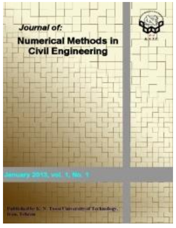
Numerical Methods in Civil Engineering, 6-4 (2022) 01-15



Numerical Methods in Civil Engineering

Journal Homepage: https://nmce.kntu.ac.ir/

Experimental and Numerical Evaluation of the Effect of Implementing Wall Posts on Seismic Behavior of Short-Period Structures

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ARTICLE INFO

RESEARCH PAPER

Article history:
Received:
August 2021.
Revised:
October 2021.
Accepted:
November 2021.

Keywords:
Combined structure
Non-structural components wall post
Shaking table
Primary-secondary structures interaction

Abstract:

The investigation of damage to buildings in terms of non-structural walls collapse in the past earthquakes have caused researchers to study the seismic behavior of walls more extensively. Furthermore, seismic design codes have considered using wall posts to prevent wall damage, however, not many studies were done on seismic behavior change in structures due to the addition of wall posts.Therefore, in this study, a two-story structure was simulated in laboratory conditions on a shaking table with a scale of 1:3. This structure was subjected to Kobe scaled ground motion in two cases including with and without the wall and wall post on the second floor. According to the experimental results, the maximum first and second floors' displacement and the first-floor acceleration of the structure with wall and wallpost compared to the structure without wall and wallpost showed a decrease by 6.52, 10.75, and 60.23%, respectively. Comparison of experimental and numerical results showed a difference of 2-10%. Moreover, 10 two- and three-story structures with different wall arrangements in height were numerically modeled and studied by time-history dynamic analysis under 7 simulated records. The results showed that by adding a wall post to the wall to restrain it, and ignoring the effects of wall stiffness in design techniques, can cause a significant error in the seismic design procedure.

1. Introduction

Secondary systems are non-structural elements with relatively low mass compared to the primary system connected to the primary system. The combined system consists of a combination of primary and secondary systems, in which the interaction of these two systems affects the behavior of the combined system.

Masonry infill walls, often used to divide the interior space of buildings according to the type of use or to separate interior space of building from the external environment are usually considered to be non-structural elements, and their influence on structural response was neglected. These secondary elements directly influence strength, stiffness, and ductility of the primary structure, and neglecting the interaction between the primary structure and the walls attached to it in the design of the structure can lead to irreparable damage during an earthquake [1,2].

Several studies were conducted on life and economic losses due to damage to the secondary system, including the study by Miranda et al. [3], who investigated the performance of non-structural components during the Chile earthquake on 27 February, 2010. They emphasized that more attention should be devoted to enforcing regulations and improving the seismic performance of non-structural components whose failure can lead to injuries, substantial economic losses, and partial or total loss of functionality. This is especially important for the facilities whose response and recovery are vital and important, such as hospitals and airports.

Schwarz et al. [4] showed that the openings in masonry infill walls produce capacity and ductility values. Khoshnoud and Marsono [5] developed a simple method, called corner opening, by replacing the corner of infill walls with a very flexible material to enhance the structural behavior of walls.

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[DOI: 10.52547/nmce.6.4.1]

By experimental work, Karimi et al. [6] tested the seismic behavior of two types of masonry walls under cyclic loading. Tidke and Jangave [7] studied the effect of masonry infill walls on the seismic behavior of Reinforced Concrete (RC) Buildings. Pasca et al. [8] studied the reliability of analytical models to predict the out-of-plane capacity of masonry infills. Ozturkoglu et al. [9] examined the effects of masonry infill walls with openings on the nonlinear response of RC frames. Baloevic et al. [10] experimentally investigated the effects of plaster on masonry-infilled steel frames' behavior under in-plane base accelerations by a shake-table test. Mohamed and Romao [11] introduced a detailed finite element modelling strategy which can be used as an alternative to experimental tests to represent the behavior of masonry-infilled RC frames under earthquake loading. Lotfi and Zahrai [12], by studying the blast behavior of steel infill panels, indicated that steel infill panels with out-of-plane behavior show proper ductility, especially in severe blast loading. De Domenico et al. [13] analyzed masonry infilled RC frames through a probabilistic approach. Dautaj et al. [14] showed that the type of masonry unit influences the failure mechanism of masonry-infilled RC frames. In an experimental study, Gong et al. [15] investigated the role of masonry infill walls in responses and failure modes of two three-story RC frames subjected to the earthquake by performing shaking table tests. Lemonis et al. [16] proposed an analytical model to estimate the initial lateral stiffness of steel moment-resisting frames with masonry infills. Aknouche et al. [17] investigated the seismic performance of typical RC frames infilled with perforated clay brick masonry walls in Algeria. Using a cost-benefit analysis, Furtado et al. [18] investigated the influence of textile-reinforced mortar solutions used to lessen the likelihood of masonry infill walls collapsing. The impact of perforated masonry walls on the gradual collapse of multistory RC buildings was explored by Nyunn et al. [19]. Mannan et al. [20] investigated the effect of masonry infill wall on a building frame under seismic load, and showed that the presence of infill masonry walls results in an improved behavior of the frames compared to the bare frame. Noorifard et al. [21], proposed an approximate method to identify soft story caused by infill walls based on 2277 macro model analysis. Jiang et al. [22] developed a simplified method to predict the fundamental period of masonry infilled RC frame. Kostinakis and Morfidis [23] conducted a study to optimize the seismic performance of masonry infilled RC buildings using artificial neural networks. Li et al. [24] found that masonry infills generally reduce the collapse risk of RC frames. Huang et al. [25], by the proposed model via the field tests of masonry-infilled RC frames with openings, suggested using ASCE 41-17[26]. De Angelis and Pecce [27] studied the Role of Infill Walls in the Dynamic Behavior of RC Framed Buildings. Ferraioli and Lavino [28] investigated the effectiveness of Eurocode 8 [29] design provisions for infill irregularity in plan and/or elevation. Jebadurai et al. [30], studied the performance of infill masonry with latex-modified mortar subjected to cyclic load. Jalaeefar and Zargar [31], investigated the effect of infill walls on the behavior of RC special moment frames subjected to multiple earthquakes.

A review of the previous studies shows that they generally focused on the seismic behavior of the non-structural walls and their effect on the seismic behavior of the primary structures and examined various fields of this issue. One of the cases which has not been considered in previous research is the change in the behavior of non-structural walls due to the addition of wall posts to them, which leads to a change in the behavior of the primary structure. Furthermore, different structural and seismic codes, including the Iranian seismic design code (Standard No. 2800) [32], have considered more conditions for wall restraint with wall posts in high importance structures such as hospitals. For this reason, it is more important to study the effect of wall posts on seismic behavior of the non-structural walls and primary structures. As a result, this study concentrated on this topic and utilized an experimental and numerical procedure to evaluate the impact of adding wall posts to walls on the seismic behavior of major and secondary buildings. Main contribution of this study is the investigation of the seismic response changes of primary or combined structures with walls compared to combined structures with walls and wall posts in prevalent design techniques that can lead to a revision of the seismic codes or design techniques to consider the effect of the wall posts. Therefore: 1- The difference in seismic response of the primary structure was investigated by adding the wall and wall post to it in the experimental process. 2- The error of calculating the seismic response of combined structures was investigated in prevalent design techniques in which only the wall and wall posts̓ mass is modelled, and the need to consider the effects of adding wall posts or modelling them was assessed by numerical process. 3- The differences in the seismic response of the combined structures due to the change in the position of the wall and wall post in the height of the structure were investigated.

