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Effect of the Use of Cross Bar Supporting of Infilled Masonry in Improving Seismic Performance of Steel Buildings

Amir Hosein veisi nezhad[1], Iraj Rasoolan[2]

[1]*Department of Civil Engineering, Behbahan branch, Islamic Azad University, Behbahan, Iran.*

[2]*Department of Civil Engineering, Shahid chamran university of Ahvaz, Iran.*

Abstract

In steel buildings filled with infilled masonry, if there is no appropriate connection between infilled and frames in the direction of vertical on plane thereby it leads the infilled masonries to throw away in the form of traversal that is likely to cause casualties. Therefore, to prevent this throwing, it is necessary to create suitable connection between infilled masonry and the frame. Since the infilled masonries in the normal direction to the plane don't have out of plane required stability, using steel elements like bars can provide stability to these infilled masonries. In this article, by the help of numerical modeling of specifications of holding bars like number, length and diameter under different loading is studied. Results indicated that the more the length of bars of connection between frame and infilled was, the more load capacity and flexibility of its frame increased regarding the area under load-displacement curves.

Keywords: Infilled, infilled masonry, seismic performance, finite element, traversal bar, steel buildings.

I. Introduction

Infilleds are used in buildings to divide spaces or coverage of building circumference. The main problem with infilleds is that they crack suddenly in earthquakes or are completely damaged. As a consequence of cracking, component of the earthquake causes in the direction vertical on wall to exit wall from its plane. This behavior has resulted in a lot of damage in recent earthquakes like Manjil (located in north of Iran, Guilan province) and Bam (located in south-east of Iran, Kerman province). The infilleds work like flat plats under transversal force from earthquake and because of ereated bending torques in it, cracks are created, which are similar to yield lines in flat plats. Among factors affecting transversal strength of infilleds, exciting the action of the infilleds masonry arch is because of the circumferential around the frame. In strong earthquakes longitudinal component causes cracking and crazing.

As a result, infilled tends to throw away from its plane. There are these fracture states of infilleds under interaction plane and traversal forces. As a result, displacement of compound frame must

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be limited, and infilled must be of enough traversal strength to sustain against earthquake. Figure (1). Otherwise, infilled is thrown away from the frame. and the structure faces rapid changes of strength and hardness with its seismic sustaining endangered. This kind of fracture is not only dangerous for the residents, but also for people around the building who might be hit by throwing infilled material.

Fig.2. traversal throwing of infilled in bam earthquake in 1382. (Iran)

Fig.1. style of connection between infilled and steel column with bar in Performance

II. Subject of problem

Compared to experimental models, numerical modeling of infilled masonry under static and dynamic loading is very affordable. A point of great importance is that these models are correct under conditions that materials and interactions between those and the loading are considered appropriately. Reasons of complexity of infilled masonry modeling are:

A) Heterogeneity and incompatibility of the final model because of creating concrete, cement block, mortar and bars.
B) Asymmetry of stress-strain formulas and nonlinear behavior of materials like cement block, concrete and mortar.
C) High complexity of interactions between materials and infilled hardness variations and lack of correct determination of frame strength.
Therefore, for correct modeling of these complex structures, the use of finite element method in micro scale is the best choice because of its generality and coverage of complexities. Because of vertical and horizontal joints, infilled masonry has an incompatible behavior that demonstrates ductile and orthotropic strength specifications. This depends not only on specifications of materials but also interactions between them. In order to analyze the infilled masonry,

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researchers consider two modeling styles namely micro-modeling and macro-modeling. In micro-modeling, all materials are modeled separately while in macro-modeling ingredients of masonry structure are considered as a composite isotropic, homogeneous and united material. (M. Dhanasekar, W. Haider, 2008).

A. Review on previous studies on infilleds

(Page, 1978) was the first to study numerical modeling of infilleds by micro-modeling. In order to model the behavior and fracture in mortar joints, he used a mixture of Mohr – colomb criterion to model sliding and shear fracture in mortar joints and maximum tension strength criterion to model tension fracture in mortar constrains.

(Lotfi and shing ,1994) provided a micro-simple model for shear behavior of masonry wall. In fact, they presented a model for contact between masonry elements and a model for mortar joints in micro-simple model.

(El-Dakkakhni et al., 2003) introduced a new technique for modeling infilled masonry. Basics of this theory are based on equivalent diagonal struts. The only difference is that in this modeling the wall is suggested with three equivalent diagonal struts which is conducted according to alternative dynamic experiments on infilled masonry of a modeled hysteresis behavior of force-displacement in plane of the infilled frames based on tension-compression constrain. In this method the filling panel is replaced by a combination of three parallel constrains (a diagonal constrain and 2 constrain parallel with it) in the direction of model loading.

