STUDY ON BEHAVIOUR OF RC STRUCTURE WITH INFILL WALLS DUE TO SEISMIC LOADS

Yadunandan C[1], Kiran Kuldeep K N[2]

[1] P.G. Student, Civil Engineering Department, Sri Jagadguru Balagangadharanatha Institute of Technology, Bengaluru - 560060, Karnataka, India
[2] Assistant Professor, Civil Engineering Department, Sri Jagadguru Balagangadharanatha Institute of Technology, Bengaluru - 560060, Karnataka, India

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Abstract – *Since long masonry infill are being used to fill up the voids between the horizontal and vertical structural elements such as beams and columns. They are treated as non-structural elements and they are not considered during the analysis and design of the structure. But, when laterally loaded they tends to interact with the RC frame, changing the structural behaviour. However, infill walls contribute to lateral stiffness and seismic resistance to the building. In this study, an attempt is being made to incorporate the masonry infill in the form of Equivalent diagonal strut whose width is calculated using the various relations proposed by the researches. A general review of the relations proposed by the researches in calculating the width of the Equivalent diagonal strut is being made and compared. The paper also focuses to study the behaviour of bare frame and infilled frame. The aim of this research work is to present a comparative study and analysis of G+3 story building with and without opening and soft story by performing linear dynamic analysis using ETABS software .Results for base shear, story drift, lateral loads, story displacement, column forces and time period are compared for different models*.

Key Words: Masonry infill, *Infill opening, Soft story, Equivalent diagonal strut Response spectrum analysis.*

1. INTRODUCTION

RC moment resisting frame buildings are the most preferred type of construction in developing countries like India. RC moment resisting frame buildings consist of moment resisting frame with masonry wall as Infill's. These walls are considered as nonstructural elements in construction practices. In present day practice of building design, buildings are designed as framed structures while effect of infill masonry walls is ignored and considered as nonstructural elements. Due to the above reason, buildings behave in different manner with infill wall when compared with only moment resisting frames. In past four decades, through lots of analytical and experimental studies importance of brick infill has been recognized however its strength and stiffness contribution has been neglected by considering it as nonstructural elements.

Another important aspect concerns the numerical simulation of the infilled frames. The structural model can be idealized by different techniques and can be divided into micro model and macro model. In the present paper the masonry infill wall is modeled has "Equivalent diagonal strut" considering the strength and stiffness of brick masonry infill .This strut is designed in such a manner that it only carries compression.

2. OBJECTIVES

- To study the behaviour of RC frame with brick infill by modeling infill as a diagonal strut.
- Understand the suitability of different macro models available for considering the infill effects in reinforced concrete infilled frames.
- Investigate the contribution of masonry infill walls to lateral strength and lateral stiffness of the building.
- To study the effect of opening and soft story on the performance of masonry infilled RC framed structures.

3. METHODOLOGY

- In the present study, the RC members and masonry infill Walls are modeled using ETABS software.
- The analytical macro models are modeled and analyzed for linear dynamic analysis.
- Response spectrum method of analysis is adopted for the analysis of infilled frame with and without opening and soft story and the results are compared.

4. REVIEW OF MACRO MODELS

4.1 EQUIVALENT DIAGONAL STRUT MODEL

The existence of infill influences the distribution of lateral loads on the framed structures due to the increase in stiffness. The investigation of interaction of infill with frames has been endeavored by utilizing many analyses like theory of elasticity or finite element analysis. Because of complexity and uncertainty in defining the interaction between infills and the frames, several approximate methods are being developed. A prominent among the most prevalent and known approaches is by replacing masonry infill by equivalent diagonal struts, the thickness of which is equal to the thickness of masonry infills. The primary issue with this approach is to find the effective width. Numerous Scientists have proposed different techniques for determining the width of equivalent diagonal strut. Strut width leans on the length of contact between the columns and the wall (αh) and between the beam and wall (αL).

