WET-MIXED SHOTCRETE WALLS TO RETROFIT LOW DUCTILE RC FRAMES

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ABSTRACT:
In this study, wet-mixed sprayed concrete is used to form infill walls in low ductile reinforced concrete (RC) frames. Nearly ½ scale one bay-one story RC frames were tested under constant vertical loads acting on the columns and lateral displacement reversals. The experimental work was composed of strengthening of one undamaged and one slightly damaged low ductile RC frames by forming an infill wall using wet-mixed sprayed concrete and one bare frame for reference. The infill walls are connected only to the beams through shear studs used at two edges of the infill wall while the other two edges are distanced to the columns. The result of the tests shows that the lateral load carrying capacity of the infilled frames retrofitted by this technique is approximately one and a half times that of the bare frame. In addition to the experimental works, the effect of the gap sizes between the columns and the infill wall is being studied analytically to understand how it affects the lateral load carrying capacity of the retrofitted frame.

KEYWORDS: low ductile RC frame, wet-mixed shotcrete, wall

1. INTRODUCTION

Shotcrete has been used for repairing of damaged surface of concrete, wood or steel structures; for underground excavations; for slope and surface protection and for new structures where thin sections and large areas are involved, for more than 90 years.

It is also used to enhance the seismic capacity of existing structures by applying on existing infill panels. Strengthening a damaged RC frame with forming a thin concrete wall on the existing masonry walls [Yuksel et al, 1998, Zarnic and Tomazevic, 1988] or using shotcrete on special wall-like structures in lieu of masonry walls [Mourtaja et al, 1998] showed that, these kinds of easily applicable retrofitting techniques increases lateral load carrying capacity and lateral rigidity of the structure.

A major drawback of this method is the need for strengthening the foundation, to resist the increased overturning moment and the larger weight of the structure. For that reason, in this study the walls had a certain distance between the columns and only connected to the beams.

2. EXPERIMENTAL PROGRAM

In this study, panels made from wet-mixed shotcrete in lieu of a traditional masonry are used to form an infill wall within a low ductile RC frame. The frames were chosen to represent weak column/strong beam type structures that were very common in Turkey especially for the buildings constructed before the current earthquake code. The specimens had non-seismic details such as large spacing of hoops, no hoop in beam-column connection region and no use of 135° seismic hooks. Panels were formed connected only to the beams by lapping the infill reinforcement to the anchorage placed in frame members.

One story, one bay RC frames with a portion of slab on top and a foundation at the bottom has been constructed in the laboratory. The cross sectional dimensions of columns and beam of the frames are 20 cm by 25 cm and 20 cm by 32.5 cm, respectively. The height and the width of the frames are 152.5 cm and 220 cm, respectively. The dimensions and the reinforcement detail of the frames are given in Figure 1 and of panels are given in Figure 2. Main reinforcement of the frames was consisted of 16 mm steel bars (yield stress f_y = 270 N/mm^2) and the reinforcement of the panels 4.5 mm steel bars (f_y = 320 N/mm^2). The longitudinal reinforcement ratio of the column and the panel are %2 and %0.2 respectively.

One of the prepared specimens was consisting of damaged RC frame, which is named as S1; the other one is consisting of non-damaged reinforced concrete frame, which is named as S2.

The damaged frame S1 was repaired by epoxy injection into the cracks formed at both ends of the columns. A wire mesh (Q 106/106) consisting of 4.5 mm steel bars was placed in the middle of the frame. By lapping the infill reinforcement to the anchorages placed in the beam and the foundation, contact of the panel was established. The anchorages used were 10 mm steel bars placed in the frame by epoxy resin. The length of the anchorage in the panel was 15 cm. By using wet-mixed sprayed concrete, a 5 cm-thick panel was formed as shown in Figure 3. The same kind of strengthening method was applied to frame S2, but this time the frame was undamaged. The panel in this case was also 5 cm. Table 1 contains the concrete compressive strengths at the time of the experiments. BF represents the reference specimen, which is a bare frame.

