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Technical Note

IMPACT OF BRICK INFILL WALLS ON THE SEISMIC BEHAVIOR OF REINFORCED CONCRETE FRAMES USING FINITE ELEMENT METHOD

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ABSTRACT

Infill walls can introduce changes in the dynamic characteristics of frames due to their features and their connection to the frames. Among the methods applied for modeling infill walls, micro modeling is able to model the infill wall and compound frame behaviors very close to their real time functioning, using Finite elements Method. In this paper, concrete frames and brick walls micro modeling technique, through application of the ANSYS 12 software is described firstly, followed by the software analysis results of 36 reinforced concrete frames with different number of stories and bays and various positioning patterns for inter panel walls, under the increasing cyclic lateral loads. The impact of infill walls on seismic behavior of structures including several patterns of hysteresis loops, the area under hysteresis loops (the amount of dissipated energy), ductility and primary stiffness are ultimately assessed.

Keywords: Brick infill wall; RC frames; hysteresis loops; finite elements method; ANSYS12

1. INTRODUCTION

There is no general consensus on whether masonry infill walls would increase or decrease the seismic vulnerability of a reinforced concrete frame. A review of the literature shows that opinions about this issue are split. Many researchers have suggested that infill walls have led to the earlier collapse of buildings (relative to the case where the building lacks infill walls) or that they may detrimentally affect the frame response; others still suggest that

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masonry infill panels may improve structural behavior. The reason for the apparent contradiction may reside in the observations made by researchers and it can be inferred that masonry infill panels might have both positive and negative effects [1].

Severe overloads would usually lead to the dominant cracking phenomenon in the infill panels. As a general finding, significant stiffness and strength is observed in frames with infill walls as compared to those lacking such walls. The interaction between infill panels and frame is continuously modified throughout loading. The infill failure is one of the most important general characteristics of the compound frame. Therefore, proper representation of this phenomenon and application of an accurate computational method seems inevitable [2].

Evaluation of infill wall frames depends on the frame and infill wall geometry and also on constituent materials of infill walls. Different behaviors of infill wall frames may generally be categorized in two distinct conditions: infill walls are highly lightweight and flexible or commonly isolated from the frame system or, in other words, they are so fragile that they may crack or crush under weak and medium earthquakes, in which case, infill walls do not show significant impact on the structural response and that's why the possible risk of infill wall collapse on the residents and equipment should be given high safety considerations. In other conditions, infill walls may positively contribute to structural response, but their deflections remain linear. Sometimes, infill walls lead structural behavior into a nonlinear state where they significantly contribute to the structural response [3].

The first and simplest method of masonry infill wall modeling is the equivalent strut method, addressed and discussed initially by Polyakov [4]. Smith [5] demonstrated that the equivalent diagonal element width depends on the common length between frame and masonry infill wall. Mainstone [6] proposed a method to calculate the equivalent diagonal element specifications. Saneinejad [7] suggested some equations for calculation of masonry infill wall strength. But Finite elements Method is a more accurate technique in masonry infill walls modeling according to which, Mehrabi [8] and Dawe [9] also suggested new methods for compound frame Finite Elements modeling. Sinan Altin experimentally investigated the behavior of RC non-ductile frames with RC infills under lateral loads [10]. Matjaž Dolšek and Peter Fajfar studied a relatively simple probabilistic approach for the seismic performance assessment of building structures, applying the combined SAC-FEMA method, which is part of the broader PEER probabilistic framework and permits probability assessment in closed form, with the N2 method [11]. Stavridis and Shing [12] developed a complex nonlinear Finite Elements model for RC frames with masonry infill. António Sousa Gago, Jorge Alfaiate and António Lamas studied the impact of the infill on arched structures [13].

2. RESEARCH METHODOLOGY

In this study, concrete frames and brick infill walls were first modeled by the Finite Elements ANSYS 12 software through which, modeling details of each component and their connection procedure are discussed as the following:

Solid elements, in ANSYS software, are modeled by massive 3D elements consisting of an octagonal element comprised of a basic material and maximally three reinforcing materials, independent of each other and capable of cracking in tension and crushing under pressure.

These elements function is based on William Warkner failure criterion that can be applied to concrete materials. This means that if tensile stress exceeds the material's strength, cracking occurs but if combination of existing stresses exceeds the compressive strength of the material, the wall would crush.

Steel bar as a one dimensional rod with tensile and compressive behavior is defined in the middle of each element in three directions. In this (SM) method, the bar element is used for unreinforced components with zero percent reinforcing steel.

