Evaluation of the Effect of Connection between RC Shear Wall and Steel Moment Frame on Seismic Performance and Reduction Factor in Dual Systems

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Abstract:

Dual systems of steel moment frame and reinforced concrete shear wall have combined the advantages of steel frames and reinforced concrete shear wall. These walls have increased the lateral stiffness of steel frames and have reduced seismic demands on steel frames thus providing opportunities to use such system. In this research intermediate dual system of steel moment frame was chosen with intermediate reinforced concrete shear wall in forms of 3, 6 and 9 story structures, similar plan and three manners of burried column in shear wall, non burried column connected to shear wall and non burried column separated frome shear wall using ETABS 2000 software and it was designed according to equivalent static analysis. In order to evaluate effect of connection between RC shear wall and steel moment frame on seismic performance and reduction factor of systems, all structures have been modelled on PERFORM- 3D software and static pushover analysis has done according to the instruction for seismic Existing buildings (360 Iranian code) and FEMA 356. The results of static pushover analysis on structures show that in dual systems of steel moment frame and reinforced concrete shear wall, the model of connection of burried column in shear wall is more regarding its deformability, strength and capacity of energy dissipation and the interaction between frame and wall is also better rather than two types of non burried column in wall. Type of wall connection to frame on reduction factor of dual systems of steel moment frame and RC shear wall has no effect in mentioning structures.

Keywords: Dual system, Reinforced concrete shear wall, Steel moment frame, Static pushover analysis, Reduction factor

1. Introduction

One of the key issues in designing and constructing tall Structures, is retrofitting and maintaining its stability against the lateral loads speciall lateral load of earthquake. Today, a variety of methods can be used to retrofit accessory structures. One of the most important and most common is the dual system of frame- wall in iran.

These systems include a combination of single moment frame and shear wall systems that increases the composition and performance of these systems as high as 50 story , and even more to deal with the adverse forces [1]. Observations of the performance of rigid moment frame structures and shear wall buildings in recent earthquakes, behavior represents the second type buildings are safer the force of the earthquake. Performance of buildings with shear walls from the point of view of safety and damage control, was excellent. Shear walls as long as the resistance of the wind load is used, a reasonable and effective solution to the problem of multi-storey buildings is a tough side. Shear walls with rigid frames are much harder and therefore expected to be larger lateral forces caused by earthquakes. In contrast, the lateral displacement of shear wall buildings with rigid

frame would be far less.

(Especially in the short and medium height) [2].

Up to now, the behavior of steel frame filled with reinforced concrete walls under lateral loads has been studied by several researchers. Liauw and Kwan (1983) in Hong Kong [3,4], the infill steel frame is divided into two groups. (1): Those with an internal connection between the frame and filling wall, that the frame of the walls are filled with filling compound called. (2): Those internal connections between frames and wall frames are filled filling does not have a separate name. Research Hayashi et al (2003) in Japan [5], Anil and Altin (2007) in Turkey [6], Liao YF et al (2009) in China [7] showed that the strength and resistance of reinforced concrete wall provide considerable side. Ali Kheyroddin and Hamed Esmaeili (2009) [8], in order to evaluate the behavior of reinforced concrete shear wall mixed and steel moment frame consisting of steel moment frame system and compare it with the harness strap, a 20-story buildings with steel moment-frame systems by the applicationETABS2000 have software analysis and design. The results showed that the lateral stiffness of shear wall containment system is more logical than the X brace classification and administrative aspects of the geometry of the system is obtained for the braceing

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system of classification. Ruey- Shyang Ju et al (2011) in Taiwan [9], in order to evaluate the effect of concrete wall connections to steel moment-frame soft-story problem in solving a series of experimental studies on four samples of steel moment frames in a span of a class conducted under cyclic loads. The results show that the slit separated features can be a viable option to eliminate the soft-story problem caused by vertically irregular configuration of RC infill walls.

In this research, effect of connection between RC shear wall and steel moment frame on seismic performance and reduction factor in dual systems with Nonlinear static analysis has been evaluated. After the non-linear static analysis of structures with the capacity curve of the studied model, the main features of the structure, such as ductility, strength, stiffness (three parameters in earthquake engineering), energy dissipation capacity, lateral force absorption by any of the structural system (frame and wall) and structural reduction factor has been studied.