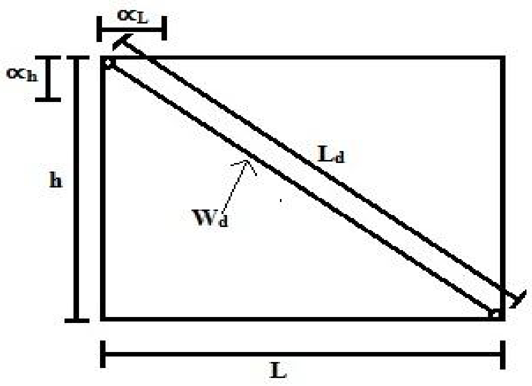

Fig -1: Equivalent diagonal strut model

4.1.1 Holmes Model

Holmes (1963) took the idea from Polyakov (1956) and stated that infilled walls can be replaced by a equivalent diagonal strut which has the same thickness and material as the infill wall.

$$b_w = d_w/3$$

Where, d_W= Diagonal length of the panel

4.1.2 Stafford Smith and Carter model

Stafford Smith and Carter (1969) have proposed a theoretical relationship for the width of the diagonal strut on the basis of relative stiffness of infill and frame.

$$w = 0.58 \left(\frac{1}{H}\right)^{-0.445} (\lambda_h H_{inf})^{0.335.d_{inf}\left(\frac{1}{H}\right)^{0.064}}$$

$$\lambda_h = \sqrt[4]{\frac{E_{inf}\, t \sin 2\theta}{4E_c I_c H_{inf}}}$$

t = Infill wall thickness,
H_{inf} = Height of the infill,
E_{inf} = Modulus of elasticity of the infill,
E_c = Modulus of elasticity of the column,
I_c = Moment of inertia of the columns,
H = Total frame height,
θ = Angle between diagonal of the horizontal and the infill,
λ_h = Dimensionless parameter.

4.1.3 Mainstone model

Mainstone (1971) performed tests on frames with brick infill walls and gave equivalent diagonal strut model this approach takes into contribution of both Infilled Frame stiffness and its ultimate strength.

$$w = 0.16\, d_{inf}\, ((\lambda_h H_{inf})^{-0.3}$$

$$\lambda_h = \sqrt[4]{\frac{E_{inf}\, t \sin 2\theta}{4E_c I_c H_{inf}}}$$

4.1.4 Paulay and Preistley model

Paulay and Preistley (1992) stated that higher estimation of width(w) will effect in a stiffer structure and potentially superior seismic reaction.

$$w = 0.25\, d_{inf}$$

Where, d_{inf} = Diagonal length of the infill

4.1.5 Hendry model

Hendry (1998) has also presented equivalent strut width that would represent the masonry that actually contributes in resisting the lateral force in the composite structure

$$w = 0.5\sqrt{\alpha_h^2 + \alpha_L^2}$$

$$\alpha_h = \frac{\pi}{2}\left[\frac{4E_c I_c H_{inf}}{E_{inf}\, t \sin 2\theta}\right]^{\frac{1}{4}}$$

$$\alpha_L = \frac{\pi}{2}\left[\frac{4E_c I_b H_{inf}}{E_{inf}\, t \sin 2\theta}\right]^{\frac{1}{4}}$$

α_h, α_L = Contact length between wall and column at the time of initial failure of wall.

I_b = Moment of inertia of the beam

L_{inf} = Length of the infill i.e. Clear distance between columns.

4.1.6 FEMA model

FEMA (1998) proposed that infill wall thickness which is represented has equivalent strut can be obtained by

$$w = 0.175\, d_{inf}\, ((\lambda_h H_{inf})^{-0.4}$$

$$\lambda_h = \sqrt[4]{\frac{E_{inf}\, t \sin 2\theta}{4E_c I_c H_{inf}}}$$

Table -1: Equivalent diagonal strut Width

Sl No	Model	Equivalent strut width (m)
1	Holmes	1.73
2	Smith and Carter	4.91
3	Mainstone	0.54
4	Paulay and Preistley	1.32
5	Hendry	0.68
6	FEMA 273	0.52

With reference to various literature reviews, Mainstone's relation was widely used for most of the experimental and analytical works, as it predicted the value of the width of the Diagonal strut which was very near/close to the Romanian code and it was commonly adopted because of its simplicity.

