COMPARATIVE STUDY ON THE SEISMIC PERFORMANCE OF BARE FRAME AND INFILLED FRAME RC STRUCTURES WITH BRICK MASONRY AND LOW STRENGTH CONCRETE BLOCK MASONRY INFILLS

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Abstract - A practice of constructing RC frame structures with unreinforced masonry infill walls is being followed all over the world from the past few years. In the start, these masonries were considered as the non-structural elements of the building, but recent researches and studies have shown that the presence of these infill masonries greatly influence the seismic performance of RC structures. This research aims at the evaluation of seismic performance of bare frame, brick masonry infilled frame and low strength concrete block masonry infilled frame RC structures. For this, a six storey (G +5) commercial building being located in Abbottabad was selected for the analysis. Three models of this building namely bare frame, brick masonry infilled frame and low strength concrete block masonry infilled frame were prepared in ETABS 2015. These models were then analyzed by linear dynamic method of seismic analysis i.e. response spectrum analysis. The comparison between seismic performance of these models of the given building was made on the basis of maximum storey displacement, maximum storey drift ratio, base shear, time period and overall stiffness of the structure. From the results of the research, it was observed that when the effect of infill masonries was considered in the analysis, the performance of the building was observed to be greatly improved. Analyzing the results, it was concluded that presence of infill masonries greatly enhances the overall seismic performance of RC structures by increasing their strength, stiffness and ability of resisting the lateral loads during seismic events. It was also concluded that brick masonry has a greater effect on the seismic performance of a RC structure as compared to that of low strength concrete block masonry because of its greater strength and stiffness properties.

Keywords- Reinforced Concrete (RC), Infill Masonries, Seismic Performance, Response Spectrum Analysis (RSA).

1 INTRODUCTION

From the past few years, a practice of constructing reinforced concrete (RC) frame structures is being followed all over the world [1] especially in the Asian sub-continent, due to their functional efficiency and ease in construction. During the construction process, the frame elements (i.e. beams and columns) are constructed first and independently without any provision of infill walls. The open space left in between the frame elements is then filled up with unreinforced masonry that generally consists of either the brick masonry or low strength concrete block masonry. In the past, these infill masonries were considered as the non-structural elements of the building [1] (elements that do not contribute towards the load resisting ability of the structure) where they were supposed to fulfill two basic functions, first, to act as a divider for the division of interior spaces and second, as a protective shield against the effects of external environment i.e. snow, rain, wind, noise etc. But this is not the case now as the recent researches and studies have shown that they are no more the non-structural elements but greatly influence the overall performance of RC structures during the seismic activities. In the bare frame idealization of a RC structure, it is considered that infill masonries do not take part in load bearing process which may lead towards the overdesign of the structure as the presence of infill masonries in between the frame elements largely increases strength, stiffness and energy dissipation ability of RC structures during the seismic events. If the effect of infill masonries is incorporated into the seismic analysis of RC structures, it will lead to the design efficiency which may result in reducing the overall cost of the structures as they are already present in the structure and there will be no need to construct them separately like shear walls which are constructed in addition to the normal structural elements.

Similar works have also been made earlier to investigate the effect of infill masonries on the overall seismic performance of RC frame structures. Hr, Chidananda., Raghu, K., and Narayana, G., [2] after analyzing a fifteen storey (G +14) residential building had found out that maximum storey displacement and fundamental time period of RC structure were reduced by 51% and 46% respectively when the effect of infill masonry was considered in the seismic analysis of the given building. Strength and stiffness of an infilled frame RC structure were found to be 5.2 and 149 times greater than that of bare frame RC structures respectively in a research made by Haldar, P., and Singh, Y. [3]. Yousuf Dinar et. al. [4] as a result of a research on the seismic performance of bare frame and infilled frame RC structures had found out that increasing the percentage of infill increases the overall performance of RC structures against seismic activities. Raza, S., and Khan, M. K. I. [5] had found out that brick masonries are the best in the business during seismic activities, then comes the hollow concrete block masonries and solid concrete block masonries. Considering the work done by previous researchers and their future work recommendations, this research aims at the detailed evaluation and comparison of seismic performance of bare frame (BF), brick masonry infilled frame (BMIF) and low strength concrete block masonry infilled frame (CBMIF) RC structures. Prime objective of this research is to compare the seismic performance parameters like maximum storey displacement, maximum storey drift ratio, base shear, time period and overall stiffness of the BF, BMIF and CBMIF RC structures.