2. PERFORM-3D nonlinear analysis of software Specifications

PERFORM-3D [10], Powerful program for seismic evaluation of structures which could be used for complex structures , including structures with shear walls to Non - linear analyzed. This software Polyline all valid behaviors FEMA356 [11] and 360 Iranian publication [12], there is a default. PERFORM-3D includes nonlinear components for brace, beams, columns, bars, shear walls, infill and fitting of seismic isolators. The components of the non-linear relationship between Force – Displacement. Linear and nonlinear analysis capabilities of the software, all are done under gravity loads, static pushover loads and dynamic loads caused by the earthquake [13].
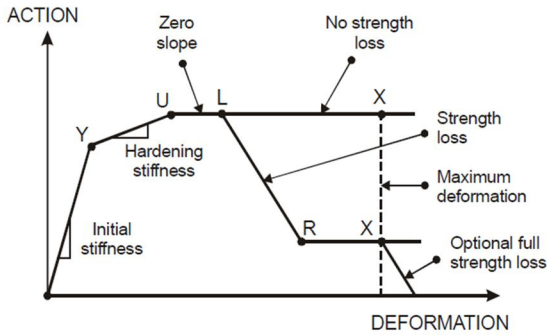

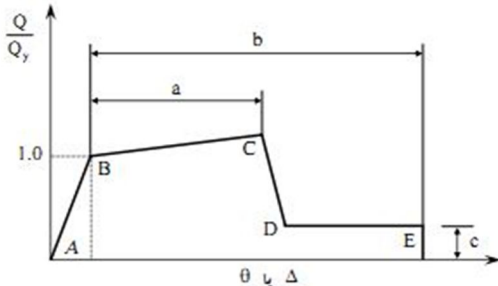Fig. 1. PERFORM Action-Deformation Relationship [10]

Fig. 2. Publication No. 360 Deformation Relationship [12]

3. Information structures studied

In this study dual systems of intermediate steel moment frames with reinforced concrete shear wall medium was selected. This review Tuesday structures for 3, 6, and 9 floors with a similar plan is being considered. In all classes, structures, altitude 3 meters and span length of 5 m. Figure (3) a plan studied structures, direction roofing and location of shear walls is shown. Sections of the Box to the column, and the same moment of inertia of the beam projected checkerboard is used in both directions. To study the behavior of reinforced concrete shear walls and steel frame composit system, in this study, three types of connections forms the common wall column (4) to (6), in all three structures 3, 6 and 9 floors totaling nine models consideredis.
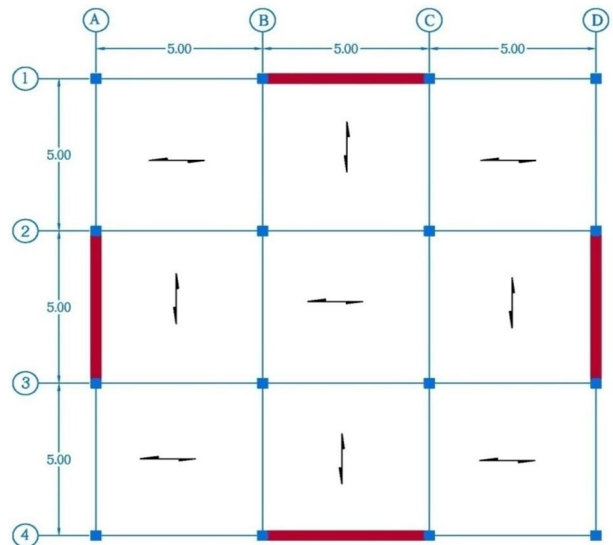

Fig. 3. typical Plan of building and location of shear walls
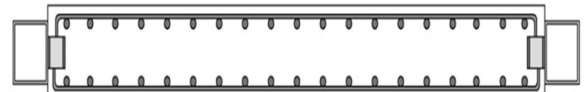

Fig. 4. Non- buried columns attached to the shear wall (Model A)
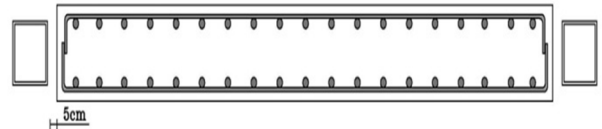

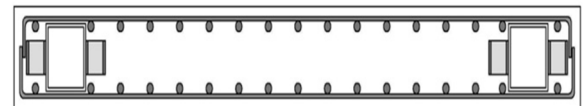Fig. 5. Non- buried columns, separate from shear walls (Model B)

Fig. 6. Buried column in the shear wall (Model C)

To evaluate and compare the results of non-linear static analysis, the study of these models in order to model A, B and C have been named. According to previous studies [9], the gap between the wall and the column in model C

is usually between 1.5 to 1.8% of the wall height is 3 meter high wall in this study, the gap 5 cm (1.6% height of the wall) is considered. Gravity and lateral loads based on the topic structures Iranian Sixth National Building Regulations [14] have been performed. Design of steel moment frames based on the law of AISC-ASD89 [15] and shear walls designed in accordance with the Code ACI 318-99 [16] carried out the terms and subject Iranian Ninth National Building Regulations [17] was controled. Member of the residential structures dead load of classes (including time equivalent blade configuration) for all models of floor 600 kg/m^2 and 550 kg/m^2 roof dead load is calculated. Floor and roof live load, respectively, 200 and 150 kg/m^2 are considered. Parapet walls, floors and roof dead load, respectively, 700 and 160 kg/m are considered. National Building Regulations for seating structures based on six topic areas with soils with very high relative risk of type 2 are considered based an acceleration scheme A=0.35. Steel used for structural steel with yield stress 2400 kg/cm^2 of ST37 Ultimate Stress 3700 kg/cm^2 and the concrete compressive strength (cylindrical samples) 210 kg/cm^2 was considered.

