International Journal of English Literature and Social Sciences
Vol-6, Issue-2; Mar-Apr, 2021

Journal Home Page Available: https://ijels.com/
Journal DOI: 10.22161/ijels

Seismic Retrofit of Reinforced Concrete Frames with Filled Masonry Materials Using Fiber Reinforced Polymers

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Received: 21 Mar 2021; Received in revised form: 19 Apr 2021; Accepted: 25 Apr 2021; Available online: 30 Apr 2021

***Abstract*— They typically behave brittle and have little or no ductility and are susceptible to various forms of damage such as invisible cracking, corrosion, and ultimately total destruction. This behavior is a major hazard during earthquakes, and this weakness in seismic performance has posed a major challenge to designers. Seismic retrofitting by adding structural frames or shear walls is impractical and very costly, and faces specific limitations in some buildings. Other retrofitting methods such as grouting, installation of reinforcing steel, prestressing, jacketing, and various surface reinforcement methods significantly increase the mass and stiffness of the structure, and as a result, impose higher seismic loads on the structure. These methods require skilled labor and disrupt the natural functioning of the building. These methods are referred to as "classical" methods of reinforcement. One of the new methods that has attracted the attention of industrialists in recent years is the reinforcement of existing buildings using composites. Much research has been conducted in this field and preliminary regulations have been prepared for their use. Composites were initially used for military applications and the aerospace industry, but with the decrease in price, these materials have attracted the attention of practitioners and industrialists in many industries due to their characteristics such as low weight and very high tensile strength, resistance to atmospheric conditions, etc. The use of fiber-reinforced polymers is a valid alternative reinforcement method due to its low thickness, high strength-to-weight ratio, high hardness, and easy application.*
***Keywords*— Concrete frame, CFRP, finite element analysis, masonry interlayer.**

I. INTRODUCTION

Based on observations of recent earthquakes, the interaction between the frame and concrete columns causes brittle failure. The presence of the frame inside the concrete frame is of great importance and has a decisive effect on the behavior of concrete structures during earthquakes. In recent earthquakes, significant failures occurred due to the interaction phenomenon between the frame and the frame. Smith and Cole proposed a design method for the frame-infill frame based on the criterion of the diagonally braced frame. They proposed a method in which three possible failure modes for the frame wall were considered:

Shear along the wall, diagonal crushing of the frame wall, and corner crushing in the frame wall. Pauli and Priestley presented a theory about the seismic behavior of the frame-infill frame and proposed a method for its design. According to this theory, although the interframe may increase the overall lateral load-bearing capacity of the structure, it causes a change in the structural response and absorbs forces to other and undesirable parts of the structure asymmetrically. This means that the masonry interframe may affect the seismic behavior of the structure. Bell and Davidson reported on the evaluation of reinforced concrete buildings with masonry interframes (Harrington & Liel 2020).

In their evaluation, they used an equivalent bracket to model the masonry wall. Their results showed that interframes, if arranged in a regular manner, have a significant beneficial effect on the behavior of reinforced concrete buildings, which was contrary to the New Zealand Strategic Code, which believed that interframes had a detrimental effect on buildings due to their interaction effect. Mohiuddin-Kermani et al. focused specifically on observations made on concrete buildings with masonry interframes in the Sichuan earthquake and identified the damage and failure modes with their causes. These failure modes, like those in previous earthquakes, are caused by the interaction between the frame and the interframe.

Baran and Seyvel studied the behavior of interframes under seismic loads. They considered hollow brick interframes as structural members in the design criteria. They emphasized that since the behavior of the structure is nonlinear and depends mainly on the interaction conditions between the frame and the interframe, analytical studies should be reviewed and confirmed by experimental results. In general, it can be said that the interaction of the frame with the infill increases the resistance and stiffness on the one hand, and increases the softness (ductility) of the infill on the other hand, and as a result, significantly improves the seismic properties.

Based on this interaction behavior, we call these frames composite. One of the important issues in studying the behavior of infill frames and their numerical modeling is knowing the properties of their materials. It has been shown in numerous experiments that increasing the resistance of the infill frame materials always increases the resistance of the infill frame.

Usually, the properties of the infill frame materials are obtained with a brickwork sample that includes a number of bricks and mortar. The standard case includes three bricks and two mortars, which is shown in Figure 1.1a, but in some studies, larger cylinders containing a larger number of bricks have been used. Powerful earthquakes exert large in-plane and out-of-plane forces on masonry walls, potentially causing catastrophic failure of these structures. However, most of the work in this area has focused on the out-of-plane behavior of masonry walls reinforced with fiber-reinforced polymers. A frame wall or part of it may be pushed out of the surrounding frame due to insufficient out-of-plane restraint at the frame-frame interface or shear or bending failure of the frame wall. In undamaged frames, this type of failure can be attributed to inertial forces, especially for frames of higher stories and large slenderness ratios.

