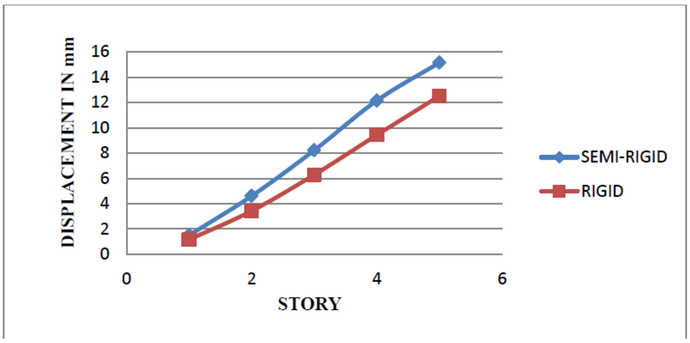

Figure 6.9 Diaphragm Displacements in Model with Opening at 3

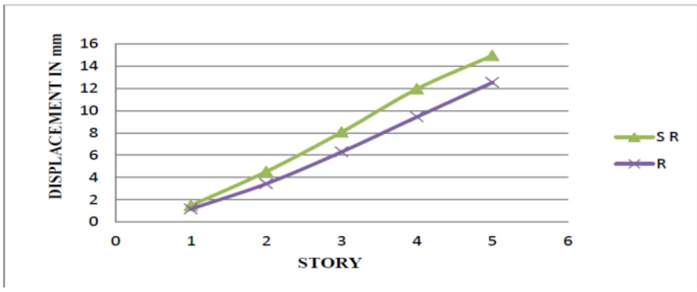

Figure 6.10 Diaphragm Displacements in Model with Opening at 4

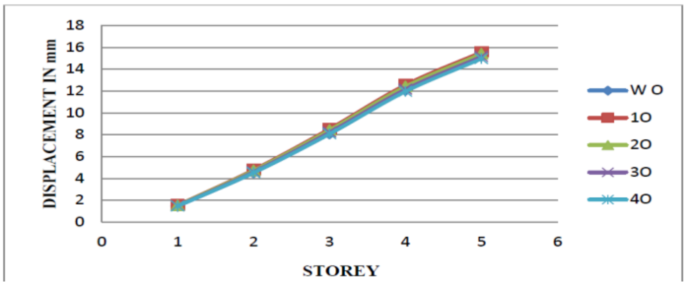

Figure 6.11 Displacements in Semi-Rigid Models with Different Opening Locations

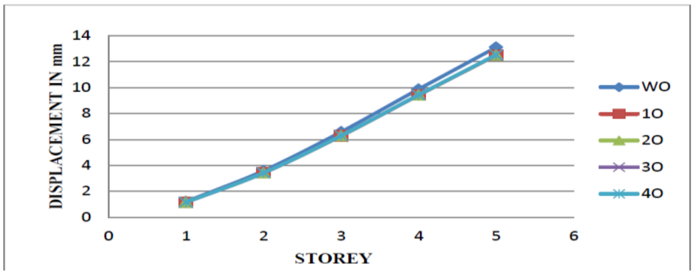

Figure 6.12 Displacements in Rigid Models with Different Opening Locations

From the above figures it is cleared that, the presence of slab can reduces the diaphragm displacement upto 86% in case of semi-rigid model, but in case of rigid model the presence of slab can increases the displacement upto a 44% compared to the model without slab.

STORY DRIFTS: Storey drift is defined as difference between lateral displacements of one floor relative to the other floor. Total building drift is the absolute displacement of any point relative to the base. As per IS:1893-2002 the storey drift in any storey due to the minimum specified design lateral force with partial load factor 1.00 shall not exceed 0.004 times the storey height. Figure 6.13 and 6.14 shows the story drifts for the models without slab and with slab in case of both semi-rigid and rigid cases. Figure 6.15, 6.16, 6.17, 6.18, 6.19 and 6.20 shows the story drifts for the rigid and semi-rigid diaphragm cases for bare frame model, model without opening, openings at 1, 2, 3 and 4 respectively. Also figure 6.21 and 6.22 summarises the effect of openings on story drifts in case of semi-rigid and rigid models.