(Moghadam and Mohamadi, 2006) conducted an analysis and experimental study on crack tolerance in concrete and steel frames filled with masonry and presented a new analytic method to assess shear strength and crack pattern in panels of infilled masonry. (*Mohebkhah, Tasnimi and Moghadame*, 2007) introduced a nonlinear model for steel frames with infilled masonry with opening using nonlinear finite element method.(*Hargreaves and Moghadame*, 1991) also conducted experimental studies on walls with infilled masonry and presented a repair plan with masonry for compound frames.

(*Fonseca,* 1998) *Silva and Lourenco* presented results of an analytical study to model a frame one floor steel infilled with masonry by finite element. (*Albanesi ,Carboni*, 2004) studied effects of infilled masonry on seismic responses of frames of reinforced concrete by the means of nonlinear model of finite element. *(Manos et al*., 2010) conducted experimental studies on the effects of infilled masonry on seismic responses of multi-floor reinforced concrete frames. Based on the behavior of infilled and inter-frame we can replace it with an equal diagonal element. This theory was initially introduced by *Holmes*.(*Moghadom*, 1988) conducted some experiments by the use of a seismic table on compound frames and seismic behavior of brick infilled frames. *Abel,* (1992) defined the nonlinear seismic response of steel frames.

(Mehrabi and shing, 1997) presented a finite element model of reinforced concrete frames infilled with masonry. (*Moghadam and Dawling*, 1989), who conducted experiments on compound steel frames with a 100mm lateral distance between frames and the infilled masonry, reported a %40 reduction in the hardness of compound frame. In their experiment, the mentioned distance continued under the loaded corner. In another sample, they provided only a 3mm distance in the loaded corner (between infilled masonry beam and the column), which caused a

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%44 percent of reduction in hardness and a little reduction (about %10) in diagonal crack resistance. Moreover, presence of a 50 mm crack between infilled masonry and columns along with sticking infilled masonry to the frame in the corner, resulted in a %43 reduction of hardness, %50 reduction of diagonal crack resistance and %44 reduction in overall hardness.

III. Modeling method and the assumptions

In this article, by using a finite element method, the behavior of infilled masonry has been studied. In this method of finite element analysis, analytical softwares have of an incremental computation process i.e. they can calculate hardness of system which is depended on geometrical changes, and changes in material properties at the end of each matrix increment; and a new hardness matrix is created in the next increment for loading or displacement. Due to the behavior of joints of connection, infilled masonry exhibits orthotropic properties; moreover, infilled masonry is weak against tension. This behavior is studied by several researchers by studying the fracture region in 3D tension spaces. Tension stress-strain curve of infilled masonry resulted from these studies is shown in figure (3). (*Lothfi and shing*, 1994).

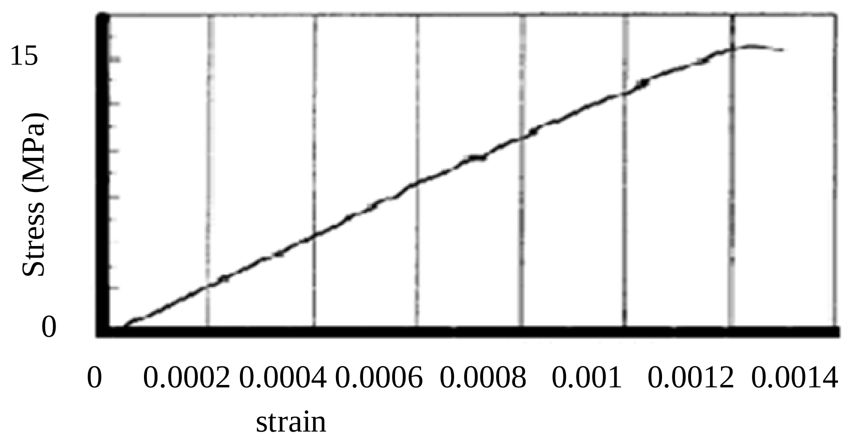

Fig.3. Stress-strain curve of concrete block (Lothfi and shing , 1994)

A. Modeling of bars

Modeling was conducted using ABAQUS and bars were modeled using an element called REBAR. In these models, we assumed that the bars are capable to tolerate a maximum of 500Mpa tension and their compressive strength is reduced by only %2 of yield point (10 Mpa) (Lothfi and shing, 1994).