Sixth Iranian National Building Regulations as listed in the paragraph 6-7-1-9-4 topic in dual systems, the moment frame must be able to stand alone, at least 25 % of the lateral force on the building this case has been considered in the design. Each of the models has a static method of analysis and design. Software analysis and design of structures in the elastic range Etabs-ver 9.7.0 [18] and non-linear static analysis software PERFORM-3D-ver 4.0.3 [10] was performed.

4. Equivalent static analysis

The analysis and design of building standard sections IPE, in which the criteria my threads compact National Building Regulations [19], observed for steel beams section and box sections is used for the design of steel columns. After designing structures, different values for beams, columns, shear walls and wall sections were obtained (Table 1) and a typical cross-sections of beams and columns is shown Figure (7).

5. verify of modeling

To control the modeling and verification of selected elements , at first a steel frame filled with reinforced concrete walls by Ruey- Shyang Ju et al (2011) in Taiwan [9], has been studied experimentally And the test results were available, with PERFORM-3D software modeling and analysis results have been compared with the experimental results. Figure (8) and (9) show the operational details and Figure (10) tested real models by Ruey- Shyang Ju et al the atmosphere. SMFW has been named by researchers and is also used here. The wall thickness is 10 cm and The wall web had a reinforcing ratio of 0.0027. The whole area of the walls with rebar stud 16 is attached to the frame. This model modeling with PERFORM-3D software and the material properties of steel and concrete sections, parameters is defined in

software. Figure (11) show the test model software structures.

The results of the analysis of nonlinear static (Pushover) software, along with a comparison with the experimental curve in Figure (12) is presented. As can be seen a good agreement between numerical and experimental results are analyzed (82 %).

Table. 1. Characteristics sections of reinforced concrete shear walls

Type of structures	stories	Wall thickness	Vertical shear reinforcement	Horizontal shear reinforcement	Percentage of vertical reinforcement
3 story	1-3	30	2 ∅10@ 15 cm	2 ∅10@ 20 cm	0.37
6 story	1-3	35	2 ∅12@ 15 cm	2 ∅12@ 25 cm	0.46
	4-6	30	2 ∅10@ 15 cm	2 ∅10@ 20 cm	0.37
9 story	1-3	35	2 ∅14@ 15 cm	2 ∅12@ 25 cm	0.63
	4-6	30	2 ∅12@ 15 cm	2 ∅10@ 20 cm	0.54
	7-9	30	2 ∅10@ 15 cm	2 ∅10@ 20 cm	0.37

Fig. 7. Cross- section of beams and columns 1 and 4 oriented (6 story Structures)

