Time History Analysis of Masonry Infilled RC Frames with soft storey and varying sizes of openings by Equivalent Diagonal Strut Method using E-Tabs software

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Abstract - *Masonry infill walls are constructed for functional requirements in most of the multi-storey buildings. The masonry infill walls are considered as non-structural elements even though they provide strength and stiffness to reinforced concrete (RC) framed buildings. However, in many cities of India, it is very common to leave the ground storey of masonry infilled RC frame building, open primarily to generate parking space or any other usage in the ground storey. Such buildings are highly undesirable in seismically active regions.*

In the present study, an attempt is made to assess the performance of masonry infilled RC frames with soft storey with and without openings. In this study, RC frame of ten storey (G+9) building located in seismic zone-V is considered. Equivalent Diagonal Strut Method is used to calculate the width of strut by using Mainstone formula. The time history analysis has been carried out on the various models such as bare frame, infill frame, ground soft storey infill frames and infill frames with 15, 30 & 45% central openings. Further, the infill models are replaced by equivalent diagonal Strut models. The analysis is performed using ETABS 2015 software from which various results are computed and compared such as story displacement, story drift, base shear, bending moment and lateral storey stiffness.

It is observed from the results that how infill panels increase the strength and stiffness of the structure. While, increase in the opening size leads to a decrease in the lateral stiffness of infilled and equivalent diagonal strut frames. The extent of decrease in lateral stiffness due to the presence of ground soft storey was also investigated.

***Key Words*: Masonry infilled frame, Soft story, Stiffness, Equivalent Diagonal Strut, Seismic Effect, Opening percentage, etc.**

1. INTRODUCTION

In multi storey buildings, maximum number of buildings in India are RC framed structures are constructed with masonry infills or brick infills for functional and architectural reasons. The masonry infilled reinforced concrete frame buildings are usually constructed for residential and commercial buildings in seismic regions. In masonry infills stiffness contributions are usually ignored in practice and masonry infills are generally considered as architectural [non-structural] elements.

Infilled frame can be a composite structure made by the combination of infill walls and moment resisting plane frame. The infills are used as internal partition walls and external walls and also infills are protecting the building from outside environment to our requirements. Infill walls along with the column and beam when the structure is subjected to earthquake load and also exhibit-dissipation characteristics under lateral loads. The presence of masonry infill has a resisting affect on the lateral load of a reinforced concrete frame building, which increases the stiffness and strength of the structure. An appropriately designed infilled frame can enhance the lateral resistance, overall strength and energy dissipation of the structure. An infill wall reduces the lateral deflection and bending moment in the frame, therefore decreasing the displacement value and probability of failure of the structure.

2. OBJECTIVES OF THE STUDY

The main objectives of the study are as follows

1. To study the non-linear behavior of RC frame building with masonry infill by time history analysis and comparing the bare frame and infilled frame.
2. To study the behavior of infilled frame by replacing the infill by equivalent diagonal strut.
3. To study the effect of soft storey infill frames subjected to seismic loads.
4. To study the effect of various sizes of openings subjected to seismic loads.

3. METHODLOGY

1. In the present thesis the non-linear behavior of RC frame building using the role of infill and equivalent diagonal strut are studied.
2. The importance of earthquake forces on ten storey building with and without the effect of brick infill with various sizes of opening for various parameters is proposed to be carried out and results of the various parameters are to be computed and discussed.

3. The effect of soft storey on the ground floor and effect of various sizes of opening on ten storey building is studied.
4. Time history analysis has been carried out using ETABS software.

4. REVIEW OF MACRO MODELS

4.1 EQUIVALENT DIAGONAL STRUT MODEL

The simplest equivalent strut model contains a single pin-jointed strut. Holmes (1961) who replaced the infill by an equivalent pin-jointed diagonal strut of same thickness and same material as that of infill panel and given from equation 4.1.

$$\frac{w}{d} = \frac{1}{3} \quad \ldots\ldots\ldots\ldots\ldots\ldots 4.1$$

The width of equivalent diagonal strut as suggested by Paulay and Priestley is shown in equation 4.2.

$$w = 0.25d \quad \ldots\ldots\ldots\ldots\ldots 4.2$$

Where,

w = Equivalent diagonal strut depth.
d = Diagonal span of infill panel

However, researchers later established that this model overestimates the actual stiffness of infilled frames and gives higher values. Further model for masonry infill panels was proposed by Mainstone in 1971, where the cross sectional area of strut was calculated in view of the sectional properties of the adjacent columns. The particulars of model are as shown in Fig. 4.1. The strut area A_s is specified by the following equation.

$$A_s = W\,t \quad \ldots\ldots\ldots\ldots\ldots 4.3$$

$$W = 0.175\,(\lambda\,H)^{-0.4}\,D \quad \ldots\ldots\ldots\ldots 4.4$$

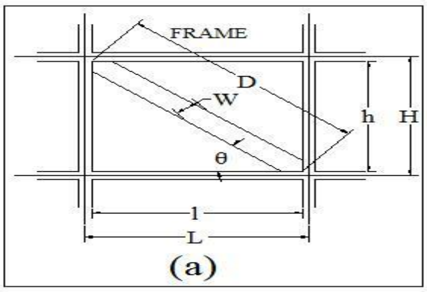

Fig 4.1 Brick Infill Panel as Equivalent Diagonal Strut

$$\lambda = \sqrt[4]{\frac{E_i t \sin(2\theta)}{4 E_f I_c h}} \quad \ldots\ldots\ldots\ldots 4.5$$

Where,

E_i = The young's modules of the infill material, N/mm^2
E_f = The young's modules of the frame material, N/mm^2
I_c = The second moment area of column, mm.^{4}
t = Thickness of infill panel, mm.
H = Centre line height of the frames.
h = Height of the infill wall.
L = Centre line length of frames.
l = Length of infill wall.
D = Diagonal length of the infill panel.
θ = Slope of the infill panel diagonal to the horizontal.

Infill frame with Openings: Area of opening, A_{op} is normalized by means of area of infill panel, A_{infill} and the fraction is termed as opening percentage (%).

$$\text{Opening percentage (\%)} = \frac{\text{Area of opening } (A_{op})}{\text{Area of infill } (A_{infill})}.$$

4.2 STRUT REDUCTION FACTOR

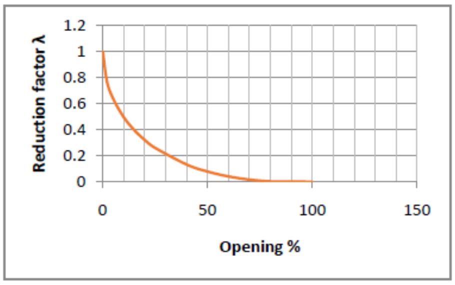

Fig 4.2 strut reduction curve

Reduction factor (λ) is given by,

$$\lambda = 1 - 2\alpha_w^{0.54} + \alpha_w^{1.14}$$

Where,

α_w = Opening percentage (%).

The above coefficient (Λ) can be used to find the width of equivalent diagonal strut for the case of an infill with opening by multiplying the width of infill without opening for central openings.

