Lateral Load Analysis of Soft Story Building and Importance of Modeling Masonry Infill with Normalized Strength and Stiffness Ratio

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Abstract— Generally Masonry infills are considered as non-structural elements and their stiffness contributions are generally ignored in practice. But they affect both the structural and non-structural performance of the RC buildings during earthquakes. RC frame building with open first storey is known as soft storey, which performs poorly during strong earthquake shaking. A similar soft storey effect can occur if first and second story used as service story. Hence a combination of two structural system components i.e. Rigid frames and RC shear walls leads to a highly efficient system in which shear wall resist the majority of the lateral loads and the frame supports majority of the gravity loads. To study the effect of masonry infill with different soft storey level, 7 models of Reinforced Concrete framed building were analyzed with two types of shear wall when subjected to earthquake loading. The results of bare frame and other building models have been compared, it is observed that model with swastika and L shape shear wall are showing efficient performance and hence reducing the effect of soft storey in model 3, model 4 and model 5.

***Keywords**:* Equivalent strut, Masonry infill, shear wall, soft storey

I. INTRODUCTION

Many urban multistorey buildings in India today have open first storey as an unavoidable feature. This leave the open first storey of masonry infilled reinforced concrete frame building primarily to generate parking or reception lobbies in the first storey. It has been known for long time that masonry infill walls affect the strength & stiffness of infilled frame structures. There are plenty of researches done so far for infilled frames, however partially infill frames are still the topic of interest. Though it has been understood that the infill's play significant role in enhancing the lateral stiffness of complete structures.Infills have been generally considered as non-structural elements & their influence was neglected during the modeling phase of the structure. A soft storey building is a multi-storey building with one or more floors which are "soft" due to structural design. These floors can be especially dangerous in earthquakes. As a result, the soft storey may fail, causing what is known as a soft storey collapse. Soft storey buildings are characterized by having a storey which has a lot of open space. Parking garages, for example, are often soft stories, as are large retail spaces or floors with a lot of windows. While the unobstructed space of the soft storey might be aesthetically or commercially desirable, it also means that there are less opportunities to install shear walls, specialized walls which are designed to distribute lateral forces. If a building has a floor which is 70% less stiff than the floor above it, it is considered a soft storey building. This soft storey creates a major weak point in an earthquake, and since soft stories are classically associated with reception lobbies retail spaces and parking garages.

Reinforced concrete (RC) structural walls, conventionally known as shear walls are effective in resisting lateral loads imposed by wind or earthquakes. They provide substantial strength and stiffness as well as the deformation capacity (capacity to dissipate energy) needed for tall structures to meet seismic demand. It has become increasingly common to combine the moment resisting framed structure for resisting gravity loads and the RC shear walls for resisting lateral loads in tall building structures. The consequence of the presence of a soft storey either in the ground storey or in the upper storey, may lead to a dangerous sway mechanism in the soft storey due to formation of plastic hinges at the top and bottom end of the columns, as these columns are subjected to relatively large cyclic deformations.

The main Objectives of the present study is

(1) To know the effect of infill in the frame.
(2) To know proper modeling technique of masonry infill.
(3) To check the strength and stiffness of each storey.
(4) To know the effect of ground and successive soft storey level.

II. DESCRIPTION OF STRUCTURAL MODEL

The study has done on 7 different models of an eleven storey building are considered the building has five bays in X direction and five bays in Y direction with the plan dimension 25 m × 20 m and a storey height of 3.5 m each in all the floors. The building is kept symmetric in both mutually perpendicular directions in plan to avoid torsional effects. The orientation and size of column is kept same throughout the height of the structure. The building is considered to be located in seismic zone V. The building is founded on medium strength soil through isolated footing under the columns. Elastic modules of concrete and masonry are taken as 27386 MPa and 3500 MPa respectively and their poisons ratio as 0.20 and 0.15 respectively. Response reduction factor for the special moment resisting frame has taken as 5.0 (assuming ductile detailing). The unit weights of concrete and masonry are taken as 25.0 KN/m^3 and 20.0 KN/m^3 respectively the floor finish on the floors is 1.5 KN/m^2. The live load on floor is taken as 3.5 KN/m^2. In seismic weight calculations, 50 % of the floor live loads are considered. Thickness of Slab, shear wall and masonry infill wall as 0.125m, 0.2 m and 0.23m respectively.

III. MODEL CONSIDERED FOR ANALYSIS

Following fourteen (7) models are analyzed in ETABS9.7 as special moment resisting frame using equivalent static analysis, response spectrum analysis.

Model 1: Bare frame model, however masses of brick masonry infill walls (230mm thick) are included in the model.

Model 2: Building model has full brick masonry infill of 230mm thick in all the stories.

