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Effect of Brick Infill on Seismic Response of Building

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Abstract:— **Due to rapidly growing population, it is inevitable to construct multistory buildings and this calls for more and more space for parking. Generally, this requirement is met by introducing parking at ground floor and hence it is not possible to construct the brick walls to enclose ground floor completely. Similar situation is also observed while providing the refuge areas at intermediate floors for fire escape. This feature is called as soft storey and past records demonstrates that building with soft storey performed poorly during earthquake.**

Main reason behind the failure of building with soft storey, during earthquake is sudden change in stiffness, which causes excessive shear on the columns in soft storey. Hence, it is very much important to study the effects of soft storey on response of building. Further, appropriate care shall be taken during design to eliminate the effects of soft storey. Although, various researchers has studied this phenomenon and recommended the remedial measures, but the modeling techniques adopted for modeling brick infill is always questionable. Hence, it becomes important to study this phenomenon with more detailed considerations to empirical time period formulas proposed in IS1893 Part 1: 2002.

Considering above facts, study has been carried out using G+7 building model, to validate the empirical time period formula proposed in IS1893 Part 1: 2002. Further, effect of soft storey on seismic response of building is also evaluated by considering G+7 building with soft storey at GF, 2nd Floor, 4th Floor & 6th Floor respectively.

Index Terms **:-- Soft Storey, Infill, Time Period, Earthquake.**

I. INTRODUCTION

In India many urban multi-storey buildings nowadays, have open first storey to accommodate parking or reception lobbies which is an unavoidable feature. A soft storey is created when lateral stiffness and/or strength of a storey is remarkably more than the floors above and below. Due to rapidly growing population, parking space is becoming a big issue for the apartments in the cities. Hence, it has become very much necessary of utilizing the ground storey for parking, for offices spaces or conference hall etc., and it is known as Soft Storey. Open Storey can be constructed at different levels of structure the refuge areas at intermediate floors for fire escape ; but in maximum cases, RC framed buildings with the ground(first) storey open are known to perform poorly during strong earthquake shaking, due to the absence of infill wall. Most of the deformations concentrate at this level and results in large rotational demand in columns.

As per IS1893-2002, a Soft Storey is one in which the lateral stiffness is less than 70 percent of that in the storey above or less than 80 percent of average lateral stiffness of three storey above. An Extreme Soft Storey is one in which the lateral stiffness is less than 60 percent of that in the storey above or less than 70 percent of average lateral stiffness of three storey above.

NEED & IMPORTANCE OF PRESENT STUDY

Soft storey is the one of which the rigidity is lower than any other storeys due to the fact that it has not got the walls with the same properties the other ones have. Most of the constructions have soft floors; because entrance floors of the buildings are used as bank branches, stores, restaurants, offices and the upper storeys are used as dwellings. Since the business stores and the dwellings are not the two sections with the same properties, there exist soft storeys. During an earthquake, more moment and shear strength fall on the columns and walls in the entrance floors than the one in the upper storeys. If the walls that exist in other storeys do not exist in the entrance floor, these columns are forced more than those in other storeys. Due to the fact that there is less rigidity in soft storeys, the structure is divided into two sections in terms of structural behaviour; the lower and the upper part of the soft storey. This can be called dangerous storey instead of soft storey. It is not so easy for a country to say that no construction would be constructed having no store and offices in them. In order to do this, it would be better to investigate the precautions to be taken. The measure of the growth in construction technology is to build a construction according to the designated place and possibility of a quake. Since no nation would leave its country because of earthquake, it is necessary for that nation to build quake resistant buildings. Building quake resistant constructions is as important as other struggles. Since earthquakes do not respectful for country borders, it is a common menace for humanity. For this reason advances in the field of earthquake studies should be presented to every individual.

LITERATURE REVIEW

Arlekar et al. (1997) analyzed different models of buildings using equivalent static analysis and multi-modal dynamic analysis of nine different models of buildings, by using ETABS. They concluded that the drift and the strength demands in the first storey columns are very large for buildings with soft ground storeys. As it is not possible to eliminate the soft storey from the building due to functional requirements, they suggested two methods to increase the stiffness of the soft storey columns. First method is the provision of stiffer columns at ground storey and second method is the provision of concrete service core in the building.

Ahmed et al. (2014) analyzed three different buildings models i.e. Building without infill, building with bottom soft storey, building with steel bracing system by carrying out dynamic analysis using ETABS. Performance of building is evaluated in terms of storey drift, lateral displacements, lateral forces, storey stiffness, base shear, time period, torsion. They have concluded that steel braced system significantly contributes to the structural stiffness, and reduces maximum inter storey drift, lateral displacement of R.C.C. building.

