Influence of Red Bricks Infill Walls on Seismic Response of a Regular RC Framed Building by (SBC-CR-18) Code

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Abstract: This paper aims to investigate the impact of red brick infill walls on seismic response of a RC framed building using the Saudi Building Code 301-2018 (SBC301-18). The Equivalent Lateral Force Procedure was utilized to conduct a seismic analysis of a ten-story office reinforced concrete building in Jizan city, both with and without infill walls. The Ordinary Reinforced Concrete Moment Resisting Frame (ORCMRF) building has been studied in accordance with SBC-301-2018's requirements. The frame under analysis used infill walls at ratios of 0% (bare frame), 20%, 40%, 60%, 80%, and 100% (fully infilled frame with walls). Dead load, live load, and seismic loads were the three main factors influencing this frame's analysis. The maximum seismic ground motion of 0.2 seconds Spectral Response Acceleration (Ss in %g) and 1.0 second Spectral Response Acceleration (S1 in %g) in the Kingdom of Saudi Arabia were used to calculate seismic loads. The findings of this investigation showed that the infill walls significantly impact the investigated frame's seismic response. By making the building parts stiffer, these walls have the impact of increasing base shear, seismic lateral forces, storey shear forces, and overturning moments, which in turn reduces the building's lateral displacements.

Keywords: Infill walls, Seismic response, base shear, lateral force, storey shear force, overturning moment.

تأثير جدران الحشو من الطوب الأحمر على الاستجابة الزلزالية لمبنى من الخرسانة المسلحة العادية حسب الكود-SBC-CR) 18)

الملخص: تهدف هذه الورقة إلى دراسة تأثير جدران الحشو من الطوب الأحمر على الاستجابة الزلزالية لمبنى من الخرسانة المسلحة العادية باستخدام الكود السعودي للبناء 301-2018 .(SBC301-18) تم استخدام إجراء القوة الجانبية المكافئة لإجراء تحليل زلزالي لمبنى مكاتب مكون من عشرة طوابق من الخرسانة المسلحة في مدينة جازان، مع أو بدون جدران الحشو. تمت دراسة مبنى الإطار الخرساني المسلح العادي المقاوم للعزم (ORCMRF)وفقًا لمتطلبات الكود السعودي للبناء 301-2018. استخدم الإطار قيد التحليل جدران حشو بنسب 0% (إطار عارٍ)، 20%، 40%، 60%، 80%، و100% (إطار حشو بالكامل مع جدران). كانت الأحمال الميتة والحيوية والأحمال الزلزالية هي العوامل الرئيسية الثلاثة التي أثرت على تحليل هذا الإطار. تم استخدام أقصى حركة أرضية زلزالية تبلغ 0.2 ثانية تسارع الاستجابة الطيفية Ss) في (g% و1.0 ثانية تسارع الاستجابة الطيفية S1) في (g% في المملكة العربية السعودية لحساب الأحمال الزلزالية. أظهرت نتائج هذا البحث أن جدران الحشو تؤثر بشكل كبير على الاستجابة الزلزالية للإطار قيد البحث. من خلال جعل أجزاء المبنى أكثر صلابة، فإن هذه الجدران لها تأثير زيادة قص القاعدة والقوى الجانبية الزلزالية وقوى قص الطابق وعزم الانقلاب، مما يقلل بدوره من النزوح الجانبي للمبنى.

1. Introduction

Because of their strength and rigidity, infill walls, which are enclosed in steel and concrete frames, can withstand part of the force generated by an earthquake. The mechanism of Infill walls to withstand forces is that they act as diagonal struts between the columns and beams that surround them when subjected to seismic forces. By carrying compressive forces, these struts can help the main structure bear some of the earthquake loads. By serving as a supplementary load path and sharing the load with the main structural system (beams, columns, or shear walls), it also adds lateral stiffness to the structure. A schematic of infill walls is shown in Figure 1. Although infill walls are usually not structural—that is, they do not support the weight of the building—they are nevertheless important for aesthetics, partitioning, and insulation. When designed and built correctly, infill walls can significantly contribute to a building's ability to withstand seismic forces. They can improve a structure's strength and stiffness, which can improve the building's performance in the case of an earthquake, despite most people considering them to be non-structural. Infill walls can aid in earthquake resistance by increasing lateral stiffness, redundancy, absorbing and dispersing seismic energy, reducing frame collapse, preventing pounding between structures, and improving structural ductility. In their work, Alessandra De Angelis et al. [1] examined the function of infill walls in the seismic upgrading and dynamic behavior of a reinforced concrete framed building. The study only looked at the life and death loads of an infilled RC frame structure that was built in a higher seismic zone in Southern Italy in the 1960s. A 4-RC building in Benevento, Campania, Southern Italy, with an acceleration of 0.26 g, is one example. Because it is based on the ratio of the in-stiffness to the plane stiffness of the floor of the vertical resisting components, this study discovered that the flexibility of the floor may be altered by the connection between the masonry panels and the frame. The FRCM approach, which increases the resistance of the masonry walls that are cut away from the RC columns, can also be used to improve the filler walls. The interference may be helpful when the increase in resistance is small compared to the difference in building rigidity. The study by Abdelkader Nour et al. focused on the role that masonry walls play in improving the seismic resilience of reinforced concrete buildings [2]. Several models of multi-story frame buildings with double-leaf hollow brick masonry, one of the most popular infill materials in Algeria, located in high seismic zones were analyzed in compliance with the country's seismic regulations.

This analysis was carried out using the finite element program ETABS and was based on the response spectrum technique. The investigation's conclusions suggest that masonry infill walls may have a major impact on the seismic behavior of reinforced concrete. In a study by shendkar mangeshkumar R. et al [3], a four-story structure was studied by modeling the case study using a double strut nonlinear cyclic model. The study's findings showed the factor of response reduction for the frames reduces in tandem with the hardened strength of the masonry infill furthermore the R values for the bare frames are less than that the BIS regulation recommends. The effect of the apertures on the seismic response of an infilled RC building was investigated by Andre furtado et al [4]. According to this study, the natural frequencies were reduced by roughly 20% as a result of the openings compared to the full infill (which without openings). Also, as comparison to the model without openings, the openings decreased the initial stiffness by roughly 20%. In order to provide a strengthening solution that incorporates the infill panels, the impacts of the infill walls on the building's seismic performance are examined in detail [5, 6, 7]. A report on the seismic behavior of reinforced concrete frames with infill panels was presented by Mrs. Sanaa Elmalyh et al. [8] with the objective of determining the impact of infill panel presence on bare frames. According to the paper's conclusion, the inclusion of infill panels increases the RC frame's stiffness, strength, deformation, failure mechanisms, and energy dissipation under lateral loads. In a study on the seismic response of RC frames, A. K. Mapari et al. [9] used SAP 2000 to simulate an 8-story special moment-resisting frame building and took the influence of infill walls into account.

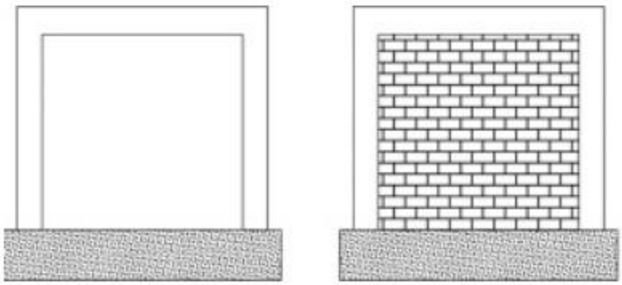
This study concludes that the stiffness of a building is significantly increased when infill is present. The stiffness of the structure is decreased with a larger opening percentage. A variety of modeling techniques have been used to assess how infill walls affect the seismic response of RC buildings with vertical irregularity and dual frames [10, 11, 12].