2 RESEARCH METHODOLOGY

For this research, a six storey (G +5) commercial building being located in Abbottabad was selected for the seismic evaluation as shown in Figure 1 (a) and (b). Three models of this building namely BF, BMIF and CBMIF were prepared in ETABS 2015. This modeling of the building involves two steps; first, the modeling of frame structure and second, the modeling of infill walls. A general modeling procedure was used for the modeling of frame structure whereas the modeling of infill walls was done according to the standard procedure of "equivalent diagonal strut method" as given in the section 7.5.2.1 of FEMA 356 [6]. According to this section of FEMA 356 [6], masonry infill walls should be replaced by a pin jointed equivalent diagonal strut of width "a", being provided between the two compression corners. The thickness and elastic modulus of which will be the same as that of infill wall whereas the length of it will be equal to the length of diagonal between the compression corners. According to FEMA 356 [6], the width of this strut "a" is given by:

$$a = \frac{0.175*D}{(\lambda_1*H)^{0.4}} \tag{1}$$

$$\lambda_1 = \left[\frac{E_m*t*Sin2\theta}{4*E_f*I_{col}*h}\right]^{0.25} \tag{2}$$

$$\theta = \tan^{-1}\left(\frac{h}{l}\right) \tag{3}$$

The strength and stiffness of a perforated panel is not the same as that of the completely infilled panel but varies in proportion with the percentage of openings. This change in strength and stiffness of a perforated panel is incorporated into the modeling as a reduction factor for percentage of openings (i.e. R_1). Al-Chaar [7] has explained this reduction factor in detail in his study. According to him, the reduced width of the strut "$a_{Reduced}$" is given by:

$$a_{Reduced} = a * R_1 \tag{4}$$

$$R_1 = 0.6 * \left(\frac{A_{openings}}{A_{panel}}\right)^2 - \left(1.6 * \frac{A_{openings}}{A_{panel}}\right) + 1 \qquad (5)$$

In (1), (2), (3), (4) and (5), "D" is the length of diagonal between the two compression corners, "H" is height of infill between centerline of beams, "h" is clear height of infill, "t" is thickness of infill, "l" is clear length of infill, "I_{col}" is moment of inertia of column, "θ" is angle of inclination of strut with beam, "E_m" is elastic modulus of masonry "E_f" is elastic modulus of frame material, "λ_1" is the strut stiffness factor, "$A_{openings}$" is the area of openings whereas "A_{panel}" is the area of infill panel.

The modeling of infill walls as an equivalent diagonal strut was done in such a way that it was provided as a pin jointed zero weight or mass element between the two compression corners of the given frame of the given building. The effect of inertial mass of infill wall was incorporated into the analysis by assigning the whole mass of infill wall as a uniformly distributed load to the entire length of the beam upon which it was supposed to be resting.