Setia et al (2012) carried out analytical study to investigate the influence of different parameters on behavior of a building with soft storey using the computer program STAAD.Pro 2006. This parametric studies has been focused on study of displacement, inter storey drift and storey shear using equivalent static analysis. This study has been carried out using five different mathematical models. They concluded that crucial displacement may be effectively reduced if the stiffness of first storey is made with in the order of magnitude equal to the storey stiffness of storey above.

Mohd. Aliuddinet et al (2014) carried out numerical study for understanding behaviour of Real life building (located in Hyderabad) in seismic zone 2 with soft storey, with bracings and without bracings for given lateral loads. Apart from the understanding, a recommendation for providing single strut at the corner columns has been made, as it will decrease the response of the structure during the earthquakes and also in parallel it will help in normal parking.

Arora Abhishek (2015) has studied the effect of soft storey on structural behaviour using two different four storey building models in ETABS for his study. He has suggested the provision of stiff columns or provision of adjacent infill wall panel to increase load carrying capacity of member. This will enhance the performance of building with soft storey.

II. METHODOLOGY

PROBLEM STATEMENT

The plan layout of the reinforced concrete moment resisting frame building with 6 models of 8storey building having full brick infills, having no brick infills (bare model) as objective 1 & no brick infills (soft storey) on Ground storey, 2ndstorey ,4thstorey& 6thstorey, respectively as objective 2 are chosen for this study is as shown in Fig. 3.

The building is considered to be located in seismic zone III and intended for residential use. The building is purposely kept symmetrical in both orthogonal directions in plan to avoid torsional response under pure lateral forces. The building is founded on medium strength soil. Poison's ratio of concrete and masonry are0.17.The unit weights of concrete and masonry are taken as 25 kN/m3 and 20 kN/m3. The floor finish on the floors is 2kN/m2. The weathering course on roof is taken as 1kN/m2.The live load on floor is taken as5kN/m2 and that on roof as 1.5 kN/m2. In the seismic weight calculations, only 50% of the floor live load is considered.

Details of Building = G + 7 as shown in fig.
Location = Mumbai
Walls = 230mm thick brick masonry
Typical floor to floor height = 3000mm
Height of Plinth = 500mm
Depth of Foundation = 2500 below ground level
Bearing capacity of soil = 200 kN/sqm

Loading on the Structure	
Dead Load	
• Roof Finish • Floor Finish	1.0 kN/sqm 2.0 kN/sqm
Live Load	
• Roof Finish • Floor Finish	1.5 kN/sqm 5.0 kN/sqm
Wind Load	Not considered for design
Seismic Load	IS 1893 (Part 1): 2002
Type of soil	Medium Soil

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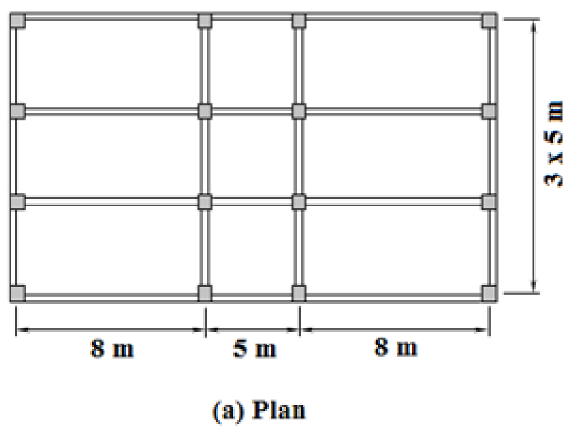

Figure 1 :: Plan at a typical storey of the example building considered in the study

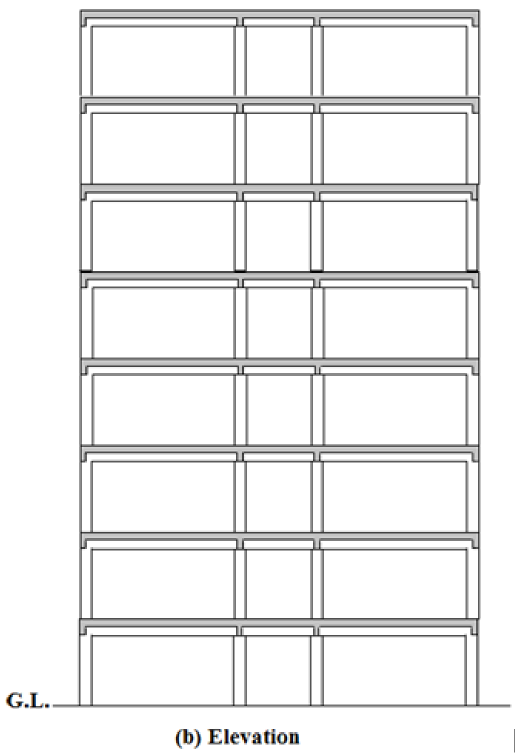

Figure 2 :: Elevation of the example building considered in the study

Objective 1: Validation of empirical time period formula of IS1893 Part 1 2002

Objective 2: Study effect of soft storey on seismic response of structure

In both objectives, Braces are provided in the structure so as to consider the effect of increased stiffness due to brick infills.

