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RESEARCH

Enhancing the earthquake resistance of RC and steel high-rise buildings by bracings, shear walls and TMDs considering SSI

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Abstract

The increasing population, limited residential space, and scarcity of suitable land for construction have led to a rise in the construction of high-rise buildings (HRBs) as a means to provide additional housing. The increase in human activities (such as excavations for geothermal resources) has led to an increase in seismic activity, making HRBs more vulnerable to earthquakes. Structural analysis of HRBs that are exposed to seismic loadings depends on one of the most important factors that judge the stability and resistance to seismic waves which is the stiffness of the buildings. Various methods that reduce flexibility and enhance stiffness for HRBs are the subject of this numerical investigation, and they were applied to a high-rise building (HRB) of 20 floors, considering soil–structure interaction (SSI). The stiffening methods adopted herein are steel or concrete shear walls (SWs) in specific arrangements, and different bracings in specific arrangements. Moreover, in this study, tuned mass dampers (TMDs) are used, as a damping method of the HRB seismic response, also considering SSI, and the results are compared with the stiffening methods results to judge how the applied methods enhance the seismic resistance of HRBs. These methods, which were used to influence the stiffness or the damping of the building, had different positive effects on the seismic response of the HRBs, which appeared in the results through the base shears, the base moments, the maximum top displacement, and the fundamental period of the building.

Keywords Stiffness · Shear wall · Bracing · Damping · Tuned mass damper (TMD) · Soil–structure interaction (SSI) · Seismic response · High-rise building (HRB) · Reinforced concrete (RC) · Steel

Introduction

High-rise buildings (HRBs) are complex structures that are required to withstand different types of loads including wind, earthquake, and gravity. Among these loads, earthquakes can cause significant damage to the building if the structure is not properly designed and detailed. One of the key design factors that affect the seismic response of HRBs is stiffness. Stiffness is a measure of the resistance of the structure to deformation under load. Increasing the stiffness of a building can improve its seismic performance by reducing the lateral top displacement response and the first mode period time (fundamental period) of the structure. However, it is important to also consider the distribution of stiffness within the building and the interaction between stiffness and other design factors (e.g., the size of structural elements) to achieve optimal seismic performance.

Many studies have been conducted to investigate the effects of stiffness on the seismic response of HRBs and the most key finding is that increasing the stiffness of the building can reduce the lateral displacements and drift during an earthquake. This is because the structure can resist lateral loads more efficiently with increased stiffness, and increasing the stiffness of the building can also reduce the acceleration response of the structure during an earthquake. This is because the structure can resist ground motion more effectively with increased stiffness. However, increasing the stiffness of a building can also increase the forces and

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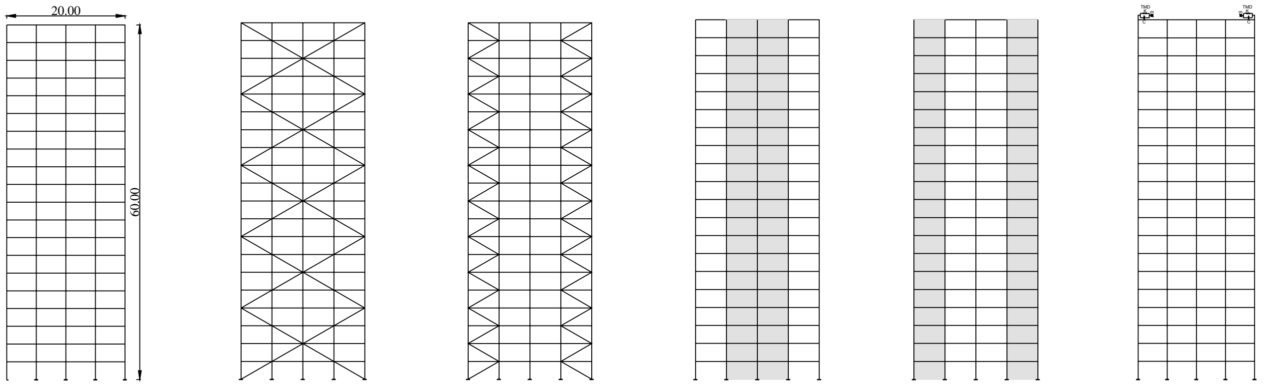
stresses within the structure during an earthquake. This can lead to increased damage or even collapse if the structure is not properly designed. The distribution of stiffness within a building can also affect the seismic response. For example, a building with a stiffer core and more flexible perimeter may have different seismic response characteristics than a building with a uniform stiffness distribution.

Several studies have been conducted on the seismic behavior of RC or steel high-rise buildings equipped with bracings, or with shear walls, or with TMDs, and some selected of them are mentioned below.

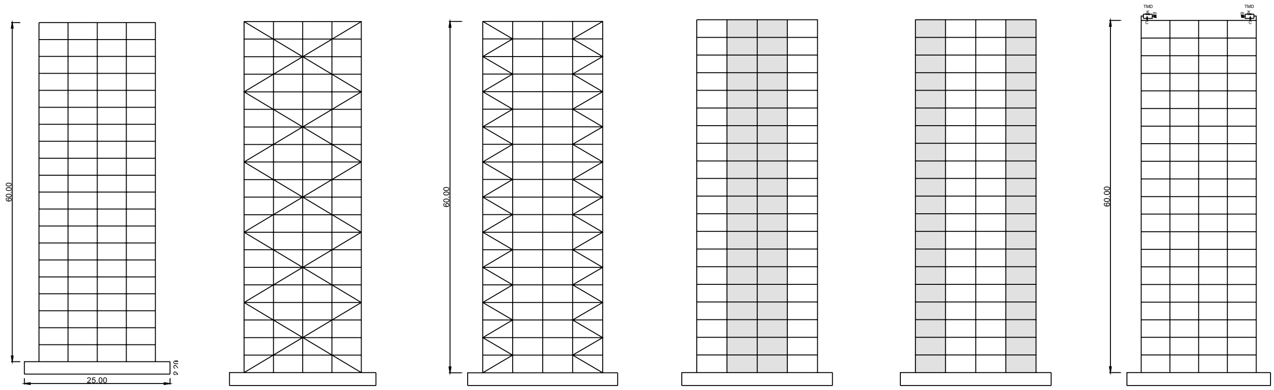
Mo et al. (2019) studied the seismic behavior of a high-rise steel–concrete hybrid structure under two-way seismic action for different thicknesses of the shear wall and the stiffness of the connection between the frame beam and the shear wall. Mule et al. (2020) studied the dynamic response of HRB subjected to the combined effect of earthquake and strong wind and observed that story displacement, story drift, depth-capacity ratio, and contributions of each hazard circumstance are sensitive to damage severity. Kamarudin et al. (2021) studied the seismic response of HRBs with shear wall (SW) and concluded that the stiffness and base shear increase with the use of shear wall (SW) in buildings and that the building with the shear wall is more resistant. Nagarajaiah et al. (2022) investigated the seismic response of high-rise structures and large-span bridges with outrigger systems incorporating dampers with negative stiffness devices (NSDs) and inerters and they concluded that adaptive passive stiffness devices that enhance damping in all modes are preferred. San Segundo (2022) investigated the dynamic performance and the optimum stiffness and mass of a HRB and found that concluded that by thickening certain floor slabs, there were considerable improvements for the base design with no outriggers.