Experimental set up and the positions of displacement transducers used are given in Figure 4. A constant axial load was applied on the columns as N/N_0=%20 for S1 and S2. Lateral cycling loading imposed as displacement reversals was applied to the specimen by means of two 250 kN-capacity hydraulic MTS actuators, which were placed at the slab level. The load history used is given in Figure 5.

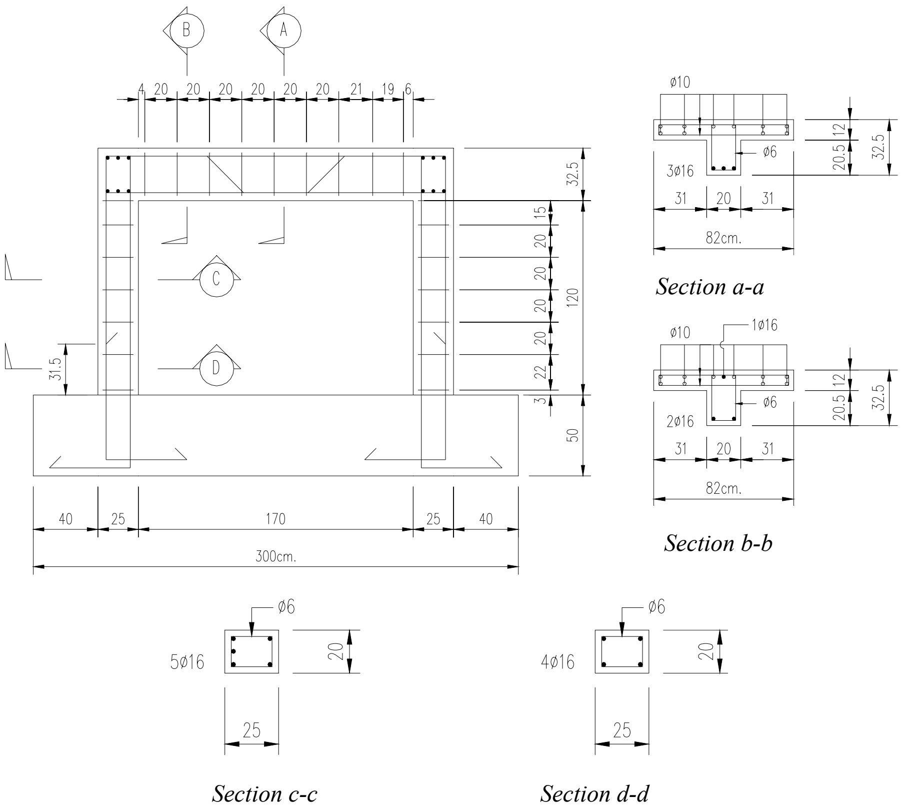

Figure 1 Dimensions and reinforcement details of low ductile RC frame

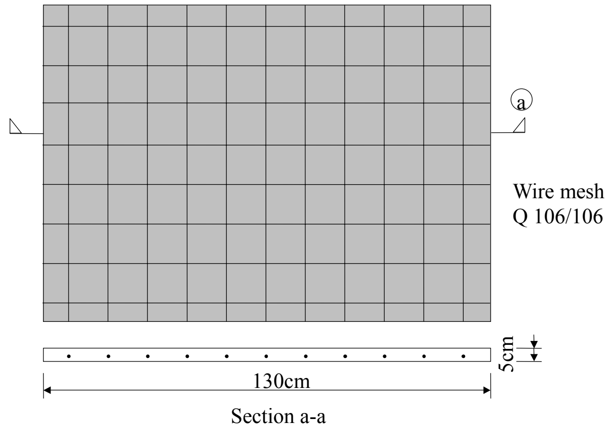

Figure 2 Dimensions and the reinforcement details of the panel

Table 1 Concrete Compressive Strengths of the specimens

Specimen Name	f_c [N/mm^2]	
	Frame	Panel
S1	12	35
S2	12	35
BF	16	

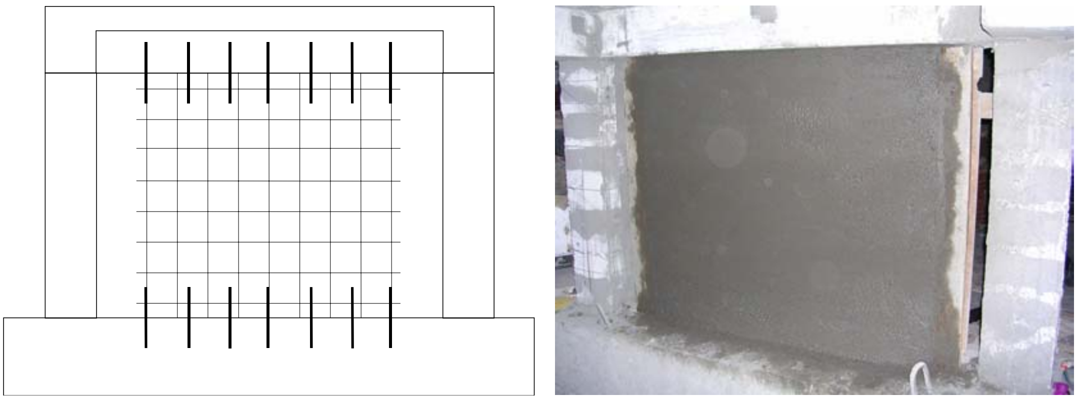

Figure 3 General view of the specimens and formation of the shotcrete wall

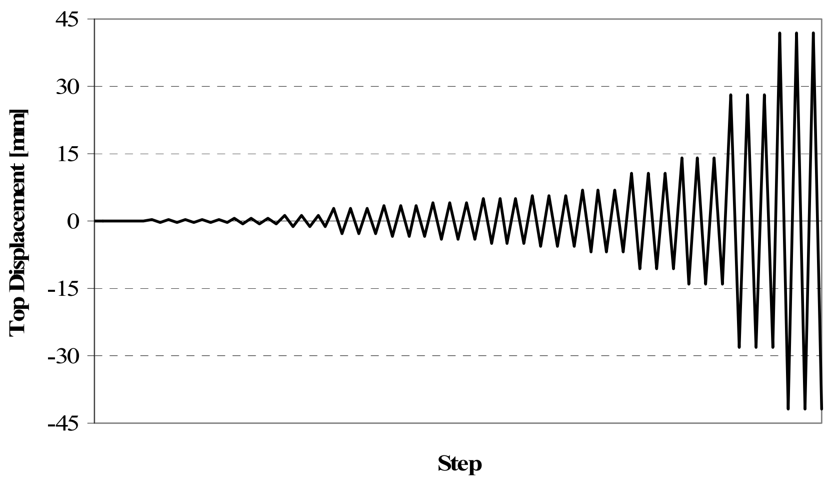