Model 3: Building model has no brick masonry infill in ground storey and has full brick masonry infill of 230mm thick in upper stories.

Model 4: Building model has no brick masonry infill wall in ground and first story and has full brick masonry infill in rest of the storeys.

Model 5: Building model has no brick masonry infill in ground, first and second storey and has full brick masonry infill in rest of all storeys.

Model 6: Building model has no brick masonry infill in ground, first and second storey. Further, swastika type of shear wall (200mm thick) is provided at corners.

Model 7: Building model is same as model 5.Further, L shaped shear wall (200mm thick) is provided in both x and y direction.

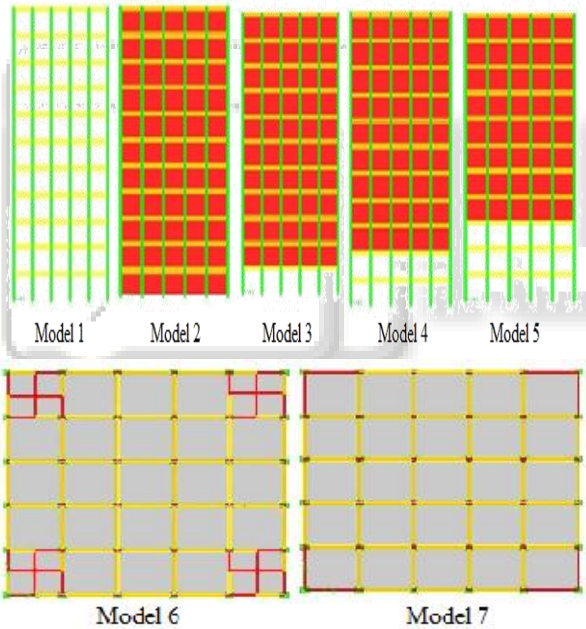
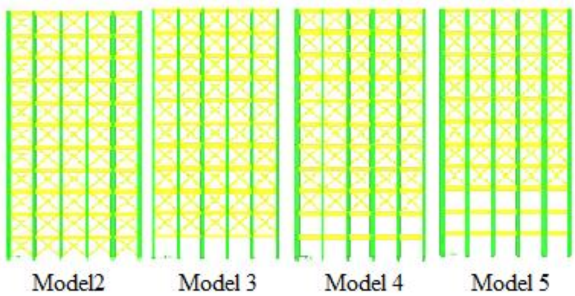


Fig. 1: Plan and Elevation of different building models with infill panel.

First set of models have been prepared while considering masonry infill as four noded quadrilateral shell element and second set is prepared while masonry infill is modelled as equivalent double diagonal strut.



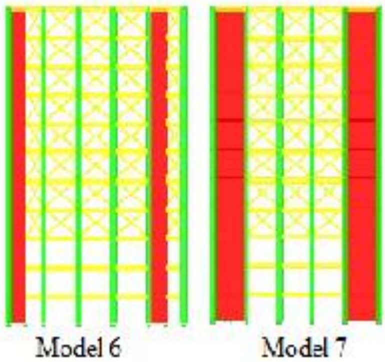


Fig. 2: Elevation of different building models

IV. MODELING OF FRAME MEMBERS, AND SHEAR WALL

The frame elements are modelled as beam elements, slab is modelled as rigid (in-plane) diaphragm and shear wall is modelled with Mid-Pier frame.

V. MODELLING OF MASONRY INFILL IN ETABS

A. *As Four Noded Quadrilateral shell element*

In this technique the masonry infill is modelled as four noded quadrilateral shell element (with in-plane stiffness) of uniform thickness of 0.23mm. The four-node element uses an Iso-parametric formulation that includes both rotational and translational degrees of freedom. (Ref fig 1)

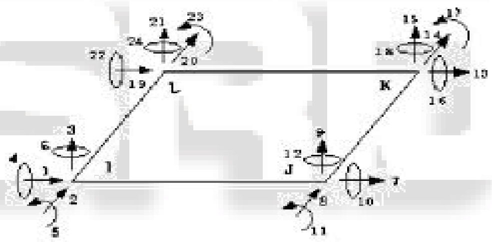


Fig. 3: Four Noded Quadrilateral Element.

