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# Investigating the Effect of Opening on Seismic Behavior of Combined System of RC Frame with Panel Sandwich Infill

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**Abstract**

Growing use of pre-cast concrete sandwich panels in the construction industry as infill has gained popularity due to better integration compared with the masonry infill against forces as well as their light weight and ease of use, which at the same evaluation of their seismic behavior have become more important. However, because of necessity of opening in the infill and change in behavior and interaction among the frame and panel sandwich with the opening effect further precise studies are required. Accordingly, the present study aims to do a non-linear dynamic analysis on the opening effect with conventional geometrical shapes on the seismic behavior of the combined system with different floors under seismic records. After verifying by the Abaqus software, the combined system with opening was investigated. The results indicated that by full infill in frames, the rectangular opening of infill has a remarkable impact on reduced stiffness and shear potential particularly in the short combined structure and in the first floor compared with the circular opening. Moreover, the reinforcement effect in different openings of infill is discussed.

**Keyword:** sandwich panel, opening shape, infill, combined structure, seismic behavior, dynamic analysis.

## INTRODUCTION

The 3D precast panels can be used in concrete and metal constructs as a lateral porter system against earthquakes. However, the use of sandwich panel infill in frames without considering them in the process of designing and connections and openings will change the failure mechanism and generally the construct behavior against earthquake. Therefore, knowing about interaction of this combined system with opening effects seems necessary. In the recent years, the studies on 3D panel walls as an infill in building frames have been increased. Kabir et al worked on the seismic behavior of 3D panel walls in different sizes inside laboratory under monotonic shear loads. The results indicated that through increased height of the panel wall the energy dissipation rate will also increase.

Furthermore, the shear and flexural behavior border of the panel sandwich wall compared with the shear wall decreases [1]. Also, studies on complete building of panel sandwich with experimental tests on shaking table over a one floor and four floor construct by Kabir et al as well as a three floor building with Polystyrene sinusoidal by Palermo et al under dynamic loads were presented. The results showed increased resistance and dissipation energy in non-linear state for high earthquake movements was shown. The construct responses included natural frequency of the system, shear capacity, ductility, and failure mechanisms of structures were examined [2-4].

Rezaifar et al investigated the dynamic behavior of combined structures of R.C Frame and 3D panel wall in a 2D state of different floors and spans in linear and non – linear forms. The findings indicate that due to complicated behavior of the system, it is required to do a non-linear-dynamic analysis. Also, the natural Period of the combined structure with complete coverage of filler significantly decreased and $\alpha$=.008. In order to prevent from creation of the soft first floor and an equal stiffness in the ground floor, 57% of whole lateral spaces coverage of the ground floor by the panel filler was resulted [5].

Yaw-jengchiou et al studied seismic behavior of pre-cast walls in concrete frame in several laboratory samples with such parameters as steel reinforcement of panel, percentage of steel and concrete resistance. It was identified that through modification of panel network and distribution of reinforcement in wall corners the rate of energy dissipation and final displacement of the system increases [6].

Kabir et al worked on some species of 3D panel wall surrounded in RC frame under the cyclic loading. It was recognized that reinforcement steel around the wall panels that have shear behavior which are effective on increased capacity of combined loading system [7].

About masonry infill, Pujol and Fick worked on vulnerability of masonry infill in the RC frame consisting three floors in a laboratory measure. the findings indicated that in no infill state , punching shear failure will occur in the incorporations and consisted of fully panels in addition to change in the failure mechanism causes increased resistance and prediction of drift approximately 1.5% [8].

Tasnimi and Mohebkhah examined the impact of masonry infill having opening on seismic behavior of steel frames and the findings suggested that the rate of total absorbed energy in the infill is similar to the masonry infill with different sizes of opening and formation of these combined systems having opening depends on failure mode in piers [9].

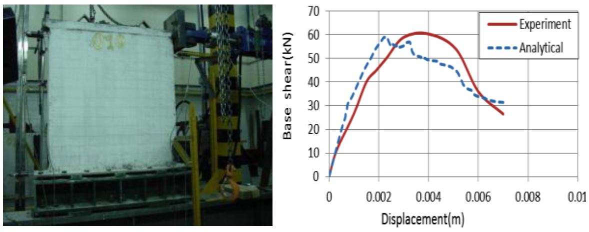
# MATERIALS AND METHODS

**Characteristics of materials and validation of modeling**

Prior to modeling the selected samples in order to check the characteristics of elements as well as features of the materials, two experimental and analytical tests were used.

