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EFFECT OF VERTICAL LOAD ON ACCEPTANCE CRITERIA OF MASONRY INFILLED STEEL FRAME FOR LINEAR PROCEDURE

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Abstract

An experimental investigation was carried out to find out the effect of vertical load on the acceptance criteria of infilled steel frames. To reach this goal 4 half-scale single-story single-bay masonry infill specimens were tested. Two specimens had moment-resisting steel frames, while the remaining specimens had simple steel frames. For each type of frame, one subjected to combined lateral and vertical loading and another applied under only lateral loading. Comparing the results of experimental test showed that the vertical load had not significant influence on the in-plane stiffness and strength of the infill specimens.

Regarding the using of infill panels for retrofitting and strengthening of the existing building, the seismic guidelines have recommended linear and nonlinear procedures to estimate stiffness and strength of infills. The parameters for linear procedure include m-factor and expected capacity. These parameters were calculated based on experimental results through idealized backbone curves. The results show that the parameters of linear procedure do not affect by vertical load in the specimen with moment-resisting frame. However, the m-factor is considerably increased in the infilled simple frame specimen by applying vertical load. Finally, it can be concluded that the vertical load is beneficial for the in-plane behavior of infilled frame especially in the infill surrounded by simple frames. Therefore it is recommended that the effect of vertical load as well as connection rigidity of frame should be considered in seismic guidelines for infilled frames.

Keywords: infill; steel frame; vertical load; m-factor;

1. Introduction

Infill walls are usually considered as non-structural members in the seismic provision. They are used to fill steel or concrete frame as interior or exterior partitions. The presence of infills increases the stiffness and strength of the infilled frame in comparison with the bare frames. The interaction between the infill wall and the frame may or may not be beneficial the seismic behavior of the structure. Although several models [1-5] have been proposed to consider the effects of infill on the structures but these models are not sufficiently reliable. This is due to inherent uncertainty and several effective variables of the infilled frames such as mechanical properties of infill, connection of infill to frame, details of surrounding frame, workmanship and vertical load applied to beam or column of the frame. During the last decades, the effect of masonry infills on in-plane behavior of steel frame is the subject of many researches which is focused on the seismic evaluation and retrofitting on existing buildings. The infills can be used in retrofitting and strengthening of the existing buildings.

The seismic guidelines such as ASCE41-06 [6], ASCE41-13 [7] and FEMA356 [8] suggest linear and nonlinear procedure to estimate the strength of infill panels. In case of linear procedure, it is needed to estimate the capacity of infill panels include the m-factor and the expected strength of it. However, the effects of applying vertical load have not been considered in proposed method that estimates the strength of infilled frame.

Some researchers studied the influence of vertical load, including the gravity load on top beam of the frame as well as axial loads of the columns, on the behavior of infilled frames. Regarding the influence of columns axial loads, Valiasis and Stylianides [9] carried out some experimental tests on 1/3 scaled RC frames with brick masonry infills. They observed that the presence of axial load on the column improves the in-plane strength of the infilled frames. Some researchers studied the effects of vertical load on the in-plane behavior of infilled frames. Stafford Smith [10] investigates the effect of vertical loading on the lateral stiffness and strength of concrete infills surrounded by steel frames. The applied vertical load was distributed on the top beam of the infilled frames. He found out that the lateral strength and stiffness of the infilled frames are increased by applying vertical load which is lower than half of compressive strength of the infill panels. Nevertheless higher levels of vertical load have adverse effect on the behavior of the system. Lafuente et al. [11] conducted ten half scaled tests on masonry walls surrounded by minor reinforced concrete frames. The specimens were subjected to combined vertical and cyclic lateral loading. The vertical load was imposed to top beam of the specimens. The amounts of vertical load were equal to 5%, 7.5%, 10% and 15% of infill compressive strength. The results showed that the maximum increase in lateral strength (90%) as a consequence of applying vertical load occurs under vertical load equal to 10% of infill compressive strength. Mehrabi et al. [12] conducted some experimental tests on reinforced concrete frames with masonry infill panels. It can be inferred from this study that the distribution of the vertical load between the columns and the top beam is not important. Also, they found out that an increase of 50% in vertical load results in 25% and 30% improvement in the strength and initial stiffness, respectively. Liu and Manesh [13] carried out an experimental investigation on concrete masonry infilled steel frames subjected to combined lateral and axial loading. This study has shown that the presence of axial load results in a considerable increase in the lateral strength of infilled frames. Based on this study, the ductility of the infilled frame is improved by applying the axial load which is less than 10% of infill compressive strength.