B. *As Equivalent Double diagonal strut*

The frames with unreinforced masonry walls can also be modelled as equivalent braced frames with infill walls replaced by equivalent diagonal strut. Many investigators have proposed various approximations for the width of equivalent diagonal strut. The width of strut depends on the length of contact between the wall & the columns (α_h) and between the wall & the beams (α_L). The formulations for α_h and α_L on the basis of beam on an elastic foundation has been used given by Stafford Smith (1966). Hendry (1998) proposed the following equation to determine the equivalent or effective strut width w, where the strut is assumed to be subjected to uniform compressive stress.

$$\alpha_h = \frac{\pi}{2}\sqrt[4]{\frac{4\,E_f I_c\, h}{E_m\, t\, \sin 2\theta}} \qquad (1)$$

$$\alpha_L = \pi\sqrt[4]{\frac{4\,E_f I_b\, L}{E_m\, t\, \sin 2\theta}} \qquad (2)$$

$$w = \frac{1}{2}\sqrt{\alpha h^2 + \alpha L^2} \qquad (3)$$

Where E_m is elastic modulus of masonry wall, E_f is elastic modulus of frame material, t is thickness of infill, h is height of infill and L is length of infill, I_c is moment of inertia of the column, I_b is moment of inertia of the beam and $\theta = \tan^{-1}(h/L)$.

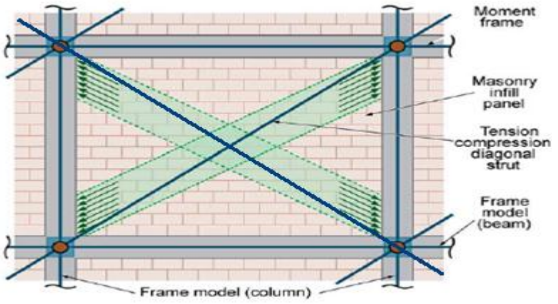


Fig. 4: Equivalent Double Diagonal strut.

VI. ANALYSIS OF THE BUILDING

Equivalent static and response spectrum analyses has been performed as per IS 1893 (part-1) 2002 for each model using ETABS 9.7 software. Lateral load calculation and its distribution along the height is done.

VII. FUNDAMENTAL TIME PERIOD

Fundamental time period(Sec						
	Is Code 1893-2002		ETABS Analysis			
			Infill		Strut	
Model No	Longitudinal	Transverse	Longitudinal	Transverse	Longitudinal	Transverse
1	1.1732	1.1732	1.6115	1.6115	1.6115	1.6115
2	0.693	0.774	0.4793	0.4793	0.592	0.592
3	0.693	0.774	0.6529	0.6529	0.8556	0.8556
4	0.693	0.774	0.931	0.931	1.1887	1.1887
5	0.693	0.774	1.141	1.141	1.4219	1.4219
6	0.693	0.774	0.4893	0.4893	0.5701	0.5701
7	0.693	0.774	0.5373	0.5373	0.6217	0.6217

Table 1: Comparison of time period between IS code method and using ETABS for various models.

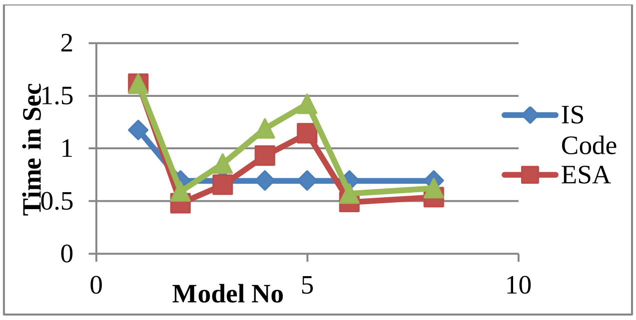


Fig. 5: Model Vs Time period for different building models along longitudinal direction.

VIII. COMPARISON OF BASE SHEAR

Base Shear (KN)				
Model No.	Equivalent Static Analysis (ETABS) With infill Wall		Equivalent Static Analysis (ETABS) With diagonal strut	
	longitudinal	transverse	longitudinal	Transverse
1	4540.8	4540.8	4540.8	4540.8
2	13903.8	13903.76	18236.73	16563.4
3	13767.8	11471.18	14332.53	11671.5
4	9365.86	7702.23	9550.8	7920.6
5	6935.95	6003.95	7195.15	6050.31
6	13565.8	13565.8	16758.41	15992.5
8	12672.8	12672.8	15347.84	13429.4

Table 2: Comparison of Base shear with infill panel and double diagonal strut models for Equivalent Static Analysis

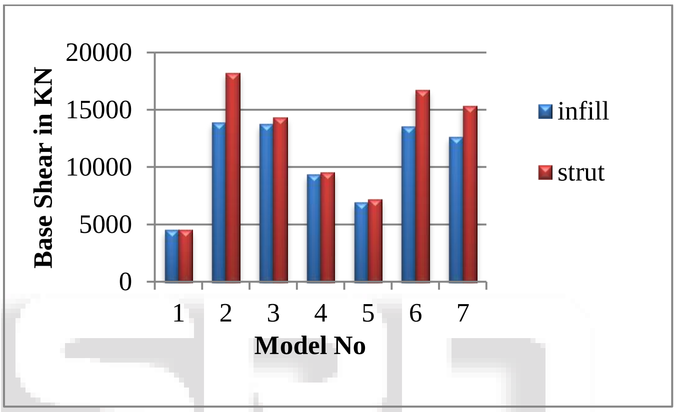


Fig 6: Comparison of Base shear with infill panel and double diagonal strut models for Equivalent Static Analysis.