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B. *Explicit finite element chart*

Explicit method is to analyze structures with dynamic behaviors like impact and collision. Additionally, this modeling method is also quasi static. In this method problems are solved in a numerical way without formulating hardness matrixes and explicit central discrepancy is used to satisfy dynamic equations in eq. (1). Where u, M, U and w, are displacement vector, total mass matrix, internal energy and internal done work respectively.

$$\mathbf{M\ u + U - W = 0}$$

ABAQUS software needs about 10.000 to 1.000.000 increments in its explicit analysis state in order to converge responses and obtain correct outputs. Therefore, calculation time for these increments is adjusted very short and overall analysis time will not be long. The Maximum increment time, which is used in these calculations, depends on the stability of the structure that is derived from calculation of natural frequency of system in the form of modes of dynamic system. Figure (4) shows infilled masonry analysis project.

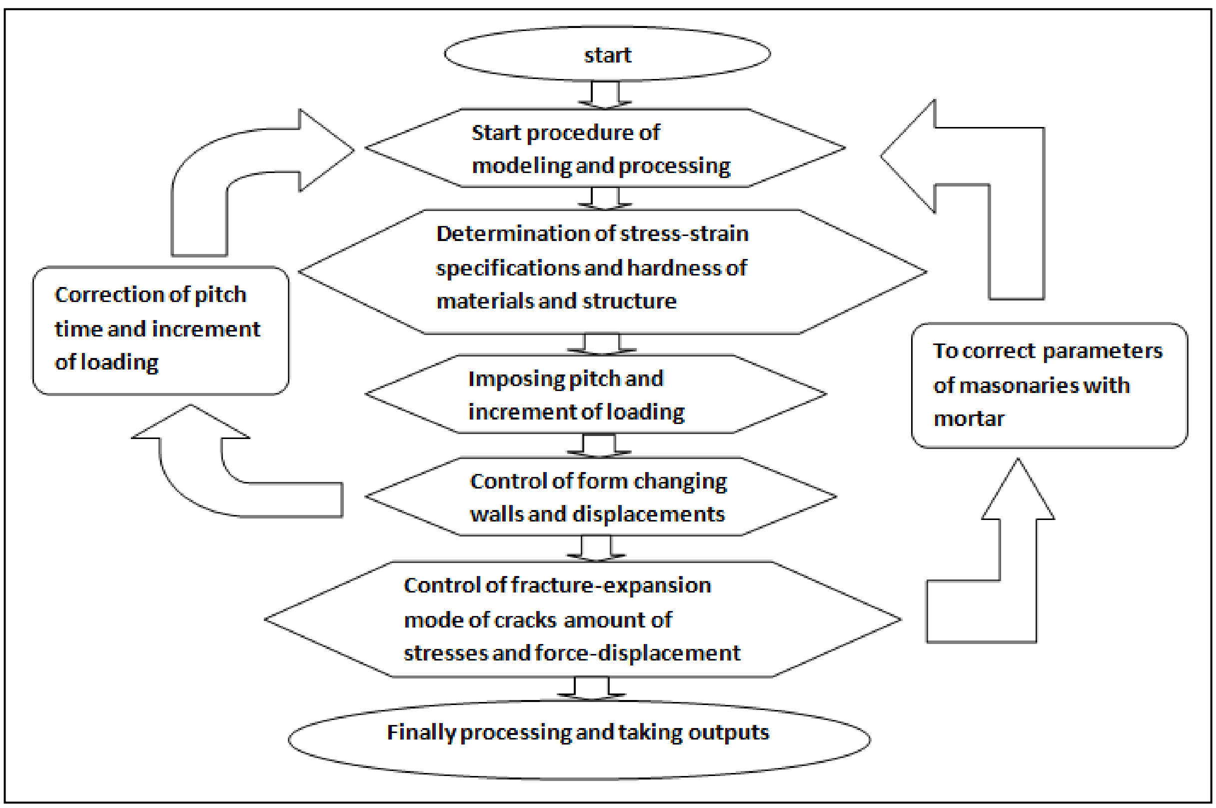

Fig.4. analysis chart of infilled masonry

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IV. Modeling of specimens

Selected experimental specimen to study infilled masonry behavior and modeling accuracy encompasses a single floor steel frame model including infilled with solid concrete masonry block which is put under a lateral force. This model was tested by *Daw* et al. in 1989. As shown in fig. (5) the compound frame is under a lateral force.