4.2 PERFORMANCE OF INFILL FRAME WITH CENTRAL OPENING

Asteris et al. (2011) presented the analytical results of the influence of opening size on the seismic response of masonry infilled frames with central opening. Fig. shows the variation of the 'λ' factor as a function of the opening % for the case of an opening on the compressed diagonal of the infill wall.

$$\text{Opening \% } (\alpha_w) = \frac{\text{Area of Opening}}{\text{Area of Infill}}$$

Width of strut with opening = Stiffness Reduction factor as per Figure x w without opening

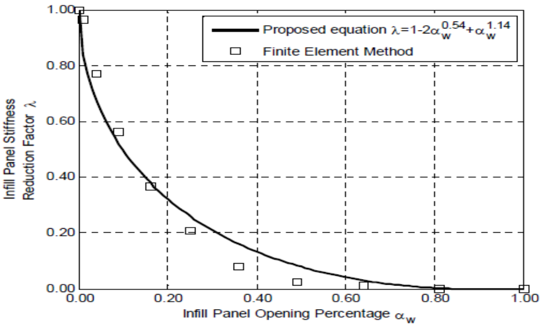

Fig -2: Stiffness reduction factor for Infill with opening

Table -2: Stiffness reduction factor and width of strut for different percentage of opening

% of opening	Stiffness reduction factor , λ	Width of strut, m
0	-	0.540
10	0.45	0.267
20	0.32	0.173
30	0.21	0.113
40	0.13	0.071

5. BUILDING DESCRIPTION

Table -3: Description of the model

Sl No	Items	Building Description
1	Number of stories	G+3
2	Seismic Zone	IV
3	Type of structure	Special RC moment resisting frame
4	Floor height	3m
5	Imposed load	3 kN/m^2
6	Infill wall	230mm
7	Materials used	Fe 415 grade steel and M_{20} grade concrete
8	Thickness of slab	150mm
9	Size of beams	230mm * 450mm
10	Size of columns	450mm * 450mm
11	Density of infill	20 kN/m^3
12	Density of RCC	25 kN/m^3

Table -4: Parameters of G+ 3 storey Diagonal strut model

Parameters	Data	Units
Size of beam	230x450	mm
Size of column	230x450	mm
Moment of inertia of columns, Ic	1.74x10^{-3}	m^4
Moment of inertia of beams, Ib	1.74x10^{-3}	m^4
Thickness of Infill wall, t	230	mm
Modulus of elasticity of concrete, Ef	22360.68	Mpa
Modulus of elasticity of brick masonry, Em	13800	Mpa
Length of masonry	4.55	m
Height of masonry	2.55	m
Angle of inclination, θ	29.26	Degrees