Base Shear (KN)				
Model No.	Response Spectrum Analysis (ETABS) With infill Wall		Response Spectrum Analysis (ETABS) With diagonal strut	
	longitudinal	transverse	longitudinal	Transverse
1	2901.42	2901.42	2901.42	2901.42
2	11908.2	11004.49	14502.9	13430.1
3	11453.3	10565.23	13785.53	11655.5
4	9219.69	7549.81	9333.56	7486.95
5	6652.02	5792.29	6936	5830.67
6	11729.2	11755.45	14598.98	14369.4
7	11308.6	11320.25	13768.15	12610.2

Table 3: Comparison of Base shear with infill panel and double diagonal strut models for Equivalent static Analysis.

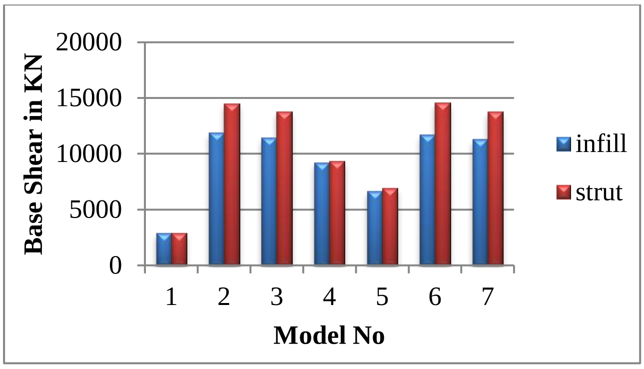


Fig. 7: Comparison of Base shear with infill panel and double diagonal strut models for Response Spectrum Analysis

IX. STOREY DRIFT

Storey Drift(mm)														
	With infill	**With strut**	**With infill**	**With strut**	**With infill**	**With strut**	**With infill**	**With strut**	**With infill**	**With strut**	**With infill**	**With strut**	**With infill**	**With strut**
	Model 1	**Model 1**	**Model 2**	**Model 2**	**Model 3**	**Model 3**	**Model 4**	**Model 4**	**Model 5**	**Model 5**	**Model 6**	**Model 6**	**Model 7**	**Model 7**
Storey	**Ux**	**Ux**	**Ux**	**Ux**	**Ux**	**Ux**	**Ux**	**Ux**	**Ux**	**Ux**	**Ux**	**Ux**		
11	0.458	0.458	0.22	0.375	0.223	0.302	0.162	0.205	0.127	0.159	0.163	0.244	0.16	0.228
10	0.775	0.775	0.269	0.457	0.271	0.367	0.194	0.249	0.151	0.192	0.19	0.283	0.191	0.274
9	1.096	1.096	0.309	0.524	0.31	0.419	0.221	0.284	0.171	0.218	0.217	0.323	0.22	0.316
8	1.363	1.363	0.337	0.572	0.339	0.457	0.241	0.309	0.186	0.238	0.239	0.357	0.243	0.352
7	1.57	1.57	0.355	0.601	0.356	0.479	0.253	0.325	0.195	0.249	0.257	0.385	0.26	0.379
6	1.72	1.72	0.361	0.611	0.364	0.488	0.258	0.33	0.199	0.255	0.27	0.404	0.273	0.399
5	1.819	1.819	0.358	0.605	0.362	0.483	0.257	0.329	0.193	0.243	0.279	0.416	0.283	0.414
4	1.868	1.868	0.346	0.583	0.351	0.467	0.243	0.305	0.242	0.319	0.295	0.433	0.306	0.445
3	1.85	1.85	0.324	0.546	0.326	0.426	0.296	0.388	1.571	2.001	0.415	0.572	0.545	0.735
2	1.671	1.671	0.297	0.499	0.361	0.483	1.797	2.294	2.177	2.442	0.382	0.507	0.531	0.686
1	0.927	0.927	0.238	0.398	1.197	1.635	1.523	1.733	1.296	1.441	0.227	0.294	0.337	0.428

Table 4: Storey Drifts for various building models along Longitudinal direction.