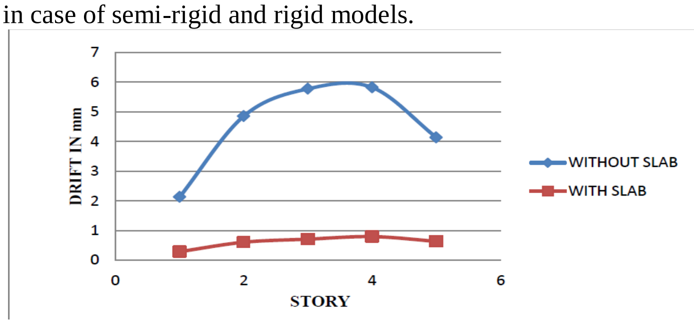

Figure 6.13 Story Drifts in Semi-Rigid Models

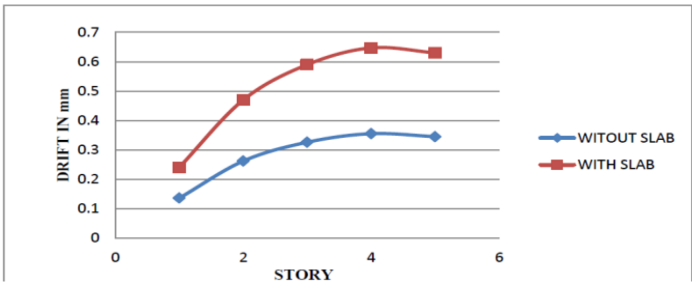

Figure 6.14 Story Drifts in Rigid Models

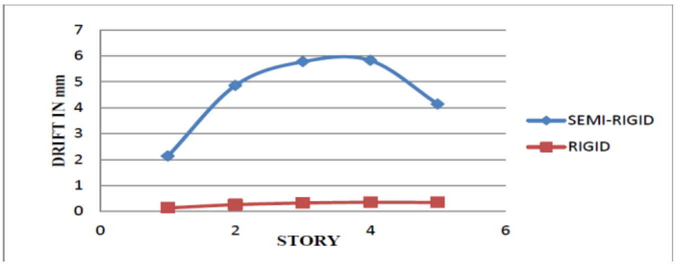

Figure 6.15 Story Drifts in Bare Frame Model

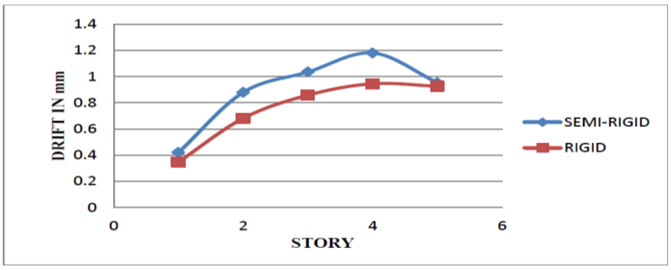

Figure 6.16 Story Drifts in Model without Opening

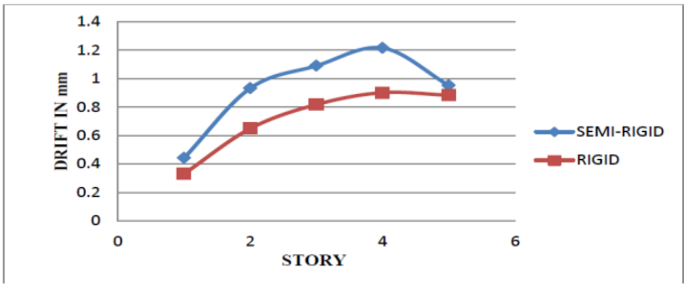

Figure 6.17 Story Drifts in Model with Openings at 1

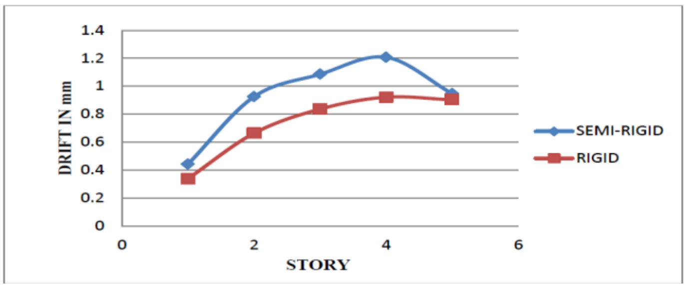

Figure 6.18 Story Drifts in Model with Openings at 2

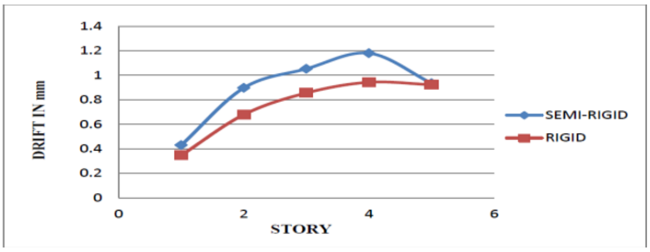

Figure 6.19 Story Drifts in Model with Openings at 3

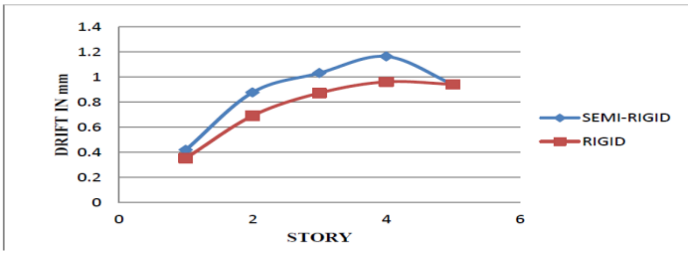

Figure 6.20 Story Drifts in Model with Openings at 4

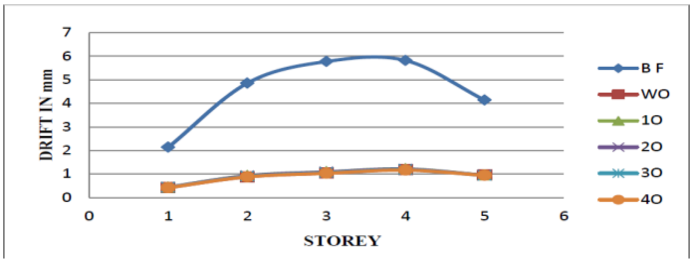

Figure 6.21 Story Drifts in Semi-Rigid Buildings with Different Opening Locations

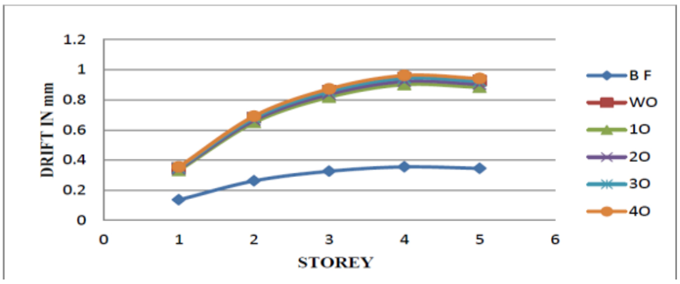

Figure 6.22 Story Drifts in Rigid Buildings with Different Opening Locations

Here also presence of slab in case of semi-rigid model can significantly reduce the story drifts. A drift upto 84% can be reduced by the slab. But in case of rigid model it is reversed, story drift upto 45% can be increased by the roof slab.

FRAME DISPLACEMENTS: The frame displacements under lateral loads for both rigid and semi-rigid models are illustrated in the table below.

Type of Building	Semi-Rigid	Rigid	% Difference
BF	76.86	4.97	93.53
WO	15.16	13.11	13.5
1O	15.46	12.5	17.3
2O	15.47	12.5	19.2
3O	15.12	12.5	17.3
4O	14.92	12.5	16.2

Table 6.3 Maximum Frame Displacements in mm

Table 6.3 shows that displacements of frames in case of semi-rigid models are higher in all cases. In case of bare frame model the displacement difference is upto 93%, and in other cases it's about 19%. From this it is cleared that the diaphragm can reduces the displacement about 79% in case 1:3 aspect ratio semi-rigid building and increases displacement upto 62% in case rigid diaphragm model.

FORCE DISTRIBUTION TO END SHEAR WALL: The shear walls are modelled as pier sections in the analysis. The lateral loads distributed to the pier sections are tabulated in the table 6.4 and 6.5 for the semi-rigid and rigid models. The lateral loads are distributed based on the stiffness of the sections.

1	2	3	4	5	**Story**
232.7	229.23	201	147.9	76.53	**Bare Frame**
2810.3	2783.17	2353.22	1788.19	843.94	**WO**
2663.16	2640.43	2237.26	1691.33	794.35	**1O**
2714.3	2690.98	2279.37	1724.71	808.82	**2O**
2765.7	2741.2	2321.04	1757.95	824.24	**3O**
2808.02	2782.21	2354.87	1785.13	837.78	**4O**

Table 6.4 Pier Force Distribution in kN for Semi-Rigid Diaphragm Buildings

1	2	3	4	5	**Story**
1066.86	1115.88	885.77	660.68	248.24	**Bare Frame**
2793.65	2868.55	2278.71	1852.32	856.47	**WO**
2663.07	2736.56	2176.13	1763.99	816.19	**1O**
2726.87	2798.31	2226.46	1804.84	836.24	**2O**
2788.78	2858.2	2275.24	1844.48	855.7	**3O**
2846.81	2914.29	2320.92	1881.66	874	**4O**

Table 6.5Pier Force Distributions in Bare Frame

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2) ANALYSIS OF 1:4 ASPECT RATIO BUILDING

TIME PERIOD: Table 6.6 provides fundamental time periods for the rigid and semi-rigid diaphragm models for different openings. Figure 6.23, 6.24 and 6.25 shows the time period for the rigid and semi-rigid diaphragm cases for the bare frame model, time period for bare frame and frame with slab for semi-rigid diaphragm case and time period for bare frame and frame with slab for rigid diaphragm case respectively. Also figure 6.26 and 6.27 shows time period for rigid and semi-rigid diaphragm models for different opening locations.

Types of model	Rigid	Semi-Rigid
Bare Frame	0.680993	0.867829
WO	0.990014	0.990123
1O	0.978488	0.978597
2O	0.978488	0.978598
3O	0.978488	0.978602
4O	0.978488	0.97861
5O	0.978472	0.978609