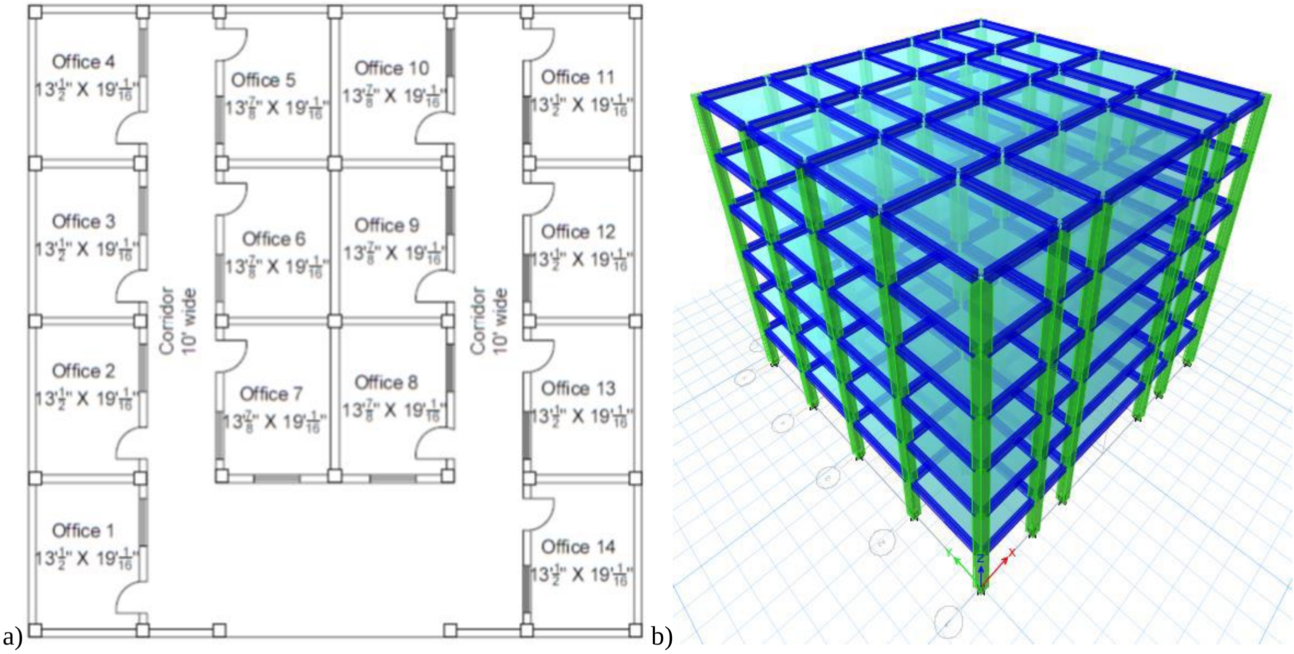

Figure 1: (a) Plan of Given Building, (b) Extruded BF 3D view of Building

Table 1: Building's Material Properties

Material Type	E	ν	Unit Weight	Design Strengths
	(psi)		(pcf)	(ksi)
Concrete	3604997	0.20	150	$f'_c = 4$
Rebar/Steel	29000000	0.30	490	$F_y = 60$; $F_u = 90$
Bricks Masonry	410000	0.2383	120	$f'_m = 0.79$
Concrete Block Masonry	250000	0.3127	120	$f'_m = 0.40$

After the modeling, all the three models of given building were analyzed by linear dynamic method of seismic analysis i.e. RSA to get an insight into the dynamic behavior of the building. The seismic performance of all these models was then evaluated and compared on the basis of maximum storey displacement, maximum storey drift ratio, base shear, time period and overall stiffness of the structure.

Table 2**:** Building's Section Properties

Section Type	**Size**	**Material**	**Shape**
	(in)		
Beam	12" X18"	Reinforced Concrete	Rectangular
Column	18" X 18"	Reinforced Concrete	Rectangular
Slab	7" Thick	Reinforced Concrete	Shell Thin

Table 3: Summary of Loads on the Building

Load Type	**Load Concentration**		**Description**
	Storey 1 - Storey 5	**Storey 6**	
Dead Load	-	-	Self-Weight
Live Load	60 psf	40 psf	-
Superimposed Dead Load	43.75 psf	60 psf	Mortar (3") + Tiles (1")
Masonry Load	1 K/ft	0.15 K/ft	Main walls Load on Beam
Masonry Load	21 psf	21 psf	Partition Walls load on Slab
Earthquake Load	BCP 2007	BCP 2007	-

3 RESULTS

After analyzing all the three models of given building, their performance was evaluated on the basis of five parameters i.e. maximum storey displacement, maximum storey drift ratio, base shear, time period and overall stiffness of the structure. The comparison was made on the basis of maximum response of the building against each of these parameters. A brief overview of the results obtained from RSA of the given building is given as under:

3.1 Maximum Storey Displacement

Displacement is an important factor to be considered, when a structure gets hit by a seismic event. It mainly depends on the stiffness of the structure, greater the stiffness lesser will be the displacement produced in the building and vice versa. From the results obtained by RSA, maximum storey displacement was observed to be reduced by 69% in case of CBMIF whereas 79% in case of BMIF. This greater reduction of displacement in case of brick masonry was observed due to its greater stiffness as compared to that CBMIF.

