EFECT OF RIGIDITY OF BEAM TO COLUMN CONNECTION ON STRENGTH AND STIFNESS OF INFILLED FRAMES

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ABSTRACT

This paper deals with an experimental program to investigate the effect of beam to column connection rigidity on the stiffness and strength of steel infilled frames. Two half scaled 1-story, 1-bay specimens were tested under in-plane lateral cyclic loading applied at the top of the frame. One of the specimens is fabricated with rigid beam to column connections and the other with pinned connections.The experimental results indicate that the less the connection of beam to column has rigidity, the less stiffness and strength of infilled frame are obtained.Also the stiffness and ultimate strength obtained from experimental tests were compared with the values calculated by Mainstone formula. The results show thatMainstone method significantly overestimates the stiffness for the specimen with pinned beam to column connection in comparison with the specimen having rigid connection.

INTRODUCTION

Infill walls are commonly used in buildings for structural and architectural purposes. Based on extensive study since 1950 up to now, it has been proved that infills have a significant effect on the behaviour of structures and alsoenergy dissipation during earthquakes. Therefore, they should not be ignored in analysis and design of structures (Moghadam and Dowling, 1987). Several methods have been proposed to model infilled wall in previous studies. One of the most prevalent models that used by many researchers and engineers and also recommended by FEMA356 (2000) and ASCE41-06 (2007) is a single compression strut model, proposed by Mainstone (1971). The stiffness and strength of infilled panels can be estimated by Mainstone formula, acceptably. On the other hand, the formula is obtained based on experiments and analyses on which beams were connected to columns with rigid connections. Therefore, using this method to determine the behaviour of infilled frames with pinned connections is doubtful.

Despite the large amount of researches on infilled frames, there is a lack of scientific evidence in literature in subject of the effects of beam to column connection rigidity of surrounding frame. For instance, Dawe and Seah (1989) found out that the specimens in which panel is enclosed in a completely hinged steel frame behave differently in comparison with that of with moment resistant frames. They concluded that pinned connection of surrounding frame causes decrease in initial stiffness, maximum strength and the ductility of infill frames. Flangan and Bennet (1999) preformed a series of experiments on steel frames with structural clay tile infills. The steel beams connected to column using double clip angles. The results show that the values of stiffness and strength of the specimens are reduced about 50% compared with calculated values from Mainstone formula.

In this paper, an experimental program is carried out to find out the effect of beam to column connection rigidity on behaviour of infill steel frames. For this purpose, two half scale steel single-story, single-frame with masonry brick infills are subjected to cyclic in plane loading.

TEST SPECIMENS

Two half scaled infilled frames were tested to investigate the influence of beam to column connection of frame on the behaviour of the steel infilled frames. The specimens have 1 bay and 1 story with 225cm length and 150cm height, respectively. One specimen has rigid connection of beam to column and another has pinned connection using double plate. The frames were designed in accordance with the third edition of Iranian standard No.2800 (2005) for seismic design and AISC-ASD89 steel code of practice.

The specimens were considered to be 1/2 scaled models representing the interior bay of a 4-story building at the bottom story.Details of the experimental models are presented in table 1. It should be noted that no shear connector were used between the surrounding frame and infill wall. The names of specimen in table 1 start by the letter M indicating the material of infill wall, where here all two specimens have Masonry infill wall. The second part of name of specimen denotes the type of beam to column connection; RC represents Rigid Connection and PC indicate the Pinned Connection and the last part, 1B, shows that the specimens have 1 Bay. The beam and column sections of the infilled frame are IPBI120 and IPBI180, respectively. The steel used in constructing the specimens was grade ST37 with mean yield stress of 300 MPa. For the infill panels 0.2×0.1×0.05 solid masonry bricks were used in the respective specimens. The mean compression strength and modules of rapture of standard masonry prism (three brick and two layers of mortar), are 9.5 MPa and 1311 MPa, respectively. This data was obtained from test of 15 standard masonry prisms.