(a): Dimensions of steel moment frame

(b) Reduced beam section at two ends
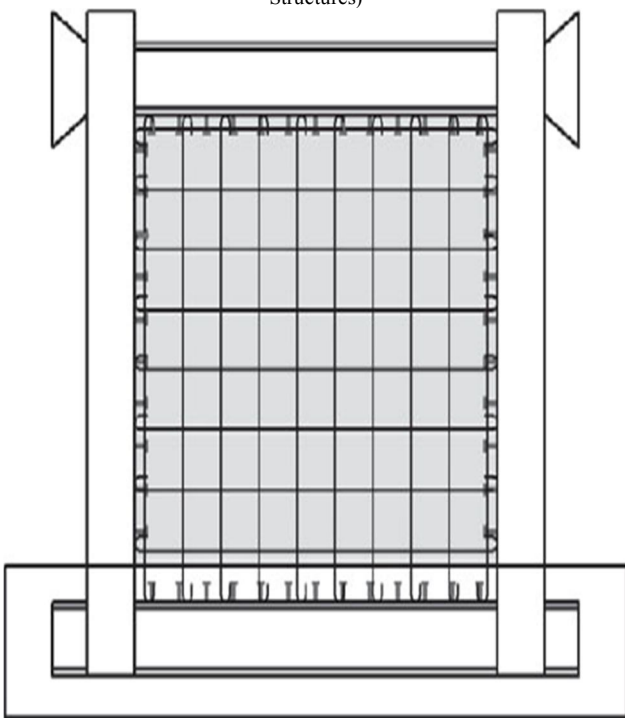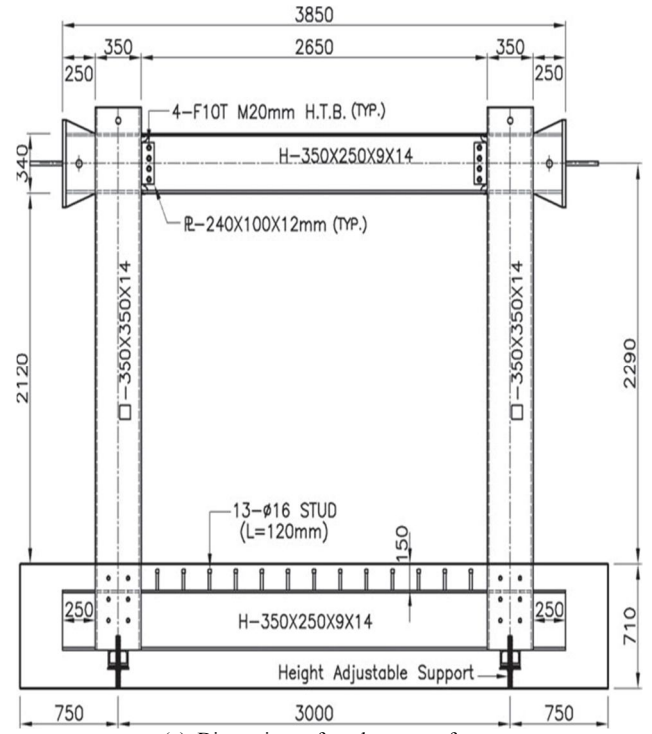
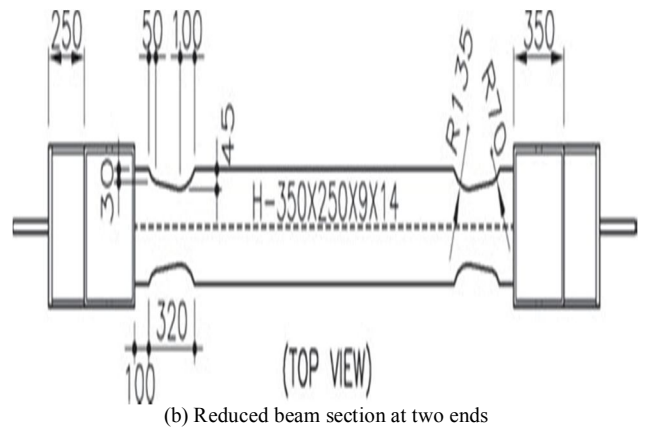Fig. 8. Benchmark steel moment frame (dimensions in mm)[9]

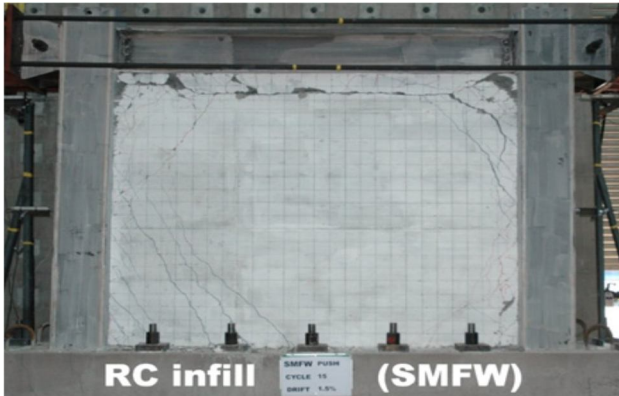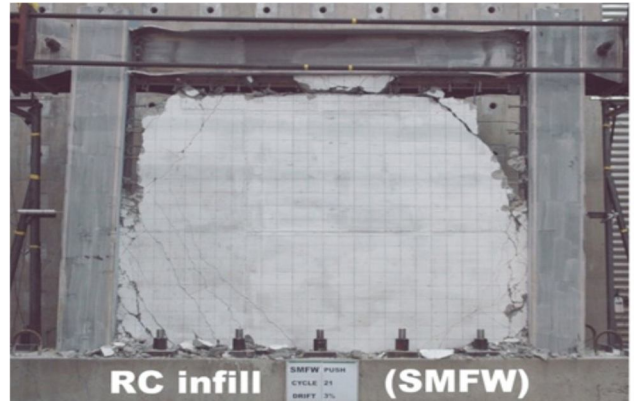Fig. 9. Reinforced concrete wall with steel moment frame (SMFW model) [9]

(a): wall damage at 1.5% drift   (b): wall damage at 3% drift
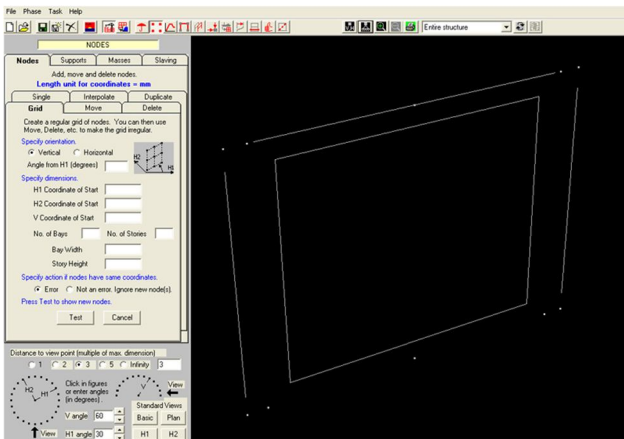
Fig. 10. Actual model tested [9]

Fig.11. software models of SMFW

improvement guidelines [12], two types of lateral load distribution is applied to the structure. In this study, load distribution is based on a modal form the third part of the first mode oscillation and a uniform distribution of the type in which the lateral load distribution is proportional to the weight of each story is used.