For deterministic and probabilistic analysis employing infill walls, Laura Liberatore et al. [13] developed a comprehensive equivalent strut model built on experiments. Several models based on the equivalent strut approach were evaluated in this work using a data set of 162 experimental tests, taking uncertainty into consideration. Apart from the masonry's mechanical characteristics, the model also considers other factors, such as whether the units have vertical or horizontal hollows. Finally, a sample of how the suggested model is put to use is given. The comparison between the experimental and expected values, the paper concluded, demonstrated that while some of these models may predict the strength to some extent, none of them can satisfactorily represent the actual stiffness. The inclusion of masonry infill action considerably alters the building model's dynamic response behavior when compared to the bare frame model, according to Ram Krishna Shrestha et al. [14]. The study revealed that, in comparison to the model with an infill wall on all levels, the natural period of the infilled models with a soft story rose. In a research published by Abdelghaffar Messaoudi et al., [15], the impact of openings and changes to the arrangement of masonry panels on the overall performance of buildings was investigated. The study's conclusions demonstrate how the distribution and openings of the brick panels changed the overall behavior of the structures, improving their strength and ability to absorb energy. Salah Guettala et al.'s research [16] showed how infill walls significantly improved lateral stiffness, which resulted in an important increase in structural rigidity. Additionally, the research demonstrated that the addition of infill walls causes a displacement decrease, which occurs more strongly in models with lower shear wall ratios but becomes less significant at higher ratios. The combined effect of shear and infill walls is extremely critical and complex in order to achieve the maximum possible structural performance. Although a lot of research has been done, there is still debate on whether infill walls make a structure more or less vulnerable [17]. The seismic performance of a structure can be enhanced by infill walls, as several studies have shown (Murty and Jain 2000). Furthermore, infill walls increase a building's susceptibility to earthquakes, according to other researchers. The lateral load transmission process is altered by masonry infill walls, which in fact greatly increase the frame's initial stiffness [18] [19]. The variation related with the uncertain positioning of wall fill may have undesirable implications on the general behavior of buildings [19]. A building may also experience multiple damages due to a sudden loss of rigidity caused by the walls that fill it breaking down. The impact of infill walls on a structure's earthquake resistance is frequently disregarded by practicing engineers, it should be noted. Consequently, the benefits and drawbacks of walls with infill on the seismic performance of the frames may be overlooked during the design phase.

Despite being considered non-structural features employed for architectural purposes and overlooked in the frame design, researchers have become more crucial in evaluating how well MI frame buildings functioned during the major earthquake [20] and [21].The results of Ayman Abd-Elhamed et al. show that, in comparison to bare frame building models, the interaction between infill walls and frames considerably alters how buildings respond to earthquakes. Additionally, they found that the RC bare frame structure's seismic study results in base shear is underestimated, leading to damage or even Under severe shaking, buildings may collapse [22]. The impacts of infills on the seismic performance of an RC manufacturing building in Pakistan were investigated by Nisar Ali Khan et al. [23]. The article investigated the nonlinear numerical effects on the lateral behavior of RC buildings filled with masonry by varying the MI wall configurations, wall opening sizes, the lack of MI walls in the first story, and the thickness of the MI walls. A comparable examination of the parametric study on the effects of infill walls on the resistance of RC buildings was carried out by Waleed Abo El-Wafa Mohamed [24].

Civil engineers typically overlook the influence of brick walls in the structural analysis throughout the building design techniques, according to Hossein Mostafaei et al. [25]. Only their masses as non-structural elements and their analysis of structures as bare frames are provided by filling walls. The results of this study and the creation of analytical models with and without openings showed that these walls significantly impacted the structural response of the building. Mouzzoun Mouloud et al. [26] presented a paper investigating infill walls on seismic behavior framed buildings adopting Moroccan earthquake code RPS2000.

The earthquake response was assessed adopting pushover analysis. The results of this investigation demonstrate that these walls show an impact on the frame resistance. Many analytical and experimental investigations have demonstrated that the inclusion of these panels considerably affects the stiffness of RC frame buildings, adding structural stiffness and strength while simultaneously introducing brittle failure mechanisms such as short columns and soft stories [27, 28]. A. Fiore et al.'s study [29] investigated the impact of infill panel uncertainty on the rigidity of current RC buildings. The objective of the study is to identify the factors that affect the building's overall response. Following the determination of important factors, the variation in the building's safety verification findings was quantified. Then, using a range of allowable values, the characteristic points (maximum point and yield strength) of the cyclic non-linear law were modified for two existing structures of varying heights. The study's final recommendations established a foundation for more investigation into modeling uncertainty concerns and the development of simpler models for evaluating existing structures built to support just vertical loads. There exist various approaches for the modeling of the infill walls. In order to investigate the impact of masonry infill wall configuration and modeling approach on the behavior of RC frame structures, Kamaran et al. [30] employed the equivalent diagonal strut model. Using a nonlinear pushover analysis, they evaluated 36 distinct RC frame models and found significant capacity loss, particularly in the case of infills that were terminated at the ground level.



a. Frame without infill wall (bare frame)   b. frame with infill wall

Figure 1. Schematic of infill walls

2. Description of the studied building

As illustrated in Figure 3, a ten-storey Ordinary Reinforced Concrete Moment Resisting Frame (ORCMRF) office building in Jazan City with a 16 m x 20 m design and a normal floor height of 3 m was examined to determine how seismically sound it was. Gravitational forces are resisted by a structure of solid slabs held up by beams and columns. Three primary elements influenced the analysis of this frame: dead load, live load, and seismic loads. Table 1 shows the sections of the beams and columns.

According to SBC301-2018, the frame under study was analyzed using the following particular load combinations (see Eqs. (1 to 3):

Load Case 1:

$$1.4\ DL + 1.7\ LL \qquad (1)$$

Load Case 2 (L/C2):

$$1.2\ DL + 1.0\ E + LL \qquad (2)$$

Load Case 3 (L/C3):

$$0.9\ DL + 1.0\ E \qquad (3)$$

Where:

DL is dead load

LL is live load

E is earthquake load

In this analysis live load is taken as follows:

On floor 2.5 kN/ m^2.

On roof 1.0 kN/ m^2.

For comparison purposes, equation 2 has only been adopted in this analysis.

Jazan region is located on the southwest corner of Saudi Arabia on the coast of the Red Sea and directly north of the border with Yemen. Jazan City lies in an active zone of earthquakes classified as zone 2B with maximum applied horizontal acceleration of 0.2g.

In this study, walls in the frame under study were filled with red bricks. Often used as building materials, red bricks are formed from natural clay and have a number of structural and physical qualities that make them perfect for building. Depending on the quality, red bricks can have a compressive strength of 3.5 to 35 MPa and a density of 1600–2000 kg/m^3. Water absorption rates for red bricks range from 10 to 20%, depending on the material and the production procedure. Because red bricks are made of clay, they can tolerate high temperatures without suffering major damage, making them extremely fire-resistant. In certain cases, they can tolerate temperatures as high as 1,000°C. Red bricks are a popular choice in many construction applications because of their strength, durability, thermal qualities, and aesthetic appeal. This is especially true in areas that experience seismic activity, as their bulk and structural qualities help improve stability. Red bricks vary widely in size from one country to another. In this analysis, 200 mm x 100 mm x 70 mm red bricks were used (Figure 2).