In another (DM) method, modeling is carried out by using the same element with zero percent reinforcing steel and a LINK8 limited element that can function as a reinforcing bar. The LINK8 element is a 3D steel bar element with 3 degrees of freedom in x, y and z directions in each joint having capability of plasticity, creeping, swelling and strain hardening. A comparison of the results of both steel bar modeling methods shows that SM method, based on bars within the element demonstrates a closer performance to the real time behavior of the structure.

2.1 Brick wall modeling

Brick walls numerical modeling is generally divided into two micro and macro modeling categories. Brick wall consists of three main components: brick, mortar and brick/mortar contact surface. In micro modeling, each component is modeled separately but in macro modeling, wall is assumed as a homogeneous and integrated material with equivalent mechanical properties that make this method very simple, in which the amount of calculations is much lesser than that of micro modeling although the accuracy is not as high and is usually applied for modeling larger sizes.

Regarding behavioral and crack-failure mechanism, two different types of behaviors may be envisioned in numerical modeling of brick walls. The first applies to the walls with high tensile and shear cohesion between brick surfaces and mortar where shear cracking and crushing passes through both brick and mortar, with almost no slide between them. In other words, brick wall acts integrated and unified in this case. Unlike the first case, the second applies to brick walls in which shear cracking and crushing never pass through bricks and masonry units and that cracking occurs entirely within mortar and the contact surface between brick and mortar.

In the first case of wall modeling, bricks and mortar joints are modeled separately with real size where the two elements are entirely connected to each other, as it is assumed that shear failure in sliding form never occurs between brick and mortar surfaces.

But since the second modeling is specified for walls with low cohesion between brick and mortar surface, it is presumed that cracking never passes through bricks and cracks simply slide through the brick and mortar surface. Since it is assumed that cracking never occurs in the bricks, brick equivalent blocks behavior may be regarded as linear elastic and is taken as the contact elements in ANSYS software to model contact surfaces. Contact elements with nonlinear behavior are used in ANSYS software to demonstrate modeling the two frictional contact surfaces behavior.

In this study, infill walls are modeled according to the first type of brick wall behavior, as the sample of mortar and brick meshing are shown in Figure 1.

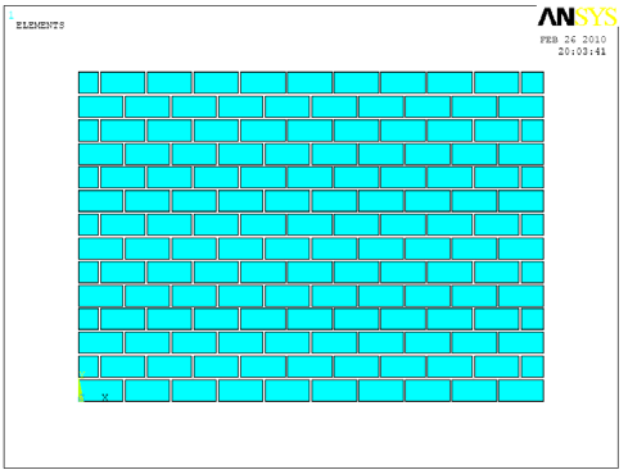

Figure 1. Meshing of bricks and mortar [14].

2.2 Software Validation

In order to consider the ability and capability of concrete and infill wall modeling by applying the said techniques, an experimental test by Mehrabi [12] has been modeling with as micro sample. A selective sample is test No. 5 from Mehrabi collection test that includes designed concrete frame against wind (or lateral loading). Geometric specifications and its designed details of inflected concrete frames are same as laboratory testing according to Figure 2) for numerical modeling.

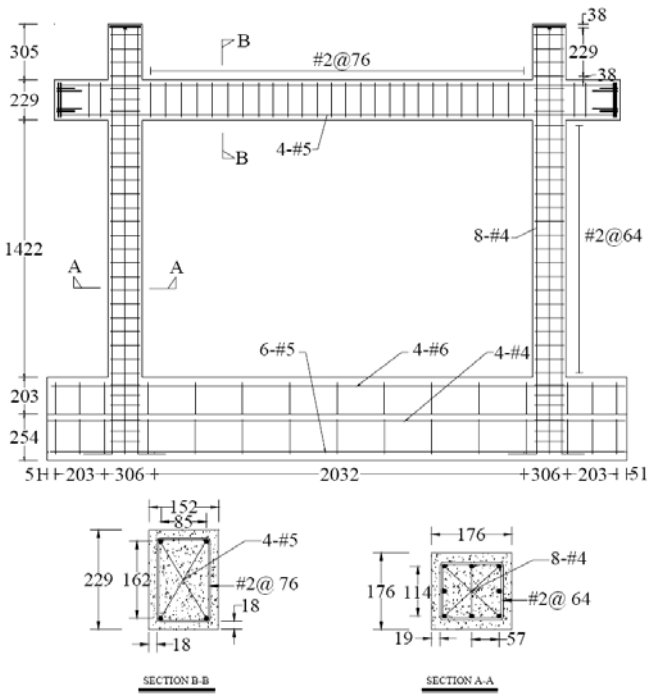

Figure 2. Frame number 5 from Mehrabi collection tests [15].