7. Analysis of Structures

After the non-linear static analysis of structures with the capacity curve of the studied model, the main features of the structure, such as ductility, strength, stiffness (three parameters in earthquake engineering), energy dissipation capacity, lateral force absorption by any of the structural system (frame and wall) and structural reduction factor has been studied. Usually, the maximum displacement for nonlinear static analysis (Pushover) 3% of the building height. Hence, the overall structural behavior of the curves for drawing curved two ideal linear structure, the spatial variation of 3% of the overall height of the building is closed. An example of the capacity curve models is shown in Figure (13).
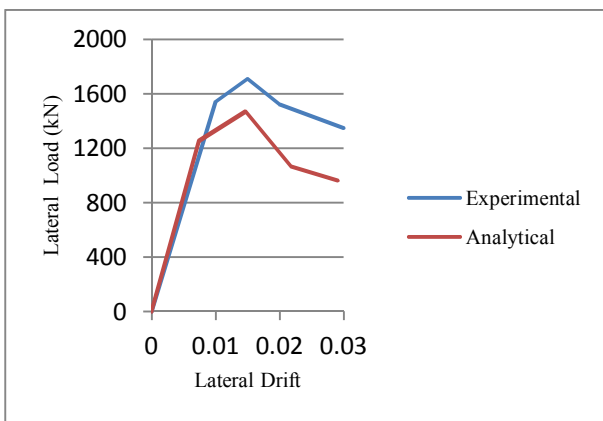

Fig. 12. Results of pushover analysis with PERFORM-3D software along comparison with the experimental curve

6. Nonlinear static analysis

Sections of elastic analysis and design were extracted with ETABS software and mined to evaluate the behavior of nonlinear static (Pushover) PERFORM-3D software using the software capabilities in modeling beam elements , columns and shear walls are modeled. According to
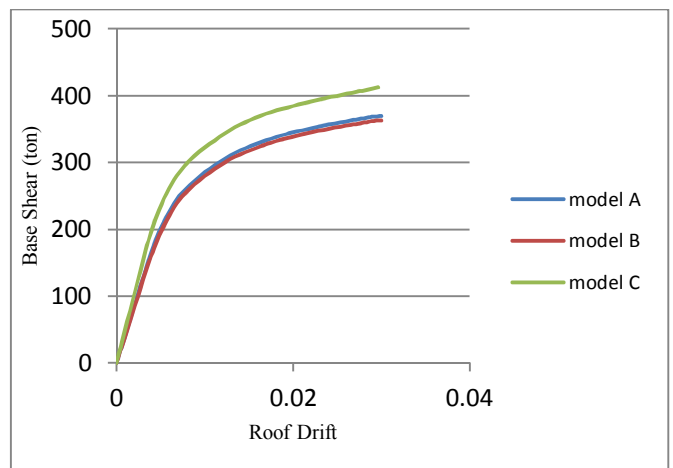

Fig. 13. Capacity curve for 9-story model structures
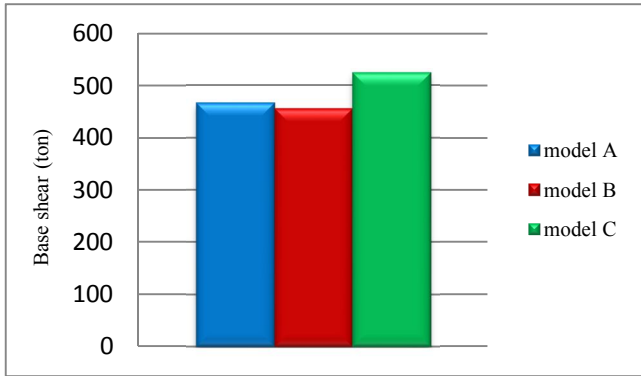
7. 1. Comparison of base shear values

Fig. 14. base shear for 3- story model structures (Drift 3%)
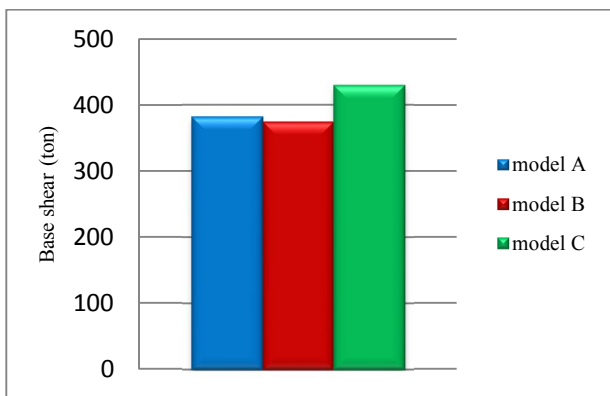

