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Beneficial Effects of Infill Walls on the Structure and Foundation Lateral Performance Under the Effect of Seismic Loads

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ABSTRACT
Reinforced concrete structures with infill walls are the most common in practice and construction in seismic zones around the globe, these structures are vulnerable to additional loads from earthquakes that may cause structure failure and collapse. The infill walls are considered as nonstructural components in the design process, the influence of its mass is considered, while neglecting its mechanical properties such as stiffness and strength leads to negative significances. Therefore, this study aims to investigate the effect of infill walls on the performance of structure, foundation, and confined soil during earthquakes. For this purpose, a full-scale model with and without walls was investigated under the effect of seismic loads. The numerical analysis program PLAXIS 3D was conducted in this current study. A residential building consisting of nine stories and a basement with a raft foundation resting over dense sand soil was modeled as a three-dimension model with and without infill walls. Results confirmed that walls improved the structure stability and increased the structure and foundation resistance to horizontal displacement. Results showed that the maximum reduction in the structure displacement and acceleration with walls was 71% and 50% respectively compared to the bare structure. Also, the infill walls reduced the foundation's horizontal displacement and vertical settlement by 38%. Finally, wall presence has a vital role in the adjustment and modification of the soil's dynamic properties. So, considering the contribution of infill walls behavior is very important as a novel technique to improve the structure resistance and dissipate seismic energy.
Keywords: *Infill Walls; Earthquakes; PLAXIS 3D; Foundation; Sand.*

1. Introduction

Reinforced Concrete (RC) structures with infill walls are the common structure systems that widespread constructed for residential, industrial, and commercial utilization in active seismic regions all over the world [1]. Infill walls are constructed in these frames between the structure columns and below both beams and slabs. The infill walls are classified as a non-elastic and inhomogeneous material, that is composed of bricks and mortar [2]. The masonry walls are used to create separations between different internal sectors of the building and the exterior environment. The masonry walls are the most common and widely used material throughout the construction processes due to many reasons such as durability, low cost, simple practice, aesthetics and providing the structure with thermal and acoustic properties [3]. However, in the design practice of reinforced concrete structures, the infill panels are thought of as a non-structural material and considered as secondary components in calculations and models, notwithstanding that infill has a remarkable role in the enhancement of the structure lateral response [4]. Also, in engineering practice, there is a misconception about the infill influence on structures during earthquakes. Thus, there is a lack of knowledge and guidelines about their design. Besides, different construction and seismic codes neglected the effect of infill walls on structure response under the effect of lateral loads [5]. Results confirmed that neglecting the effect of infill walls' interaction with frames in seismic areas is not practical and far from the safe side [6]. The infill walls' presence increased the system stiffness, strength, and seismic energy dissipation; thus, infill walls act as an equivalent compressed diagonal strut. So as a result of the wall's contribution, a remarkable change in seismic demands and structure lateral behavior to resist horizontal actions as a result of natural period reduction is achieved as confirmed by different experimental and analytical research [7,8]. Previous studies conducted on reinforced concrete frames confirmed that walls decreased the structure's lateral response by 60% [2,3]. Also, an experimental investigation illustrated that wall presence enhanced the system lateral response by 64% and reduced the structure ductility than bare structures by 51%. This reduction is a result of the walls interlocking with the structure columns; thus, the composed system acts as one block to overcome the horizontal action effects [9]. So, there is a dire need to consider the influence of infill walls throughout the designing processes as an alternative and low economic method [1]. Early analytical and experimental investigations carried out in this zone concentrated on the infill parameters such as infill thickness, material, and stiffness on the structure stability. On the other hand, there is a lack of knowledge about the influence of infill walls on both the foundation and confined subgrade soil. From the previous literature, it's evident that previous analytical and experimental studies focused on the influence of infill walls on the structure lateral response while ignoring both the foundation and subsoil response. Modeling and analysis of structures while ignoring the foundation and subsoil's real effect and behavior leads to either unsafe designs or unnecessary costs. Therefore, this paper presents a full-scale numerical model adopted by the finite element program PLAXIS 3D to investigate and study the influence of adding walls on the structure, foundation, and confined soil under the effect of lateral loads. So, a full-scale model with and without walls was conducted in this study. Besides, an advanced constitutive soil model namely Hardening soil was used to represent the real soil dynamic properties. Moreover, the infill walls were represented by the Jointed Rock Model (JRM) to simulate the infill walls' behavior. The derived results from the numerical analyses are presented in various charts and comparisons.

2. Aim and Research Significance

Based on the above comprehensive literature, previous numerical and experimental studies focused on the infill walls' effect on the structure lateral response. In most of the previous extensive studies, the Soil Structure Interaction (SSI) was neglected. In general, in most engineering investigations the structure foundation is considered as a fixed base, such that there is no geological or geotechnical data. Considering the soil structure interaction in the analysis processes has a remarkable effect on the improvement of the structure and foundation lateral response due to seismic loads. Therefore, this study discovers the real behavior of structure, foundation, and confined soil, with the influence of infill walls packing with different thicknesses on the structure system lateral response. The output findings were presented in terms of acceleration, displacement, straining actions, and the improvement in different soil dynamic parameters. These findings will be used to assess the influence of wall packing on the structure's lateral response and to develop our seismic codes.

3. Numerical Modelling and Research Strategy

3.1 The Soil Profile Constitutive Model

The geometry of the problem under investigation was modeled by the PLAXIS 3D. The soil domain consists of dense sand with a volume of 172 x 30 m in length and width respectively, while the soil layer depth was 40 m. The Hardening Soil Model was employed in this study. It's an advanced model and is recommended in the modeling and simulation of soil structure interaction analysis under the effect of dynamic loads to achieve more realistic and accurate results [10]. The subsoil properties and parameters according to the Hardening Soil Model (HSM) are summarized in Table 1. The soil Rayleigh damping at the vertical boundaries is considered to be α, β = 0.23, and 8×10-3, respectively for the soil Rayleigh waves resistance. The Rayleigh damping principle equation is defined by equation (1).

$$C = \alpha M + \beta K \qquad (1)$$

Such that, (C) is the damping matrix, (M) is the mass, (K) is the stiffness matrices and (α, β) are the Rayleigh damping coefficients mass-proportional and stiffness-proportional respectively [10].