Width of strut without opening (W) = $0.175\,(\lambda\,H)^{-0.4}\,D$

Width of strut with central opening,

(W') = Strut reduction factor × W

Table 4.1 Equivalent diagonal strut width formula by various researchers

Researchers	Strut width (w)	Remark
Holmes (1961)	0.333 dm	dm is diagonal length of infill
Mainstone (1971)	0.175 D (λ1 H)- 0.4	λ1H=H[EmtSin2θ /4 EfIchm]$^{1/4}$
Liauw and Kwan(1981)	0.95 hm Cos θ/√(λhm)	λ = [EmtSin2θ/4EfIchm]$^{1/4}$
Paulay and Priestley(1992)	0.25 dm	dm is diagonal length of infill
Hendry (1998)	0.5[αh + αL]1/2	αh= π/2[EfIchm/2Emt sin2θ]1/4 and αL = π[EfIbL/ 2 Emtsin2θ]1/4

4.3 BUILDING DETAILS

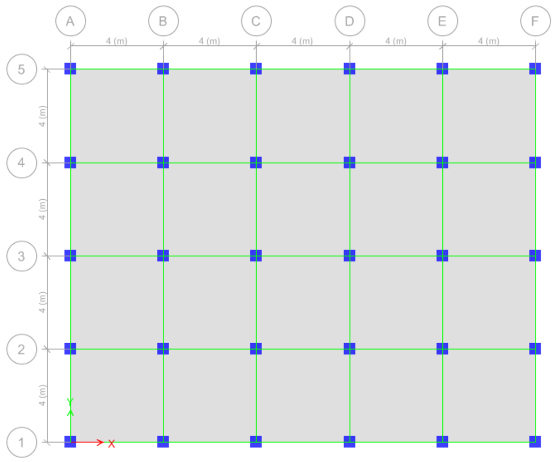

Fig.4.3 plan view of building

Table 4.2 Details of the model

Number of storey's	G+9
Height of each storey	3.0 m
Material property	
Grade of concrete	M30
Grade of steel	Fe 500
Density of concrete	25 KN/m^3
Density of brick wall	20 KN/m^3
Modulus of elasticity of concrete, Ec	27386.12 Mpa
Modulus of elasticity masonry, Em	5500 Mpa
Poisson ratio of concrete	0.2
Poisson ratio of brick wall	0.15
Member property	
Beam size	300 x 450 mm
Column size	500 x 500 mm
Thickness Slab	150 mm
Wall thickness	230 mm
Load intensities	
Live load	4 KN/m^2
Floor finish	1 KN/m^2
Seismic zone	V
Time history	Bhuj, Ahmedabad
Zone factor (Z)	0.36
Response Reduction Factor, R	5 (SMRF)
Importance factor, I	1.5
Type of soil	Medium
Damping of structure	5%

4.4 DIFFERENT MODELS CONSIDERED

Model 1: Bare frame
Model 2: Complete infill frame
Model 3: Complete equivalent diagonal strut frame
Model 4: Complete infill 15% opening
Model 5: Complete strut 15% opening
Model 6: Complete infill 30% opening
Model 7: Complete strut 30% opening
Model 8: Complete infill 45% opening
Model 9: Complete strut 45% opening
Model 10: Soft storey infill frame
Model 11: Soft storey strut frame
Model 12: Soft storey infill 15% opening
Model 13: Soft storey strut 15% opening
Model 14: Soft storey infill 30% opening
Model 15: Soft storey strut 30% opening
Model 16: Soft storey infill 45% opening
Model 17: Soft storey strut 45% opening

Table 4.3 Width of equivalent diagonal strut by various researches

Researchers	Strut width (w)
Holmes (1961)	1665mm
Mainstone (1971)	575mm
Liauw and Kwan(1981)	1039mm
Paulay and Priestley(1992)	1250mm
Hendry (1998)	1712mm

5. RESULTS AND DISCUSSION

5.1 Storey displacement

Table 5.1 Storey displacement of bare frame, infill frame and soft storey infill frame along x- direction

	BARE FRAME	C-INFILL FRAME	SOFT STOREY INFILL FRAME
Storey10	80	5.5	10.6
Storey9	76.7	5.1	10.1
Storey8	71.4	4.6	9.5
Storey7	64.4	4	8.9
Storey6	56	3.4	8.2
Storey5	46.6	2.8	7.5
Storey4	36.5	2.1	6.8
Storey3	26	1.5	6.1
Storey2	15.5	0.9	5.5
Storey1	5.7	0.4	4.8
Base	0	0	0

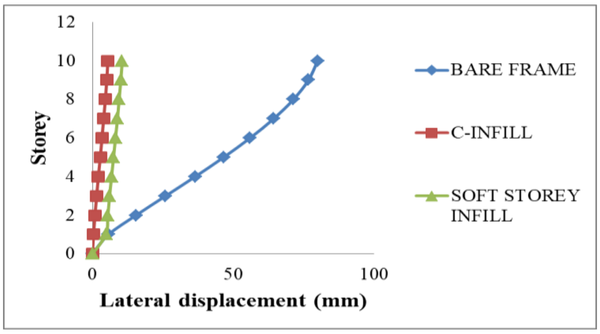

Fig 5.1 Variation of storey displacement of bare frame, infill frame and soft storey infill frame along x-direction

From Table 5.1 the maximum displacement in bare frame is 80mm and in complete infill frame is 5.5mm. Hence infill reduces the displacement along x-direction by 93% compared to the bare frame. The maximum displacement in ground soft storey infill frame is 10.6mm which is 48% high compared to the complete infill frame. Similarly the maximum displacement in complete equivalent diagonal strut frame is 15.3mm. From the results it is concluded that equivalent diagonal strut frame reduces the displacement by 80% compared to that of bare frame.

Table 5.2 Storey displacement of infill frames with various sizes of openings along x- direction

	C-infill	infill15% opening	infill 30% opening	infill 45% opening
Story10	5.5	7.3	10	13.8
Story9	5.1	6.7	9.4	13.1
Story8	4.6	6.1	8.6	12.1
Story7	4	5.4	7.6	10.8
Story6	3.4	4.6	6.6	9.4
Story5	2.8	3.8	5.5	7.8
Story4	2.1	3	4.3	6.2
Story3	1.5	2.2	3.2	4.6
Story2	0.9	1.4	2.1	3
Story1	0.4	0.7	1	1.5
Base	0	0	0	0

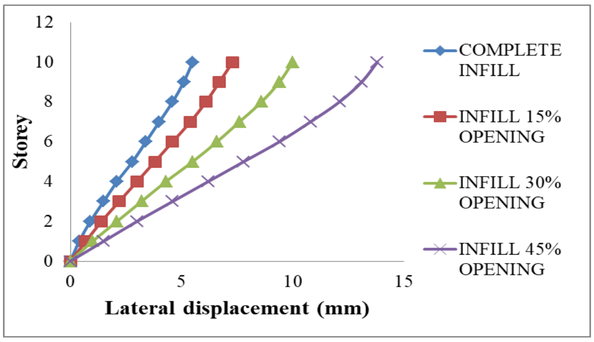

Fig 5.2 Variation of storey displacement of infill frames with various sizes of openings along x- direction

From Table 5.2 the maximum displacement in case of complete infill and infill with 15, 30 and 45% openings are 5.5, 7.3, 10 and 13.8mm respectively. Similarly the displacement in case of equivalent diagonal strut frame and strut frame with 15, 30 and 45% openings are 15.3, 27.3, 38.5 and 51.7mm respectively. From the results it is concluded that as the opening size increases displacement also increases in both infill and equivalent diagonal strut frames.

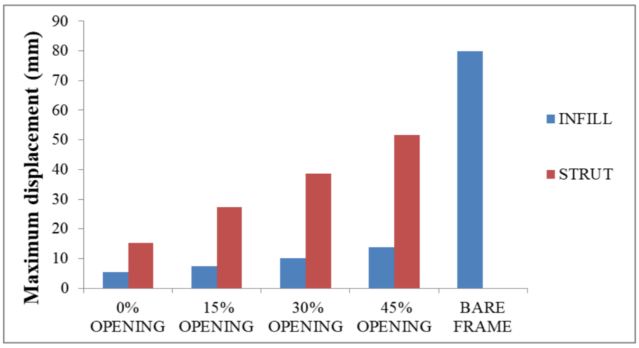

Fig 5.3 Comparison of maximum storey displacement of infill and strut frames with various sizes of openings along x-direction

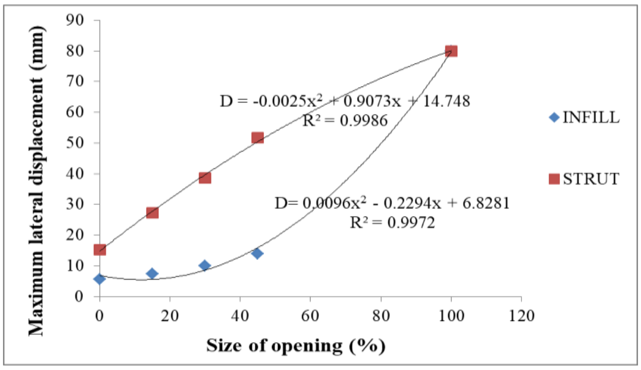

Fig 5.4 variation of maximum storey displacement of infill and strut frames with various sizes of openings