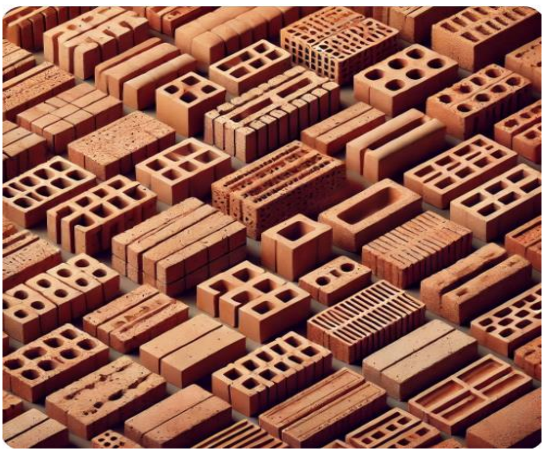
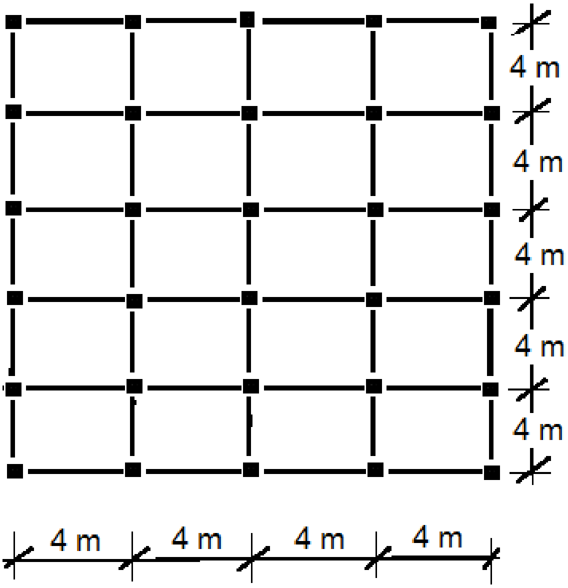
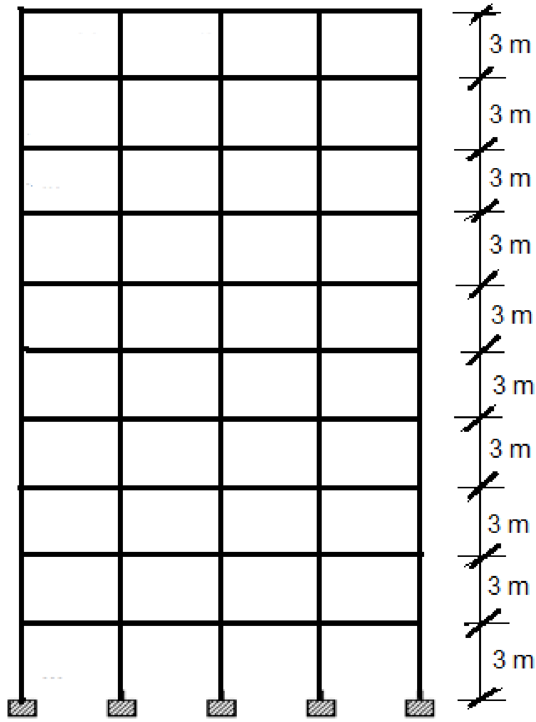


Figure 2. Variety of red clay bricks



a. Plan



b. Elevation

Figure 3. Building configuration (plan and elevation)

Table 1. Sections of columns and beams

Building	Floor Level	Typical beams sections (mm)	Column sections (mm)
	Ground – 4th Floor		600 x 300
10-Storey office	5th – 7th Floor	500 x 300	500 x 300
	8th - Roof		400 x 300

Typical slabs' thicknesses = 150 mm

3. Results and discussion

3.1 Calculations of design acceleration for Jizan city using the Saudi Building Code (SBC301-18) [31]

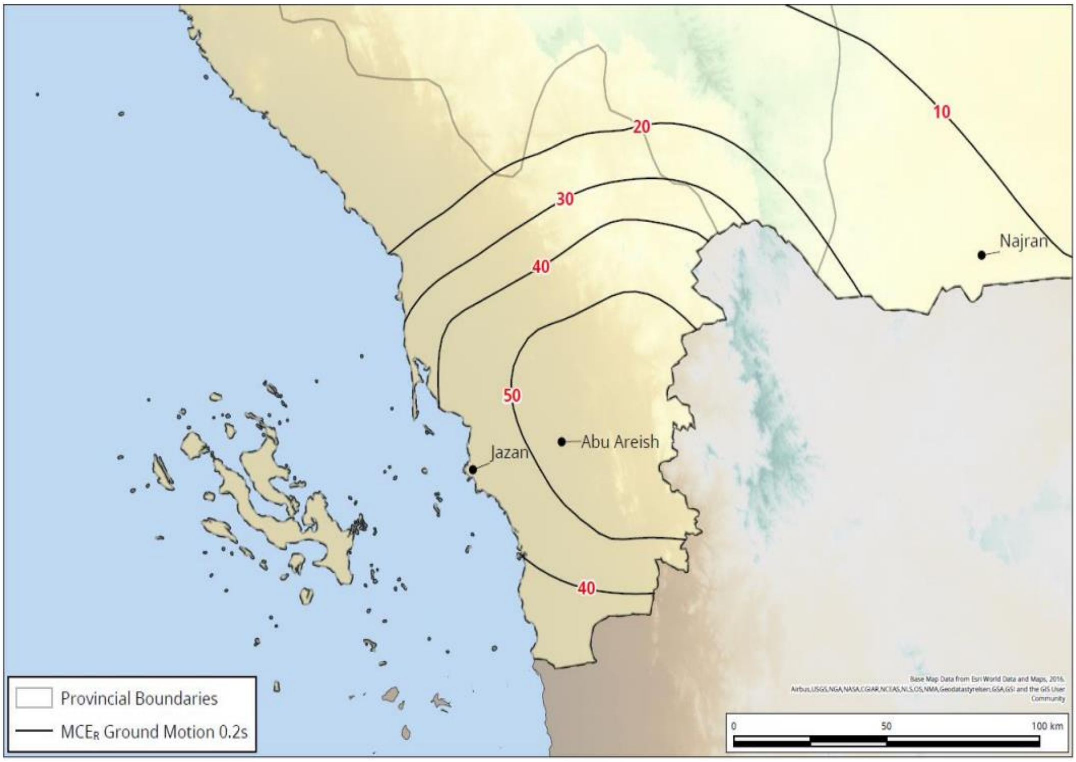


Figure 4. The ground motion for the S_S Risk Targeted Maximum Considered Earthquake (MCER) at site class B in Southern Saudi Arabia for a 0.2 sec spectral response acceleration (5% of critical damping) [31].

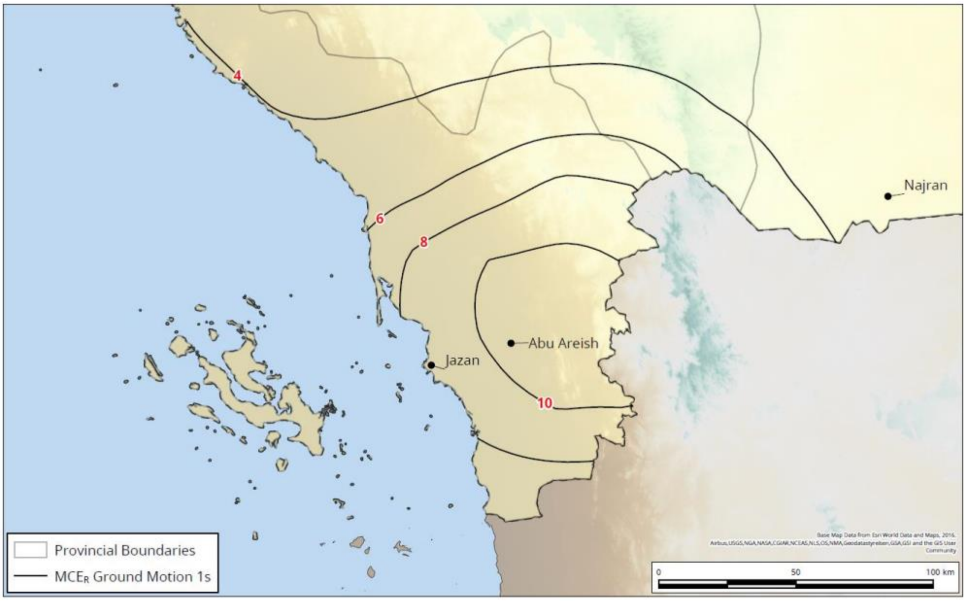


Figure 5. The ground motion parameter for the S_1 Risk-Targeted Maximum Considered Earthquake (MCER) at site class B in Southern Saudi Arabia for a 1 sec spectral response acceleration (5% of critical damping) [31].

The designed response coefficients $S_{S,}$, S_1, S_{MS}, S_{M1}, Fa and Fv are calculated using SBC 301-18, as follows:

S_S = 0.4 g (From Figure 4)

S_1 = 0.08 g (From Figure 5)

Fa and Fv = site coefficients

S_{MS} = The Maximum considered earthquake spectral acceleration for short periods, adjusted for site class effects

$S_{MS} = Fa\, Ss = 1.2\ x\ 0.4 = 0.48\ m/sec^2$

S_{M1} = The Maximum earthquake spectral acceleration for at 1-sec periods, adjusted for site class effects

$S_{M1} = Fv\, S1 = 1.7\ x\ 0.08 = 0.136\ m/sec^2$

R = the structural system factor (SBC-301-2018):

R = 2.5 (Ordinary Reinforced Concrete Moment Resisting Frame)

I = importance factor determined from (SBC-301-2018):

I = 1 (for occupancy category I and II)

S_{DS} = the design spectral response acceleration at short periods.