The brick infill wall includes bricks in 19.2×19.2×9.2 cm dimensions and horizontal and vertical layers of mortar in 10 mm thickness and that they are entirely supposed within the frame. The vertical load is 294 kN that is applied between frame beam and column as distribution mode. The summary of other specification of samples are given in table (1).

Table 1: Specification of Mehrabi samples

Type of load	**Concrete of frame**			**Brick**			
	Secant module	***f´c (Mpa)***	**Strain in max of stress**	***f´c (Mpa)***	**Secant module**	***f´c (Mpa)***	**Strain in max of stress**
Dynamic (hysteretic)	18070	20.9	0.0026	1.81	8.95	13.86	0.0023

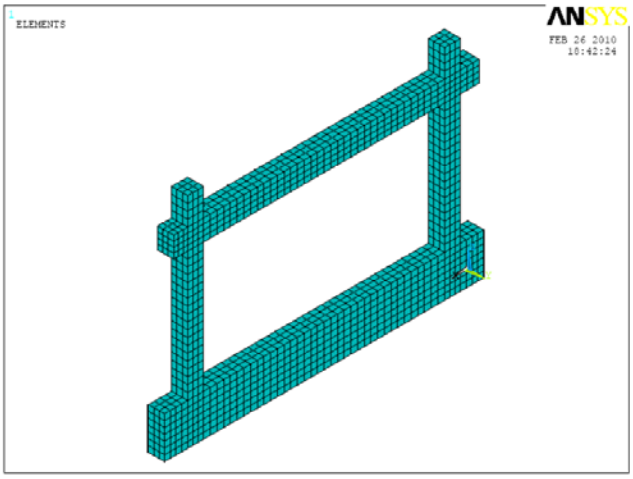

Figure 3. Meshing of frame number 5 from Mehrabi collection tests.

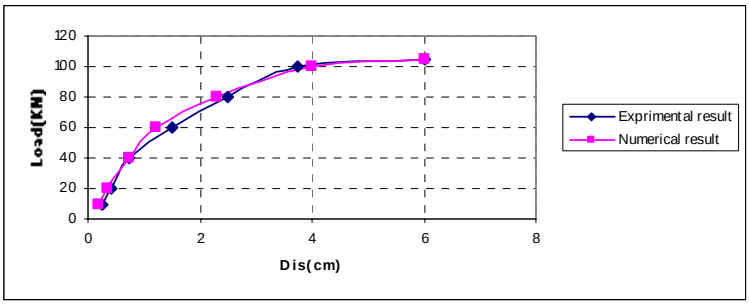

Figure 4. Comparison between experimental results and that of the numerical method in frame without infill wall.

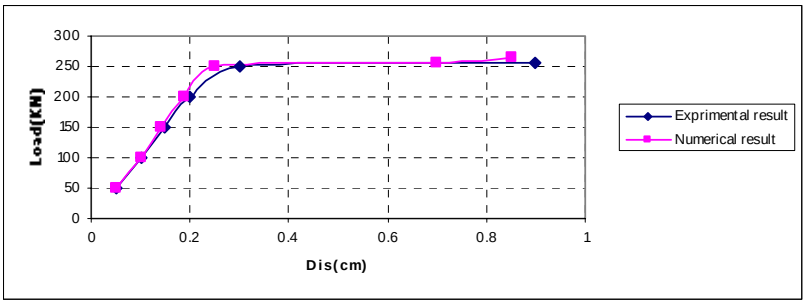

Figure 5. Comparison between experimental results and that of the numerical method in frame with infill wall.

2.3 Analyzed models

In this study, 36 reinforced concrete frames designed based on the Concrete Code of Iran (CCI) and the Iranian code of practice for seismic resistant design of buildings (Standard 2800) (third edition), with medium ductility are modeled in 3D by ANSYS software. The SOLID 65 element is utilized in arranging reinforced concrete component and the SM method used for modeling steel bars, due to above-mentioned concerns. The element applied for modeling compressed bricks and mortars is also SOLID 65 with zero percent steel bars to which the same characteristics of brick and mortar is assigned. Elements CONTACT 174 and TARGET 170 are used for modeling the contact surface between surrounding bricks and concrete frame. Wall modeling is based on the first type of walls behavior, i.e. bricks and mortar joints are modeled according to real size and a considerable shear and tensile cohesion between brick and mortar surface. Shear cracking and crushing can pass through both brick and mortar with almost no slide between them. In other words, brick wall operates as a unified and integrated component.