SCOPE OF WORK: OBJECTIVE 1

In this objective, building with brick infill throughout height is considered. Effect of brick infill is simulated on following 2 methods

a. Considering time period of type 3 structure as per IS1893 Part 1: 2002 (Cl 7.6.2)

b. Modelling the brick infill as per Ch 17 of book "Earthquake Resistant Design of Structures", by Agarwal Shrikande

Result is computed in terms of Base Shear, Storey Shear & Deflection by considering two number of STAAD Models

a. Model 1: Bare frame model with all applicable wall loads. Time period of the building is simulated as explained in 2a

b. Model 2: Structure has been modeled with brick infill as specified in 2b.

SCOPE OF WORK: OBJECTIVE 2

In this objective, building with soft storey at Ground, 2nd, 4th & 6th Floor considered for study.

Effect of brick infill is simulated by modelling diagonal strut as per Ch 17 of book "Earthquake Resistant Design of Structures", by Agarwal Shrikande. Results are computed in terms of Base Shear, Storey Shear & Deflection by considering following STAAD Models

a. Model 1: Soft storey at Ground/first storey

b. Model 2: Soft storey at 3rdStorey

c. Model 2: Soft storey at 5thStorey

d. Model 2: Soft storey at 7thStorey

ANALYSIS OF THE BUILDING

Linear elastic analysis is performed for the six models of the building usingSTAADPro-v8i. The frame members are modeled with rigid end zones, the walls are modeled as panel elements, and the floors are modeled as diaphragms rigid in-plane. The soil flexibility is introduced as linear Winkler spring sunder the footing. Two different analysis are performed on the models of the building considered in this study, namely the equivalent static analysis and the Response Spectrum analysis. These are briefly described below.

Equivalent Static Analysis

The natural period of the building is calculated by the expression, given in IS:1893-2002, wherein H is the height and D is the base dimension of the building in the considered direction of vibration. Thus, the natural periods for all the models in this method, is the same. The lateral load calculation and its distribution along the height is done as per

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IS:1893-2002. The seismic weight is calculated using full dead load plus 50% of live load.

Response Spectrum analysis

Dynamic analysis of the building models is performed on STAADPro-v8i. The lateral loads generated by STAADPro-v8icorrespond to the seismic zone III and the 5% damped response spectrum given in IS:1893-2002. The natural period values are calculated by STAADPro-v8iby solving the eigen value problem of the model. Thus, the total earthquake load generated and its distribution along the height correspond to the mass and stiffness distribution as modeled by STAADPro-v8i. Here, as in the equivalent static analysis, the seismic mass is calculated using full dead load plus 50% of live load.

MODELLING

Open ground storey in building has a several advantages over building without open ground storey (with brick infills). However, when we observe building in perspective of earthquake, when we consider effect of earthquake forces, soft storey fails due to less stiffness than storeys above.

In this study a typical 8 storied RCC building is modelled using the software STAAD Pro.v8i. Typical rectangular plan has been taken with 3 bays in X-direction each of having span of 8m ,except middle one which is of 3m span & in Z-direction 3 bays each of having 5m span except middle one which is again of span 3m.Heights are taken as 3m for each storey (floor to floor).Wall thickness is taken as 0.23m. All 6 models are developed with this same plan. Effect of brick infill is simulated as per Ch 17 of book "Earthquake Resistant Design of Structures", by Agarwal Shrikande, In the modelling of the structure equivalent diagonal struts are provided for considering the stiffness of brick infill panel's. The main problem in this method is to find out effective width of equivalent diagonal strut.So the geometric properties i.e. effective width & thickness are found out by following method,

$$w = \frac{1}{2}\sqrt{\alpha_h^2 + \alpha_L^2}$$

Where,
w = Effective width of equivalent diagonal strut
The effective width of equivalent diagonal strut depends on the length of contact between wall and the columns, α_h& between the wall and beams α_L which are calculated as following,

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

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

Where,
E_m&E_f = Elastic modulus of the masonary wall and frame material, respectively
t,h,L= Thickness, height and length of infill wall
I_c, I_h= Moment of inertia of column and beams
$\Theta = \tan^{-1}(h/L)$.
So, by this calculations, effective width for struts are calculated and are provided in the models 2,3,4,5 and 6. The equivalent static analysis is then performed for the modelled RCC building using *STAAD Pro.v8i*. and results are calculated and all the respective observations are checked & studied.
Model 1 and model 2 are included in objective 1 which includes validation of empirical time period formula of IS1893 Part 1 2002.