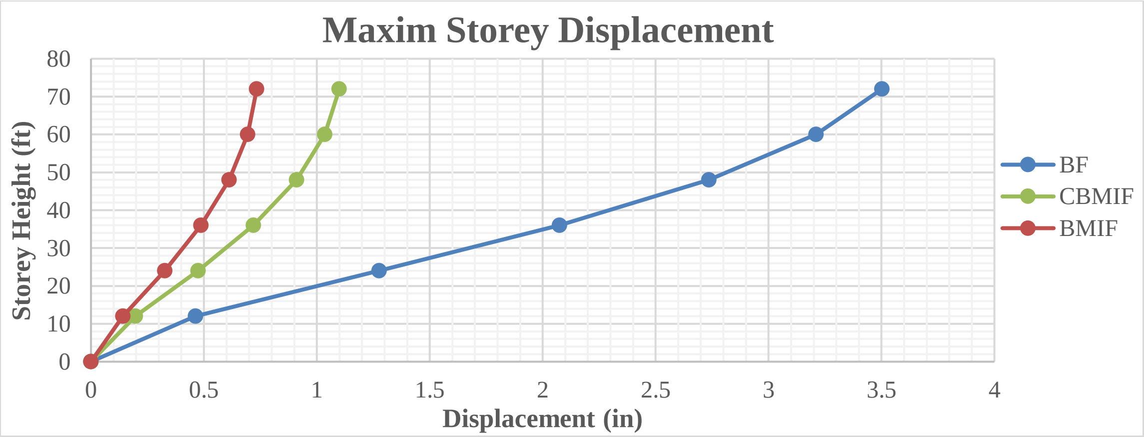

Figure 2: Comparison of Maximum Storey Displacement

3.2 Maximum Storey Drift Ratio

Storey drift ratio is the ratio of relative displacement between the adjacent stories to the storey height. It measures the displacement changing characteristics of a building; gradual changing characteristics ensure structural stability, uniform stiffness and less probability of structure getting damaged. From the results obtained by RSA, maximum storey drift ratio was observed to be reduced by 79% in case of CBMIF whereas 88% in case of BMIF. This greater reduction of storey drift ratio in case of brick masonry was observed due to its greater stiffness as compared to that of CBMIF.

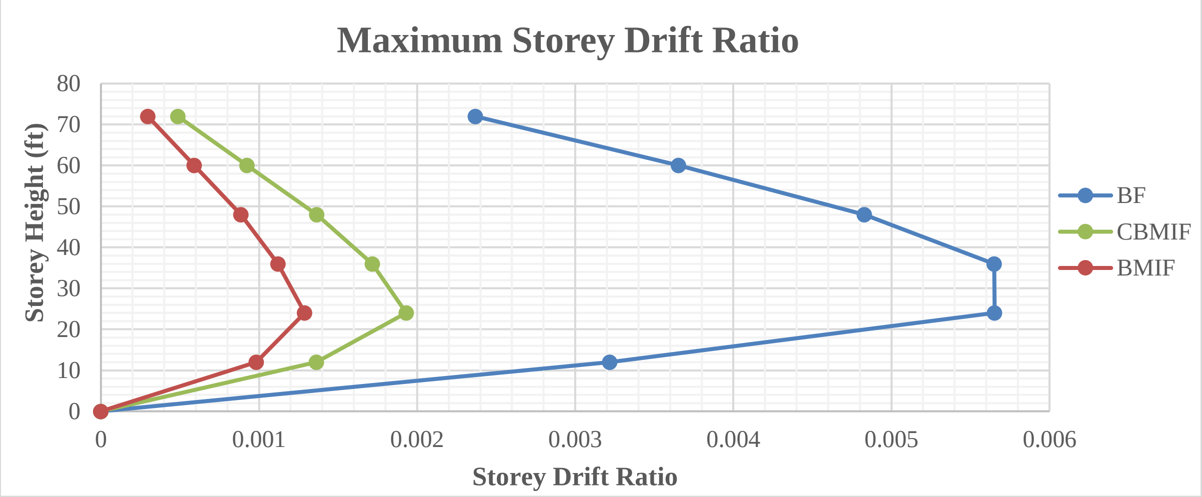

Figure 3: Comparison of Maximum storey Drift Ratio

3.3 Stiffness

Stiffness refers to the rigidity of a structure which means extent to which it can resist deformation under the application of a lateral load. Stiffness of a RC frame structure depends on the stiffness of individual structural elements, their concentration and orientation in the structure. Stiffness of individual elements on the other hand depends on their material and geometric properties i.e. modulus of elasticity and moment of inertia. Greater the elastic modulus or moment of inertia of an element, greater will be its stiffness resulting in increase of overall stiffness of the structure. From the results obtained by RSA, overall stiffness of the structure was observed to be increased by 238% in case of CBMIF whereas 413% in case of BMIF. This greater increase of overall stiffness in case of BMIF was observed due to its greater elastic modulus as compared to that of CBMIF.