Table 6.6 Fundamental Time Periods in Seconds

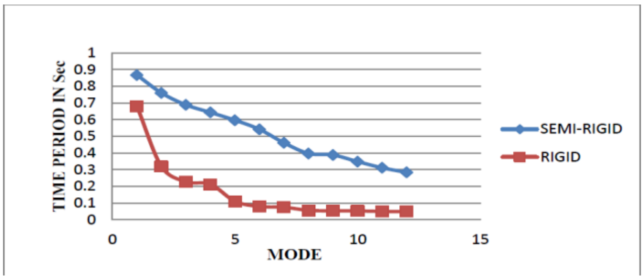

Figure 6.23 Time Period for Bare Frame Models

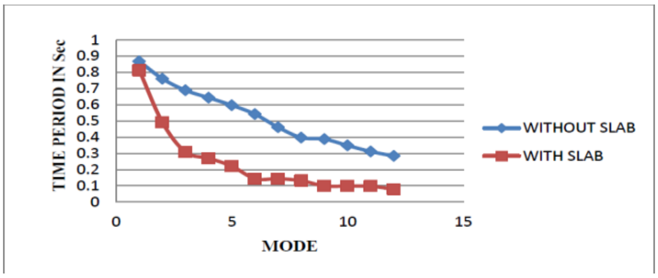

Figure 6.24 Time Period for Semi-Rigid Models

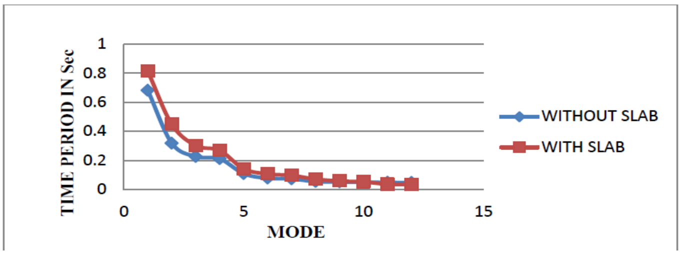

Figure 6.25 Time Period for Rigid Models

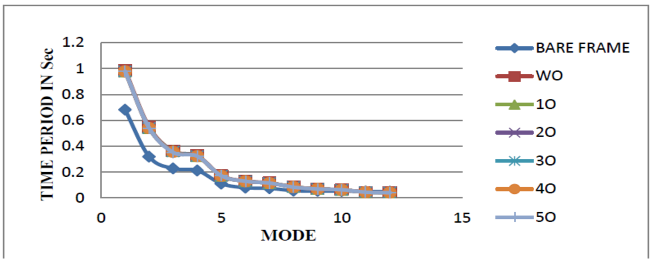

Figure 6.26 Time Period for Rigid Model for Different Openings

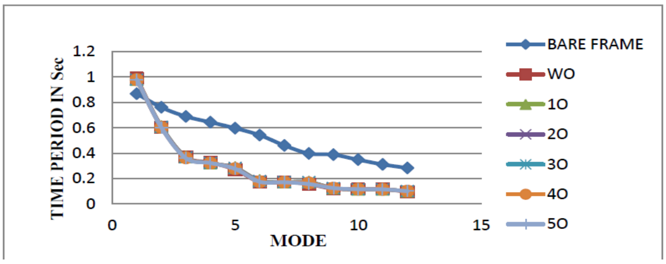

Figure 6.27 Time Period for Semi-Rigid Model for Different Openings

STORY SHEAR: Table 6.7 and 6.8 shows the distribution of story shear to the different stories in case of semi-rigid and rigid diaphragm models respectively

Story	Bare Frame	WO	1O	2O	3O	4O	5O
1	689.62	2857.68	2695.69	2696.52	2706.87	2724.27	2730.13
2	1732.84	5321.06	5099.28	5097.77	5089.13	5102	5108.32
3	2519.32	7041.46	6784.89	6780.19	6761.9	6774.69	6777.76
4	2987.57	8102.69	7818.38	7816.86	7804.38	7804.08	7805.89
5	3131.17	8507.85	8197.3	8197.3	8197.3	8197.3	8197.3

Table 6.7 Story Shear Distribution for Semi-Rigid models in kN

Story	Bare Frame	WO	1O	2O	3O	4O	5O
1	777.07	2957.95	2834.72	2834.79	2834.93	2835.14	2835.39
2	1764.44	5296.86	5093.54	5093.58	5093.66	5093.78	5093.93
3	2449.42	6893.48	6635.87	6635.88	6635.92	6635.96	6636.03
4	2923.36	7988.92	7695.48	7695.48	7695.48	7695.49	7695.49
5	3131.18	8507.85	8197.3	8197.3	8197.3	8197.3	8197.31

Table 6.8 Story Shear Distribution for Rigid models in kN

In both rigid and semi-rigid diaphragm models openings at different locations can alter the story shear distribution only upto 1.2%. But when compared to rigid and semi-rigid models the distribution of story shear can varied upto 4.9%.

DIAPHRAGM DISPLACEMENT: Figure 6.28 and 6.29 shows the diaphragm displacement in case of semi-rigid and rigid model for the models without slab and with slab. Figure 6.30, 6.31, 6.32, 6.33, 6.34, 6.35 and 6.36 shows the diaphragm displacement for the rigid and semi-rigid diaphragm cases for bare frame model, model without opening, openings, openings at location 1, 2, 3, 4 and 5 respectively. Also figure 6.37 and 6.38 summarises the effect of openings at different locations in case of semi-rigid and rigid models.

