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An experimental study on impact of anchor bars at the steel frames with infilled walls

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ABSTRACT

In this study, a series of experimental study was conducted to investigate the effect of anchor bars on steel frame systems where the connections were provided by anchor bars between frame and infilled walls. Seven one over four scaled specimens having one story and one bay of frames were tested. Experimental study was carried out by damage-controlled and incrementally applied load up to loading cracks. The test results relieved that with the help of using anchor bars the capacity of energy absorption with initial stiffness were increased. It has been found that the frames without using anchor bars failure at the loading edge, the crushing behavior of infilled walls and separations at free edges were occurred. These observed failure behaviors replies with tensile cracking for the frames having anchor bars. There for it should be underlined that anchor bars have a significant effect on improving the behavior of the frames.

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1. Introduction

Infilled walls mainly defined as a wall which separates the place from each other. Infilled walls directly affect the structural behavior. Although infilled walls affect the structural behavior of buildings, it has not been consider for the structural design analysis (Budak, 1997). This may be explained by the difficulties and the non-practical calculation methods which were provided by the available literature.

In the available literature considerable research has been conducted particularly the behavior of infilled walls under the impact of lateral loading. For this purposes the capacity of infilled walls load-carrying capacities, ductile, stiffness and energy absorption properties were examined. Performed studies generally used hysteretic and cycling loadings were applied (Öztürkoğlu et al., 2015; Aksoy et al., 2015; Özdemir et al., 2014; Yakut et al., 2013; Peynirci, 2007; Kara, 2006; Celep et al., 2003; Ataman, 2003; Orbay, 2001). Depending on the increases by loads some regions between frame and infilled walls are separated, and cracks occurred at inside of the infilled walls. Since separations and cracks depending on the changing loads occurred between infilled walls and the frames where infilled walls are in contact with those cracking regions; friction forces appear. Beside of occurred friction forces, damping provided by infilled walls increase overall strength and stiffness with energy absorption (Budak, 1997). Up to a certain value of slippage, slipping of anchor bars provides ductility and the capacity of energy absorption (Yalciner et al., 2015).

In Turkey, lessons learned from previous earthquake show that most of the constructed buildings with infilled walls cause ductile problems, non-adequate lateral stiffness for the damaged buildings (Kızıloğlu, 2006). In order to repair and strengthening of such buildings against to further expected earthquakes, it has been began to use anchor bars for infilled walls (Tekeli et al., 2014; Özen et al., 2014; Erdem et al., 2004).

In contrast to previous studies in this study the behavior of steel frames constructed with infilled walls by using anchor bars were examined. It is believed that infilled walls with anchor bars provide better stability of the structural systems under the applied lateral loads.

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2. Assumptions of the Current Study

The assumptions done for the current study were listed below:

- Monolithic loading has been applied until the cracking loading. Thus applied lateral loading of infilled walls distributed as diagonal that because of the bending behavior of the system an effective experimental program was performed.
- The placing of anchor bars at column-beam joints were done according to the conventional densification.
- The infilled model was preferred as slenderness walls. This may be explain by the bending behavior for the infilled walls which are having slenderness ratio less than 20.
- For the trial test four millimeter diameter of aggregate was used according to the described guideline by ACI. In order to observe the cracking patterns seven millimeter diameter of aggregate were selected for the real tests.
- For $\phi 4$ millimeter diameter of anchor bars were selected to provide the ratio of total area of anchor bars to area of infilled walls which was 0.8 (Phan et al., 1995).

3. Experimental Program and Setup

3.1. Experimental program

In this study, seven one over four scaled specimens having one story and one bay of frames were tested. While the material of the infilled walls was done by in-place concrete, the frame was constructed with steel profile. Fig. 1 shows the connections between frame and infilled walls provided by anchor bars. All specimens were cured for seven days. The characteristic properties for the samples were given in Table 1. The tests were ended until the defined damaged degree was provided where the loading program was done by using incremental loading and damage-controlled.