Kontoni and Farghaly (2018) studied the stiffness effects of the structural elements (columns, beams, and slabs) on



(i) Bare (ii) X bracing (iii) xx bracing (iv) Inner SW (v) Outer SW (vi) Top 4 corners TMDs

(a) Fixed base model



(i) Bare (ii) X bracing (iii) xx bracing (iv) Inner SW (v) Outer SW (vi) Top 4 corners TMDs

(b) Raft foundation model (SSI model)

Fig. 1 Front view of the 3D models of the reinforced concrete (RC) and steel HRBs

Table 1 Abbreviations of added systems to the bare HRB

Abbreviations	Descriptions
(i) Bare	Bare frame model
(ii) X bracing	Big bracing all over the frame model
(iii) xx bracing	Small bracing at corners
(iv) Inner SW	Inner (middle) shear walls all over the height and all sides of the frame model
(v) Outer SW	Outer (edge) shear walls all over the height and all sides of the frame model
(vi) Top 4 corners TMDs	Top 4 corners two-directional TMDs

the seismic response of RC high-rise buildings. Kontoni and Farghaly (2019a) performed a seismic evaluation of mixed steel and RC columns in hybrid high-rise buildings. Kontoni and Farghaly (2019b) studied the effect of base isolation and tuned mass dampers on the seismic response of RC high-rise buildings considering soil–structure interaction. Kontoni and Farghaly (2020) studied the TMD effectiveness for a steel high-rise building subjected to wind or earthquake including soil–structure interaction. Farghaly and Kontoni (2022) investigated the mitigation of seismic pounding between RC twin high-rise buildings with piled raft foundation considering SSI.

Kaveh and Zakian (2014a, 2014b) investigated the optimal seismic design of RC moment frames and dual shear wall-frame structures. Kaveh and Farhadmanesh (2019) studied the optimal seismic design of steel plate shear walls using metaheuristic algorithms. Kaveh et al. (2020a) investigated the optimal design of planar RC frames considering CO2 emissions using ECBO, EVPS and PSO metaheuristic algorithms. Kaveh et al. (2020b) studied the optimal structural control of tall buildings using tuned mass dampers via a chaotic optimization algorithm. Kaveh et al. (2020c) investigated the robust optimum design of the tuned mass damper inerter (TMDI) to control a base-excited shear building. Kaveh et al. (2020d) compared H2 and H∞ algorithms for the optimum design of tuned mass dampers under near-fault and far-fault earthquake motions. Kaveh and Rezazadeh Ardebili (2021) conducted a comparative study of the optimum tuned mass damper for high-rise structures considering soil–structure interaction.

Shendkar et al. (2021a) studied the effect of lintel beam on the seismic response of RC buildings with semi-interlocked and unreinforced brick masonry infills. Shendkar et al. (2021b) and Shendkar et al., (2022a, 2022b) investigated the seismic evaluation and retrofit of RC buildings with masonry infills and the influence of masonry infill on seismic design factors of RC buildings.

Salimi et al. (2021) performed a numerical 3D finite element assessment of a bending moment-resisting frame

Table 2 Soil properties

Properties	Specific gravity	Liquid limits %	Plastic limit %	Plasticity index %	Uniformity coefficient	Coefficient of curvature	Dry density (g/cm^3)	E (N/mm^2)	ν	G (kPa)
Soil	2.65	41.5	22.6	18.9	1.46	1.09	1.75	20	0.40	15

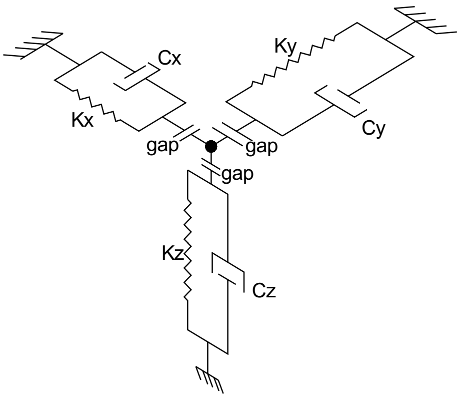


Fig. 2 3D soil element

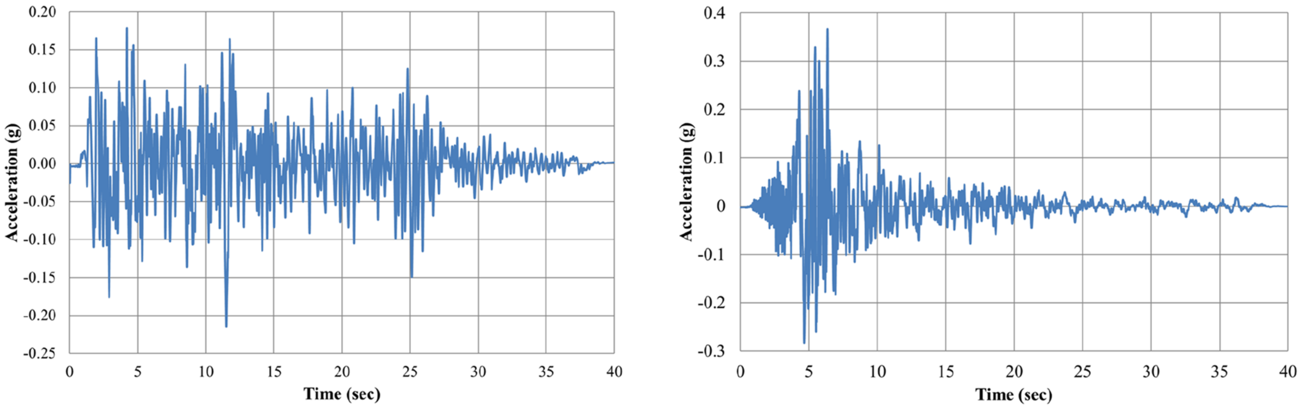
equipped with a semi-disconnected steel plate shear wall and yielding plate connection. Ebadi-Jamkhaneh and Kontoni (2022) investigated numerically thin steel shear walls retrofitted with CFRP layers under reversed cyclic loading. Kontoni et al. (2022) investigated the fire effect on the behavior of corrugated steel plate shear walls. Ghamari and Haeri (2021) researched improving the behavior of high-performance steel plate shear walls using low-yield point steel. Ghamari and Johari Naeimi (2023) investigated the seismic behavior of high-performance steel plate shear walls. Alshimmeri et al. (2021) researched improving the seismic performance of reinforced concrete frames using an innovative metallic-shear damper. Alshimmeri and Kontoni (2022) performed research on improving the behavior of steel plate shear wall using double infill plates. Rouhi and Gholhaki (2022), Salimbahrami and Gholhaki (2022) and Rouhi and Kontoni (2023) investigated the seismic behavior of reinforced concrete frames equipped with and without steel plate shear walls.

Kaveh and Farhoudi (2016) utilized Dolphin Monitoring (DM) to improve the performance of the metaheuristic algorithms for layout optimization of braced frames. Kaveh et al. (2021) studied the optimal design of 3D frames equipped with buckling restrained braces. Ahiwale et al. (2023) investigated the seismic performance assessment of reinforced concrete frames with different bracing systems.

In this research, a 3D 20-story steel or reinforced concrete HRB of 20 × 20 m plan with different stiffening or damping systems was analyzed. To achieve the smallest response of HRBs subjected to earthquakes, various methods were used, including (1) X bracing on all external facades of the structure, (2) single bracing on the outside corners of the structure, (3) RC shear walls with internal distribution, (4) RC shear walls with distribution on the corners of the structure, (5) steel shear walls with internal distribution, 6) steel shear walls with distribution on the corners of the structure, and (6) 4 top corner two-directional TMDs. These methods were applied to the HRB, whether steel or RC, and the base shear, base moment, and top maximum displacement of the building were evaluated under two famous earthquakes, El Centro and Northridge. The SSI was taken into consideration and the results were compared to fixed base models.