$S_{DS} = \frac{2}{3} S_{MS} = \frac{2}{3}\ x\ 0.48 = 0.32\ m/sec^2$

S_{D1} = the design acceleration at 1-sec periods.

$S_{D1} = \frac{2}{3} S_{M1} = \frac{2}{3}\ x\ 0.136 = 0.09\ m/sec^2$

Calculation of time perid, T_0, T_s, T and T_L:

$T_0 = 0.2 \times \frac{S_{D1}}{S_{DS}} = 0.2 \times \frac{0.09}{0.32} = 0.056$ sec

$T_s = \frac{S_{D1}}{S_{DS}} = \frac{0.09}{0.32} = 0.28$ sec

T = 0.1 N = 0.1 x 10 = 1 sec
$T_L = 4$ sec (for Jazan region- SBC-301-2018)

the design acceleration, Sa, can be calculated as following:

- For periods less than T_0 (Eq. 4):

$$S_a = S_{DS} \left(0.4 + 0.6 \frac{T}{T_0}\right) \tag{4}$$

For periods greater than or equal to T_0 and less than or equal to T_s (Eq. 5):

$$S_a = S_{DS} \tag{5}$$

For periods greater than T_s , and less than or equal to T_L (Eq. 6):

$$S_a = \frac{S_{D1}}{T} \tag{6}$$

Using the calculated accel vs time period the design curve for jizan city is constructed as shown in Table 2 and Figure 6.

Table 2. Design response spectrum for Jizan city

Coordinates of Design Response Spectrum Curve	
Time Period	Spectrum Response Acceleration
0.000	0.128
0.056	0.320
0.280	0.320
0.400	0.225
0.600	0.150
0.800	0.113
1.000	0.090
1.200	0.075
1.400	0.064
1.600	0.056
1.800	0.050
2.000	0.045
2.200	0.041
2.400	0.038
2.600	0.035
2.800	0.032
3.000	0.030
3.200	0.028
3.400	0.026
3.600	0.025
3.800	0.024
4.000	0.023
4.200	0.021

The design response spectrum curve shown in Figure 6 is used to determine the design spectral response accelerations for a given structure in a specific site.

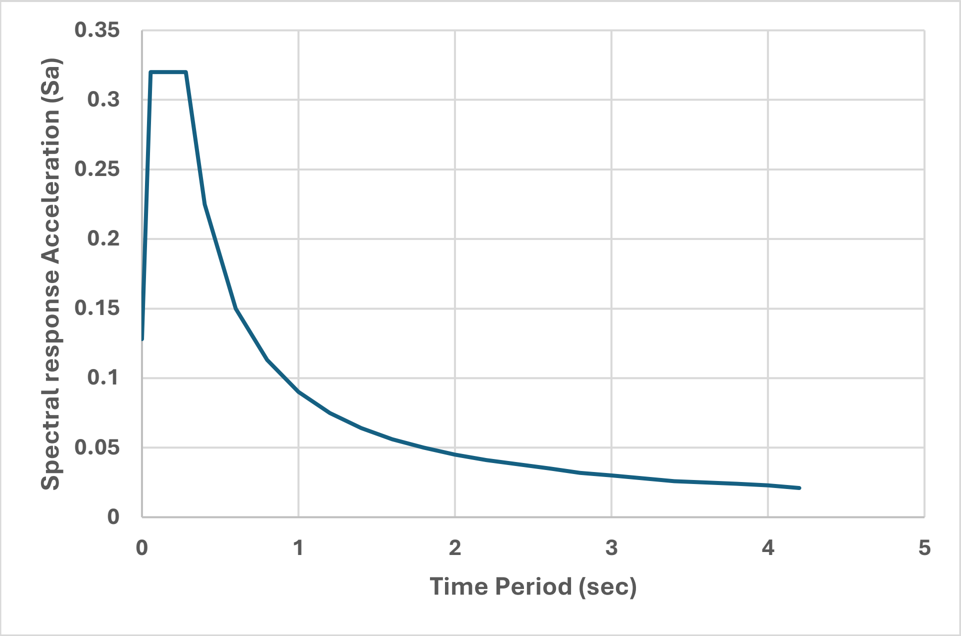


Figure 6. Design Response Spectrum for Jizan city

3.2 Seismic Base Shear (V)

Seismic base shear can be calculated using the equivalent static lateral force procedure as given in Eq. 7:

$$V = Cs\ W \tag{7}$$

Where W is the effective seismic total weight of building

Cs = The seismic response coefficient determined in accordance with SBC301-CR-18), as defined in Eq. 8:

$$Cs = S_{DS} /(R/I) \tag{8}$$

S_{DS} = The design spectral acceleration parameter in the short period range

R = The response modification factor.

I= The importance factor.

$\text{Cs} = (0.32/\ (2.5/1))\ =\ 0.128$

$V\ =\ 0.128\ x\ 30718\ = 3931.9\ kN$

Fx can be obtained using Eq. 9:

$$Fx\ =\ Cvx\ V \tag{9}$$

$$C_{vx} = \frac{w_x h_x^k}{\sum_{i=1}^{n} w_i h_i^k} h_n \qquad (10)$$

Where:

Cvx = vertical distribution factor, calculated using Eq. 10.

V = total design lateral force or shear at the base of the structure (kN).

w_i and w_x = the portion of the total effective seismic weight of the structure (W) located or assigned to Level i or x.

h_i and h_x = the height (m) from the base to Level i or x.

k = an exponent related to the structure period as follows:

For structures having a period of 0.5 s or less, k = 1.

For structures having a period of 2.5 s or more, k = 2.

For structures having a period between 0.5 and 2.5 s, k shall be 2 or shall be determined by linear interpolation between 1 and 2.

Horizontal Distribution of Forces.

Any story's seismic design story shear (Vx in kN) can be calculated using Eq. 11 as follows:

$$Vx = \sum_{i=x}^{n} Fi \qquad (11)$$

where, Fi = the portion of the seismic base shear (V in kN) induced at Level i.

Overturning Moment

The overturning moments at level x (Mx) (kN.m) shall be determined from the Eq. 12:

$$Mx = \sum_{i=x}^{n} (F_i(hi - h_x) \qquad (12)$$

Where:

Fi= the portion of the seismic base shear (V) induced at level i.

hi and hx= the height "m" from the base to level i or x.

The following Tables and Figure show the results of the seismic analysis of the studied frame

Table 3. influence of infill walls on base shear of the frame

% Difference in base shear	Base shear (kN)	Infill walls (%)
100%	6601.6256	10.05
80%	5938.0736	11.17
60%	5274.5216	12.58
40%	4610.9696	14.39
20%	3947.4176	16.81
0%	3283.8656	