3.2 The Superstructure Constitutive Model

In this current study, a resident structural model without walls, and with different wall thicknesses was adopted in this research. This model consists of a basement and nine stories with a total height of twenty-seven meters. Both structure length and width are 12 meters, the structure plan configurations and sectional elevation are presented in Figure 1. The structure is rested over a raft foundation of 1 m thickness. Besides, the structure's self-weight, a static uniform load was applied to the building's different stories. The load is (5.3 kN/m^2), which is the combination of the (W =1.4D. L+1.6L. L), where the Dead and the Live Load is assumed to be (1.5, 2.0 kN/m^2) respectively [12].

It's worth mentioning that for the symmetric condition and to reduce the computational analysis time, only one strip of the investigated model was simulated and modeled [13,14]. The structure columns and beams were defined as beam elements, while the floor slabs and foundations were defined as plate elements. The different structure material properties are listed in Table 2.

Table 1. Details of soil geotechnical and mechanical parameters for Hardening Soil Model (H.S.M) [11]

Soil Parameter	Dense Sand Soil
Material Type	Drained Soil
Relative Density (D_r)	85%
Unsaturated unit weight (γ)	17.7 kN/m^3
Saturated unit weight (γ)	18.2 kN/m^3
E_{50}^{ref}	60000 kN/m^2
E_{oed}^{ref}	60000 kN/m^2
E_{ur}^{ref}	180000 kN/m^2
M	0.5
Cohesion (C)	1 kN/m^2
Angle of Friction (φ)	40°
Dilatancy Angle(Ψ) (φ -30)	10°
γ 0.722	0.0001
G_0^{ref}	250000 kN/m^2
Poisson's Ratio	0.3
P_{ref}	100 kN/m^2
R_f	0.9

Table 2. Structure material properties

Parameter	Structure material properties
Material Type	Elastic Linear Isotropic
Unit Weight (γ)	24 kN/m^3
Young Modulus (E)	3*10^7 kN/m^2
Poisson Ratio (υ)	0.2
Raleigh Damping (α & β)	0.2320 and 0.008

3.3 The Infill Walls Constitutive Model

The infill walls model was represented by the linear elastic-plastic anisotropic constitutive model which is defined by the Jointed Rock Model (JRM). This model is aimed to model and simulate the response of different structure blocks [15,16]. The infill blocks are constructed in horizontal layers, so both the tensile and shear stresses along the head joints (expressed by directions 1-1) are improved due to the influence and contribution of the bed joints (expressed by directions 2-2) which is subjected to a remarkable increase in vertical stresses as presented in Figures 2 and 3. The infill wall properties are listed in Table 3.

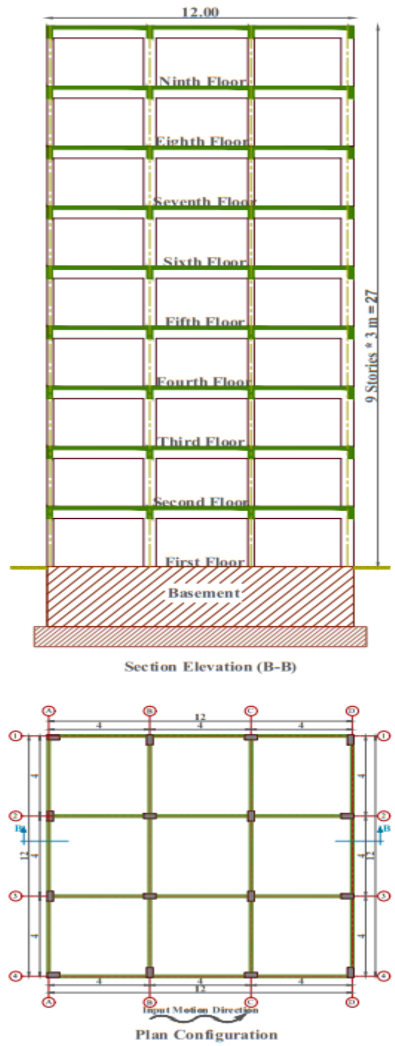

Figure 1: Structure plan configurations and sectional elevation

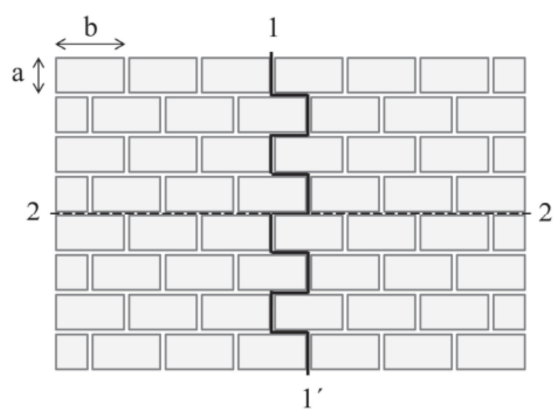

Figure 2. Head (1-1') and bed (2-2') joints direction of infill walls model [15,16]

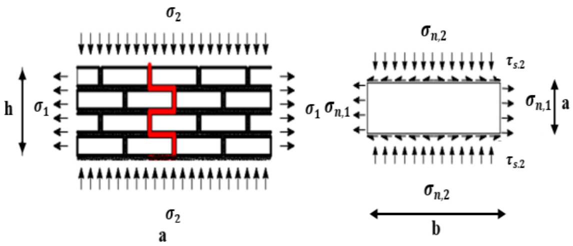

Figure 3: Stress state acting on: (a) a portion of the masonry wall; (b) the single block [15,16]

Table 3: Material properties of walls [15,16]

Parameter	Value
Unit weight (γ)	19.2 kN/m^3
Infill dimension (thickness and length)	0.06 - 0.25 m
Young's modulus (horizontal direction) (E_1)	2.91*10^6 kN/m^2
Young's modulus (vertical direction) (E_2)	2.78*10^6 kN/m^2
Stiffness (G)	0.89*10^5 kN/m^2
Number of planes (N)	2
Cohesion (C1.2)	50.0 kN/m^2
Friction angle (Φ1,2)	37.0 °
Dilatancy (ψ1,2)	0.0 °
Tensile strength (horizontal direction) $f_{tens,1}$	80.0 kN/m^2
Tensile strength (vertical direction) $f_{tens,2}$	50.0 kN/m^2
Rayleigh damping coefficients (α, β)	0.5712
	1.447*10^{-3}

After modeling the soil domain and the super and substructure. The interfaces were assigned between the embedded structure elements and the surrounding subsoil. The interface value was adjusted to 0.67 for different embedded structure elements [2]. The default program earthquake function was imposed by assigning a prescribed horizontal displacement function at the base of the soil domain bedrock with the following properties (Ux =1.0 m, Uy = 0, and Uz = 0) [3]. The soil bedrock was set as a compliment base, while the soil boundaries were assigned as viscous properties [2,3]. Before generating the mesh, the water pressure was activated to consider the excess water pressure on the soil liquefaction.