Table 5.3 Storey displacement of soft storey infill frames with various sizes of openings along x-direction

	Soft storey infill 0% opening	Soft storey 15% opening	Soft storey 30% opening	Soft storey 45% opening
Story10	10.6	12.2	14.3	17.3
Story9	10.1	11.6	13.6	16.5
Story8	9.5	11	12.8	15.5
Story7	8.9	10.2	11.8	14.2
Story6	8.2	9.4	10.8	12.8
Story5	7.5	8.5	9.6	11.2
Story4	6.8	7.7	8.5	9.6
Story3	6.1	6.8	7.3	8
Story2	5.5	6	6.2	6.4
Story1	4.8	5.1	5.2	5.2
Base	0	0	0	0

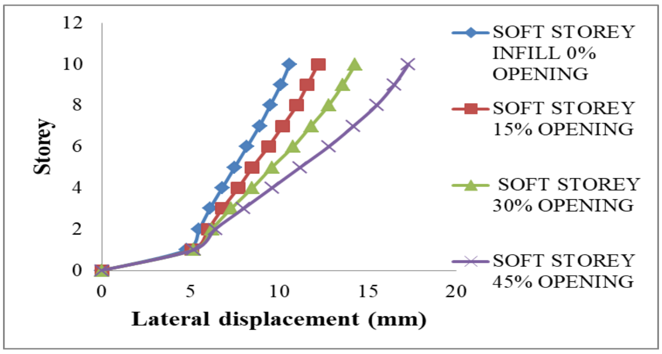

Fig 5.5 Variation of storey displacement of soft storey infill frames with various sizes of openings along x- direction

From Table 5.3 the displacement in case of ground soft storey infill frame with 15, 30 and 45% openings are 10.6, 12.2, 14.3 and 17.3mm respectively. Due to the presence of soft storey at first floor level there is drastic increase in storey displacement at first floor level. Similarly the displacement in case of soft storey equivalent diagonal strut frame with 0, 15, 30 and 45% openings are 18.5, 29.6, 40.3 and 52.9mm respectively. From the results it is concluded that as the opening size increases displacement also increases in both infill and equivalent diagonal strut frames. Due to the presence of soft storey at first floor level there is drastic increase in storey displacement at first floor.

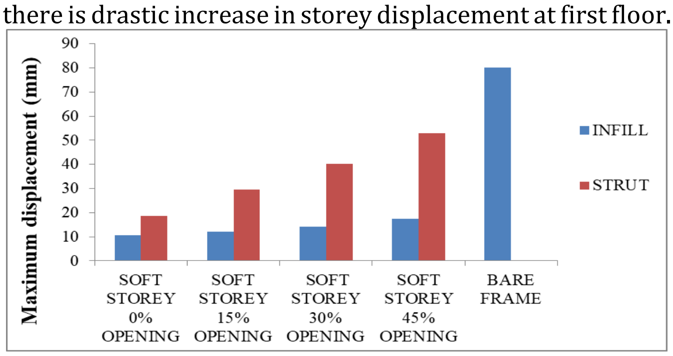

Fig 5.6 Comparison of maximum storey displacement of soft storey infill and soft storey strut frames with various sizes of openings in x- direction.

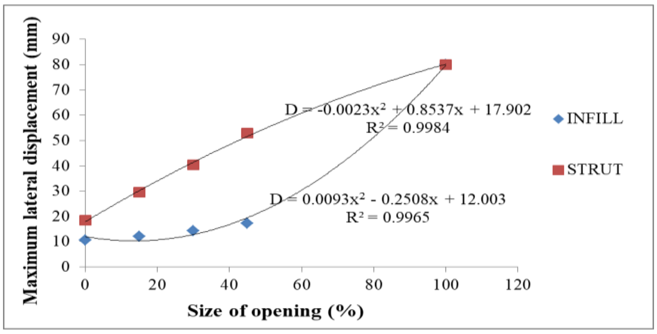

Fig 5.7 variation of maximum storey displacement of soft storey infill and strut frames with various sizes of openings

5.2 STOREY DRIFT

Table 5.4 Storey drift of bare frame, infill frame and soft storey infill frame in x-direction

	Bare frame	C-infill frame	Soft storey infill frame
Story10	0.0011	0.00014	0.00016
Story9	0.00175	0.00017	0.00019
Story8	0.00234	0.00019	0.00021
Story7	0.0028	0.00021	0.00023
Story6	0.00314	0.00021	0.00023
Story5	0.00337	0.00021	0.00023
Story4	0.0035	0.00021	0.00023
Story3	0.00351	0.00019	0.00021
Story2	0.00325	0.00017	0.00022
Story1	0.0019	0.00014	0.00161
Base	0	0	0

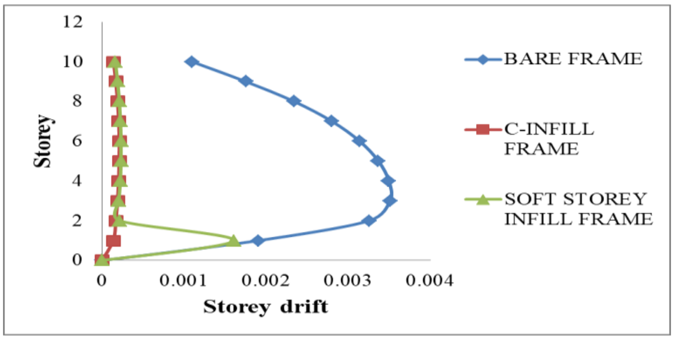

Fig 5.8 Variation of storey drift of bare frame, infill frame and soft storey infill frame in x- direction

From the results it is concluded that the infill reduces the storey drift in x-direction by 94% compared to the bare frame. The maximum storey drift in soft storey infill frame is 0.00161 which is 7.6 times more than complete infill frame. The storey drift of soft storey infill frame is 11.5 times greater than complete infill frame at first floor. Hence there is drastic increase in storey drift of the structure due to the presence of soft storey at first floor. Similarly equivalent diagonal strut reduces the storey drift in x-direction by 82%

compared to the bare frame. The maximum drift in soft storey equivalent diagonal strut frame is 0.00144 which is 2.36 times high compared to the complete strut frame. The storey drift of soft storey strut frame is 3.34 times more than complete strut frame at first floor. Hence there is drastic increase in storey drift of structure due to the presence of soft storey at ground floor.

Table 5.5 Storey drift of infill frames with various sizes of openings along x-direction

	Complete infill	Infill 15% opening	Infill 30% opening	Infill 45% opening
Story10	0.00014	0.00017	0.0002	0.00025
Story9	0.00017	0.00021	0.00027	0.00035
Story8	0.00019	0.00024	0.00032	0.00042
Story7	0.00021	0.00026	0.00035	0.00048
Story6	0.00021	0.00027	0.00037	0.00052
Story5	0.00021	0.00028	0.00038	0.00054
Story4	0.00021	0.00027	0.00038	0.00054
Story3	0.00019	0.00026	0.00037	0.00053
Story2	0.00017	0.00023	0.00035	0.00051
Story1	0.00014	0.00021	0.00032	0.00048
Base	0	0	0	0

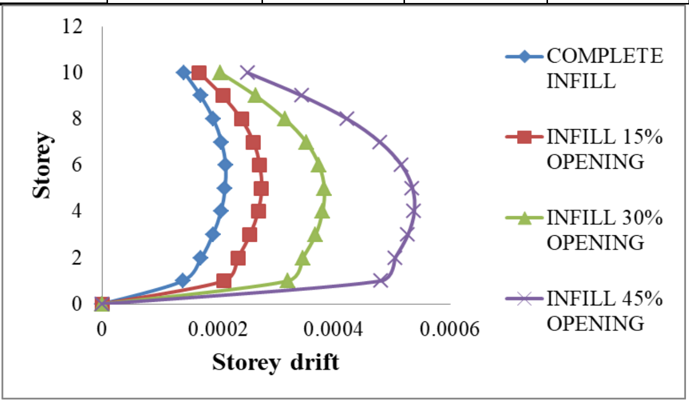

Fig 5.9 Variation of storey drift of infill frames with various sizes of openings along x- direction

From Table 5.5 the maximum storey drift in case of complete infill and infill with 15, 30 and 45% openings are 0.00021, 0.00028, 0.00038 and 0.00054 respectively. Similarly the storey drift in case of complete equivalent diagonal strut frame and strut with 15, 30 and 45% openings are 0.00061, 0.00112, 0.00162and 0.00222 respectively. From the results it is concluded that as the opening sizes increases storey drift also increases.