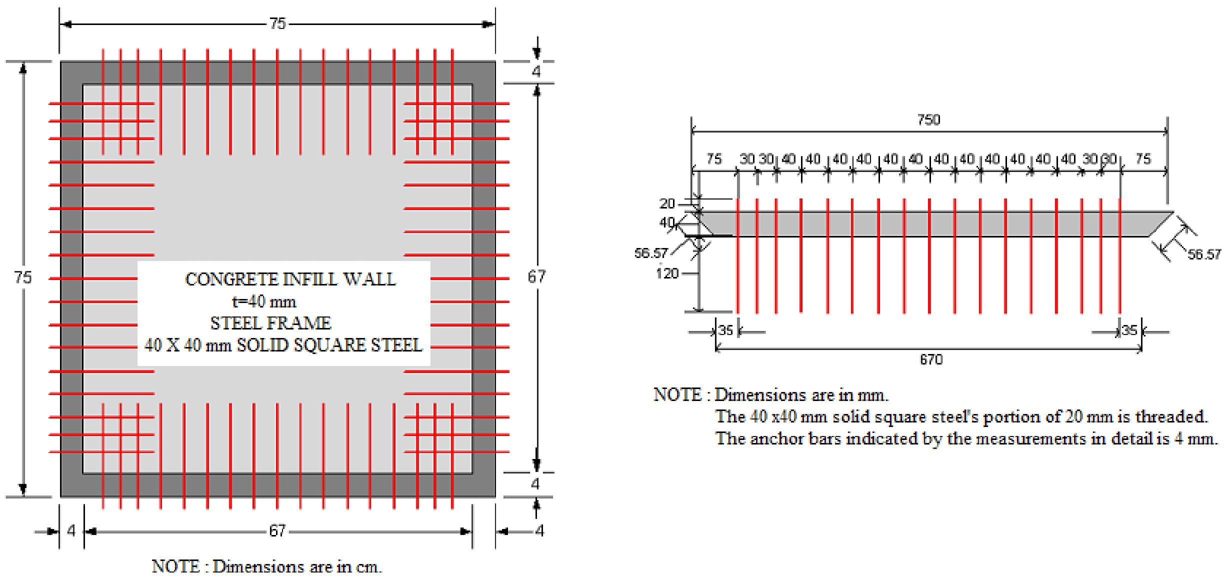


Fig. 1. Demonstration of test specimen.

3.2. The setup of the experimental study

Fig. 2 shows the setup for the performed experimental study. Steel frames with infilled walls were hold with the help of its own weight at the setup platform and the loads were applied to the edge of the frame.

The damage degree to the cracking loading constitutes the linear curvature region of load-displacement and separation of walls at free support. In this study the considered cracking loading was not limited by initial cracking or interface surface cracking. The loading was continued until tension and cross cracking occurs at the surface of the infilled walls, crushing occurs at fixed support and edge failure-crushing, separation of infilled walls at free supports.

After obtaining the damage to the cracking load while the load constant since the displacements were continued and the behavior of the system exceed the plastic region in order to be able to discuss the contribution of the anchor bars the experimental tests were ended.

The expectation until the occurring of the cracking loading was initial cracking or interface cracking, tensile or cross cracking, crushing of walls supports and edge failure-crushing and separation of walls at free supports.

Table 1. Characteristics of test specimens.

Frame without Infilled Wall		Steel Frame	$E_{\text{steel frame}}$=198000 MPa $\gamma_{\text{steel frame}}$=7,25e-6 kg/mm^3 $\upsilon_{\text{steel frame}}$=0,30
Frame with Infilled Walls	First Test Specimen	Steel Frame	$E_{\text{steel frame}}$=198000 MPa $\gamma_{\text{steel frame}}$=7.25e-6 kg/mm^3 $\upsilon_{\text{steel frame}}$=0.30
		Infilled Walls	$E_{\text{infilled walls}}$=17300 MPa $\gamma_{\text{infilled walls}}$=2.20e-6 kg/mm^3 $\upsilon_{\text{infilled walls}}$=0.20 $\sigma_{\text{infilled walls}}$=11.14 MPa
	Second Test Specimen	Steel Frame	$E_{\text{steel frame}}$=198000 MPa $\gamma_{\text{steel frame}}$=7.25e-6 kg/mm^3 $\upsilon_{\text{steel frame}}$=0.30
		Infilled Walls	$E_{\text{infilled walls}}$=13400 MPa $\gamma_{\text{infilled walls}}$=2.20e-6 kg/mm^3 $\upsilon_{\text{infilled walls}}$=0.20 $\sigma_{\text{infilled walls}}$=3.57 MPa
	Third Test Specimen	Steel Frame	$E_{\text{steel frame}}$=198000 MPa $\gamma_{\text{steel frame}}$=7.25e-6 kg/mm^3 $\upsilon_{\text{steel frame}}$=0.30
		Infilled Walls	$E_{\text{infilled walls}}$=19300 MPa $\gamma_{\text{infilled walls}}$=2.20e-6 kg/mm^3 $\upsilon_{\text{infilled walls}}$=0.20 $\sigma_{\text{infilled walls}}$=15.10 MPa
	Forth Test Specimen	Steel Frame	$E_{\text{steel frame}}$=198000 MPa $\gamma_{\text{steel frame}}$=7.25e-6 kg/mm^3 $\upsilon_{\text{steel frame}}$=0.30
		Infilled Walls	$E_{\text{infilled walls}}$=18900 MPa $\gamma_{\text{infilled walls}}$=2.20e-6 kg/mm^3 $\upsilon_{\text{infilled walls}}$=0.20 $\sigma_{\text{infilled walls}}$=13.95 MPa
Frame with Infilled Walls + Anchor Bars	First Test Specimen	Steel Frame	$E_{\text{steel frame}}$=198000 MPa $\gamma_{\text{steel frame}}$=7.25e-6 kg/mm^3 $\upsilon_{\text{steel frame}}$=0.30
		Infilled Walls	$E_{\text{infilled walls}}$=18900 MPa $\gamma_{\text{infilled walls}}$=2.20e-6 kg/mm^3 $\upsilon_{\text{infilled walls}}$=0.20 $\sigma_{\text{infilled walls}}$=13.95 MPa
		Anchor Bars	$E_{\text{anchor bar}}$=123000 MPa $\gamma_{\text{anchor bar}}$=7.80e-6 kg/mm3 $\upsilon_{\text{anchor bar}}$=0.30
	Second Test Specimen	Steel Frame	$E_{\text{steel frame}}$=198000 MPa $\gamma_{\text{steel frame}}$=7.25e-6 kg/mm^3 $\upsilon_{\text{steel frame}}$=0.30
		Infilled Walls	$E_{\text{infilled walls}}$=16500 MPa $\gamma_{\text{infilled walls}}$=2.20e-6 kg/mm^3 $\upsilon_{\text{infilled walls}}$=0.20 $\sigma_{\text{infilled walls}}$=10.49 MPa
		Anchor Bars	$E_{\text{anchor bar}}$=123000 MPa $\gamma_{\text{anchor bar}}$=7.80e-6 kg/mm3 $\upsilon_{\text{anchor bar}}$=0.30
Note: E: Modulus of Elasticity, γ: Density, υ: Poisson's Ratio and σ: The average compressive strength of infilled wall			