Three selected monitoring points along the building, foundation, and directly beneath the subsoil were chosen to identify the performance of the system and the infill effect during the earthquake. These three points (A, B, and C) were selected on the top of the building, at the foundation level, and directly in confined subsoil layer below the foundation respectively. The mesh was generated and it was set to be medium, while the cluster beneath and surrounding the foundation was refined twice. This is related to the high concentration of stresses that will be generated under the raft and to gain more accuracy in the analysis processes and results. The geometry of the adopted finite element model is presented in Figure 4.

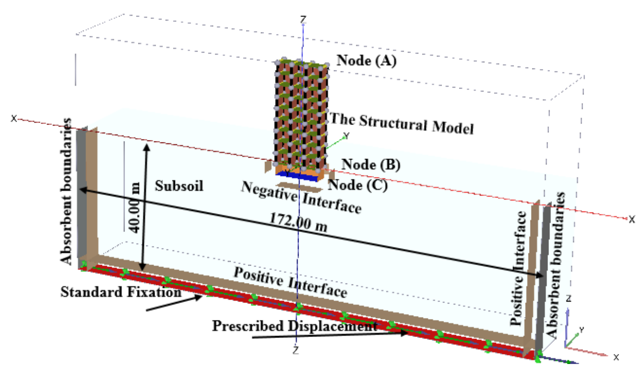

Figure 4: The geometry of the finite element model

4. Boundary Conditions and Model Constitutive

For numerical modeling and analysis of structures subjected to both static and seismic loads while considering the soil subgrade behavior, and to overcome the scale effect and shaking table errors, the finite element program PLAXIS is employed in this current study [17]. PLAXIS analysis processes consider the pseudo-static approach, by imposing the horizontal acceleration functions on soil bulk [18]. So, for the simulation of the investigated model with adequate boundaries with a suitable soil domain to represent the effect of dynamic loads, its suggested to simulate the studied soil region, whereas the rest of the domain is defined as an artificial boundary condition [19].

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4.1 Lateral Boundary and Bedrock Boundary Conditions

Previous comprehensive numerical analysis and studies recommended that the horizontal distance between both the soil domain and the investigated structure should be set in the range of five to ten times the structure width [2]. Therefore, in this study, the soil domain width was chosen to be 172m which is about seven times the structure width. It's worth mentioning that, these dimensions are enough to prevent the soil from failing under the effect of both the static and dynamic conditions [20]. Besides, the soil strata depth was set to be 40 m for dynamic analysis, which is in good agreement with different seismic codes [2,3] that recommended taking into consideration the effect of the first 40 meters to evaluate the soil local effects.

4.2 Dynamic Boundary Conditions

The Compliant base boundary is utilized and assigned in this study to represent the soil domain bedrock. Hence, its recommended in dynamic modeling to overcome and avoid the reflection of waves produced by the soil's lateral boundaries [21].

5. Study Procedures

A series of dynamic numerical models were conducted to examine the influence of infill walls on the soil structure interaction under the effect of lateral loads. Different models of structures with no walls and with walls with different thickness (t_w= 0.06, 0.12 and 0.25 m) were adopted in this study.

The calculation procedure has four phases. The first one is defined as the initial phase where the soil initial conditions are generated. The second phase is the construction phase, where the structure and foundation are created, also the vertical loads are applied. In the third phase the free vibration is adopted for all the models to create the structures natural frequencies [22]. Finally, the fourth phase is created, the dynamic stage, where the earthquake load is imposed. It worth mentioning that, in this phase the displacement will be modified to zero, and for more accuracy in the results the additional steps will be modified to 100 in the Numerical and Control Parameters options, finally, the time interval will be adjusted as 10.00 sec. The finite element program default acceleration time history Loma Prieta earthquake (1990) was conducted in this analysis, with the maximum horizontal acceleration of (0.3g = 2.94 m/sec^2 at a time of 2.53 Sec.).

Program verification is very critical features of numerical modeling and analysis to avoid any modeling errors. To verify the program capabilities in dynamic modeling, a solved foundation example in PLAXIS has been resolved manual by the utilization of the Equivalent Static Load Method (Response Spectrum) as recommended by the Egyptian Code of Practice 2020 [23]. Base on the program results, the stresses were 190 kN/m^2 as presented in Figure 5, while the stresses from the (Response Spectrum) were 183 kN/m^2. So, results confirmed that a good agreement is achieved between the two mentioning approaches.

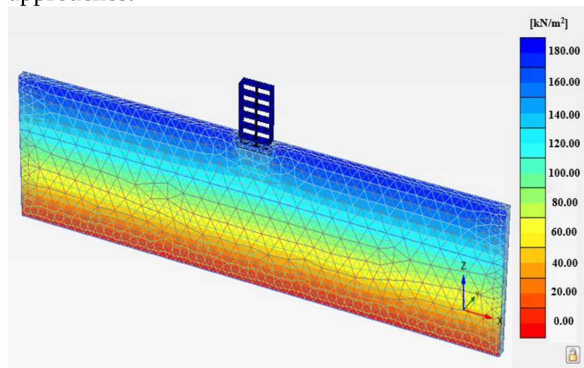

Figure 5: Shading of stress at the foundation level= 180 kN/m^2

6. Results and Analysis

The main objective of this studied research is to examine the contribution of the infill walls as an alternative technique to mitigate the earthquake effects and improve the structure, foundation, and soil system lateral response and deformation. These main findings are presented in details in the following subsections.

6.1 Influence of The Infill Walls on The Structure Lateral Response

This section presents the significant role of infill walls in controlling and decrease the structure's lateral response during an earthquake.

6.1.1Effect of infill walls on the structure displacement

During the earthquakes, a large amount of energy is initially received by the soil layers and then this energy transfers to the substructure and the confined soil. This energy effects on the structure with cracks, deformation and causes failure. Results showed that existence of walls has a vital role in the modification of the structure lateral response. The relationship between both the horizontal displacement and the dynamic time at the monitoring point (A), was recorded and presented in Figure 6. The structure maximum horizontal displacement was 0.07m in the case of without walls. Results confirmed that existence of walls with different thickness improved the structure lateral response, the horizontal displacement decreased to 0.055 m with a reduction percentage of 21% in the case of t_w =0.06 m, then decreased to 0.04 m and 0.02 m in the case of t_w = 0.12 and 0.25m with a reduction percentage of 42% and 71% respectively.