Table 1.Summary of specimens

Specimen	Height (cm)	Length (cm)	Column	Beam	Beam to Column Connection
M-RC-1B	150	225	IPBI 180	IPBI 120	rigid
M-PC-1B	150	225	IPBI 180	IPBI 120	Pinned

EXPRIMENTAL SETUP

The test setup is illustrated in figure 1. The in-plane lateral load was applied using hydraulic actuator. The maximum capacity of actuator was 50 ton with stroke of ±150mm. The actuator was connected to a stiff triangle support that was attached to the strong floor of laboratory. The lateral load was applied to a loading beam which is connected to the frame through shear keys. These shear keys areembeddedon the top the beam and columns of the infilled frame. In fact, this arrangement leads to a rather uniform distribution of lateral load throughout the frameas is done in practical case.

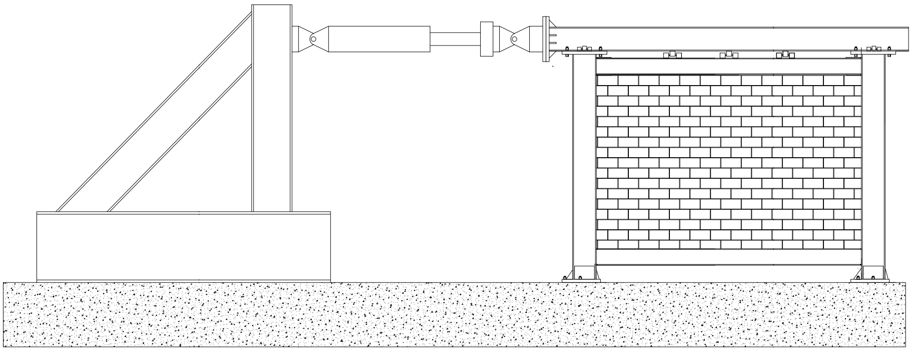

Figure 1.Test setup

The displacement control loading was applied to the specimens. A predetermined cyclic displacement history, recommended by Federal Emergency Management Agency-FEMA461 (2007), was imposed on the experimental models. The applied displacement history consists of 28 repeated cycles of step-wise increasing deformation amplitude, which starts from 1.7mm and continues in a way that, the next displacement multiplies by 1.4 of previous one so that the last cycle reaches to 135mm. The used displacement history is presented in figure 2.

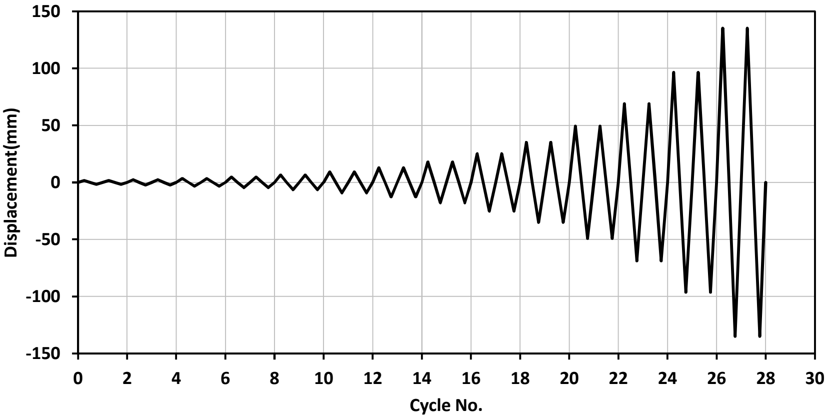

Figure 2.Applied displacement history

EXPERIMENTAL RESULTS

M-RC-1B

The first test was the infilled frame with rigid beam to column connections. The load-displacement response is depicted in figure 3. The obtained practical stiffness (K_{exp}) is 12.97kN/mm. The practical stiffness used in this study is the slope of a line tangent to the load-displacement diagram of first cycle at the interface cracking strength (Mohammadi (2007)). The maximum strength is 325kN which is occurred at the drift of 5.1%. The test was stopped at first cycle of 135mm because of severe damage in the loading beam.