First, through an experimental process, change in seismic behavior of a two-story steel structure was investigated after adding a wall and wall post. This 1:3 scaled structure was tested on a shaking table. Once alone and then with the wall and wall post on the second floor, this simulated model was subjected to the Kobe-scaled ground motion. The first and second floors̓ displacement and the first-floor acceleration were calculated. The consistency of experimental and numerical results was controlled by numerical modelling of this structure. Also, 10 two- and three-story combined structures with different arrangements of walls in height

[DOI: 10.52547/nmce.6.4.1]

were numerically modelled. Seismic behavior of these structures was investigated numerically by time history dynamic analysis under 7 simulated records, and possible errors due to neglecting the effects of wall and wall posts in design techniques were numerically calculated.

2. Experimental Process

This study tried to prove the change in seismic behavior of the structure by adding wall and wall posts via an experimental simulation. All experimental processes were performed in the Central laboratory of Urmia University.

Considering shaking platform size and loading capacity, the models had to be geometrically reduced from the original prototypes; thus, a two-story steel structure was selected as the primary structure and was simulated on a shaking table. This structure was first subjected to the Kobe-scaled ground motion. In the second experiment, clay brick walls and wall posts were added to the structure on the second floor and the experiment was performed again under the same record. In both experiments, displacement of the first and second floors, and the first-floor acceleration, was calculated and compared as the seismic parameters by the embedded sensors.

2.1 Test Set-up

Scalable models are widely used for the experimental research on large structures in terms of the limited capacity of experimental equipment and to reduce costs. Simulation laws are used to scale the models for converting the results of an experimental test into real sample results and vice versa. Cauchy similitude law was chosen in the present study. Given shaking platform size and loading capacity, a geometrical scale factor of 1:3 was adopted. Accordingly, the relations for different parameters in terms of geometrical scale factors are presented in Table 1.

In Table 1, the index M represents the experimental model parameters and the index P represents the real model parameters. The parameters λ, e and ρ are determined based on the Cauchy method, which is respectively set to 3, 1 and 1 in this experimental study.

Table. 1: Scale factors of the Cauchy similitude law

Parameters	Dimensions	similitudes	SF
Length	L	$L_P = \lambda L_M$	3
Time	t	$t_P = \lambda e^{-1/2}\rho^{1/2}t_M$	3
Specify Mass	ρ	$\rho_P = \rho\rho_M$	1
Elasticity	e	$E_P = eE_M$	1
Area	A	$A_P = \lambda^2 A_M$	9
Volume	V	$V_P = \lambda^3 V_M$	27
Velocity	v	$v_P = e^{1/2}\rho^{-1/2}v_M$	1
Acceleration	a	$a_P = e^{-1}\lambda^{-1}a_M$	1/3
Force	F	$F_P = e\lambda^2 F_M$	9
Stress	σ	$\sigma_P = e\sigma_M$	1
strain	ε	$\varepsilon_P = \varepsilon_M$	1
Frequency	F	$f_P = e^{1/2}\rho^{-1/2}\lambda^{-1}f_M$	1/3

Considering the experimental limitations, a simplified model consisting only exterior walls and floors was developed. Dimensions of the model were directly derived from the application of geometric scale factor to the prototype. Simulated model with the dimensions of 150×150 cm in plan and height of 150 cm on each floor was selected as the primary structure.

Hospital structures are mostly low-height and rigid structures, and their period is in the range of the maximum response spectrum. According to the range of hospital structures̉ period, characteristics of beams and columns from the box section (Box 60×60×4) were determined in such a way that the primary structures̉ period in real scale was between 0.2 0.7. For avoiding the use of different materials in the laboratory, the roof of the stories was simulated using a steel plate with a thickness of 5 mm, where a secondary beam with the box section was installed underneath to prevent from buckling. All fixed connections were made with proper welding. The walls were selected from the walls conventionally used in Iran made of clay bricks with a

[DOI: 10.52547/nmce.6.4.1]

thickness of 9 cm installed in an exciting seismic direction. Characteristics of the wall posts were also selected based on their details in the hospital structures in accordance with Appendix 6 of the Iranian Seismic Design Code (Standard No. 2800) [32]. Therefore, in real scale, 2L60×60×6 should be used next to the columns and 4L60×60×6 in the middle of the span as a wall post, simulated based on the scale factors presented in Table 1 in experimental dimension.

For seismic excitation, the simulated Kobe ground motion record was used as scaled based on the scale factors presented in Table 1. This record is shown in Fig. 1.

Four sensors (2 accelerometers and 2 linear variable differential transformers (LVDTs)) were used to measure and record the response of the model and shaking table. The first accelerometer was installed on the shaking table platform to control excitation accuracy. The second accelerometer was installed on the steel plate of the first floor to determine the acceleration of the first floor. Two LVDTs were also located next to the experimental model at the floor level on a lateral fixed structure to measure the displacement of the structural floors. Fig. 2 shows the details regarding implementation of the primary and combined structures and sensor’s positions.

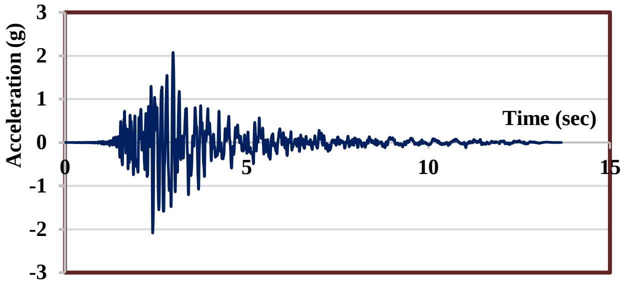


Fig. 1: Simulated Kobe ground motion record in experimental scale

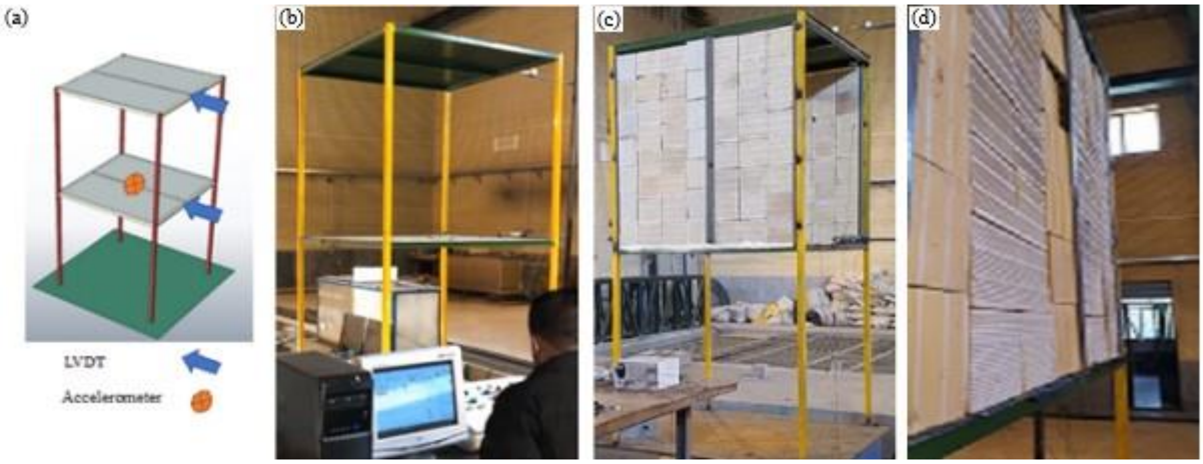


Fig. 2: Test set-up. (a) Details of sensors position, (b) The primary structure, (c) The combined structure (d) The structure after the test

2.2 Test Results

After performing tests and analyzing the recorded data, for better investigation of the change in the seismic behavior of the primary structure due to the addition of a wall and wall post, the first and second floors̓ displacements and the first-floor acceleration in the primary and combined structures were compared (Fig. 3).