Specifications of the samples and concrete material appropriated for concrete frame, compressed bricks and mortar joints are shown in Tables 2 to 5.

Vertical loading according to the sixth section of the National Building Regulations and lateral loading as an incrementing lateral cyclic loading with linear distribution in the floor levels (according to the Iranian code 2800) is steadily continued until structural failure moment (disruption of analysis based on software settings). Hysteresis curves may be obtained for each frame and each story of a frame, according to cyclic lateral loading. Capacity curve may be obtained from the outermost (or the maximum) hysteresis curve of the structure which is then converted to an ideal bilinear curve and all computations are carried out on such ideal curves. In order to calculate the fundamental period of frames, the samples are again analyzed based on the modal analysis method.

In order to obtain various positioning arrangements of infill walls, various parameters including the impact of number of floors, number of frames bays and the height to width ratio of infill walls are analyzed. Various numbers of bays and floors are modeled in three cases of the three-story frames each with three bays, three-story frames and five bays and finally five-story frames and three bays. Furthermore, the height to width ratio of infill walls in each case is modeled once with the ratio 1:1 and once with 1:1.5. Considering the increased number of elements and the subsequent required time for each computer analysis

case and the need for advanced hardware facilities, analyzing larger samples was not practical.

Samples are numbered such that the 36 samples are arranged in six structural groups each containing six frames with varied infill wall positioning patterns, according to Table 1. In each group, the first pattern is assumed as the frame pattern without infill walls, the second pattern as the filled frame pattern (covering all bays with infill walls), the third pattern as the soft ground floor story pattern, the fourth pattern as the side bays infill wall pattern for three-bay frames where the first, third and fifth bay infill wall patterns are for five-bay frames, the fifth pattern as the middle bay infill wall pattern for three-bay frames and the second and fourth bays infill wall for five-bay frames and finally the sixth pattern as the strong first floor pattern for three-story frames and strong first two floors pattern for five-story frames.

Table 2: Characteristic of the samples

Sample number	**1 ~ 6**	**7 ~ 12**	**13 ~ 18**	**19 ~ 24**	**25 ~ 30**	**31 ~ 36**
Preamble	Three stories three bays with height to width ratio of 1:1 frame	Three stories five bays with height to width ratio of 1:1 frame	Five storie s three bays with height to width ratio of 1:1 frame	Three stories three bays with height to width ratio of 1:1.5 frame	Three stories five bays with height to width ratio of 1:1.5 frame	Five stories three bays with height to width ratio of 1:1.5 frame

Table 3: Characteristic of the concrete material specified to concrete frames

Parameter	β_{to}	β_{tc}	f_t	f_c	f_{cb}	σ_h^a	f_1	f_2	T_c	E	υ
Unit	-	-	MPa	MPa	MPa	MPa	MPa	MPa	-	MPa	-
Amount	0.2	0.6	-2.1	21	25.2	36.37	30.45	36.225	0.6	23000	0.2

Table 4: Characteristic of the concrete material specified to compressed bricks

Parameter	β_{to}	β_{tc}	f_t	f_c	f_{cb}	σ_h^a	f_1	f_2	T_c	E	υ
Unit	-	-	MPa	MPa	MPa	MPa	MPa	MPa	-	MPa	-
Amount	0	0.6	-0.5	11	13.2	19.05	15.95	18.975	0.6	7500	0.15

Table 5: Characteristic of the concrete material specified to mortar joints

Parameter	β_{to}	β_{tc}	f_t	f_c	f_{cb}	σ_h^a	f_1	f_2	T_c	E	υ
Unit	-	-	*MPa*	*MPa*	*MPa*	*MPa*	*MPa*	*MPa*	-	*MPa*	-
Amount	0	0.6	0	8.5	10.2	14.73	12.325	14.67	0.6	2000	0.2

3. FINDINGS

3.1 The impact of masonry infill walls on the form of the frames hysteresis curves

In comparison of hysteresis curves graphs between patterns containing masonry infill walls with empty frame patterns, in all situations, masonry infill wall causes thinner hysteresis curves and heightened peak points in curves which indicates having a stronger structure, decreased ultimate deflection and increased stiffness. Two cases of hysteresis curves for the empty frame pattern and fully covered frame are shown in graphs 6 and 7.

