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Investigate the effect of concrete shear wall arrangement on the roof diaphragms stiffness and floor shear transfer in steel buildings

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ABSTRACT

Civil engineering emphasizes the reinforcement of structures against applied loads during their lifespan and aims to optimize design economy. Structural designers prioritize structures that can efficiently withstand various loads. However, non-structural factors often influence the choice of structural form and system. The positioning and shape of lateral elements, especially shear walls, play a vital role in a structure's actual performance. This paper examines the impact of shear wall arrangement on roof diaphragm stiffness. The study involves three models of metal structures with 4, 6, and 8 roofs, each with three samples. Analysis revealed that shear wall arrangement significantly affects roof stiffness. Changing the arrangement reduced the stiffness of the models by 146%, 148%, and 668%, respectively, and altering it further decreased stiffness by 339%, 1003%, and 900%, respectively. Consequently, the ceilings of all models shifted from rigid to semi-rigid. It highlights the importance of considering diaphragm stiffness in structural design to ensure optimal performance. The study's findings underscore the crucial role of shear wall arrangement in determining roof stiffness and emphasize the need for careful consideration in structural design to achieve desired performance.

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1. Introduction

Civil engineering considers the importance of reinforcement of structures against the loads applied to it during the structure lifetime, along with efforts to optimize and observe the design economy. According to a structural designer, the best form of a structure is when the leading members of the structure can withstand different combinations of horizontal and vertical loads optimally; however, non-structural considerations generally play an in alienable and decisive role in choosing the shape of the structure. Many important factors are involved in the decision on the form of the structure, including the internal plan, materials, method of implementation, architectural considerations and external shape of the building, location and path of installation systems, type and amount of lateral load, and height of the building. The importance of the effect of lateral force increases rapidly with the increasing height of the building. At a certain height, the lateral displacement of the building determining its seismic capacity and requirements. Measuring the behavior of nonlinear systems has many complexities, and appropriate analytical methods must be adopted to model the structure's performance against lateral loads such as earthquakes. Computer technology advances have paved the way for nonlinear analysis, making it possible to ignore the assumption of diaphragms stiffness concerning flexible diaphragm calculations becomes so great that stiffness considerations are more controlling than the strength of the building materials. To measure the structure behavior necessitates determining its seismic capacity and requirements. Measuring the behavior of nonlinear systems has many complexities, and appropriate analytical methods must be adopted to model the structure's performance against lateral loads such as earth-quakes. Computer technology advances have

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paved the way for nonlinear analysis, making it possible to ignore the assumption of diaphragms stiffness concerning flexible diaphragm calculations.

A suitable analysis model necessitates a relatively accurate estimate of the building's structural behavior. A multi-story structure is essentially a vertical plane subject to axial weight loads and lateral wind and earthquake loads. Lateral loads entering the external surface of the building are distributed among lateral load-resistant members. These loads stimulate the concentrated masses of the structure and cause displacements. In buildings, the accumulation of masses is generally concentrated on the structure roofs; therefore, the mass points of the structure that incline the direction of lateral loads towards themselves are the roofs of the building. The main effect of diaphragm type on the structure behavior is the distribution of lateral force between the vertical members. However, other influential factors in addition to characteristics of the structure behavior include natural rotation of the structure, base shear, displacement of the whole structure, and displacement of the floor diaphragm.

In addition to their primary function of bearing and transmitting gravitational forces, roof diaphragms play a significant role in distributing forces between strong members such as frames, shear walls, and braces. The integrity of the members of the structures will increase the degrees of freedom and will be a complete unit in the design. In most cases, these rigid members are uniformly attached to the roof diaphragms, so the diaphragms must be de-signed for lateral forces in addition to gravity [1]. Horizontal braces in industrial buildings transmit load to strong components, so they are considered a diaphragm. Diaphragms are classified into three types: rigid and semi-rigid, and flexible. A rigid roof can transfer the forces applied in the horizontal roof direction to the resistant components with-out any deformation in the roof surface. There is no local displacement in the direction perpendicular to the diaphragm surface. In this case, the lateral forces are distributed through the roof in proportion to the relative stiffness of the resistant components. Figure 1 shows the lateral force distribution between the diaphragm and the lateral load-bearing members.

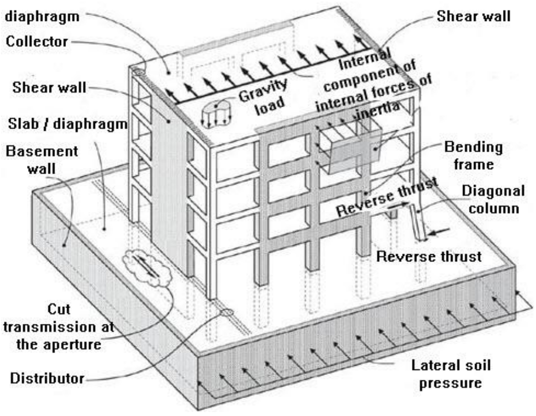

Fig 1. Distribution of lateral forces in the roof diaphragm.