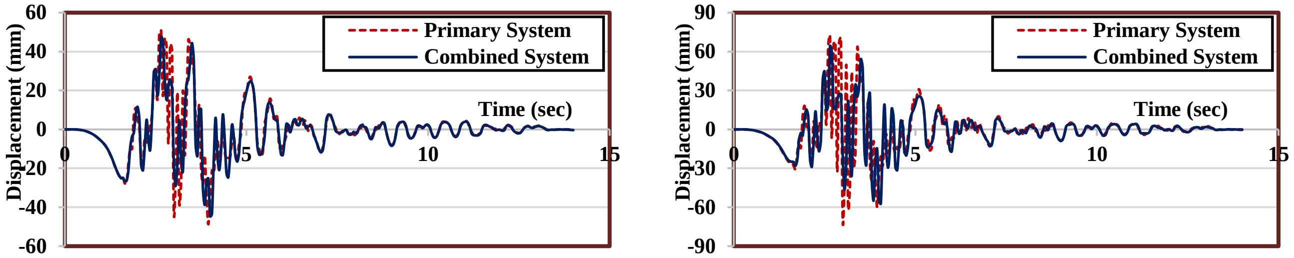
Evaluating the diagrams, it was found that while the maximum displacement of the first and second floors of primary structure was equal to 50.73 and 71.72 mm, respectively, after the addition of wall and wall post on the second floor, it was decreased to 47.42 and 64.01 mm, respectively. A significant reduction in structural response occurred at acceleration. Hence, the maximum acceleration of the first floor in the primary structure was decreased from 57.97 to 23.05 mm/sec^2 in the combined structure. Based on the experimental results, the maximum displacement of the first and second floors and the maximum acceleration of the first floor in the primary structure were decreased by 6.52, 10.75, and 60.23%, respectively, compared to the combined structure.

These results confirm a significant change in seismic behavior of the primary structure after the addition of wall and wall posts which should be considered in design techniques and seismic code requirements.

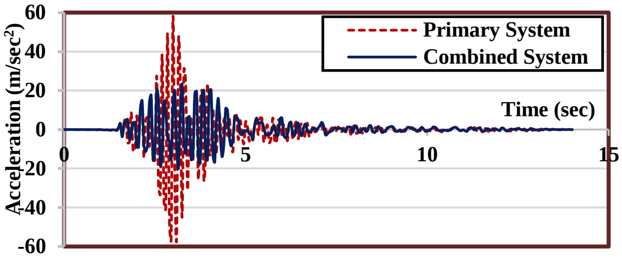
[DOI: 10.52547/nmce.6.4.1]

3. Numerical Modeling

Considering the importance regarding uninterrupted operation of important structures after the earthquake, it is necessary for these buildings to show proper performance after the earthquake and provide the necessary services. Therefore, three main objectives were considered in the numerical part of the research: firstly, estimation of the error in analyzing seismic behavior of the combined structures in the absence of modelling of walls (with or without wall post) and merely considering their mass effects in design techniques, secondly, determining changes in seismic behavior of the combined structures by the addition of wall post to wall compared to the wall without wall post, and thirdly, investigating the effects of walls' arrangement in height on the seismic behaviors of combined structures.



(a) The first floor's displacement (b) The second floor's displacement



(c) The first floor acceleration

Fig. 3: Comparison of response of the primary and combined structures (experimental results)

According to these aims and test model dimensions, 2 regular two- and three-story steel structures were selected as the primary structures. These primary structures were combined with wall and wall posts in 10 different arrangements of walls in height. These structures were modelled in finite element software and analyzed by non-linear time history dynamic analysis method under 7 simulated ground motion records. Each of the above models was modelled in four different types to achieve the objectives of the research. According to prevalent design techniques, in the first modelling (W.L.), only the walls were modelled as a mass concentrated on the primary structure. Similarly, in the second modelling (WWP.L.), the mass of wall posts and walls was applied to the primary structure. However, for investigating the interaction effects of the walls, walls without wall post were added to the primary structure in the third modelling (W.M.). Finally, in the fourth modelling (WWP.M.), the combination of walls and wall posts with the primary structure was modelled and non-linear time history dynamic analysis of the structures was performed. For nominating the structures, a code with a combination of the letters ST and a two- or three-digit number was used. The number of digits indicates the number of floors of the structure, and if a wall was implemented on each floor, the number of that floor was written. If the wall was not implemented in a floor, the number zero was replaced by the number of that floor. List of the studied structures is shown in Table 2.

Table. 2: List of the studied structures

Structure Code		ST-10	ST-02	ST-12	ST-100	ST-020	ST-003	ST-120	ST-023	ST-103	ST-123
Number of floors		2	2	2	3	3	3	3	3	3	3
Wall Existence on floor	1	✓	×	✓	✓	×	×	✓	×	✓	✓
	2	×	✓	✓	×	✓	×	✓	✓	×	✓
	3	---	---	---	×	×	✓	×	✓	✓	✓

[DOI: 10.52547/nmce.6.4.1]

3.1 Numerical Modelling of the Structures

According to the experimental conditions and dimension of simulated sample in the laboratory, dimensions of the structures were selected for numerical modelling from the inverse scale factor of the experimental model. Moreover, each floor of the primary structures was regularly selected at 450 × 450 × 450 cm, and the primary structure was modelled in 2 cases of 2nd and 3rd floors. All the structural characteristics were the same on all the floors. Numerical modelling was performed in finite element software, which used a 4-node shell element with reduced integral (S4R) to mesh structural elements such as column, beam, roof and wallposts. Also, 8-node brick element with reduced integral (C3D8R) was used for meshing the clay bricks. Dimensions of all the structural elements were scaled based on the scale factors presented in Table 1 of the experimental sample in numerical modelling. Beams and columns were modelled with the Box 180×180×12, and the roof of floors was modelled using a steel plate with a thickness of 15 mm, where a secondary beam with the box section was installed under it. The clay brick walls were modelled with the thickness of 27 cm installed only in the exciting direction and characteristics of wall posts were 2L60×60×6 used next to the columns and 4L60×60×6 in the middle of the span. A general view of the primary and secondary structures is shown in Fig. 4.