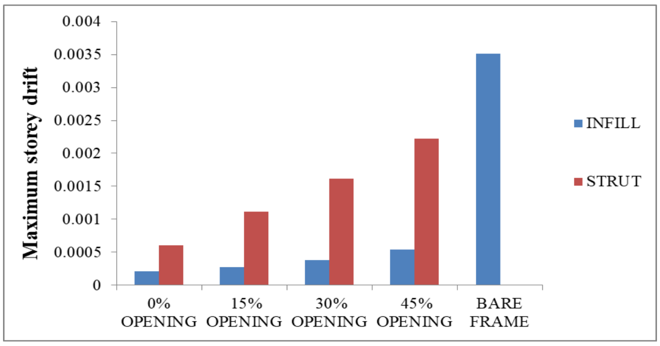

Fig 5.10 Comparison of maximum storey drift of infill and strut frames with various sizes of openings along x-direction.

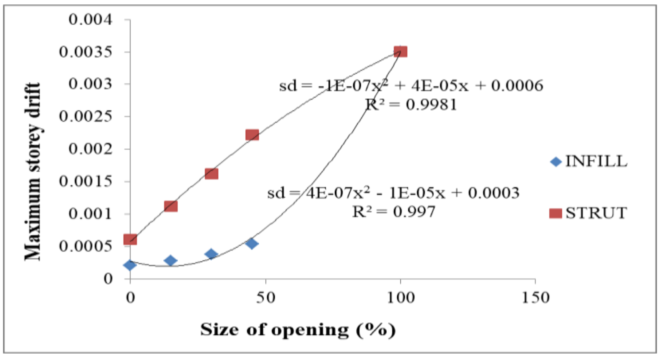

Fig 5.11 variation of maximum storey drift of infill and strut frames with various sizes of openings

Table 5.6 Storey drift of soft storey infill frames with various sizes of openings along x-direction

	Soft storey infill 0% opening	Soft storey infill 15% opening	Soft storey infill 30% opening	Soft storey infill 45% opening
Story10	0.00016	0.00018	0.00021	0.00026
Story9	0.00019	0.00022	0.00027	0.00035
Story8	0.00021	0.00025	0.00032	0.00043
Story7	0.00023	0.00027	0.00036	0.00048
Story6	0.00023	0.00029	0.00038	0.00052
Story5	0.00023	0.00029	0.00039	0.00054
Story4	0.00023	0.00028	0.00039	0.00054
Story3	0.00021	0.00027	0.00038	0.00053
Story2	0.00022	0.0003	0.00043	0.0006
Story1	0.00161	0.00171	0.00173	0.00183
Base	0	0	0	0

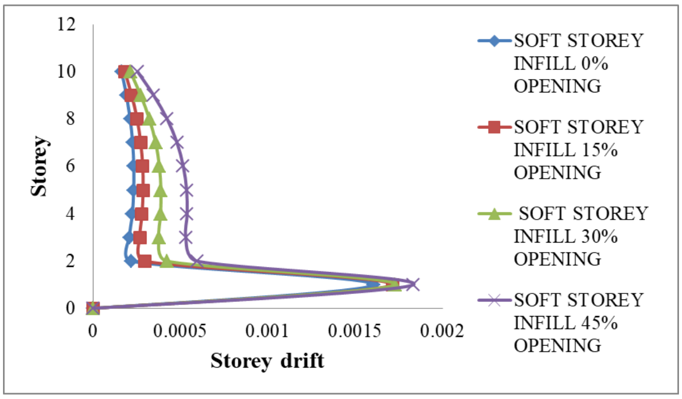

Fig 5.12 Variation of storey drift of soft storey infill frames with various sizes of openings along x- direction

From Table 5.6 the storey drift in case of soft storey infill frames with 0, 15, 30 and 45% openings are 0.00161, 0.00171, 0.00173 and 0.00183 respectively. Due to the presence of soft storey, storey drift is maximum in first floor level compared to other floors. Similarly the storey drift in case of soft storey equivalent diagonal strut frame with 0, 15, 30 and 45% openings are 0.00144, 0.00147, 0.00176 and 0.00237 respectively. From the results it is concluded that as the opening sizes increases storey drift also increases. Due to the presence of soft storey, Storey drift is maximum in first floor compared to other floors.

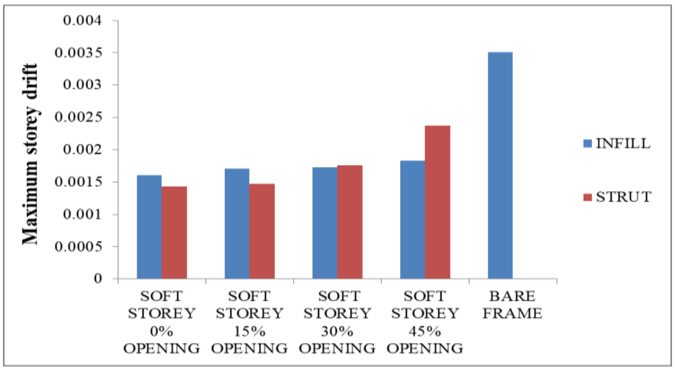

Fig 5.13 Comparison of maximum storey drift of soft storey infill and strut frames with various sizes of openings along x-direction

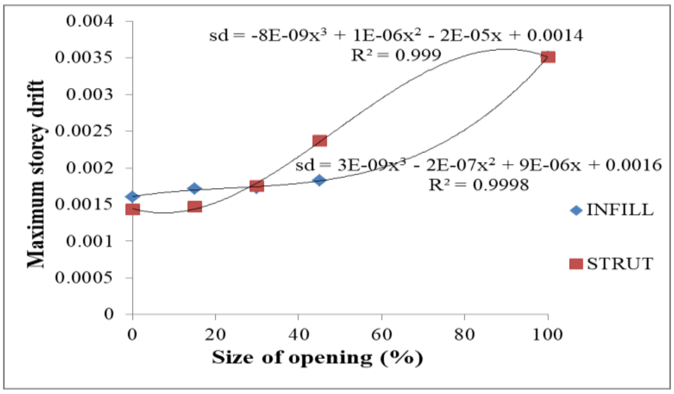

Fig 5.14 variation of maximum storey drift of soft storey infill and strut frames with various sizes of openings

5.3 BASE SHEAR

Table 5.7 Base shear of bare frame, infill frame and equivalent diagonal strut frame along x-direction

MODELS	BASE SHEAR (kN)	
	INFILL	STRUT
BARE FRAME	4106	4106
COMPLETE	7678	4969
SOFT STOREY	7490	4924

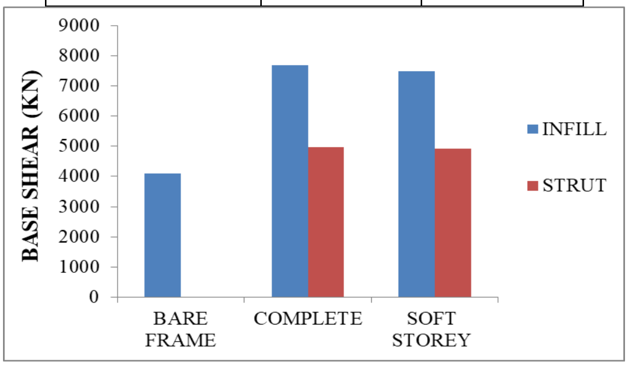

Fig 5.15 Comparison of base shear of bare frame, infil frame and equivalent diagonal strut frame along x- direction

From the results it is concluded that Infill and equivalent diagonal strut increases the base shear of structure by 87% and 21% compared to bare frame respectively. Therefore, both infill and equivalent diagonal strut frame increases base shear of the structure. However, the base shear of infill frame is 54% more than equivalent diagonal strut frame. Hence the base shear is more in infill frame compared to equivalent diagonal strut frame. From the results it is also concluded that the base shear decreases in soft storey infill and soft storey equivalent diagonal strut frames by 2% and 1% respectively compared to complete infill and complete equivalent diagonal strut frame.