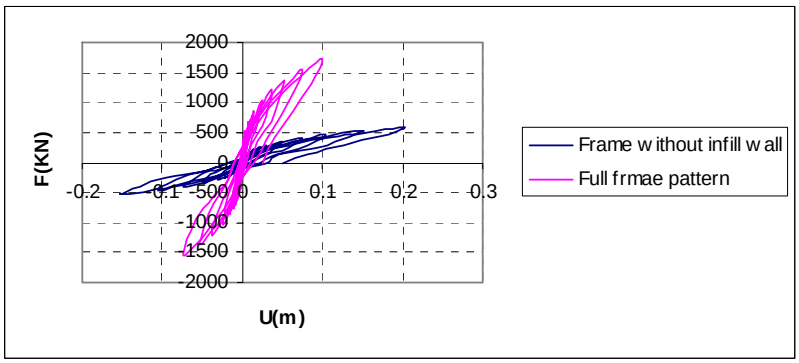

Figure 6. Hysteretic loops of samples 1 and 2.

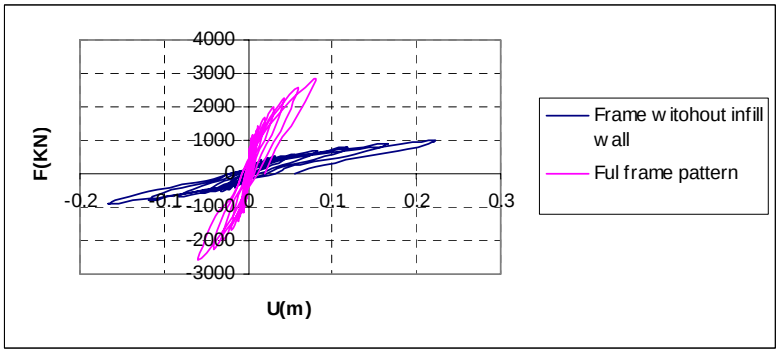

Figure 7. Hysteretic loops of samples 7 and 8.

3.2 The impact of masonry infill walls on the area under hysteretic curves - dissipated energy
The comparison between total areas under hysteresis curve in the two structural cases is demonstrated in graphs 8 and 9. Comparing the amount of dissipated energy in all models indicates that area under hysteresis curve in patterns containing masonry infill walls lessens relative to empty frame pattern. In all cases, the least reduction can be tracked in the full frame pattern which maximizes to 43% in three stories, three bays with 1:1.5 height to width ratio of masonry infill walls and minimizes to 18% in five stories, three bays with 1:1 height to width ratio. Uttermost reduction of area under hysteresis curve reaches to 68% which belongs to the lateral bays patterns and strong first floor in the three stories, three bays and the three stories, five bays, and the pattern of infill walls in the second and fourth bays in three stories five bays structures.

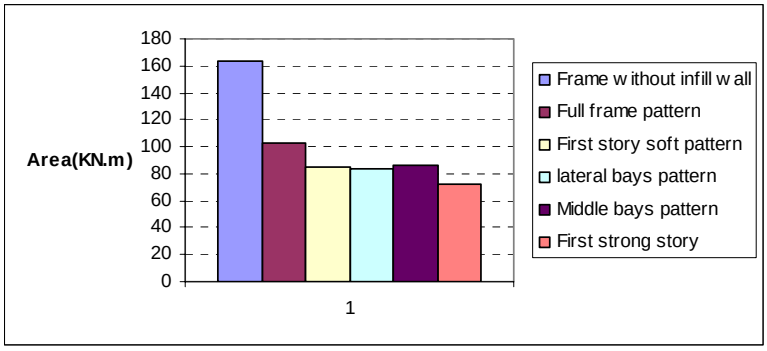

Figure 8. Patterns 1- 6.

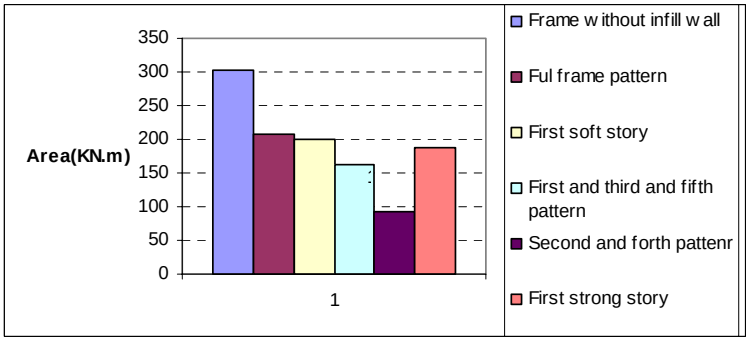

Figure 9. Patterns 7-12.