$$Ta = \frac{0.09h}{\sqrt{d}}$$

Where,
h= Height of building, in m, as defined in7.6.l
d= Base dimension of the building at the plinth level, in m, along the considered direction of the lateral force
Structure in Model 1 is modelled without brick infills by considering all applicable wall loads as shown in *figure 3*.Structure in Model 2 is modelled with brick infills throughout by providing diagonal braces having stiffness equivalent to that of brick infill, by calculating width of equivalent diagonal strut as percalculations given in modelling part as shown in *figure 4*. Braces are provided throughout the structure so as to consider the effect of increased stiffness due to brick infills. Objective 2 involves models 1,2,3 and 4, for determining response of structure having soft stories at different levels in terms of base shear, storey shear and deflection. So, structure in model 1 is modelled with ground i.e. first storey as open storey (soft storey) as shown in *figure 5* and similarly, structure in model 2, 3 and 4 with 3rd, 5th, and 7h stories as open stories, respectively, as shown in the figures 6, 7 and 8.

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STAAD MODELS

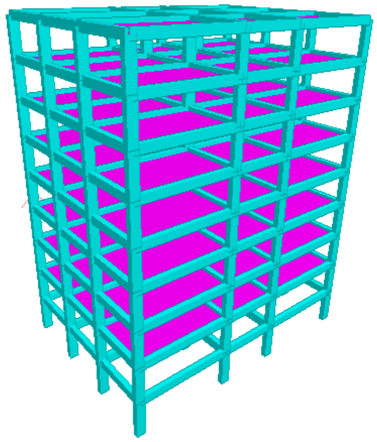

Figure 3 :: STAAD.Pro model
(Bare frame model : Objective 1;model 1)