Many earthquake damages observed in buildings indicate that structures suffer severe damage for the absence of or improper execution of the floor diaphragm in the construction phase. Moreover, another influential factor is the absence of under-standing of diaphragm behavior and its unrealistic model in the analysis and design stages. For example, inaccurate determination of stresses and required strength of members leads to the incorrect design of members. Therefore, the structure's behavior and distribution against lateral forces' forces depend on the diaphragm characteristics and behavior. The rigid diaphragm hypothesis in the structural analysis was first proposed Macleod [2] and later by Wilson et al. [3] Muto [4] also used a beam with flexural and shear deformation to examine a flexible diaphragm behavior. Using the Muto beam model, Jain [5] showed that this vibrating model creates a noticeable deformation inside the floor for tall and slender buildings. In a study using some Response Spectrum analyses, Ju and Lin concluded that the rigid floor model is as flexible as the flexible model for buildings without shear walls, even for irregular floor systems. Cleary, the hypothesis of a rigid and flexible floor varies for buildings with shear walls due to the high lateral stiffness of the shear wall. Therefore, it is not ac-curate to ignore the intraplate deformation [5, 6].Following the 1994 Northridge earthquake, Fleischman et al. examined the extensive damage to prefabricated parking structures. They attributed the damages to the flexible performance of the floor diaphragm. However, the designers assumed that the floor diaphragm was rigid [7].

Safarini and Qudaimat [8] investigated the error due to the assumption that the floor diaphragm is rigid in structures with different plans in the linear range and showed that the error is higher for buildings with shear walls. Kolunga (1996) investigated the effect of floor flexibility on the seismic response of buildings by com-paring the calculated seismic response for flexible diaphragm structures and rigid diaphragm structures. This study examined three buildings affected by the 1989 Loma Prieta earthquake. The structures include a two-story fire station with unreinforced masonry walls, a two-story wooden office building with shear walls, and an eight-story concrete hotel with concrete shear walls, which showed torsional effects on the structure as the ductility of the roof increased. In some cases, the shear walls and diaphragm accelerations increase [9, 10].

Nakaki (2000) studied concrete diaphragms' flexural capacity and lateral stiffness. He also pointed out that UBC1997, the coefficient used alone to determine the stiffness and rigidity of the diaphragms, is not sufficient, but the size of the aperture, its stiffness, and the stiffness ratio of the stiffener to the rigidity of the lateral bearing system should be considered in the analysis and design of diaphragms. As stated in UBC97 Regulations, it is a higher mode to consider the effect of participation. This should at least be considered in the designs [7]. Rodriguez et al. examined the acceleration caused by earthquakes in the floor diaphragm in conventional buildings with rigid roofs. Their theoretical studies showed that the horizontal acceleration of the floor diaphragms is greater than the maximum amount of structural excitation acceleration. This increase in acceleration is already seen in the FEMA 450 and IBC regulations. It is taken into account in diaphragms analysis and design [11]. Fleischman et al., (2006) examined the seismic response of structures to which the lateral load-bearing system is propagated and showed that the design force of diaphragms could significantly differ from the force used for design in regulations. Fleischman et al. suggested that all diaphragms of the structure should be designed to have the same resistance throughout the structure's height. In this re-search, the design strength of each diaphragm is determined by the diaphragm resistance of the highest layer, which is determined by coefficients that de-pend on various factors, including diaphragms flexibility coefficient, and number of stories, and diaphragms ductility coefficient [12, 13]. Yang (2003) showed that the flexibility of the floor diaphragm increases the periodicity of the structure, and the non-structural components of the diaphragm increase the shear time of the diaphragm by increasing the shear stiffness [7]. In 2004, Basu and Jain examined the torsional constraints of regulations for asymmetric buildings with flexible behavior. They concluded that torsional effects in semi-rigid buildings and asymmetric planar shapes could be significant, with neither flexibility nor torsional constraints can be ignored. They also acknowledged that torsional effects decrease with increasing flexibility. Torsional structures can be ignored in fully flexible diaphragms [14]. In a laboratory study on a roof with a large steel deck, Tremblay et al. (2008) showed that the stiffness and main period of the diaphragm change with changing dynamic range amplitude and that damage occurs at high dynamic forces around the diaphragm joints [15, 16]. Zaregarizi (2008) showed that for braced steel structures, increasing the flexibility of the floor increases the natural period of the structure [17]. Eivani et al. investigated the effect of roof diaphragm flexibility on the seismic behavior of the structure. The order of shear wall placement in this study was considered a symmetrical system, and 5, 11, 16, and 22-story buildings with a floor height of 3 meters and a column spacing of 7 meters are examined. The plan of the buildings is rectangular, U-shaped, and T-shaped, and all the shear walls are continued along the right and left. As a result, the amount of error determined by computational methods is used to calculate the difference between the analysis results of rigid and flexible roof models in shear wall structures [18].

Hadianfard et al. conducted a study on the flexibility of beam floor and block diaphragms on the inelastic behavior of braced steel structures. In this paper, they investigate the nonlinear responses of braced steel structures. The floor diaphragms of flexible concrete block beam under static lateral load, and dynamic ground motion were investigated and compared with the responses of the structures assuming rigid diaphragms. The study showed that the diaphragm ratio is an essential parameter in the flexibility of floor diaphragms. If this ratio is greater than three, the resulting variations be-tween the two assumptions of flexible and rigid diaphragms cannot be ignored. In addition, the results showed that diaphragm flexibility changes the seismic response of structures and linear analysis is not sufficient to explain this behavior [7]. Sriscantan et al.