Figure 5 Loading History

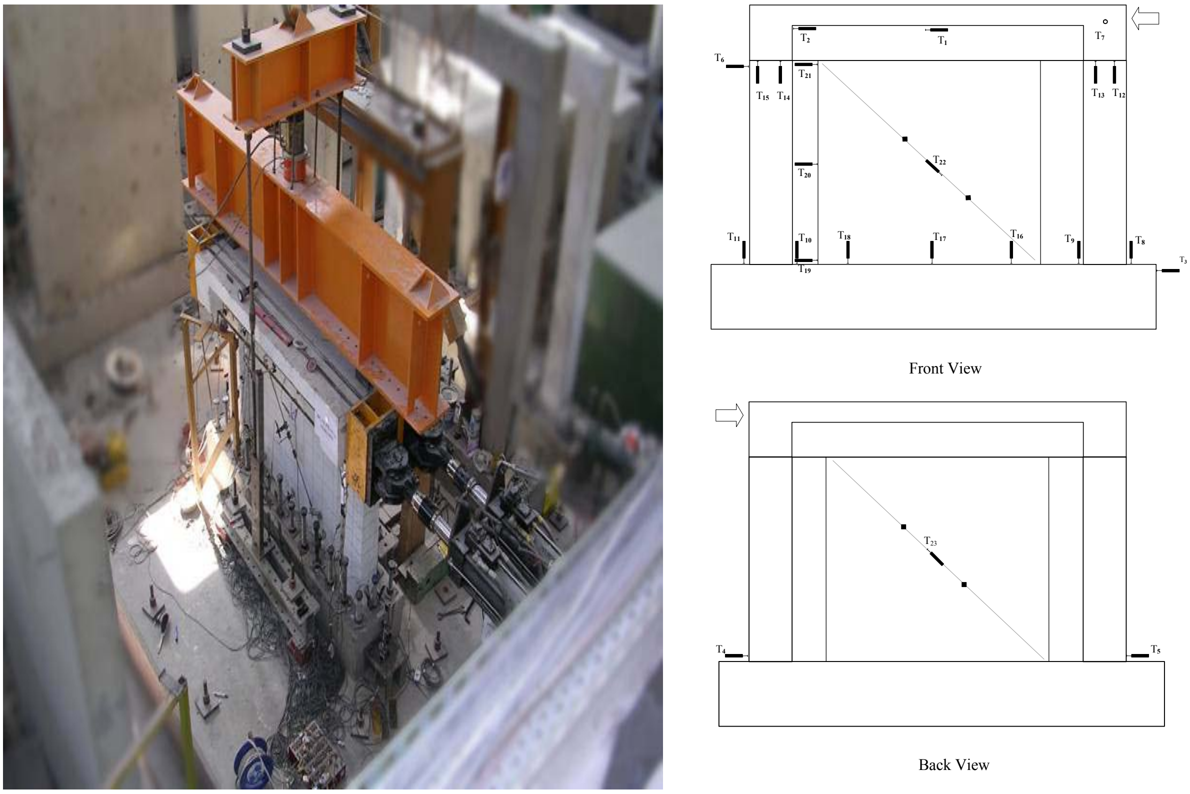

Figure 4 Experimental set up and the positions of transducers

3. EXPERIMENTAL RESULTS

Although there are several deformation measurements on the specimens, the envelope curves of the top displacement versus base shear relationships are selected to be presented here in Figure 6. Figure 7 and Figure 8 show the specimens after test. The stiffness just before the first cracking, the failure modes, maximum loads and displacements at that loads, ultimate loads and displacements at that loads are given in Table 2. The crack patterns of all specimens at the ultimate state are also shown in Figures 9 and 10.

Maximum load that has occurred at the end of the positive displacement cycles was 242 kN and -190 kN in negative displacement cycles for S1. The first shear crack on left side of the beam and the shear crack at the bottom end of the column observed during the -2.8 mm cycles. The load was reported as 147 kN. The first diagonal crack observed on the panel during the -14 mm cycles. At that cycle, the load was 150 kN.

Maximum load occurred at the end of the positive displacement cycles was 217 kN and –223 kN in negative displacement cycles for S2. The first diagonal crack on the panel, the first shear crack on left side of the beam and the separation at the ends of the left column observed during the -2.8 mm cycles. The load was reported as 150 kN.

Table 2 Effect of strengthening in general

Specimen Name	Stiffness (kN/mm)	Failure Mode	P_{max} (kN)	Δ_{max} (mm)	$P_{ultimate}$ (kN)	$\Delta_{ultimate}$ (mm)
S1	134	Frame- Shear dominant	242	28	160	42
S2	114	Frame- Shear dominant	217	28	100	42
BF	22	Bending + Shear failure at column ends	133	28	110	42