**3D panel walls**

Small sample of 3D panel wall (120×124) was tested under the lateral loads [1] was modeled in Abaqus and under static analysis; the load-deflection curve was compared with the laboratory sample. As Figure(1)shows, the curve in both laboratory and analytical states has an acceptable consistency. Variance in the ascending parts could be because of lack of presenting complete characteristics of the stress-strain in laboratory shotcrete. For unknown variables, logical assumptions are considered according to the stress-strain curve of the concrete.




(b) (a)

**Figure 1**.a- diagram of shear –displacement for 3D panel wall resulted from finite element analysis and the test [1]
b- Location of the 3D panel wall samples and the loading system in laboratory [1]

***Properties of Shotcrete***

In modeling process of this 3D panel wall for the shotcrete characteristics in software, the Concrete Damaged plasticity method was used. the most important feature of this model is considering two failure mechanism in form of cracking caused by tension and crushing resulted by compression in concrete materials and the shotcrete element is modeled with 3D Solid elements(C3D8R).

***Wire Meshes (WWF)***

The physical characteristics of the welded wire meshes consists of WWF80/80/ ϕ3.5/ϕ3.5 and for introduction of characteristic of this material in the software, the Elastoplastic multi-linear isotropic model will be used as a failure criterion for the selected element of T3D2.

The WWF behavior is used based on the tensile strength tests have been performed on some samples in experimental studies in 2003 and the strain-stress curve is provided [1].

Other mechanical characteristics of materials in the present study are listed in Table 1.

**Combined system model**

To verify a combined frame-panel system with full details of panel in actual size, the combined system F2S2-003 which in 2004 was modeled in a numerical study was applied. The details of panel infill with micro modeling and with the same elements of sample panel wall in 3D form were molded in the Abaqus software. Under the record of NAGHAN with specific scaling factor in the base article [5] was used.

***Characteristics and modeling of frames***

For physical characteristics of the frame according to properties of the research article in 2004[5], beams and columns cross sections were determined in 30×30 size and ratio of steel reinforcement in all section of 2.5%. The selected element of beam and column in frames is the solid element type C3D8R was used.

***Frame interaction and 3D panel wall***

It is assumed that infill is connected to the frame and has no space, which participate in lateral stiffness. For frame interaction with infill the connection reinforcement ϕ8 in 450 mm length are used. Since reinforcements function according to the selected element is important, thus the element type of such connections due to the shear behavior and transition of shear forces among frame-panel, the Beam 31 is used.

**Table 1.** Mechanical characteristics of 3D Panel materials

| Compression strength<br>$kN/m^2$ | Tensile strength<br>$kN/m^2$ | Young Modulus<br>$kN/m^2$ | .Sp Gravity<br>$kN/m^3$ | Poisson-ratio | Material |
|---|---|---|---|---|---|
| _ | _ | 2.06E+08 | 78.5 | 0.28 | steel |
| 16E+03 | 2.4E+03 | 1.5E+07 | 22 | 0.15 | shotcrete |

**Table 2.**Mechanical characteristics of frame

| Compression strength<br>kN/m2 | Tensile strength<br>kN/m2 | Yield stress<br>kN/m2 | Young Modulus<br>kN/m2 | .Sp Gravity<br>kN/m3 | Poisson-ratio | Material |
|---|---|---|---|---|---|---|
| 30E+03 | 3E+03 | - | 2.4E+07 | 24 | 0.2 | concrete |
| - | - | 3.70E+05 | 2.1E+08 | 78.55 | 0.3 | steel |

The hysteresis curve and the results of comparison of both combined system where the 3D panel was utilized in the second floor only are shown in Figure2 and Table 3. This indicates a similar behavior of both samples. However, the existing disparity could be because of interaction of frame and infill in the 3D model.