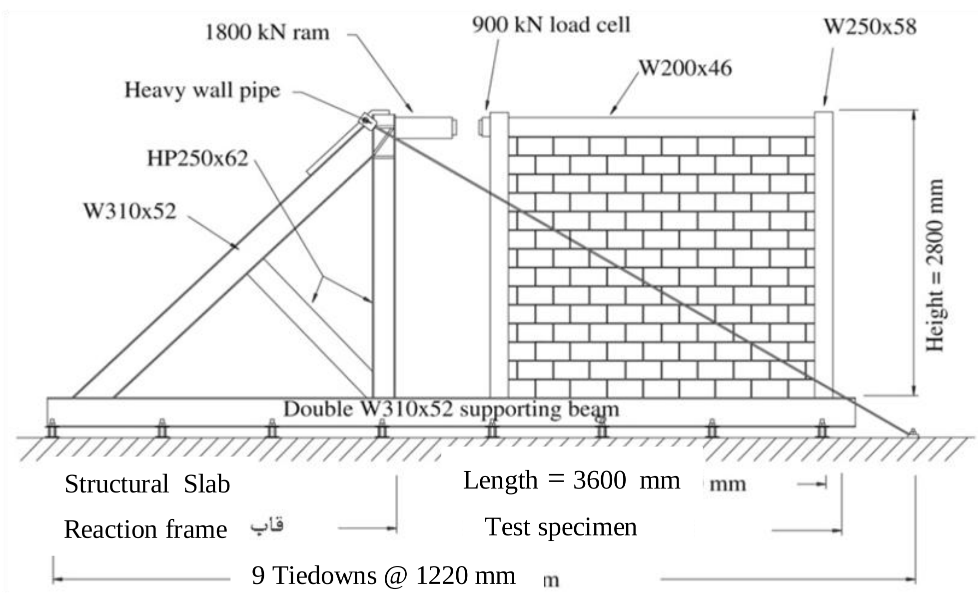

Fig.5. experimental model experimental model compound from (Dawe JL, Seah CK1989)

A. Theories of modeling

Numerical modeling of specimen frame is identical to the experimental test in ABAQUS finite element software and it is a micro type. Mortar dimensions are neglected and blocks are put together directly on and beside one another. Neglecting mortar elements is only to simplify the model and calculations. Instead of modeling mortar, its properties are allocated to contact regions of blocks. Mortar specifications which are allocated to contact constrains are: hardness coefficients of penalty methods in tangential and vertical directions on contact plane, friction coefficient and mortar shear strength (for infilled masonry plastic behavior Mohr-Colomb criterion was used). Contact constrains between blocks must act in a way that on one hand allows bricks to slide on each other and on the other hand lower the possibility of indenting them. Deleted mortar elements and its mechanical specifications as contact constrains are allocated to all block areas. Specifications of these elements are shown in table (1).

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Table 1

Specifications of materials and used elements in masonry (Dawe JL, Seah CK. Liu Y. 2001)

<table>
<tr><td rowspan="4">Specifications of solid concrete block</td><td>Dimensions (mm)</td><td colspan="6">400 × 400 × 200</td></tr>
<tr><td>Elastic Specifications</td><td colspan="6">E= 15 Gap ν = 0.15</td></tr>
<tr><td>density</td><td colspan="6">ρ = 2100 kg/m3</td></tr>
<tr><td>Compressed strength</td><td colspan="6">fc = 31 Map</td></tr>
<tr><td rowspan="5">Specifications of steel frame</td><td rowspan="3">Plastic Specifications</td><td colspan="3">Yield Stress</td><td colspan="3">Plastic strain</td></tr>
<tr><td colspan="3">240</td><td colspan="3">o</td></tr>
<tr><td colspan="3">360</td><td colspan="3">0.2</td></tr>
<tr><td>Elastic Specifications</td><td colspan="6">E = 200000 ν = 0.15</td></tr>
<tr><td>density</td><td colspan="6">ρ = 7850 kg/m3</td></tr>
<tr><td rowspan="2">Specifications of contact constraint</td><td>Mortar stoking coeficient</td><td colspan="6">C = 0.6 Map</td></tr>
<tr><td>Friction coefficient between blocks filled with mortar</td><td colspan="6">μ = 0.25</td></tr>
<tr><td rowspan="3">Specifications of cohesive element</td><td rowspan="2">Plastic Specifications</td><td colspan="2">Angle of Friction</td><td colspan="2">Folw stress Ratio</td><td colspan="2">Dilation Angle</td></tr>
<tr><td colspan="2">12</td><td colspan="2">1</td><td colspan="2">35</td></tr>
<tr><td>Normal and tangential penalty hardness coefficients on contact surface</td><td colspan="2">Knn = 20 e 9</td><td colspan="2">KSS =8 e9</td><td colspan="2">Ktt = 8e 9</td></tr>
</table>

The mentioned model is a steel frame including an infilled masonry with the dimensions of 280×360 cm. Infilled masonry is constructed with blocks of 400×200×200 mm dimensions. sections of connection between beam and column are W 200× 46 and W250× 58 respectively. The connection of the beam and the column to the frame and the connection of columns to the ground is fixed. In the conducted numerical modeling, SHELL and Solid elements where used to model frame and blocks respectively. (*Dawe JL, Seah CK, Liu Y*, 2001).