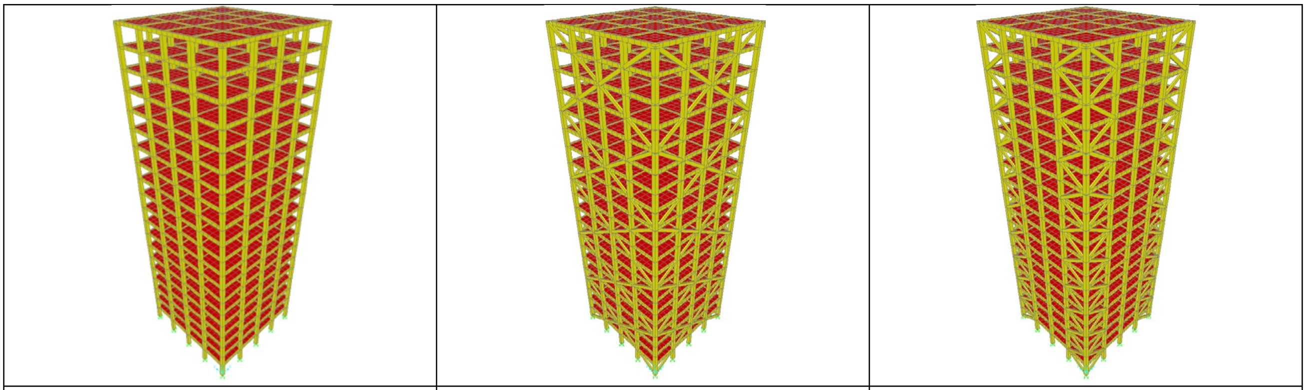
Methodology

To investigate the effects of stiffness on the seismic response of HRBs, a numerical analysis will be conducted using the finite element software SAP2000 version 17 (2015). A parametric study will be conducted to investigate the effects of different levels and distributions of stiffness on the seismic response of the building. The building model, which is a 20-story RC or steel HRB with and without the SSI effect, will be subjected to two different ground motions

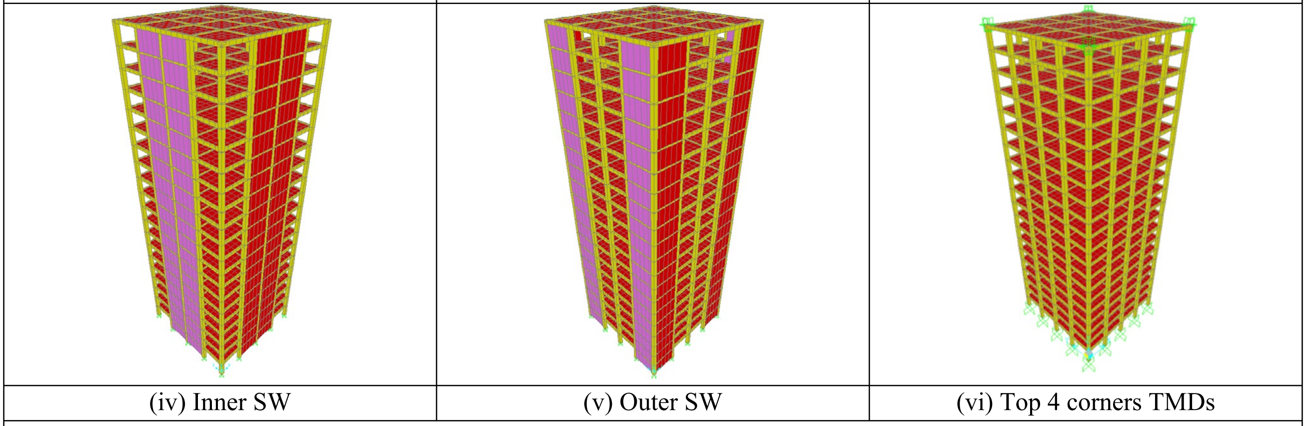


(a) El Centro **(b)** Northridge

Fig. 3 Accelerograms of the two different used earthquakes



(i) Bare | (ii) X bracing | (iii) xx bracing



(iv) Inner SW | (v) Outer SW | (vi) Top 4 corners TMDs

(a) Fixed base reinforced concrete (RC) structure

Fig. 4 3D SAP2000 models of the RC HRB and the steel HRB

(with different spectral characteristics and intensities) to evaluate the seismic performance of the building under these two different earthquakes. Figure 1 shows the front view of the models for the reinforced concrete (RC) and steel HRBs (the four sides of each 3D model are alike). Figure 1 also represents different structural systems that increase the stiffness or decrease the flexibility of the building model, such as bracing systems with different configurations, and shear walls (SWs) with different configurations and material types (RC or steel). In addition, Fig. 1 shows structural systems with top 4 corners two-directional TMDs. These added systems enhance the earthquake resistance, and when the model is subjected to earthquakes, its response will change in terms of top displacement and base straining actions with and without SSI. Table 1 represents the abbreviations used in this study for the added systems to the HRB.

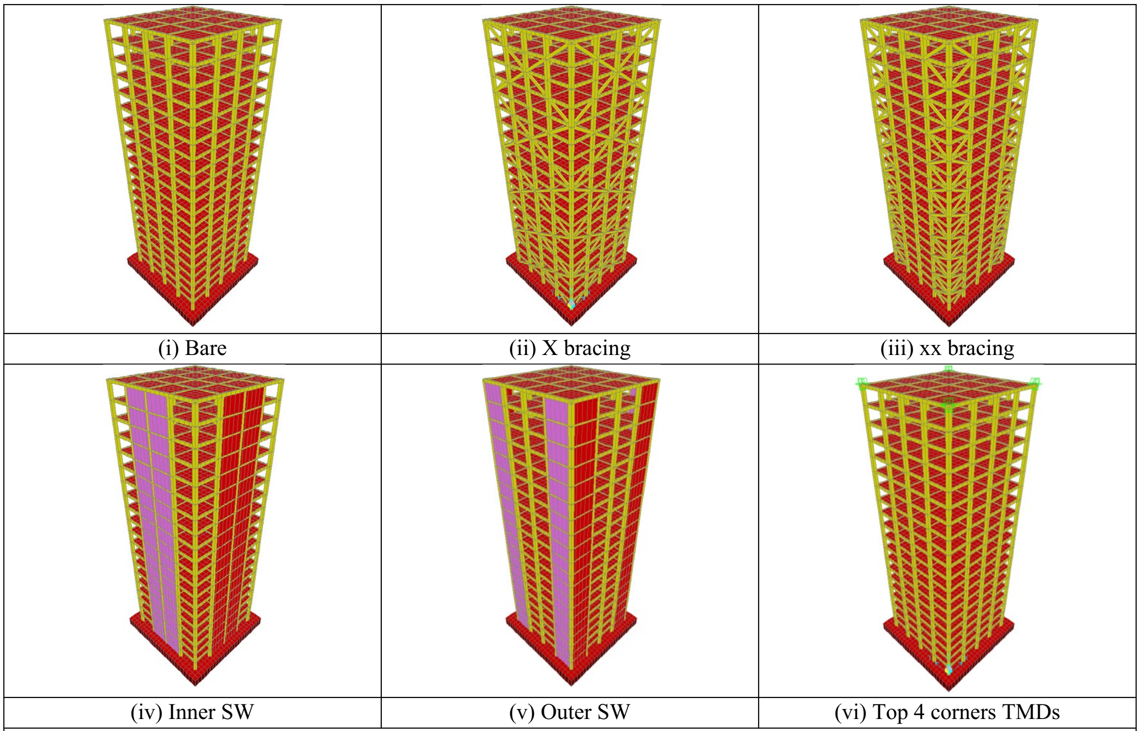
Soil–structure interaction (SSI)

The properties of the used soil (medium soil) are shown in Table 2. The stiffness and damping parameters of the soil in the vertical and horizontal directions for the 3D soil elements with three gaps in x, y and z directions to ensure the separation between the soil and the raft foundation when subjected to a lateral force (earthquake loads) as shown in Fig. 2 and are calculated as in Newmark and Rosenblueth (1971).

The used earthquake accelerograms (Fig. 3) are of the 1940 El Centro earthquake that occurred in the Imperial Valley in southeastern Southern California with a magnitude of 6.9, and the 1994 Northridge earthquake that occurred in the San Fernando Valley region of the County of Los Angeles with a magnitude of 6.7.