This paper is focused on the effect of vertical load on the parameters which is required for linear procedure of infilled frames. For this purpose four masonry infill specimens were experimentally tested. Two specimens had moment-resisting frame and two others simple frame. In each frame type, one subjected to simultaneous lateral and vertical loading while, another was imposed under only lateral loading. The in-plane behavior of the specimen is compared. Afterward, the idealized backbone curve for each specimen is derived from hysteresis behavior. Finally the m-factor and expected strength of the specimen are compared.

2. Experimental program

2.1 Test specimens

Four specimens consisted of two moment-resisting steel frames and two simple steel frames were tested under reversed lateral cyclic loading. In the former, the frames had rigid beam-column connections, while in the latter the frames had pinned beam-column connections. The frames were single-story single-bay with 1.5 m height and

2.25 m length. The thickness of the infill panels was 10 cm. IPBL120 and IPBL180 sections were used for the beams and columns of the frames, respectively.

Table 1 summarizes the overall properties of the specimens. The first column of Table 1 shows the name of the specimens. The letter M at the beginning of the names indicates that the material of the infills is masonry (M). The PC or RC represents the type of beam-column connections of the frame (RC for rigid and PC for pinned connections). The specimens having vertical load are demonstrated by VL in the last part of their names.

Table 1– Summary of specimens

Specimen	**Column**	**Beam**	**Beam to column connection**	**Vertical load (kN)**
M-RC	IPBL 180	IPBL 120	Rigid	0
M-RC-VL	IPBL 180	IPBL 120	Rigid	200
M-PC	IPBL 180	IPBL 120	Pinned	0
M-PC-VL	IPBL 180	IPBL 120	Pinned	200

2.2 Test setup

The overall schematic view of the experimental setup, including the specimen, lateral and vertical loading setups and some other details are illustrated in Fig.1. The lateral load was applied to the specimens by an actuator with 50 ton capacity. The assumed directions of the lateral loading which will be used in following of paper to explain the behavior of the specimens are shown in Fig. 1. The vertical load was imposed to the top beam of the bounding frame by a hydraulic static jack. The vertical load setup is design in a way that the load uniformly applied to the specimen. A view of the vertical loading setup is depicted in Fig. 2. The vertical load was 20 ton, approximately equal to 10% of compressive strength of the infill panel and remained constant during testing.