Table 5.8 Base shear of infill and strut frames with various sizes of openings along x-direction

OPENING PERCENTAGE	BASE SHEAR (kN)	
	INFILL	STRUT
0	7678	4969
15	7142	4448
30	6606	4287
45	6070	4195
BARE FRAME	4106	4106

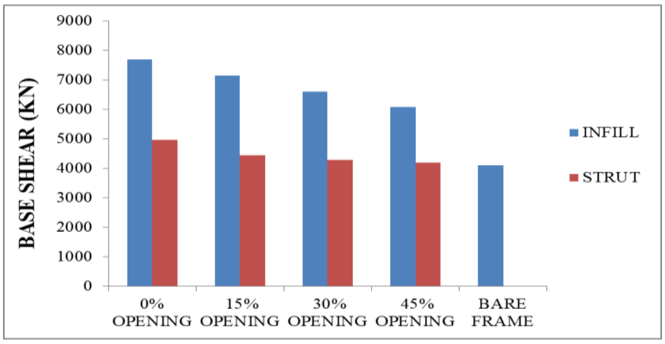

Fig 2.16 Comparison of base shear of infill and strut frames with various sizes of openings along x-direction

From the results it is concluded that as the opening sizes increases base shear decreases in both infill and equivalent diagonal strut frame. However, the base shear of infill frame with 0, 15, 30, and 45% openings is 54, 60, 54 and 45% higher than equivalent diagonal strut frame respectively. Hence the base shear is more in infill frame compared to equivalent diagonal strut frame.

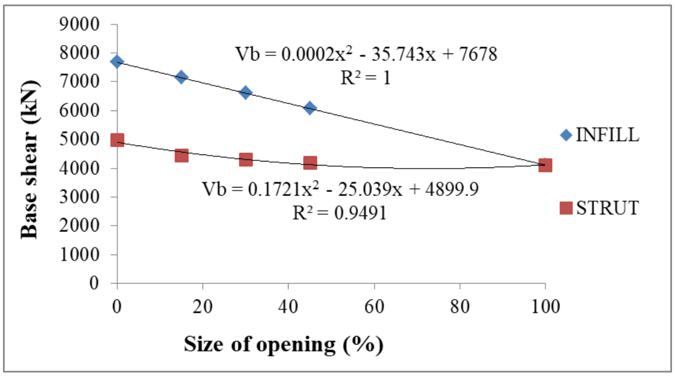

Fig 5.17 variation of base shear of infill and strut frames with various sizes of openings

Table 5.9 Base shear of soft storey infill and strut frames with various sizes of openings along x-direction.

OPENING PERCENTAGE	BASE SHEAR (KN)	
	INFILL	STRUT
0	7490	4924
15	6982	4430
30	6475	4278
45	5967	4190
BARE FRAME	4106	4106

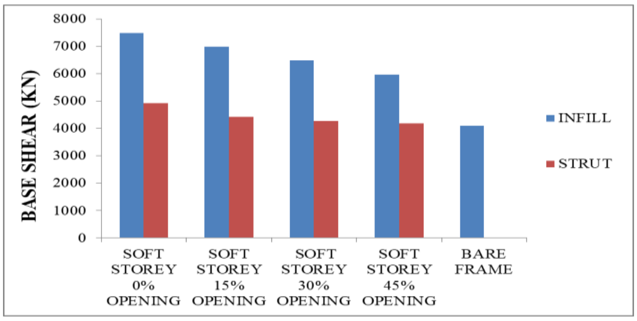

Fig 5.18 Comparison of base shear of soft storey infill and strut frames with various sizes of openings along x-direction

From the results it is concluded that as the opening sizes increases base shear is decrease in both infill and equivalent diagonal strut frame. However, the base shear of soft storey infill frame with 0, 15, 30, and 45% openings is 52, 57, 51 and 42% higher than soft storey equivalent diagonal strut frame respectively. Hence the base shear is more in soft storey infill frame compared to soft storey equivalent diagonal strut frame.

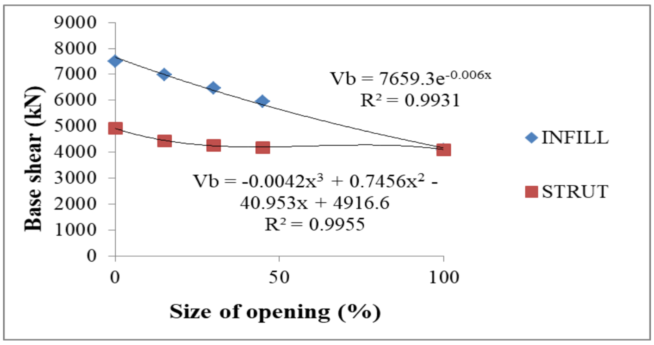

Fig 5.19 variation of base shear of soft storey infill and soft storey strut frames with various sizes of openings

5.4 TIME PERIOD

Table 5.10 Time period of bare frame, infill frame and equivalent diagonal strut frame

TIME PERIOD (sec)		
	INFILL	STRUT
BARE FRAME	1.141	1.141
COMPLETE	0.307	0.544
SOFT STOREY	0.472	0.609

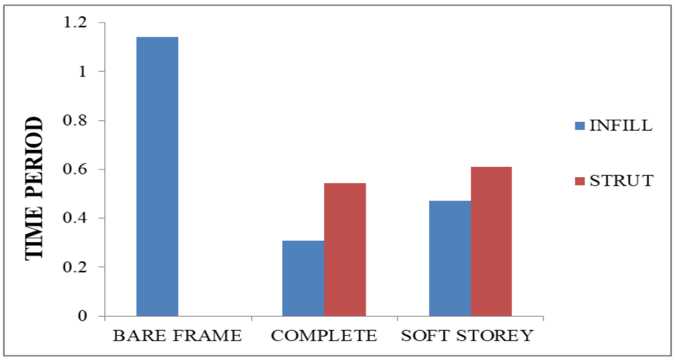

Fig 5.20 Comparison of time period of bare frames, infill frame and equivalent diagonal strut frames

From the results it is concluded that Infill and equivalent diagonal strut frames reduces the time period of structure compared to that of bare frame. The time period of complete infill frame is 43% less compared to complete equivalent diagonal strut frame. From the results it is also concluded that the time period increases in soft storey infill and soft storey equivalent diagonal strut frames compared to complete infill and complete equivalent diagonal strut frame. However, time period in case of soft storey infill frame is 22% less compared to soft storey equivalent diagonal strut frame.

Table 5.11 Time period of infill and strut frame with various sizes of openings

OPENING PERCENTAGE	TIME PERIOD (sec)	
	INFILL	STRUT
0	0.307	0.544
15	0.343	0.694
30	0.392	0.811
45	0.446	0.93
BARE FRAME	1.141	1.141

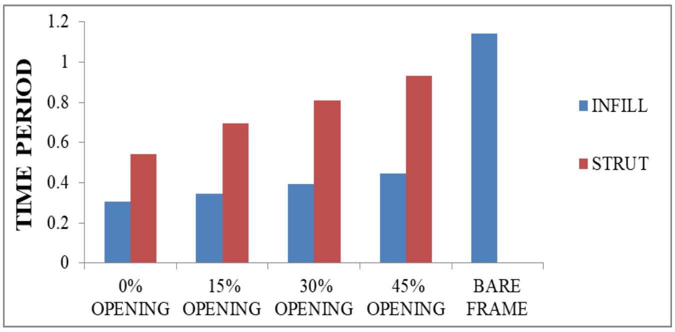

Fig 5.21 Comparison of time period of infill and strut frame with various sizes of openings

From the results it is concluded as the opening sizes increases time period also increases in both infill and strut frames. However, the time period of infill frame with 0, 15, 30, and 45% openings is 38, 47, 49 and 50% less compared to equivalent diagonal strut frame respectively