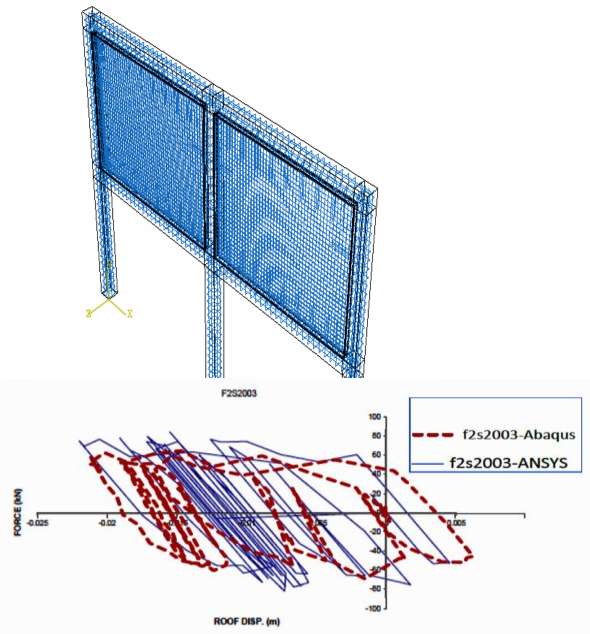



**Figure2.**a) Comparison of the hysteresis curve of load-displacement under acceleration b) Modeled sample according to the reference [5]

**Table 3.** Comparing the results of the combined system

| Models compare of | Base shear (kN) | Max Disp. (m) | Pick (m) Disp. |
|---|---|---|---|
| [5] reference | 74.96 | 0.0240 | 0.0189 |
| Analysis with Abaqus | 68.10 | 0.0215 | 0.0149 |
| Variance (%) | 9.1 | 10.4 | 21 |

**Introduction of models and procedure**

In the present study, samples of the 3Dsandwich panels having openings were modeled in the RC Frame. These samples consisted of a two-story and two-span frame (F2S2) and three-story and two-span frame (F3S2) with panel coverage in above floors except for the first floor of pilot (softstory in ground floor) as well as full panel infill through making rectangular and circular openings. Table 4 illustrates characteristics of all modeled samples.

To compare the results in all samples the position of opening in both rectangular and circular modes equally and for 25% of the infill level was selected. According to the details of opening effect in infill and precise determination of absorbed forced, besides 32kN mass is allocated to beams of each span according to [5]. The infill and frame mass were also included in the dynamic analysis. Table 5 and 6 illustrates modeled samples in the present study.

**Table 5.** Two-story and two-span models

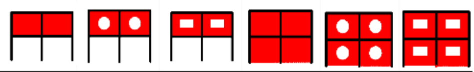
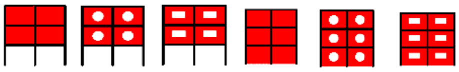
| Name of Models | FP1 | FP1-CIR | FP1-REC | FP2 | FP2-CIR | FP2-REC |
|---|---|---|---|---|---|---|
| F2S2 |  | | | | | |

**Table 4.** Properties of models

| Type of frame | Combined samples name | frame: Total height *Total Width (m) | frame: Steel ratio (%) | frame: Cross section (m×m) | Panel wall: Height * width(m) | Panel wall: Diagonal (m) | Panel wall: Network spring dimension (m) | Openings shape |
|---|---|---|---|---|---|---|---|---|
| F2S2 | FP1 | 6×8 | 2.5 | 0.3×0.3 | 3.7×2.7 | 0.0035 | 0.08 | * |
| | FP1-REC | 6×8 | 2.5 | 0.3×0.3 | 3.7×2.7 | 0.0035 | 0.08 | rectangular |
| | FP1-CIR | 6×8 | 2.5 | 0.3×0.3 | 3.7×2.7 | 0.0035 | 0.08 | circular |
| | FP2 | 6×8 | 2.5 | 0.3×0.3 | 3.7×2.7 | 0.0035 | 0.08 | * |
| | FP2-REC | 6×8 | 2.5 | 0.3×0.3 | 3.7×2.7 | 0.0035 | 0.08 | rectangular |
| | FP2-CIR | 6×8 | 2.5 | 0.3×0.3 | 3.7×2.7 | 0.0035 | 0.08 | circular |
| F3S2 | FP3 | 9×8 | 2.5 | 0.3×0.3 | 3.7×2.7 | 0.0035 | 0.08 | * |
| | FP3-REC | 9×8 | 2.5 | 0.3×0.3 | 3.7×2.7 | 0.0035 | 0.08 | rectangular |
| | FP3-CIR | 9×8 | 2.5 | 0.3×0.3 | 3.7×2.7 | 0.0035 | 0.08 | circular |
| | FP4 | 9×8 | 2.5 | 0.3×0.3 | 3.7×2.7 | 0.0035 | 0.08 | * |
| | FP4-REC | 9×8 | 2.5 | 0.3×0.3 | 3.7×2.7 | 0.0035 | 0.08 | rectangular |
| | FP4-CIR | 9×8 | 2.5 | 0.3×0.3 | 3.7×2.7 | 0.0035 | 0.08 | circular |