3.3. The impact of masonry infill wall on the idealized bilinear structural capacity curve
Idealized bilinear curves for different structural capacity samples of structural groups are exhibited in Fig.10 and11. Comparison between the graphs indicates that by placing masonry infill wall in the frame, the idealized bilinear curve changes and frame capacity increases in all cases. Observations show that in all cases, the greatest capacity appertains to the full frame pattern.

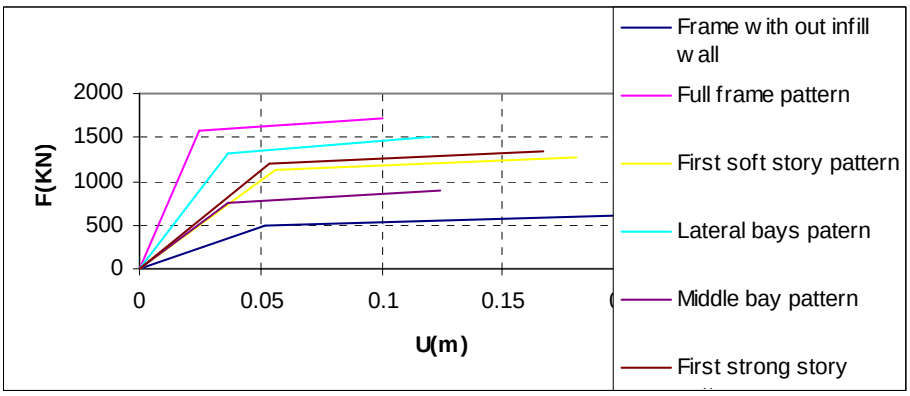

Figure 10. Bilinear capacity curve of samples 1- 6.

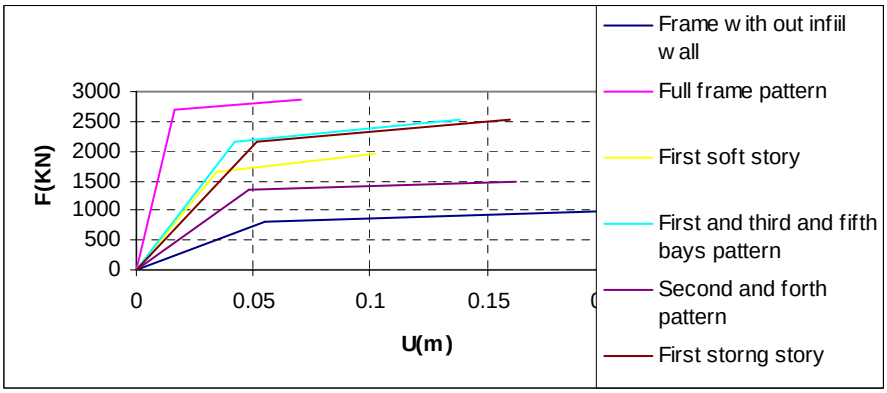

Figure 11. Bilinear capacity curve of samples 7-12.

3.4 The impact of masonry infill wall on the frames ductility

Regarding ductility coefficient, defined as the structure's ultimate displacement divided by the displacement due to the yield condition, a comparison of the empty frames ductility and different patterns of masonry infill wall placement for four groups of structures is illustrated in Figures 12 and 13. It can be concluded that from the comparison in the full frame pattern with increase in the number of stories and bays and also in the height to width ratio of masonry infill walls, overall ductility of the full frame pattern becomes greater than that of the empty frame pattern. The least and greatest ductility enhancement of the full frame pattern relative to the empty frame pattern was observed in the case of three stories, three bays with the height to width ratio of 1:1 with 4% increase and in the case of five stories, three bays with 20% increase, respectively. The most important factor in the ductility enhancement lies in the increase of the number of stories, and then the number of bays and the frame width.