numerically examined the effects of diaphragm stiffness and stiffness on the seismic response of multi-story modular buildings. Discontinuities in this diaphragm can potentially lead to structural instability or possible diaphragm failure if left unattended; therefore, the main purpose of this study was to evaluate the effect of stiff-ness and strength of intra-plane diaphragm on the seismic performance of multi-story modular buildings. A simple method for creating diaphragm service stiffness is provided by considering the shear deformation of the single-module diaphragms and the shear and axial deformation of the diaphragm joints. This method is used to build numerical models of a four-story modular steel building in four bays. The results show that increasing the flexibility of the diaphragm leads to understory drifts that are significantly larger and the inertial forces that differ significantly from the values calculated using the equivalent lateral force method described in the current seismic codes [19]. Kolonga et al. assessed the diaphragm status of floor systems used in urban buildings. In this study, two variables (a) the ratio of the dimensions of the building plan and (b) the stiffness of the floor system, which are related to the potential flexibility of the diaphragm, were evaluated. Using refined meshes, all models were analyzed under uniformly distributed lateral loading with ANSYS finite element software. They concluded that a floor system designed following building codes and manufacturers' recommendations, in addition to the experience of reputable professional engineers, could lead to floor systems that reasonably behave like rigid diaphragms [20]. Senaldi et al. (2014) examined the effect of hardened floor and ceiling diaphragms on the experimental seismic response of a full-scale unarmed masonry building. The central part of the experimental program was devoted to shock table experiments on three full-scale two-story, one-room proto-type buildings made of uncovered two-leaf masonry. The first building tested represented unreinforced stone masonry structures with flexible wooden diaphragms, without any special anti-seismic design or details. In the second and third buildings, reinforcement interventions were simulated on structures that were theoretically similar to the first model, improved wall-to-floor and wall-to-ceiling connections, and increased diaphragm stiffness. Especially in the third example, steel and RC ring beams were used to improve the diaphragm connection to the walls and RC cooperation. Boards and plywood were used to tighten the floor and ceiling diaphragms. This paper describes the reinforcement interventions applied to the prototype of the third building. It presents the experimental results obtained during the shaking table experiments. The obtained results allow the calibration of a macro-element model that represents the non-linear behavior of the structure [21].

Bernas et al. conducted quasi-dynamic experiments on a full-scale three-story prefabricated concrete building to determine the behavior of mechanical joints and floor diaphragms. A full-scale prefabricated three-story building was tested under seismic conditions at the European Structural Assessment Laboratory under the SAFE-CAST project. 160 sensors were used for monitoring. Dry mechanical joints were applied to make connections between floor to floor, floor to beam, and wall to the structure. Intra-plate stiffness of three pre-coated diaphragms with or without diaphragm was assessed. In addition, two types of beam-to-column connections were experimentally investigated, namely beam-column hinged joints using dowel rods and beam-column joints simulated using innovative dry mechanical joints. Therefore, experimentally investigated the seismic behavior of floor diaphragms and pinned beam-column joints in a multi-story prefabricated building. The results showed that the new beam connection system to the proposed column is a suitable solution to increase the response of prefabricated RC frames under seismic loads, especially when the system is applied to all joints and qualitative measures are applied in its implementation [22]. Ashour et al., investigated the effect of floor-to-wall diaphragm coupling on the seismic performance of the system surface of an asymmetric rein-forced concrete block building. The analysis showed that the off-plane stiffness of the floor diaphragms plays an important role in the flexural coupling of Reinforced Masonry Shear Walls (RMSW) in the direction of loading with vertically aligned walls. This aspect at the system level affects not only the strength and displacement of different walls but also the arrangement of the failure mechanism and the torsion reaction of the building. For the studied building system, the diaphragm to wall connection led to the initial stiffness doubling in the building and a significant increase in the strength of the building. The results show that ignoring the effect of off-plane diaphragm pairing on RMSW at the system level may lead to non-conservative designs and possibly failure states at the level of undesirable components due to violation of capacity design principles [23]. Kim and White proposed a static linear method that can only be used for buildings with flexible diaphragms. This method is based on the assumption that the stiffness of the diaphragm is minor compared to the stiffness of the walls and flexible diaphragms in a building structure tend to respond independently of each other [24]. Jeong and Elnashai proposed a three-dimensional seismic assessment method for irregular plan buildings. Analysis showed that irregular plan structures suffer a lot of earthquake damage due to torsional effects. The analysis also showed that conventional injury monitoring approaches might be inaccurate or even non-conservative [25]. Therefore, this study investigated the effect of shear wall arrangement and placement on the stiffness of roof diaphragms. It also examines and compares rigid and non-rigid diaphragms and how analyzes and designs them to improve the overall performance of the structure against lateral loads. The irregularities in the plan are also considered for their role in different structure behavior against lateral load. Despite the importance of the issue, in most structures, little attention is paid to this issue in executive calculations. Considering that no significant research and studies have been done in this field so far, it is possible to draw the attention of analysts and engineers to this issue by conducting this research and emphasizing the importance of the issue, and highlighting the risks arising from its non-observance.

2. Research and modeling methods

2.1. Material specifications

This section introduces the models in detail and presents the loading and adjustments made for the design. The method is explained below. Then, having obtained the earthquake coefficients of all the models, we obtain the allowable displacement of the models according to the 2800 standard. The sections used in the design of the beams and columns are IPE and BOX types. Also, Table depicts the specifications of the consumed steel in the design. Where, f_y is specified yield strength; f_u, final yield strength; f_{ye}, expected yield stress; f_{ue}, final expected yield stress; E, modulus of elasticity and ν, Poisson's ratio. Specifications of concrete and rebar used: longitudinal rebars of type AIII with yield stress 400 N/mm^2 and final stress 600 N/mm^2; AII type transverse rebars with yield stress 340 N/mm^2 and final stress 500 N/mm^2 with modulus of elasticity 2.5×105 N/mm^2. The specified concrete strength was 225 N/mm^2.