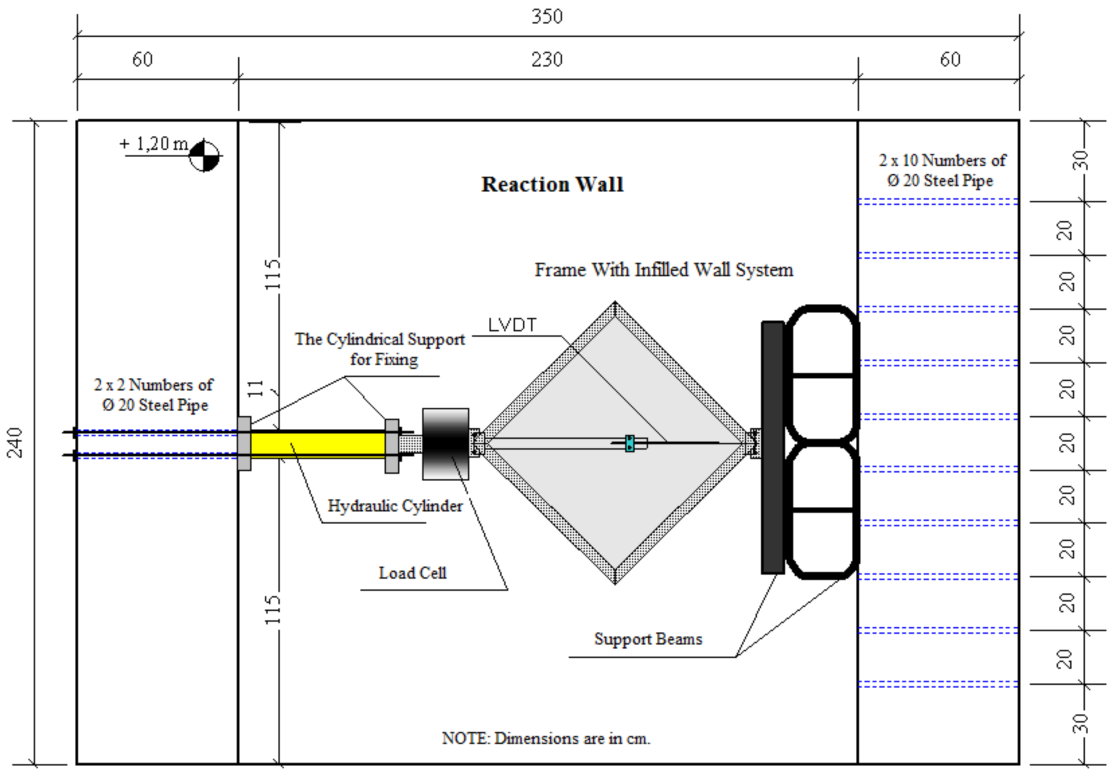


Fig. 2. Experimental setup.