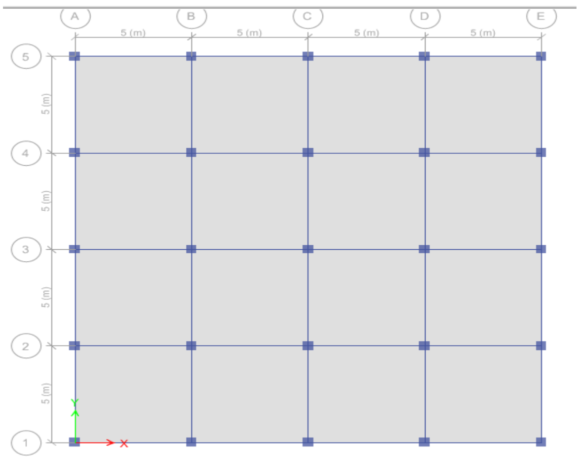

Fig -3: Plan layout of G+3 story building model

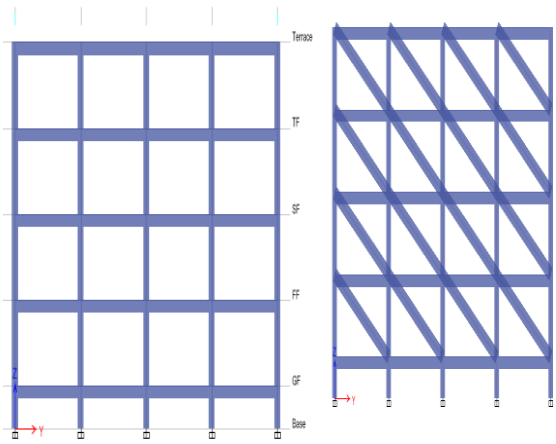

Fig -4: Elevation of bare frame and infilled frame

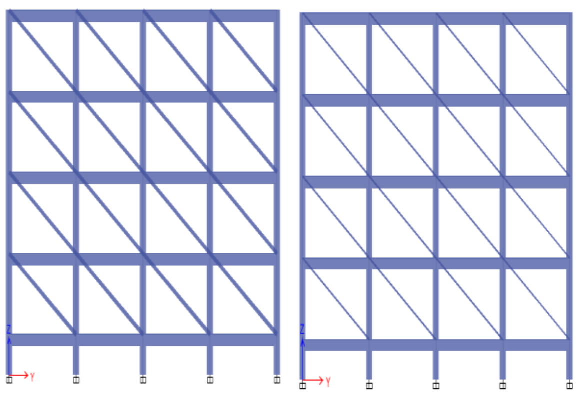

Fig -5: Elevation of 20% and 40% opening infilled frame

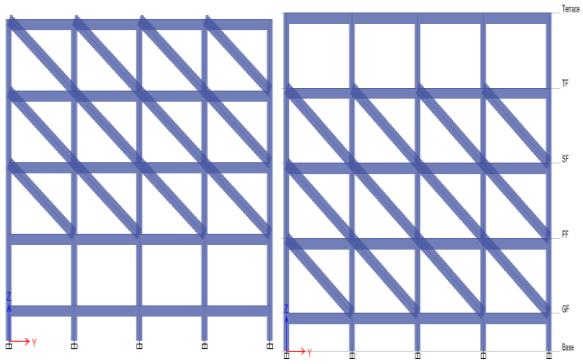

Fig -6: Elevation of soft story at ground floor and third floor

6. RESULTS AND DISCUSSIONS

6.1. Comparision with bare frame, infilled frame and infilled frame with 20 and 40% opening

6.1.1 BASE SHEAR

The Base shear is more in infilled frame than bare frame because it depends on the stiffness in the frame. Due to the presence of infill (strut) the stiffness of the frame is increased resulting in increased sesmic forces than bare frame.

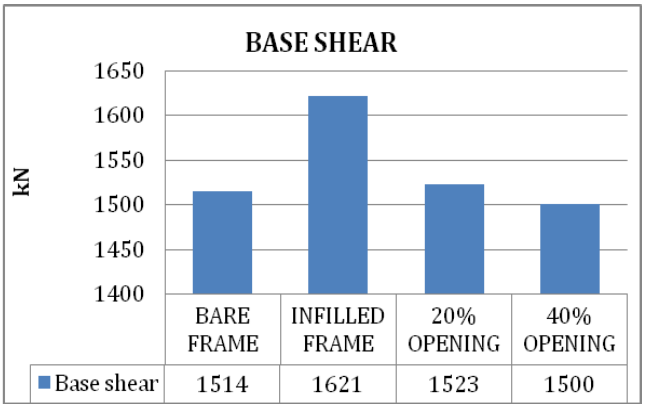

Chart -1: Bar graph showing variation of base shear

6.1.2 STORY DRIFT

Introduction of infill in the building structure reduces the seismic demands of the building both in terms of storey drift and the horizontal displacement. Story drift is more in bare frame than 20% and 40% infill.

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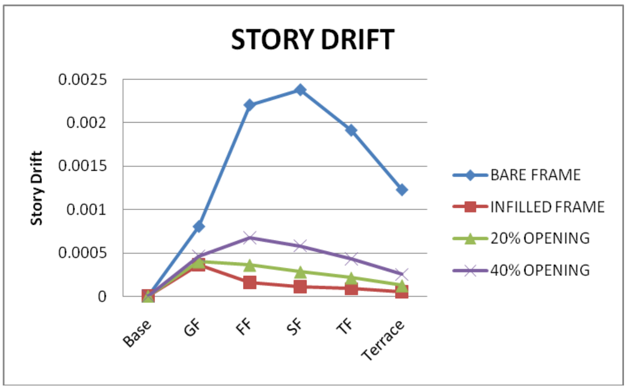

Chart -2: Variation of story drift

6.1.3 LATERAL LOADS

Infilled frame has highest lateral load when compared with bare and infilled frame with openings. As the percentage of infill wall decreases the lateral load also decreases .