After the masonry is separated from the frame, out-of-plane failure is possible. One of the objectives of this research is to investigate the effect of fiber reinforced polymer layers on the change of failure modes, strength, deformation and energy dissipated by the structure in different layer arrangements. Another objective is to investigate the improvement of shear and compressive strength of the interframe reinforced with fiber reinforced polymer. Reinforcement with fiber reinforced polymer maintains the structural integrity of the interframe wall and prevents its brittle failure and crushing, and given that this type of crushing is a major risk for residents, despite the safety of the entire structure, its prevention is of great importance.

II. THEORETICAL

Joints. Test results on a number of infill frames have shown that the presence of a 0.1% joint does not significantly change the ultimate load of the infill frame, but it increases its horizontal displacements significantly. Other tests show that a 0.7% gap at the top of the infill frame causes a sharp decrease (about 50%) in the ultimate strength, and the reason for this is the sharp decrease in the contact lengths between the frame and the infill frame. Other research also shows that the presence of a joint on any side of the wall reduces the stiffness and strength of the infill frame. If the frame is built after the infill frame is installed, it will be stronger because there is practically no gap between them. Observations of the 1999 Athens earthquake showed that placing 45-degree bricks at the top of the wall and filling the remaining gaps with mortar can provide a large degree of connection between the frame and the infill frame (Wang, 2023).

Reinforcement. The effect of reinforcement on brick frames has been studied in many past studies, and almost all of them have pointed out the necessity of its presence in the frame. The presence of reinforcement in the frame always increases its resistance in the direction perpendicular to the plane, and in some cases, it can increase the resistance in the plane direction and improve the hysteresis behavior of the infill frame. In addition to the infill frame, the presence of reinforcement in ordinary walls also improves the behavior and increases ductility, so that in many cases it is not recommended to implement them without using reinforcement (Sleiman, 2021). It should be noted that changing the amount of reinforcement in the infill concrete frame column does not cause a significant change in its behavior and stiffness. The use of reinforcement in concrete and brick frames also does not cause much change in its stiffness, but depending on the type and method of its connection to the frame, it can significantly affect its resistance, ductility, and stability against out-of-plane loads.

Dimensional Ratio. According to previous research, changing the dimensional ratio (ratio of height to length of the frame) is one of the factors affecting the behavior of the frame. In a study, three series of experiments with different dimensional ratios were tested, the results of which are given in Table (1).

Table 1: Effect of dimensional ratio and vertical load on the resistance of the frame

Strength (kN)	Vertical load (as a percentage of the compressive strength of the brickwork specimen)	Next ratio	Sample name
120	0	0.71	1M
230	10	0.71	2M
180	5	0.71	3M
120	5/7	1/14	4M
80	0	1/14	5M
140	10	1/14	6M
160	15	0.94	7M
100	0	0.94	8M
160	5	0.94	9M
110	0	0.94	10M

As can be seen in this table, increasing the dimension ratio from 0.71 to 1.14 reduces the ultimate strength of the frame (Aydin et al. 2020). In addition, increasing the vertical load usually increases the ultimate strength. However, some researchers believe that changing the dimension ratio does not have much effect on the behavior of the frame as long as it does not change the failure mode, which does not seem to be a correct result because changing the dimensions of the stress distribution in the frame and the length of the wall contact change, which causes changes in the cracking and ultimate strength (Shen et al., 2024).

Failure modes of infill frames. Modeling the behavior of infill frames under lateral loading (mainly earthquake loads) is a complex issue. Because these structures exhibit a strong nonlinear response due to the interaction between the masonry frame and its enclosing frame. Masonry walls are often designed for "allowable stress", although it is better to design based on "ultimate strength" methods to save cost. However, in the case of designing a structure based on ultimate strength, it is necessary to identify the corresponding failure modes and calculate the failure forces for the different failure modes to enable the ultimate capacity of the structure and the serviceability criterion to be determined using the acting loads (Baran, 2021). At the intermediate loading level of the intermediate frame, the separable intermediate frame separates from its surrounding frame and acts as a diagonal brace. As the load increases, failure eventually occurs in both the frame and the intermediate frame. The typical type of frame failure is due to tension in the load-side column and shear in the column or beams.