Table 1. Specifications of consumed steel.

F_y	F_u	F_{ye}	F_{ue}	E	ν
2400	3700	2880	4440	2000000	0.3

2.2. Models under consideration

To conduct this research, 9 models of 4, 6, and 8 stories with a building frame system with a concrete shear wall were considered according to the standard criteria of 2800. The residential use of all models was assumed. The land of the construction site is located on type 3 soil in Sabzevar. First, it is loaded according to the sixth topic of the National Building Regulations (6th issue, 1398) and then analyzed and designed according to the criteria of the 2800 standard (Standard 2800, 1393) and the 10th topic of the National Building Regulations (10th topic, 1392) and using ETABS 2016.v1.0 software. The height of the floors in all models is 3.4 meters, and the use of structures for better comparison is the same in all models. Figures 2 and 3 depict the assumed general geometry for the structures, including the plan and three-dimensional view.

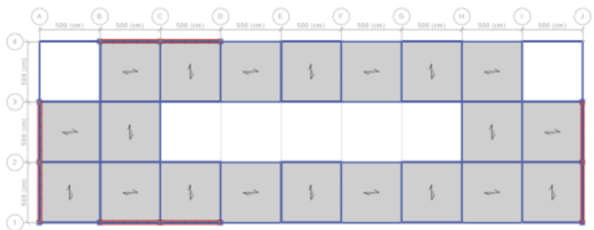

Fig 2. Studied structure plan.

2.3. Gravity loading and assumptions applied in the design

The weight loading of the models is done according to the sixth topic of the National Building Regulations (6th topic, 1398). Tables 2 and 3 depict the assumptions considered in the structures analysis and design (Standard 2800, 2014). These structures are designed by the ultimate strength method. It is assumed that the studied models are located in Sabzevar, and the soil of the construction site is assumed to be type 3. The acceleration ratio is the basis of the project for Sabzevar city with high relative risk.

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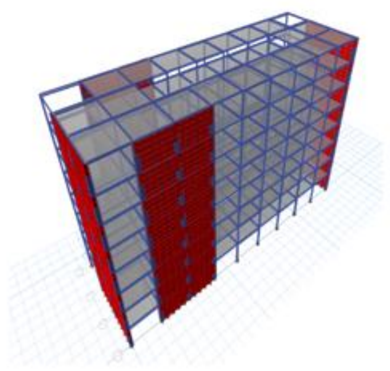

Fig 3. Studied structure three-dimensional.

Table 2. Intensity of gravity loads on the walls and floors.

Load Type	Load description	Load intensity	Unit
Dead	Roof	550	Kg/m^2
Dead	Stairs	650	Kg/m^2
Dead	Stories	500	Kg/m^2
Live	Stories	200	Kg/m^2
Live	Stairs	500	Kg/m^2
Live	Roofs	150	Kg/m^2
Dead	External walls load	700	Kg/m
Dead	Shelter load	300	Kg/m

Table 3. Assumptions considered in models liner analysis and design.

The basis acceleration ratio of the design (A)	Soil type	Structural significance coefficient (I)	Behavior factor (R)	Magnificent coefficient (Cd)	Excess resistance coefficient (Ω0)
0.3g	Type 3	1	5	4	2.5

3. Discussion and Analysis

In this section, drift diagrams and rigidity control of the samples studied in Section 2 are discussed following the instructions for seismic improvement and the realization of the objectives of Regulation 2800. According to the definition given in Standard 2800, if the $\frac{\Delta_{Displacement}}{\Delta_{story}}$ value is less than 0.5, the roof is rigid. If it is between 0.5 and 2, the ceiling is considered semi-rigid; however, the roof intends to be flexible when the value is higher than 2. The most critical Δ value is always examined in the presented models. The last roof in buildings is always subject to the most critical displacements. Therefore, the last floor delta is used to study and analyze rigidity. In this case, the center mass value or Δ_{story} equals to the displacement of the last ceiling minus the displacement of the lower ceiling of the last ceiling.

3.1. Shear wall arrangement in the four-story model floors plan and rigidity check

3.1.1. Four-story model floors arrangement

Figures 4 to 6 show the building plan and the shear wall location. The placement and thickness of the shear walls in Figures 5 and 6 have been changed compared to Figure 4 to investigate stiff-ness and drift changes in structure. Figure 5 examines the change in the structure drift rate by moving the shear wall and determines the roof diaphragm's rigidity or non-rigidity. The model in Figure 6 investigates the effect of thickening the shear wall on the mentioned cases. It should be noted that all connections are joint connections in all models pro-vided. The building openings are five meters each with the building length to width ratio of 3 based on the maximum allowable amount by regulation 2800.

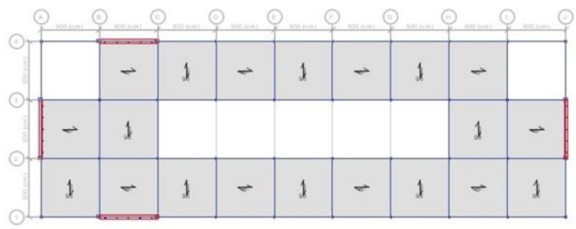

Fig 4. Four-story plan of model No. 1.

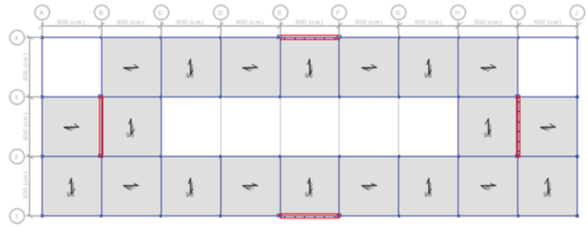

Fig 5. Four-story plan of model No. 2 with a change in the position of the shear walls.