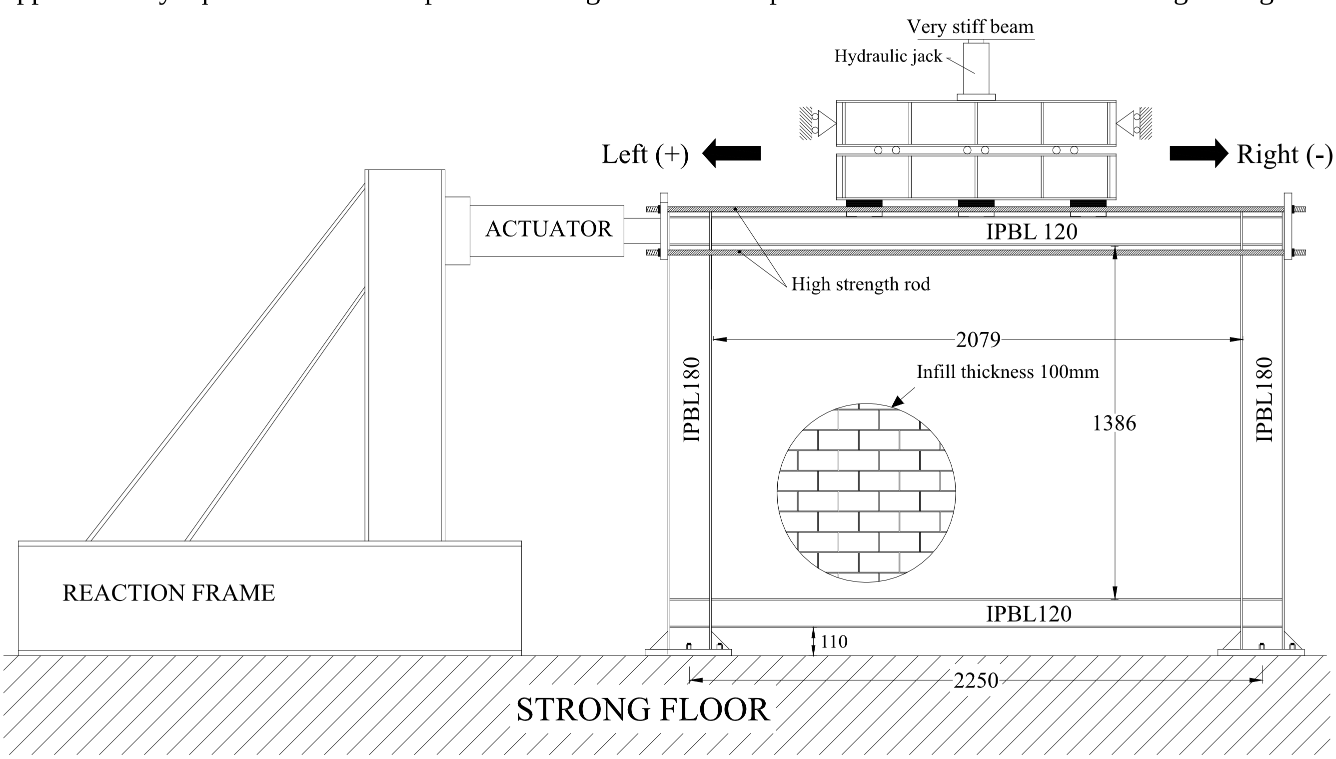


Fig. 1 – schematic view of test setup, dimension in mm.

2.3. Material properties and loading history

The average compressive strength of the mortar specimen was obtained 8.3 MPa. The average compressive strength and module of elasticity of 15 masonry prisms, measured based on ASTM C1314 [14], were obtained as 9.5 MPa and 1710 MPa, respectively. The mean values of yield stress, ultimate stress and modulus of elasticity of the steel were 313, 485 MPa and 182.815 GPa, respectively.

Displacement control loading pattern recommended by FEMA461 [15] was applied to the infill specimens, shown in Fig. 2; the amplitude of the first cycle was 1.6 mm. Each cycle was repeated twice and gradually increased to 125mm by multiplying 1.4 by previous cycle amplitude.

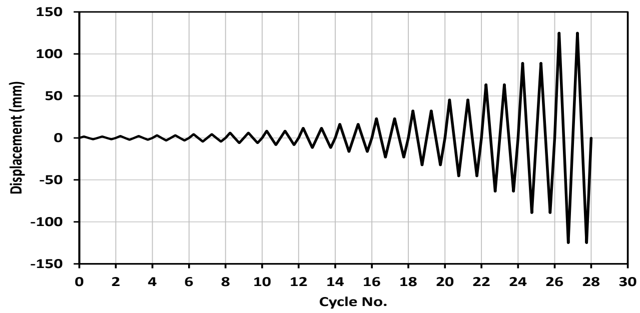
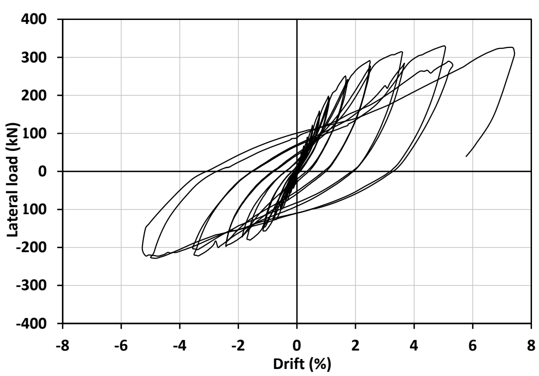