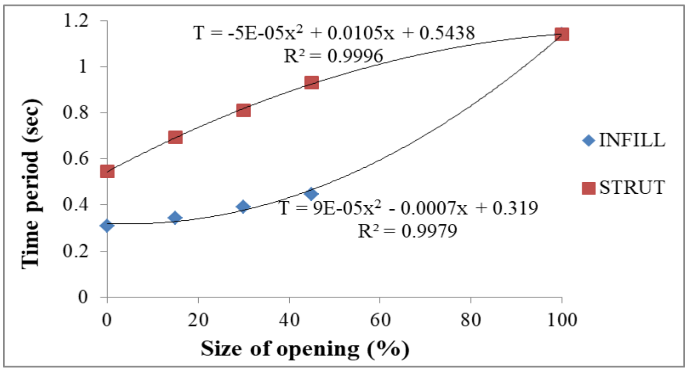

Fig 5.22 variation of time period of infill and strut frames with various sizes of openings

Table 5.12 Time period of soft storey infill and strut frame with various sizes of openings

OPENING PERCENTAGE	TIME PERIOD (sec)	
	INFILL	STRUT
0	0.472	0.609
15	0.502	0.733
30	0.529	0.837
45	0.568	0.945
BARE FRAME	1.141	1.141

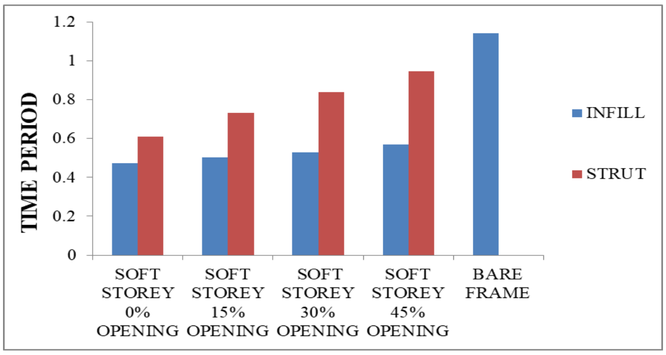

Fig 5.23 Comparison of time period of soft storey infill and strut frames with various sizes of openings

From the results it is concluded that as the opening sizes increases time period also increases. However, the time period of soft storey infill frame with 0, 15, 30, and 45% openings is 22, 31, 37 and 40% less compared to equivalent diagonal strut frame respectively.

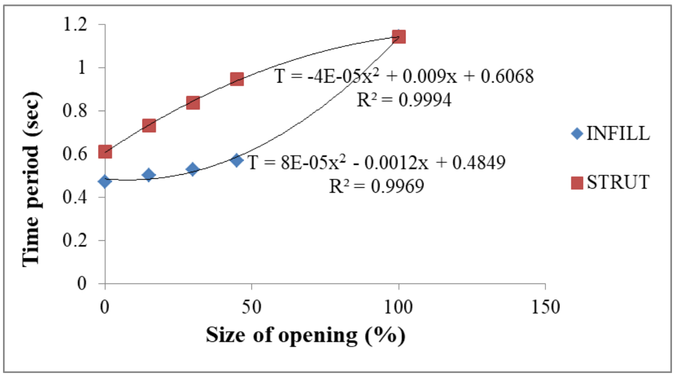

Fig 5.24 variation of time period of soft storey infill and soft storey strut frames with various sizes of openings

5.5 BENDING MOMENT OF COLUMN

Table 5.13 Bending moment of bare frame, infill frame and soft storey infill frame along x-direction

BENDING MOMENT OF COLUMN (kN-m)			
	Bare frame	C-infill	Soft storey infill
Story10	51.0213	4.1272	4.3023
Story9	78.2187	6.769	6.7775
Story8	106.839	11.9656	11.861
Story7	144.646	16.0766	15.8961
Story6	180.166	19.3172	19.0926
Story5	206.822	21.7096	21.4593
Story4	225.578	23.2921	23.0923
Story3	238.184	24.1079	23.5918
Story2	247.182	24.2661	26.8492
Story1	265.131	22.8489	18.1795
Base	324.231	29.8123	397.473

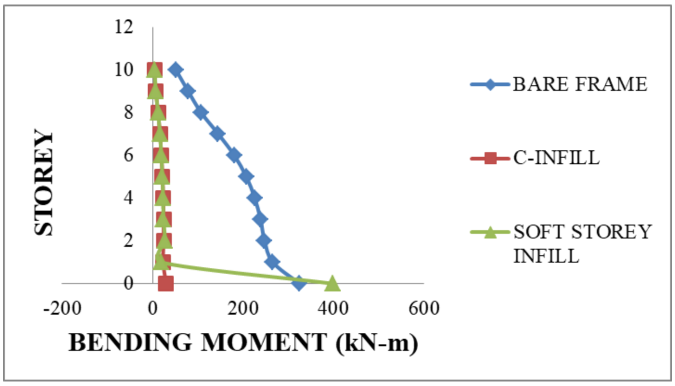

Fig 5.25 Variation of bending moment of bare frame, infill frame and soft storey infill frame along x-direction

From the results it is concluded that infill reduces the bending moment of column by 91% compared to the bare frame. The maximum bending moment in soft storey infill frame is 397.473kN-m which is 92% high compared to the complete infill frame. In case of soft storey infill frame bending moment of first floor is 95% less compared to ground floor. Hence there is a drastic increase in bending moment of the column due to the presence of soft storey at ground level. It is also concluded from the result that equivalent diagonal strut frame reduces the bending moment of column by 81% compared to the bare frame. The maximum bending moment in soft storey equivalent diagonal strut frame is 299.947KN-m which is 79% high compared to the complete equivalent diagonal strut frame. In case of soft storey frame the bending moment of first floor is 88% less compared to ground floor.

Table 5.14 Bending moment of infill frames with various sizes of openings along x-direction

BENDING MOMENT OF COLUMN (KN-m)					
	Bare frame	C-infill	Infill 15% opening	Infill 30% opening	Infill 45% opening
Story10	51.0	4.1	4.2	7.03	17.7
Story9	78.2	6.7	8.2	10.5	22.6
Story8	106	11.9	15.6	17.8	37.2
Story7	144	16.0	18.2	23.8	49.4
Story6	180	19.3	22.2	28.5	58.7
Story5	206	21.7	24.8	31.9	65.4
Story4	225	23.2	28.0	34.2	69.7
Story3	238	24.1	30.8	35.3	71.8
Story2	247	24.2	30.2	35.6	72.5
Story1	265	22.8	31.6	35.2	71.1
Base	324	52.4	101.4	132.1	157.6

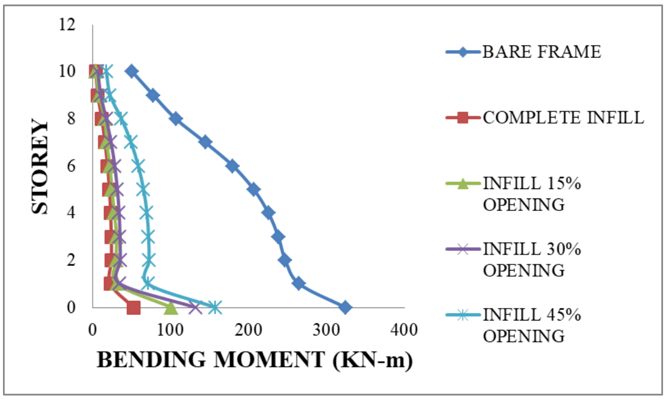

Fig 5.26 Variation of bending moment of infill frames with various sizes of openings along x-direction

From Table 5.14 the maximum bending moment in case of complete infill and infill with 15, 30 and 45% openings are 52.487, 101.498, 132.187 and 157.689kN-m respectively. Similarly the maximum bending moment in case of complete equivalent diagonal strut frame and strut with 15, 30 and 45% openings are 73.199, 137.95, 186.62 and 235.69kN-m respectively. From the results it is concluded that as the opening sizes increases bending moment of column also increases in both infill and equivalent diagonal strut frames.