**Table 6.** Three-story and two-span models

| Name of Models | FP3 | FP3-CIR | FP3-REC | FP4 | FP4-CIR | FP4-REC |
|---|---|---|---|---|---|---|
| F3S2 | | | | | | |



**Non-linear dynamic analysis of constructs with opening effect**

In order to examine the seismic behavior and interaction of panel infill having opening in RC frame in 3D mode and making a precise analysis of the effects openings in combined structures in Table (4), using a non-linear dynamic analysis through the Abaqus software seems necessary.

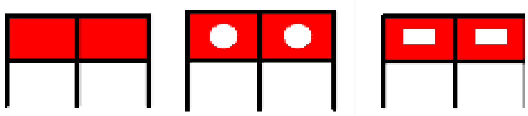
To compare the results of the samples with and without opening effect in the present study, all parameters and properties of materials are kept constant and the structures responses and behaviors were compared and analyzed. also, the imposed acceleration over all structures , the acceleration factor x of NAGHAN earthquake with time step 0.005 per second with the maximum intensity at 0.5g as the natural earthquake was selected, within which the structure response and behavior was occurred in the initial 10 seconds under this record.

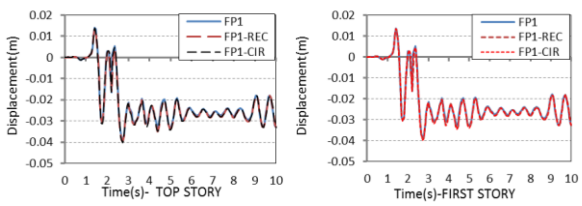
**The effect of openings on displacement responses of combined structure**

***The effect of combined structures with the first floor of pilot***

Like models without opening in the first floor, samples having 25% infill opening with the first floor of pilot in incorporation of beams showed the highest concentration of stress and in the first floor still the soft floor is dominant and it behaves the same a one degree freedom structure .

Example 1: the effect of rectangular and circular opening on the first floor pilot






(a) (b)

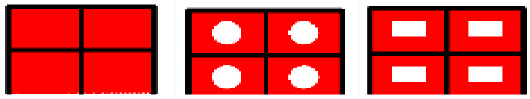
**Figure 3.**Comparing displacement changes curve in terms of time for FP1, FP1-REC and FP1-CIR a) Top story b) First story

For instance, in Figure3 the displacement responses of roof level and first of structures without opening (FP1) as well as the samples FP1-REC and FP1-CIR with rectangular and circular opening are shown. The discrepancy of displacement among floors in the samples with 25% opening effect is very insignificant like the sample without opening and displacement of the above floor depends on the first soft story and the highest rate of displacement in top story level and the first story of the samples are 39, 41, 41 mm respectively.

**The effect of opening on displacement of combined structure with full infill**

In these types of combined structures the effect of opening causes increased displacement in different stores and creates residual plastic deformations in the combined structure. But, the effect of opening on the first floor is more significant in increasing deformation compared with the higher floors especially in rectangular opening.