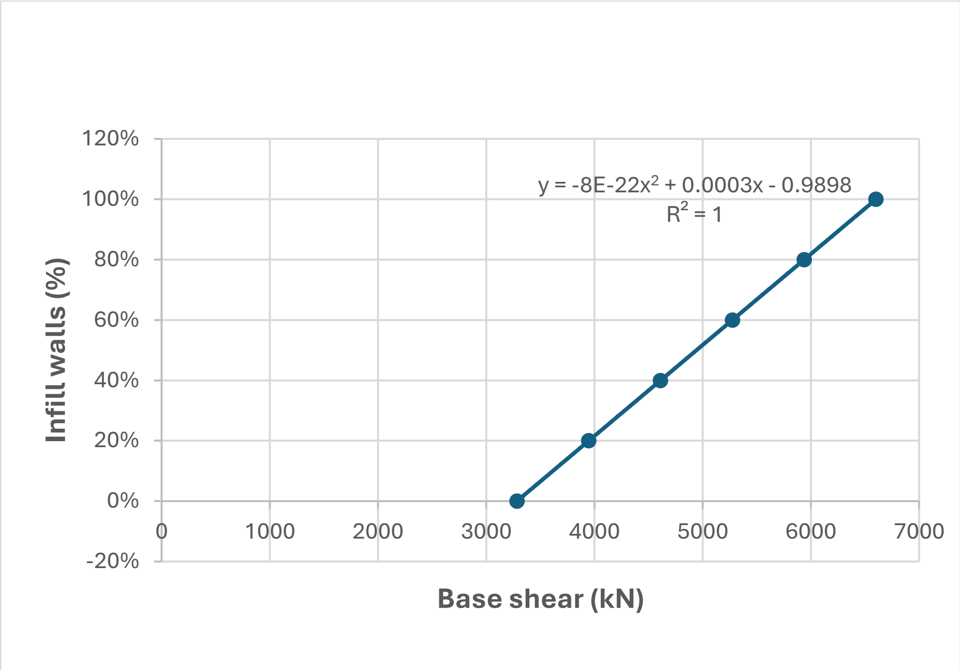


Figure 7. Effect of infill walls on base shear in the frame

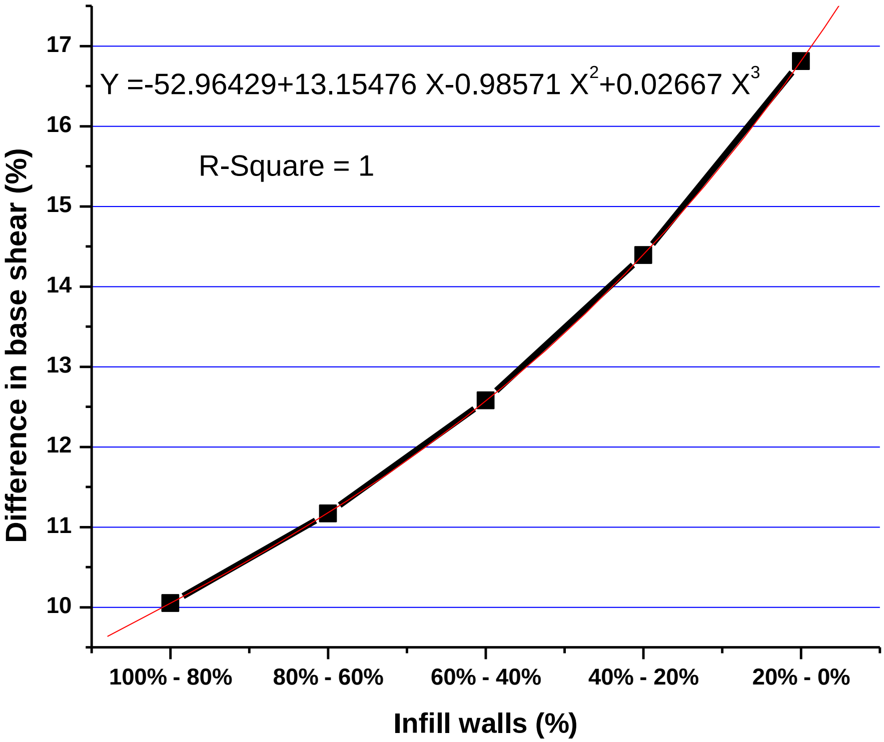


Figure 8. Relation between infill walls and % difference in base shear

Table 3 and Figures 7 and 8 demonstrate that the base shear reported for frames with heavier infill wall weights is higher, and the percentage difference in base shear increases as the percentage of infill walls decreases. This indicates that the seismic response of buildings is certainly influenced by infill walls carrying significant loads. For example, base shear is increased by 50.3% higher by a fully infill wall than by a bare frame. In comparison to the bare frame, the fully infilled frame's base shear is amplified by 2.0.

Table 4. Influence of infill walls on the seismic lateral forces

Floor level	Infill walls (%)						% Difference
	0%	20%	40%	60%	80%	100%	
Roof	597.066472	717.712290	838.358109	959.003927	1079.6497	1200.29556	0
8th	537.359825	645.941061	754.522298	863.103534	971.684770	1080.26600	10
7th	477.653178	574.169832	670.686487	767.203141	863.719796	960.236450	11.1
6th	417.946530	502.398603	586.850676	671.302749	755.754821	840.206894	12.5
5th	358.239883	430.627374	503.014865	575.402356	647.789847	720.177338	14.3
4th	298.533236	358.856145	419.179054	479.501963	539.824872	600.14778	16.7
3rd	238.826589	287.084916	335.343243	383.601570	431.859898	480.118225	20.0
2nd	179.119941	215.313687	251.507432	287.701178	323.894923	360.088669	25.0
1st	119.413294	143.542458	167.671621	191.800785	215.929949	240.059112	33.3
Ground	59.7066472	71.77122909	83.83581091	95.90039273	107.964974	120.02955	50.0

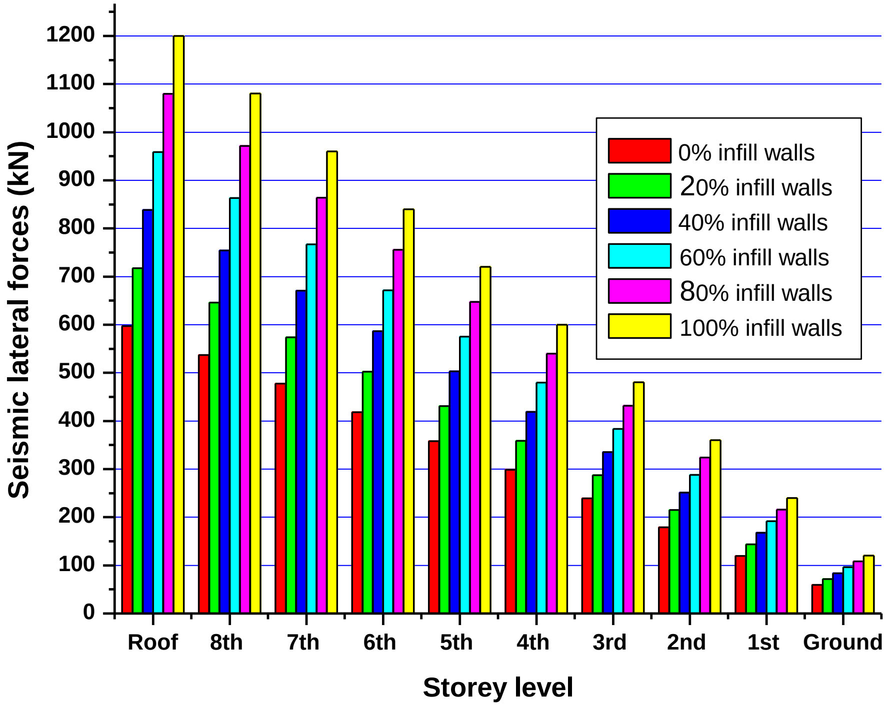


Figure 9. Influence of infill walls on the seismic lateral forces

Despite the fact that infill walls are often considered as non-structural elements, Table 4 and Figure 9 demonstrate how much of an impact they have on the distribution and magnitude of seismic lateral forces in buildings. On the other hand, it is evident that the lateral forces increased as building height increased maximum at the roof. This is due to the fact that the base shear distributes laterally along the floor levels based on how high each floor is raised above the ground.