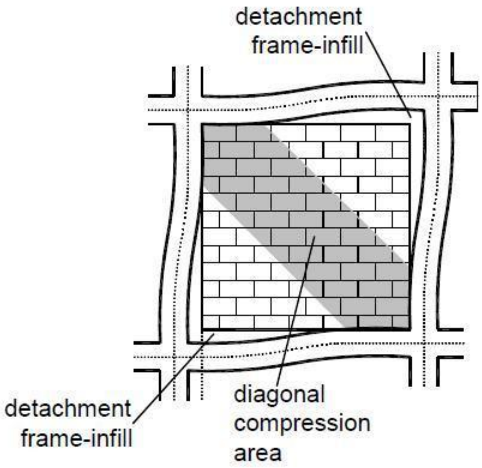

Fig.1: Compression brace model of a web frame

While the frame strength is sufficient to prevent these failure modes from occurring, the increased load will eventually cause the web frame to fail. In typical conditions, an in-plane lateral load applied to one of the top corners of the frame is supported by an equivalent truss system consisting of a loaded column and an equivalent compression brace connecting the loaded corner to the opposite corner at the bottom of the frame (Pohoryles & Bournas, 2020). The amount of stress in the web frame increases to the principal compressive stress along the diagonal brace and the principal tensile stress in the direction perpendicular to it. The occurrence of different failure modes based on the lateral resistance between the frame and the web frame has been formulated by Wood . Based on analytical and experimental results, different failure modes have been proposed for infill frames in the past 5 decades, which can be divided into 5 distinct modes:

1) Corner crushing mode, which indicates the collapse of the infill frame at least at one of the corners, is shown in Figure (1-3). This mode usually occurs in infill frames with weak connections and strong members with weak masonry infill.
2) Diagonal compression mode, which indicates the collapse of the infill frame in its central area. This mode occurs in relatively slender infill frames, where the failure is due to out-of-plane buckling of the infill frame.
3) Shear slip mode, which indicates a horizontal sliding shear failure at the bed connections of the masonry infill frame and is shown in Figure (1). This type of failure occurs in the frame with weak mortar joints and strong frames.
4) Diagonal cracking mode, which occurs as cracks in the compression diameter of the frame simultaneously with the shear slip mode and is shown in Figure (2). This failure mode occurs in weak frames or frames with weak joints and strong members with relatively strong frames.
5) Frame failure mode, which propagates as plastic hinges in columns or beam-to-column connections. This failure mode occurs in weak frames or frames with weak joints and strong members with relatively strong frames.

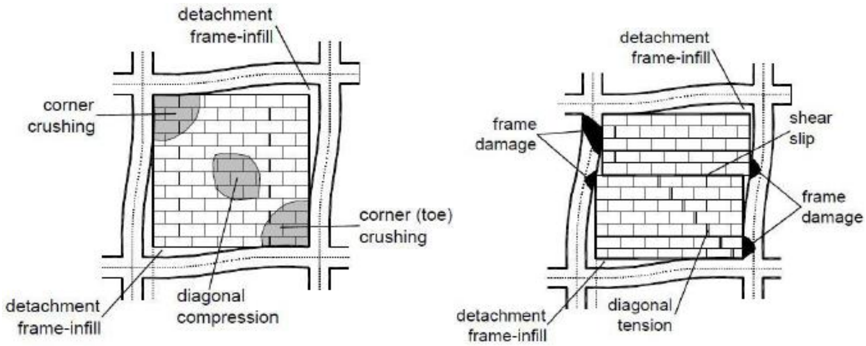

Fig.2: Failure modes of infill frames

It is noteworthy that in the Wood lateral resistance variable relationship, failure modes 4, 2, 1 and 5 are possible when the value of m is less than 1, while mode 3 only occurs for m greater than or equal to 1.

How to model the effect of the infill on stiffness. The most common method for modeling the infill in a structure is to use an equivalent compression member whose cross-sectional area is such that its stiffness is the same as the stiffness of the infill. In this method, instead of the infill, a compression diagonal member is used whose thickness is assumed to be equal to the wall thickness and its width is determined according to the properties of the frame and infill. It is important to note that the equivalent member of the infill always works in compression and cannot withstand tension. Therefore, the infill is modeled with only one equivalent member that is placed in one of the two diameters depending on the direction of load application (Gkournelos et al., 2021).

The experiment shows that the stiffness of the infill frame decreases with increasing load, such that the static stiffness at the final load is equal to half the initial stiffness, and at half the final load, the width of the compression member is assumed to be 0.75 of the width of that member in the calculation of the initial stiffness. Zarnik also believes in the change in stiffness depending on the amount of load applied, and in his proposed formulas, he has presented stiffness as a function of the effective stiffness, which in this process is the stiffness of the sample at 30% of the ultimate strength of the sample.

It is noteworthy that the stiffness of the frame cannot be accurately estimated by the finite element method. Because if the measured properties of the materials are used in the analysis, the calculated stiffness will be several times the experimental stiffness. Even if no friction is considered in the entire contact surface between the frame and the frame and it is assumed that the force between the frame and the frame can only be in the form of compression, the stiffness obtained from the finite element analysis is still much greater than the actual stiffness.

Frame strength. Many factors affect the strength of the frames, including the material properties of the frame and the frame, the bending capacity of the frame, the scale factor, the relative stiffness of the frame to the frame, etc. In addition to these, other factors also affect the strength, including the lack of good adhesion between the frame and the frame in the execution, the adhesion strength between the brick and mortar, and the skill of the worker. The skill of the worker is one of the factors that often changes from one sample to another and cannot be easily converted into numerical quantities, and the difference in the strength of seemingly similar walls is due to these factors.