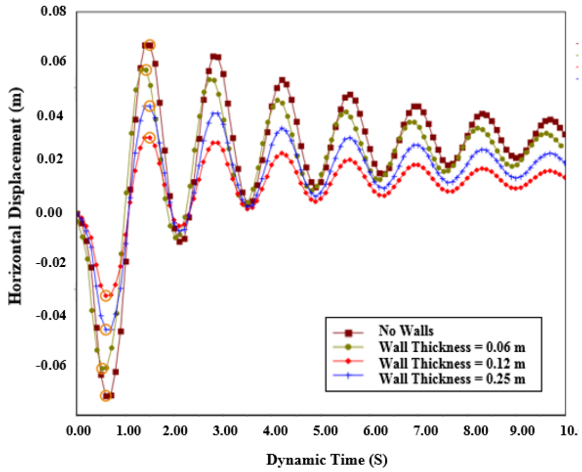

Figure 6: Reduction in the building horizontal displacement (Point A) with no walls and with different walls thickness

The reduction in the structure horizontal displacement with the variation of walls thickness in dimension less ratio (I/ Io) where (Io) refers to the initial wall thickness and (I) is the increase in walls thickness is presented in Figure 7.

Where, Rd= $\frac{\text{Horizontal displacement of different walls thickness}}{\text{Horizontal displacement of no walls condition}}$

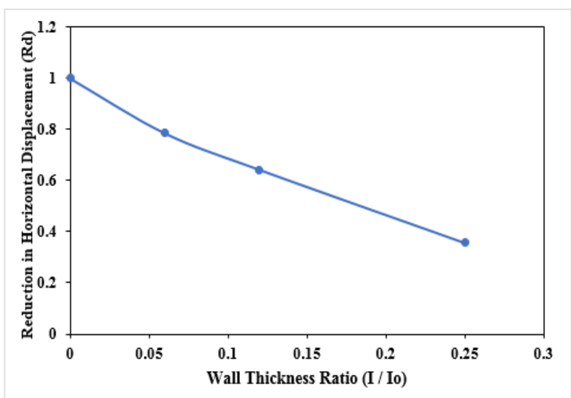

Figure 7: Reduction of horizontal displacement at the top of the structure with increasing the infill walls thickness

This reduction in the structure lateral displacement leads to that the infill walls improves both the structure stability and stiffness; thus, the walls acts as an equivalent diagonal strut and similar to a bracing member between the structure spans as illustrated in Figure 8.

6.1.2 Effect of infill walls on the structure drift

The structure behavior during the seismic loads is forth and sway.

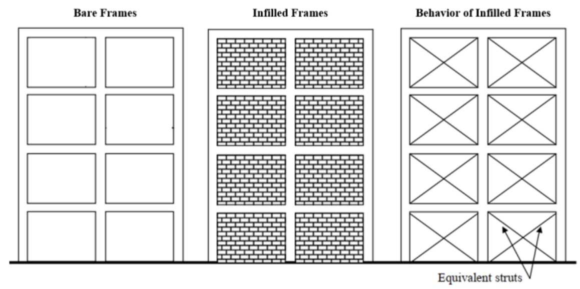

Figure 8: Schematic diagram of the bare, infilled and the behavior of infilled frame during earthquakes [24]

During the seismic loads, structure members are under the effect of stresses and deformation, which leads to generate cracks in the structure members which causes damages or in some times structure failure under the high ground motions. Consequently, controlling and limitation of the structure drift is one of the main aims of the design process. Structure drift ratio is formed by the difference in the drift values between two consecutive floors divided by the floor height. The numerical findings showed the influence of infill walls to control the drift ratio as seen in Figure 9. Results confirmed that the bare building have the maximum drift values, while after the installation of infill walls the drift ratio decreased by increasing the walls thickness. Infill walls acts as a bracing member between the building columns to restrict and control the building extreme sway and mitigate the building lateral deformation through the seismic loads. So, as a main conclusion, buildings with suitable infill walls thickness and distribution will not suffer from inter drift under the effect of seismic loads [25].

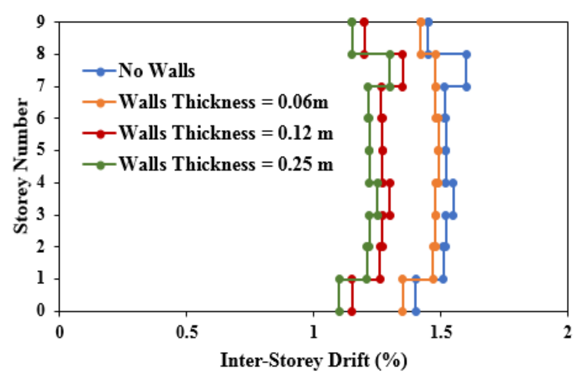

Figure 9: Inter-stories drift for the investigated structure

6.1.3 Effect of infill walls on the structure acceleration

This part presents the variation in the building acceleration at the monitoring point (A) with the existence of walls with different thickness. The building horizontal acceleration and the equivalent dynamic time was recorded. Results confirmed that walls existence have a major role in the adjustment of the building acceleration as seen in Figure 10. The maximum acceleration was in the case of the bare structure, existence of walls of t_w =0.06 m decreased the acceleration a little bit, then a remarkable reduction in the soil acceleration was achieved by increasing the wall thickness to 0.12 and 0.25 m, the reduction value estimates to 29% and 50% respectively.

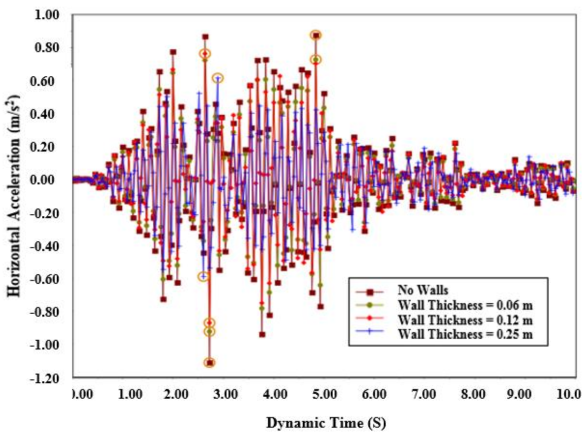

Figure 10: Reduction in the building horizontal acceleration (Point A) with no walls and with different walls thickness

The reduction rate in the horizontal acceleration in case of no walls and case of walls existence with different thickness in the form of the ratio of acceleration reduction factor (Ra) is presented in Figure 11.