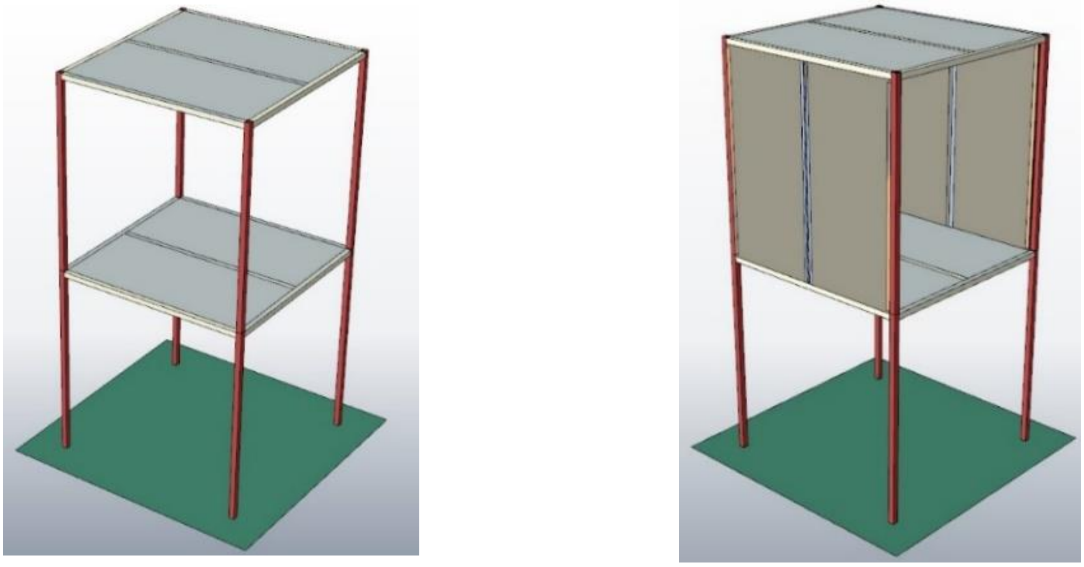

(a) The primary structure (b) The combined structure

Fig. 4: General view of modeling of the primary and combined structures in software

As mentioned in Section 2.1, the characteristics of structural elements were determined in such a way that the primary structures̓ period in real scale was in the range from 0.2-0.7 seconds. Given the above characteristics, the period of primary two- and three-story structures was estimated at 0.46 and 0.69 seconds, respectively. The elasticity modulus of steel in modelling the primary structure and wall posts of 200 Gpa, its yield stress of 240 Mpa, and Poisson’s coefficient of 0.3 were considered, and for simulating non-linear and inelastic properties of steel materials, a two-line model with strain hardening capability was used so that plastic strain ranged from yield strain of 0.6 to the ultimate strain. Masonry materials were modelled by clay bricks conventionally used in Iran with an elasticity modulus of 1441 MPa, Poisson's coefficient of 0.25, and compressive strength of 2.5 MPa [33]. The concrete damage plasticity (CDP) model was used to define the non-linear behavior of the walls. For applying the damping effects in modeling, the damping ratio in modeling all the structures was set at 5% and applied in the software.

3.2 Input Earthquakes

Site conditions completely influence the seismic behavior of the structures, and the occurred earthquake. The most accurate and reliable analytical method is time history dynamic analysis, as it calculates structural responses during the time it is subjected to an input earthquake. In this study, 7 earthquake records were used to study the structures̓ seismic behavior. Records were selected according to the federal emergency management agency (FEMA) P695 standard [34], the characteristics of which are presented in Table 3. These 7 earthquake records were simulated based on the conditions of the Iranian Seismic Design Code (Standard No. 2800) [32], for soil type III and 5% damping. Fig. 5 shows response spectra of the simulated records.

[DOI: 10.52547/nmce.6.4.1]

Table. 3: Characteristics of the records used in the study

ID	Earthquake		Recording Station	PGA (g)	PGV (cm/sec)
	M	Name			
EQ1	6.7	Northridge	Beverly Hills	0.52	63
EQ2	7.1	Duzce, Turkey	Bolu	0.82	62
EQ3	6.9	Kobe, Japan	Nishi-Akashi	0.51	37
EQ4	7.3	Landers	Coolwater	0.42	42
EQ5	6.9	Loma Prieta	Capitola	0.53	35
EQ6	7.4	Manjil,Iran	Abbar	0.51	54
EQ7	7.6	Chi-Chi,Taiwan	TCU045	0.51	39

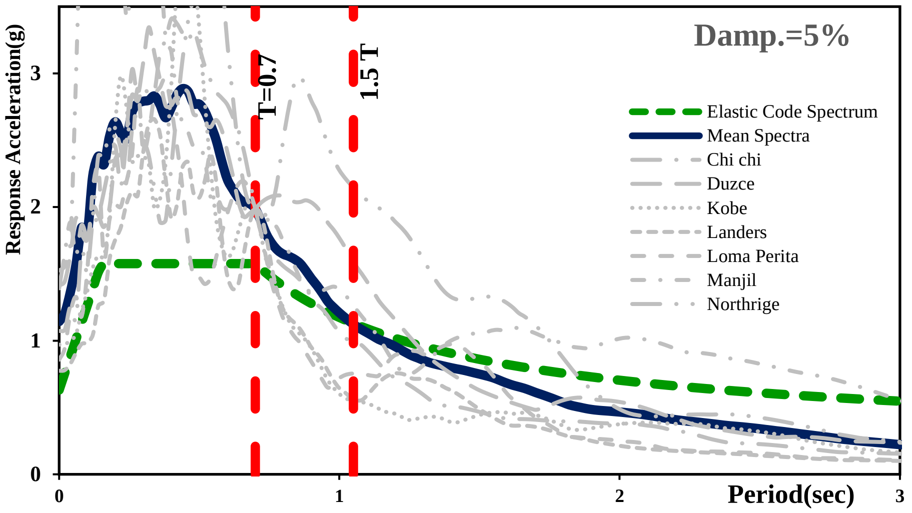


Fig. 5: Response spectrum of the simulated records

3.3 Results of Numerical Modelling

After performing time history dynamic analysis, fundamental period, base shear, and drift of the floors were calculated and compared with each other, in different types of analysis in all structures. Fig. 6 shows the calculated structures̉ periods in different types of analysis, and Fig. 7 presents the percentage of difference related to the periods in different types of analysis relative to each other.

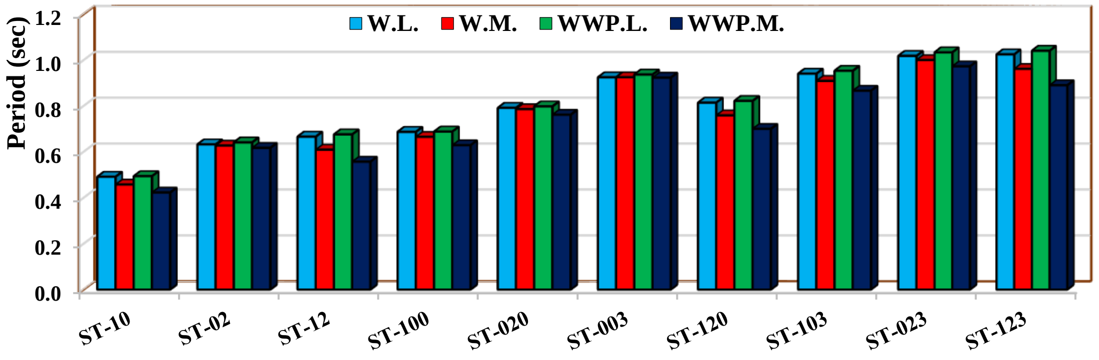


Fig. 6: Fundamental period in four types of analysis

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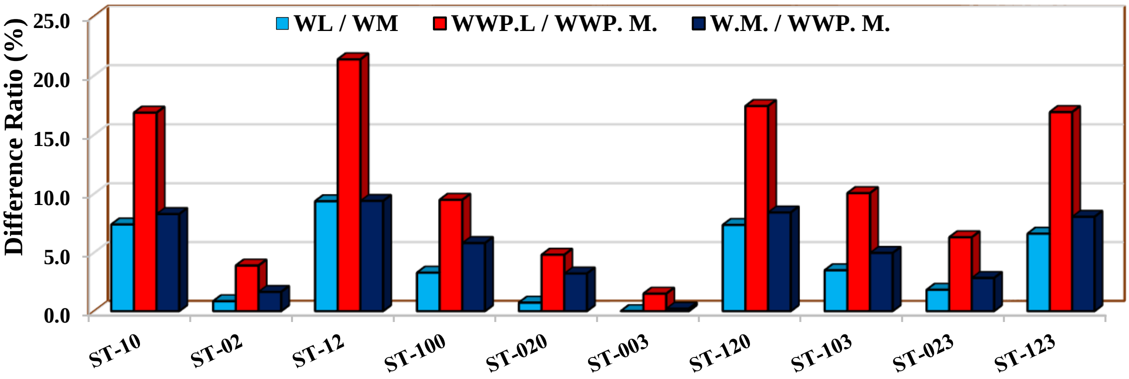