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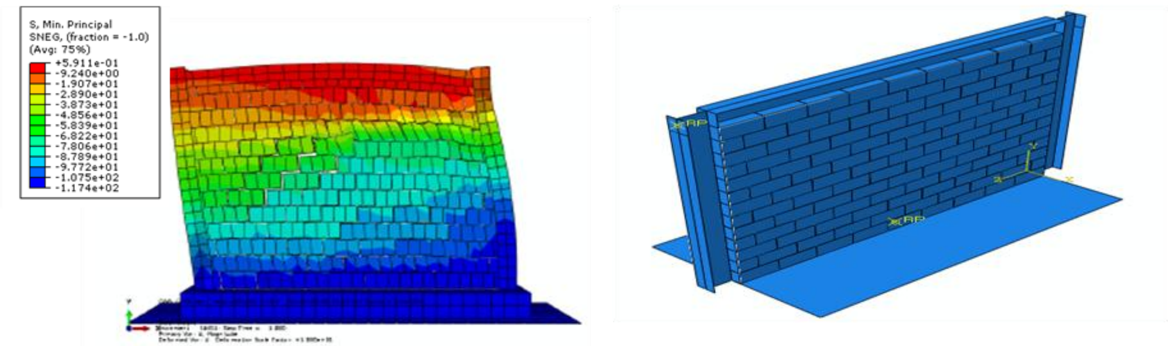

Fig.6. Modeled infilled and resulting displacement under horizontal force.

B. Comparison between experimental results and numerical modeling results (Calibration)

In order to guaranty the accuracy of the constructed model in figure (7), the analysis results it in ABAQUS software are compared with the results of the experimental model. As shown in figure (7), there is a good match between strength and initial hardness of the numerical model and which of the experimental model (error percentage is %4).

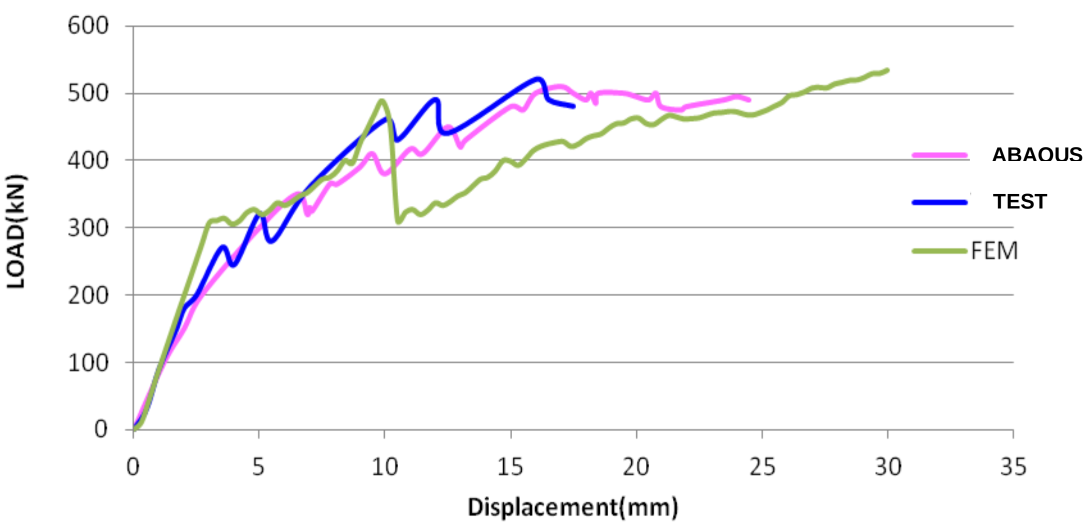

Fig.7. Basic shear- displacement curve

V. Effects of diameter, length and distance of the bar on compound frame behavior in steel frame, Longitudinal loading in the direction of infilled masonry (In line Z axis)

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In this article we study the effects of diameter, length and bar distance on infilled masonry in a parametric way.