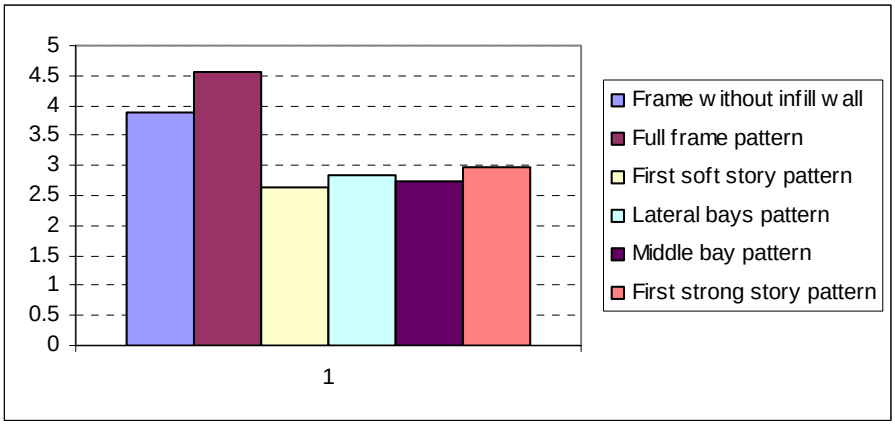

Figure 12. Ductility of samples 13-18.

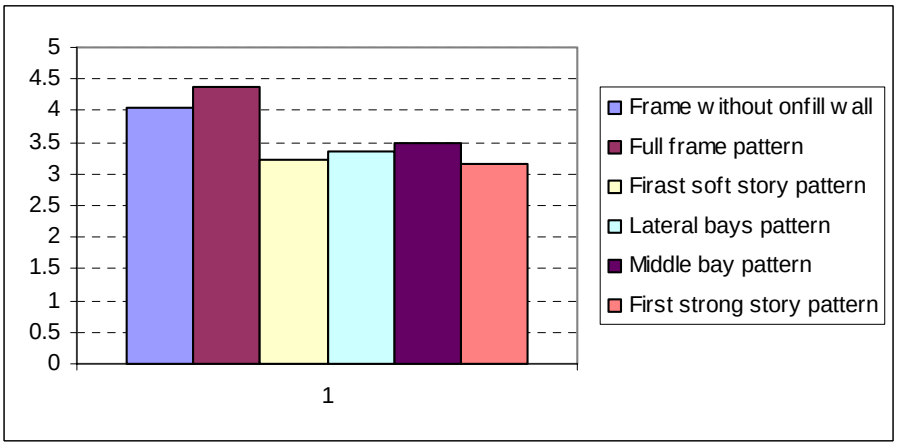

Figure 13. Ductility of samples 19-24.

3.5 The impact of masonry infill wall on the primary stiffness of the frames

Increases in primary stiffness of all structural groups are shown in Figures 14 to 17. It can be observed that in all patterns, primary stiffness increases compared with the empty frame pattern that the maximum increasing amount of primary stiffness occurs in the full frame pattern in all cases. Increasing the number of stories and the number of bays lead to the enhancement of the primary stiffness but with increasing the frame width, primary stiffness decreases.

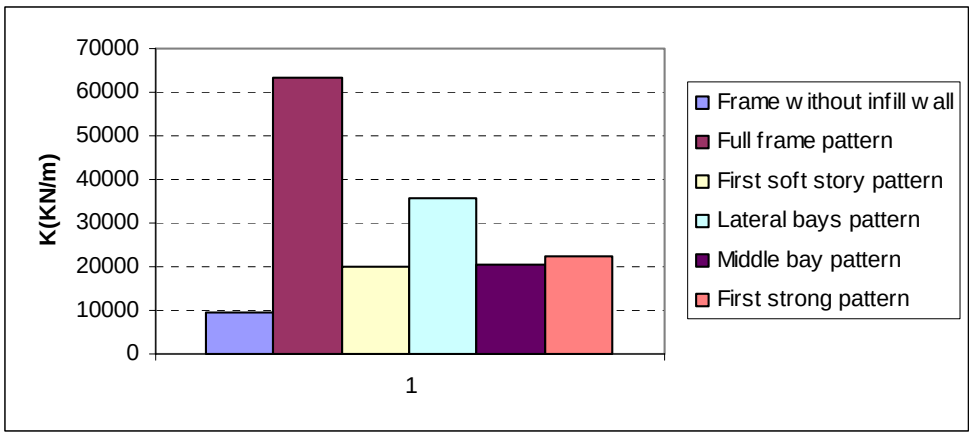

Figure 14. Primary stiffness of samples 1- 6.