Fig. 7: Percentage of difference related to the periods in different types of analysis

Studying the period in four types of the analysis showed that the structureś period was decreased in the case of complete modelling of the wall or wall and wall post compared to the case where only their weight was applied to the structure. In the case of neglecting the effects of its stiffness in modelling and equating it with a mass system, the determined period error in two- and three-story structures was equal to 9.35 and 7.33%, respectively. The same error was increased to 21.36, and 17.41%, respectively, when the wall was restrained with a wall post, showing that the effects of wall stiffness are greater on the behavior of the structure and error of neglecting the effects of wall stiffness and wall post is increased by implementing the wall post for lateral restraint of the wall.

To investigate the effect of addition of wall post to wall on changing the structureś behavior response, the period of the combined structures in the cases of using wall and the wall plus wall post should be compared with each other, as shown in the third part of Fig.7. In the two-story structures, the highest change in period in terms of the wall restraint by wall post was equal to 9.37% in ST-12 and the lowest change was equal to 1.64% in ST-02, and in the three-story structures, the highest changes were about 8.3% in ST-123 and ST-120, and the minimum change was calculated by 0.2% in ST-003, confirming that in the presence of irregularity in arrangement of walls in height, the concentration of the walls in lower floors causes higher effects by the wall post on changing the combined structureś period.

Another important parameter in the structural seismic design is seismic base acceleration. Based on the results of time history dynamic analysis, seismic base acceleration of all 10 structures in all four types of analysis were calculated for 7 simulated records, and their average was determined as the seismic base acceleration of the structure (Fig. 8). The difference between seismic base accelerations of the structures in different types of analysis relative to each other was also calculated (Fig. 9).

According to Figs. 8-9, the value of seismic base acceleration in all the structures was at the maximum level in the case where a wall was restrained with wall post in comparison with other types of analysis. This exhibited a significant difference with other types, which is due to the increase in stiffness of the combined structure caused by the effect of implementing wall post on increasing the stiffness effect of the walls and wall post in addition to the stiffness of the primary structure.

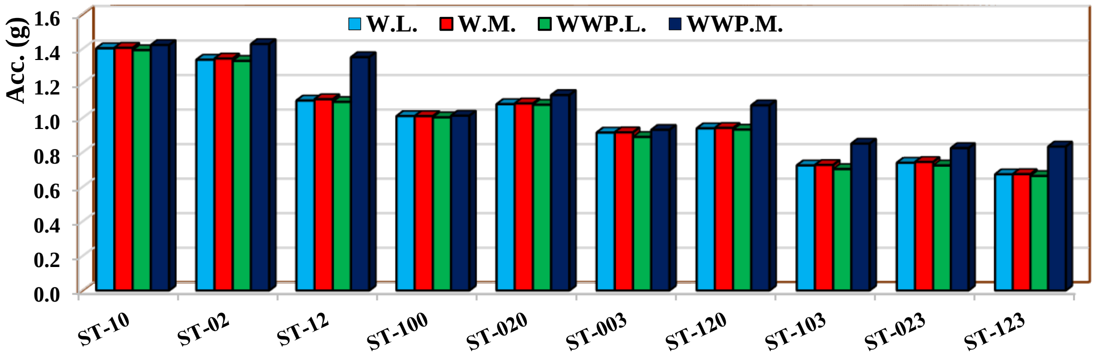

Fig. 8: Seismic base acceleration in four types of analysis

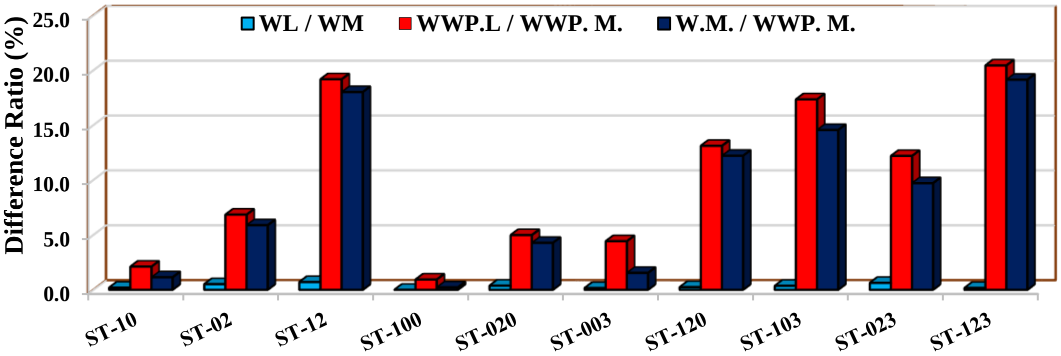

Fig. 9: Percentage of difference related to seismic base accelerations in different types of analysis

As shown in Fig. 9, the difference in the structures̓ base acceleration in both full and mass models where the wall post was not implemented was very small and close to zero, the maximum value of which was equal to 0.7% in the ST-12 structure. This means that when the walls are implemented in a structure without wall post, they have little effect on the seismic base acceleration of the combined structure and, instead of modelling the wall on the structure, the weight of the wall can be applied to the structure with a very small error. This conclusion is only for clay brick walls, and it cannot be generalized to all non-structural walls with different materials.

This small error was increased significantly by adding wall post to the wall (Part 2 of Fig. 9) and was no longer negligible. As in ST-12 and ST-123 structures, error rates of 19.18 and 20.44% were observed, respectively. In other words, wall posts cause complete interaction between the structure and wall by preventing the collapse of walls and their lateral restraint, and as a result, seismic base acceleration of the combined structure will be changed significantly and, it can no longer be said with certainty that mass modelling is a correct model with small error. The maximum calculated error in three-story structures with one, two, and three-story walls was equal to 4.98, 17.35, and 20.44%, respectively. Furthermore, in the three-story structures with one wall floor in three different cases where the wall was in the first, second, and third floors, the calculated error of seismic base acceleration was equal to 0.94, 4.99, and 4.43%, respectively, showing the need for considering interaction effects of the walls and structures with the increase in number of walls, which is especially more important in height.