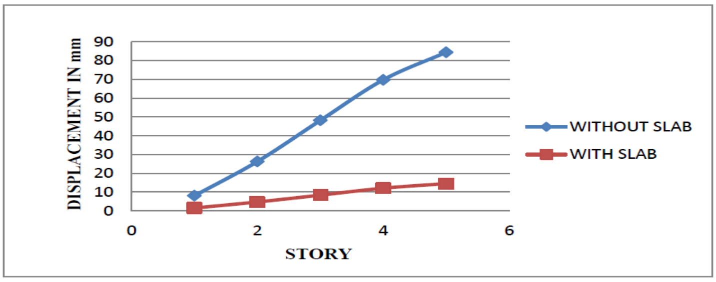

Figure 6.28 Diaphragm Displacements in Semi-Rigid Building

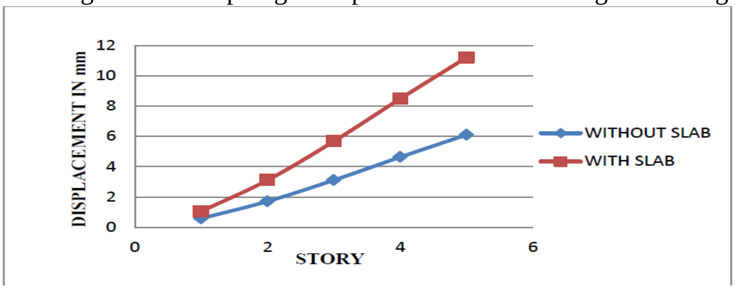

Figure 6.29 Diaphragm Displacements in Rigid Building

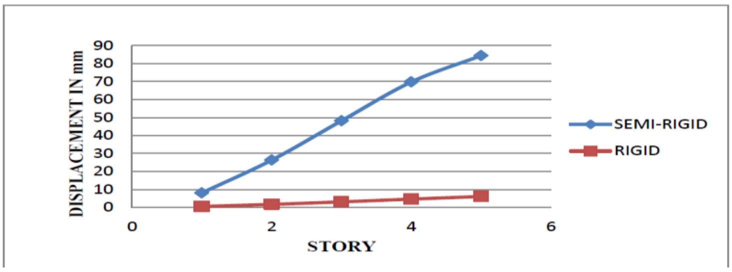

Figure 6.30 Diaphragm Displacements in Bare Frame

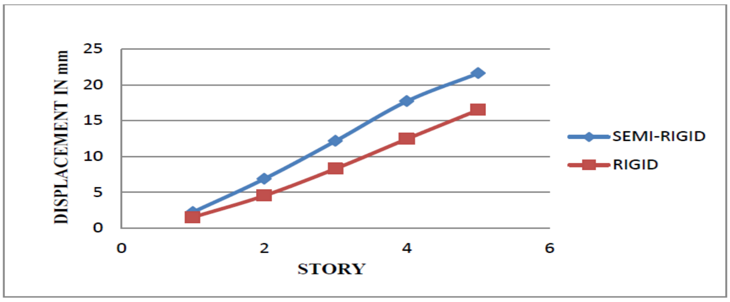

Figure 6.31 Diaphragm Displacements in Model without Opening

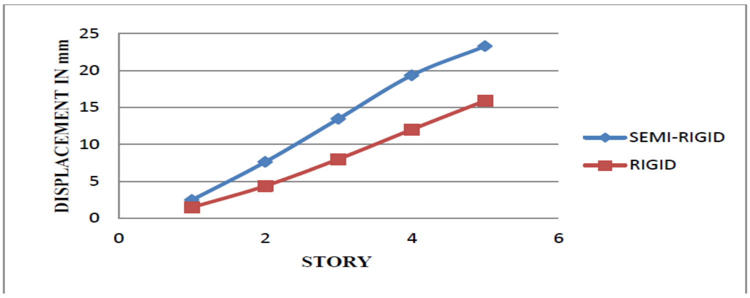

Figure 6.32 Diaphragm Displacements in Model with Openings at 1

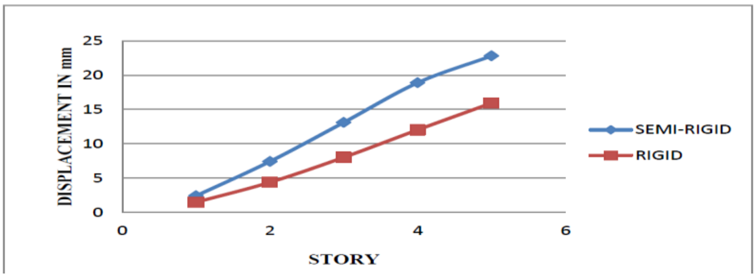

Figure 6.33 Diaphragm Displacements in Model with Openings at 2

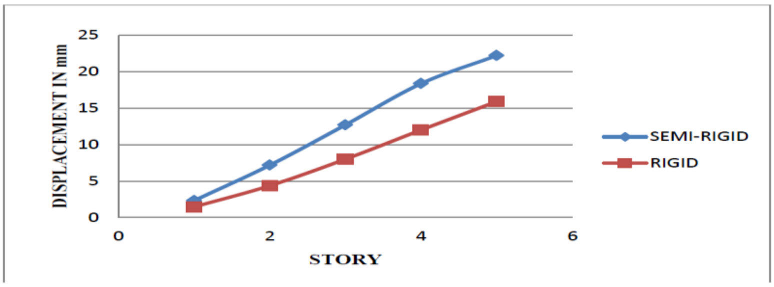

Figure 6.34 Diaphragm Displacements in Model with Openings at 3

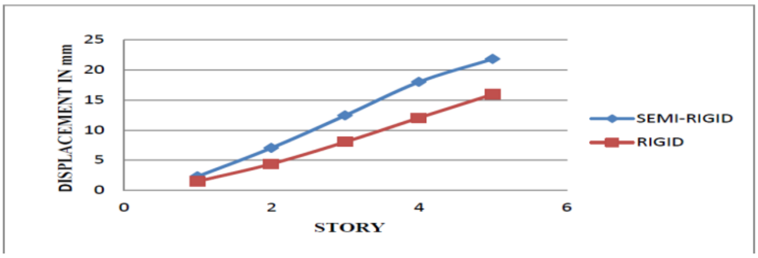

Figure 6.35 Diaphragm Displacements in Model with Openings at 4

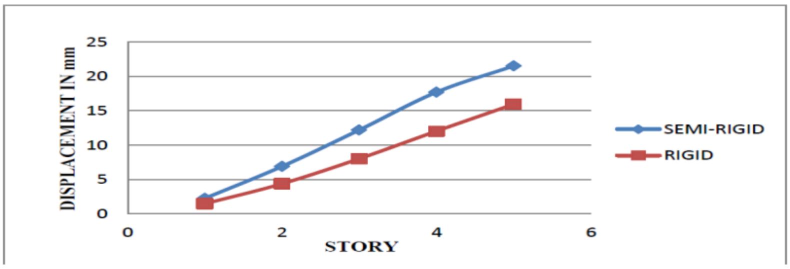

Figure 6.36 Diaphragm Displacements in Model with Openings at 5

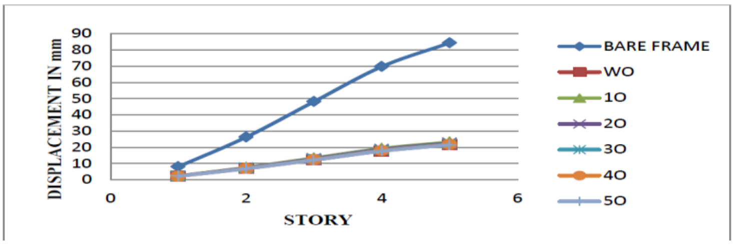

Figure 6.37 Displacements in Semi-Rigid Models with Different Opening Locations

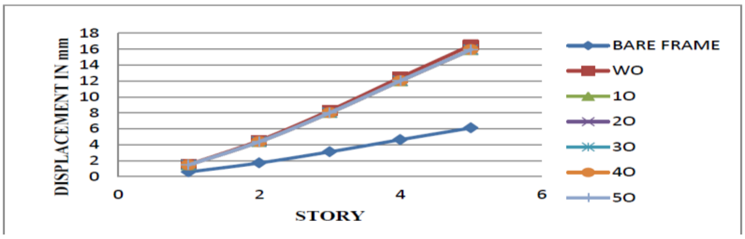

Figure 6.38 Displacements in Rigid Models with Different Opening Locations

From the above figures it is clear that the diaphragm can reduces the displacements upto 83% in case of semi-rigid model, but in case of rigid model the diaphragm can increases the displacement upto an 45%.

STORY DRIFTS: Figure 6.39 and 6.40 shows the story drifts for the model without slab and with slab in case of semi-rigid and rigid diaphragms. Figure 6.41, 6.42, 6.43, 6.44, 6.45, 6.46 and 6.47 shows the story drifts for the rigid and semi-rigid diaphragm models for bare frame model, model without opening, openings at 1, 2, 3, 4 and 5 respectively. Also figure 6.48 and 6.49 summarises the effect of openings on story drifts at different locations in case of semi-rigid and rigid models.