4. Experimental Results

For each samples load-displacement curves were obtained and by using those results the capacity of energy absorption with initial stiffness were calculated. At the obtained load-displacement curve since initial stiffness was calculated at the 1.50 mm displacement, the capacity of the energy absorption was also calculated based on these quantities.

Table 2 gives the obtained load-displacement curve with cracking patterns occurred at cracking load. Based on obtained test, results initial stiffness with capacity of energy absorption summarized in Table 3.

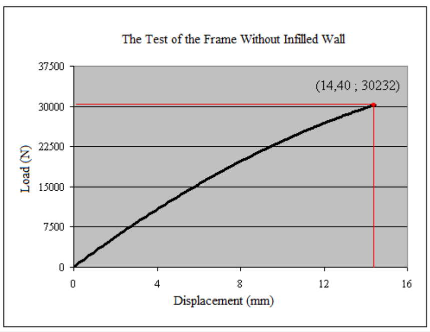
By using the material constant of the concrete infilled walls damage level occurred until to the cracking loading, with the assumption of the plane strain, stress-based evaluation was done by calculating the shear stresses occurred at infilled walls. Obtained tests results for the average shear stresses were summarized in Table 4.

In this study also plane stresses were recorded by installing the strain gauges to the anchor bars. The interaction between the frames lends to bending and the slippage of the infilled walls was investigated. The installed strain gauges are shown in Fig. 3. Table 5 also shows the transferred loads to the infilled walls and plane stresses passes to anchor bars.

Table 3. Displacement-based evaluation of the test specimens.

Frame With Infilled Wall Systems		Load (N)	Energy Absorption Capacity (Joule) (10^{-3})	Initial Stiffness (N/m) (10^{6})
Frame without Infilled Wall		4264	3.23	2.80
Frame with Infilled Walls	First Test Specimen	71906	59.05	57.35
	Second Test Specimen	17896	15.51	15.96
	Third Test Specimen	34695	27.98	29.69
	Forth Test Specimen	84323	69.35	131.06
Frame with Infilled Walls + Anchor Bars	First Test Specimen	82752	71.26	72.12
	Second Test Specimen	70892	59.75	56.72

Table 2. Load-displacement curves of the experimental specimen and the damage pattern in cracking load.