Example 2: The effect of rectangular and circular opening with full infill coverage



For instance, in Figure (4) the responses to displacement of the first floor for FP2-CIR, FP2-REC and, FP2 are provided. In the combined structure of FP2, as it is clear after increased intensity of earthquake at 1.5 -2.5 seconds, the structure shows a non-elastic behavior. After decreased ground motions, the structure turns around the zero axis .but after establishment of rectangular and circular opening in the combined structure, there is a reduced stiffness of panels and increased displacement of the floors. Based on geometrical forms of the openings, the transformations vary in the record.

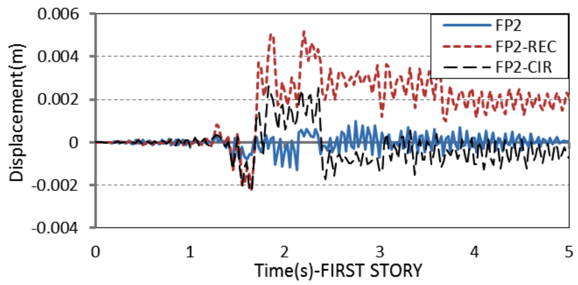



**Figure 4.** The displacement curve in terms of time for FP2, FP2-REC and FP2-CIR samples in the first story

The results of the maximum displacement of floors in the combined structures with full infill coverage of the FP2 and FP4 samples with the impact of rectangular and circular opening are shown in Figure (5) and (6). Increased displacement in the rectangular opening is greater in the first story than in the circular opening.

It can be mentioned here that this increased displacement is resulted because of Concentration of stress incorner openings and creation of plastic points incorner opening of the first and second stories. But, in the first story increasing cracking and yielding wire meshes incorner opening infill are effective on increased displacement and destruction of infill.

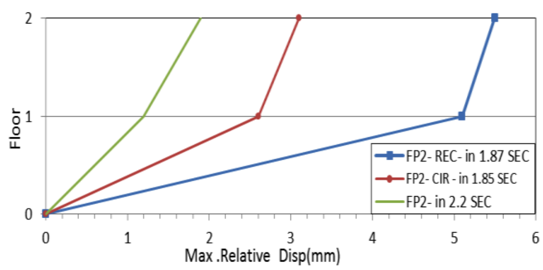



**Figure 5.**Comparing displacement of combined structures stories FP2-CIR, FP2-REC, FP2

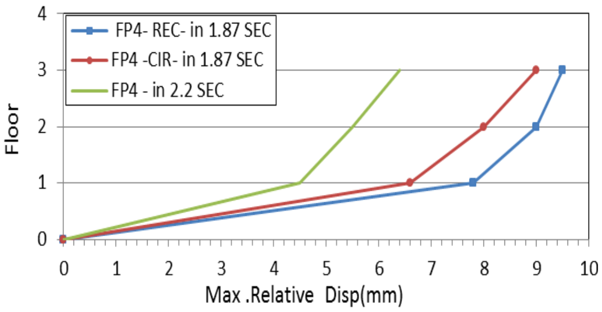


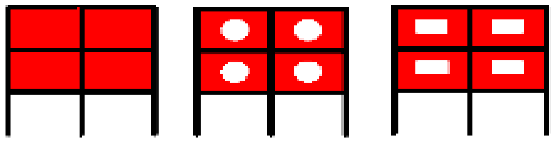

**Figure 6.** Comparing displacement of combined structure floors of FP4, FP4-REC, FP4-CIR

**The effect of opening on behavior and the hysteresis curve of combined structures**

***The effect of opening on combined structure behavior with the first soft floor***

Comparing the behavior of two and three story combined structures with the first soft story without opening and with the effect of opening indicated that the area under the curve is similar.

Example 3: Three stories and two span combined structure behavior with Pilot



For instance in Figure (7), the hysteresis curves of force-displacement of three FP3-CIR, FP3-REC and FP3 samples are shown under the consistent record of NAGHAN. In the structures having opening, concentration of stress and absorbed forces in the first story level in corners and the beams connections are influential in increase of cracking and the structure mechanism.

In fact the main concentration of stress and plastic points is not around the opening, but they are in the first soft store of beam and column conjunction near to critical regions on the beams. However, with the rectangular and circular openings the shear potential will decrease up to a bit smaller than 19276 kg in the FP3 sample to 18615 and 19185 kg in the FP3-REC and FP3-CIR samples respectively.