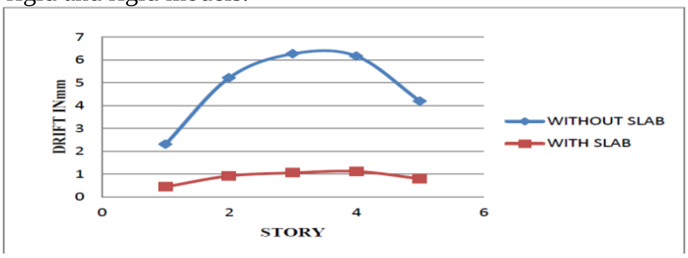

Figure 6.39 Story Drifts in Semi-Rigid Models

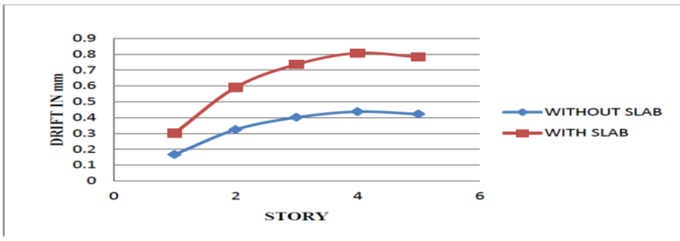

Figure 6.40 Story Drifts in Rigid Models

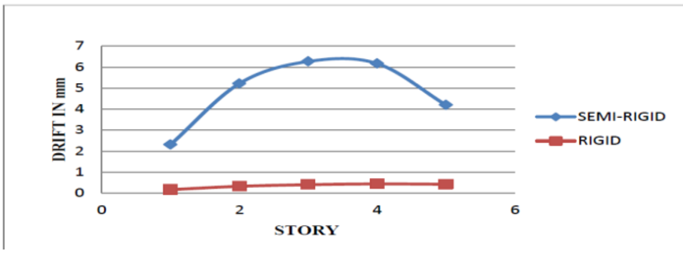

Figure 6.41 Story Drifts in Bare Frame Model

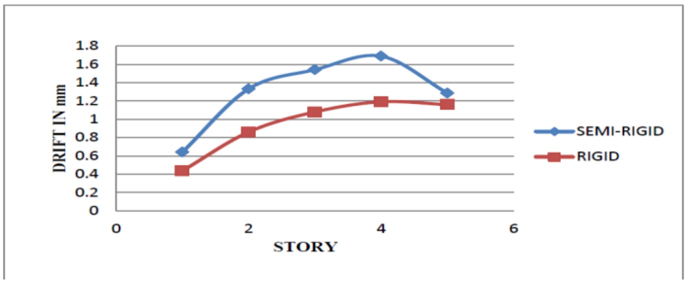

Figure 6.42 Story Drifts in Model without Opening

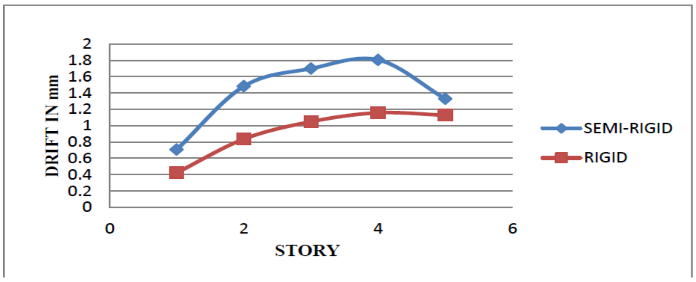

Figure 6.43 Story Drifts in Model with Openings at 1

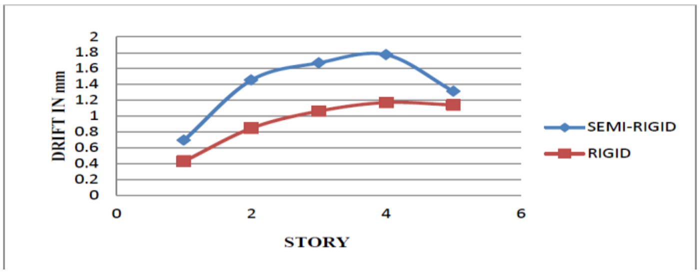

Figure 6.44 Story Drifts in Model with Openings at 2

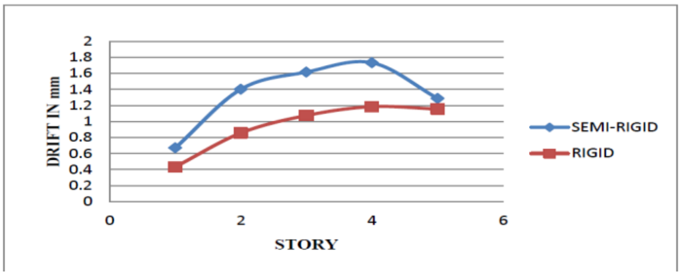

Figure 6.45 Story Drifts in Model with Openings at 3

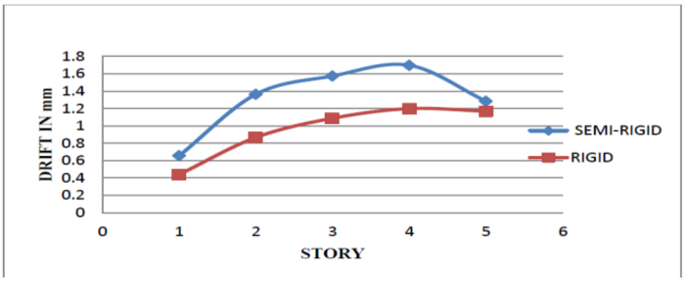

Figure 6.46 Story Drifts in Model with Openings at 4

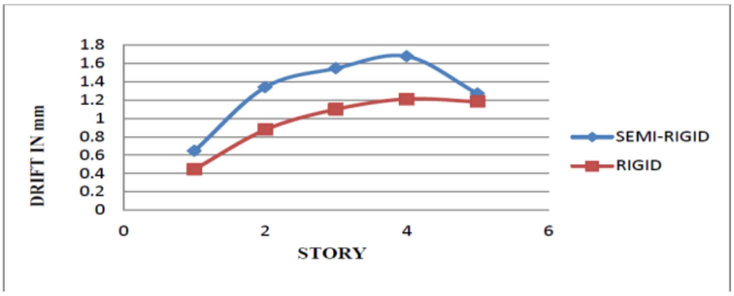

Figure 6.47 Story Drifts in Model with Openings at 5

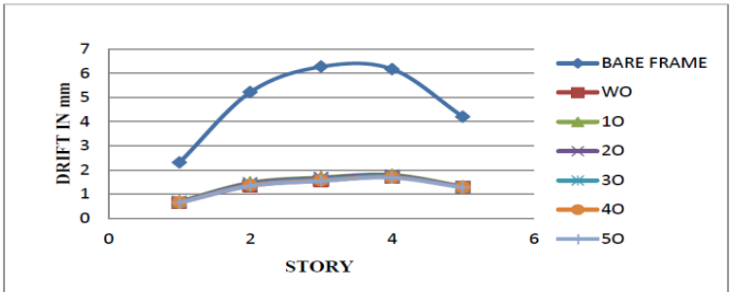

Figure 6.48 Story Drifts in Semi-Rigid Buildings with Different Opening Locations

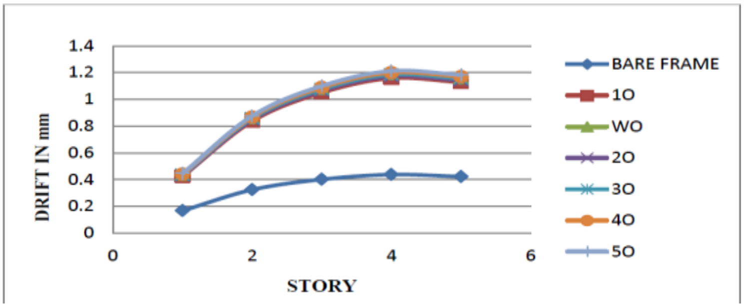

Figure 6.49 Story Drifts in Rigid Buildings with Different Opening Locations

FORCE DISTRIBUTION TO END SHEAR WALL: The shear walls are modelled as pier sections in the analysis. The lateral loads distributed to the pier sections are tabulated in the table 6.9 and 6.10 for the semi-rigid and rigid models. The lateral loads are distributed based on the stiffness of the sections, figure 6.50 shows the lateral force distribution for the bare frame model in case of both rigid and semi-rigid models.

Story	Bare Frame	WO	1O	2O	3O	4O	5O
1	297.23	1037.69	1009.24	1022.73	1035.98	1048.79	1061.1
2	818.38	2359.64	2289.26	2317.54	2345.3	2372.18	2397.9
3	1087.67	2862.7	2783.72	2818.19	2852	2884.71	2915.97
4	1387.68	3669.45	3563.43	3606.23	3648.23	3688.88	3727.73
5	1296.16	3496.56	3394.41	3438.37	3481.54	3523.34	3563.31

Table 6.9 Pier Force Distribution in kN for Rigid Diaphragm Buildings

Story	Bare Frame	WO	1O	2O	3O	4O	5O
1	67.2	1017.18	966.21	961.31	956.02	952.25	950.03
2	130.13	2173.82	2062.54	2047.45	2028.62	2015.51	2003.67
3	177	2889.91	2743.89	2725.26	2701.88	2687.17	2676.4
4	201.85	3416.51	3238.59	3216.47	3189.56	3169.48	3153.03
5	204.88	3445.11	3262.3	3240.62	3215.52	3196.15	3183.58

Table 6.10: Pier Force Distribution in kN for Semi-Rigid Diaphragm Buildings

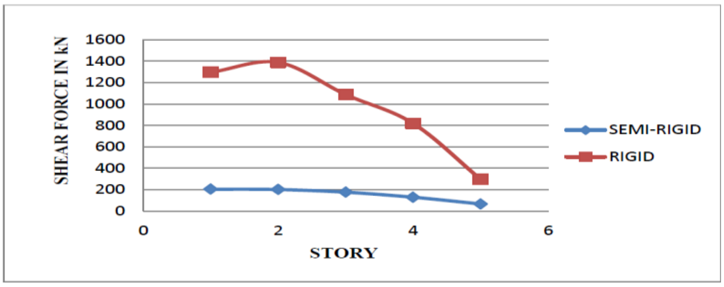

Figure 6.50 Pier Force Distributions in Bare Frame

The force distribution to the pier sections in case of rigid models is slight higher than the semi-rigid models. As the opening location moves towards the pier section, load distribution to that section can increase slightly. From the above Figure 6.50 it is clear that, in case rigid diaphragm bare frame model force distribution to the pier section is very higher compared to semi-rigid model. Shear force upto 1296 kN is assigned to the first story shear wall for rigid model and about 204 kN is assigned in case of semi-rigid model. In case of bare frame model the distribution percentage is varied upto 84%. The diaphragm can reduces this variation in higher order. As the plan aspect ratio increases, pier force distribution percentage also increases.

C. PUSHOVER ANALYSIS RESULTS

In the present work, a five storey, 1:3 and 1:4 aspect ratio buildings are considered for the analysis purpose. Initially, buildings are analyzed and designed as per IS: 456 - 2000 provisions in ETABS. Further, pushover analysis is carried out using ETABS. The default hinge properties available in ETABS as per ATC-40 are used to assign hinge properties. Hinges are considered at both the ends of beam and column elements.

1) RESULTS OF 1:3 ASPECT RATIO BUILDINGS

Figure 6.51 presents the pushover curves for semi-rigid diaphragm models for seismic zone V of India for Maximum Credible Earthquake (MCE) for different opening locations. Base shear carried is plotted along the vertical axis and roof displacement experienced is plotted along the horizontal axis. Here it is observed that buildings with openings have not decreases performance level significantly, and it can also be seen that the building with slab have lesser vulnerability compared to the buildings without slab. Figure 6.52 shows the pushover curves for rigid diaphragm models for different opening locations. Here also openings do not alter the performance level significantly. The curves are initially linear, but when the building is pushed well into the inelastic range, the curves become linear again. The curves could be approximated by a linear relationship.Figure 6.53 and 6.54 shows the pushover curves for the model with slab and without slab for both semi-rigid and rigid cases.