A. Effects of bar diameter

To study the effects of diameter, several same length bars placed in 70cm distances with different diameters of 10, 12 and 14 cm, were considered schematically in figure (8) modeling. In the case where bars were present, the frame load capability is increased and compound frame tolerates much stresses results of which are illustrated in force-displacement curve in figure (9). According to stress counters in fig (10), there were stresses in the location of bars, which shows stress transmission between the column and infilled masonry. It should be noted that the thickness of infilled masonry, anchorage length of bars in concrete and vertical distance of stocked bars to the column are 20 cm, 40 cm and 70 cm respectively.

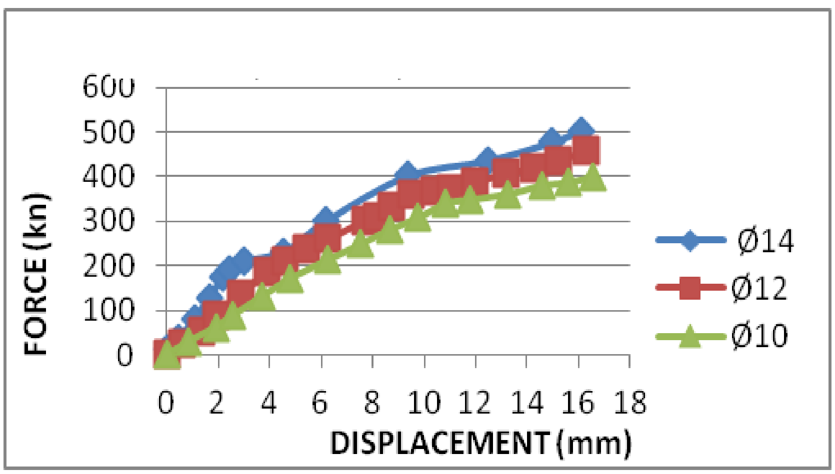

Fig.9. Comparison of force-displacement curve related to effects of bar sizes on compound frame behavior

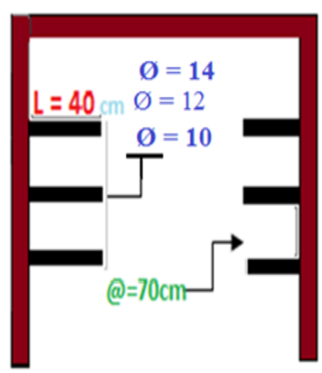

Fig.8. arrangement of traversal bars

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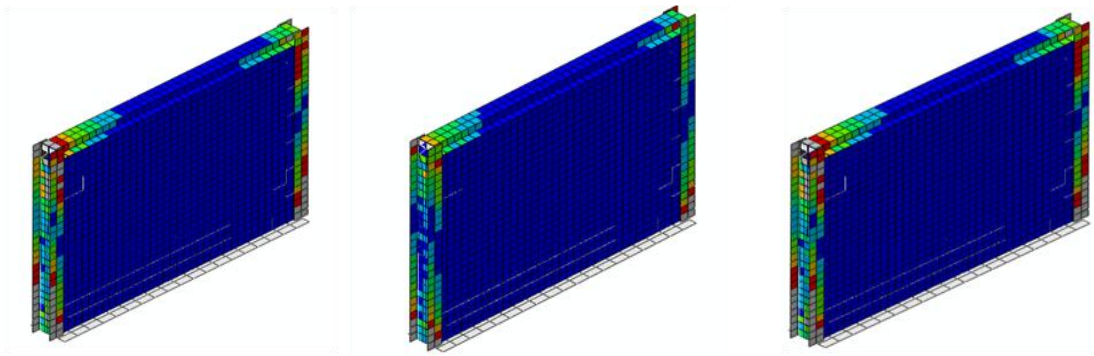

Fig .10.situation of stress in supported compound frame with bars with dimensions of 10, 12, 14 Cm

B. Effects of bar length

In this case, diameter and distance of the bars are considered constant and according to figure (11) bars with different lengths are used in compound frame. As shown in figure (12), the longer the connecting bars between the frame and infilled masonry are, the higher load capacity goes and its formability under the load-displacement curve is improved. In figure (13) there are also some stress in the location of bars which show stress transition between the column and block infilled masonry.