<table>
<tr><td colspan="2">Frame without Infilled Wall</td><td>
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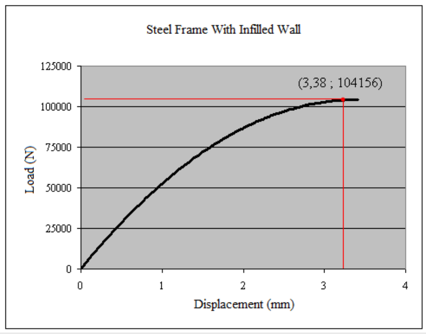
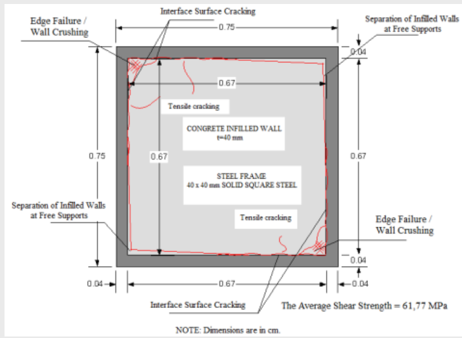
<tr><td rowspan="4">Frame with Infilled Walls</td><td>First Test Specimen</td><td>
</td><td>
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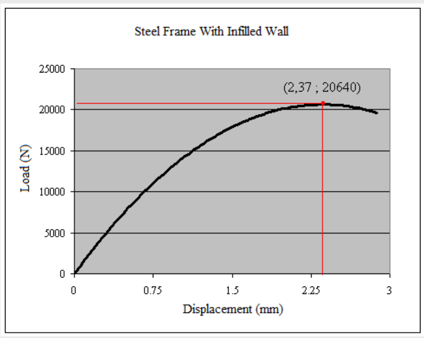
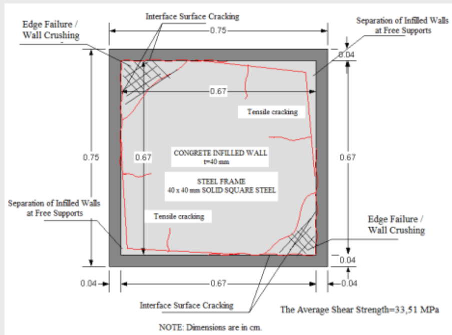
<tr><td>Second Test Specimen</td><td>
</td><td>
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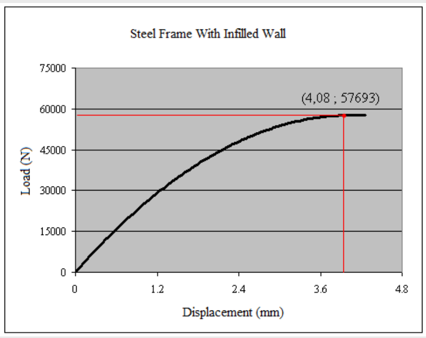
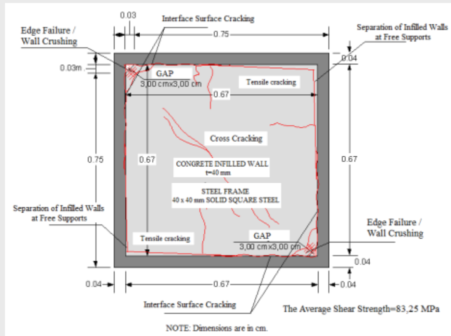
<tr><td>Third Test Specimen</td><td>
</td><td>
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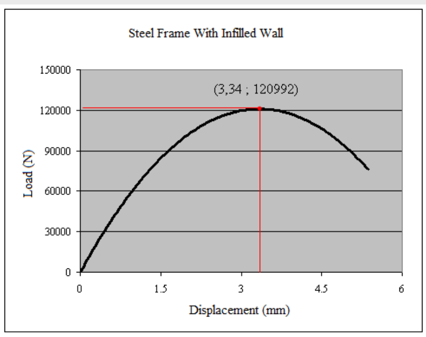
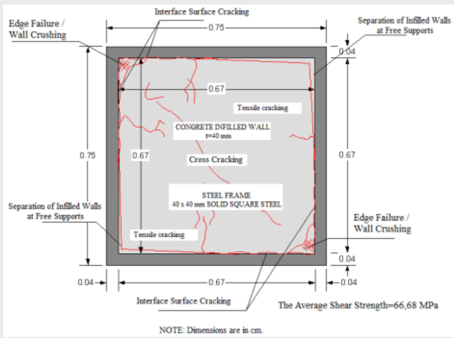
<tr><td>Forth Test Specimen</td><td>
</td><td>
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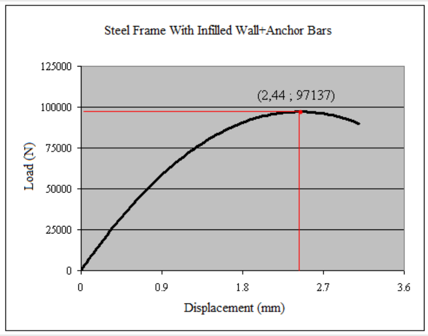
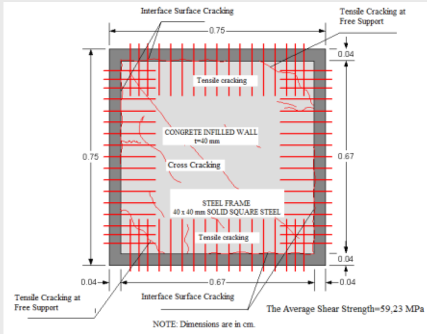
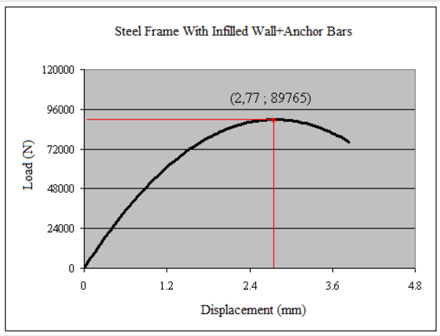
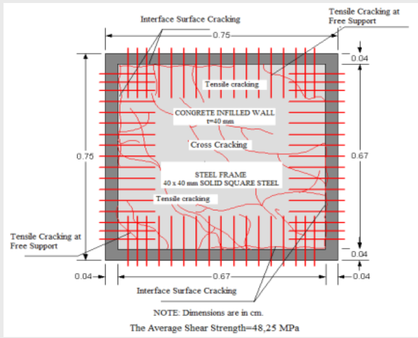
* Table 2			
Frame with Infilled Walls + Anchor Bars	First Test Specimen		
	Second Test Specimen		

Table 4. Stress-based evaluation of the test specimens.