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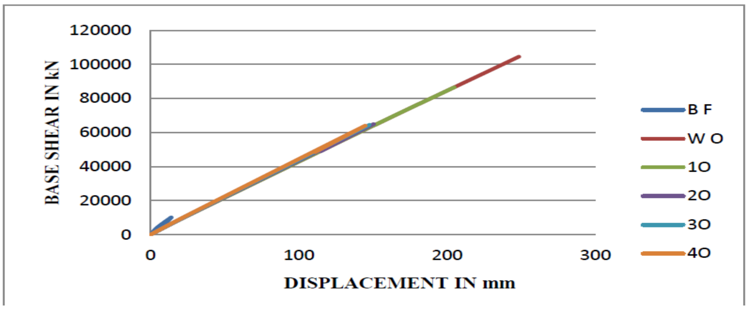

Figure 6.51 Pushover Curves for Different Opening Cases in Semi-Rigid Model

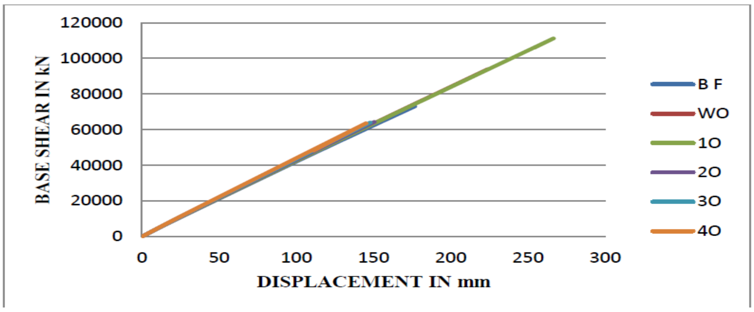

Figure 6.52 Pushover Curves for Different Opening Cases in Rigid Model

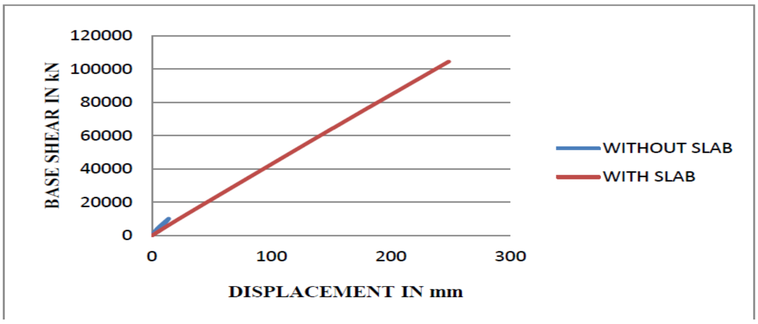

Figure 6.53 Pushover Curves for Semi-Rigid Case

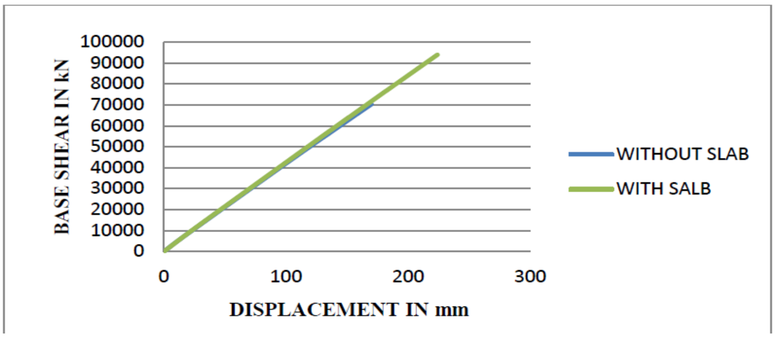

Figure 6.54 Pushover Curves for Rigid Case

Figure 6.55, 6.56, 6.57, 6.58, 6.59 and 6.60 presents pushover curves between rigid and semi-rigid diaphragm models for different opening cases namely bare frame, without opening and openings at location 1, 2, 3 and 4 respectively. From the below figures it can observed that performance of rigid diaphragm models are higher. The rigid diaphragm assumption in case bare frame model increases the base shear carrying capacity significantly. Table 6.11 and 6.12 gives the base shears and corresponding displacements for different models at performance point for semi-rigid and rigid cases.

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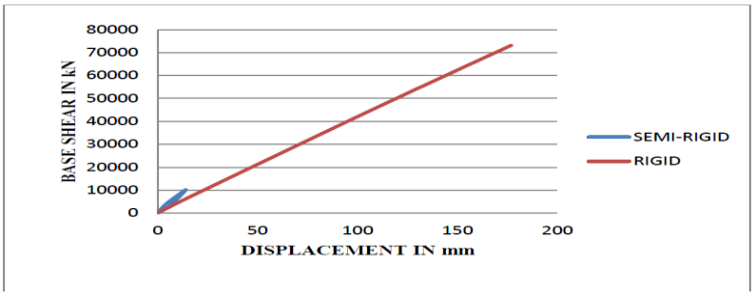

Figure 6.55 Pushover Curves for Bare Frames

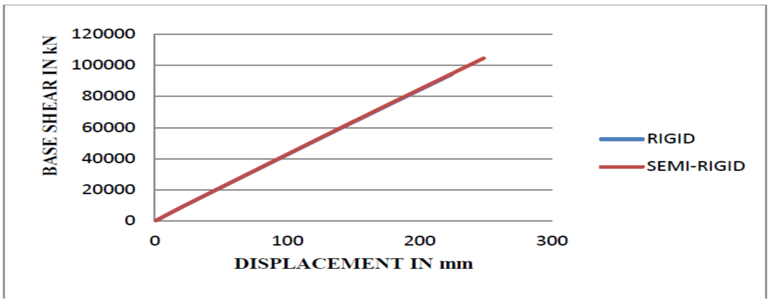

Figure 6.56 Pushover Curves for Models without Opening

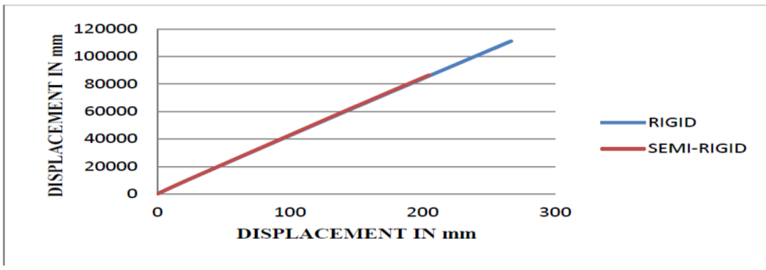

Figure 6.57 Pushover Curves for Models with opening at 1

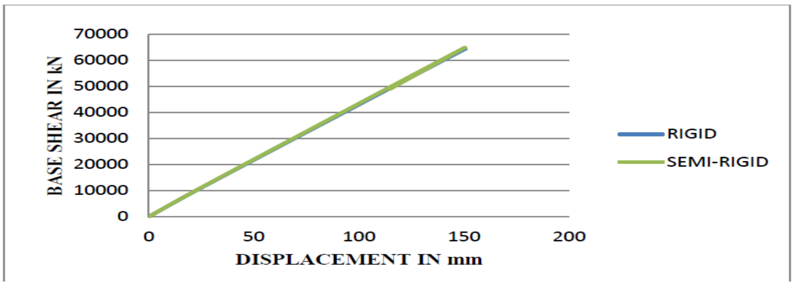

Figure 6.58 Pushover Curves for Models with Openings at 2

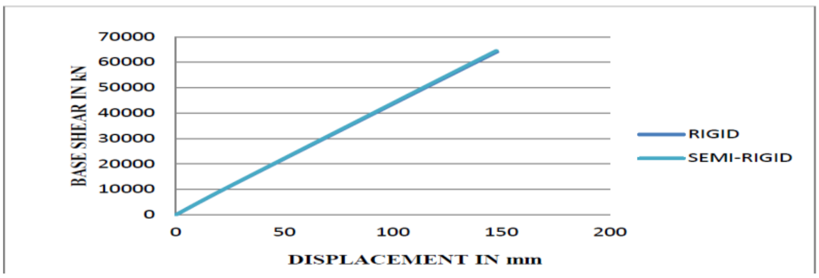

Figure 6.59 Pushover Curves for Models with Openings at 3

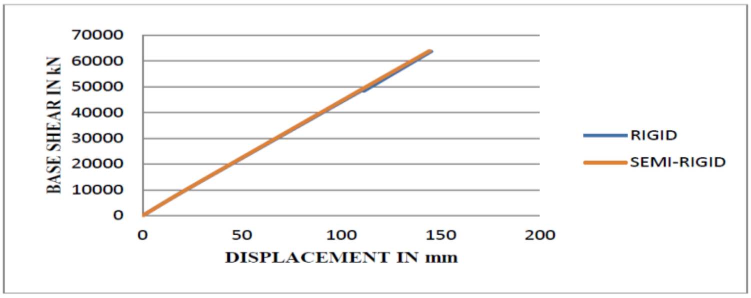

Figure 6.60 Pushover Curves for Models with Openings At 4

SL.NO	Type Of Model	Base Shear in kN	Displacement in mm
1	Bare Frame	5557.601	6.736
2	WO	34888.737	81.179
3	1O	33046.918	76.779
4	2O	34932.064	80.23
5	3O	33078.826	75.009
6	4O	33105.812	74.174