Where, Ra=

$$\frac{\textbf{Horizontal acceleration of different walls thickness}}{\textbf{Horizontal acceleration of no walls condition}}$$

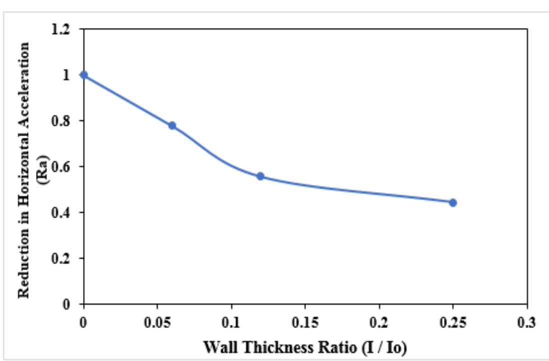

Figure 11: Reduction of horizontal acceleration at the top of the structure with increasing the infill walls thickness

The reduction in the building acceleration is related to the dynamic interlock between the infill walls and structure columns. Walls increased both the structure stiffness and stability to resist the seismic loads. Thus, the walls behave as a massive shear walls during the effect of lateral loads [2,3].

6.1.4 Effect of infill walls on the structure straining actions

Results showed that existence of infill walls has a great role in the reduction of the structure straining actions throughout the seismic loads. From the results, increasing of infill walls thickness leads to a significant reduction in the bending moment and the shear force. Walls of thickness =0.12 m, reduced the induced moment and shear force by 44% and 41% respectively. Besides, its evidence seen that increasing of thickness to 0.25 m, reduced both the moment and the shear force by 58% and 65% respectively compared to the bare building case. The variation of walls thicknesses in stiffness ratio (I / Io) and the reduction in the induced straining actions rate (Rsa) is presented in Figure 12.

Where, Rsa=

$$\frac{\textbf{Straining action of different walls thickness}}{\textbf{Straining action of no walls condition}}$$

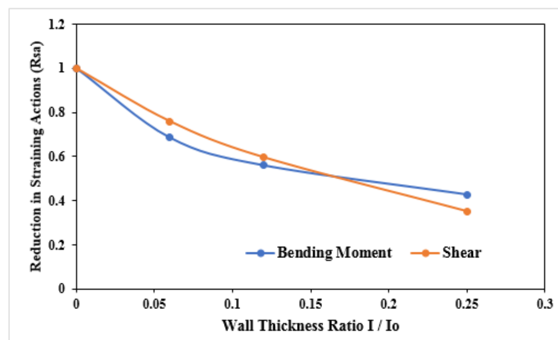

Figure 12: Reduction in straining actions at the top of the structure with increasing the infill walls thickness

Walls will contribute to reduce the transmitted loads to the different structure members, therefore, the forces on the structure element is partly decreased. This reduction is related to the interact between both the infill walls and the structure different members, thus walls and structure behaves as one unit to decrease the induced vibration periods which leads to a significant reduction in the building straining actions. In fact, walls change the structure from frame behavior to truss behavior, where the truss diagonal members reduce the transferred straining action to structure columns as seen in Figure 13 [26]. So, considering the existence of walls in the design process has an economic benefit to reduce the amount of used steel in the different structure members.

It is worth mention that, increasing of walls panels reduces the applied straining actions as agreement with previous studies of (Maintane, 1974) [26] equation:

$$w/d = 0.175\,(\lambda_h)^{-0.4} \qquad (2)$$

And,

$$\lambda_h = h\left[\frac{E_m . t . \sin 2\theta}{4 E_c . I_c . h_m}\right]^{\frac{1}{4}} \qquad (3)$$

Where,

(w, d, h, h_m and θ) are presented in Figure 13.

E_m= Panel modulus of elasticity

E_c= Frame modulus of elasticity

I_c= Column moment of inertia

t = Panel thickness.

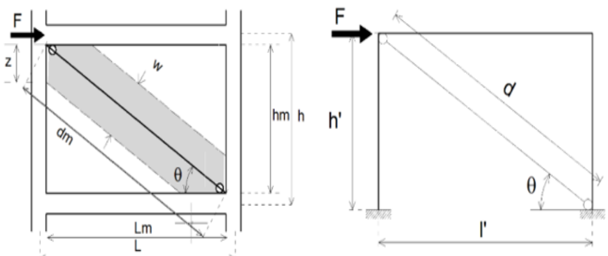

Figure 13: Schematic diagram of the idealization of the infill panel as an equivalent strut modified after (Maintane, 1974) [26]

6.2 Influence of The Infill Walls on The Foundation Lateral Response

This part illustrates the influence of infill walls to increase and improve the foundation stability and relieve the stresses under the effect of lateral loads.

6.2.1 Effect of infill walls on the foundation displacement

Earthquakes generate a huge number of waves that affect on both the foundation and confined soil layers stability. As clearly seen in Figure 14, at the monitoring point (B) the walls reduced the foundation peak horizontal displacement with a reduction percentage of 23% and 38% of for walls thickness of 0,12 and 0,25 m respectively. Besides, walls reduced the foundation vertical settlement along the foundation path. Based on the dimension less ratio of (X/B), which X is different spaces from the foundation center, and B is the space between the foundation center to the foundation edge. It has been founded that, enlarging the walls thickness decreased the foundation vertical settlement, and the maximum reduction estimated to 38% as illustrated in Figure 15. As a main conclusion, the walls act as a strut that decrease the building and foundation movement by generating a resilient system against lateral loads. Also, walls increased the mass over the foundation and enlarged the foundation stiffness that reduced the soil voids and improved the soil particles' stability [2,3]. The variation value of the horizontal displacement and vertical settlement at the foundation level with the variation of walls thickness' is presented in Figure 16.