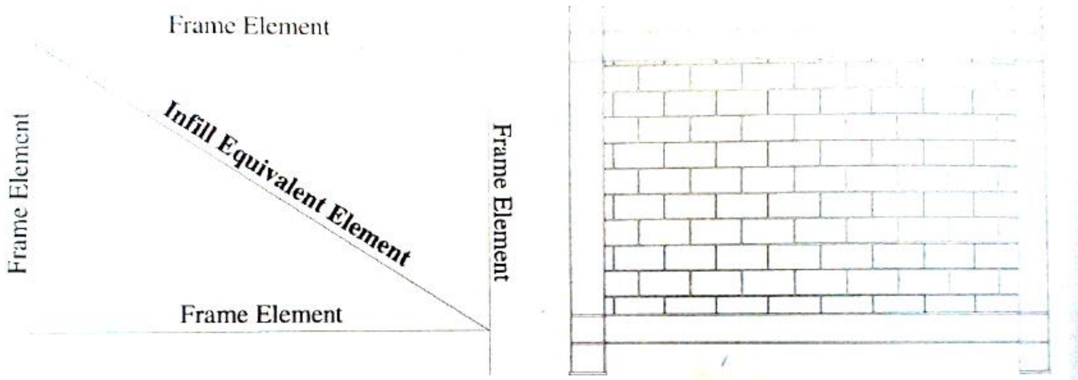

Fig.3: Frame and its equivalent member

The effect of some of these factors is briefly described below:

1) ***Type of bricks.*** Usually, walls made of solid bricks are stronger than hollow bricks because they have greater strength. Such walls also lose their strength later than walls made of hollow bricks under cyclic loads.
2) ***Relative hardness.*** The results of laboratory research show that with increasing the stiffness of the frame to the frame or the ultimate strength corresponding to the crushing of the corner decreases, which of course is also due to the reduction of the effective surface of the wall and the contact surface between the frame and the frame.
3) ***Dimensional ratio h/l.*** The dimensional ratio is one of the factors that can affect the behavior mode and strength of the interframe. According to some research, as long as the change in the dimensional ratio does not change the failure mode of the interframe, it does not affect its strength, but in many experiments, changing it, especially in cases where h/l (height to length ratio of the wall) is greater than one, leads to a change in the failure mode, behavior and strength of the interframe.
4) ***Flexural strength of the frame.*** Numerical and laboratory research shows that the resistance value increases with increasing the flexural strength of the frame.
5) ***Scale factor.*** The experiment shows that the scaled resistance increases with decreasing the scale factor. In general, scaling brick samples is not recommended because this involves a lot of work, and the results obtained cannot be easily attributed to the real sample. In such a way that using a scale of less than 33% is not recommended at all.
6) ***Adhesion between mortar and brick.*** This factor only affects the cracking resistance and does not have a significant effect on the final strength, which is related to the corner crushing mode.
7) ***Reinforcement.*** According to past research, it is not possible to reach a firm conclusion about the effect of reinforcement on the strength of the interlayer. However, the results of some experiments show that if the interlayer crack is horizontal, reinforcement has no effect on the strength, but if the crack is diagonal, especially when the two cracked parts move horizontally relative to each other, reinforcement will increase the final strength.
8) ***Mortar strength.*** The higher the strength of the mortar, the greater the crack resistance and the final strength of the interlayer. The better the mortar, the greater the adhesion to the brick and therefore the greater the crack strength.
9) ***Effect of adjacent panels.*** A number of experiments were conducted to investigate the effect of adjacent panels on the strength of a set of single-span and double-span specimens. The results show that the ultimate load of the double-span specimen is approximately twice the ultimate resistance of the single-span specimen.
10) ***Presence of joints***. Experimental results show that a small upper or side joint (between the frame and the intermediate frame) reduces the cracking resistance but does not change the ultimate resistance much.
11) ***Opening.*** The presence of an opening can cause a severe reduction in the ultimate strength of the intermediate frame.
12) ***Vertical load.*** The results of ten experiments in which the vertical load was increased by a maximum of 15% of the compressive strength of the intermediate frame materials showed that the vertical

load has a great effect on increasing the strength of the intermediate frame, such that by increasing it, the ultimate resistance can be increased by 80%.

III. METHODOLOGY

Based on the finite element method and considering the elements of the interface between the frame and the wood frame, it was confirmed and the order of occurrence of the mentioned failure modes was determined. It is important to remember that only the corner crushing and shear sliding modes are of practical importance and the second mode (diagonal compression) occurs very rarely and requires a very high slenderness ratio of the frame for the occurrence of out-of-plane buckling of the frame under in-plane loading. The fourth mode (diagonal cracking) should not be considered a failure mode because the frame is capable of withstanding additional loads after cracking. Although the fifth mode is of great importance in the case of reinforced concrete frames, this mode hardly occurs in the case of steel frames with hollow concrete block frames.