Table 6.11 Base Shear and Displacements at Performance Point for Semi-Rigid Models

SL.NO	Type of Model	Base Shear in kN	Displacement in mm
1	Bare Frame	13189.946	30.764
2	WO	35220.51	82.523
3	1O	33486.769	78.567
4	2O	33488.655	77.624
5	3O	33488.806	76.672
6	4O	33493.086	75.726

Table 6.12 Base Shear and Displacements at Performance Point for Rigid Models

2) RESULTS OF 1:4 ASPECT RATIO BUILDINGS

Figure 6.61 presents the pushover curves for semi-rigid diaphragm models for seismic zone V of India for Maximum Credible Earthquake (MCE) for different opening locations. Base shear carried is plotted along the vertical axis and roof displacement experienced is plotted along the horizontal axis. Here it is observed that buildings with openings have not decreases performance level significantly, and it can also be seen that the building with slab have lesser vulnerability compared to the buildings without slab. Figure 6.62 shows the pushover curves for rigid diaphragm models for different opening locations. Here also openings do not alter the performance level significantly. The curves are initially linear, but when the building is pushed well into the inelastic range, the curves become linear again. The curves could be approximated by a linear relationship. Figure 6.63 and 6.64 shows the pushover curves for the model with slab and without slab for both semi-rigid and rigid cases.

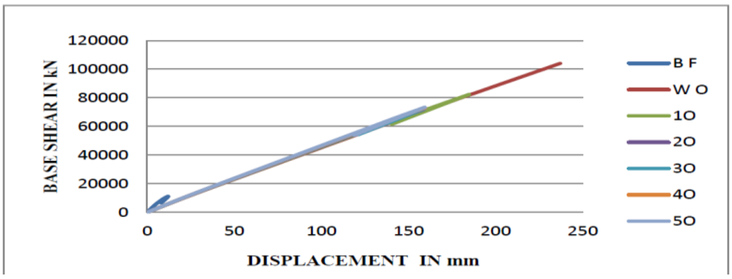

Figure 6.61 Pushover Curves for Different Opening Cases in Semi-Rigid Model

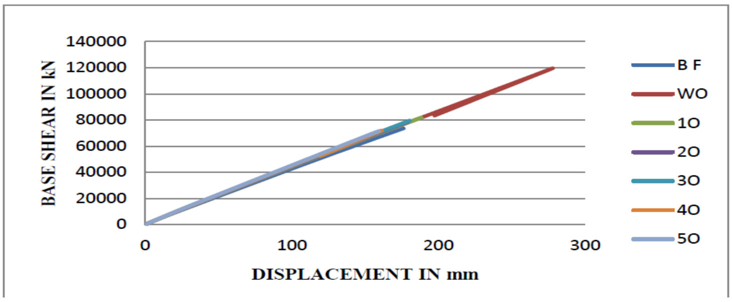

Figure 6.62 Pushover Curves for Different Opening Cases in Rigid Model

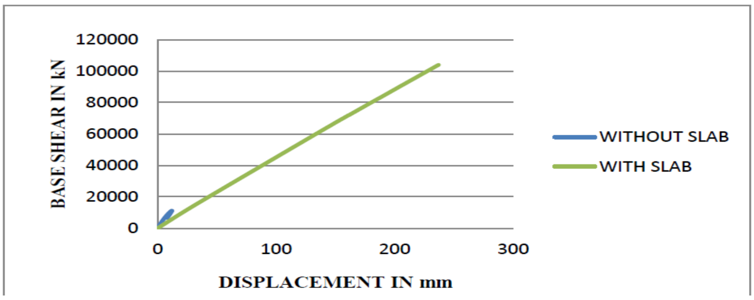

Figure 6.63 Pushover Curves for Semi-Rigid Case

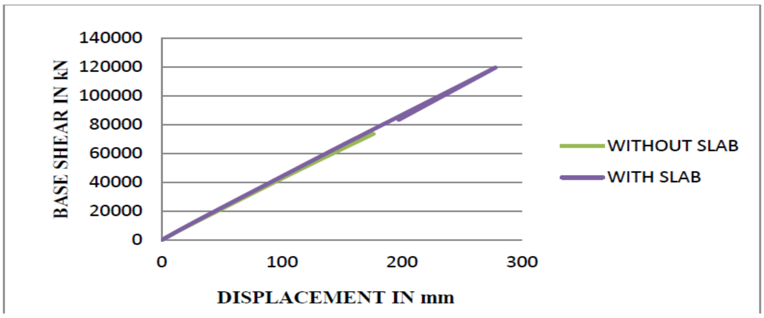

Figure 6.64 Pushover Curves for Rigid Case

Figure 6.65, 6.66, 6.67, 6.68, 6.69, 6.70 and 6.71 presents pushover curves between rigid and semi-rigid diaphragm models for different opening cases namely bare frame, without opening, and openings at location 1, 2, 3, 4 and 5 respectively. From the below figures it can observed that performance of rigid diaphragm models are higher. The rigid diaphragm assumption in case bare frame model increases the base shear carrying capacity. Table 6.13 and 6.14 gives the base shears and corresponding displacements for different models at performance point for semi-rigid and rigid cases.