X. STOREY DISPLACEMENT

Storey Displacement (mm)														
	With infill	**With**	**With infill**	**With strut**	**With infill**	**With strut**	**With infill**	**With strut**	**With infill**	**With strut**	**With infill**	**With strut**	**With infill**	**With strut**
	Model 1	**Model 1**	**Model 2**	**Model 2**	**Model 3**	**Model 3**	**Model 4**	**Model 4**	**Model 5**	**Model 5**	**Model 6**	**Model 6**	**Model 7**	**Model 7**
Storey	**Ux**	**Ux**	**Ux**	**Ux**	**Ux**	**Ux**	**Ux**	**Ux**	**Ux**	**Ux**	**Ux**	**Ux**	**Ux**	**Ux**
11	52.9	52.9	12	20.2	15.6	21.0	19.1	23.6	22.8	27.2	10.2	14.5	11.7	16.3
10	51.3	51.3	11.2	18.9	14.8	20.0	18.5	22.9	22.3	26.6	9.6	13.7	11.2	15.5
9	48.6	48.6	10.2	17.3	13.9	18.7	17.8	22.0	21.8	25.9	8.9	12.7	10.5	14.5
8	44.8	44.8	9.2	15.5	12.8	17.2	17	21.0	21.2	25.2	8.2	11.6	9.7	13.4
7	40.0	40.0	8	13.5	11.6	15.6	16.2	20.0	20.6	24.3	7.4	10.4	8.9	12.2
6	34.5	34.5	6.7	11.4	10.4	13.9	15.3	18.8	19.9	23.5	6.5	9.1	8.0	10.9
5	28.5	28.5	5.5	9.2	9.1	12.2	14.4	17.7	19.2	22.6	5.5	7.7	7.0	9.5
4	22.1	22.1	4.2	7.1	7.8	10.5	13.5	16.5	18.5	21.7	4.6	6.3	6.0	8.0
3	15.6	15.6	3	5.1	6.6	8.9	12.7	15.5	17.7	20.6	3.6	4.8	4.9	6.5
2	9.1	9.1	1.9	3.1	5.5	7.4	11.6	14.1	12.2	13.6	2.1	2.8	3.0	3.9

1	3.2	3.2	0.8	1.4	4.2	5.2	5.3	6.1	4.5	5.0	0.8	1.0	1.2	1.5

Table 5: Storey Displacement for various building models along longitudinal direction

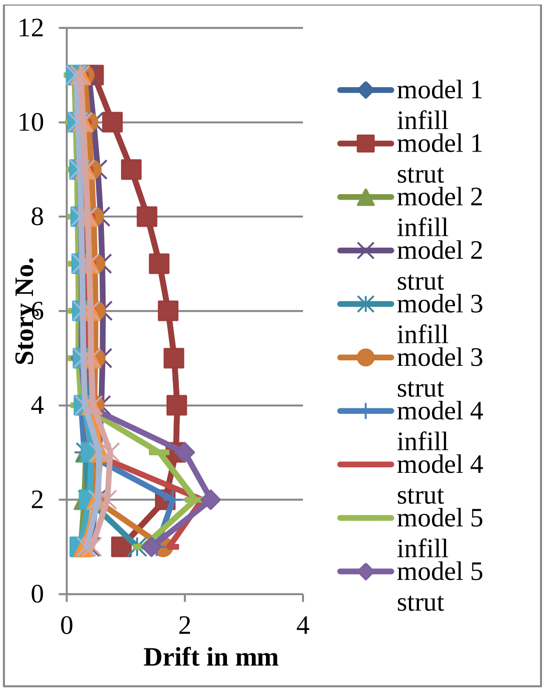


Fig. 8: Comparison of storey drift for different building models along longitudinal direction.

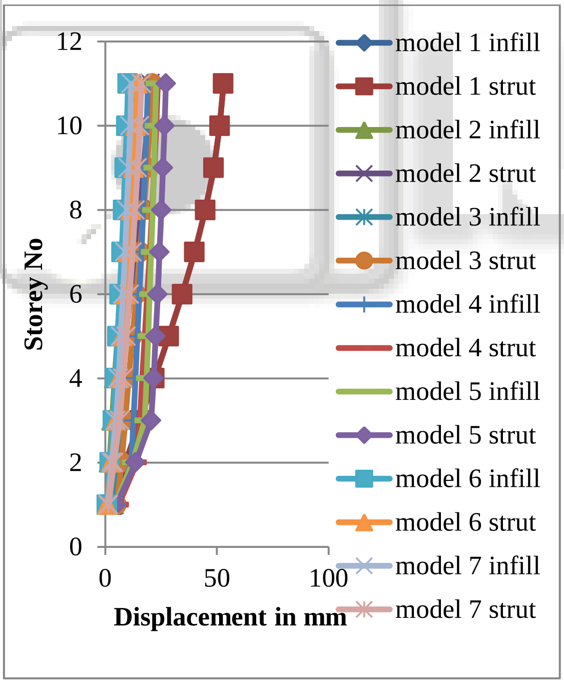


Fig. 9: Comparison of storey Displacement for different building models along longitudinal direction

XI. NON-DIMENSIONAL STRENGTH AND STIFFNESS PARAMETERS

For purpose of calculating strength and stiffness of different storey level, the strength and stiffness ratio i.e. Qi/Vb and di/d are worked out, and have plotted as shown in (Chart 1 to14). Further a linear trendline is drawn for normalized parameters in Microsoft Excel 2007 so as to know the best fitting of scattered points. And a co-relation is developed between them.