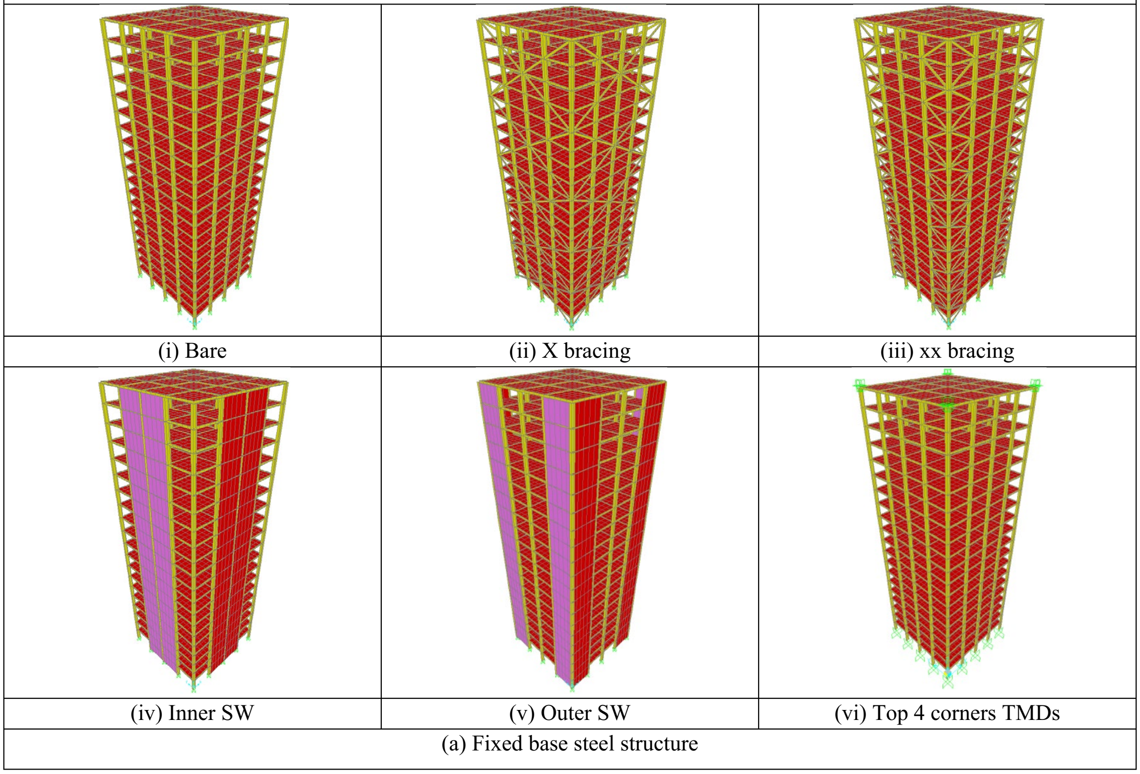
Model description

The HRB is represented in SAP2000 as a 3D model (as shown in Fig. 4). The beams and columns are modeled as frame elements, and the slabs and raft foundation are



(i) Bare
(ii) X bracing
(iii) xx bracing
(iv) Inner SW
(v) Outer SW
(vi) Top 4 corners TMDs

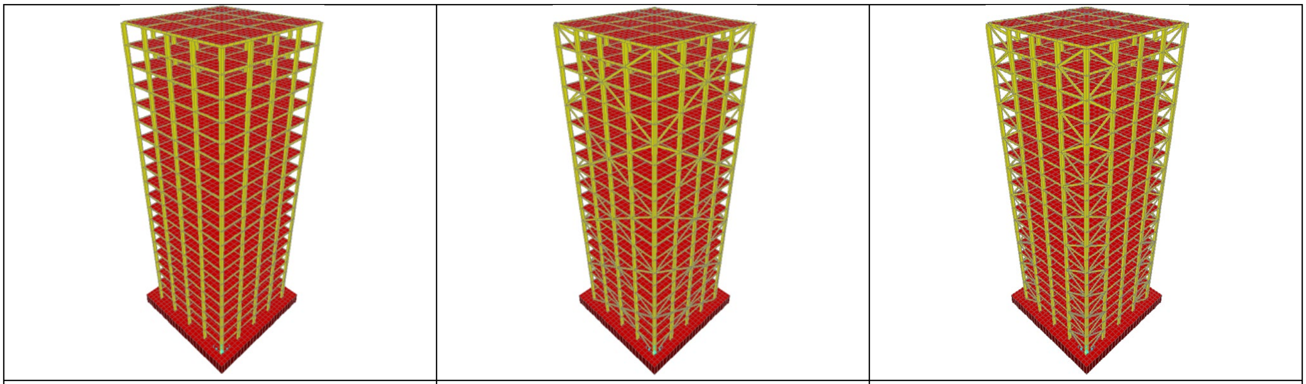
(b) Raft foundation (SSI) reinforced concrete structure



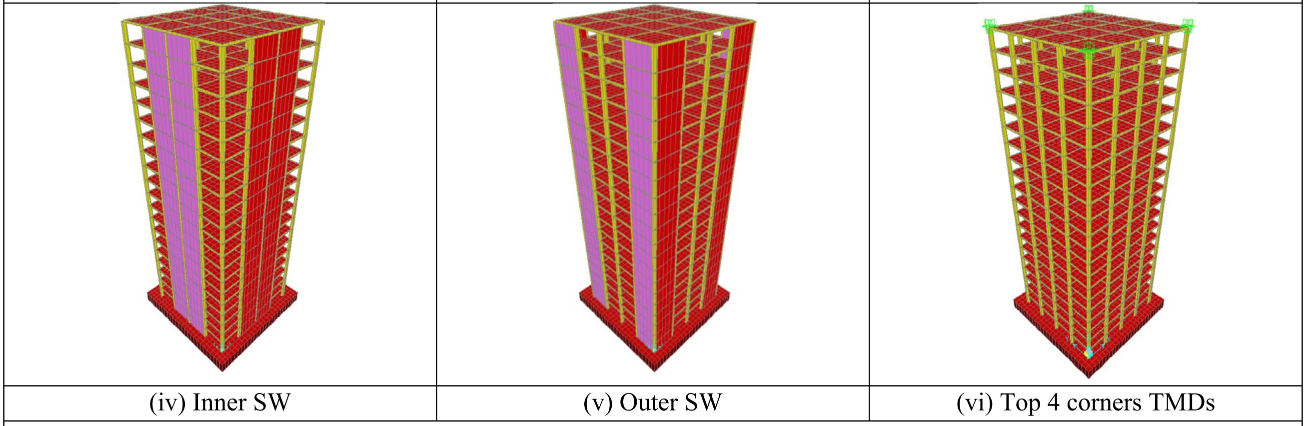
(i) Bare
(ii) X bracing
(iii) xx bracing
(iv) Inner SW
(v) Outer SW
(vi) Top 4 corners TMDs

(a) Fixed base steel structure

Fig. 4 (continued)



(i) Bare (ii) X bracing (iii) xx bracing



(iv) Inner SW (v) Outer SW (vi) Top 4 corners TMDs

(b) Raft foundation (SSI) steel structure

Fig. 4 (continued)

modeled as shell elements (Fig. 5). The raft foundation of the 20-floor HRB with a 2 m projection is shown in Fig. 5(b).

Table 3 shows the details of the structural elements of the HRB structural plans shown in Fig. 5.

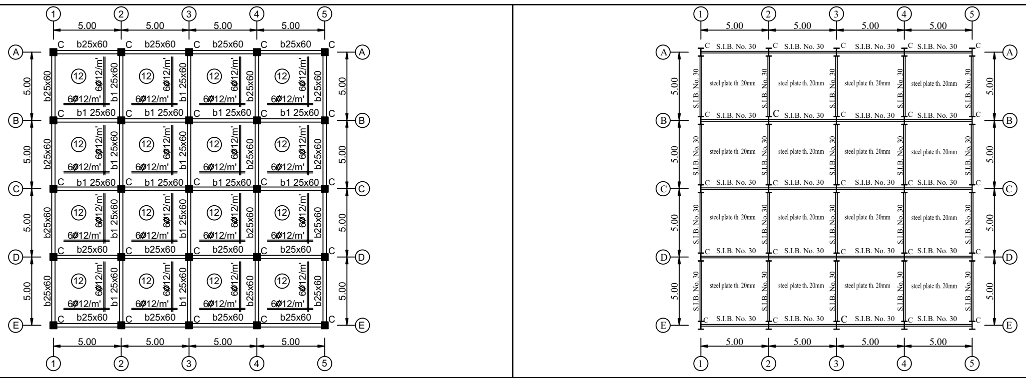
Results and discussion

The results of the numerical analysis will be presented and discussed in detail. The effects of bracings, shear walls, and TMDs on the seismic response of RC and steel high-rise buildings (HRBs) considering SSI will be evaluated and compared. Table 4 represents the abbreviations of the various HRB models analyzed under two earthquakes.

