An Experimental Investigation of Infill Behaviour in RC Frames

I.O. Demirel, A. Yakut, B. Binici, E. Canbay

Middle East Technical University, Ankara, Turkey.

ABSTRACT: Seismic performance of infilled reinforced concrete (RC) frames are investigated. Three code designed, half scale, single frame, namely bare frame (BF), infilled frame without plaster (IF) and bilateral steel mesh fastened infilled frame with plaster (SMF) were tested under cyclic excitation in METU Structural Mechanics Laboratory. Each column is preloaded to 17.5 percent of its axial load capacity and a sequence of increasing lateral displacement reversals was applied up to 4.0 percent inter-story drift level. The RC frame and infill panel are instrumented with strain gages, LVDT's and load cells at various locations. It was observed that the infill wall enhanced the base shear capacity of bare frame by 43 percent but decayed rapidly and converged to the bare frame response at higher drift levels. However application of bilateral steel mesh with plaster both increased the base shear capacity by 220 percent and helped infill wall remain intact, sustaining its contribution at high drift levels.

1 INTRODUCTION

Although the response of infilled frames under seismic actions has long been analytically and experimentally investigated by many researchers, infill walls are still unaccounted in earthquake design of recent building codes. Conceiving the infill walls as a reserve member increasing the capacity and the stiffness of the building and just ignoring their existence might be a simple solution regarding the difficulty of modeling a heterogeneous and anisotropic medium. However, past earthquakes (Kocaeli 1999, Van 2011) have clearly demonstrated the importance of infill walls that they are very susceptible to damage under moderate earthquakes and might be critical for the stability of highly damaged buildings under severe earthquakes. Besides, economical and psychological effects of infill damage should not be underestimated (Sucuoglu, 2013).

The aim of this study is to reveal the contribution of infill panel to the response of a simple RC frame under cyclic loading. For this purpose bare frame and infilled frame tests are conducted. Additionally, an easy to apply yet economical method is proposed for superior seismic resistance via bilateral application of steel mesh fastened to each other by tie wires through holes drilled on mortar joints on the infill wall.

In addition to the frame tests, extensive material testing including uniaxial testing of rebar, concrete, mortar and brick specimens, displacement based diagonal and uniaxial compression testing of infill prisms were conducted to determine mechanical properties of the materials and the wall assemblages.

2 MATERIAL AND PRISM TESTS

Mechanical properties of concrete, mortar and brick are determined using MTS testing machine according to the related ASTM standards; ASTM C39, ASTM C469, ASTM C348, ASTM C349 (**Table 1**). Super liquid ready mixed concrete with 28 day nominal compressive strength of 25 MPa is used. 150 mm cylindrical core concrete samples are tested under compression and split tension on the day of frame test. Two different types of reinforcing steel is used. For longitudinal reinforcement Φ8 (diameter of 8 mm) deformed bars with nominal yield strength of 420 MPa is utilized. For transverse reinforcement Φ6 plain bars with nominal yield strength of 220 MPa is employed. The volumetric ratio of sand/cement/lime for mortar is 6/1/1. The water ratio of the mortar is arranged using flow table test (ASTM C1437) such that flow diameter is around 105. 40mmx 40mm x 160mm mortar prism samples are taken for the flexural tension and compression tests. Additionally 100 mm cylindrical core mortar samples are taken for the determination of young's modulus. Clay bricks with 185mm x

100mm x 95mm dimensions and 60 % void ratio are utilized. Unit weight of each clay brick is around 1120gr. Bricks are cut into half using diamond saw whenever needed.

Table 1. Material properties

Material	Compressive Strength (MPa)	Tensile Strength (MPa)	Young's Modulus (MPa)
Concrete	27.9	2.6*	26,100
Mortar	2.24	0.65**	2136
Brick	3.7		

*Split tension strength **Flexural tension strength

Prism tests are conducted using a screw jack which is capable of displacement controlled loading. The uniaxial compression, diagonal compression and split shear tests are conducted according to ASTM C1314, ASTM E519 and EN 1052-3 standards (**Fig 1**). For each test, 3 brick prisms and 3 bilateral steel mesh fastened and plastered prisms are prepared for comparison. Displacements are monitored with LVDT's attached on both sides of prisms and averaged to minimize possible bending deformations. In order to calculate young's modulus and shear modulus, a secant line between 5% and 50% of ultimate strength is drawn for the relevant stress-strain curve.