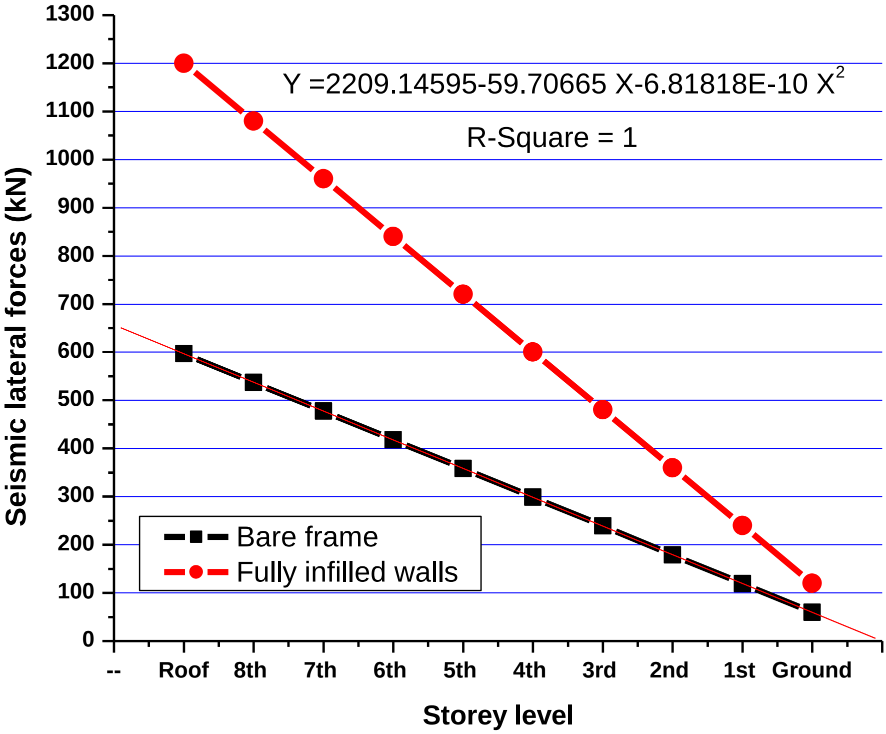


Figure 10. Seismic lateral force of the analysed frame

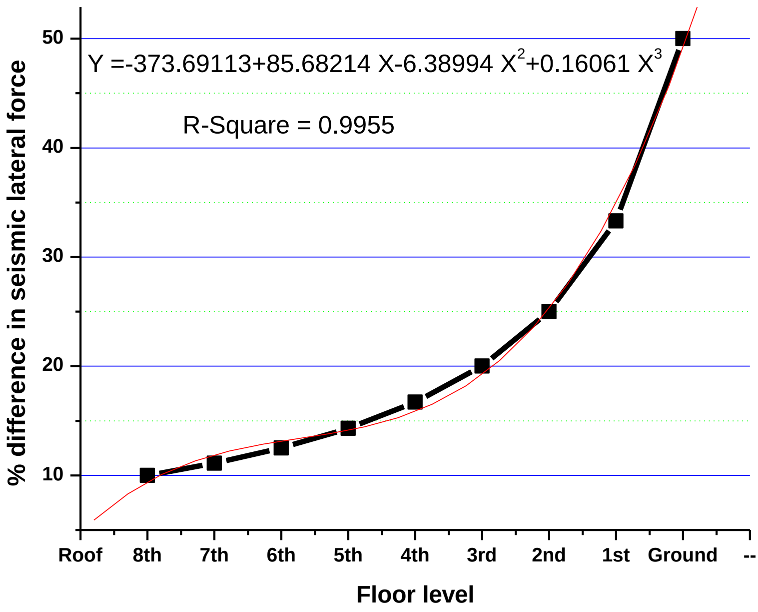


Figure 11. % difference of lateral forces with floor level

Figure 10 illustrates the seismic lateral force relationship between bare frame and completely infilled structures. At each story, the lateral pressures in the frame with infill walls were found to be 50% more than those in the bare frame due to the fact that infill walls improve a building's overall stiffness. This is because the walls serve as braces, fortifying the structure and minimizing lateral displacements inside the frame. Stiffer constructions tend to be more susceptible to seismic forces. According to seismic principles, there is a proportionate link between structural stiffness and lateral seismic force. In the lower floors, the difference between the ground floor and the first floor rises considerably to 50%, whereas in the upper floors, the percentage difference in lateral forces grows little. Figure 11 illustrates the fluctuations in the percentage difference, which indicate a non-linear connection for the weight of the infill walls employed in this study.

Table 5. Influence of infill walls on the lateral displacements of the frame (mm)

Storey level	Infill walls (%)						% Difference
	0%	20%	40%	60%	80%	100%	
Roof	240	199.7	170.9	149.4	132.7	119.4	0
8th	216	179.7	153.8	134.5	119.5	107.5	9.97
7th	192	159.7	136.8	119.5	106.2	95.5	11.16
6th	168	139.7	119.6	104.6	92.9	83.6	12.46
5th	144	119.8	102.5	89.6	79.6	71.6	14.35
4th	120	99.8	85.4	74.7	66.4	59.7	16.62
3rd	96	79.8	68.4	59.8	53.1	47.7	20.10
2nd	72	59.9	51.3	44.8	39.8	35.8	24.95
1st	48	39.9	34.2	29.9	26.5	23.9	33.24
Ground	24	20	17.1	14.9	13.3	11.9	50.21