Figure 6 represents the top displacements and the straining actions of the RC HRB with a 20-floor height subjected to two earthquakes (El Centro and Northridge earthquakes), with and without the SSI effect. The first mode period time for all RC models without and with the SSI effect is also presented.

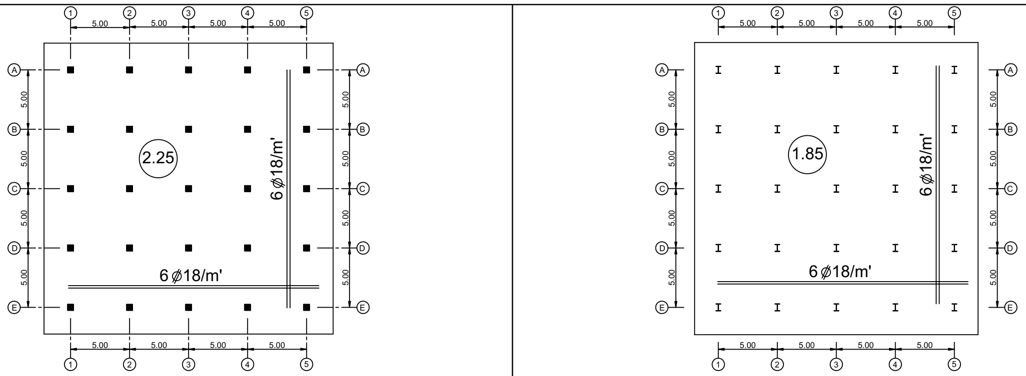
Figure 6(a–i, ii) represents the maximum top displacements of the model in the different methods without and with the SSI effect for both earthquakes (El Centro and Northridge). Figure 6(a–i) represents the top displacements of the models without the SSI effect. At the bare frame and the edge (outer) xx bracing, the maximum values of top displacements appeared, while in the rest of the methods, lower values are noted. The ratio between the maximum and minimum top displacement values is nearly 3. Figure 6(a–ii) represents top displacements for the model with the SSI effect. The minimum values appeared in the TMDs case, the rest of the cases are nearly equal, and the ratio between the maximum and minimum values is nearly 2.

Figure 6(b) shows the effect of the various methods on the base shear of the RC HRB without and with the SSI effect. Figure 6(b–i) shows the base shear for the fixed base case



(i) Reinforced concrete (ii) Steel structure

(a) Structural plan

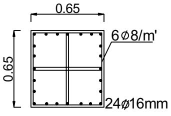
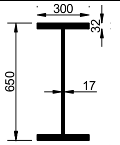
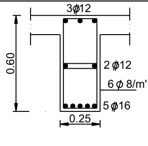
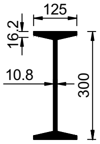
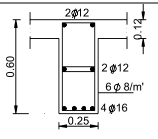


(i) Reinforced concrete (ii) Steel structure

(b) Raft foundation

Fig. 5 Structural plans and details of the RC HRB and the steel HRB

Table 3 Structural details of the structural elements

Element	Reinforcements and concrete sections details	Steel sections details
Column (C)	 (Constant cross-section)	 B.F.I.B. No. 65
Beam (b2: 25x60)		 S.I.B. No. 30
Beam (b1: 25x60)		----
Slab (s)	Thickness 120mm, net reinforcement 6 Φ 12/m' on both sides	Steel Sheet thickness 20 mm

in the different methods. The maximum base shear in the x and y directions occurs at the bare frame and X bracing cases, while is lower in the rest cases. The average minimum values are less than the maximum values by about 5 times. Figure 6(b–ii) represents the base shear with the SSI effect in different methods. The maximum base shear in the x and y directions occurs at the bare frame and xx cases, while is lower in the rest of the cases. The minimum values are less than the maximum values by about 3 times.

Figure 6(c–i) represents the base moments in the x and y directions for the fixed base model in different methods. The maximum base moments in the x and y directions occur at the bare frame, and the minimum values occur in the X and xx cases, then the rest of the cases, and they are averagely less than the maximum values by about 5 times. Figure 6(c–ii) shows the base moments in the x and y directions for the model with the SSI effect. It can be noted that the maximum base moments occur in the bare frame case, and the minimum values occur in the rest of the cases.

Table 4 The various HRB models analyzed under two earthquakes

Abbreviations	Descriptions
El Centro	Bare frame model under El Centro earthquake
Northridge	Bare frame model under Northridge earthquake
El Centro X	X (big) bracing model under El Centro earthquake
Northridge X	X (big) bracing model under Northridge earthquake
El Centro xx	xx (small bracing at corners) bracing model under El Centro
Northridge xx	xx (small bracing at corners) bracing model under Northridge
El Centro SW edge RC	Outer (edge) RC shear walls model under El Centro
Northridge SW edge RC	Outer (edge) RC shear walls model under Northridge
El Centro SW middle RC	Inner (middle) RC shear walls model under El Centro
Northridge SW middle RC	Inner (middle) RC shear walls model under Northridge
El Centro SW edge steel	Outer (edge) steel shear walls model under El Centro
Northridge SW edge steel	Outer (edge) steel shear walls model under Northridge
El Centro SW middle steel	Inner (middle) steel shear walls model under El Centro
Northridge middle steel	Inner (middle) steel shear walls model under Northridge
El Centro TMD	Top 4 corners two-directional TMDs model under El Centro
Northridge TMD	Top 4 corners two-directional TMDs model under Northridge

The ratio between the maximum and the average minimum values is nearly equal to 5.

Figure 6(d) shows the first mode period time for models with different methods without and with the SSI effect. Even if the results are presented in the same cases' axis, it is obvious that the first mode period time depends only on the structure's properties (and not on the earthquake). It is clear that the first mode period times in the case of SSI are bigger than that of the fixed base model by about 2.5 times, and the maximum first mode period time occurs in the TMDs case. The ratio between the maximum and minimum cases at the fixed base and SSI case equals 7 and 3 times, respectively.

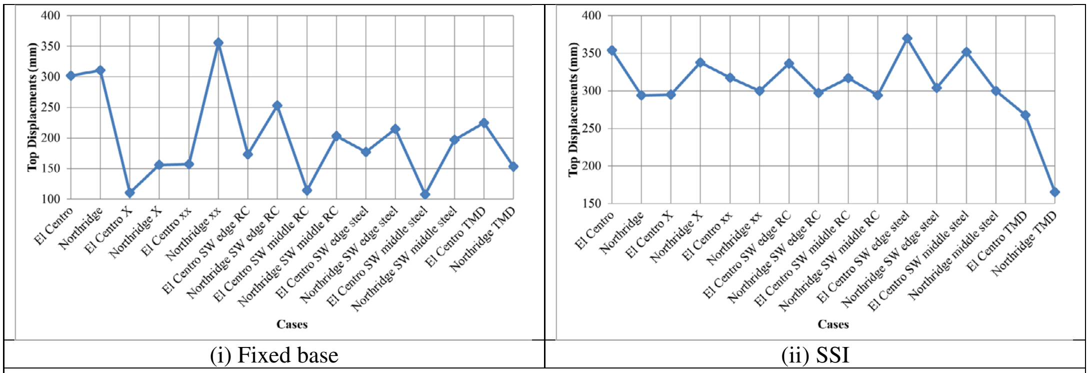
Figure 7 represents the top displacements and the straining actions of the steel HRB with 20-floor height subjected to two earthquakes (El Centro and Northridge), without and with the SSI effect. The first mode period time for all RC models without and with the SSI effect is also presented.

Figure 7(a–i) represents the top displacements of the models without the SSI effect, where in the bare frame, xx bracing and TMDs models the maximum values of the top displacements appeared, but in the rest of the methods lower values are noted, and the ratio between the maximum and the average minimum top displacements values is nearly 2. Figure 7(a–ii) represents the top displacements for the model with the SSI effect, where the minimum values appeared in the TMDs, X bracing and SW cases, while in the rest of the cases, top displacements are nearly equal, and the ratio between the maximum and the average minimum values is about 2 times.