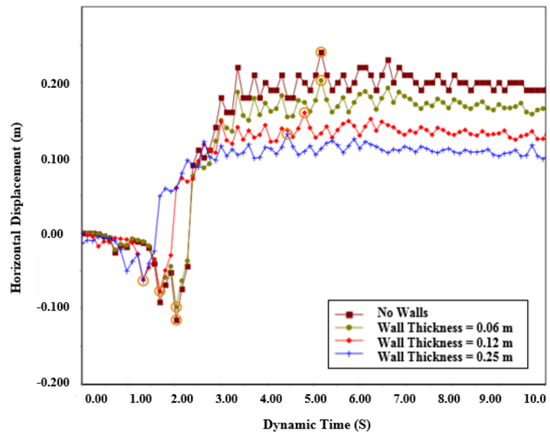

Figure 14: Reduction in the foundation horizontal displacement (Point B) with no walls and with different walls thickness

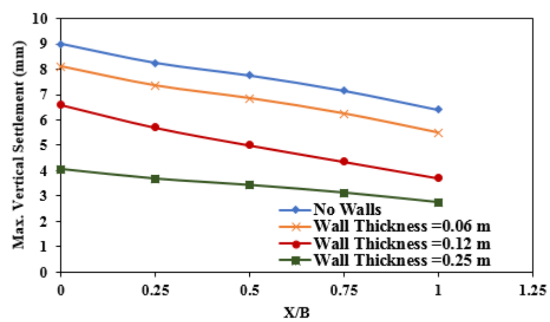

Figure 15: Reduction of foundation vertical settlement for no walls and for different walls thickness

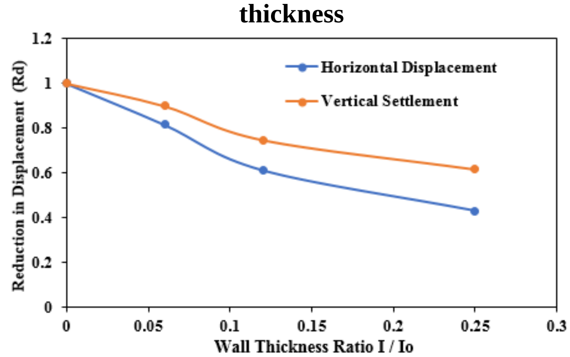

Figure 16: Reduction of horizontal displacement and vertical settlement in the foundation with increasing the infill walls thickness

6.2.2 Effect of infill walls on the foundation acceleration

In addition, the infill walls reduced the foundation acceleration as seen in Figure 17. Results showed that the infill walls decreased the maximum foundation acceleration by as much as 50% from its peak acceleration in case of walls thickness =0.25m. The reduction in the foundation acceleration is related to the existence of walls increased both the foundation and soil stiffness. Besides, the walls and the foundation interlock behave as a mass shear wall to absorb the dynamic response and reduce the transferred vibration to the foundation [3]. The reduction rate in the horizontal acceleration in case of no walls and case of walls existence with different thickness in the form of the ratio of acceleration reduction factor (Ra) is presented in Figure 11.

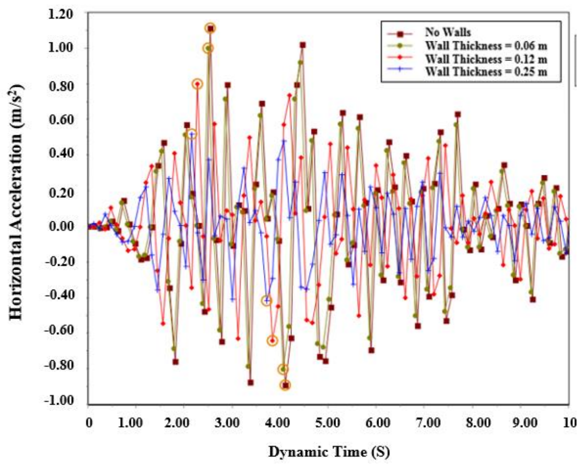

Figure 17: Reduction in the foundation horizontal acceleration (Point B) with no walls and with different walls thickness

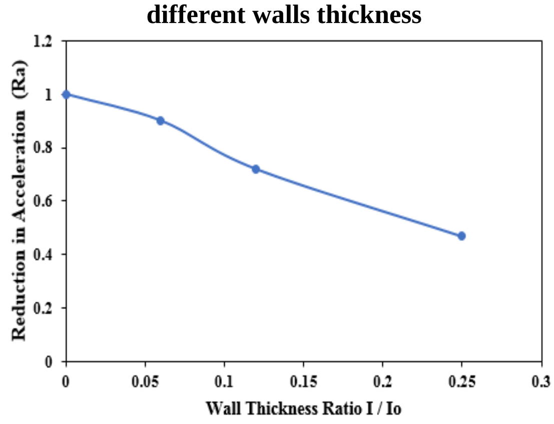

Figure 18: Reduction of foundation horizontal acceleration with increasing the infill walls thickness

6.2.3 Effect of infill walls on the foundation straining actions

Moreover, results showed that, existence of walls and increasing the walls thickness leads to a significant reduction and dissipating of the induced straining actions on the foundation. Figure 19 presents the variation of walls thickness and the reduction in the shear force and bending moment. The walls benefits will be in the mitigation of the foundation shear force, while the walls will not be useful to even mitigate or control the bending moment, such that the different structure vertical loads cause bending moment during the construction stage.

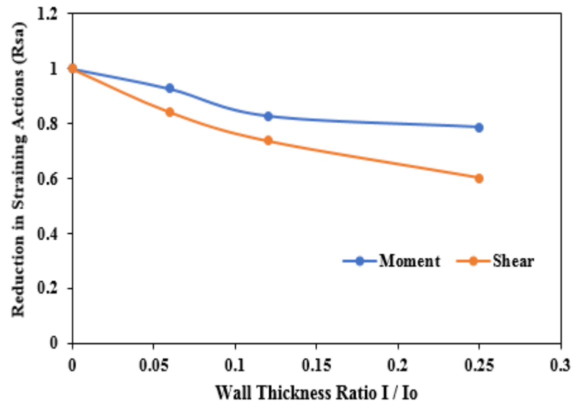

Figure 19: Reduction of induced straining actions moment and shear at the foundation (Point B) with increasing of walls thickness

6.3 Influence of The Infill Walls on The Subsoil Lateral Response

One of the main prerequisites of this study is to examine and evaluate the presence of infill walls on the dynamic behavior of the subsoil during the earthquake.

6.3.1 Effect of infill walls on the soil displacement

Earthquake waves cause spreading and scatter of the confined soil particles in both directions. Results confirmed that, existence of infill walls and increasing its thickness improve the confined subsoil and foundation to interact as a one massive block to reduce the soil lateral displacement. As presented in Figure 20 the soil maximum displacement was 0.24 m in the case of bare structure, while after the owing of the infill walls this value decreased gradually by increasing the walls thickness to be 0.12 m, while in the case of walls thickness of 0.25m the reduction percentage estimate to 50%. This reduction is related to walls will redistribute the induced vibration from the waves on the structure, and interlock with the structure different elements to decrease the absorption of vibration to the soil layers [27]. The reduction in the soil lateral displacement with the variation of walls thickness is presented in Figure 21.