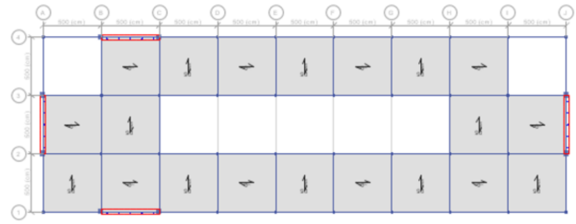

Fig 6. Four-story plan of model No. 3 with change in shear wall thickness.

3.1.2. Examine the drift diagrams and rigidity of four-story samples

Figure 7 shows a comparison diagram of the drifts of the three four-tier models. In this figure, the diagrams of model number 1 and model number 2 are matched, so the displacement of the shear wall from plan 3 to plan 4 does not affect the structure drift. However, in model number 3, it is seen that the increase in shear wall stiffness has the opposite effect on the structure drift rate. Less drift is achieved by the increased thickness and hardness of the shear wall. As a result, the structure of Model 3 has less ductility than the other two models, and this value in the diagram is approximately equal to 0.0005%. As shown in Figure 7, none of the models exceeded the allowable drift rate.

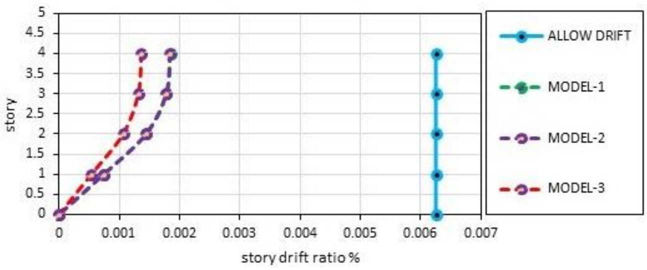

Fig 7. Four-story model drift comparison.

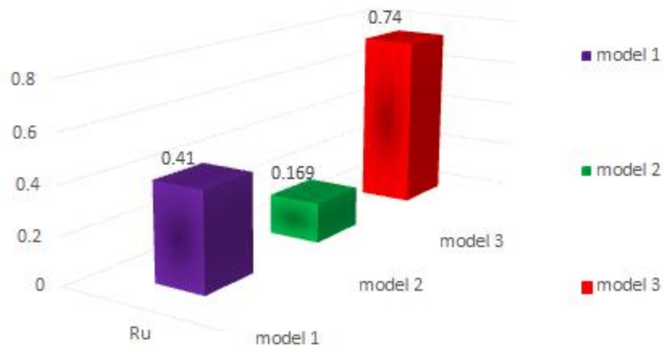

Fig 8. Four-story model roof stiffness comparison.

To examine the roof rigidity in the three four-story models, as shown in Figure 8, in model No.3, the rigidity is 0.41. The roof diaphragm of model No.1 is rigid but close to the semi-rigid limit. $\frac{\Delta_{Displacement}}{\Delta_{story}} \leq 0.5$ is a condition for the rigidity of structure. In model No. 2, it is observed that the amount of the structure rigidity has increased significantly by getting closer to the shear wall. This increase is about 24%.

The $\frac{\Delta_{Displacement}}{\Delta_{story}}$ value for the model No.3 was 0.74, which is more than the allowable rigidity value, which is 0.5. Therefore, by increasing the stiffness

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of the shear wall through increasing its thickness, the roof is no more rigid. In this part, it was observed that, contrary to expectations, the increase in stiffness of the diaphragm structure removes the roof from the rigid state. The rate of stiffness reduction in model No.3 compared to model No.1 is 33%.

3.2. Shear wall arrangement in the six-story model floors plan and rigidity check

3.2.1. Examine six- story samples drift diagrams and rigidity

Figure 12 shows a comparison diagram of the drifts of the three six-story models. In the diagram of Figure 12, as in Figure 7, although the diagrams of models No.1 and No.2 do not match; however, they are not much different from each other. Thus, it is clear that the displacement of the shear walls from Figure 9 to Figure 10 had little effect on the structure drift. In model No. 3, (Figure 11) it can be seen that increasing the shear wall stiffness has the opposite effect on the amount of drift in the structure so that less drift is obtained by adding a wall in the direction of the Y-axis on both sides of the structure and increasing the shear wall stiffness. As a result, the structure of model No. 3 has less ductility than the other two models. This value in the diagram is approximately equal to 0.0045%. Although none of the structures exceeded the allowable drift, in models No.1 and No.2, the drift value is close to the allowable value. It shows that the structure drift increases with increasing the number of building floors with a fixed shear wall arrangement.

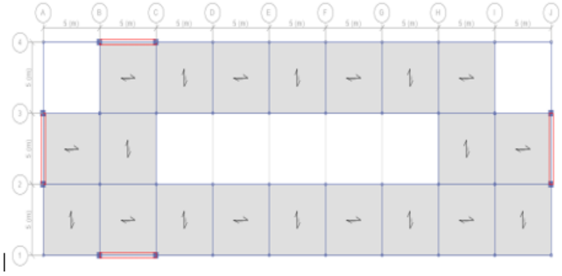

Fig 9. Six-story plan of model No.1.