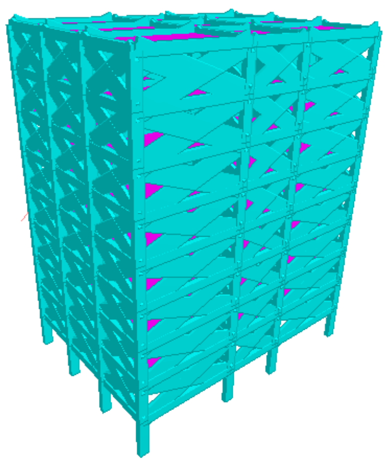

Figure 4 :: STAAD.Pro model
With brick infill model, Objective 1;model 2

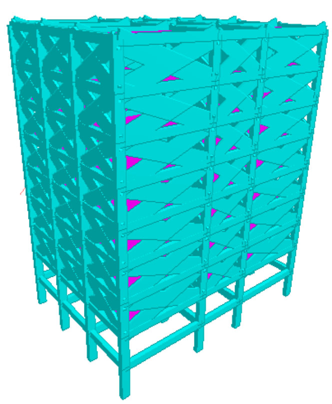

Figure 5 :: STAAD.Pro model
Model with 2nd soft storey, Objective 2 ;model 1

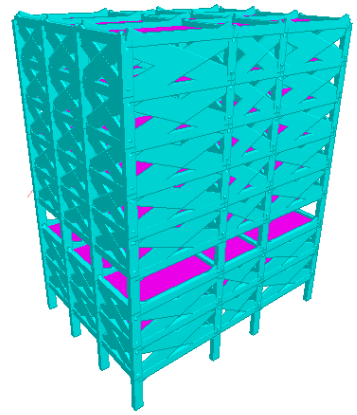

Figure 6 :: STAAD.Pro model
Model with 2nd soft storey, Objective 2 ;model 2

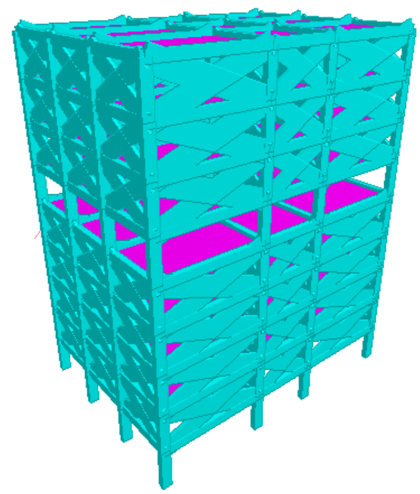

Figure 7 :: STAAD.Pro model
Model with 2nd soft storey, Objective 2 ;model 3

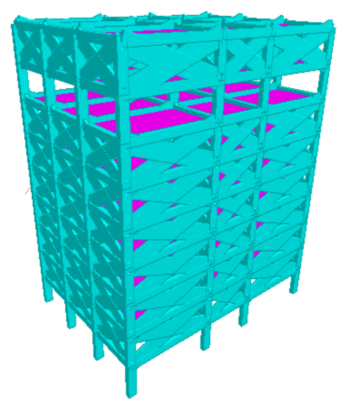

Figure 8 :: STAAD.Pro model
Model with 2nd soft storey, Objective 2 ;model 4

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III. RESULTS AND DISCUSSION

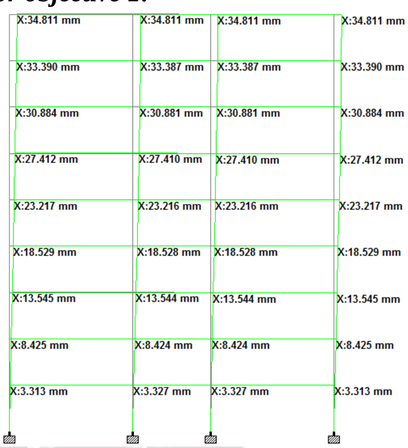
Results are calculated in terms of base shear, storey shear and deflections for each model of every objective and are compared and represented as graphs.

OBJECTIVE 1: DEFLECTION IN X AND Z DIRECTION (OBJECTIVE 1)

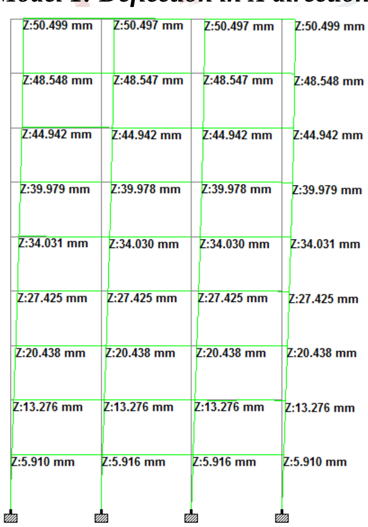
For objective 1, as stiffness of brick infills in not considered in model 1, deflection of structure is much larger than that of model 2, in which brick infills play a vital role in increasing the stiffness of structure, thereby reducing it's deflection. If we compare deflection of 8th storey of both models,

8th Storey	In X Direction	In Z direction
Model 1	34.811mm	50.499mm
Model 2	4.365mm	8.441mm

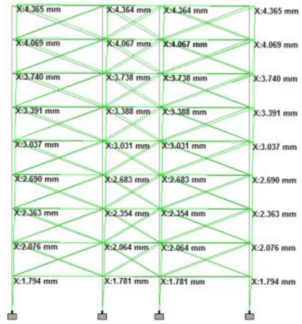
Results for objective 1:



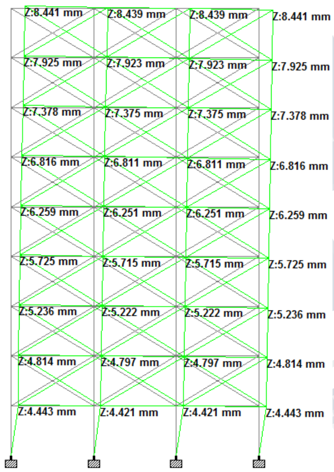
Model 1: Deflection in X direction



Model 1: Deflection in Z direction



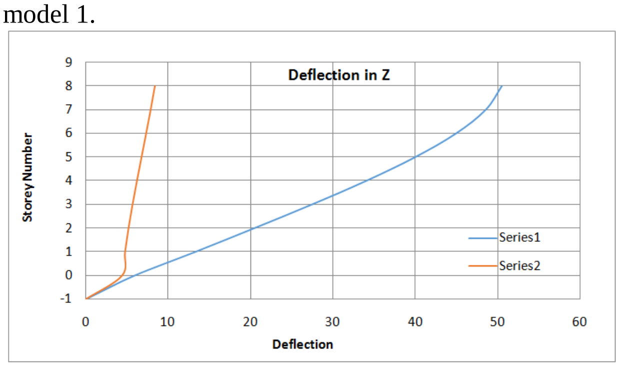
Model 2: Deflection in X direction



Model 2: Deflection in Z direction

COMPARISON OF DEFLECTION IN X AND Y DIRECTION OF MODEL 1 AND 2 (OBJECTIVE 1):

Graph of comparison of deflection of model 1 and 2 in both X and Z directions is plotted by taking storey number in Y direction and deflection in mm in X direction. From the graphs, it can be concluded that due to presence of brick infills there is increased stiffness in model 2 than that of in model 1, so deflection in model 1 is much lesser than that of model 1.