Fig. 15. base shear for 6- story model structures (Drift 3%)
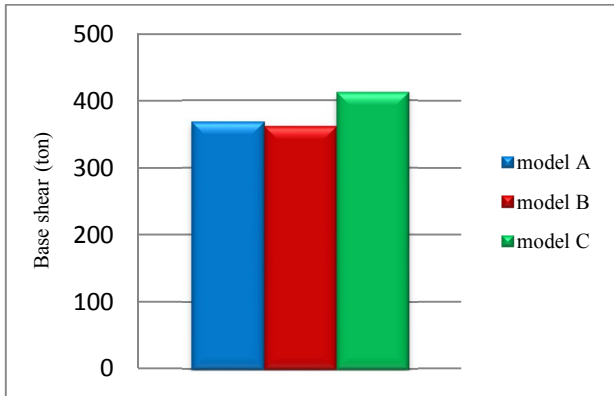

Fig. 16. base shear for 9- story model structures (Drift 3%)

The curve of capacity resulting in a displacement effect equal area under the curve of force – displacement of the models tested were different in all three structures 3, 6, 9, classified, model C has the largest area under the curve. Therefore, model C of energy absorption is better than the other two models. Also Comparison of the figures shows that the base shear values in a similar lateral displacement, Model B, at all three structures 3, 6 and 9, story minimum and Model C the maximum base shear has been suffering. In other words, Model B with lowest and Model C with maximum lateral load is determined to reach maximum displacement. Therefore, model C of lateral resistance and energy dissipation capacity has more than the other two

models. Comparing the relative displacement and main period of the structure of studied Show little difference in the structures of 3 and 6 story displacement relative to different classes of models not found but increasing the height of the structure, the relative displacement classes in model C more than other models. Therefore, with increase structure height the lateral stiffness of the story in model C is reduced. Also the Model C minimum and Model B maximum period have fluctuated. So given the same weight in all three model structures, the lateral stiffness of the entire system model B is better than the other two models. And Model C lateral stiffness is less than the other two models.
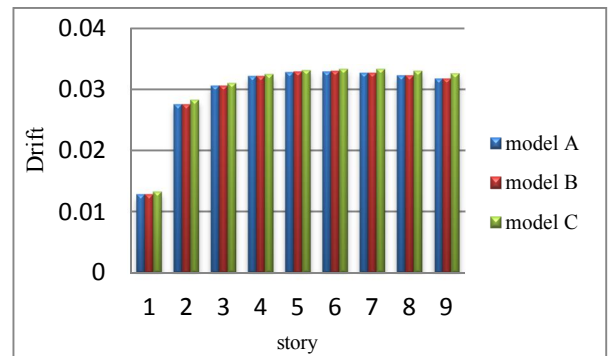

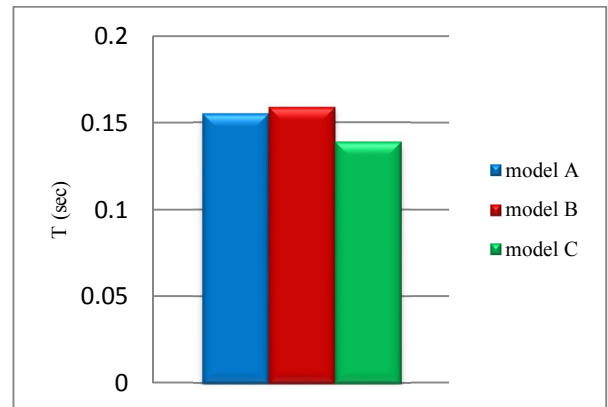Fig. 17. Drift of 9-story structures
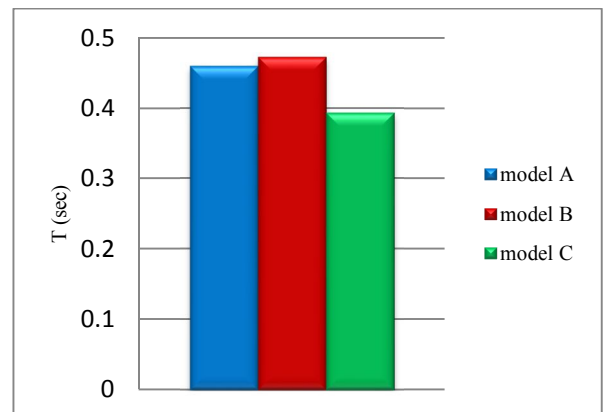

Fig. 18. main period of 3- story structures

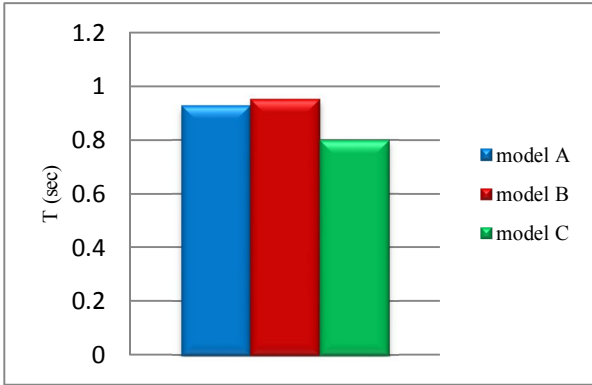Fig.19. main period of 6- story structures