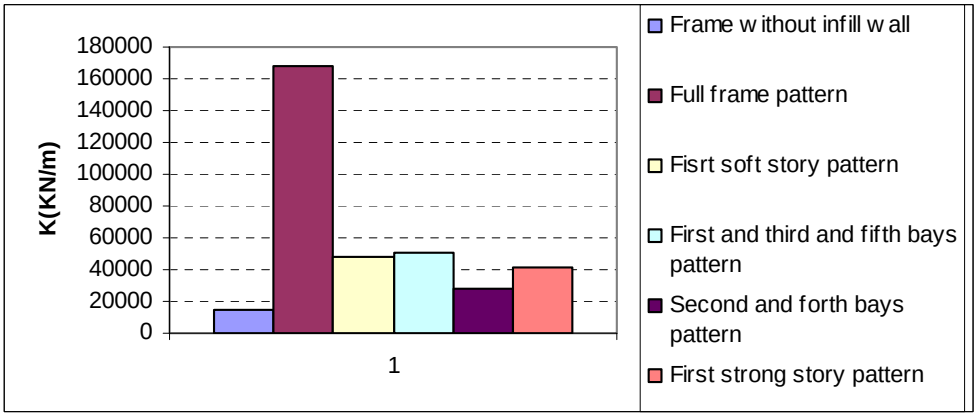

Figure 15. Primary stiffness of samples 7-12.

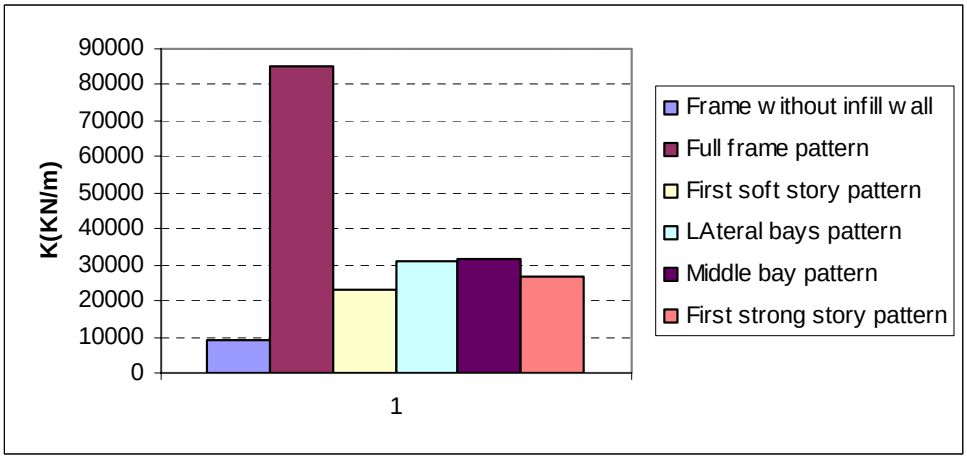

Figure 16. Primary stiffness of samples 13-18.

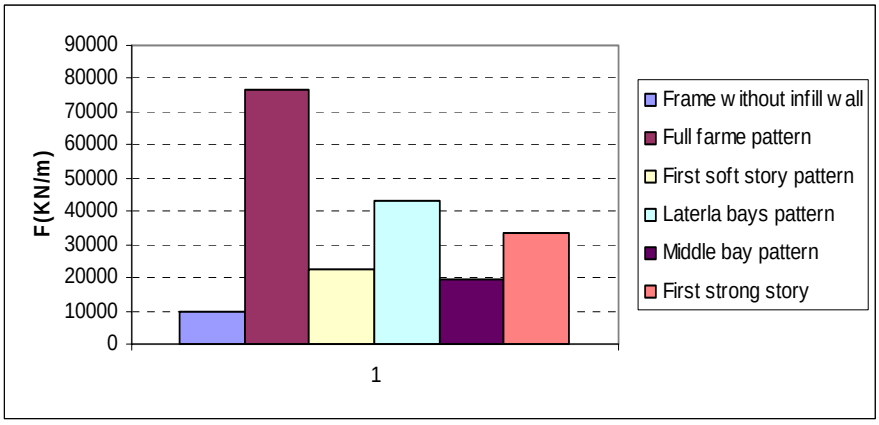

Figure 17. Primary stiffness of samples 19-24.

4. CONCLUSIONS

1. By comparing the amount of energy dissipation in the analyzed samples, it can be observed that the area under the hysteresis curves decreases in all patterns with infill walls as compared to the empty frame pattern.
2. In all cases of different numbers of stories, bays and infill walls height to width ratio, it was observed that ductility increases only in the full frame pattern and decreases in the other patterns.
3. Ductility enhancement in the full frame pattern is proportional to the number of stories, bays and infill walls height to width ratio, and increases with increasing any of the above items. The most important factors in enhancement of the ductility of the empty frame pattern are the number of stories, number of bays and the frame width, respectively.
4. Any increase in the number of stories and bays results in the higher primary stiffness of samples as compared to the empty frame pattern, but increasing the width of frame reduces the primary stiffness of samples.

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