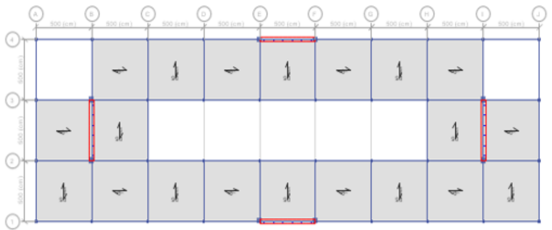

Fig 10. Six-story plan of model No. 2.

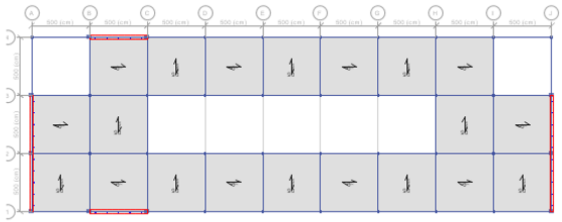

Fig 11. Six-story plan of model No. 3.

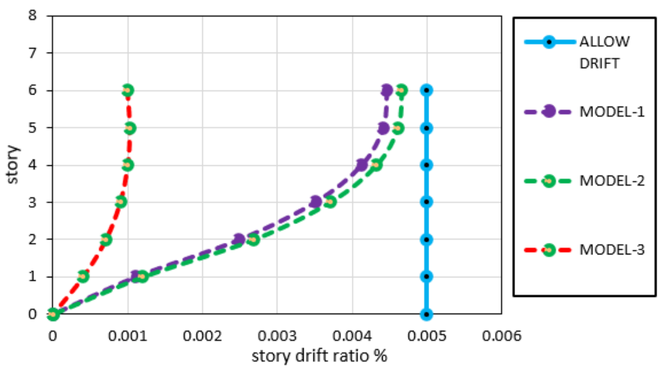

Fig 12. six-story drift comparison.

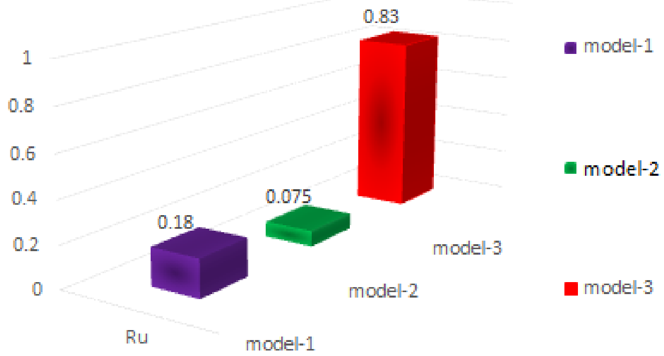

Fig 13. Six-story roof stiffness comparison.

To check the rigidity of the roof in three six-story models, as shown in Figure 13, in model No. 3, the rigidity is 0.4. The roof diaphragm of model No. 1 is rigid, but it is close to the semi-rigid limit. $\frac{\Delta \text{ Displacement}}{\Delta_{\text{story}}}$ is a condition for the structure to be rigid. In model No.2, it is observed that the amount of structure rigidity has increased significantly by getting closer to the shear wall. This increase is about 35%.

By obtaining the value of $\frac{\Delta \text{ Displacement}}{\Delta_{\text{story}}}$ for model No. 3, it is observed that the value of 0.52 is obtained for it, which is more than the allowable value of rigidity. So, the roof is placed in a semi-rigid position. Therefore, it can be seen again that increasing the shear wall stiffness through increased the roof thick-ness has taken it out of rigidity. The rate of stiffness reduction in model No. 3 compared to the model No. 1 is 12 percent.

3.3. Shear wall arrangement in the eight-story model floors plan and rigidity check

3.3.1. Eight-story model shear wall

Figures 14 to 16 show the plan of the building and the location of the shear wall. In Section 3-2, we observed that with increasing the floors height, the structure drift increased and approached the allowable value. To prevent the drift from rising above the allowable value, the position of the shear wall had to be changed to increase the structure rigidity. In the model No.2, many changes have been made compared to model No.1, such as get-ting closer and increasing the number of these shear walls. However, in eight-story model No. 3, the plan is the same as the model No.1, with merely in-creased the thickness and consequently the stiffness of the shear. This stiffness increase will affect the structure roof drift and rigidity.

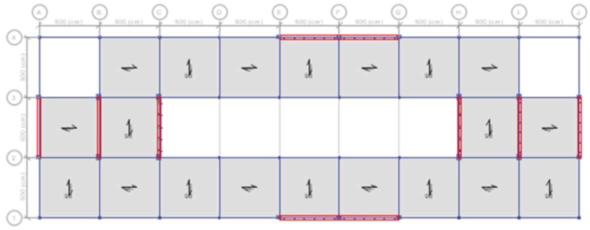

Fig 14. Eight-story plan of model No. 1.

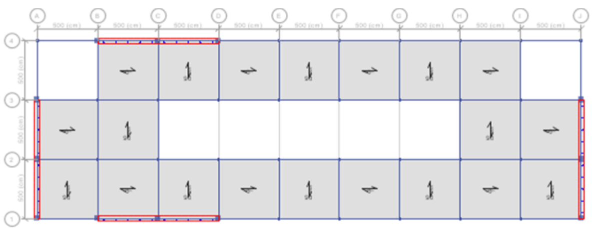

Fig 15. Eight-story plan of model No. 2.

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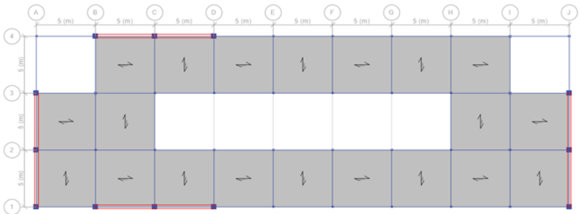

Fig 16. Eight-story plan of model No. 3.