The confining pressure for the split tension specimens are applied through a unique test setup (Fig 1c). The horizontal force is applied and kept constant throughout the test by tightening nuts of the screws which are also attached to S type load cells on both side of the specimen. Once the confining pressure is applied, shear strength at various normal stress levels are determined leading to draw Mohr-Coulomb surface at the interface between brick and mortar joints. After 7 successful tests at various pre-compression levels, cohesion is determined as 0.161 MPa and friction angle is calculated as 60 degrees.

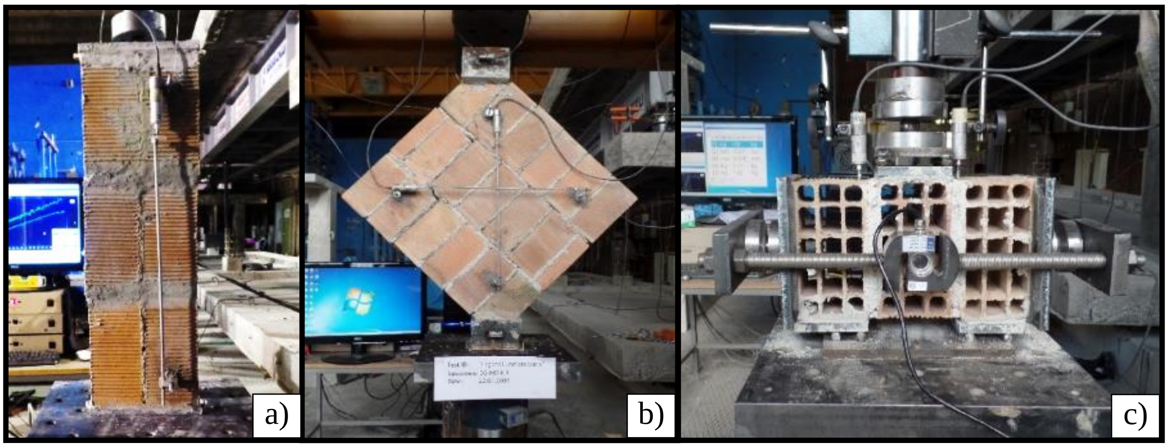

Fig 1. Prism tests; a) uniaxial compression, b) diagonal compression, c) split tension

Shear stress and shear strain are calculated from diagonal compression test readings according to the formulas given in ASTM E519:

$$\tau = \frac{0.707P}{A_n} \tag{1}$$

where p = applied load, A_n = net area of the specimen

$$\gamma = \frac{\Delta V + \Delta H}{g} \quad (2)$$

where ΔV = vertical shortening, ΔH = horizontal extension; and g = gage length
Uniaxial and diagonal compression test results are provided at Table 2 and Figure 2.

Table 2. Prism test results

Specimen	σ_u (MPa)	E (MPa)	τ_u (MPa)	G (MPa)
Plain Prism	1.08	2045	0.15	772
Steel Mesh Fastened Prism	1.00	-	0.33	1106

It is clearly seen that the steel mesh + plaster application increased shear capacity, shear modulus and displacement capacity of infill prisms under uniaxial and diagonal compressive loadings.