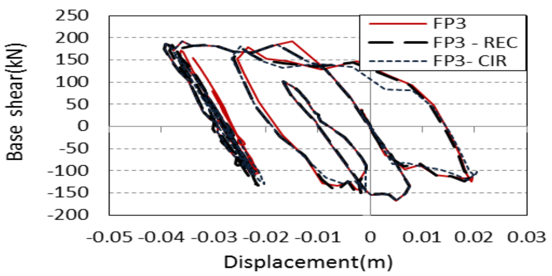



**Figure 7.** Hysteresis curves of force- displacement of combined structures (FP3 ‹FP3-REC‹and FP3-CIR)

***The effect of opening on behavior of combined structures with the full infill coverage***

Examining the hysteresis curve of combined structures of FP2, FP2-REC and FP2-CIR, as Figure (8) shows, increases the rate of energy dissipation in the models. The value of decreased of base shear and increased displacement in the FP2-REC sample is considerably higher than the FP2-CIR. So, this indicates that the performance of circular opening is better than the rectangular opening.

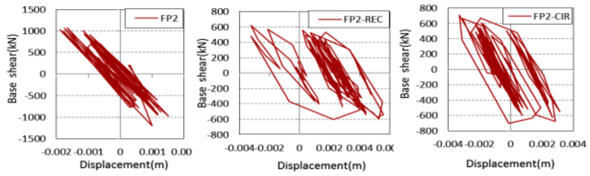
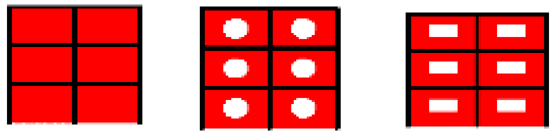



**Figure 8.** Hysteresis curves of force - displacement of structure basis of FP3 ‹FP3-REC‹and FP3-CIR

Example (4): Three stories and two span combined structure behavior with full coverage



In Figure (9) the three stories and two span hysteresis curve of the samples without opening and the samples with rectangular and circular opening (FP4, FP4-CIR and FP4-REC) are illustrated. As it is clear, under the acceleration of NAGHAN after some initial earthquake cycles, the samples experienced residual plastic deformation and there could be seen inappropriate behavior of the combined system especially with the rectangular opening.

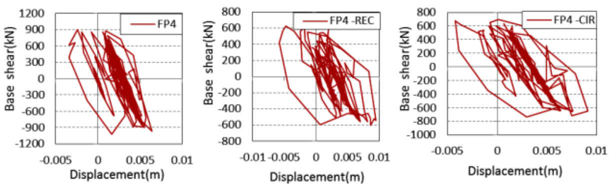



**Figure 9.** Hysteresiscurves of force - displacement of structure basis of FP4 ‹FP4-REC‹and FP4-CIR

Comparing the effect of the opening results in the combined system of two and three story in the FP4 and FP2 samples presented in Table (7) and (8) , it can be observed that the impact of opening in the two-story combined system is greater particularly in the first floor than three-story combined structure.

**Table 7.** The results of shear and displacement of the FP2 combined structure with the opening effect

| Sample | FP2 | FP2-CIR | FP2-REC |
|---|---|---|---|
| base shear (kN) | 1067 | 707.4 | 619 |
| maximum top story (m) displacement | 0.0019 | 0.0033 | 0.0055 |
| percentage of reduced base shear(%) | - | 34 | 42 |
| percentage of top story increased displacement (%) | - | 74 | 189 |
| Percentage of increased displacement of first story (%) | - | 116 | 325 |

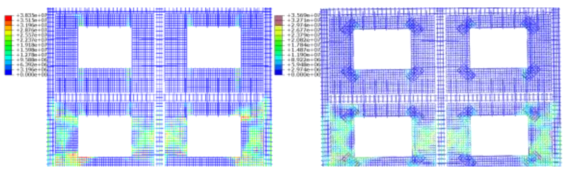
**Table 8.** The results of shear and displacement of the FP4 combined structure and with the opening effect

| Sample | FP4 | FP4-CIR | FP4-REC |
|---|---|---|---|
| Base shear (kN) | 906 | 694.4 | 629.81 |
| Maximum top story (m) displacement | 0.0064 | 0.009 | 0.0095 |
| Maximum displacement of (m) first story | 0.0046 | 0.0066 | 0.0078 |
| Percentage of reduced base shear (%) | - | 23 | 30 |
| Percentage of increased top story displacement (%) | - | 40 | 48 |
| Percentage of increased displacement of first story (%) | - | 43 | 70 |