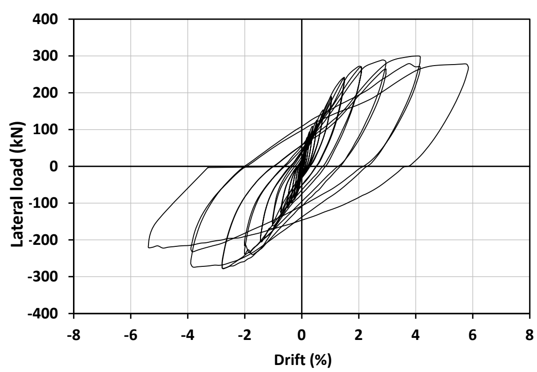
Fig. 2 – Displacement history

2.3. Experimental Result.

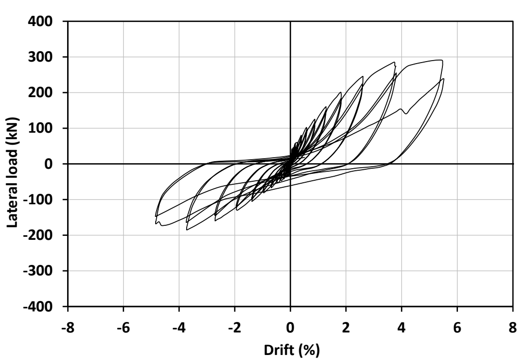
Hysteresis behavior of the specimens are depicted if Fig. 3. It is obvious from the hysteresis curves that the vertical load has not significant effect on the general behavior of the both specimen with rigid or pinned connections of beam to column. It should be mentioned that the strength of specimen M-RC in negative direction was less than expected due to out of plane movement of the specimen during the test.



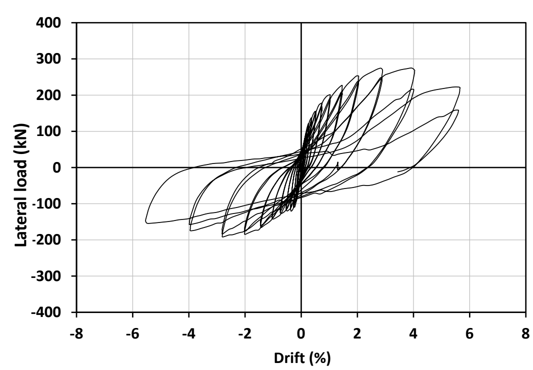
(a) Specimen M-RC



(b) Specimen M-RC-VL



(c) Specimen M-PC



(d) Specimen M-PC-VL

Fig.3 – Lateral load-drift relation of specimens.

Stiffness, strength of the specimens and their corresponding are available in Table. 2. The crushing strength (load at major infill cracking) of the specimen with rigid beam-column connections was raised by applying the vertical load. However, the vertical load almost did not change the crushing capacity of the infilled simple frames. Moreover, the influence of the vertical load on the practical stiffness [16] and maximum strength was not considerable.

Table 2– Strength and stiffness of the specimens and their corresponding drifts

Specimen	Practical stiffness (kN/mm)	Major infill cracking		Maximum strength	
		Load (kN)	Drift at (%)	load (kN)	Drift (%)
M-RC	35	10.6	197	1.07	325
	-39	-8.4	-125	-0.79	-218
M-RC-VL	40.8	8.4	242	1.49	300
	-35.7	-6.5	-200	-1.45	-278
M-PC	52	5.6	200	1.8	290.2
	-29	-3.6	-130	-1.9	-185.3
M-PC-VL	43.5	6.8	201	1.03	274
	-33.3	-5.4	-142	-0.98	-191.8