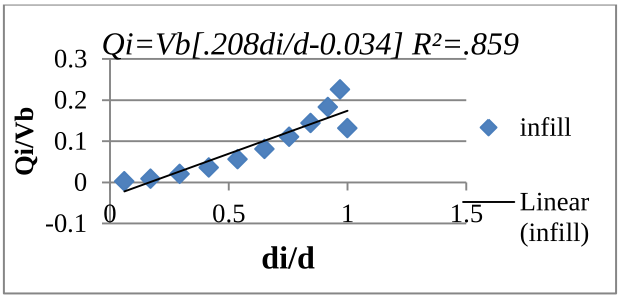


Chart 1: Normalized strength and stiffness parameters along x direction for model 1

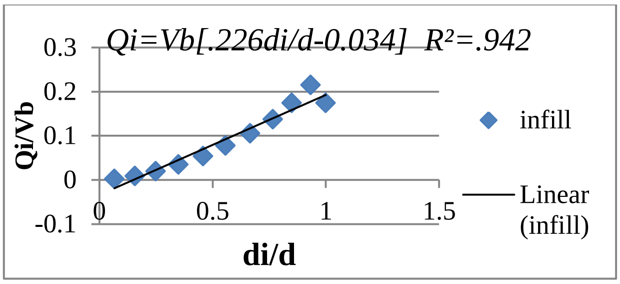


Chart 2: Normalized strength and stiffness parameters along x direction for model 2

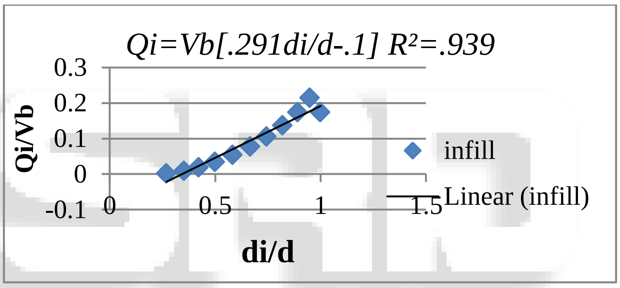


Chart 3: Normalized strength and stiffness parameters along x direction for model 3

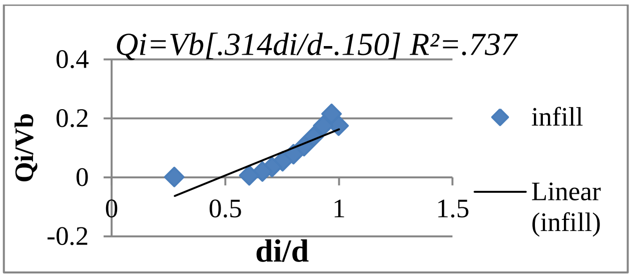


Chart 4: Normalized strength and stiffness parameters along x direction for model 4.

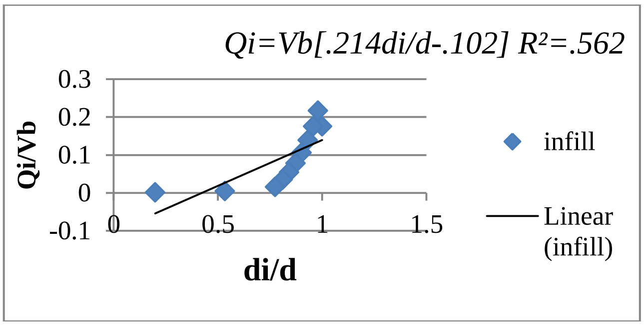


Chart 5: Normalized strength and stiffness parameters along x direction for model 5

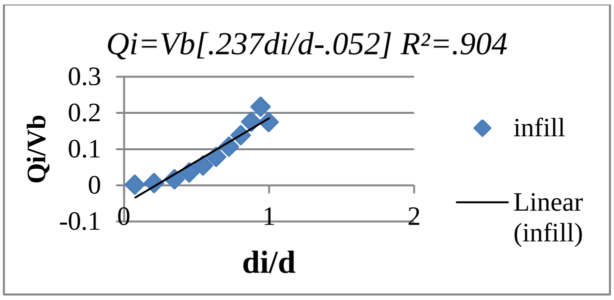


Chart 6: Normalized strength and stiffness parameters along x direction for model 6