Figure 7(b) shows the effect of changing the methods on the base shears of steel HRB without and with the SSI effect. Figure 7(b–i) shows the base shear for fixed base case in different methods, the maximum base shear in x and y directions occurs at edge (outer) xx bracing and middle (inner) X bracing cases, while they are lower at the rest of the cases; the average minimum values are less than the maximum values by about 5 times. Figure 7(b–ii) represents the base shear with SSI effect case in different methods, where the maximum base shears in x and y directions occur at the bare frame, the SW with different configurations (RC and steel) and the TMDs cases, while they are lower in the rest of the cases; the ratio between the maximum and the average minimum values nearly equals to 3 times.

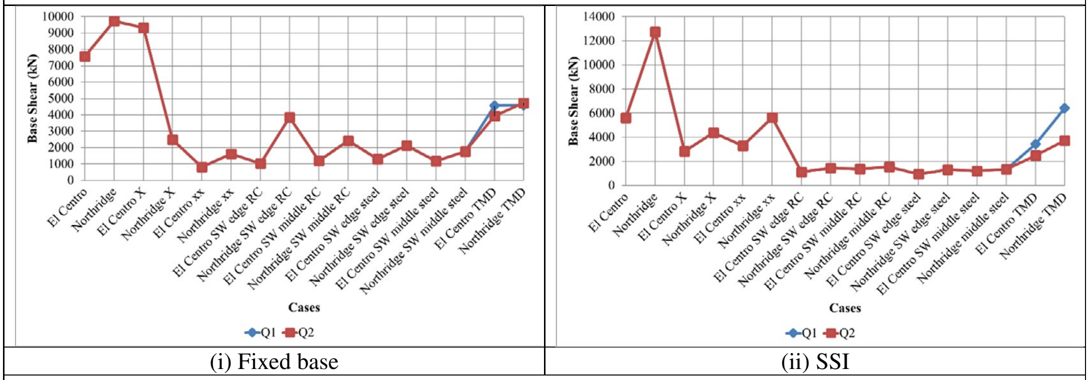
Figure 7(c–i) represents the base moments in the x and y directions for the fixed base model in different methods, where the maximum base moments in the x and y directions occur at the bare frame, edge (outer) xx bracing, and middle X bracing, while the minimum values occur at the rest of cases, and are less than the maximum values by about 5 times. Figure 7(c–ii) shows the base moments in the x and y directions for the model with the SSI effect, and it can be noted that the maximum base moments occur at the bare frame case while the minimum values occur at the rest of the cases; the ratio between the maximum and the average minimum values nearly equals to 4.

Figure 7(d) shows the first mode period time for models with different methods without and with the SSI effect. Even if the results are presented in the same cases' axis, it is obvious that the first mode period time depends only on the structure's properties (and not on the earthquake). It is clear that the first mode period time in the case of the SSI is higher than that of the fixed base model by nearly 2



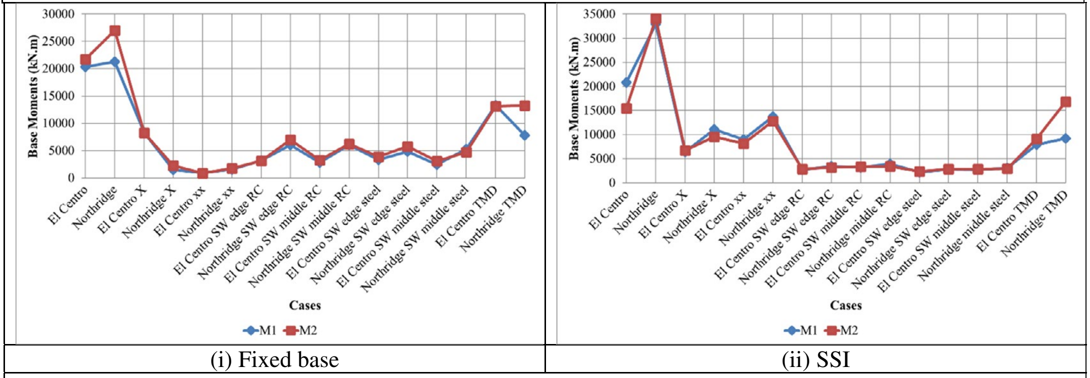
(i) Fixed base (ii) SSI

(a) Top displacements



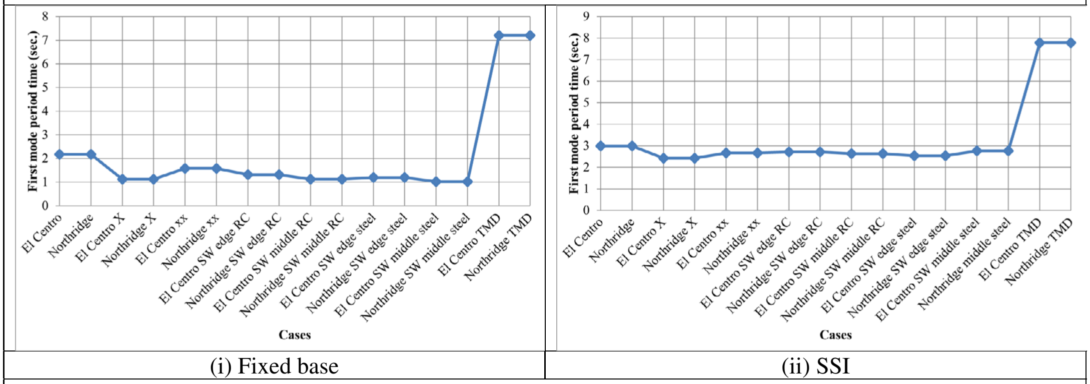
(i) Fixed base (ii) SSI

(b) Base shear forces (Q_x, Q_y)



(i) Fixed base (ii) SSI

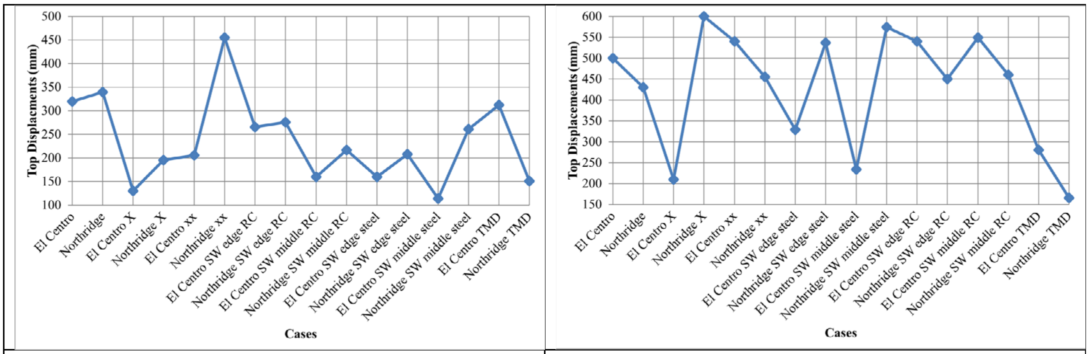
(c) Base moments (M_x, M_y)



(i) Fixed base (ii) SSI

(d) First mode period time (sec.)