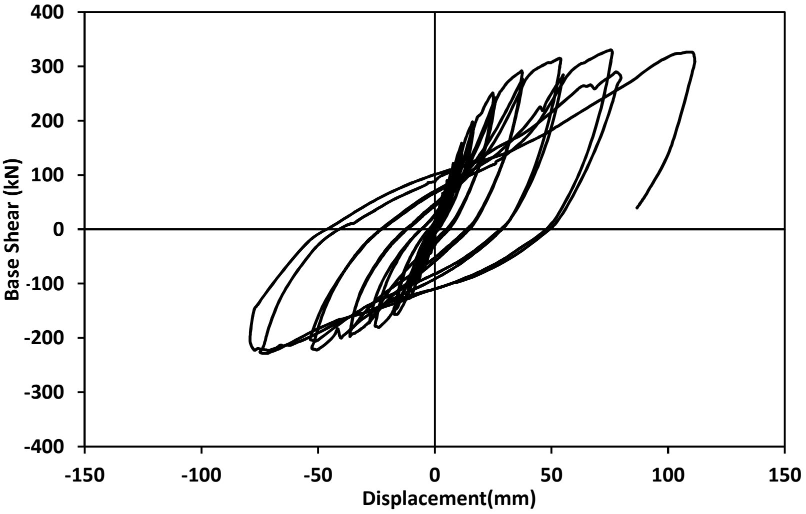

Figure 3. Load-displacement relation for M-RC-1B

M-PC-1B

The load-displacement of this specimen is shown in figure 4. The practical stiffness of this specimen is reduced by 57% in comparison with M-RC-1B and is 5.56kN/mm. the peak load of this specimen is 290kN at 82mm lateral displacement, corresponding to drift of 5.5%. It is worth noting that the plate of pinned connection of top beam to column was ruptured at 70.5mm lateral displacement (drift of 4.7%) at cycle number 25. As a result of this event, there is no interaction between frame and infill wall anymore.

Figure 5 illustrates the response comparison of specimens in the form of envelop of a load–displacement relationship. The stiffness and strength of specimen M-RC-1B were 2.33 and 1.12 times respectively greater than those of specimen M-PC-1B.

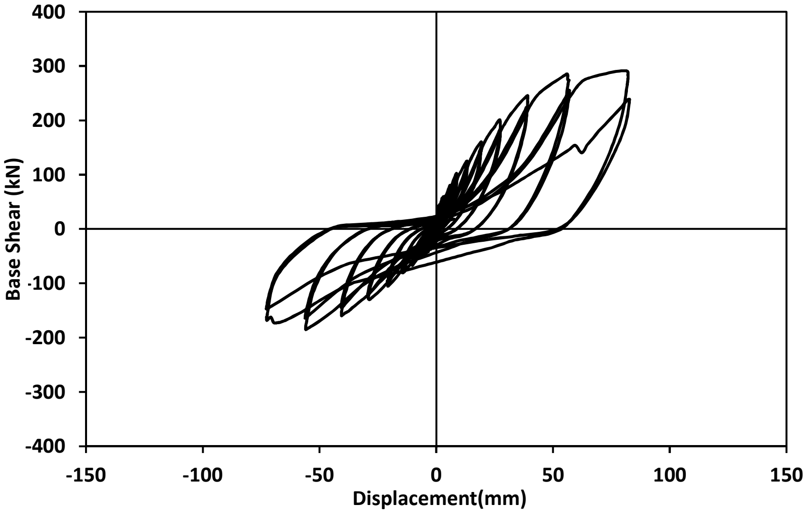

Figure 4. Load-displacement relation for M-RC-1B

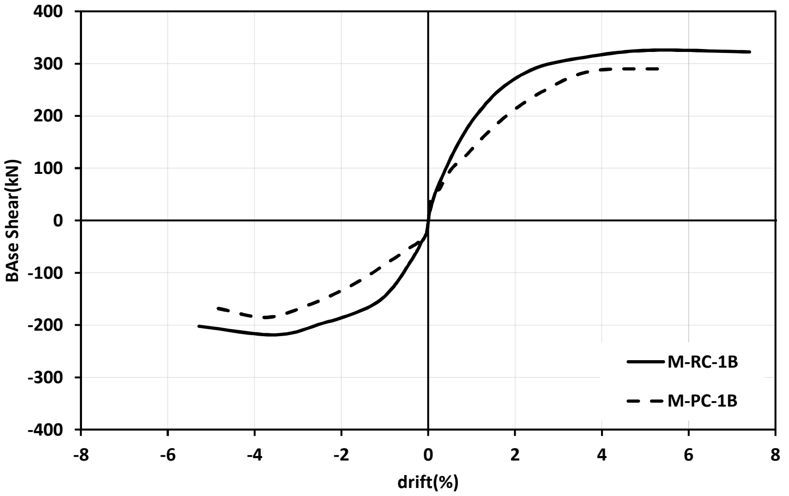

Figure 5. Comparison between Envelope curves of M-RC-1B & M-PC-1B

ANALYTICAL ESTIMATION OF STIFFNESS AND STRENGH AND COMPARISON WITH EXPERIMENTAL VALUES

In order to estimate the strength and stiffness of infill frames, a macro modelling strategy is used in this study. In this method, the infill wall is replaced by an equivalent compression strut. One of the convenient models which is recommended by seismic guidelines such as FEMA356 and ASCE41-06, was proposed by Mainstone (1997). In this model the strut width is determined by