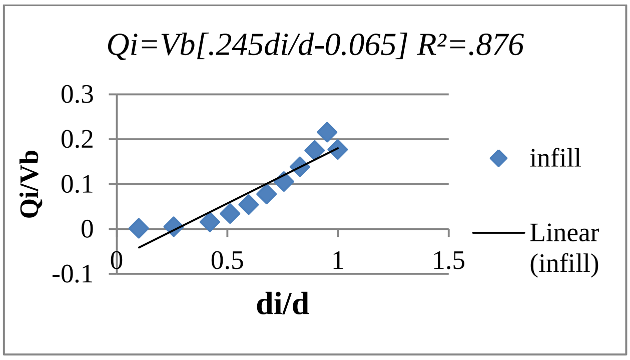


Chart 7: Normalized strength and stiffness parameters along x direction for model 7

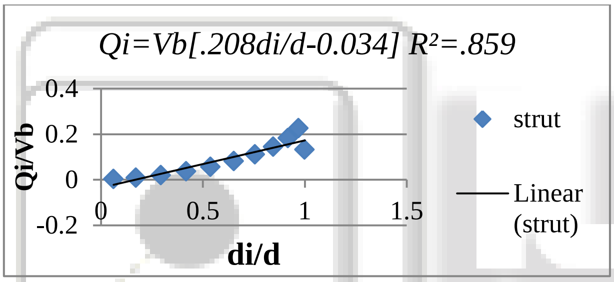


Chart 8: Normalized strength and stiffness parameters along x direction for model 1.

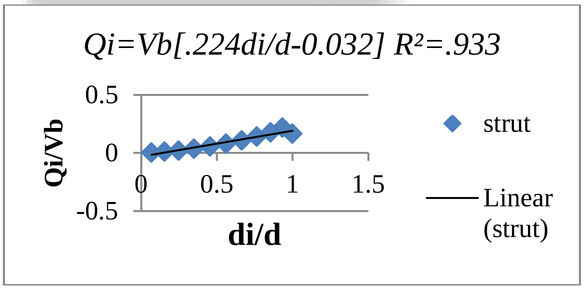


Chart 9: Normalized strength and stiffness parameters along x direction for model 2.

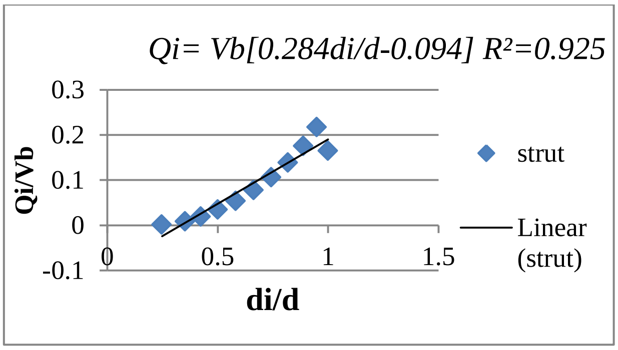


Chart 10: Normalized strength and stiffness parameters along x direction for model 3.

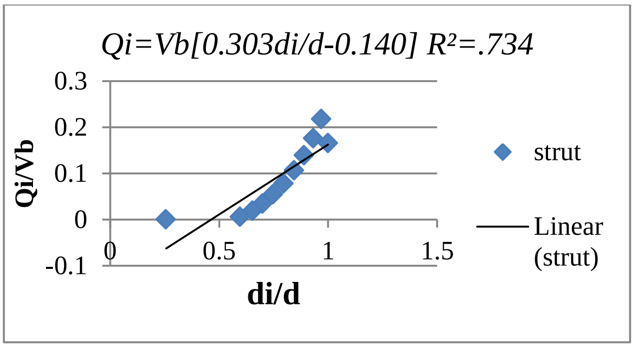


Chart 11: Normalized strength and stiffness parameters along x direction for model 4

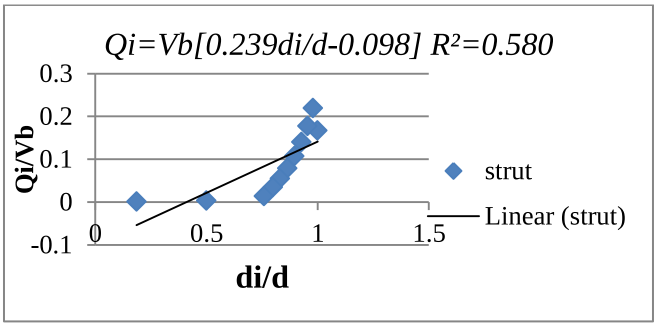


Chart 12: Normalized strength and stiffness parameters along x direction for model 5.