Frame With Infilled Wall Systems		Cracking Load (N)	The Average Shear Strength (MPa)	The Average Compression Strength of Infilled Wall (MPa)
Frame without Infilled Wall		-	-	-
Frame with Infilled Walls	First Test Specimen	104156	61.77	11.14
	Second Test Specimen	20640	33.51	3.57
	Third Test Specimen	57693	83.25	15.10
	Forth Test Specimen	120992	66.68	13.95
Frame with Infilled Walls + Anchor Bars	First Test Specimen	97137	59.23	20.44
	Second Test Specimen	89765	48.25	10.49

5. Discussions of the Test Results

When the obtained results of load-displacement curve and the capacity of energy absorption were examined, the tests results 1.52 times less for infilled walls without anchor bars, 20.28 for times of frame without infilled walls. The test results of the capacity of energy absorption are summarized in Fig. 4.

When the tests results consider for the initial stiffness the obtained results for the initial stiffness was 1.18 times was more for the anchor system compare to frames without anchor bars and 23.13 times compare to frames without infilled walls at the displacement of 1.50 mm and the load corresponding to cracking load. The test results of the initial stiffness are summarized in Fig. 5.

As shown in Fig. 6, it has been found that there have been no significant differences for the obtained results of shear stresses between the frame with infilled walls having anchor bars and the infilled walls frames not having anchor bars. According these results steel frames transfers the loads uniformly and provide adequate confinement.

Obtained results of the plane stresses and transferred normal loads passes through anchor bars having fixed support and free support are shown in Table 6.

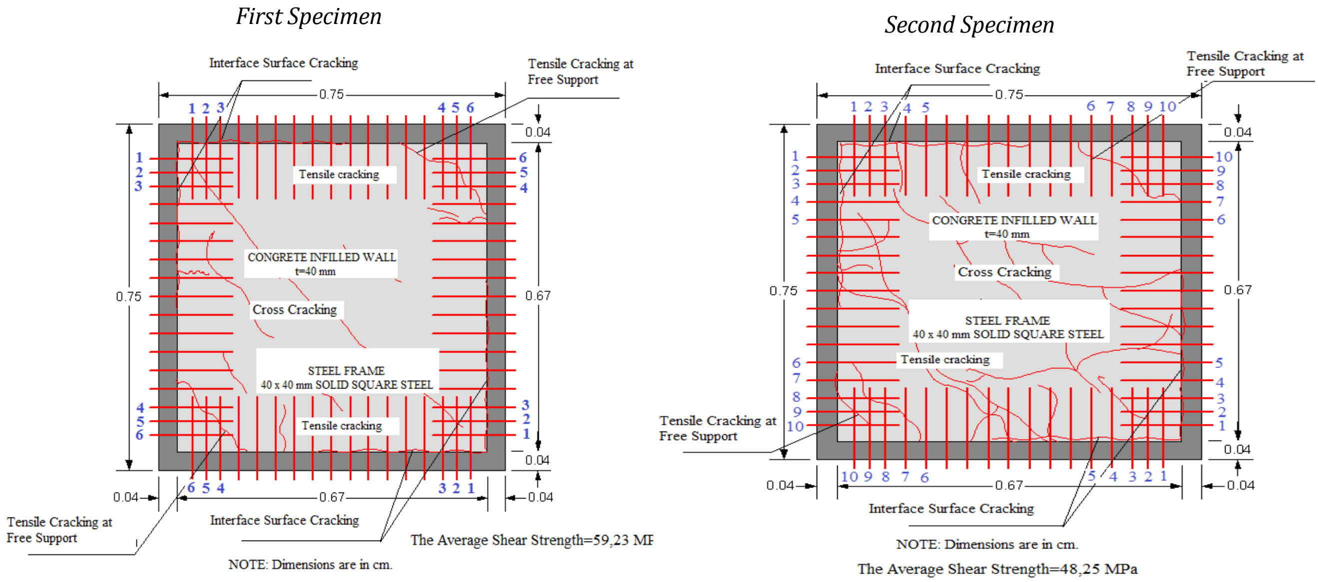
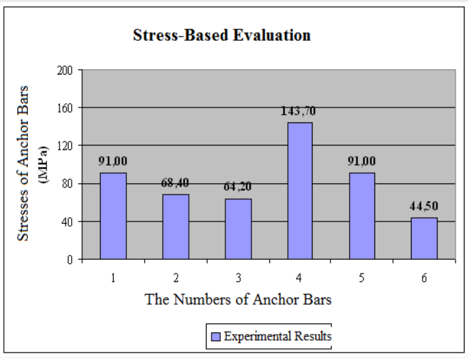
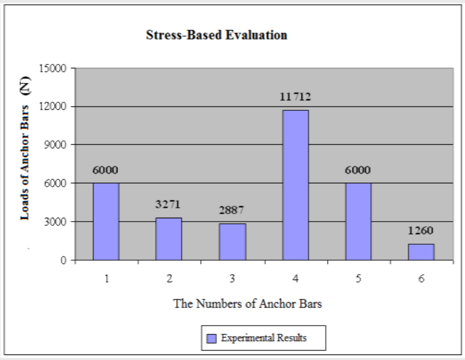
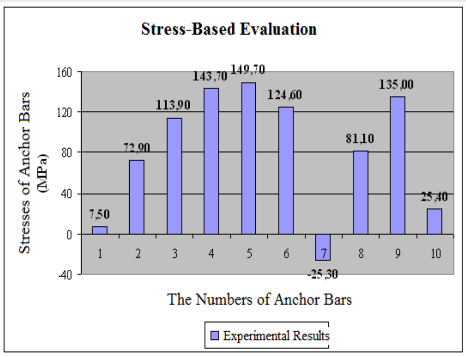
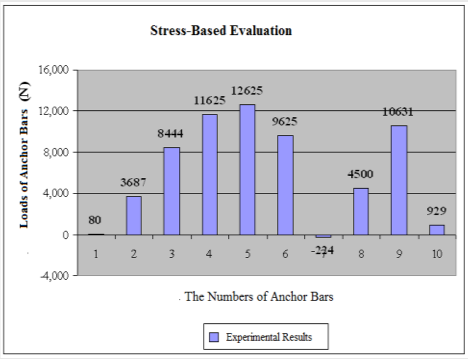