3. Analytical Investigation

In the following, regarding the linear procedure in seismic guidelines, analytical investigation is carried out to find out the influence of vertical load on the in-plane performance of infilled steel frames. For this purpose, required parameters for doing linear analysis of the specimens are calculated. In the seismic guidelines such as FEMA356 [8] & ASCE41-13 [7], infilled frames are considered as Deformation-Controlled elements. For linear analysis of these elements two important parameters, m-factor and Q_{CE} are required. The former is "modification factor for expected ductility at desired performance level" and the latter is the expected strength of the element. For deformation-controlled action, the element or component must satisfy Eq. (1).

$$m\times \kappa \times Q_{CE} \geq Q_{UD} \tag{1}$$

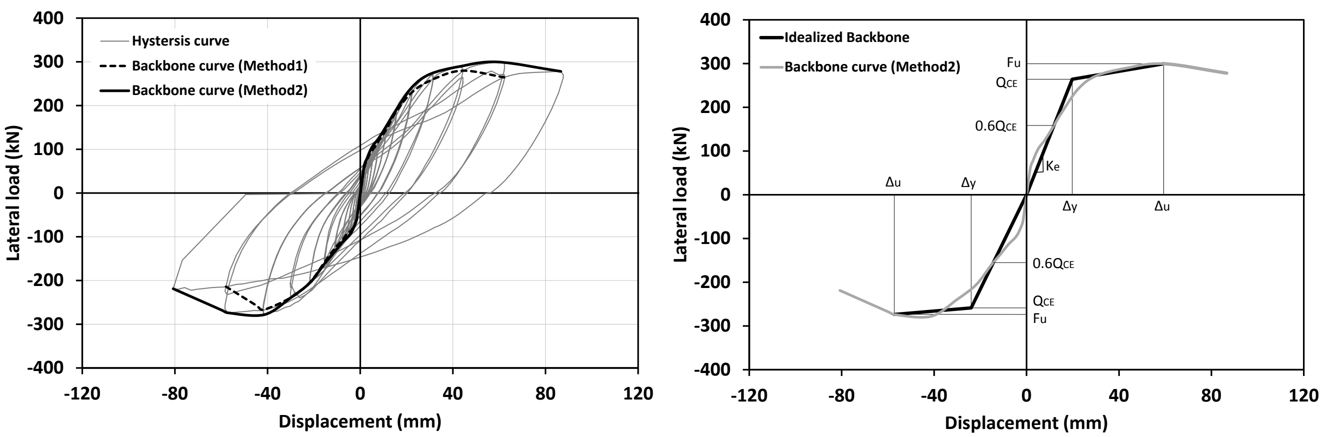
Where Q_{UD} is the load caused by gravity and earthquake forces and κ is the knowledge factor [30], which is assumed as 1.0 in this study. In the following, the m-factors and expected strengths (Q_{CE}) of the infill specimens are calculated.

The required parameters of linear analysis can be calculated through the idealized backbone curve. The idealized curve should be derived from backbone of load-displacement hysteresis behavior. There are two general methods to derive backbone curve from experimental hysteresis data;

1- The backbone curve shall be drawn through the intersection of first cycle curve for *i*-th amplitude step with the second cycle curve of the *(i*-1*)*-th deformation step for all *i* step [6].
2- The backbone curve could be extracted through the points corresponding to the maximum displacements of the first cycle of each increment of loading [7].

In this study, the backbone curves obtained from two explained methods are referred as Method1 and Method2, respectively. Fig. 4a shows the backbone curves of specimen M-RC-VL derived from hysteresis curve in each direction of loading for the two mentioned methods.

Before calculating the m-factor and Q_{CE}, the backbone curve should be converted to an idealized bilinear curve. There are different methods to idealize the backbone curve [6-7, 17]. The recommended method of ASCE41-13 is applied in this study and summarized as follows: the first line of idealized relationship begins from the origin with a slope equal to effective lateral stiffness, K_e. The effective lateral stiffness, K_e, is calculated as the secant stiffness at base shear corresponding to 60% of expected strengths (Q_{CE}). The expected strength should not take greater than maximum strength at any point of backbone curve. The second line, which has positive slope, is determined by a point corresponding to the target displacement and another point at the intersection with first line such that the areas below the idealized and backbone curve become approximately equal. The target displacement is taken as the displacement corresponding to the maximum strength. One should keep in mind that the procedure of developing the idealized backbone curve needs graphical or computational iterations. For instance, the idealized curve corresponding to Method2 backbone curve of specimen M-RC-VL is depicted in Fig. 4b.