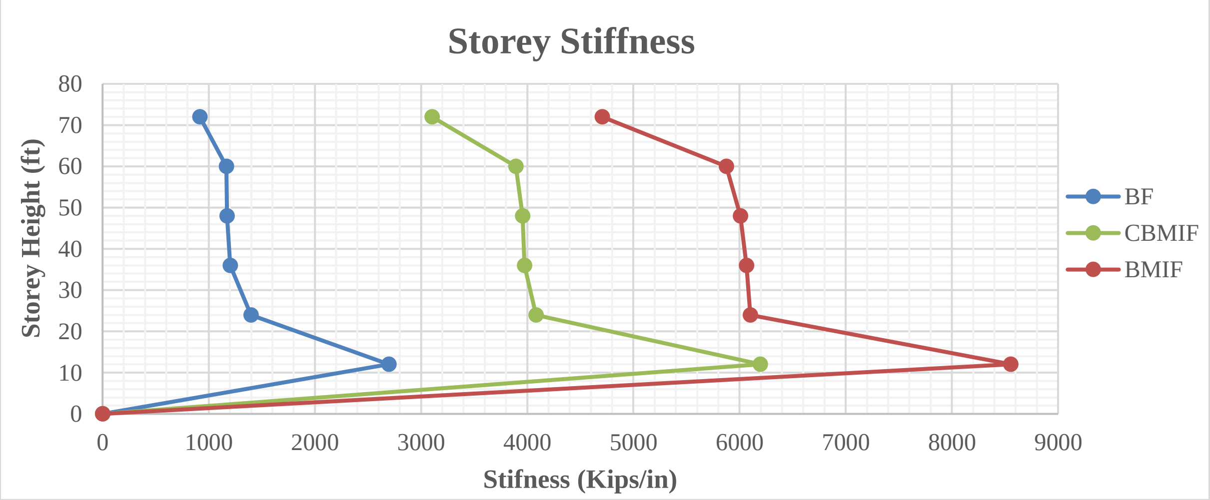

Figure 4: Comparison of Storey Stiffness

3.4 Base Shear

Base shear is an estimate of maximum anticipated sideways forces at the base of the structure as a result of a seismic event. Base shear generally depends on weight of the structure, stiffness of the structure and site characteristics of the structure. For the structures having equal weight and similar site characteristics, stiffness is the ultimate parameter that base shear depends on. Flexible structures usually have lesser base shear as compared to stiffer ones. Base shear of all the three models considered in the research was found to be approximately the same because the analysis was terminated at same termination condition i.e. when dynamic base shear becomes greater than or equal to 85% of the static base shear. Therefore, base shear was expressed in terms of its scale factor for the sake of making comparison. Greater scale factor represents lesser base shear. From the results obtained by RSA, base shear was observed to be increased by 43% in case of CBMIF whereas 53% in case of BMIF. This greater increase of base shear in case of BMIF was observed due to its greater stiffness as compared to that of CBMIF.