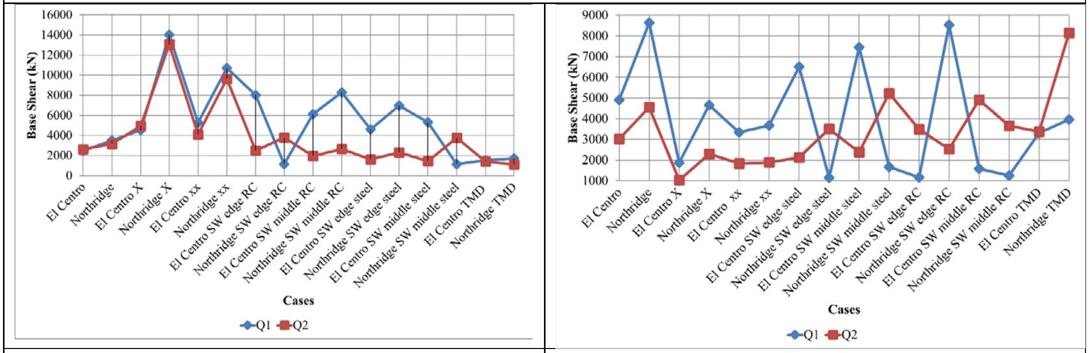
Fig. 6 Reinforced concrete (RC) high-rise building (HRB)



(i) Fixed base

(ii) SSI

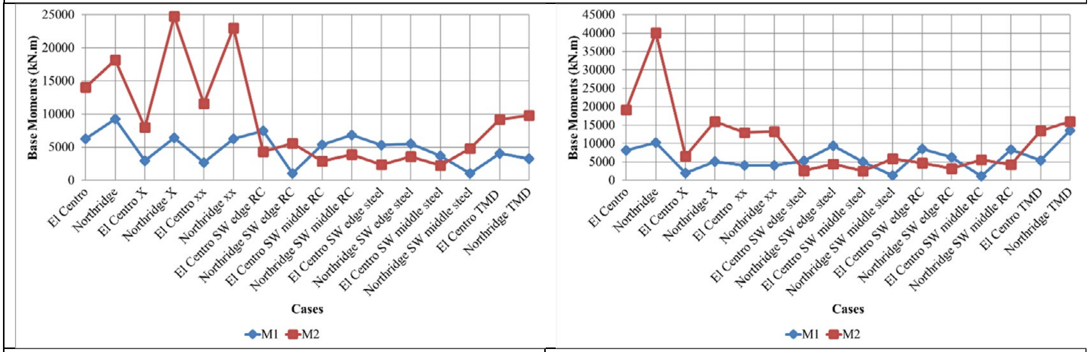
(a) Top displacements



(i) Fixed base

(ii) SSI

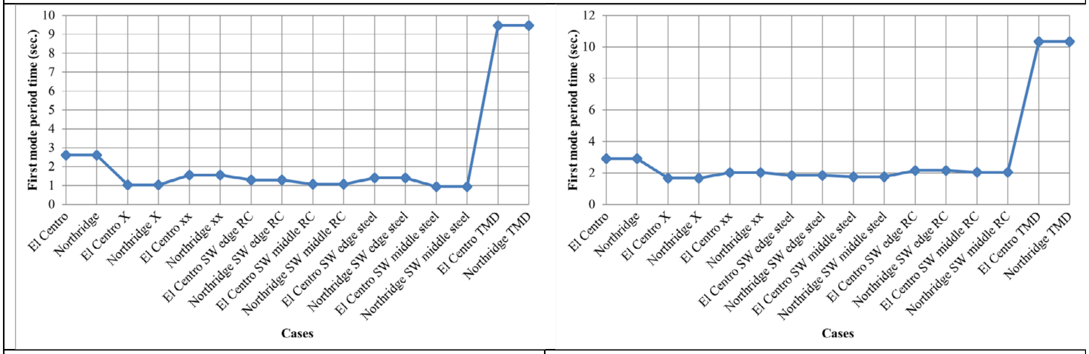
(b) Base shear forces (Q_x, Q_y)



(i) Fixed base

(ii) SSI

(c) Base moments (M_x, M_y)



(i) Fixed base

(ii) SSI

(d) First mode period time (sec.)

Fig. 7 Steel high-rise building (HRB) times and also the maximum first mode period time occurs in the TMDs case. The ratio between the maximum and minimum cases at the fixed base case and SSI case is equal to 8 and 5 times, respectively.

Conclusions

The stiffening methods adopted herein are steel or concrete shear walls (SWs) in specific arrangements, and different bracings in specific arrangements, considering SSI. Moreover, tuned mass dampers (TMDs) are used, as a damping method of the HRB seismic response, also considering SSI, and the results are compared with the stiffening methods results to judge how the applied methods enhance the seismic resistance of HRBs. These methods, which were used to influence the stiffness or the damping of the building, had different positive effects on the seismic response of the HRBs, which appeared in the results through the base shears, the base moments, the maximum top displacement, and the fundamental period of the building. The findings of this research can be used to improve the design of HRBs for seismic resistance, as follows:

- SSI increases the fundamental period in both the RC structures and steel structures compared to the fixed base condition. This increase in the fundamental period is bigger in the RC structures.
- The top TMDs increase the first mode period time (fundamental period) and reduce the top displacements.
- Steel structures are more flexible than RC structures and also have lighter weight, as shown by the reduction in base shear and base moment and the increase in top displacements of the steel structures compared to the RC structures.
- Each method had a different effect on the seismic response of HRBs, which depends on the type of seismic wave and the type of material from which the HRB is constructed.
- In the seismic response of both RC HRBs and steel HRBs, the most effective method in reducing their seismic response seems to be TMDs.
- When HRBs are designed, whether of steel or RC, the effect of the SSI must be taken into consideration and one of the seismic resistant methods (bracing, shear walls, or TMDs) should be adopted in the analysis and construction.

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Declarations

Conflict of interest The authors declare that there is no conflict of interest regarding the publication of this paper.

References

Ahiwale, D. D., Kontoni, D.-P. N., & Darekar, P. L. (2023). Seismic performance assessment of reinforced concrete frames with different bracing systems. *Innovative Infrastructure Solutions, 8:102*, 1–18. https://doi.org/10.1007/s41062-023-01071-3

Alshimmeri, A. J. H., Kontoni, D.-P. N., & Ghamari, A. (2021). Improving the seismic performance of reinforced concrete frames using an innovative metallic-shear damper. *Computers and Concrete, 28*(3), 275–287. https://doi.org/10.12989/cac.2021.28.3.275

Alshimmeri, A. J. H., & Kontoni, D.-P. N. (2022). Improving the Behavior of Steel Plate Shear Wall Using Double Infill Plates. Proceedings of the 7h World Congress on Civil, Structural, and Environmental Engineering (CSEE'*22)*, Lisbon, Portugal, 10–12 April 2022, Paper No. ICSECT 161, pp. 1–10. https://doi.org/10.11159/icsect22.161

Ebadi-Jamkhaneh, M., & Kontoni, D.-P. N. (2022). Numerical finite element investigation of thin steel shear walls retrofitted with CFRP layers under reversed cyclic loading. *Journal of Building Pathology and Rehabilitation, 7:62*, 1–10. https://doi.org/10.1007/s41024-022-00200-2

Farghaly, A. A., & Kontoni, D.-P. N. (2022). Mitigation of seismic pounding between RC twin high-rise buildings with piled raft foundation considering SSI. *Earthquakes and Structures, 22*(6), 625–635. https://doi.org/10.1298/EAS.2022.22.6.625

Ghamari, A, & Haeri, H. (2021). Improving the behavior of high performance steel plate shear walls using Low Yield Point steel. *Case Studies in Construction Materials, 14*, e00511. https://doi.org/10.1016/j.cscm.2021.e00511

Ghamari, A., & Johari Naeimi, A. (2023). Investigating the seismic behaviour of high-performance steel plate shear walls. *Proceedings of the Institution of Civil Engineers - Structures and Buildings, 176*(3), 177–189. https://doi.org/10.1680/jstbu.20.00108

Kamarudin, M. A. A., Ahmad, S. W., & Ariffin, W. A. R. W. (2021). The behaviour of high-rise building with or without shear wall under different earthquakes. *Construction, 1*(2), 93–101.

Kaveh, A., & Farhadmanesh, M. (2019). Optimal seismic design of steel plate shear walls using metaheuristic algorithms. *Periodica Polytechnica, 63*(1), 1–17. https://doi.org/10.3311/PPci.12119

Kaveh, A., & Farhoudi, N. (2016). Dolphin monitoring for enhancing metaheuristic algorithms: Layout optimization of braced frames. *Computers and Structures, 165*, 1–9. https://doi.org/10.1016/j.compstruc.2015.11.012

Kaveh, A., & Rezazadeh Ardebili, S. (2021). A comparative study of the optimum tuned mass damper for high-rise structures considering soil–structure interaction. *Periodica Polytechnica Civil Engineering, 65*(4), 1036–1049. https://doi.org/10.3311/PPci.18386

Kaveh, A., & Zakian, P. (2014a). Seismic design optimisation of RC moment frames and dual shear wall-frame structures via CSS algorithm. *Asian Journal of Civil Engineering, 15*(3), 435–465.