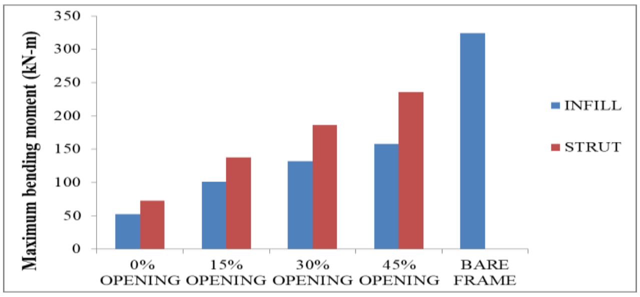

Fig 5.27 comparison of maximum bending moment of infill and strut frame with various sizes of openings along x-direction

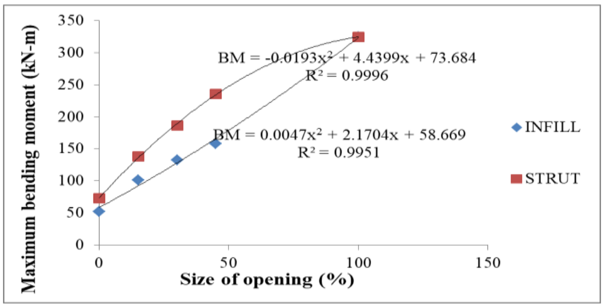

Fig 5.28 variation of maximum bending moment of infill and strut frame with various sizes of openings along x-direction

Table 5.15 Bending moment of soft storey infill frames with various sizes of openings along x-direction

BENDING MOMENT OF COLUMN (kN-m)				
	Soft storey infill 0% opening	Soft storey 15% opening	soft storey 30% opening	Soft storey 45% opening
Story10	4.3023	3.1718	7.2464	18.1196
Story9	6.7775	8.1058	10.5182	23.6017
Story8	8.861	10.6546	17.6895	37.0236
Story7	11.4922	15.8961	23.6337	48.974
Story6	13.7154	19.0926	28.2426	58.1763
Story5	15.361	21.4593	31.6056	64.7975
Story4	16.4621	23.0923	33.8016	69.0134
Story3	23.5918	23.4297	34.981	71.2496
Story2	19.8492	25.7604	34.3512	70.8446
Story1	13.1795	128.053	124.875	111.197
Base	397.473	390.809	366.657	341.956

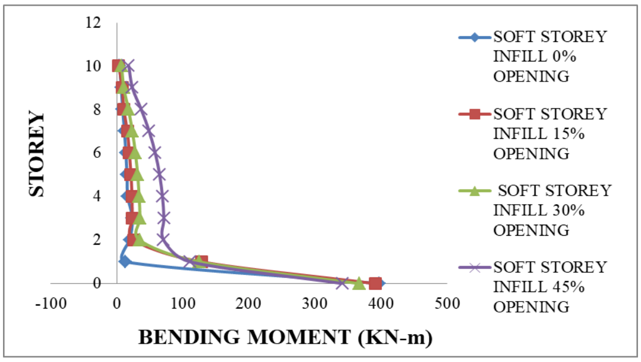

Fig 5.29 Variation of bending moment of soft storey infill frames with various sizes of openings along x-direction

From the results it is concluded that as the opening sizes increases bending moment of column also increases in both infill and equivalent diagonal strut frames. Due to presence of soft storey the bending moment value are higher at ground floor level compared to other floors.

Fig 5.39 comparison of maximum bending moment of infill and strut frame with various sizes of openings along x-direction

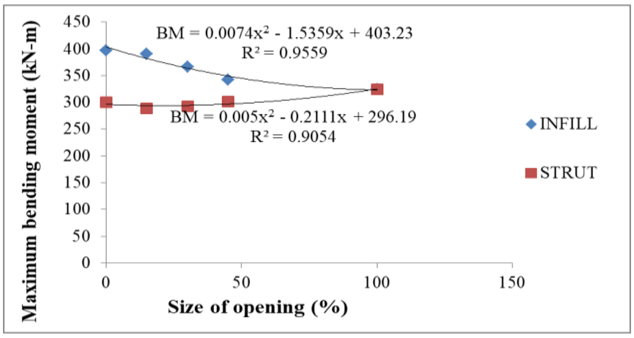

Fig 5.30 variation of maximum bending moment of infill and strut frame with various sizes of openings along x-direction

5.6 Lateral storey stiffness

Table 5.16 Storey stiffness of bare frame, infill frame and soft storey infill frame along x-direction

	Bare frame	C-infill	Soft storey infill
Storey 10	300432	3612372	3048001
Storey 9	356553	6429111	5566150
Storey 8	366647	8093604	7113711
Storey 7	370066	9246701	8193564
Storey 6	372091	10174434	9046291
Storey 5	374013	11051605	9823291
Storey 4	376951	12019566	10624374
Storey 3	384916	13246810	11774460
Storey 2	419548	14912038	11319643
Storey 1	719715	18545965	1554776

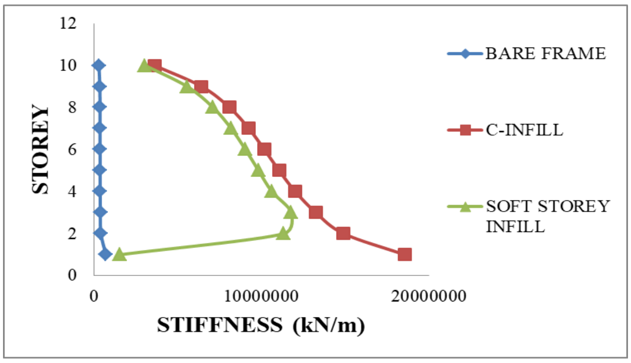

Fig 5.31 Variation of storey stiffness of bare frame, infill frame and soft storey infill frame along x-direction

The storey stiffness in an infill frame is increasesd by 25 times compared to bare frame. The storey stiffness in soft storey infill frame is 12 times less compared to the complete infill frame. Similarly The storey stiffness of equivalent diagonal strut frame is 4.26 times higher compared to that of bare frame. The storey stiffness in soft storey strut frame is 2 times less compared to the complete equivalent diagonal strut frame at ground floor. From the results it is concluded that infill and diagonal strut increases stiffness of the structure and there is a drastic decrease in storey stiffness due to the presence of soft storey at ground floor level.

Table 5.17 Storey stiffness of infill frames with various sizes of openings along x-direction

Storey	C-infill	Infill 15% opening	Infill 30% opening	Infill 45% opening
10	3612372	2617644	1972709	1457450
9	6429111	4616304	3303288	2313223
8	8093604	5818508	4042061	2758072
7	9246701	6659979	4536310	3044768
6	10174434	7348343	4924054	3260317
5	11051605	7990653	5278190	3453061
4	12019566	8664394	5634166	3642602
3	13246810	9522209	6075957	3866424
2	14912038	10454312	6464930	4025963
1	18545965	11680632	6989099	4258128

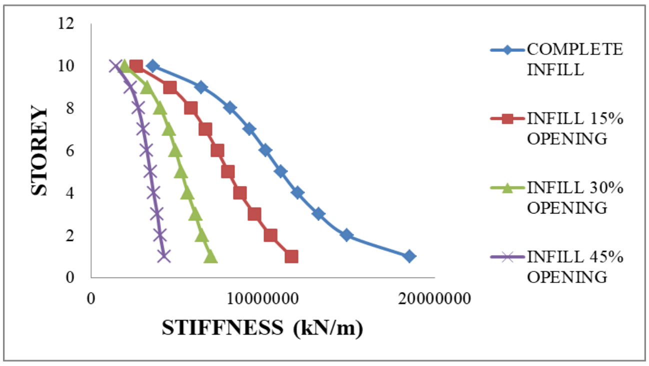

Fig 5.32 Variation of storey stiffness of infill frames with various sizes of openings along x-direction

From Table 5.17 the maximum storey stiffness in case of complete infill frame and infill with 15, 30 and 45% openings are 18545965, 11680632, 6989099 and 4258128 kN/m respectively. Similarly the maximum storey stiffness in case of complete equivalent diagonal strut frame and strut with 15, 30 and 45% openings are 3071371, 1725894, 1276224 and 1003612 kN/m respectively. From the result it is concluded that as the opening sizes increases storey stiffness decreases.