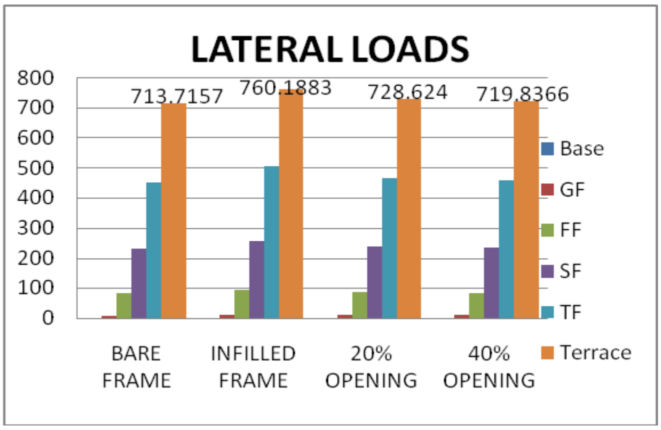

Chart -3: Bar graph showing lateral loads

6.1.4 STORY DISPLACEMENT

Bare frame structure has a maximum story or roof displacement when compared with infilled frame and frames with opening. This is because infill wall increases strength and stiffness in moment resisiting RC frames.

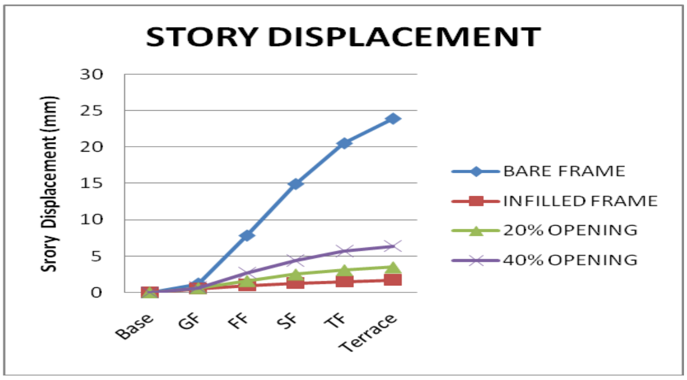

Chart -4: Comparision of story displacement

6.1.5 COLUMN FORCES

Outer columns are taken for the comparision because it will be greater than the inner columns. Due to the action of strut, frame action is changed to truss action resulting in reduction of bending moment.

It is noted that the decrease in bending moment is more in the smaller openings because of the fact that smaller opening has more infill effective i.e. the impact of infill is high in small openings.

Table -5: Corner Column Forces

	C1		C5		C9		C22	
	AXIAL FORCE (KN)	MOMEN T (KN-m)	AXIAL FORCE (KN)	MOMEN T (KN-m)	AXIAL FORCE (KN)	MOMEN T (KN-m)	AXIAL FORCE (KN)	MOMEN T (KN-m)
BARE FRAME	174.60	102.39	174.60	102.39	174.60	102.39	174.60	102.39
INFILLED FRAME	164.89	52.40	167.71	61.07	175.82	66.93	167.71	57.24
20% OPENING	169.47	57.42	170.65	63.96	173.94	66.64	170.65	59.75
40% OPENING	173.81	65.00	174.51	70.40	176.05	71.76	174.51	66.23

6.1.6 TIME PERIOD

The presence of infill has found to reduce the time period of bare frame and enhances stiffness of the structure. Bare frame has high time period when compared with infilled frame and infilled frame with 20 and 40% opening.