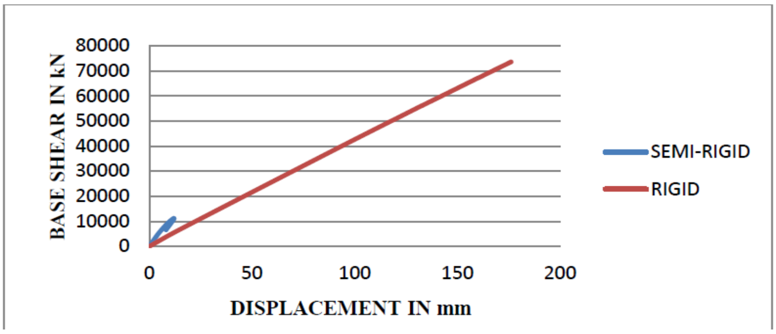

Figure 6.65 Pushover Curves for Bare Frames

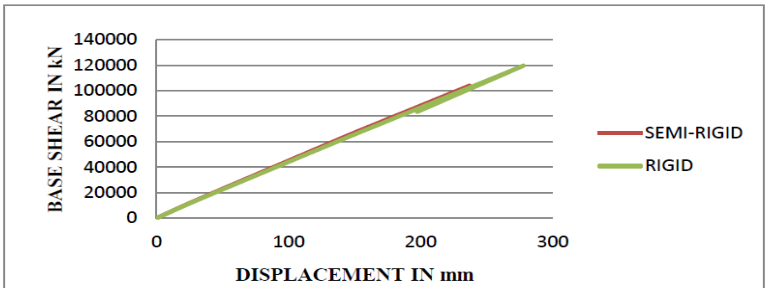

Figure 6.66 Pushover Curves for Models without Opening

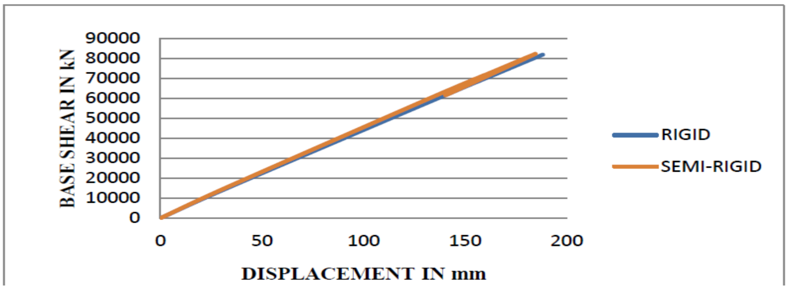

Figure 6.67 Pushover Curves for Models with Openings at 1

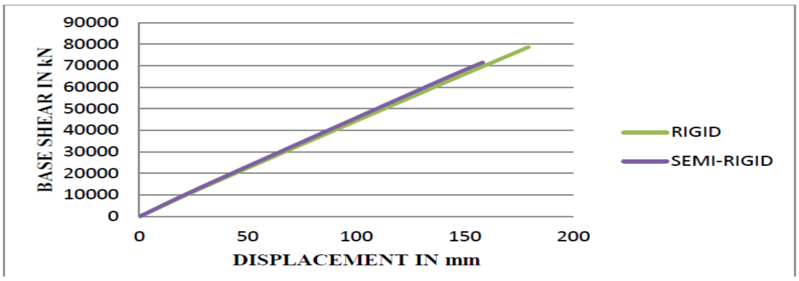

Figure 6.68 Pushover Curves for Models with Openings at 2

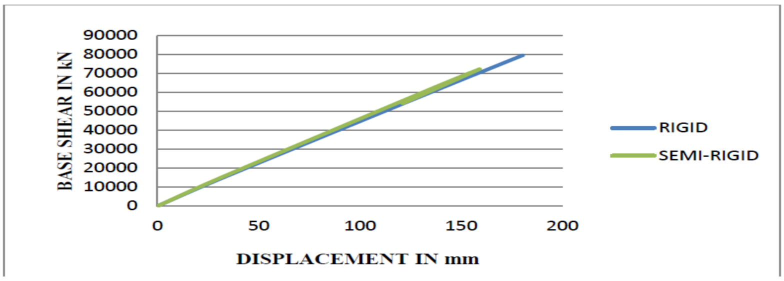

Figure 6.69 Pushover Curves for Models with Openings at 3

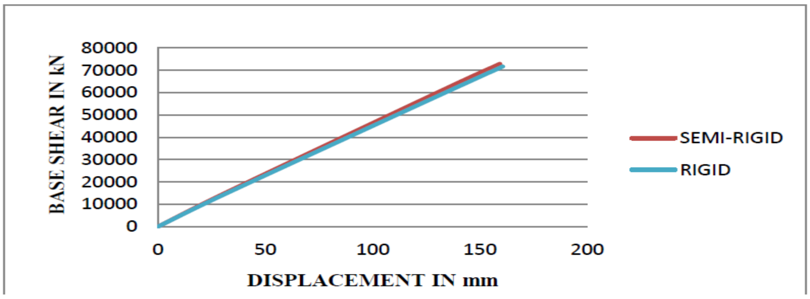

Figure 6.70 Pushover Curves for Models with Openings at 4

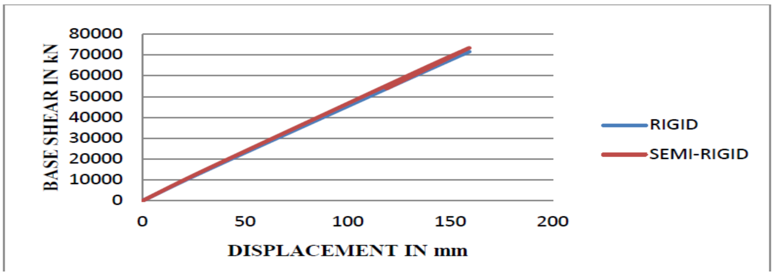

Figure 6.71 Pushover Curves for Models with Openings at 5

SL.NO	Type of Model	Base Shear in kN	Displacement in mm
1	BARE FRAME	7220.053	6.76
2	WO	40214.98	88.925
3	1O	38171.392	83.56
4	2O	38278.25	83.25
5	3O	38448.842	83.123
6	4O	38642.002	83.064
7	5O	38786.293	82.88

Table 6.13 Base Shear and Displacements at Performance Point for Semi-Rigid Models

SL.NO	Type of Model	Base Shear in kN	Displacement in mm
1	BARE FRAME	16551.451	38.074
2	WO	44381.781	100.657
3	1O	43491.277	98.554
4	2O	43482.175	97.852
5	3O	43508.212	97.245
6	4O	43498.074	96.539
7	5O	43848.687	95.818

Table 6.14 Base Shear and Displacements at Performance Point for Rigid Models

From the above tables it is seen that, openings in diaphragm not much affects the performance of buildings.

VII. Conclusion

In this study an attempt has been made to investigate the influence of diaphragm flexibility on the seismic response of 5 story RC buildings with plan aspect ratio 1:3 and 1:4 with end shear walls. Also investigates the effects of Floor openings placed in symmetric and asymmetric plan locations in order to investigate the influence of floor diaphragm flexibility on the distribution of lateral loads to frames and shear walls. From comparison of results following are the major conclusion drawn:

- The diaphragm can significantly alter the time period in case of semi-rigid model. Difference of time periods for the semi-rigid case is small for the first two modes, whereas the difference is large for the mode 3 & onward. This means that for higher modes the structural behavior becomes critical for models with slabs.
- Inclusion of diaphragm flexibility changed the little natural time period of the structure. In rigid diaphragm case the slab can show higher difference in first two modes, whereas the condition is exactly opposite for the rest of the modes.
- The influence of openings on both 1:3 and 1:4 aspect ratio buildings is shows negligible difference in time period.
- When comparing the rigid and semi-rigid diaphragm model analyses, the distribution of story shear is varied only upto 3.2% and 4.9% in 1:3 and 1:4 aspect ratio buildings respectively. Also openings can alter the distribution upto 0.62% and 1.2% in 1:3 and 1:4 aspect ratio models respectively.

- For almost all analyses of the case study buildings, semi-rigid diaphragm model produces more diaphragm displacement and inter-story drift than a rigid diaphragm model in both 1:3 and 1:4 plan aspect ratio buildings. The presence of openings not shows significant differences in both diaphragm displacements and story drifts.
- In case of semi-rigid model the presence of slab can decreases the diaphragm displacements upto 86% and 83% in 1:3 and 1:4 aspect ratio buildings respectively. However in case of rigid model the slab can increases the displacements upto 45% in both plan aspect ratio buildings.
- By modelling building as a rigid diaphragm model, the displacements can be reduced to 25% and 29% in 1:3 and 1:4 aspect ratio buildings.
- The diaphragm can decreases the story drifts 84% and 81% in semi-rigid models for 1:3 and 1:4 aspect ratio models. Story drifts of 45% can be increased by the diaphragm in rigid model for both plan aspect ratio models.
- By modelling building as rigid diaphragm the frame displacements can be reduced upto 19% and 30% in 1:3 and 1:4 aspect ratio buildings respectively.
- The force distribution to the shear walls in case of rigid models is slight higher than the semi-rigid models for both plan aspect ratios. As the opening location moves towards the shear wall, load distribution to that section can increase slightly.
- The diaphragm can increases the performance of the building in both rigid and semi-rigid cases. The diaphragm can increases the performance significantly in case of semi-rigid compared to rigid case.
- The openings at different locations in rigid and semi-rigid models for both 1:3 and 1:4 plan aspect ratio buildings are not affecting the performance significantly.
- The performance of rigid diaphragm models is higher compared to semi-rigid model for both plan aspect ratios.
- The overall performance of the all the buildings except semi-rigid bare frame model is said to be immediate occupancy to Life Safety. All the hinges are within the Collapse Prevention limit therefore the structure is said to be safe. Therefore no need to be retrofitting.
- As the plan aspect ratio increases diaphragm displacements, story drifts, distribution of story shears and frame displacements increases. It shows that diaphragm effect decreases with increase in plan aspect ratio.

Scope of Future Work

1) Similar studies can be carried out by increasing the plan aspect ratios
2) Similar studies can be carried out by providing openings of various sizes.
3) Similar studies can be carried out for similar RC buildings include the placement of the shear wall near the interior to surround a service core. In this case, the in-plane deformations of the diaphragms would be largest at the end frames of the buildings.
4) Pushover analysis results can be compared with time history analysis results.

VIII. References

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