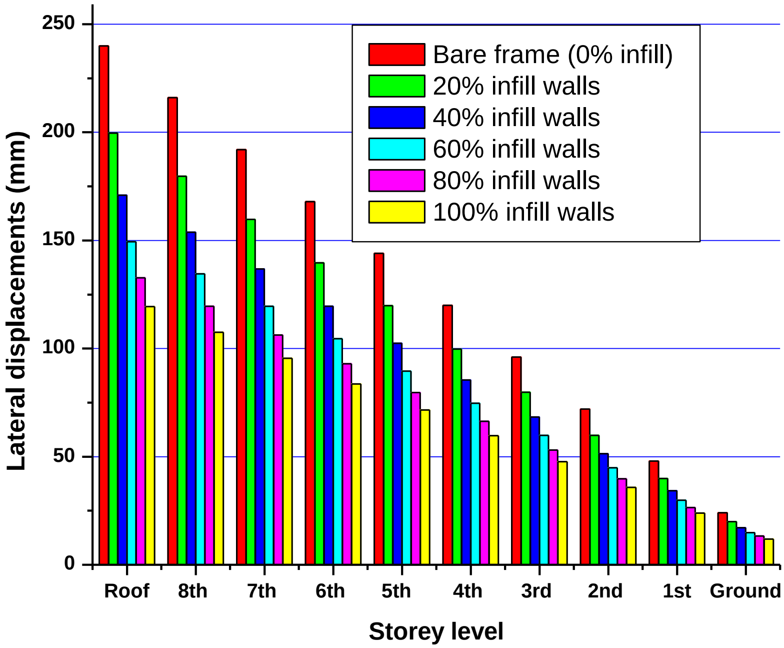


Figure 12. Seismic lateral displacements of the analysed frame

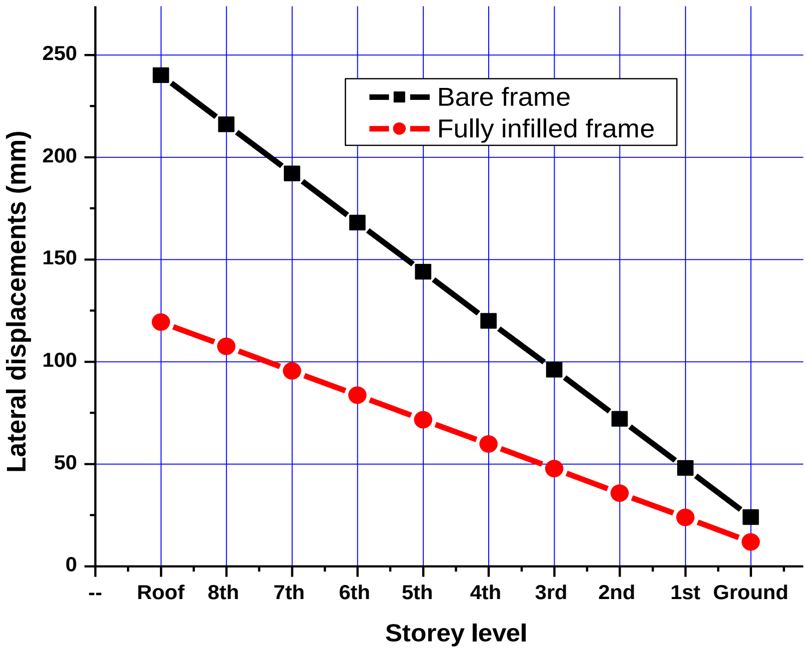


Figure 13. % difference of lateral displacements with floor level

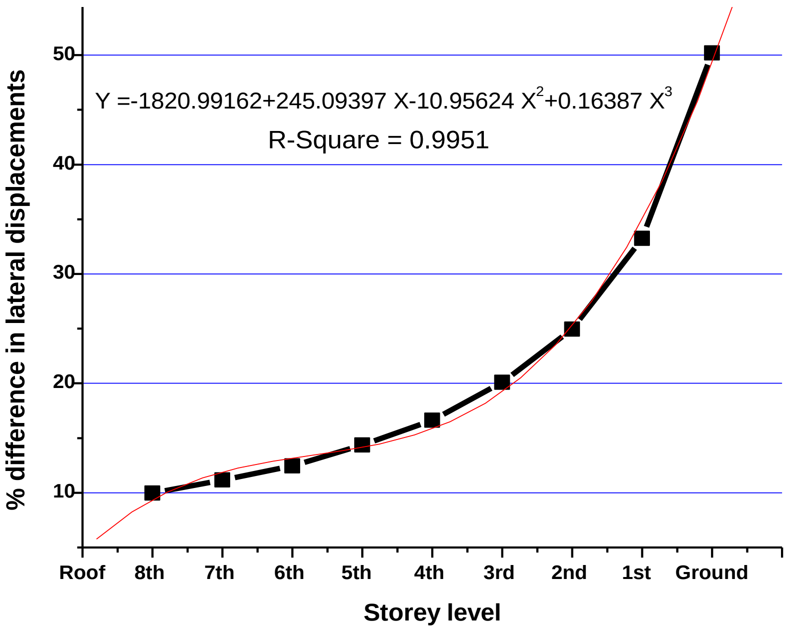


Figure 14. % Difference of lateral displacements with floor level

Table 5 shows that Infill walls have a clear impact on the lateral displacements of building by reducing the displacement capacity of the studied frame by a value of 50.0 % comparing to the bare frame. Reducing displacements and drift, by providing significant initial stiffness and strength, may decrease after cracking. Similar to the behavior of seismic lateral forces, the percentage difference in lateral forces increases little in the upper floors; however, in the lower floors, the difference increases significantly, reaching up to 50% between the ground floor and the first floor as illustrated in Figures 12 to 14.

Table 6. Influence of infill walls on the storey shear forces.

Floor level	Infill walls (%)					
	0%	20%	40%	60%	80%	100%
Roof	597.066472	717.712290	838.358109	959.003927	1079.65	1200.29556
8th	1134.42629	1363.65335	1592.88040	1822.10746	2051.33451	2280.56157
7th	1612.07947	1937.82318	2263.56689	2589.31060	2915.05431	3240.79802
6th	2030.02600	2440.22178	2850.41757	3260.61335	3670.80913	4081.00491
5th	2388.26589	2870.84916	3353.43243	3836.01570	4318.59898	4801.18225
4th	2686.79912	3229.70530	3772.61149	4315.51767	4858.42385	5401.33003
3rd	2925.62571	3516.79022	4107.95473	4699.11924	5290.28375	5881.44826
2nd	3104.74565	3732.10391	4359.46216	4986.82042	5614.17867	6241.53693
1st	3224.15895	3875.646371	4527.133789	5178.621207	5830.10862	6481.5960
Ground	3283.8656	3947.4176	4610.9696	5274.5216	5938.07	6601.625

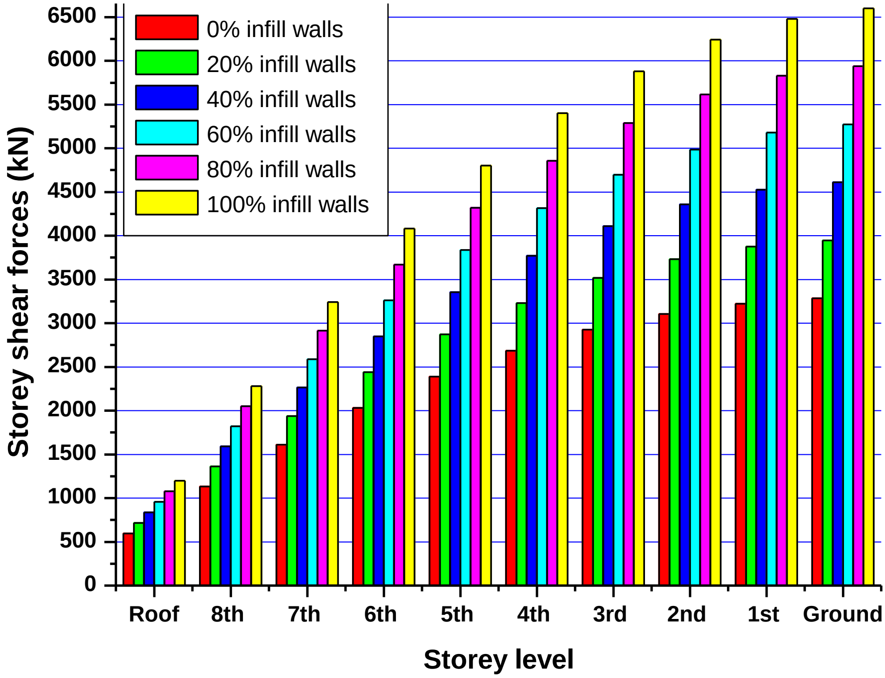


Figure 15. Influence of infill walls on the storey shear forces

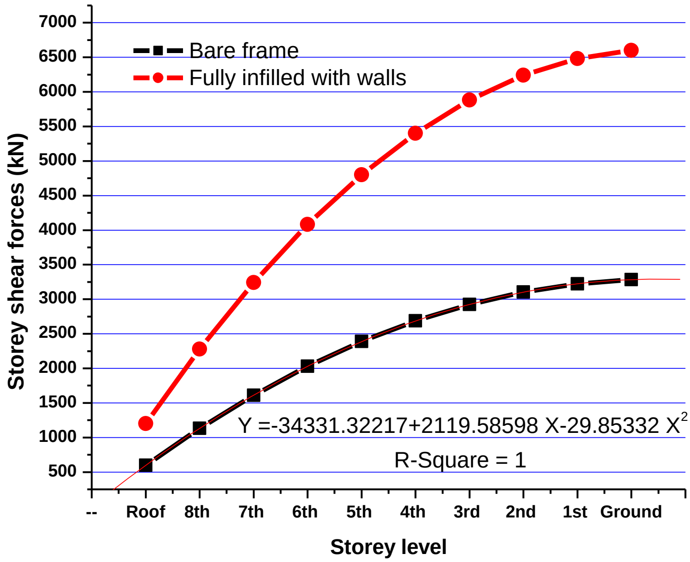


Figure 16. Influence of infill walls on the storey shear forces for fully infilled and bare frames

Referring to Table 5 and Figures 12 and 13 infill walls show a significant impact on the seismic storey shear forces in buildings by modifying the building's dynamic behavior during an earthquake.

There is a large difference in storey shear forces in the upper three stories. The shear force in 9th floor is less than that in 8th floor by an amount of 47 % and 30 % between 8th and 7th floor for (fully infilled frame). Then the difference becomes very slight in the lower stories; between ground and first storey it was found to be 1.8%. in this case, higher seismic storey shear forces in the lower stories result from the increased stiffness due to the presence of infill walls. Finally, the value of storey shear forces increased by 50.3% in fully infill walls compared to bare frame in all levels.

Table 7. Influence of infill walls on the overturning bending moments

Floor level	Infill walls (%)					
	0%	20%	40%	60%	80%	100%
Roof	0	0	0	0	0	0
8th	1791.19941	2153.13687	2515.07432	2877.01178	3238.9492	3600.88669
7th	6985.67773	8397.23380	9808.78987	11220.3459	12631.9020	14043.4580
6th	17016.3944	20454.8002	23893.2061	27331.6119	30770.017	34208.4235
5th	33137.1892	39833.0321	46528.8750	53224.7179	59920.56	66616.4037
4th	56422.7816	67823.8114	79224.8413	90625.8711	102026.9	113427.930
3rd	87768.7714	105503.706	123238.642	140973.577	158708.5	176443.447
2nd	127891.638	153733.972	179576.307	205418.641	231261	257103.309
1st	177328.742	213160.550	248992.358	284824.166	320656	356487.782
Ground	236438.323	284214.0672	331989.8112	379765.555	427541.29	475317.04

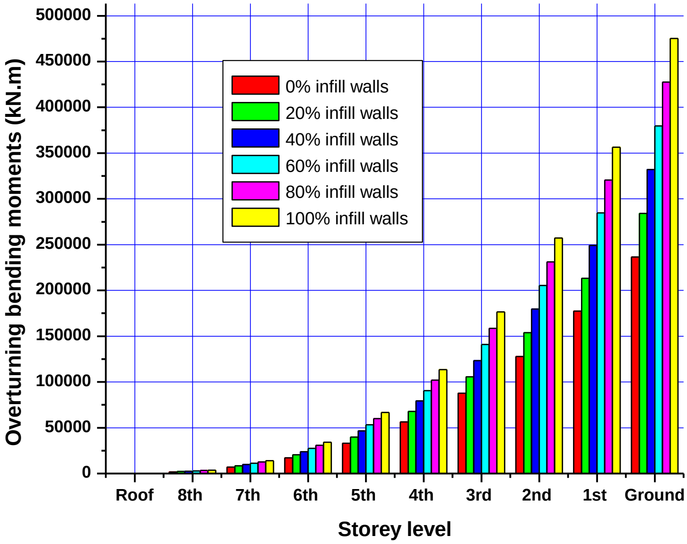


Figure 17. Influence of infill walls on the overturning bending moments

As seen in Figure 14, Table 6 demonstrates that the Infill walls significantly impact the seismic overturning moments in the buildings under study. The building becomes stiffer in the lower stories, which causes the moments to steadily increase from the top to the base of the frame. This relationship is in good agreement with the findings of I. K. Ejiogu et. al. [4].