(a) (b)

Fig.4 – (a) Backbone curves of specimen M-RC-VL; (b) Idealized of backbone curve (Method2) of specimen M-RC-VL.

The m-factor can be calculated as $0.75^2 \times \Delta_u/\Delta_y$ for Life Safety (LS) performance level. The Δ_u and Δ_y are displacements corresponding to ultimate and yield strength, respectively as illustrated in Fig. 4b. Table 3 shows the parameters of linear analysis of the infill specimens. The parameters are not calculated for specimen M-RC in negative direction of loading, due to unreliable results caused by out of plane movement of the specimen.

Table 3 – Parameters of linear analysis of the specimens

Specimen	**K_e (kN/mm)**		**m-factor**		**Q_{CE} (kN)**		**m×Q_{CE} (kN)**	
	Method1	**Method2**	**Method1**	**Method2**	**Method1**	**Method2**	**Method1**	**Method2**
M-RC	12.5	13.8	1.7	2.2	226.4	263.1	379.6	590.6
	N.C.	N.C.	N.C.	N.C.	N.C.	N.C.	N.C.	N.C.
M-RC-VL	13.3	13.4	1.4	1.7	231.3	264.1	331.7	446.4
	12	10.8	1.4	1.3	-201.5	-258.6	-283.5	-347.3
M-PC	9.7	8.6	1.9	1.5	160.2	254.3	308.8	394.1
	5.3	6.9	1.4	2.1	-117.9	-103.7	-165.4	-217.1
M-PC-VL	33.4	29.6	4.8	4.7	168.8	210.2	810.9	982.3
	36.5	36.6	5.2	6.3	-118.8	-136.7	-620	-865.8

Considering the results shown in Table 3, there is significant difference between the $m \times Q_{CE}$ of the specimens with pinned connections (M-PC and M-PC-VL), due to applying the vertical load. However, this difference is marginal for the specimens with rigid connections (M-RC and M-RC-VL). In these specimens, the Q_{CE} is not considerably changed by applying the vertical load. Whereas, the maximum difference between the Q_{CE} of specimens M-PC and M-PC-VL is observed in negative direction as 32% (comparing -136.7 with -103.7). Regarding the m-factor, the presence of the vertical load causes an increase from 250% (comparing 4.8 with 1.9) to 372% (comparing 5.2 with 1.4) in the specimens with pinned connections, while, it decreases slightly in the specimens with rigid connections. Therefore, it can be concluded that for the infill specimens having moment-resisting frame, the applying of vertical load has negligible effects on the parameters of linear analysis. However, it improves the m-factor of the infilled simple frame specimens at least by 2.5 times.

4. Conclusions

The effect of vertical load on the parameters of linear procedures recommended by seismic guideline was investigated. For this purpose an experimental program was carried out on 4 infilled steel frame specimens. To consider the influence of beam-column connection rigidity of bounding frame, the infill specimens included two moment-resisting steel frames (with rigid beam-column connections) and two simple steel frames (with pinned beam-column connections) were tested. In each type of frame, one specimen was imposed under combined lateral and vertical loading and another was subjected only to lateral loading. The vertical load was about 10% of compressive strength of the infill and applied on the top beam of infilled frames. Considering the results of experimental tests, an analytical procedure was done to find out the vertical load effects on the parameters of linear analysis for infill specimens. The following results can be concluded from this study:

The practical stiffness and maximum strength of the specimens were slightly affected by the vertical load. Regarding the parameters of linear procedures, it can conclude that the presence of the vertical load results in increasing of the m-factor by 2.5 times in the specimen with pinned connections, while it is not considerably changed in the specimen with rigid connections. More researches are required to show that if the seismic guidelines should consider the effects of vertical load as well as connections rigidity of bounding frame in infill frames analysis procedures.

5. Acknowledgements

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