$$a = 0.175(\mathrm{a}_l h_{col})^{-0.4} r_{\inf}$$

$$\mathrm{a}_l = \left[\frac{E_{me} t_{\inf} \sin 2\overline{\;}}{4 E_{fe} I_{col} h_{\inf}} \right]^{\frac{1}{4}}$$

Where

a = equivalent diagonal strut width,

h_{col} = column height between centreline of beam,

$r_{\inf}$ = diagonal length of infill panel,

E_{me} = module of elasticity of infill material,

$t_{\inf}$ = thickness of infill panel and equivalent strut,

E_{mfe} = module of elasticity of frame material,

I_{col} = moment of inertia of column,

$h_{\inf}$ = height of infill panel,

$$- = \tan^{-1}\left(\frac{h_{\inf}}{l_{\inf}}\right),$$

$l_{\inf}$ = length of infill panel.

When the strut width is obtained, the analytical stiffness (K_{anl}) value can be calculated readily through a frame analysis using available commercial software SAP2000. Also the shear capacity of infills failing in corner crushing is calculated as:

$$F = a t_{\inf} f_{me} \times \cos^{-}$$

Where

f_{me} = compressive strength of masonry prism.

To examine the efficiency of the equivalent strut method in estimation of stiffness and strength of infilled frames considering their beam to column connection types, test result are compared in table 2.

This table shows that Mainstone method significantly overestimates the stiffness for the specimen M-PC-1B that have pinned beam to column connection in comparison with the specimen M-RC-1B with rigid connection.

In case of strength comparison, contrary to stiffness comparison, the result shows that the equivalent strut model underestimates the strength of specimen M-RC-1B more than the strength of specimen M-PC-1B.

Table 2. Experimental and Analytical comparison

specimen	**strut width (cm)**	**Practical Stiffness (kN/mm)**		K_{anl}/K_{exp}	**Ultimate strength (kN)**		F_{anl}/F_{exp}
		Experimental	**Analytical**		**Experimental**	**Analytical**	
M-RC-1B	32	13	19	1.46	325	252.8	0.77
M-PC-1B	32	5.6	16	2.85	290.2	252.8	0.87

The results show that the current design formula recommended by provision such as FEMA356 (2000) and ASCE41-06 (2007) does not show enough accuracy to estimate the behaviour of the infill frames with pinned connections of beam to column especially in case of stiffness. The authors suggest applying a modification factor to Mainstone formula to estimate the stiffness and strength of steel infilled frames with pinned connections of beam to column. Therefore, further investigations must be carried out to propose a verification factor to consider the influence of the connection rigidity.

CONCLUSIONS

This paper describes an experimental program to investigate the effects of beam to column connection rigidity on behaviour of steel infilled frames. The experimental specimens include two steel infilled frames with various beam to column connections types. One of the specimens is fabricated with rigid beam to column connection (M-RC-1B) and another with pinned connection (M-PC-1B). The infills were unreinforced masonry and the cyclic lateral displacement was imposed in the plane of the frames. The practical stiffness and ultimate strength obtained from experimental tests were compared with the values calculated by Mainstone formula. The results show a significant effect of connection rigidity on the strength and stiffness of steel infilled frames. The following conclusions can be inferred from the experimental and analytical investigations:

- The practical stiffness of specimen M-PC-1B is reduced by 57% in comparison with M-RC-1B.
- The maximum strength of the infilled frame which has rigid connection is 12% more than the specimen with pinned beam to column connection.
- The comparison of practical stiffness with analytical one shows that Mainstone formula significantly overestimates the stiffness of M-PC-1B in comparison with the M-RC-1B.
- In case of strength the results show that the equivalent strut model underestimates the strength of specimen M-RC-1B more than the strength of specimen M-PC-1B.

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