3.3.2. Examine eight- story samples drift diagrams and rigidity

Figure 17 shows a comparison diagram of the drifts of the three eight-story models. According to the diagram, it can be seen that different values of drift were obtained for the three samples. In samples 1 and 2, a change of about 0.0015 in the amount of drift is observed, which indicates the effect of shear wall displacement and increased structural stiffness. In model No. 3, it can be seen that increasing the shear wall stiffness has the opposite effect on the structure drift, so that less drift is obtained by adding the thickness of the shear wall and increasing the shear wall stiffness. As a result, the structure of model No.3 has less ductility than the other two models. This value in the diagram is approximately equal to 0.0004%. Although none of the structures exceeded the allowable drift, in model No. 2 the drift value is closer to the allow-able value.

To check the roof stiffness in three eight-story models, as shown in Figure 18, in first model No. 1, the rigidity is 0.4. The roof diaphragm of model No. 1 is rigid, but it is close to the semi-rigid limit. $\frac{\Delta_{\text{Displacement}}}{\Delta_{\text{story}}} \leq 0.5$ is a condition for the structure to be rigid. In model No.2, the amount of structure rigidity has increased significantly by getting closer to the shear wall. This increase is about 35%.

Obtaining the value of $\frac{\Delta_{\text{Displacement}}}{\Delta_{\text{story}}}$ for model No. 3 is 0.52, which is more than the allowable value of rigidity, i.e. 0.5. So the roof is placed in a semi-rigid position. Therefore, it can be seen again that increasing the shear wall stiffness through increased the roof thickness has taken it out of rigidity. The rate of stiffness reduction in model No. 3 compared to the model No. 1 is 12 percent.

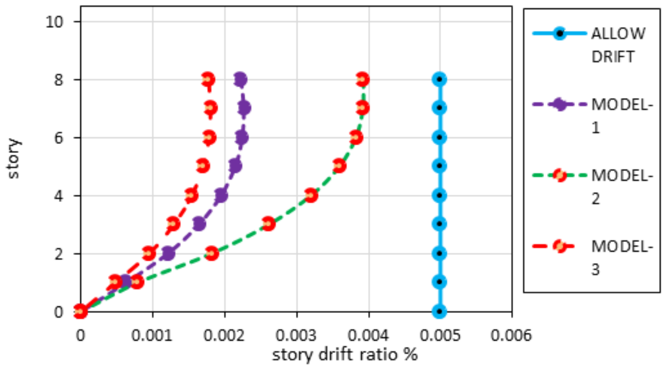

Fig 17. Eight- story drift comparison.

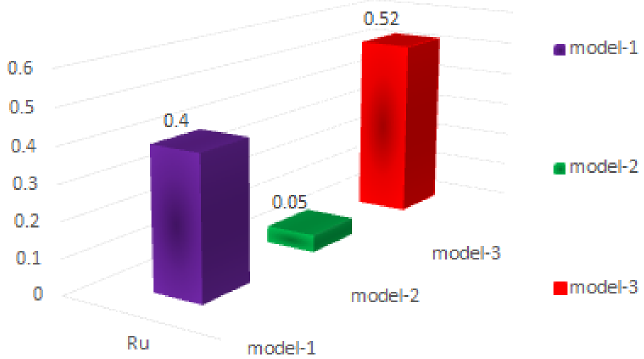

Fig 18. Eight-story roof stiffness comparison.

4. Conclusions

This paper examined the syntactic effect of shear wall arrangement on the roof diaphragms' stiffness of a residential building in Sabzevar. Accordingly, the stiffness of 9 samples of residential buildings was compared. The results based on the initial assumptions and research conditions are presented in the following:

1. With the increase of the height of the buildings from four floors to eight floors, the drift of the structures was more than the allowed amount; this was prevented by increasing the number of openings in which the shear wall is executed.

2. In the structures whose shear wall stiffness in-creased either by increasing the thickness or by adding the shear wall, the stiffness of the roof diaphragm of the structure decreased. Practically the roof diaphragm was changed from rigid to semi-rigid. Contrary to expectations, this increase in stiffness in the shear wall is not in favor of the structure.

3. In structures in which the stiffness of the shear walls increased, the drift rate of the structure decreased significantly.

5. Suggestions

This section offers suggestions for future research:

1. The connections of all the models discussed in this research were of the joint type; the gripped connections can be used for the future research of the models.
2. Controlling the effect of shear wall stiffness in high torsion structures requires spectral analysis.

Conflict of interest

There is not conflict of interest.

References

[1] Pramod, J.A., Karale, S.A., and Ansari, U.S. (2017). Analysis of Floor Diaphragm in Multi–Storied Reinforced Concrete Building. *International Advanced Research Journal in Science, Engineering and Technology*, 4(3), 126-131. https://doi.org/10.17148/IARJSET.2017.4324

[2] MacLeod, I.A. (1971). Shear wall-frame interaction: A design aid. Portland cement Association.

[3] Wilson, E.L., Hollings, J.P., and Dovey, H.H. (1979). Three Dimensional Analysis of Building Systems. *National Information Service for Earthquake Engineering*.

[4] Mutō, K. (1974). Aseismic design analysis of buildings. Maruzen.