Based on analytical studies of the seismic performance of reinforced concrete frames with infill, Kapus concluded that including the infill in the calculations increases the stiffness by 440%. It is clear that, based on the spectral characteristics of the design earthquake, the dynamic behavior of the two hollow and infill frame systems is significantly different. Kapus also provided a useful and global picture of the seismic performance of the studied infill frames with reference to the energy dissipated by each structural component. It is clear that the service level of energy dissipation above 95% occurs in the infill (due to cracking), while at higher levels the reinforced concrete frame members make a significant contribution (Filippou, 2021).

This confirms the fact that the masonry infill wall is the first line of defense in a structure under earthquake load, while the concrete frame system is crucial for the performance of the structure against stronger excitations (Padalu et al., 2024).

Stiffness of the interframe. According to previous research, the force-displacement diagram of the interframe has the following stages:

- From the beginning of the loading stage to the formation of a boundary crack
- From the boundary crack to the occurrence of a diagonal crack
- From the diagonal crack to reaching the ultimate strength of the interframe, which is generally related to corner failure.

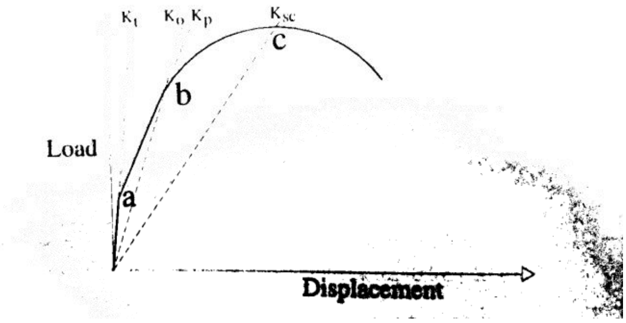

Fig.4: Types of stiffness of the infill frame

The infill frame undergoes boundary cracking at very small drifts and then its behavior until the occurrence of a diagonal crack is very close to linear behavior. Assuming linear behavior in this range, the practical stiffness of the infill frame, shown in Figure (4), can be estimated as the slope of the curve in this distance (Markou, 2021). It seems that using practical stiffness, the behavior of the infill frame can be better estimated because walls usually undergo boundary cracking and separate from their surrounding frame in the first moments of an earthquake (Garcia Ramonda, 2020). One of the characteristics of practical stiffness is that its value is almost the same in the direction of the infill frame's movement and reciprocation, which does not apply to other stiffnesses, which adds to its value. The stiffness of the infill frame depends on several factors, which are discussed below:

1) ***Relative hardness or λ_1:*** This quantity is defined by Smith as follows:

$$\lambda_1 = \sqrt{\frac{E_i \times t \times l^3}{4 \times E_f \times I_f}}$$

2) Dimensional ratio (ratio of height to length of the frame). Redington showed that for aspect ratios greater than 0.5, the stiffness of the infill frame decreases with increasing aspect ratio, but for those with aspect ratios less than 0.5, the stiffness is independent of the aspect ratio.

3) Frame connection tightness. According to the results of the experiments, the stiffness of the assembly also decreases with decreasing the degree of frame connection tightness.

4) Horizontal reinforcement. Many experiments have been conducted to investigate the effect of horizontal reinforcement on the stiffness of the infill frame, which shows that the presence of horizontal reinforcement does not have much effect on the stiffness of the infill frame.

5) Mortar strength. The experiment has shown that the strength of the mortar has a great effect on the stiffness of the infill frame and its increase causes an increase in stiffness.

6) Brickwork Unit Size. The smaller the size of the bricks used in the construction of the wall, the more mortar is used in the construction of the wall, which is often less resistant to mortar than brick, resulting in a lower stiffness of the assembly (Gkournelos, et al., 2022).

7) Effect of adjacent panels. The experiment has shown that the stiffness of a one-story, three-span frame is not linearly related to the number of intermediate frames inside it. Another experiment showed that the stiffness of samples with two spans is 1.7 times that of a single-span sample (Longo et al., 2021). Contrary to the above research that indicates the nonlinearity of the relationship between stiffness and the number of intermediate frames, Reddington has shown that this relationship is completely linear and the value of r is equal to unity, which is implicitly assumed in finite element analysis or in replacing the intermediate frame with an equivalent diameter member.

8) Joint between frame and intermediate frame. The initial stiffness of an intermediate frame with an upper joint (between the intermediate frame and the upper beam) is much lower than that of a sample without a joint. Initially, this intermediate frame moves upwards until it contacts the upper beam on the loading side, and then the stiffness of the sample increases (Park et al., 2022). The experiment shows that the presence of a joint always reduces the stiffness of the sample by at least 40%.