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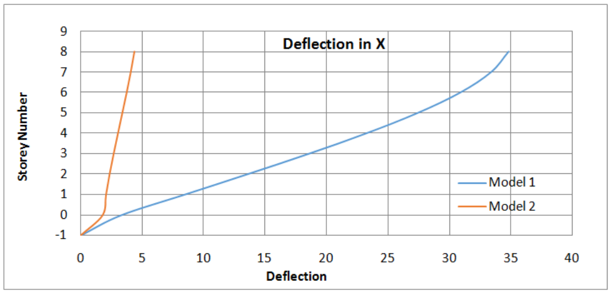
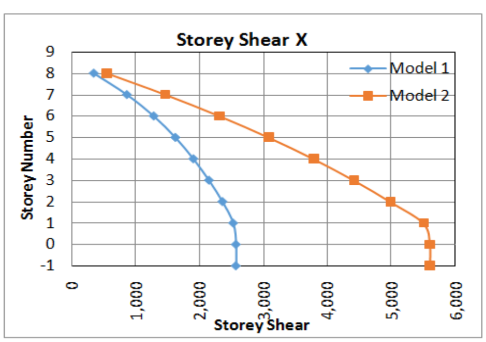


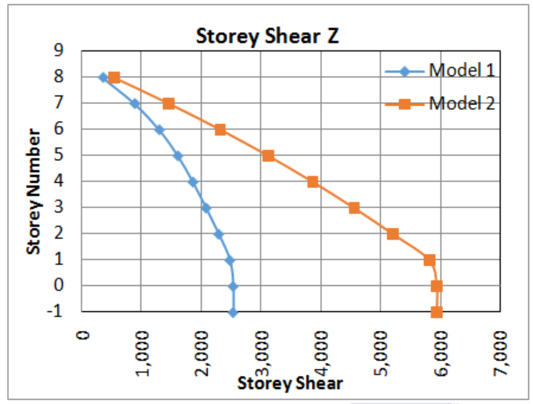
COMPARISON OF STOREY SHEAR AND BASE SHEAR IN X AND Y DIRECTION (OBJECTIVE 1)

Graph of comparison of storey shear for models 1 and 2 in both directions is plotted by taking storey number in Y direction and Storey Shear in X direction. For Objective 1, as a result of stiffness and presence of brick infills, storey shear and base shear in model 2 is more than that of in model 1.

Comparison of Storey Shear X			
Storey	Level	Model 1	Model 2
8	24	336.58	537.54
7	21	856.61	1459.78
6	18	1277.65	2307.43
5	15	1616.47	3080.78
4	12	1898.34	3782.46
3	9	2142.49	4416.79
2	6	2355.52	4988.82
1	3	2522.65	5505.81
0	0	2565.77	5606.07
-1	-3	2565.77	5606.07

Comparison of Storey Shear Z			
Storey	Level	Model 1	Model 2
8	24	344.02	530.94
7	21	876.98	1452.32
6	18	1287.79	2312.71
5	15	1600.30	3113.84
4	12	1851.13	3859.08
3	9	2074.18	4553.13
2	6	2285.32	5201.55
1	3	2471.52	5811.16
0	0	2527.27	5936.55
-1	-3	2527.27	5936.55



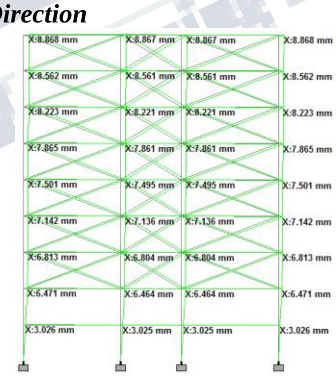


OBJECTIVE 2: DEFLECTION IN X AND Z DIRECTION (OBJECTIVE 2)

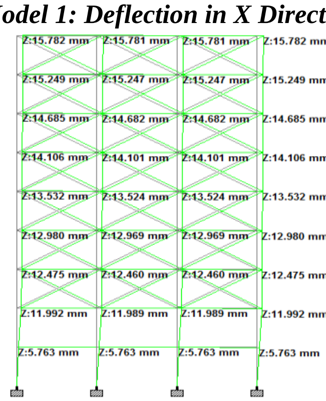
In objective 2, deflections of four models are worked out and compared. Deflection of floors with each other of any structure is gradual, but due to presence of open storey, there is sudden change in stiffness of the floors. So, there is sudden and more deflection at the level where there is open soft storey in the structure. For example, for model 2 of objective 2 in figure, there is sudden increase in values of deflection after 2ndstorey, which is due to presence of soft storey at the 2ndstorey. Similar results are obtained in other models also for deflection.