The main purpose of this study was to investigate changes in the seismic behavior of the combined system due to the addition of a wall post to the wall compared to the case where the wall was implemented alone (Part 3 of Fig. 9). It is quite clear that implementation of the wall with wall post in all the cases has increased seismic base acceleration compared to the case where the wall was implemented alone. Percentage of increase in seismic base acceleration in the two-story structures varied from 1.14% in ST-10 to 18.02% in ST-12. This range in the three-story structures was from 0.22% in ST-100 structure to 19.14% in ST-123 structure, showing that wall post causes the secondary components of the wall to interact more with the primary structure by lateral restraining of the wall and preventing its collapse so that, the combined structure becomes stiffer. As a result, seismic base acceleration of the structure is increased compared to the case of implementing wall without wall post via increasing stiffness of the structure. This increase is more noticeable when there are walls on all the floors. Furthermore, evaluating the structures with the same number of wall floors but with different arrangements shows that placement of the wall on the first floor has the least effect on changing seismic base acceleration. For example, the percentage of increase in acceleration of the seismic base acceleration in the three-story structures with one wall floor in three different arrangements, in which the wall was implemented in the first, second, and third floors, was obtained as 0.22, 4.28, and 1.54%, respectively.

The third parameter studied in the numerical study section was the drift of floors in all the structures and all four types of analysis. This parameter is not only one of the important parameters in seismic design techniques in various seismic codes, but also it is twice as much important in this study, due to the measurement of displacement of the floors in the simulated structure in the experimental study section. Unlike seismic base acceleration, which is a comparable parameter for the whole structure, the drift of the floors is a function of various parameters that can be influenced by local behaviors of the structure and perhaps comparison and commenting on drift of the floors, such as period and seismic base acceleration would not be a simple and reliable issue. Figs. 10-13 provide comparative diagrams regarding drift of different structures in all four types of analysis.

[DOI: 10.52547/nmce.6.4.1]

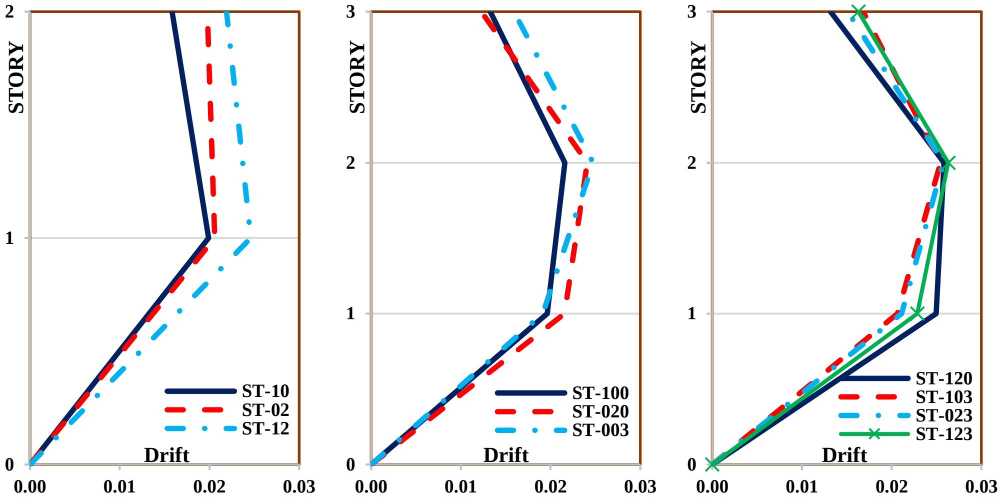

Fig. 10: Floors̓ drift by applying wall mass (without wall post)

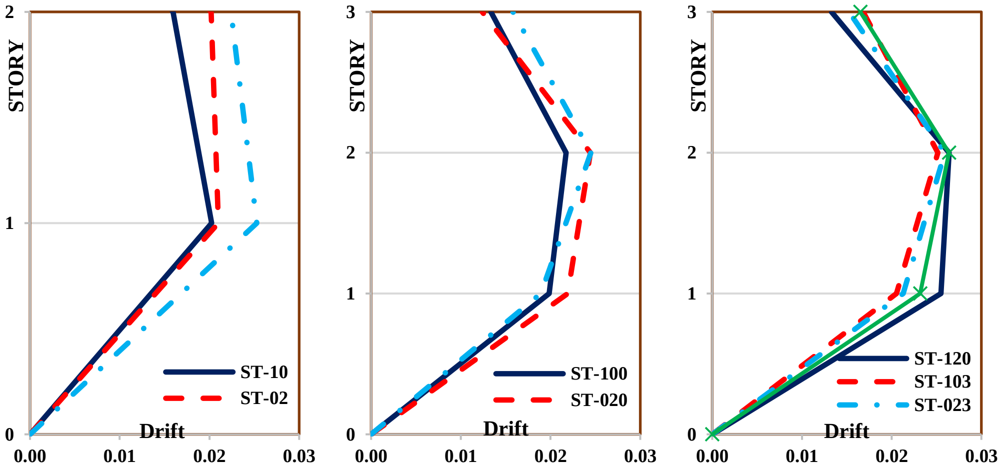

Fig. 11: Floors̓ drift by applying wall and wall post mass

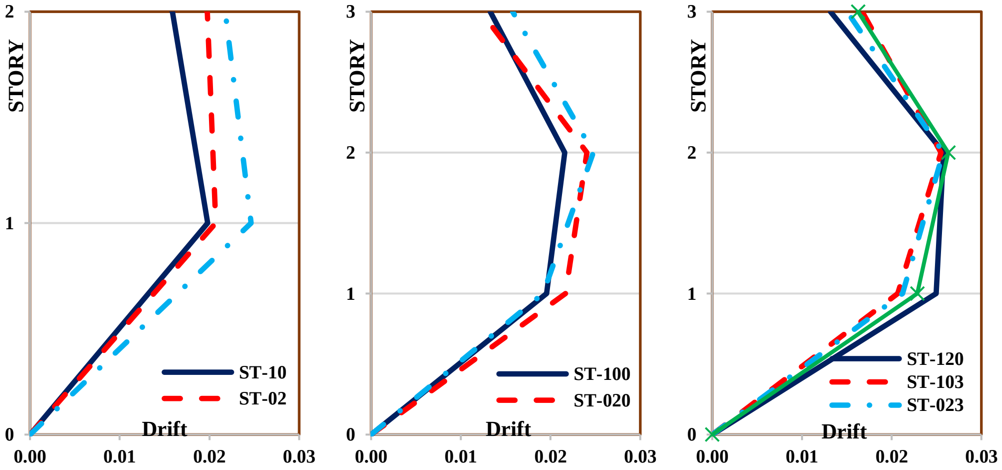

Fig. 12: Floors̓ drift in a combined structure with wall and without wall post

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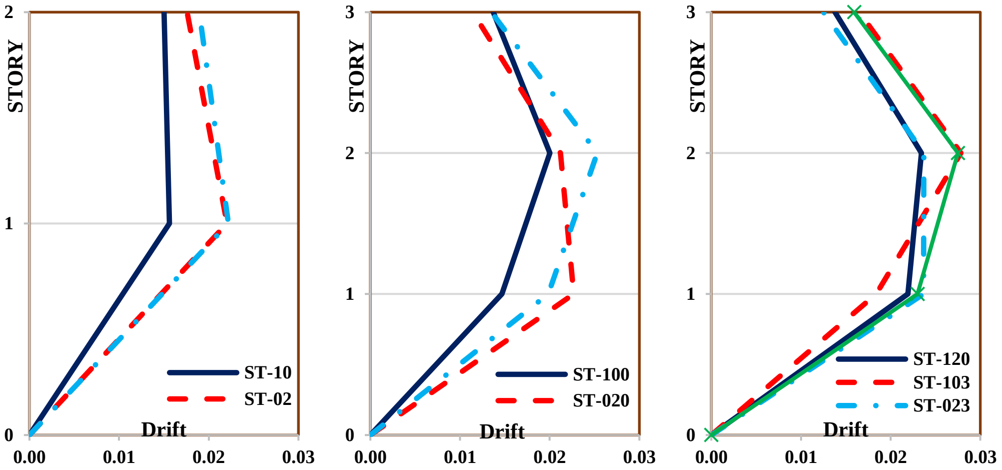