**The effect of reinforcement around opening on the combined structure**

In this section, the effect of reinforcement around rectangular and circular opening of infill in the frame-panel combined systems in the FP2-REC and FP2-CIR samples were compared and evaluated with each other. The infill opening surroundings was reinforced by the butterfly mesh network in the opening corners and in the place of diagonal cracks in size of 600× 320mm.

Furthermore, the centralized steel reinforcement in form of 2ϕ10 was used for replacing disconnected meshes in both sides of the opening and in each layer of concrete equal to disconnected meshes of panel for reinforcement. In Figure (10), the mesh stress counter at time of 3.75 SEC is shown in the FP2-REC sample. The maximum stress in corner of the opening in the first floor is reduced with the reinforcement effect of 384Mpato 356Mpa, which result in approximately 7.3% reduced stress in the networks around the first-floor opening.

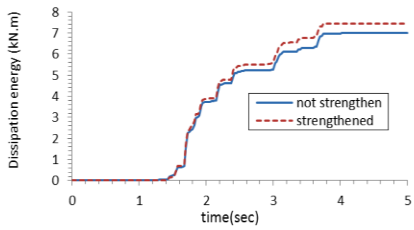


(a) (b)

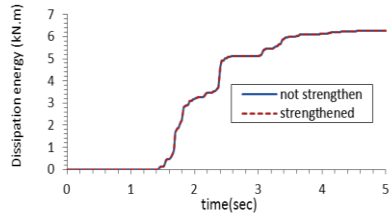
**Figure 10.** The mesh stress counter in the combined structure of FP2-REC with and without the reinforcement effect a) Without reinforcement b) With the reinforcement effect

The results indicate that the effect of reinforcement on the rectangular and circular opening of the samples FP2-REC and FP2-CIR to some extent decreases the maximum displacement. The reduced displacement in the first floor is 13.8% and 11.5% respectively.

In Figure (11) the dissipated plastic energy in the combined structures of FP2-REC and FP2-CIR are shown in two reinforced and unreinforced modes. This indicates that the reinforcement effect too much extent has increased the dissipated energy in the FP2-REC model with the rectangular opening. However, reinforcement of circular opening in the FP2-CIR sample has no effect on dissipated energy of the structure.




(a)




(b)

**Figure 11.** Energy dissipation in the combined structure FP2-CIR, FP2-REC with reinforcement effect a) FP2-REC b) FP2-CIR

# RESULTS AND DISCUSSION

In the present study the effect of openings and their reinforcement on the seismic behavior of the combined system of frame-panel through imposing the opening impact with equal area and different rectangular and circular shapes were examined. Considering the seismic behavior of the combined system with RC frame and in different floors, the following results were obtained.

(A) Imposing openings with 25% of infill level in upstairs of the combined structures with the first story pilot suggest that with such level of opening, the system behavior is in much extent similar to the one degree of freedom structure system and along with absorption of abundance energy in the first floor and it slightly different from the similar sample without opening. Deformation of the samples is mostly because of concentration of stress in the first soft story and not in openings and displacement of the top story level depends upon the first soft story.

(B) The effect of openings with different geometrical shapes in the combined structures of frame-panel with full infill (distribution of panel infill in all floors) indicates that reduced shear capacity and increased displacements in infill having rectangular opening particularly in the short combined structure in the first floor is greater than the circular opening.

(C) By the openings effect and increased cracks in columns of the critical region, the share of frame in reducing absorbed base shear is considerably higher compared with the infill.

(D) Reinforcement around openings in the full combined structure frame-panel has a considerable impact on reduced displacement particularly in the rectangular openings. Moreover, it leads to reduced plastic stress and strain around openings especially in the first story and to some extent causes increased depreciated energy in the full combined panel-frame structure with the rectangular openings.

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