Results for objective 2:

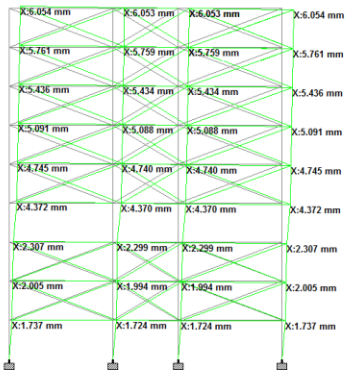
Model 1 – X Direction



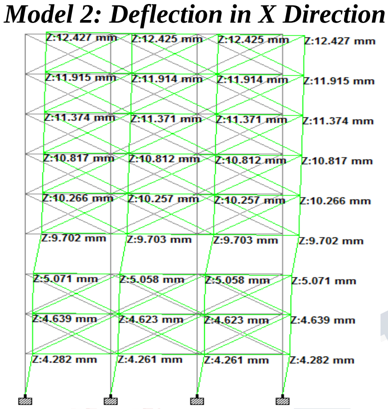
Model 1: Deflection in X Direction



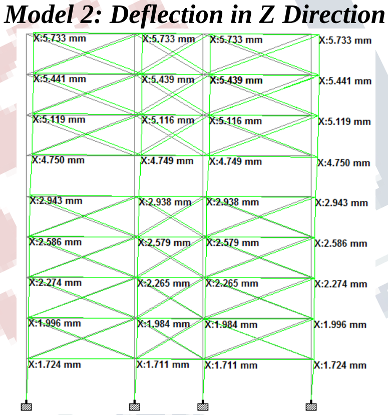
Model 1: Deflection in Z Direction



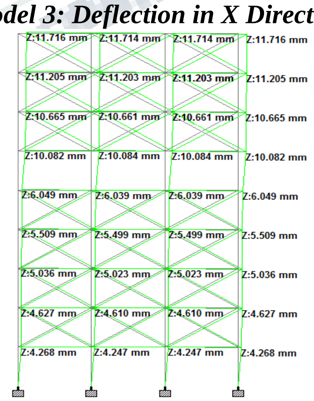
Model 2: Deflection in X Direction



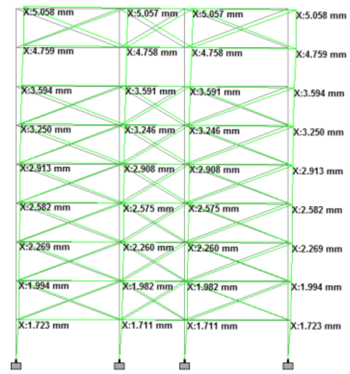
Model 2: Deflection in Z Direction



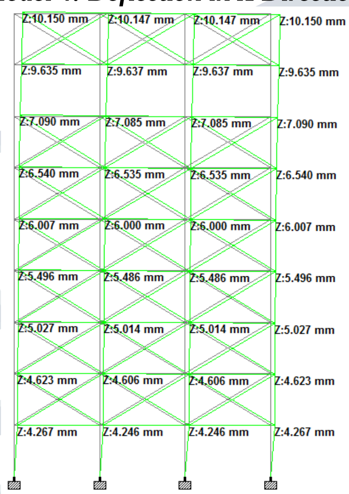
Model 3: Deflection in X Direction



Model 3: Deflection in Z Direction



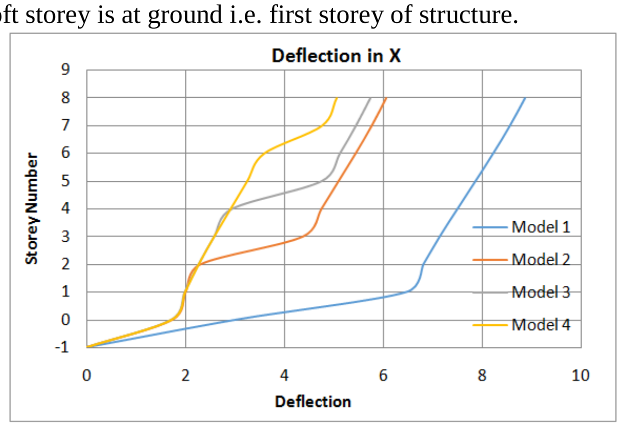
Model 4: Deflection in X Direction



Model 4: Deflection in Z Direction

COMPARISON OF DEFLECTION OF ALL FOUR MODELS IN X AND Y DIRECTION (OBJECTIVE 2) :

Graph of comparison of deflection of models 1, 2, 3 and 4 in both X and Z directions is plotted by taking storey number in Y direction and deflection in mm in X direction. From the graphs, it can be concluded that deflection is maximum when soft storey is at ground i.e. first storey of structure.