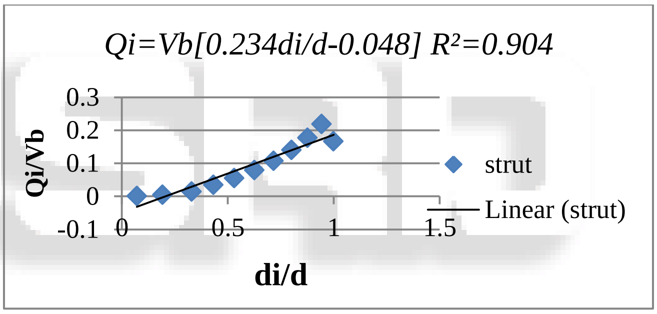


Chart 13: Normalized strength and stiffness parameters along x direction for model 6.

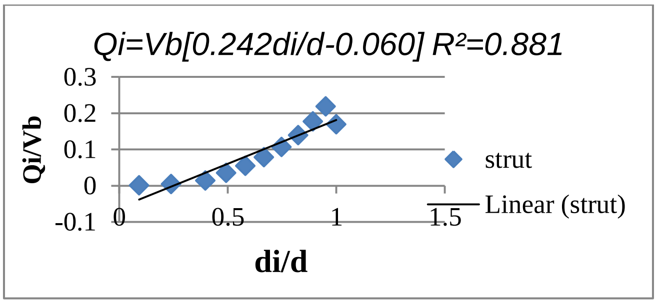


Chart 14: Normalized strength and stiffness parameters along x direction for model 7

XII. RESULTS AND DISCUSSIONS

Table 1 shows natural time period, for bare frame model, from ETABS, it is 27.19 more than the IS code method. When the structural action of masonry infill is taken the fundamental natural time got reduced 70.25% when compare with bare frame model, The soft storeys mode 3, model 4, model 5 the increase time period 26.58%, 48.15%,57.99. The time period get reduces for shear wall model 6, model 7 is 57.11%, 52.90%. the time period reduction in double diagonal strut little more compared to infill panel. [Ref table 1 and Fig 5]

Seismic base shear obtained for double diagonal strut models are considerably higher than infill panel models for ESA and RSA in both the directions. [Ref table 2and 3 Fig 6,7]

Storey drift drastically increased when a successive soft storey is exist, for model 5 at ground, first, second storey level it is increased by 86.35% in case of infill panel and 79.56% in case of double diagonal strut as compared with Model 2. Shear walls of different shapes drastically reduces the inter storey drift. [Refer table 4 Fig 8]

Model1(bare frame) model shows highest storey displacement values in all different building models model 2 (full brick infill) shows considerable reduction in storey displacement with a maximum reduction of 77.31% in case of masonry infill panel and 61.81% in case of double diagonal strut as compared with model 1 and model 6, model 7 shows 80.71% and 77.88% reduction in displacement value compared with model 1. [Refer table 5, Fig 9]

Thus it can be concluded that addition of infill and concrete shear wall act as drift and displacement controlled elements in RC buildings.

Chart 1 to 14 shows the normalized Strength and stiffness ratios, R^2 value for bare frame model is least as compared to all other models which shows the frame is very much flexible in nature and susceptible earthquake threatening. Ground and successive soft storey model 5 shows least strength and stiffness ratio which leads to dangerous sway mechanism. Ground and successive soft storey models shows scattering of points and not fitting a good curve. Model 2 and 6, 7 shows the best fit, which means it has got sufficient strength and stiffness to resist seismic loading. Models with double diagonal strut are showing slightly lesser R^2 values than models with infill panel which shows double diagonal strut models are flexible than masonry infill panel.

XIII. CONCLUSIONS

– Fundamental time period decreases when the effect of masonry infill wall and concrete shear and core wall is considered.
– IS Code method gives same time period for masonry infill and shear wall models, when time period calculated by ETABS is different for different models. So that the software like ETABS must be used to calculate fundamental natural time period of structure.
– Double diagonal strut models are showing large time period as compared with infill panel model.
– Seismic base shear is considerably more for masonry infill and shear wall models as compared with bare frame model and storey drifts and joint displacements considerably reduces, Hence consideration of masonry infill and shear wall will increases strength and stiffness of structure when subjected to lateral seismic loading.
– Models with successive soft stories have got highest storey drift values at soft stories levels, which leads to dangerous sway mechanism. Therefore providing shear wall is essential so as to avoid soft storey failure.
– Masonry infill panel models are showing much strength and stiffness as compared with double diagonal strut models, therefore masonry infill panel can be a good solution to model masonry infill. And therefore depending upon the importance of structure and type of design it has to be modeled.
– From the non-dimensional analysis it is observed that for full masonry infill and shear wall models, R^2 value is nearly equal to 1, which means each storey has got sufficient strength and stiffness to resist lateral seismic loading.
– The non dimensional analysis shows the R^2 value is lesser than the bare frame model for successive soft storeyes model 4, 5. Which means that strength and stiffness for each soft storey less has got reduced.

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