Fig. 20. main period of 9- story structures

7. 2. Investigating lateral force absorption by structural systems

To investigate the interaction between systems, steel moment frames and shear walls in height of buildings, cutting uptake by both systems have been studied in various classes. The load absorbed by the 6-story structure represents the shear walls shown in Figure (21). By comparing the curves obtained from the three structures 3, 6 and 9 story, we can see that in model C the absorption of shear force story, shear walls have better performance than the other two models.
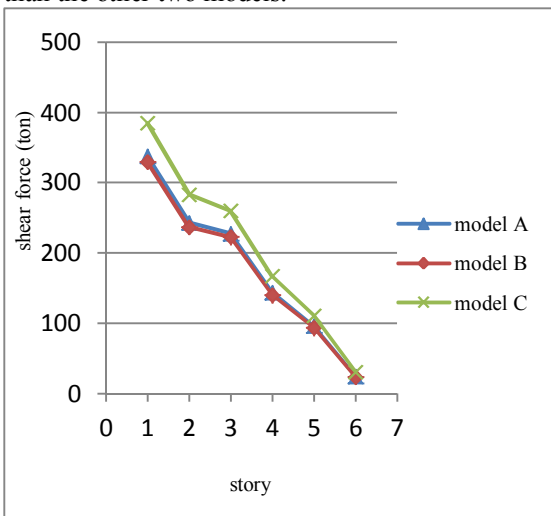

Fig. 21. the absorption of shear force by shear walls
(6- story structures)

7. 3. Calculation of reduction factor ductility method:

In order to calculate the reduction factor using the ideal structure of capacity Curve according to 360 Iranian code, responded structures as relations between the base shear and the roof drift estimated. Then values required to calculate the reduction factor of ductility way, the answer was extracted based on the ideal structure calculations were used.
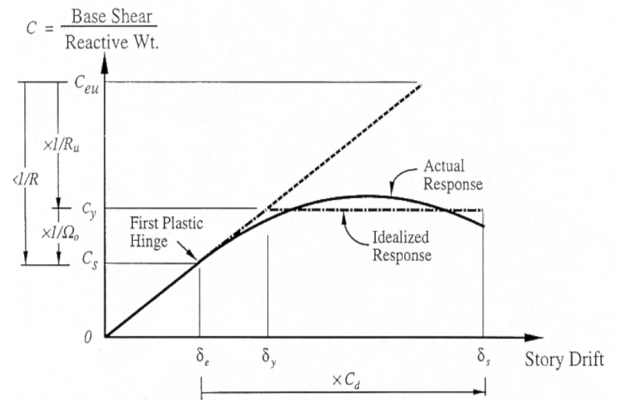

Fig. 22. General structural response envelope [20]

7. 3. 1. 1. General structural ductility factor

The figure (22) the general structural ductility factor as the ratio of the maximum drift (δ_t) to yielding drift (δ_y) is defined.

$$\mu_s = \frac{\delta_t}{\delta_y} \qquad (1)$$

7. 3. 1. 2. earthquake force reduction of ductility factor (Rμ)

Reduction of ductility factor, is the ratio of the ultimate strength of the structure (C_{eu}) (if they remain elastic behavior), corresponding to the failure mechanism of the formation of structures during the public submission (C_y).

$$R_\mu = \frac{C_{eu}}{C_y} \qquad (2)$$

This parameter was calculated according to the period of construction to the various relations proposed by various researchers. In this study the relation Rμ, Newmark and Hall method was used as follows.

$$T \leq 0.03 \text{ sec} \qquad R_\mu = 1.0 \qquad (3)$$

$$0.12 \leq T \leq 0.5 \text{ sec} \qquad R_\mu = \sqrt{2\mu_s - 1} \qquad (4)$$

$$1.0 \text{ sec} \leq T \qquad R_\mu = \mu_s \qquad (5)$$

7. 3. 1. 3. increasing resistance factor (Ω)

Increasing resistance factor, is the ratio of total surrender force structures during the formation of the corresponding failure mechanism (Cy), corresponding to the formation of the first plastic hinge in the structure (Cs).

$$\Omega = \frac{C_y}{C_s} \qquad (6)$$

37

7. 3. 1. 4. Allowable Stress coefficient (Y)

In formulation of reduction factor, Y is a coefficient based approach to design regulations designed to stress (yield stress and allowable stress) is determined by the value of this coefficient is usually between 1.4 to 1.5

7. 3. 1. 5. The general reduction factor of the structure

In this study the structural reduction factor according to allowable stresses method are calculated as follows.