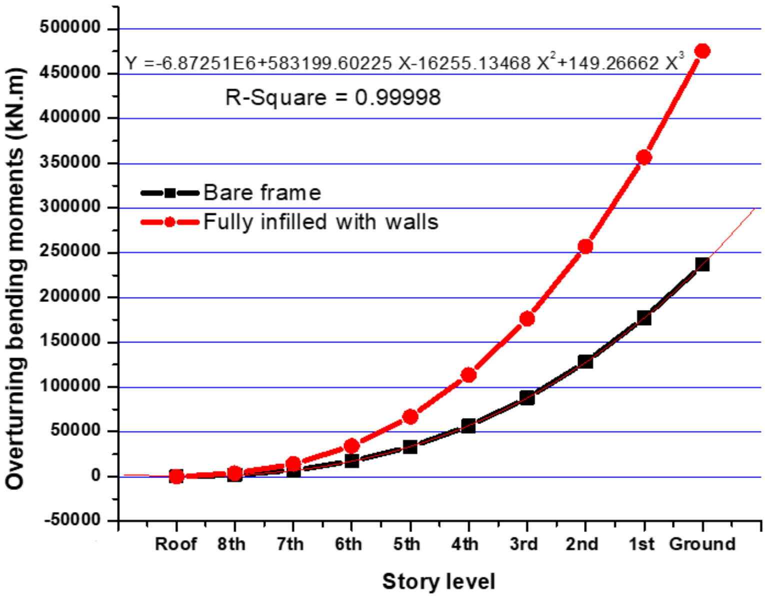


Figure 18. Overturning moments for bare and fully infilled frame

Table 8. % Difference in overturning moments with floor levels

Floor Level	% difference in overturning moment
Roof	0
8th	100
7th	74.4
6th	58.9
5th	48.6
4th	41.3
3rd	35.7
2nd	31.4
1st	27.8
Ground	25.0

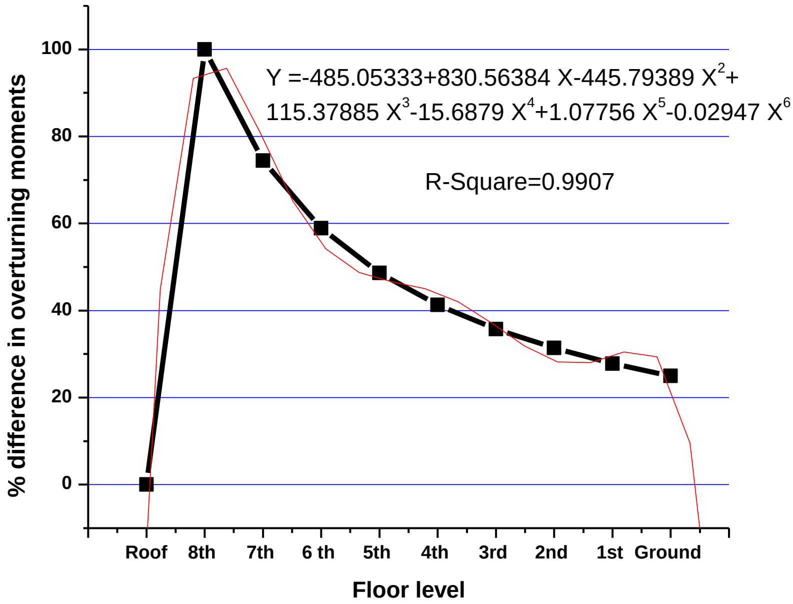


Figure 19. % difference in overturning moments with floor heights

For this polynomial formula, the coefficient of determination (R2) is R2 = 0.9907 as shown in Table 7 and illustrated in Figure 15. Because the overturning moment at the roof is zero, the difference in moments increases by 100% at the eighth floor, and then there is a gradual decrease until the ground floor, which gave the lowest value, this relationship could not have been achieved without the use of the highest power of polynomial (exponent = 6).

The findings of this study closely align and bear similarities to those of Abdelkader Nour (2022), Ayman (2015), Waleed Abo El-Wafa (2012), Ram Krisna (2024), Abdelghffar (2022), and Robin (2004) as a sample of results' agreement.

This paper investigates into how infill walls influenced an ordinary RC moment-resisting frame (ORCMRF) in Jizan city, Saudi Arabia. A 10-storey moment-resisting frame with and without infill walls was analyzed for purposes of comparison. Investigations were conducted on the effects of infill walls on seismic base shear, lateral forces, storey shear forces, and overturning moments. The study's findings demonstrated that the inclusion of infill walls significantly increased the building's base shear when compared to a building without infill walls; in fact, this increase was 100%. This indicates the infill walls' weights have noticeable effects on the building's seismic response.

Even though infill walls are sometimes regarded as non-structural elements, they have significant effects on how much and where seismic lateral forces are distributed throughout buildings. On the other hand, it is evident that the lateral forces and displacements increased as building height increased peaking at the roof. This is due to the fact that the base shear distributes laterally within the floor levels based on how high each floor is raised above the ground. The weight of the infill walls used in this investigation has a non-linear relationship to the variation in the percentage difference between these values. In the upper floors, the percentage difference in lateral forces increases little; however, in the lower floors, the difference increases significantly, reaching 50% between the ground floor and the first floor. A non-linear relationship between the height of floors and the ratios of infill walls utilized in this study can be found by observing variations in the percentage difference in lateral forces across successive floors. Additionally, when the weight of the infill walls increases from top to bottom of the investigated frame, the storey shear forces increase significantly. It was found that, for all floor levels, the value of shear forces is increased by 50.3% more than that of the bare frame. Additionally, because the building becomes stiffer in the lower stories, it has been noticed that adding infill walls to the frame increased the overturning moment from the top to the base of the structure. Moreover, the overturning moments increased by 50.3% in the fully filled frame compared to the bare frame. Because infill walls improve a building's total stiffness, they usually increase base shear, lateral force, shear force, and bending moments. This decreases lateral displacements, or drifts, during seismic events. In general, it is found that, compared to the bare frame model, the dynamic response behavior of the building model is considerably changed by the inclusion of masonry infill action.

4. Conclusion

The impact of wall filling on an ordinary RC frame in jizan city, Saudi Arabia was checked in this trial. Investigation was performed into how filling with walls affected base shear, lateral forces, shear forces and overturning moments.

From the results obtained, it can be concluded that:

1. The addition of infill walls significantly increased base shear by 100 % when compared to a bare frame.
2. The lateral forces and displacements increased as building height increased peaking at the roof, due to the fact that the base shear distributes laterally within the floor levels based on how high each floor is raised above the ground.
3. In the upper floors, the percentage difference in lateral forces increases little; however, in the lower floors, the difference increases significantly, reaching 50% between the ground floor and the first floor.
4. It was found that, for all floor levels, the value of shear forces increased by 50.3% more than that of the bare frame.
5. It was noticed that the overturning moments increased by 50.3% in the fully filled frame compared to the bare frame.
6. In general, it was found that, compared to the bare frame model, the dynamic response behavior of the building model is considerably changed by the inclusion of masonry infill action.

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The author confirms sole responsibility for the following: study conception and design, data collection, analysis and interpretation of results, and manuscript preparation.

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The author declares no conflicts of interest.

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