[5] Jain, S.K. (1984). Seismic response of buildings with flexible floors. *Journal of Engineering Mechanics*, 110(1), 125-129. https://doi.org/10.1061/(ASCE)0733-9399(1984)110:1(125)

[6] Ju, S.H., and Lin, M.C. (1999). Comparison of building analyses assuming rigid or flexible floors. *Journal of Structural Engineering*, 125(1), 25-31. https://doi.org/10.1061/(ASCE)0733-9445(1999)125:1(25)

[7] Hadianfard, M.A., and Sedaghat, S. (2013). Investigation of joist floor diaphragm flexibility on inelastic behavior of steel braced structures. *Scientia Iranica*, 20(3), 445-453. https://doi.org/10.1016/j.scient.2012.11.016

[8] Saffarini, H.S., and Qudaimat, M.M. (1992). In-plane floor deformations in RC structures. *Journal of Structural Engineering*, 118(11), 3089-3102. https://doi.org/10.1061/(ASCE)0733-9445(1992)118:11(3089)

[9] Ju, S.H. (2000). Closure to "Comparisons of Building Analyses Assuming Rigid or Flexible Floors" by SH Ju. *Journal of Structural Engineering*, 126(2), 272-274. https://doi.org/10.1061/(ASCE)0733-9445(2000)126:2(272)

Please cite this article as: Khajooei, M.S. (2024). Investigate the effect of concrete shear wall arrangement on the roof diaphragms stiffness and floor shear transfer in steel buildings. Journal of Civil Engineering and Structures, 8(1), pp.15-21

[10] Tena-Colunga, A., and Abrams, D.P. (1996). Seismic behavior of structures with flexible diaphragms. *Journal of Structural Engineering*, 122(4), 439-445.
https://doi.org/10.1061/(ASCE)0733-9445(1996)122:4(439)

[11] Rodriguez, M.E., Restrepo, J.I., and Carr, A.J. (2002). Earthquake-induced floor horizontal accelerations in buildings. *Earthquake Engineering & Structural Dynamics,* 31(3), 693-718.
https://doi.org/10.1002/eqe.149

[12] Fleischman, R., Farrow, K.T., and Eastman, K. (2002). Seismic performance of perimeter lateral-system structures with highly flexible diaphragms. *Earthquake Spectra*, 18(2), 251-286.
https://doi.org/10.1193/1.1490547

[13] Fleischman, R., and Farrow, K.T. (2001). Dynamic behavior of perimeter lateral-system structures with flexible diaphragms. *Earthquake Engineering & Structural Dynamics*, 30(5), 745-763.
https://doi.org/10.1002/eqe.36

[14] Basu, D., and Jain, S.K. (2004). Seismic analysis of asymmetric buildings with flexible floor diaphragms. *Journal of Structural Engineering*, 130(8), 1169-1176.
https://doi.org/10.1061/(ASCE)0733-9445(2004)130:8(1169)

[15] Rogers, C.A., and Tremblay, R. (2010). Impact of diaphragm behavior on the seismic design of low-rise steel buildings. *Engineering Journal*, 47(1), 21-36.
https://doi.org/10.62913/engj.v47i1.974

[16] Tremblay, R., et al. (2008). Dynamic seismic testing of large size steel deck diaphragm for low-rise building applications. In *14th World Conference on Earthquake Engineering*.

[17] Zaregarizi, S. (2008). Comparative investigation on using shear wall and infill to improve seismic performance of existing buildings. In *14th World Conference on Earthquake Engineering*.

[18] Eivani, H., Moghadam, A.S., Aziminejad, A., and Nekooei, M. (2018). Seismic response of plan-asymmetric structures with diaphragm flexibility. *Shock and Vibration*, 1-18.
https://doi.org/10.1155/2018/4149212

[19] Srisangeerthanan, S., Hashemi, M.J., Rajeev, P., Gad, E., and Fernando, S. (2018). Numerical study on the effects of diaphragm stiffness and strength on the seismic response of multi-story modular buildings. *Engineering Structures*, 163, 25-37.
https://doi.org/10.1016/j.engstruct.2018.02.048

[20] Tena-Colunga, A., Chinchilla-Portillo, K.L., and Juárez-Luna, G. (2015). Assessment of the diaphragm condition for floor systems used in urban buildings. *Engineering Structures*, 93, 70-84.
https://doi.org/10.1016/j.engstruct.2015.03.025

[21] Senaldi, I., Magenes, G., Penna, A., Galasco, A., and Rota, M. (2014). The effect of stiffened floor and roof diaphragms on the experimental seismic response of a full-scale unreinforced stone masonry building. *Journal of Earthquake Engineering*, 18(3), 407-443.
https://doi.org/10.1080/13632469.2013.876946

[22] Bournas, D.A., Negro, P., and Molina, F.J. (2013). Pseudo dynamic tests on a full-scale 3-storey precast concrete building: Behavior of the mechanical connections and floor diaphragms. *Engineering structures*, 57, 609-627.
https://doi.org/10.1016/j.engstruct.2013.05.046

[23] Aly, N.E. (2019). Seismic Performance and Building Height Limits of Ductile Reinforced Concrete Masonry Shear Walls with Boundary Elements, Concordia University.

[24] Kim, S.C., and White, D.W. (2004). Linear static analysis of low-rise buildings with flexible diaphragms using the structural separation method. *Engineering Structures,* 26(1), 83-93.
https://doi.org/10.1016/j.engstruct.2003.08.013

[25] Jeong, S.H., and Elnashai, A.S. (2004). Analytical and experimental seismic assessment of irregular RC buildings. *In Proceedings of 13th World Conference on Earthquake Engineering*.

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