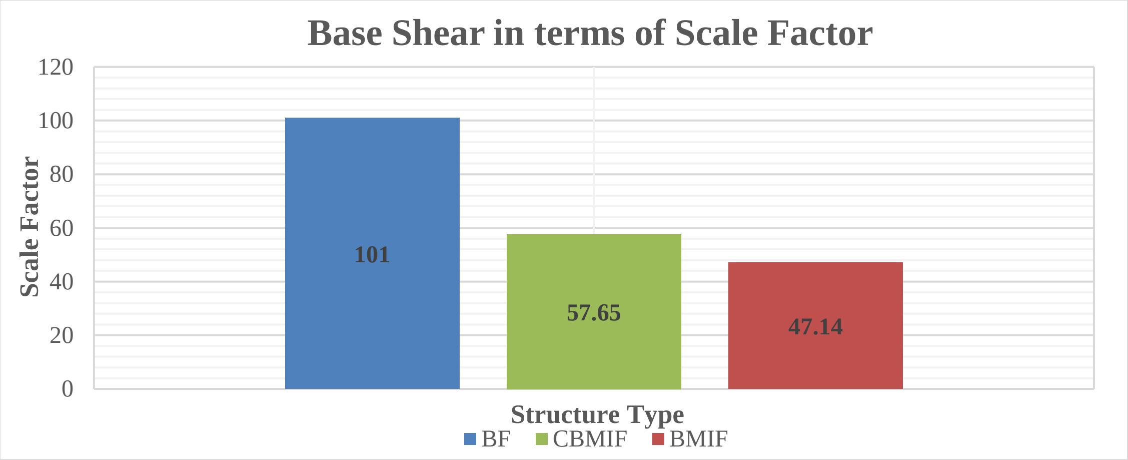

Figure 6: Comparison of Base Shear in terms of Scale Factor

3.5 Time Period

Time period of a structure is the time that it takes for each complete cycle of oscillation when hit by a seismic event. It is the inherent property of the structure that generally depends on mass and stiffness of the structure. For the structures of equal mass, stiffness is the only parameter determining the fundamental time period of the structure. Greater the stiffness of the structure, lesser will be its time period and vice versa. From the results obtained by RSA, time period of the structure was observed to be reduced by 39% in case of CBMIF whereas 51% in case of BMIF. This greater reduction of time period in case of BMIF was observed due to its greater stiffness as compared to that of CBMIF.

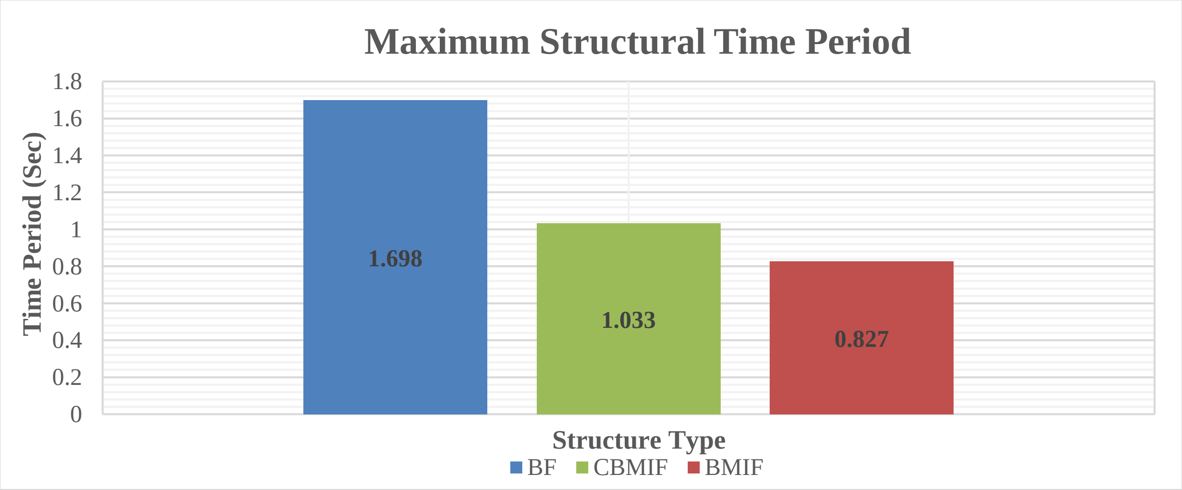

Figure 7: Comparison of Maximum Structural Time Period (Computational Model)

Building code of Pakistan (BCP 2007 [8]) also provides empirical relationships for the determination of fundamental time period of the building. According to BCP 2007 [8] time period of a building can be calculated by using (6), where H is the height, C_t is a coefficient (0.03 for bare frame and 0.02 for all other RC frame structures) and T is the fundamental time period of the building. From the results obtained by empirical formulae, time period of the structure was observed to be reduced by 33% when the effect of infill masonries was incorporated into the analysis. A comparison between the time period obtained from computational model and empirical formulae is also made in table 4.