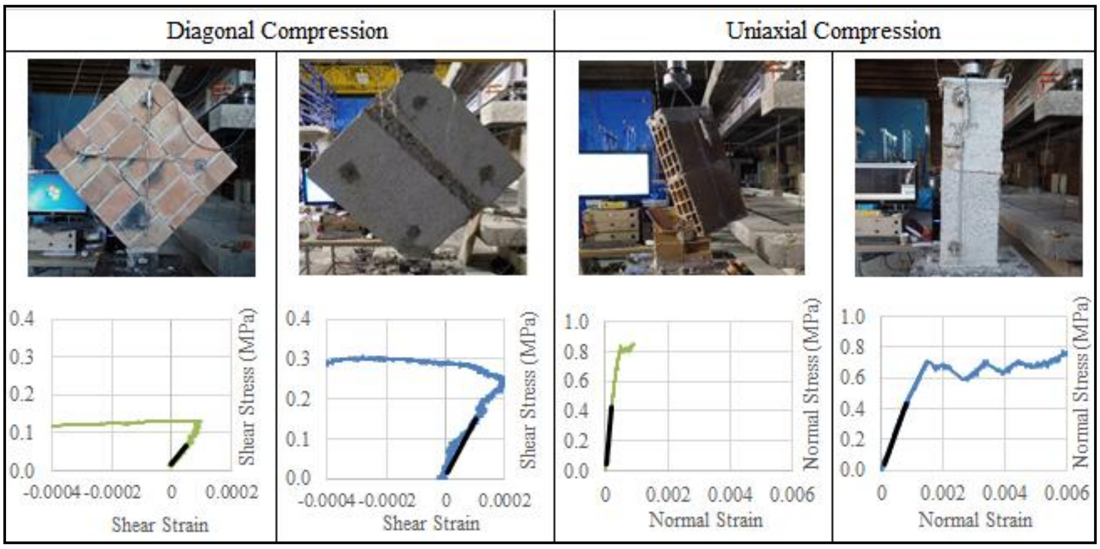

Fig 2. Prism failure modes and stress-strain curves

3 TEST FRAME

The test frame represents a frame in the ground story of a typical five story reference RC building. For this reason, a hypothetical building was designed according to Turkish Earthquake Code (TEC07) satisfying high ductility level (**Fig 3**). In the seismic design of the building, the capacity design, strong column - weak beam, confinement of member edge principles are taken into account. The effective slab width is accounted in the test frame including slab reinforcements. The gross reinforcement ratio in the columns is 1.0%. Due to limitations of lab environment the frame is scaled to half keeping the axial stress ratio in columns, the ratio of longitudinal and transverse reinforcements almost the same as the reference designed building.

The clay bricks are stacked such that their holes are parallel to horizontal axis which is typical for the Turkish construction practice. The infill panel is built after steel weight blocks representing the weight of slab are placed on the bare frame letting the beam to deform freely under gravity loads. Steel meshes having 25 mm nominal pitch and 2 mm diameter are utilized for the Steel Mesh Frame (SMF).

Two steel meshes are placed on both sides of the infill panel and tied to each other by tie wires passing through various holes drilled at mortar joints. 10mm plaster is applied over the mesh afterwards (**Fig 4**).