9) Opening: Testing two similar infill frames, one with an opening measuring one-third of the length and height of the infill frame, showed that the presence of an opening has little effect on stiffness up to a load of about 50% of the ultimate strength, but after that it reduces the stiffness drastically. Some studies have suggested this range as 30% of the ultimate strength instead of 50% and have shown that the closer the opening is to the loading site, the greater its reducing effect on stiffness.

IV. FINDINGS

So far, much research has been conducted to estimate the ultimate strength of infill frames. Wood was the first to use the theory of plasticity for this purpose. He calculated four different modes for the assumed ultimate state and the resistance of each, but a comparison of the results with experimental work showed that his proposed formulas are not accurate enough, which is why they have been omitted. Liao improved the previous method and assumed three failure modes to estimate the ultimate strength of infill frames (Majumder et al., 2021).

A. Corner crushing with plastic deformation in the column:

In this mode, the corners of the frame are crushed and plastic hinges are formed in the columns.

B. Corner crushing with plastic deformation in the beam:

In this mode, the corners of the frame are crushed and plastic hinges are formed in the beams. The resistance of this mode is calculated from the following formula:

$$\frac{H_u}{\sigma_c th} = \frac{1}{\tan\theta}\sqrt{\frac{2(M_{pj}+M_{pb})}{\sigma_c th^2}}$$

Where the angle of the diagonal of the frame with the horizon and the rest of the quantities are the same as before.

C. Diagonal crushing: The resistance of this mode is calculated according to the dimensional ratio from one of the following relations. For dimensional ratios less than unity:

$$\frac{H_u}{\sigma_c th} = \frac{4M_{pj}}{\sigma_c th^2} + \frac{1}{6}$$

For dimensional ratios greater than unity:

$$\frac{H_u}{\sigma_c th} = \frac{4M_{pj}}{\sigma_c th^2} + \frac{1}{6\tan^2\theta}$$

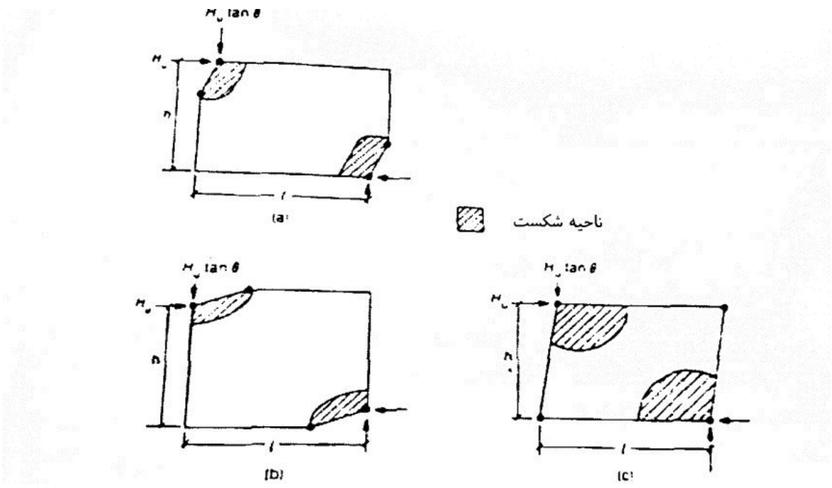

Fig.5: Assumed failure modes for estimating the ultimate strength of the interframes

Resistance of the interframe in the direction perpendicular to the plane. The interframe is considered one of the hard and brittle components of the structure, which in the first moments of a severe earthquake, a boundary crack and then transverse cracks are formed in it. The transverse crack that is formed due to a force in the plane direction is very similar to the failure mode of the wall due to acceleration perpendicular to the plane, the existence of which greatly reduces the resistance of the interframe in the perpendicular direction, so that sometimes the resistance of the wall in the perpendicular direction is ignored, while it is necessary to provide the resistance of the wall in the perpendicular direction (Maheswaran et al., 2022, April).

The effect of the destruction of the interframe due to forces in the plane on the resistance in the perpendicular direction has been investigated, during which tests were carried out for interframes with dimensions of about 160 cm in height, 236 cm in length and 9 cm in thickness (Pohoryles & Bournas, 2020). The first sample, which was completely intact, resisted up to an acceleration of g10 and then became unstable. In the second test, the loading was first carried out in the plane direction up to a drift of 51%, which caused the wall to crack diagonally, and then, like the first test, it was tested in the perpendicular direction and withstood an acceleration of 5 g. Some research shows that the resistance of the interframes without a crack in the perpendicular direction is usually sufficient to withstand the accelerations caused by earthquakes.