Fig. 3. Installation of strain gauges.

Table 5. Transferred loads to the infilled walls and plane stresses passes to anchor bars.

Frame with Infilled Wall Systems		Plane Stresses Passes to Anchor Bars	Transferred Normal Loads to the Infilled Walls
Frame with Infilled Walls + Anchor Bars	First Specimen		
	Second Specimen		

In Fig. 7 for the first sample plane stresses of the anchor bars at the fixed support were approximately 25% more compare to free support. For the second sample these results were approximately achieved to 43%.

At the first sample with the help of anchor bars transferred normal loads to the infilled walls was approximately 56% more for the fixed support compare to free support. For the second sample these values reduced to 43% at the fixed support compare to free support. According to results with the help of anchor bars plane stresses occurred at the steel frame systems successfully were distributed.

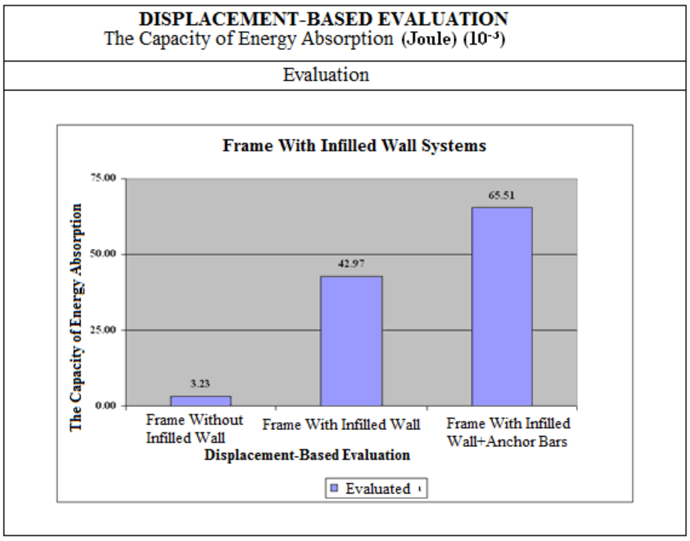


Fig. 4. Test results of the energy absorption capacity.

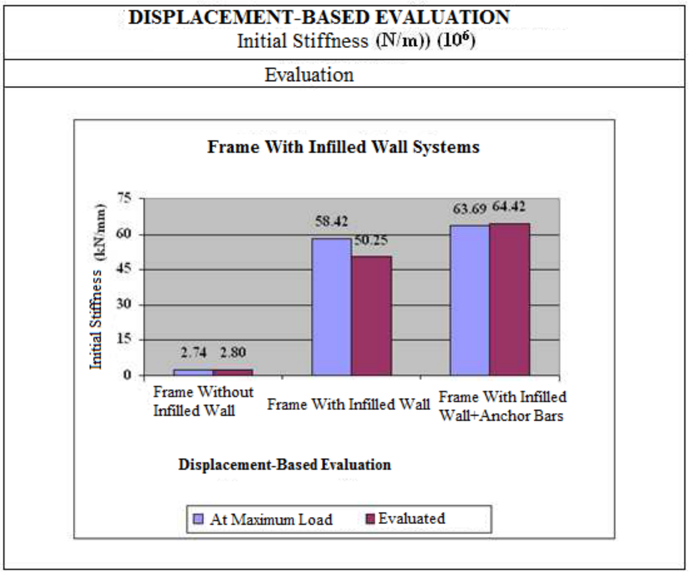


Fig. 5. Test results of the initial stiffness.