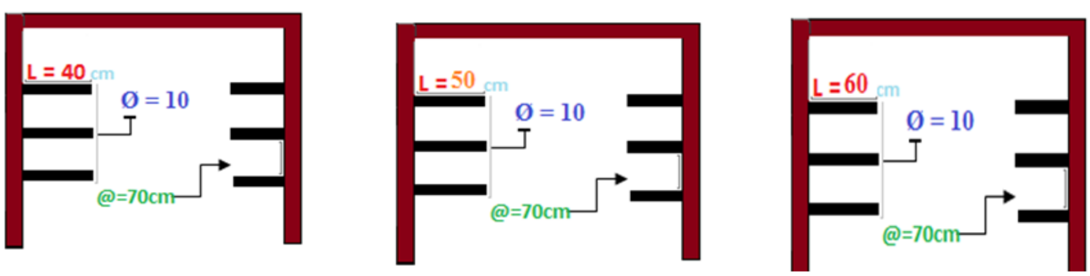

Fig .11.different length of bars in compound frame to prevent traversal throwing

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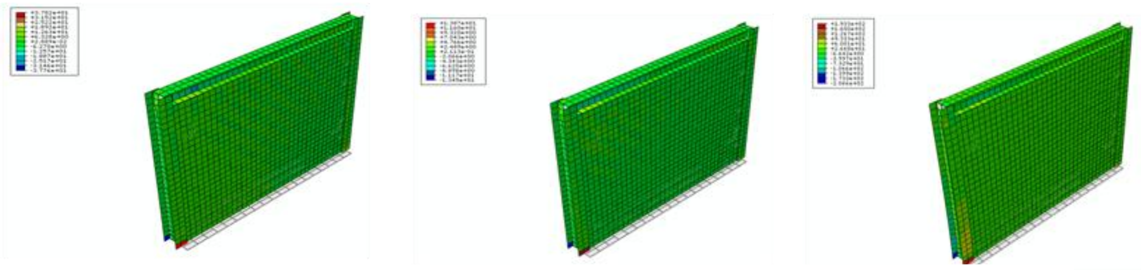

Fig. 13. Situation of stress in supported compound frame with bars with thickness 20 cm and lengths 40, 50 and 60cm.

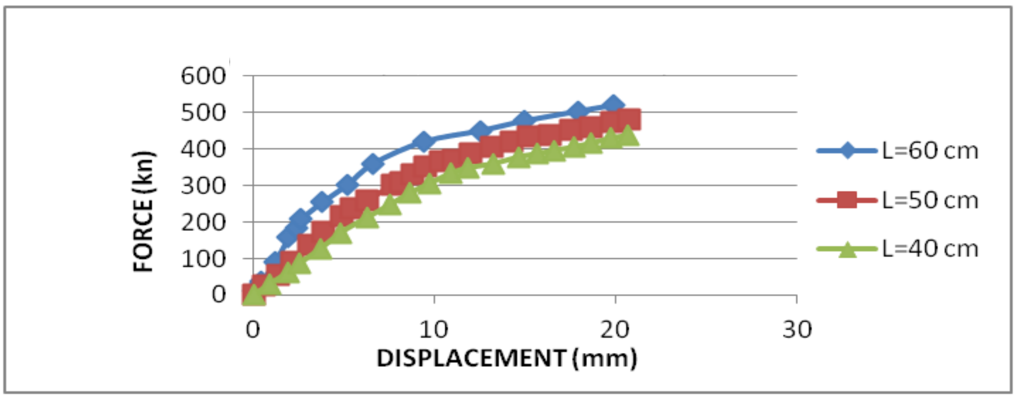

Fig.12. Comparison of force- displacement figure related to bar length effects on compound frame behavior

C. Effects of number of the bars

In this section diameter and length of the bars are considered constant and according to figure (14) the distance between the bars is variable. According to Von-Misses stress counters in figure (15), it is clear that the more numbers of bars connected to the frame, the less vertical distance there is between the bars. So the capacity of load capability is increased and its formability is improved based on the area under the load-displacement curve. The results of this case are presented in figure (16).

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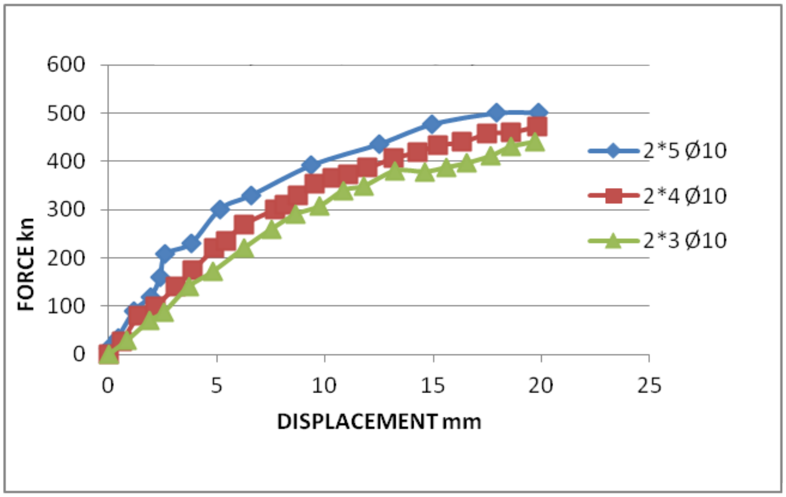