A square wall with a height of 2.5 meters and a thickness of 8 centimeters can withstand accelerations of 1.3 to 1.75 g in the direction perpendicular to its plane. Other tests show that loading in the perpendicular direction has no effect on the resistance of the wall in the plane direction. This means that if the wall is initially loaded in the plane direction even to 75% of the ultimate strength, its resistance in the perpendicular direction will decrease between zero and 15%, and in any case, its resistance is sufficient for the accelerations that usually occur in earthquakes (Keshmiry et al., 2024)**.**

Some also suggest that the resistance in the perpendicular direction of the wall be ignored and that reinforcement be used to provide sufficient resistance, the required area of which is calculated as follows. In this method, the resistance of the wall in the transverse direction is ignored and first the middle third of the frame is considered as a flexural strip under the earthquake component perpendicular to the wall surface, in which case the earthquake inertia force in tons will be equal to the following value. In this case:

$$P = 0.5 \times W \times h/3 = 0.17\mathrm{W} \times \mathrm{h}$$

The bars are placed horizontally in the mortar joint so that their distance from both sides of the frame is the same because concentrating them on one side of the wall is not beneficial due to the periodic nature of the earthquake.

In this case, the bending moment created in the wall against the transverse force caused by the earthquake is equal to:

$$M = \frac{P \times l^2}{8}$$

where is the length of the wall.

$$M_n = \varphi \times A_s \times f_y \times \frac{t}{2}$$

For example, for a brick frame with a volumetric mass of 1.8 tons/square meter, dimensions of 0.2 meters thick, 4 meters long, and 3 meters high, and assuming that the yield stress of the reinforcement is 2.8 tons/square centimeter and the earthquake acceleration in the

ISSN: 2456-7620
https://dx.doi.org/10.22161/ijels.62.71

transverse direction is half the acceleration of gravity, we will have:

$$W = 0.2 \times 1.8 = 0.36 (t/m^2)$$

$$P = 0.17 \times 0.36 \times 3 = 0.18 (t/m)$$

Strength of reinforced wall with reinforcement A_s amount in the middle third

$$M_n = 0.7 \times A_s \times 2.8 \times \frac{0.2}{2} = 0.196 A_s$$

$$M = M_n \Longrightarrow 0.196 A_s = 0.36 \Longrightarrow A_s = 1.48 cm^2$$

Which will practically be three grade 10 bars. The reinforcement of the middle third is conditional on the frame being supported on all four sides, and if there is a gap between the frame and the upper beam, the upper third must also be reinforced with this method in addition to the middle third. In this method, it is not necessary for the wall reinforcement to be connected to the frame. It seems that all the above relationships estimate the out-of-plane resistance of a sample that is first loaded in the plane direction and then subjected to a load perpendicular to the plane, more than the amount that may occur in an earthquake because in all the above cases, the wall is first loaded in the plane direction and, without returning to its normal position, is subjected to a load perpendicular to the plane in the same final displacement.

While an earthquake may cause the maximum acceleration in the perpendicular direction in a state where the frame has returned to its normal position and its deflection has become zero, in which case there is the least connection between the frame and the middle frame. In view of this, it is suggested to ignore the resistance in the perpendicular direction of the wall and to provide sufficient resistance, special devices such as reinforcement, wire mesh cladding, tension beams, etc. that are connected to the frame or at least to the columns should be used. There are also methods for estimating the resistance in the perpendicular direction of a brick wall (and not the frame), which are omitted from the discussion.

V. CONCLUSION

The experimental results for the two series were discussed and compared in terms of the quantities of resistance, stiffness, lateral deformation (drift), and energy dissipation characteristics. The test results such as the initial stiffness of the lateral force at the moment of cracking and the maximum points, the corresponding displacement of the floors corresponding to the maximum points and also the 85% maximum points. The hysteresis curve diagrams of the lateral force versus the displacement of the first and second floors of the samples of series 2 are shown. The envelope of the hysteresis curves obtained by connecting the maximum points of the hysteresis curve cycles. Comparison between the first and second reference specimens in both series highlighted a significant increase in base shear due to the addition of the intermediate frame.

Applying CFRP layers to the intermediate frames of the specimens with cover patch resulted in a further increase in base shear. As can be seen from the graphs of the two series, the proposed strengthening method significantly increases the base shear capacity of the specimens regardless of the lateral ratio. The test results also showed that the presence of cover patch in the longitudinal column reinforcement has an adverse effect on the ultimate bearing capacity of the specimens. Another noteworthy point is that the strengthening of the frame in series 1 does not change the initial stiffness of the frame. Observations showed that the use of CFRP on the intermediate frame wall increases the base shear capacity without changing the dynamic properties of the frame.