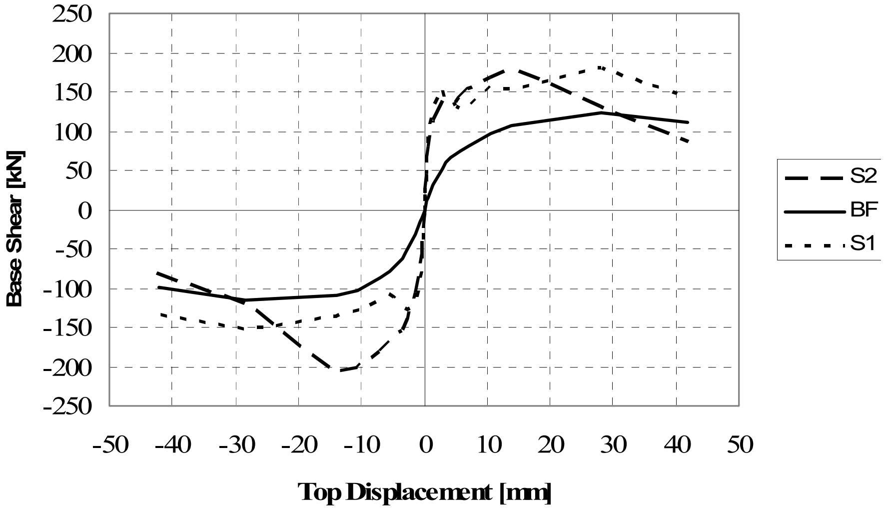

Figure 6 The base shear versus top displacement envelopes of specimens

Figure 7 S1 after failure

Figure 8 S2 after failure

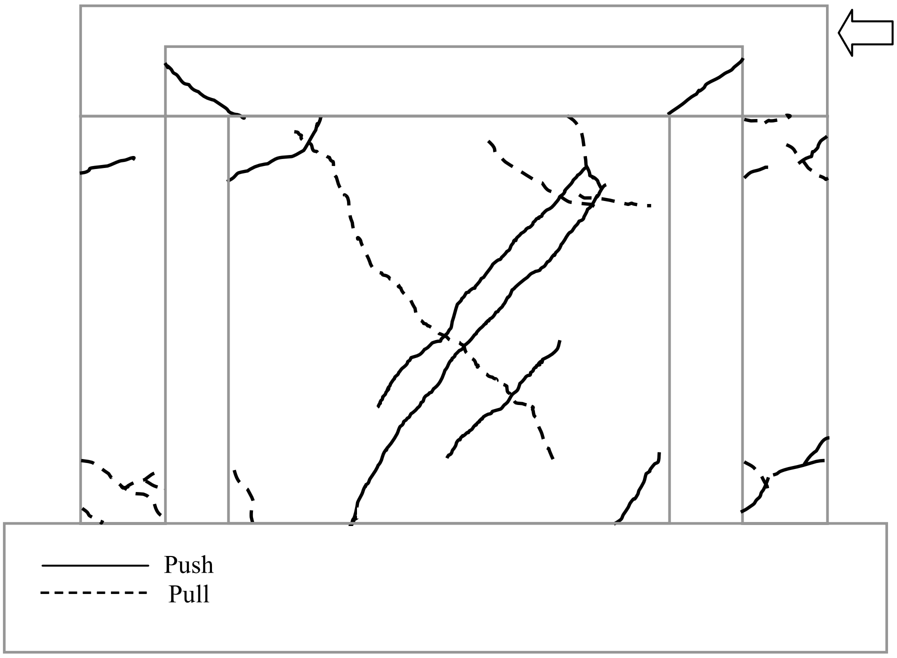

Figure 9 Crack pattern of S1 at the end of test

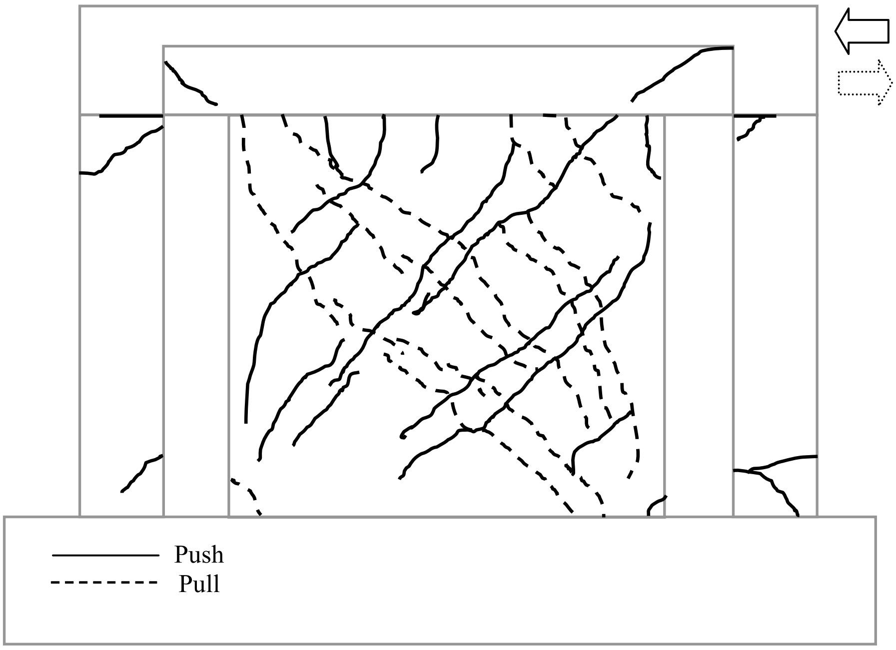

Figure 10 Crack pattern of S2 at the end of test

4. ANALYTICAL STUDY

Analytical studies using the finite element method was performed by SeismoStruct [Seismosoft, 2006]. Inelastic beam-column frame elements are used. Material inelasticity spreads along the member length and across the section area, and is explicitly represented by implementing a fibre modeling approach. Uniaxial steel model Monti-Nutti steel model is used to model the reinforcement, uniaxial nonlinear constant confinement material model for concrete and a four-node masonry panel element for the modelling of the nonlinear response of infill panels in framed structures are used. Each panel is represented by six strut members; each diagonal direction features two parallel struts to carry axial loads across two opposite diagonal corners and a third one to carry the shear from the top to the bottom of the panel shown in Figure 11. The displacement pattern of the experiments is applied in static time-history analysis. The comparison of the results of the analytical model for S2 and the experimental study is presented in Figure 12.