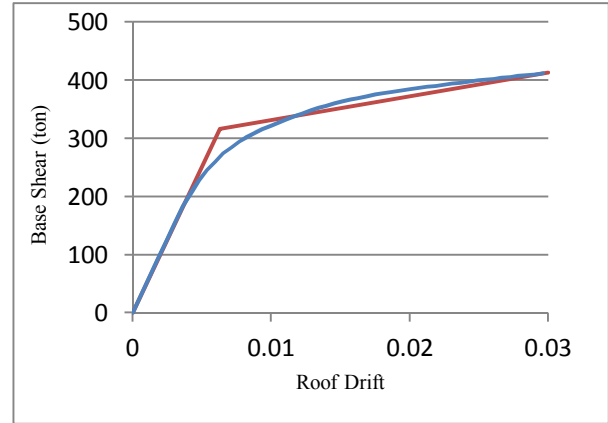$$R_w = R_\mu \times \Omega \times Y \qquad (7)$$

Fig. 23. An example of a ideal capacity curve 9-story structure

(model C)

Table. 2. Results of pushover curves for the 3- story structure models

model	T(sec)	Vy (ton)	Vs (ton)	$_s\mu$	Ω	R_μ	Y	$R_w = R_\mu \times \Omega \times Y$
A	0.1553	274.5	182.09	10.6	1.51	4.49	1.4	9.49
B	0.1591	265.7	171.09	10.4	1.55	4.45	1.4	9.66
C	0.139	318.7	225.3	11.6	1.41	4.71	1.4	9.3

Table. 3. Results of pushover curves for the 6- story structure models

model	T(sec)	Vy (ton)	Vs (ton)	$_s\mu$	Ω	R_μ	Y	$R_w = R_\mu \times \Omega \times Y$
A	0.4599	254.3	128.81	5.78	1.97	3.25	1.4	8.96
B	0.4728	249.2	129.44	5.6	1.93	3.19	1.4	8.62
C	0.394	290.9	161.21	6.43	1.8	3.44	1.4	8.67

Table. 4. Results of pushover curves for the 9- story structure models

model	T(sec)	Vy (ton)	Vs (ton)	$_s\mu$	Ω	R_μ	Y	$R_w = R_\mu \times \Omega \times Y$
A	0.9284	284.6	195.76	4.31	1.45	4.09	1.4	8.30
B	0.9528	279.3	190.34	4.27	1.47	4.12	1.4	8.48
C	0.8008	316.7	208.99	4.75	1.52	4.03	1.4	8.58

By comparing the ductility coefficients and reduction factor obtained, Model C is observed in all three structures, 3,6 and 9 storey ductility is compared to two other models. However, no significant difference between the reduction factor of models is not observed in the range of structures. Reduction factor of the models proposed to construct 3 -story threads Sixth National Building Regulations [14] (R=8) is greater when increasing building height (6 and 9 categories), this ratio is closer to number 8. This means that the reduction factor of the proposed design is conservative and regulations for building low- rise building height seems more reasonable number. It is worth noting that there are different ways of calculating the reduction factor of which can be rather different results. But what is clear is the scattering reduction factor of the structural parameters. For the overall index introduction of this model, more study is needed.

8. Conclusion

Summary results of this study are as follows:

1. In all three structures, 3, 6 and 9 story Model C base shear has suffered more than other models with more lateral force is in failure mode. The dual system of steel moment frame - shear wall form of buried column in the concrete shear walls structure increases resistance than non-column mode is buried.

2. Ductility of structures, in form of buried column in shear walls in all three structures 3, 6 and 9 story is higher than the other two model. (Fig 13).

3. Energy dissipation capacity in all three structures 3, 6 and 9 story in form of buried column in the wall is more than the other two model. (Fig 13).

4. In the case of buried column, reinforced concrete shear walls due to absorbing column shear force levels, have good performance.

5. How to connect the frame to the wall with the model presented, the structure of short (3 and 6 story), the drift

of story has the effect of increasing the height classes (9 story), the drift of more than two classes in a buried column other state has.

6. Lateral stiffness of the system, in the case of buried column, is less than the other two. in the case of non-buried column gap between the wall and the other column frame structure is increased lateral stiffness.

7. How to connect to the frame on the wall in the dual system on reduction factor of steel moment frame-concrete shear wall structures in the area were not affected. To introduce the general index model more study is needed.

8. According to the ductility and strength (two parameters in earthquake engineering), energy dissipation capacity and appropriate interaction frame walls and pillars buried in the wall better than non-column mode is buried, it is recommended that the dual system of steel moment frames and shear walls of reinforced concrete columns adjacent to the wall are embedded in the wall properly. The only slight drawback to this circuit model, the model of non-buried columns stiffness little difference which side to solve this problem is to increase the wall area can be selected.

9. If for any reason (such as retrofitting projects), to be non- buried columns in the wall, the better the performance gap, the column must be separated from the wall (due to the lateral stiffness of the connection of these models).

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