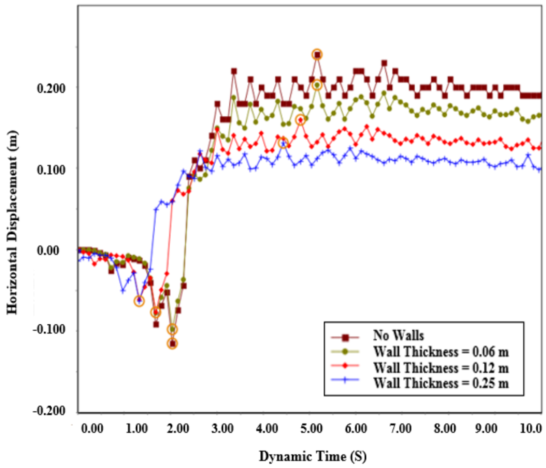

Figure 20: Reduction of soil lateral displacement (Point C) with no walls and with different walls thickness

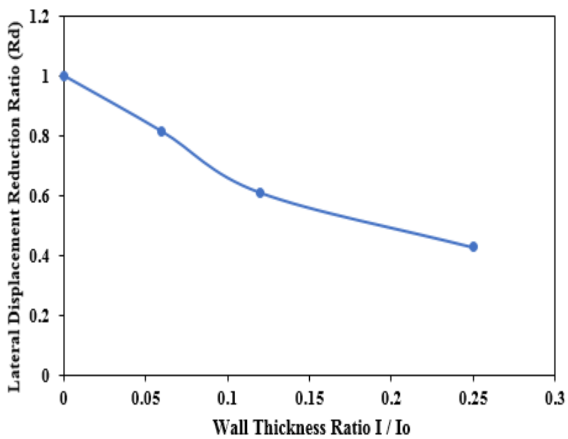

Figure 21: Reduction of soil lateral displacement with the ratio of different walls thickness, at (point C)

6.3.2 Effect of infill walls on the soil acceleration

Soil acceleration is one of the most dynamic soil properties through the effect of seismic loads. Numerical studies were conducted to investigate the relationship between the soil acceleration and the variation in walls thickness. Its evidence seen that, existence of the infill walls and increasing its thickness leads to a significant reduction in the soil acceleration as presented in both Figures 22 and 23. Based on the result, the maximum reduction in the soil acceleration achieved 29% in the case of walls thickness 0.25m. This reduction is related to that infill walls increased the structure system mass which improvs the system stability and stiffness. Also, enhancement the foundation stability during the seismic waves [2,3]. The reduction in the soil horizontal acceleration with the variation of wal**ls** thickness is presented in Figure 24.

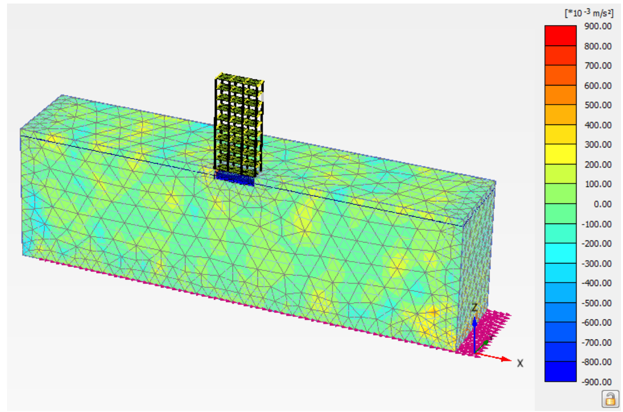

Figure 22: The horizontal acceleration shading for bare model (Max. Acceleration = 0.90 m/s^2)

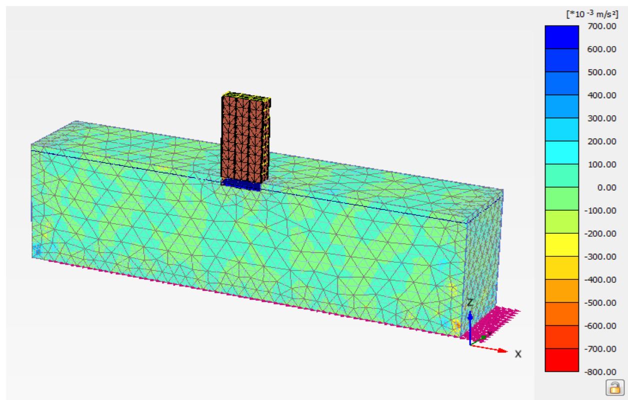

Figure 23: The horizontal acceleration shading for infill walls model of 0.25 m (Max. Acceleration = 0.75 m/s^2)

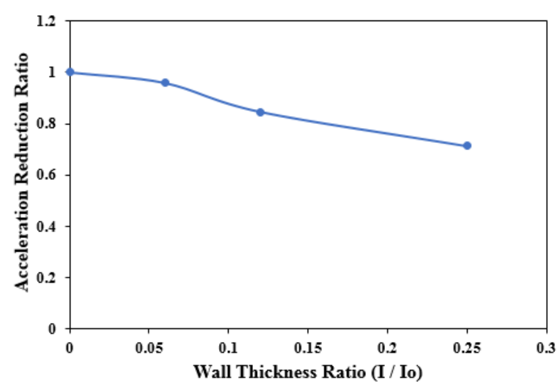

Figure 24: Reduction of soil horizontal acceleration with the ratio of different walls thickness, at (point C)

6.3.3 Effect of infill walls on the soil velocity

Actually, there is a strong relationship between both the confined subsoil velocity and acceleration. Numerical results confirmed that infill walls have a major role to control and limit the soil velocity during earthquakes as seen in Figures 25 and 26. Results showed that the subsoil velocity decreased from 40 m/s in the case of the bare structure to be 24 m/s with a reduction value of 40%. The reduction in the soil velocity is related to the infill walls enhancement the foundation stability by increasing its mass, thus the foundation prevents the soil particles from flow and spread during the lateral loads [2,3]. The reduction in the soil horizontal velocity with the variation of walls thickness is presented in Figure 27.