$$T = C_t * H^{0.75} \tag{6}$$

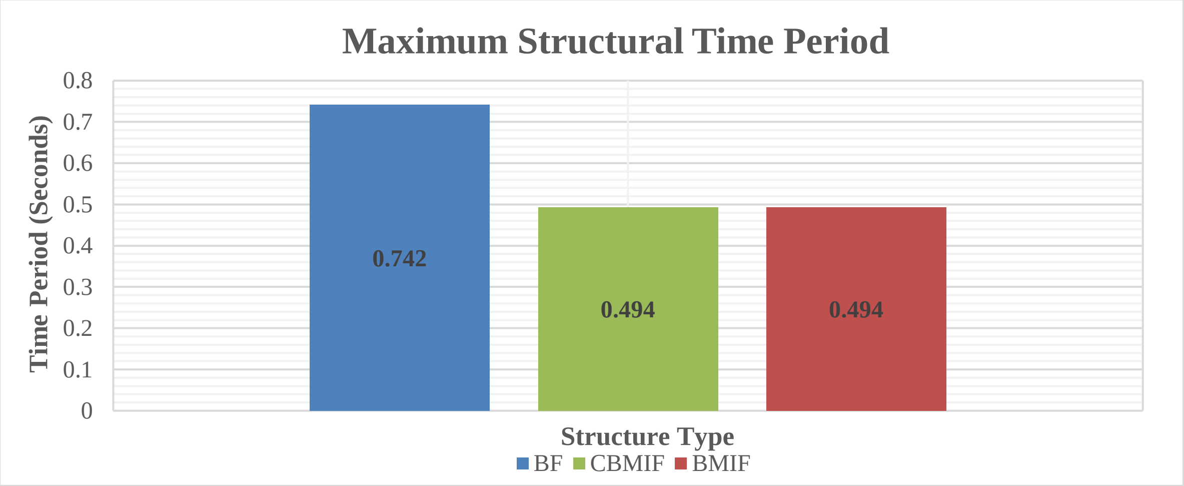

Figure 8: Comparison of Maximum Structural Time Period (Empirical Formulae)

Table 4: Comparison of Time Period Obtained from Computational Model and Empirical Formulae

	Time Period			
Structure Type	**Empirical Formulae**	**Computational Model**	**Increase**	**% Increase**
	(Sec)	**(Sec)**	**(Sec)**	
BF	0.742	1.698	0.956	128.8409704
CBMIF	0.494	1.033	0.539	109.1093117
BMIF	0.494	0.827	0.333	67.40890688

4 CONCLUSION

From the findings of this research, following conclusions can be drawn:

- Presence of infill masonries greatly improves the overall seismic performance of RC frame structures by increasing their strength, stiffness and ability of resisting the lateral loads during seismic events.
- Maximum storey displacement, maximum storey drift ratio and time period can be reduced whereas base shear and overall stiffness can be increased significantly by considering the effect of masonry infill walls in the seismic analysis of RC frame structures.
- Incorporating the effect of masonry infill walls into the seismic analysis of RC frame structures lead to the design efficiency which may result in reducing the overall cost of the structures.
- Brick masonry can be considered as the best in the business among the two masonry types considered in the study during seismic events due to its greater strength and stiffness properties.

On the basis results of this research, future works are recommended on this topic in order to develop detailed guidelines for the analysis and design of RC frame structures with infill masonries.

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6 REFERENCES

[1] S. Sattar and A. B. Liel, "SEISMIC PERFORMANCE OF REINFORCED CONCRETE FRAME STRUCTURES WITH AND WITHOUT MASONRY INFILL WALLS," *9th US National and 10th Canadian Conference on earthquake engineering.*, p. 10, 2010.
[2] . C. H., "ANALYSIS OF RC FRAMED STRUCTURES WITH CENTRAL AND PARTIAL OPENINGS IN MASONRY INFILL WALL USING DIAGONAL STRUT METHOD," *Int. J. Res. Eng. Technol.*, vol. 04, no. 04, pp. 640–647, Apr. 2015, doi: 10.15623/ijret.2015.0404110.
[3] P. Haldar, "Modeling of URM Infills and Their Effect on Seismic Behavior of RC Frame Buildings," *Open Constr. Build. Technol. J.*, vol. 6, no. 1, pp. 35–41, Oct. 2012, doi: 10.2174/1874836801206010035.
[4] Y. Dinar, Md. I. Hossain, R. Kumar Biswas, and Md. Masud Rana, "Descriptive Study of Pushover Analysis in RCC Structures of Rigid Joint," *IOSR J. Mech. Civ. Eng.*, vol. 11, no. 1, pp. 60–68, 2014, doi: 10.9790/1684-11126068.
[5] S. Raza and M. K. I. Khan, "Seismic vulnerability assessment of bare and masonry infilled reinforced concrete frame structures," *Int. J. Civ. Struct. Eng.*
[6] "FEMA 356 Prestandard and Commentary for the Seismic Rehabilitation of Buildings," p. 519, 2000.
[7] G. Al-Chaar, "Evaluating Strength and Stiffness of Unreinforced Masonry Infill Structures" Defense Technical Information Center, Fort Belvoir, VA, Jan. 2002. doi: 10.21236/ADA407072.
[8] "Building Code of Pakistan (Seismic Provisions 2007)," *Ministry of Housing and Works.*