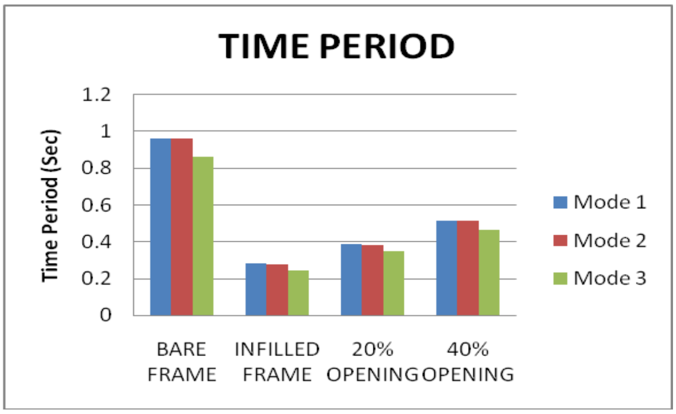

Chart -5: Bar graph showing variation in base shear

6.2. Comparision with bare frame, infilled frame,soft stories at ground and third floor

6.2.1 BASE SHEAR

Base shear is more in infilled frame when compared with bare frame and soft story frames. Here the soft story at GF and soft story at TF is compared and its base shear obtained is almost same.

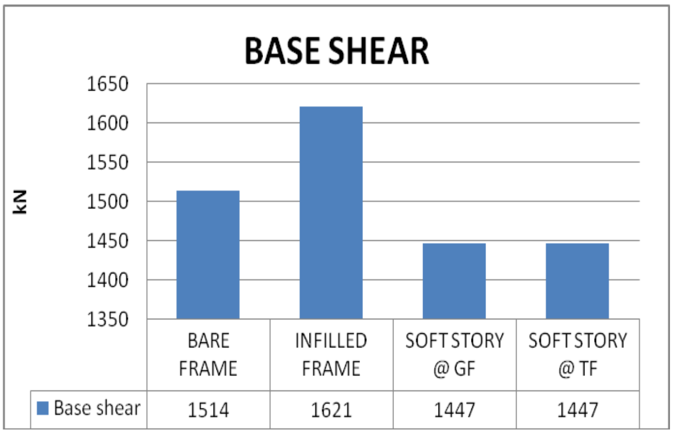

Chart -6: Bar graph showing variation in base shear

6.2.2 STORY DRIFT

Story drift is maximum in bare frame and minimum in infilled frame.The behaviour of story drift in the soft stories at GF and TF shows that maximum story drift occurs near the soft stories

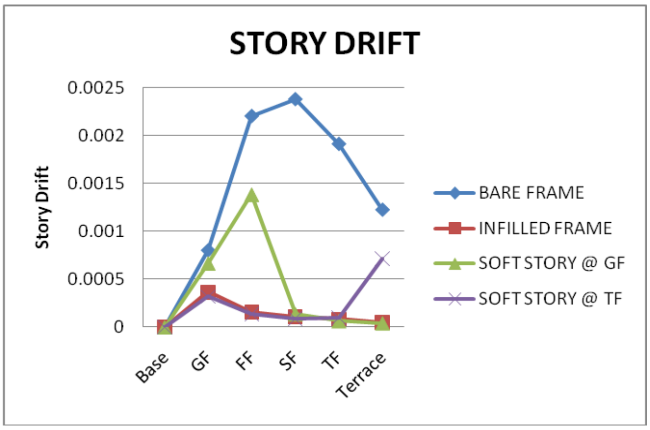

Chart -7: Variation of story drift

6.2.3 LATERAL LOADS

The soft story at TF has highest lateral load at top story whereas soft story at GF has least lateral load at top story. Fig below shows the variation of lateral loads among different models

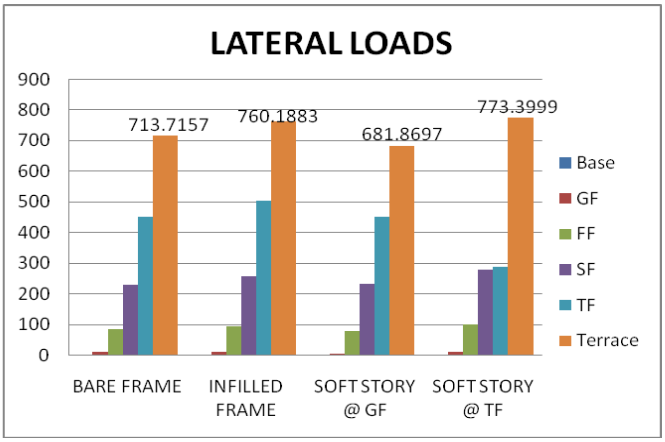

Chart -8: Bar graph showing lateral loads

6.2.4 STORY DISPLACEMENT

The presence of infill reduces the lateral displacement because of increase in rigidity of the structure. The bare frame has maximum displacement while infilled frame has least displacement.