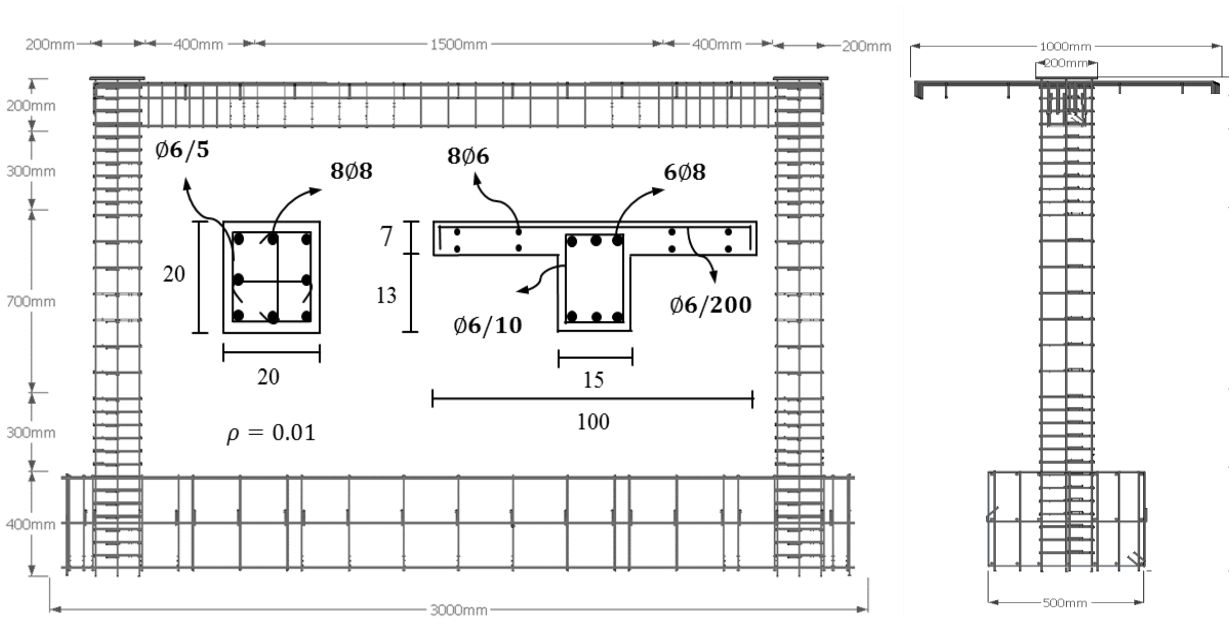

Fig 3. Reinforcement details of the test frame

Contrary to typical strengthening techniques, the steel mesh is not anchored to the surrounding frame. In this configuration the role of the steel mesh is to keep the infill panel intact at high drift ratios sustaining contribution of infill panel resistance to lateral loads and displacements. So a relatively weak mesh is selected for the application.

Fig 4. Construction details of SMF

4 EXPERIMENTAL SETUP

An experimental setup capable of simultaneous application of vertical and horizontal load is constructed in Structural Mechanics Laboratory of METU (**Fig 5**). Gravity loading is represented by weight blocks on the beam and hydraulic jacks on top of columns. After the test frame is preloaded in vertical direction such that axial load ratio of columns are 0.175, a sequence of increasing lateral displacement reversals was applied up to 4.0 percent inter-story drift level. Lateral loads were applied by the help of a servo controlled horizontal actuator. The drift ratios of 0.35, 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5 and 4.0 percent were applied twice in both the positive and negative directions.

Fig 5. Experimental Setup

The RC frame and infill panel are instrumented by 3 load cells (each attached to a hydraulic jack), 12 strain gages and 30 LVDT's (**Fig 6**). Strain gages are located on the longitudinal reinforcements at the edge of each column and the beam. LVDT's are placed to derive member end rotations, diagonal strut displacements, joint displacements and lateral displacement of slab.

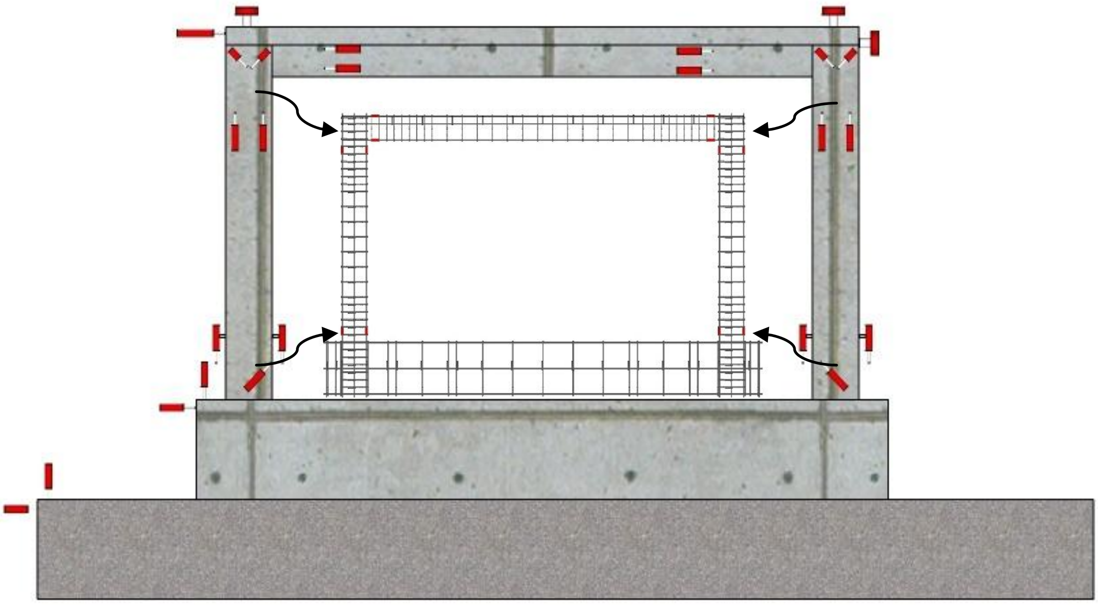

Fig 6. Instrumentation

5 TEST RESULTS

Experimental results containing damage patterns and load deformation response were investigated for each frame. The Bare Frame (BF) experienced a ductile response through flexural hinging of column and beam ends. Clear signs of steel yielding, excessive concrete cracking, cover concrete crushing and bar buckling is observed at 4.0 % drift ratio. The Infilled Frame (IF) reached the ultimate state through sliding failure of infill wall, spilling of upper layer of infill panel due to beam deformation and flexural hinging of columns at the column base. The SMF showed superior infill panel performance in terms of little visual damage in terms of disintegration at the interface and little corner damage (**Fig 7**). Although corner crushing of infill panel is observed the steel mesh prevented disintegration of the crushed bricks. The presence of steel meshes appears to improve out of plane behaviour of the panel as well.