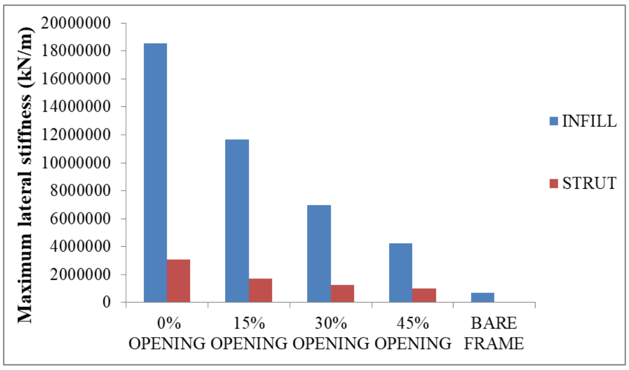

Fig 5.33 comparison of storey stiffness of infill and strut frames with various sizes of openings along x-direction

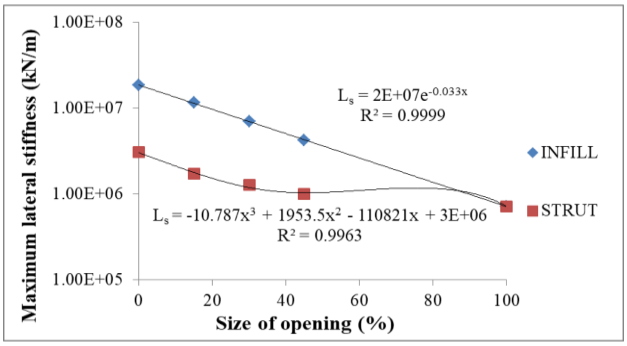

Fig 5.34 variation of storey stiffness of infill and strut frame with various sizes of openings along x-direction

Table 5.18 Storey stiffness of soft storey infill frames with various sizes of openings along x-direction

Storey	Soft storey infill	Soft storey infill 15% opening	soft storey infill 30% opening	Soft storey infill 45% opening
10	3048001	2378200	1859737	1412425
9	5566150	4258093	3149459	2257464
8	7113711	5413129	3877575	2701335
7	8193564	6224352	4366079	2987764
6	9046291	6880187	4746688	3202608
5	9823291	7480549	5087821	3391748
4	10624374	8096185	5422378	3574093
3	11774460	9613476	5686271	3530761
2	11319643	7852000	5062715	3323167
1	1554776	1359604	1326153	1299629

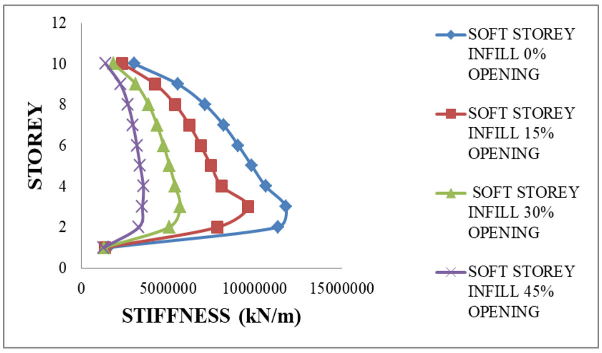

Fig 5.35 Variation of storey stiffness of soft storey infill frames with various sizes of openings along x-direction

From Table 5.18 the maximum storey stiffness in case of soft storey infill frames with 0, 15, 30 and 45% openings are 1554776, 1359604, 1326153 and 1299629 kN/m respectively. From the result it is concluded that as the opening sizes increases storey stiffness is decreases in both infill and equivalent diagonal strut frames. Due to presence of soft storey, the storey stiffness is decreases in ground floor compared to above floor level.

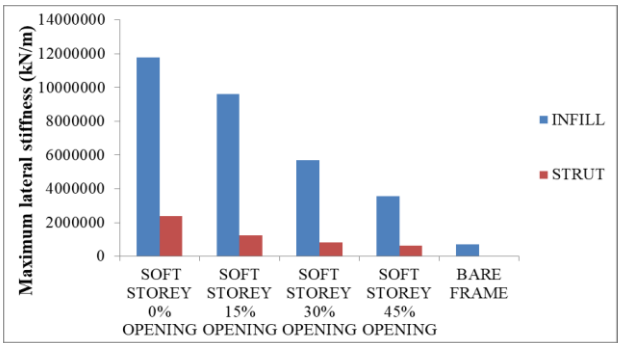

Fig 5.36 comparison of storey stiffness of soft storey infill and strut frames with various sizes of openings along x-direction

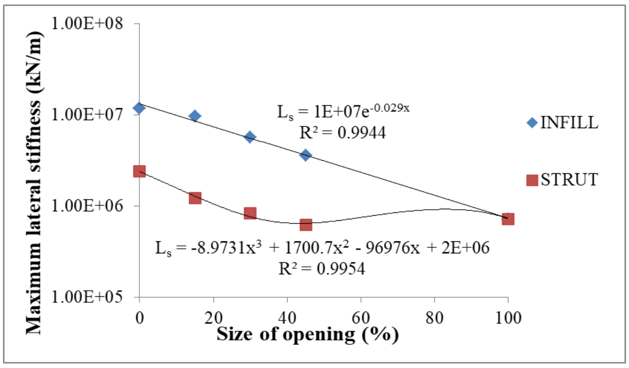

Fig 5.37 variation of storey stiffness of soft storey infill and strut frame with various sizes of openings

CONCLUSIONS

From the time history analysis of ten storey RC building following conclusions are obtained.

a) Storey displacement

1. Infill and equivalent diagonal strut reduces the displacement of the structure by 93% and 80% compared to bare frame.

2. Due to the presence of soft storey at first floor, displacement at soft storey is 12 and 3.3 times greater than complete infill and complete diagonal strut frames respectively. It can be concluded from the above results that, displacement in case of soft storey is increased drastically.

3. It can be concluded from the above results that as the opening sizes increases, displacement also increases in both infilled and equivalent diagonal strut frames.

b) Storey drift

1. Infill and diagonal strut frames decreases the storey drift value by 94 and 82% compared to that of bare frame respectively. It can be concluded from the

above results that, infill and diagonal strut decreases the storey drift value of the structure.

2. The maximum storey drift of soft storey infill and soft storey diagonal strut frames are 7.6 and 2.36 times greater compared to complete infill and complete strut frames respectively.

3. It can be concluded from the above results that, as the opening sizes increases storey drift also increases.

c) Base shear

1. The base shear of infill and equivalent diagonal strut frames are 87 and 21% greater compared to bare frame respectively. It can be concluded from the above results that, infill and equivalent diagonal strut frames increases base shear of the structure compared to bare frame.

2. It can be concluded from the above results that, due to the presence of soft storey, base shear is decreases in both infill and strut frames.

3. It can be concluded from the above results that, as the opening size increases base shear decreases in both infill and diagonal strut frames.

d) Time period

1) Infill and diagonal strut reduces the time period of the structure compared to that of bare frame.

2) Time period of soft storey infill and soft storey diagonal strut frames are 0.472 and 0.609s respectively. From the results it is concluded that time period for ground soft storey frame is increases in both infill and diagonal strut frames.

3) It can be concluded from the results that as the opening size increases time period also increases.

e) Bending moment of column

1. It can be concluded from the above results that, infill and equivalent diagonal strut frames reduces the bending moment of column by 91 and 81% compared to that of bare frame respectively.

2. The bending moment of soft storey infill and soft storey equivalent diagonal strut frames are 92 and 79% greater compared to complete infill and complete diagonal strut frames respectively. From the results it is concluded that soft storey increases the bending moment of the structure.

3. It can be concluded from the above results that, as the opening size increases bending moment of column also increases and beyond 45% opening bending moment of column behaves like bare frame.

f) Lateral storey stiffness

1) The lateral stiffness of infilled frame and equivalent diagonal strut frames are 25 and 4.26 times greater compared to that of bare frame respectively. It can be concluded from the above results that, infill and equivalent diagonal strut frames increases the lateral stiffness of the structure.

2) It can be concluded from the above results that, soft storey decreases the lateral stiffness of the structure.

3) The increase in opening sizes leads to the decrease on lateral stiffness of both infilled frame and equivalent diagonal strut frame and it is found that stiffness increases in fully infilled frame compared to the infilled frame with openings.

Studying the above all parameters we concluded that, infilled and diagonal strut frames increases the strength and stiffness of the structure compared to bare frame structure.

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