Fig. 13: Floorś drift in a combined structure with wall and wall post

Studying drift diagrams of different structures showed that in the case where the wall was implemented alone without wall post, the drift of the floors was not very different in the full and mass models. In other words, similar to seismic base acceleration, if the walls are implemented without wall post, their stiffness effects on the combined structure and the existing interaction can be easily neglected and the walls can be applied to the structure only as a weight load. On the contrary, drift of the floors would not be the same between the two types of mass modelling and full modelling after addition of wall posts to the walls, and it is not possible to easily neglect the effects of wall, and wall post, and model them as a weight load in the primary structure.

Regarding investigating the effects of irregularity in arrangement of the walls in height on the drift of floors, Fig. 14 shows differences in the drift of combined structural floors in two cases of wall implementation alone and its implementation along with wall post.

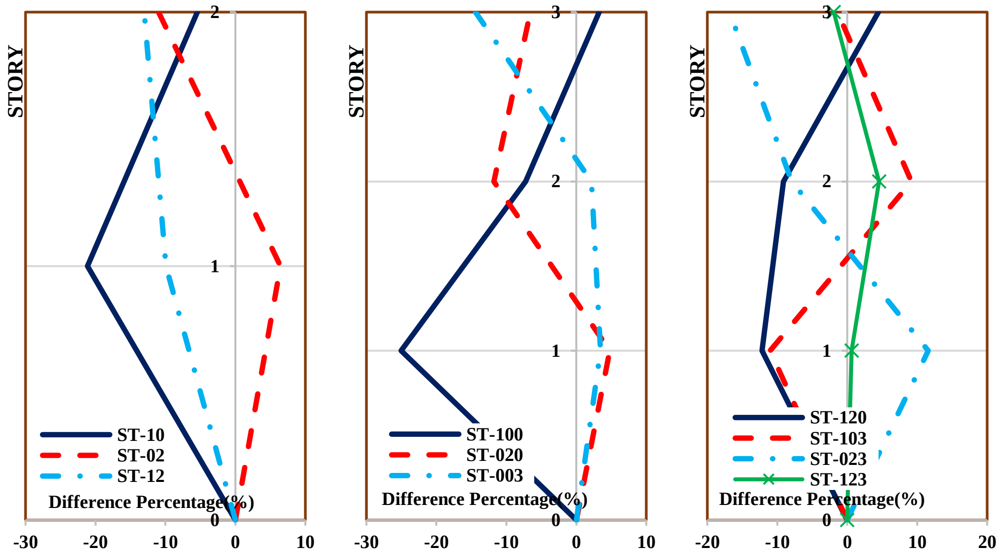


Fig. 14: Difference percentage in drift of the floors in the combined structures in two cases of implementing wall without wall post and implementing it along with wall post

As shown in Fig. 14, if there is no irregular height arrangement, adding a wall post to the wall reduces the floorś drift from 10 to 30%, which is a significant value. Moreover, in each floor where the wall was implemented, drift was significantly reduced by the addition of a wall post, but in the floors without a wall, different behaviors were observed depending on the location of the wall and wall post in height. For example, in the two-story structures with one wall, when the wall was on the first floor, the addition of wall post significantly reduced drift on the first floor, but reduction on the second floor was not as great as on the first floor. Now, if the same wall is implemented on the second floor, the addition of wall post not only does not reduce the first floorś drift, but also increases the drift, and a decreasing trend would be observed on the second floor. This is also evident in the three-story structures where in any floor, there is a wall and wall post in the same floor and the addition of wall post creates a significant decreasing trend in the floorś

[DOI: 10.52547/nmce.6.4.1]

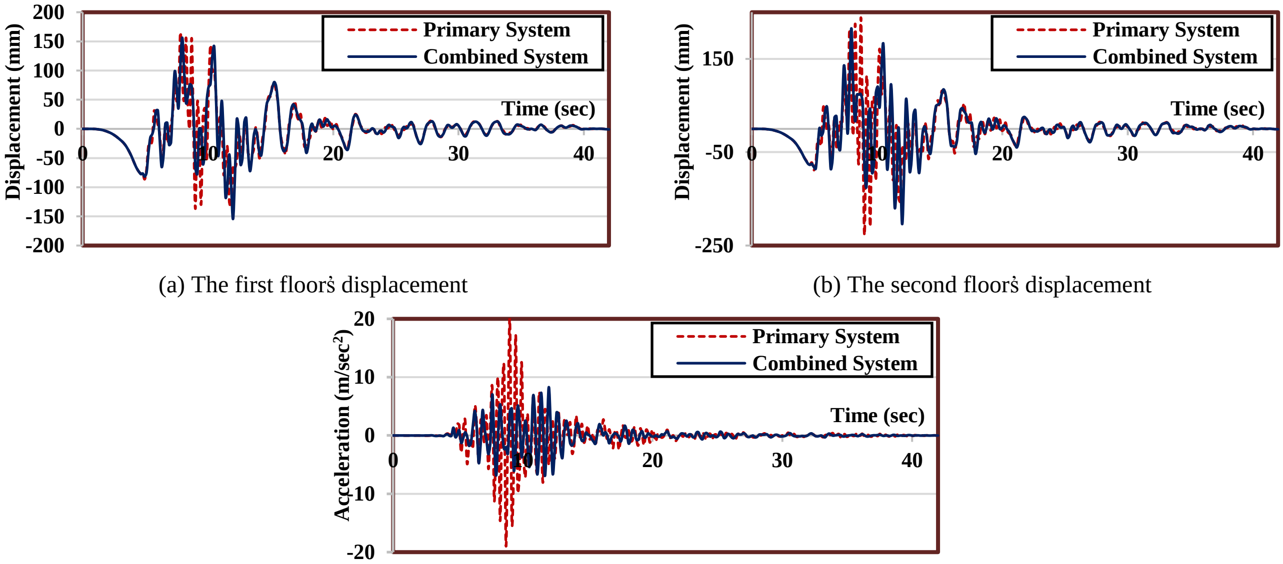
drift. However, in the floors without walls, depending on where the wall is located relative to this floor, the trend of drift changes may be positive or negative. The maximum value of decrease in the floorś drift occurs in a floor, in which stiffness of the floor has increased through addition of wall stiffness to the floor stiffness due to restraint of wall by wall post. Another noteworthy point is that in the structures with the same number of walls in height but different arrangements, if two structures in a particular floor both have walls, the rate of reduction of the drift of same floor due to addition of wall post to the wall is almost the same.

4. Comparison of Numerical and Experimental Results

For investigating the variation in the seismic behavior of primary structure in terms of the addition of wall and wall post in numerical modelling, and the possibility of comparing it with the experimental results (Fig. 3), time history changes in the first and second floorś displacement and the first-floor acceleration in the primary and combined structures were compared as shown in Fig. 15 based on numerical results.