Fig.16. comparison of force – displacement curve related to numbers of bars on compound frame behavior

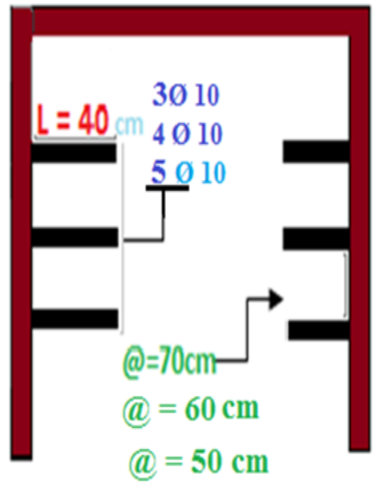

Fig.14. Numbers, anchorage length, vertical length and bar diameter in compound frame

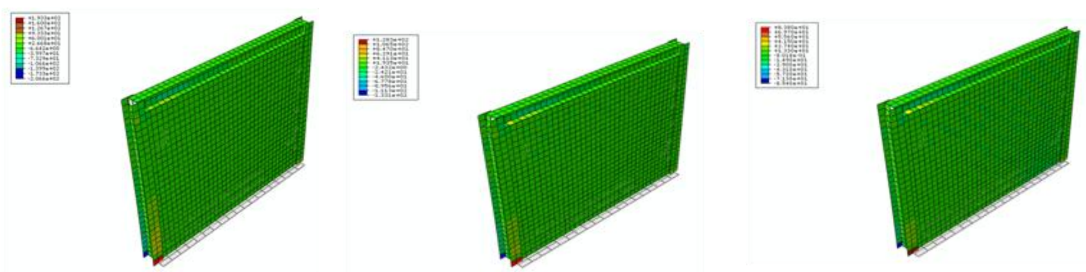

Fig.15. Stress situation in supported compound frame with bars with tichness20 cm and distance 50 cm, 60 cm, 70cm

VI. **Conclusions**

In assessment and parametric analysis of infilled masonry with a modeled steel frame, these results were obtained:

1- The behavior of supported infilled masonry can be improved significantly against shear forces caused by earthquake by the use of connecting bars between the steel frame and infilled masonry. Application of connecting bars with appropriate diameter, distance and length results in increased formability of the compound frame.

2- Cracks in materials and infilled masonry are diagonal and separation is obvious in horizontal joints.

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3- The strain imposed on the bars and force-displacement curves of compound frame show that bars are actively contributing to load capability actively; as a result, their behavior is considered appropriate.
4- According to the area under the force-displacement curve and various studied bar diameters, a bar with a 14cm diameter and a length of 40 cm with 70cm distance is considered as a basic for supporting masonry wall and column to prevent traversal throw.
5- The longer length of the bars connecting frame and infilled masonry, the more load capability there is and according to the area under the force-displacement curve the formability is improved.
6- The more number of bars connected to the frame, the less vertical distance there is among bars. Therefore, load capability is increased and its formability is increased according the area under the force-displacement curve.
7- Infilled masonries provide stability for the structure against traversal loading and by creating extra strength in the frame, play a key role in the overall stability of the structure against earthquake forces (positive effect of infilled masonry on the frame).
8- Infilled masonry imposes an extra hardness on the frame around it; therefore, in structures with structural bearing systems, in case of an earthquake, frames absorb a greater deal of the force (negative effect of infilled masonry on frame). This situation can be improved by including interaction between frame and infilled masonry and spacing them. It also helps to fix infilled masonry to the frame using steel bars with appropriate distances to prevent imposition of an extra hardness to the frame and throw-out of the infilled masonry.
9- Although infilled masonries stand a major force, this significant force in the first loading cycles causes brittle fracture of infilled masonry and it is then is transferred suddenly the columns. This sudden transition breaks down the columns and compound frames (negative effect of infilled masonry on frame). However, by accounting steel connector elements between infilled masonry and frame, this problem is greatly solved.

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