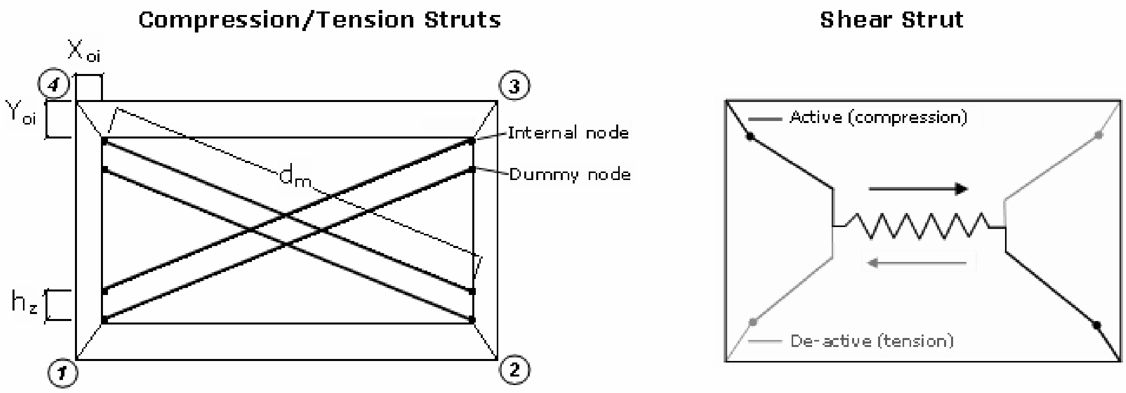

Figure 11 Strut model used

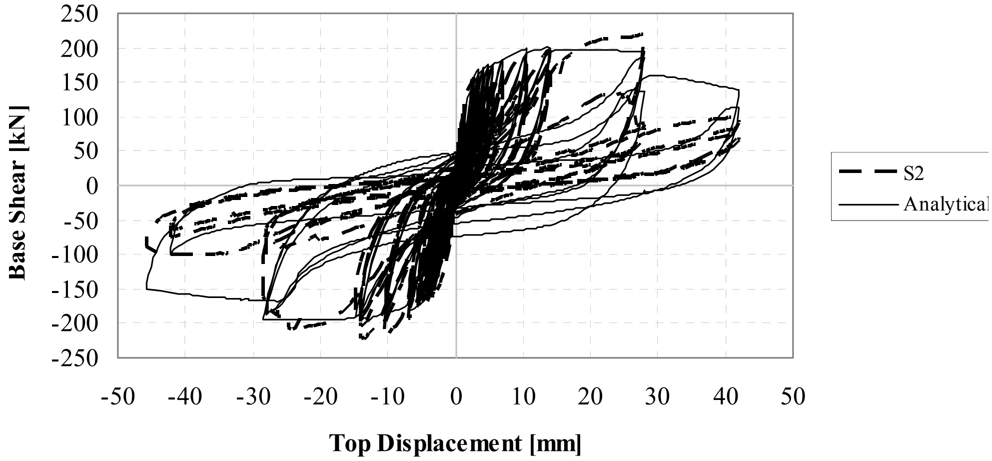

Figure 12 Comparison of the results of the analytical model for S2 and the experimental study

The effect of the gap dimension between the panel and the frame is studied analytically in this section. The gap dimension is changed proportional to the distance between the inside face of the columns as shown in Table 3. The effect of the gap dimension investigated with the analytical study can be seen in Figure 13.

Table 3 The change in the distance between the column and the panel

Case	Frame width [cm]	Gap between panel and column [cm]	Proportion	Panel width
1	170	1.7	0.01	166.6
2	170	8.5	0.05	153.0
3	170	17.0	0.10	136.0
4	170	25.5	0.15	119.0
5	170	34.0	0.20	102.0

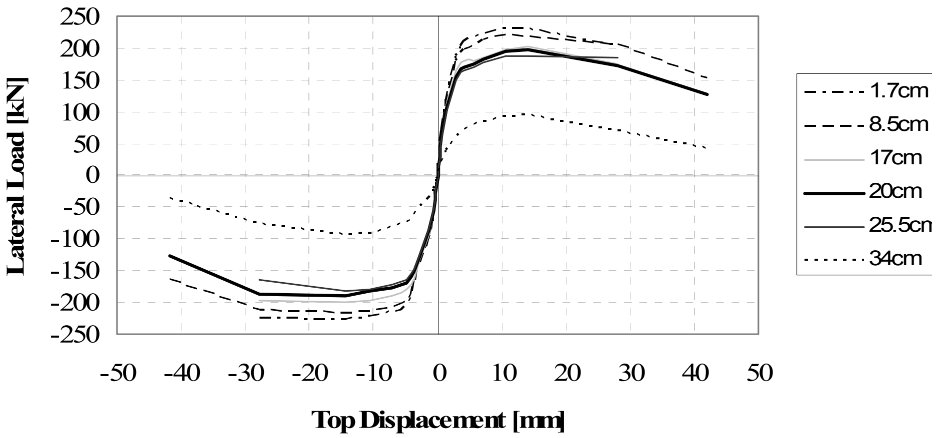

Figure 13 Results for the partially infilled frame

5. CONCLUSIONS

The envelope curves of the hysteretic responses of the three specimens are given in Figure 6 and compared. Experimental results pointed out the positive effect of strengthening a RC frame with wet-mixed sprayed concrete panels on its lateral stiffness and lateral load carrying capacity. The performed experimental study yields the following results:

a) The lateral stiffness of the frames, right before the first cracks occurred in the system, increased by 6 times for specimen S1 and 5 times for specimen S2 compared with the bare frame's,
b) The lateral load carrying capacity increased by 1.8 times for S1 and 1.6 times for S2 compared with the bare frame's,
c) The lateral stiffness difference between S1 and S2 specimens, right before the first cracks occurred, was about %18,
d) Although the strengthening technique used has increased the lateral load carrying capacity, the ultimate failure mode of the system has become as shear failure at column ends,
e) The analytical study shows us that when the panel dimension is %1 and %20 of the distance between the columns, the initial stiffness of the infilled frame is 105 kN/mm and 38 kN/mm, respectively. While the maximum lateral load obtained 230 kN and 95 kN, respectively.

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