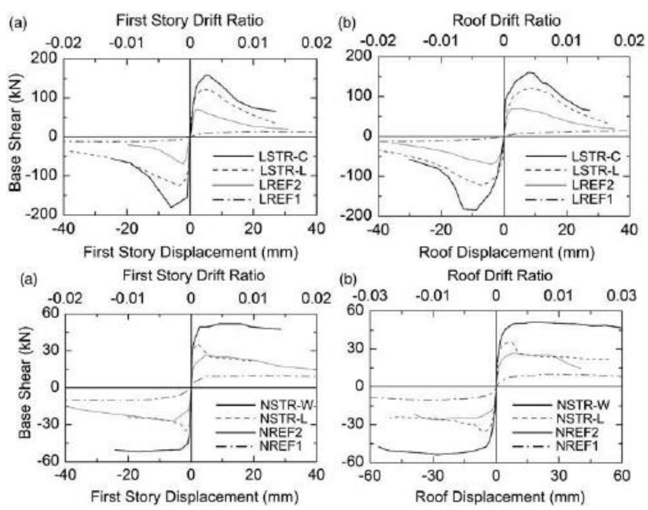

Fig.6: Base Shear Hysteresis Curve Envelope - First Floor Displacement Series 1 and 2

ISSN: 2456-7620
https://dx.doi.org/10.22161/ijels.62.71

Based on the tests conducted on 8 reinforced concrete frames with a scale of 1/3 and also the numerical analysis of the tested specimens, the following results were obtained. By applying the mentioned strengthening method, the lateral load-bearing capacity of the specimens increased significantly. The use of continuous/welded longitudinal reinforcement of the column caused a further increase in the strength and stiffness of the strengthened specimens. It is important to note that the weldability of the reinforcements must be examined before welding. The tests once again proved the fact that the use of FRP cover to confine the reinforcements in the patched area is not an appropriate measure to ensure the transfer of stresses between non-ribbed reinforcements in the cover patch area.

Welding the reinforcements at the patch in the specimens of series 2 caused further improvement in the drift characteristics. The ductility of the infill frame increased by 100%. CFRP reinforcement significantly increases the energy dissipation capacity of the specimens, regardless of their aspect ratio. The experimental results showed that the reinforcement design applied to wider frames was more effective than that of thinner ones. However, to further improve the effectiveness, the use of insufficiently long cover patch should be avoided. The analytical model can be considered a successful model in predicting the nonlinear monotonic response of reinforced concrete frames strengthened with the proposed method. The important results of this study are:

- Adding a web to the frame significantly increases the ultimate lateral strength and stiffness of the frame, but reduces the lateral ductility of the frame.
- Reinforcing the frame with masonry materials using CFRP carbon fiber reinforced polymers significantly improves its performance and prevents its brittle failure against cyclic loads, so that by using it, the lateral load-bearing capacity, lateral deformation, ductility and the amount of wasted energy increase.
- By comparing the general types of CFRP layer arrangements used for reinforcement, we conclude that the highest lateral resistance and ductility are obtained in a case where the layers are used in the entire frame and frame, which is not economically viable due to the high price of the layers.
- By carefully examining the stress and plastic strain contours of the test specimens, we conclude that the performance of the CFRP layers is in the diagonal direction, such that they bear the highest stresses in this direction, so the philosophy of choosing the diagonal of the layers is this fact.
- Using a cover patch at the base of columns without proper connection causes poor stress transfer in the rebars and the relevant reinforcement does not eliminate this defect, so it is recommended to avoid its use in connections as much as possible.
- Considering that the performance of the diagonally reinforced specimens is very desirable in terms of strength and lateral load and is economically cost-effective due to the low use of CFRF layers, it is therefore recommended as the best reinforcement method here.
- In Table (2), a general comparison between the specimens in terms of lateral resistance and floor drift has been made:

Table 2: Summary of the results of the finite element analysis

Maximum intra-storey drift (storey 1)	**Maximum energy dissipated (kilonnewton-meter)**	**Initial hardness (kN/m)**	**Maximum lateral force (kN)**	**Sample number**
0.023	26/0	1879	9/15	1
0.00712	5/5	15210	30	2
0.0128	5/22	41322	54	3
0.0106	12	39793	6/99	4
0.0181	180	44437	170	5
0.0104	10	40098	7/113	6
0.01	20	41651	5/120	**7**

To continue research in this field, it is suggested that the adhesive material of the FRP layer on the wall, which is usually epoxy resin, be also modeled in the software to take into account the effects of separation of FRP layers from the brick interlayer. For this, there is a need for accurate laboratory information on the mechanical properties of epoxy resin. For epoxy modeling, adhesive elements can be used in the Abaqus software. According to previous research, the effects of openings on the behavior of interlayers are significant. The presence of openings changes the failure modes of the interlayer. As another field of research, it is suggested to investigate the effect of openings on the behavior of the frame and interlayer. In this study, only CFRP composites were used, but the effect of other composites, namely AFRP and GFRP, on interlayers and masonry walls can be investigated. As well as different layer arrangements and examining the effect of each can be on the agenda. Examining the failure of the middle frame in off-screen loading mode is also a significant issue.

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ISSN: 2456-7620
https://dx.doi.org/10.22161/ijels.62.71