Kaveh, A., & Zakian, P. (2014b). Optimal seismic design of reinforced concrete shear wall-frame structures. *KSCE Journal of Civil Engineering, 18*, 2181–2190. https://doi.org/10.1007/s12205-014-0640-x

Kaveh, A., Izadifard, R. A., & Mottaghi, L. (2020a). Optimal design of planar RC frames considering CO2 emissions using ECBO, EVPS and PSO metaheuristic algorithms. *Journal of Building Engineering, 28*, 101014. https://doi.org/10.1016/j.jobe.2019.101014

Kaveh, A., Javadi, S. M., & Moghanni, R. M. (2020b). Optimal structural control of tall buildings using tuned mass dampers via chaotic optimization algorithm. *Structures, 28*, 2704–2713. https://doi.org/10.1016/j.istruc.2020.11.002

Kaveh, A., Fahimi Farzam, M., & Hojat Jalali, H. (2020c). Statistical seismic performance assessment of tuned mass damper inerter. *Structural Control and Health Monitoring, 27*, e2602. https://doi.org/10.1002/stc.2602

Kaveh, A., Farzam, M. F., & Maroofiazar, R. (2020d). Comparing H2 and H∞ algorithms for optimum design of tuned mass dampers under near-fault and far-fault earthquake motions. *Periodica Polytechnica Civil Engineering, 64*(3), 828–844. https://doi.org/10.3311/PPci.16389

Kaveh, A., Mahdipour Moghanni, R., & Javadi, S. M. (2021). Optimal design of 3D special steel buckling-restrained braced structures. *The Structural Design of Tall and Special Buildings, 30*(17), e1893. https://doi.org/10.1002/tal.1893

Kontoni, D.-P. N., Ghamari, A., & Mahmudi, S. (2022). Investigation of the fire effect on the behavior of corrugated steel plate shear walls considering environmental aspects. *3rd International Conference on Environmental Design (ICED2022)*, 22-23 October, Hybrid (Athens, Greece and Virtual). IOP Conference Series: Earth and Environmental Science 1123:012063. https://doi.org/10.1088/1755-1315/1123/1/012063

Kontoni, D.-P. N., & Farghaly, A. A. (2018). Stiffness Effects of structural elements on the seismic response of RC high-rise buildings. *Archives of Civil Engineering, 64*(1), 3–20. https://doi.org/10.2478/ace-2018-0001

Kontoni, D.-P. N., & Farghaly, A. A. (2019a). Seismic evaluation of mixed steel and RC columns in hybrid high-rise buildings. *Archives of Civil Engineering, 65*(2), 3–17. https://doi.org/10.2478/ace-2019-0015

Kontoni, D.-P. N., & Farghaly, A. A. (2019b). The effect of base isolation and tuned mass dampers on the seismic response of RC high-rise buildings considering soil–structure interaction. *Earthquakes and Structures, 17*(4), 425–434. https://doi.org/10.12989/eas.2019.17.4.425

Kontoni, D.-P. N., & Farghaly, A. A. (2020). TMD effectiveness for steel high-rise building subjected to wind or earthquake including soil–structure interaction. *Wind and Structures, 30*(4), 423–432. https://doi.org/10.1298/was.2020.30.4.423

Mo, H., Hou H., Nie J., Tian L., & Wu S. (2019). Seismic Performance Analysis of High-rise Steel-concrete Composite Structures under Earthquake Action Based on Sound-Vibration Method. *International Journal of New Developments in Engineering and Society (ISSN 2522–3488), 3(1)*, 302–308. https://francis-press.com/papers/529 Accessed 8 Jan 2023

Mule N. R., Tupe D.H., & Gandhe G. R. (2020). Analysis and Design of High Rise Building Subjected to Combined Effect of Earthquake and Strong Wind using E-Tab Software. *International Research Journal of Engineering and Technology (IRJET), 07(11),* 1114–1119. https://www.irjet.net/archives/V7/i11/IRJET-V7I11185.pdf Accessed 8 Jan 2023

Nagarajaiah, S., Chen, L., & Wang, M. (2022). Adaptive Stiffness structures with dampers: seismic and wind response reduction using passive negative stiffness and inerter systems. *Journal of Structural Engineering, 148*(11), 04022179. https://doi.org/10.1061/(ASCE)ST.1943-541X.0003472

Newmark, N. M., & Rosenblueth, E. (1971). *Fundamentals of earthquake engineering*. Prentice-Hall.

Rouhi, H., & Gholhaki, M. (2022). Nonlinear behavior of reinforced concrete frames equipped with and without steel plate shear wall under sequence of real and artificial earthquakes. *Advances in Civil Engineering, 9512286*, 1–26. https://doi.org/10.1155/2022/9512286

Rouhi, H., & Kontoni, D.-P. N. (2023). Calculation of the spectral correction factor for the design of reinforced concrete frames equipped with steel plate shear wall under near-field earthquakes. *Asian Journal of Civil Engineering*. https://doi.org/10.1007/s42107-023-00646-w

Salimbahrami, S. R., & Gholhaki, M. (2022). Response of concrete buildings with steel shear walls to near- and far-field earthquakes. *Proceedings of the Institution of Civil Engineers—Structures and Buildings, 175*(1), 17–33. https://doi.org/10.1680/jstbu.18.00233

Salimi, S. M., Rahimi, S., Hoseinzadeh, M., Kontoni, D.-P. N., & Ebadi-Jamkhaneh, M. (2021). Numerical 3D finite element assessment of bending moment-resisting frame equipped with semi-disconnected steel plate shear wall and yielding plate connection. *Metals, 11*(4), 604. https://doi.org/10.3390/met11040604

San Segundo A. A. (2022). Dynamic performance of a tall building to earthquake loading - Finding the optimum mass and stiffness. AF223X Degree Project in Structural Engineering and Bridges (Supervisors: R. Karoumi, J. C. Mosquera & P. García), School of Architecture and the Built Environment, KTH Royal Institute of Technology, Stockholm, & Ove Arup & Partners S.A.U. https://kth.diva-portal.org/smash/get/diva2:1660433/FULLTEXT01.pdf Accessed 8 Jan 2023

SAP2000® Version 17 (2015). *Integrated Software for Structural Analysis and Design*. Computers and Structures, Inc., Walnut Creek, CA and New York, NY, USA. https://www.csiamerica.com/products/sap2000

Shendkar, M. R., Kontoni, D.-P. N., Mandal, S., Maiti, P. R., & Gautam, D. (2021a). Effect of lintel beam on seismic response of reinforced concrete buildings with semi-interlocked and unreinforced brick masonry infills. *Infrastructures, 6(1):6*, 1–18. https://doi.org/10.3390/infrastructures6010006

Shendkar, M. R., Kontoni, D.-P. N., Mandal, S., Maiti, P. R., & Tavasoli, O. (2021b). Seismic evaluation and retrofit of reinforced concrete buildings with masonry infills based on material strain limit approach. *Shock and Vibration, 2021:5536409*, 1–15. https://doi.org/10.1155/2021/5536409

Shendkar, M. R., Kontoni, D.-P. N., Kumar, R. P., Farghaly, A. A., Mandal, S., & Maiti, P. R. (2022a). A refined procedure for the seismic evaluation and retrofit of reinforced concrete buildings.

Current Science, 123(8), 1020–1030. https://doi.org/10.18520/cs/v123/i8/1020-1030

Shendkar, M. R., Kontoni, D.-P. N., Işık, E., Mandal, S., Maiti, P. R., & Harirchian, E. (2022b). Influence of masonry infill on seismic design factors of reinforced-concrete buildings. *Shock and Vibration, 2022:5521162*, 1–15. https://doi.org/10.1155/2022/5521162