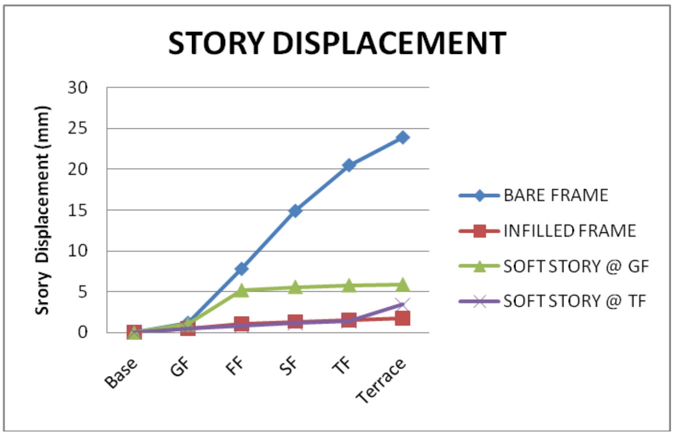

Chart -9: Comparision of story displacement

6.2.5 COLUMN FORCES

The compared results shows that bare frame has highest axial force and bending moment. Whereas soft story at TF has higher value of axial force and lesser bending moment.

Table -6: Corner Column Forces:

	C1		C5		C9		C22	
	AXIAL FORCE (KN)	MOMENT (KN-m)	AXIAL FORCE (KN)	MOMENT (KN-m)	AXIAL FORCE (KN)	MOMENT (KN-m)	AXIAL FORCE (KN)	MOMENT (KN-m)
BARE FRAME	174.60	102.39	174.60	102.39	174.60	102.39	174.60	102.39
INFILLED FRAME	164.89	52.40	167.71	61.07	175.82	66.93	167.71	57.24
SOFT STORY @ GF	139.20	87.70	140.00	87.30	145.50	87.70	140.00	88.20
SOFT STORY @ TF	150.00	47.50	154.00	55.40	165.30	58.50	154.00	50.20

6.2.6 TIME PERIOD

In soft story models time period is depending on the location of soft story provided.Here the soft story at GF has higher time period than soft story at TF.

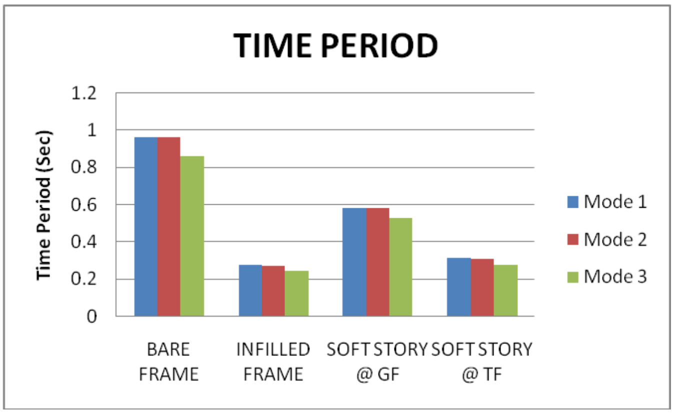

Chart -10: Bar graph showing time period

7. CONCLUSIONS

1. The infill wall predominantly changes the behaviour of the structure and it is essential to consider infill walls for seismic analysis of structure.

2. Introduction of infill panels in the RC frame reduces the time period of bare frames and also enhances the stiffness of the structure. The fully infilled frame has the lowest storey drift value and the highest base shear value.

3. The percentage of opening and the soft story influence the fundamental period of infill frame and the period increases as the percentage of opening increases.

4. The effect of infill on the lateral stiffness of the infilled frame may be ignored if the area of opening exceeds 40% of the area of the infill and the frame is analyzed as bare frame.

5. Deflection is very large in case of bare frame as compared to that of infill frame with opening and deflection will increase as the percentages of opening increases.

6. The story displacement and time period of soft story at third floor is less when compared with soft story at ground floor.

7. Infill increases the initial stiffness of the structure and also increases the base shear carrying capacity of the structure.

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