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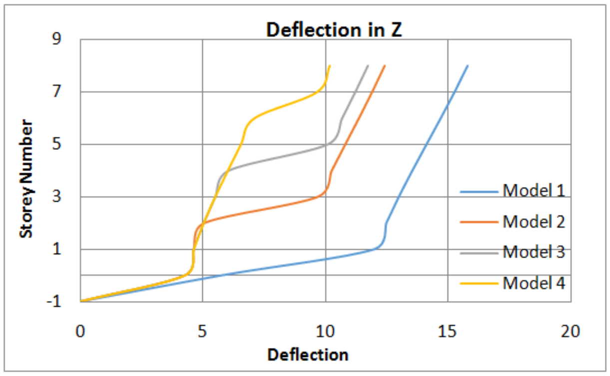
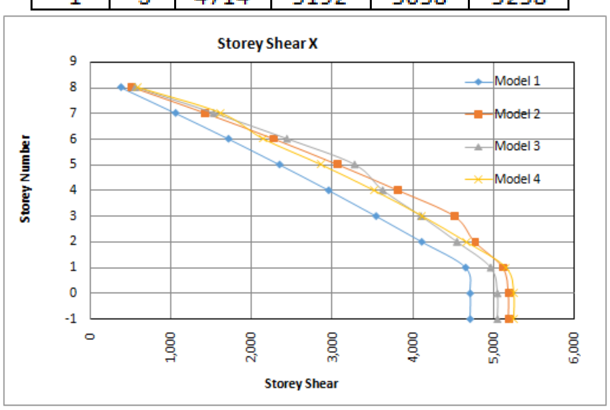


COMPARISON OF STOREY SHEAR OF ALL FOUR MODELS IN X & Z DIRECTION (OBJECTIVE 2) :
Graph of comparison of storey shear for models 1 and 2 in both directions is plotted by taking storey number in Y direction and Storey Shear in X direction. For Objective 2, base shear and storey shear is maximum in model 4 wherein soft storey is at 7th storey and minimum in model 1 wherein soft storey is at ground i.e first storey.

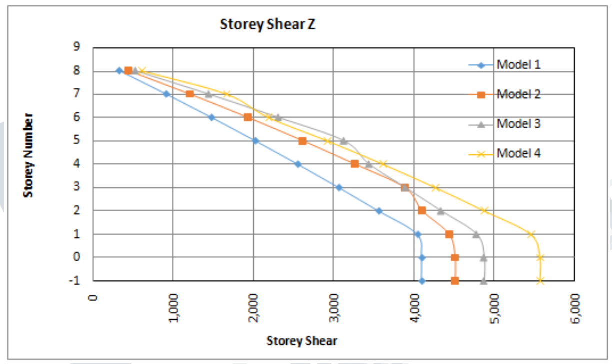
Comparison of Storey Shear X

Storey	Level	Model 1	Model 2	Model 3	Model 4
8	24	379	520	559	597
7	21	1058	1424	1533	1628
6	18	1714	2274	2444	2153
5	15	2347	3070	3285	2866
4	12	2958	3818	3634	3523
3	9	3546	4518	4109	4123
2	6	4113	4774	4555	4667
1	3	4658	5122	4975	5162
0	0	4714	5192	5058	5258
-1	-3	4714	5192	5058	5258



Comparison of Storey Shear Z

Storey	Level	Model 1	Model 2	Model 3	Model 4
8	24	328	438	520	603
7	21	912	1204	1436	1661
6	18	1477	1927	2304	2184
5	15	2022	2611	3122	2918
4	12	2550	3260	3436	3610
3	9	3061	3878	3888	4261
2	6	3559	4098	4336	4872
1	3	4043	4432	4778	5448
0	0	4094	4505	4872	5566
-1	-3	4094	4505	4872	5566



IV. FUTURE SCOPE

Current research is focused on design of soft storey columns for additional forces generated during earthquake. It is also possible to propose Energy dissipation devices to reduces the storey drift and thereby forces induced in columns. Tuned mass friction damper is one of such device which can be evaluated for its effectiveness in reducing soft storey effect. Pisal & Jangid (2013, 2014 & 2016) has studied these devices and demonstrated its effectiveness in vibration control of general structures

V. CONCLUSIONS

After all the calculations and results of base shear, storey shear and deflection of all models, following things are concluded

a. Brick infills make a considerable increase in stiffness of the structure thereby reducing sway/deflection of the structure.
b. Deflection is inversely proportional to stiffness of the structure, as stiffness increases deflection decreases.
c. Soft storey effect is maximum when soft storey is at ground i.e. first storey.(Ground i.e. first soft storey causes maximum damage, deflection during seismic conditions).

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d. Soft storey causes drastic change in stiffness of that storey respective of other storey of the structure, so there is more deflection of the structure at that level which causes failure of structure at that level under seismic activities.

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