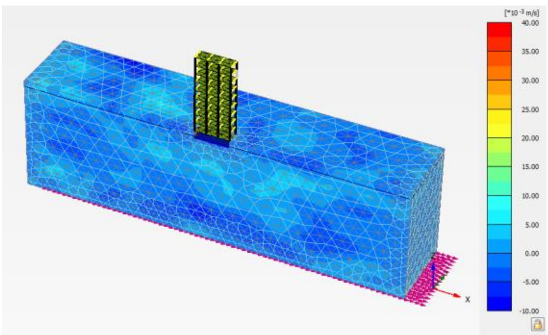

Figure 25: The horizontal velocity shading for bare model (Max. Velocity = 0.40 m/s)

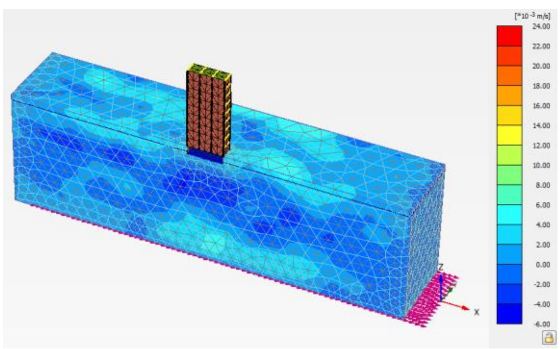

Figure 26: The horizontal velocity shading for infill walls model of 0.25 m (Max. Velocity = 0.24 m/s)

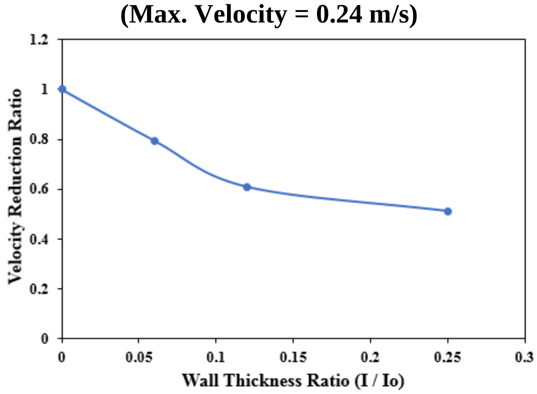

Figure 27: Reduction of soil horizontal velocity with the ratio of different walls thickness, at (point C)

6.3.4 Effect of infill walls on the soil shear strain

One of the most earthquake hazards the effect of shear waves on the soil subgrade which leads to a disturbance in the soil particles especially underneath the foundation level. Results showed that infill walls existence can modify and decrease the soil shear strain. As presented in both Figures 28 and 29, the soil maximum shear strain was 152.6 kN/m^2 in the case of the bare structure, after the existence of the walls this value decreased to be 127 kN/m^2 with a reduction value of 16.4%. The effect of infill walls is similar to the mass damper behavior during earthquake, thus act as a vertical mass block which dissipate and resist the shear waves and stresses through the seismic loads [24]. The reduction of the soil shear strain with the variation of walls is presented in Figure 30.

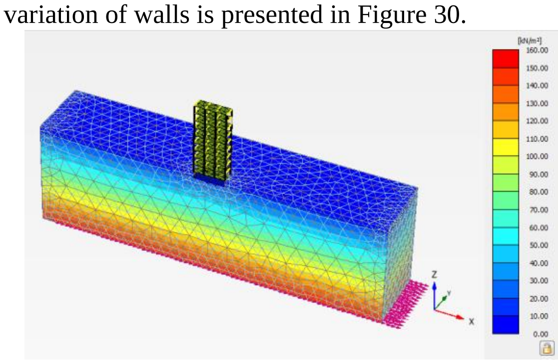

Figure 28: The shear shading for bare model (Max. shear 152.6 kN/m^2)

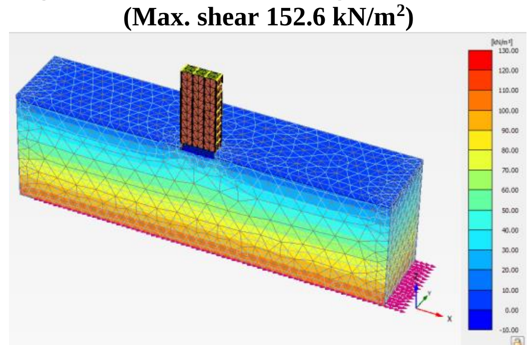

Figure 29: The shear shading for infill walls model of 0.25 m (Max. shear 127 kN/m^2)

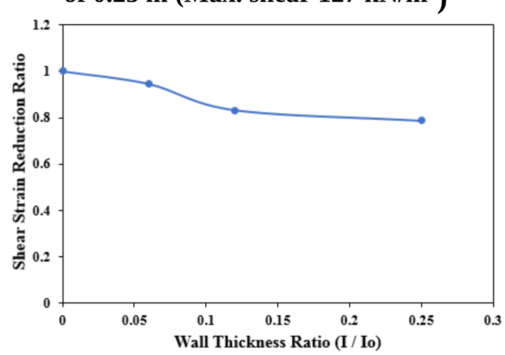

Figure 30: Reduction of soil shear strain with the ratio of different walls thickness, at (point C)

7.Conclusions

This current study aims to investigate and examine the effectiveness and contribution of infill walls on the lateral performance of the structure, foundation, and subsoil during seismic loads. By the utilization of the finite element program PLAXIS 3D, a structure model consisting of a basement and nine floors resting over sand soil strata was modeled and analyzed, without walls and with different infill wall thicknesses. This current research presents a novel and economical technique that can be used to decrease or even control the different earthquake hazards on the structure and foundation. Based on the previous above analysis, the main findings of this study can be drawn as the following:

1. The existence of infill walls is a novel technique and a good method to control and limit the structure, foundation, and subsoil lateral deformation.
2. Increasing the wall's thickness can significantly improve the structure stiffness, and foundation stabilization and modify the soil dynamic properties during seismic loads.
3. Walls existence decreased the structure displacement by as much as 21%, 42%, and 71% for wall thickness of 0.06, 0.12, and 0.25 m respectively.
4. Results confirmed that the existence of walls decreased the structure drift compared to the case of the bare structure.
5. The maximum reduction in the structure's horizontal acceleration is estimated at 50% compared to the bare structure.
6. Walls have a major role in the reduction of structure-straining actions, which leads to economic benefits in the design processes.
7. Walls of 12 cm thickness decreased the foundation's horizontal displacement and vertical settlement by 23% and 20% respectively, while after enlarging the wall's thickness to 25 cm the reduction in the horizontal displacement and vertical settlement achieved 38 % and 22% respectively.
8. A considerable reduction in both the foundation horizontal acceleration and straining actions was achieved after the existence of infill walls.
9. Results confirmed that walls decreased the subsoil horizontal displacement by as much as 37 % and 50% in the case of walls thickness 12 and 25 cm respectively.
10. The subsoil acceleration and velocity maximum reduction were 29% and 40% respectively in the case of walls thickness 25 cm.
11. A significant reduction in the soil shear strain along the foundation path was achieved after the owing of the walls.

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