Fig 7. Infill panel damage of IF and SMF at 0.5%, 2% and 4% drift ratios

The Backbone curves in positive direction together with hysteretic responses are provided for each frame in Figure 8. It is clear that the infill improves the lateral strength and stiffness of the bare frame significantly. Both systems, IF and SMF, tend to converge to the BF response at large drift ratios after reaching the lateral load capacity. Although, the steel mesh does not seem to change the stiffness it increases the capacity significantly.

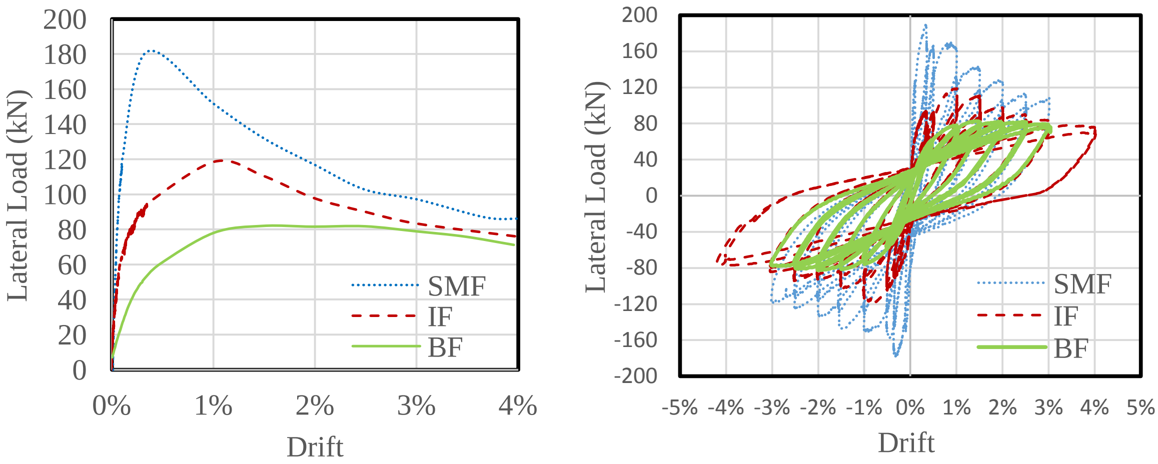

Fig 8 Backbone curves and hysteretic responses of tested frames

6 CONCLUSIONS

It is observed that the infill wall enhanced the base shear capacity of the bare frame by 43 percent but decayed rapidly and converged to the bare frame response at high drift levels. However SMF both increased the base shear capacity by 220 percent and helped the infill wall remain intact sustaining its contribution at high drift levels. We believe that SMF (which is currently not addressed in seismic design codes) is a rational alternative to improve the infilled frame behavior during earthquakes through both increasing the capacity and stability at large drift levels. This system may be used in earthquake prone regions where infill walls are used.

Table 3. Frame Test Results

Frame ID	K_i* (kN/mm)	V_{max} (kN)	$\frac{V_{max}}{V_{max,BF}}$	d_{max}
BF	10.0	82.8	1.00	1.50%
IF	36.4	118.6	1.43	1.00%
SMF	85.9	181.1	2.19	0.35%

*Secant stiffness passing through $0.6V_{max}$

7 ACKNOWLEDGEMENTS

This research work has been funded by the European Commission under the program “Research for the benefit of SME Associations”, research project INSYSME “Innovative systems for earthquake resistant masonry enclosures in RC buildings”, grant FP7-SME-2013-2-GA606229, 2013-2016. Authors acknowledge the valuable labour of METU Structural Mechanics Laboratory workers: Hasan Metin, Osman Keskin, Murat Demirel, Barış Esen and Salim Azak.

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