Studying these diagrams showed that based on the numerical results, the maximum first and second floorś displacement of the primary structure was equal to 165.33 and 237.86 mm, respectively. It was reduced to 156.26 and 215.36 mm, respectively by the addition of wall and wall post on the second floor. Moreover, the first floor acceleration in the primary structure was decreased from 19.73 to 8.27 mm/sec^2. Therefore, based on the numerical results, the maximum first floorś displacement of the combined structure was decreased compared to the primary structure by 5.48%, as well as the maximum second floorś displacement by 9.46% and the maximum first-floor acceleration by 58.08%. These numbers were calculated based on the experimental results by 6.52, 10.75, and 60.23%, respectively, showing appropriate adaptation of both experimental and numerical processes. However, comparison of variation percentage in seismic response of the primary and combined structures in the numerical and experimental results showed an appropriate consistency, and for fully investigating the issue, the time history responses recorded in the experimental condition were scaled with respect to the numerical modelling conditions based on the scale factors presented in Table 1 and were compared with each other. Fig. 16 shows the results of this comparison. Studying the diagrams presented in Fig. 16 showed that the difference between the maximum response of the primary structure in the numerical and experimental results in the three cases of the first floorś displacement, second floorś displacement, and first-floor acceleration was obtained as 7.95, 9.55, and 2.04%, respectively. This difference in the combined structure with wall and wall post was equal to 8.95, 10.84, and 7.06%, respectively.

Our results, while confirming appropriate consistency of the experimental and numerical results, highlight the need for special attention to a change in seismic behavior of the structures due to the addition of wall posts to restrain the walls, which has not received much attention in seismic codes.



(a) The first floorś displacement

(b) The second floorś displacement

(c) The first floor acceleration

Fig. 15: Comparison of response of the primary and combined structures (numerical results)

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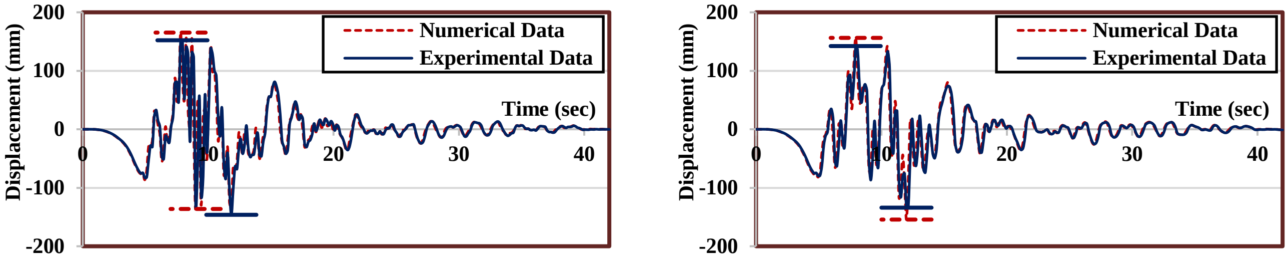
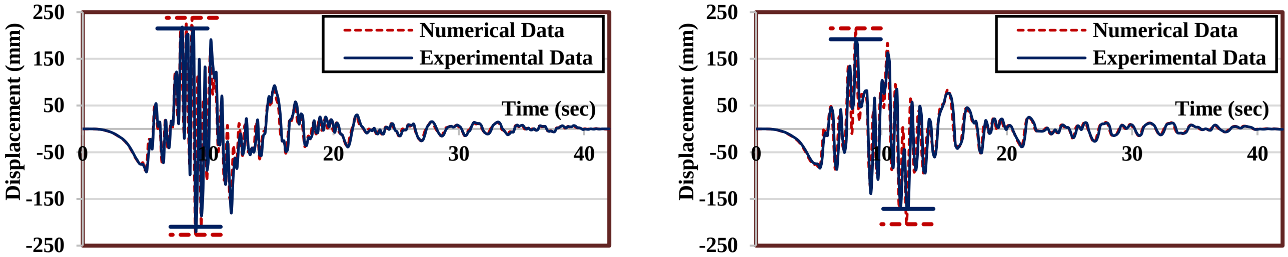
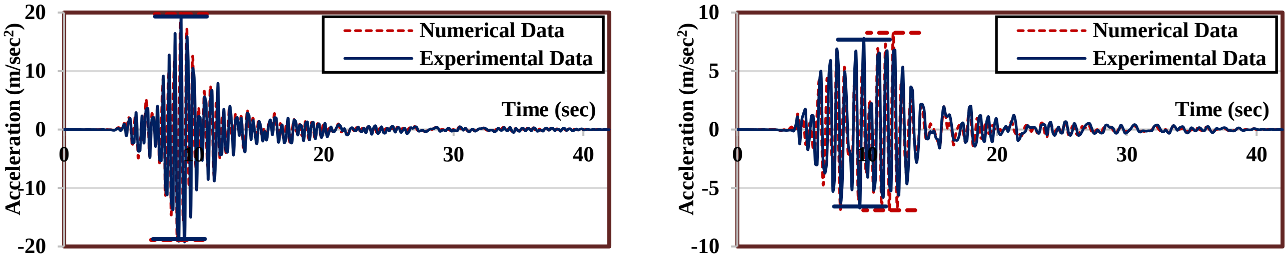


(a) The first floor's displacement of the primary structure (d) The first floor's displacement of the combined structure



(b) The second floor's displacement of the primary structure (e) The second floor's displacement of the combined structure



(c) The first floor acceleration of the primary structure (f) The first floor acceleration of the combined structure

Fig. 16: Comparison of the numerical and experimental results

5. Conclusion

In this research, during an experimental and numerical process, change in seismic behavior of short period steel structures was investigated after adding a wall alone or wall and wall posts, and possible errors due to neglecting the effects of wall and wall posts in design techniques were calculated.

- The results of experiments performed on a two-story steel structure with a clay brick wall and wall post on the second floor, simulated on a shaking table with a scale of 1:3 and subjected to Kobe-scaled ground motion, showed a reduction of the maximum first floor's displacement by 6.52%, a decrease in the maximum second floor's displacement by 10.75% and a decrease in the maximum first floor acceleration by 60.23% in the combined structure compared to the primary structure.
- The results of numerical modelling of the tested structure, with a difference ranging from 2 to 10%showed an appropriate consistency with the experimental results.
- If the clay brick wall is implemented alone without a wall post, the effect of wall stiffness on the behavior of the primary structure can be neglected with a suitable safety margin, and only the wall mass can be applied in modelling.
- By adding a wall post to the wall to restrain it, mass modelling of the wall and wall post causes an error in the results of numerical analysis and prediction of seismic behavior of the combined structures, which was calculated up to 20% in some of the studied structures.
- The implementation of wall with wall post results in the reduction of combined structure's period, which can lead to the reduction of the safety level of structure.
- In all studied structures, implementation of the wall with wall post increased seismic base acceleration compared to the case where the wall was implemented alone. The highest increase in seismic base acceleration was observed in the structures where the wall and wall posts were implemented in all floors of the structure.
- Implementation of walls and wall posts in all the floors of the studied structures reduced the floor's drift from 10 to 30%, especially on the last floors, which is a significant value.
- In the structures with the same number of walls in height, but different arrangements, if two structures in a particular floor have walls, the rate of reduction of drift in the same floor is approximately identical under the effect of addition of wall post to the wall.

[DOI: 10.52547/nmce.6.4.1]

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