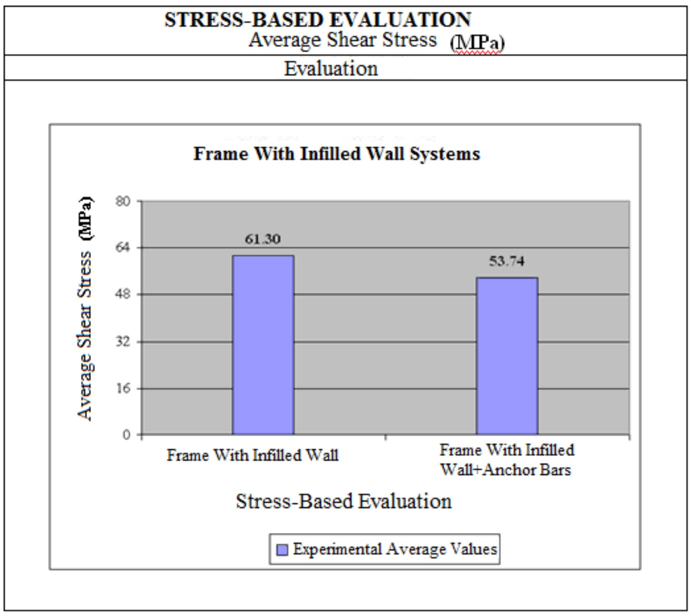
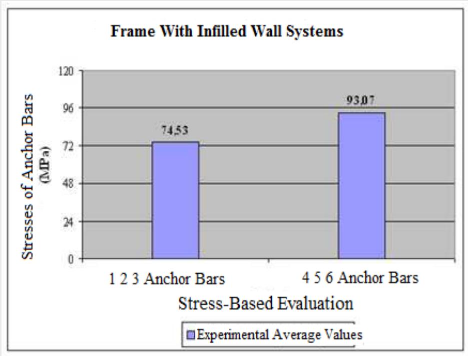
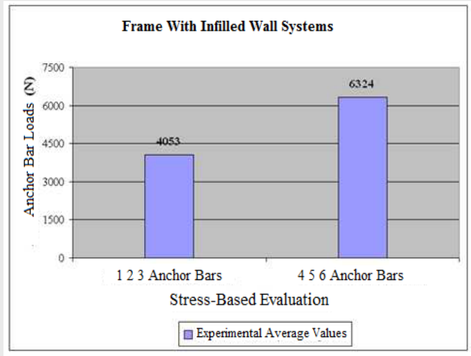


Fig. 6. Test results of the average shear stresses.

Table 6. Obtained results of the plane stresses and transfer normal loads passes through anchor bars having fixed support and free support.

<table>
<tr><th colspan="2">Frame with Infilled Wall Systems</th><th>Plane Stresses Passes to Anchor Bars</th><th>Transferred Normal Loads to the Infilled Walls</th></tr>
<tr><td rowspan="2">Frame with Infilled Walls + Anchor Bars</td><td>First Specimen</td><td>
</td><td>
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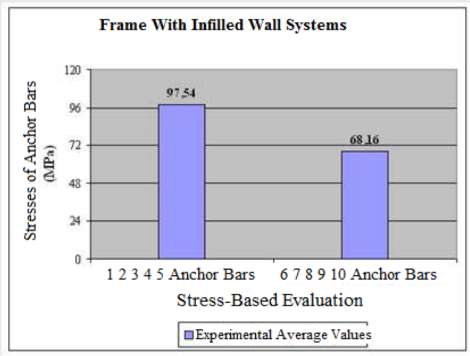
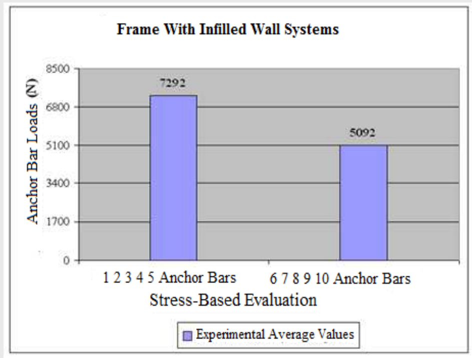
<tr><td>Second Specimen</td><td>
</td><td>
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6. Conclusions

Test results indicated that placed anchor bars for the steel frames remarkable increase the capacity of the energy a sorption and initial stiffness. It has been found that average shear stresses were not change significantly. These may be explained by the rigidity of the steel frames and the applied load until to the cracking loads. While the behavior of the edge failure/wall crushing occurred at the applied load on the edge of the infilled walls frames not having anchor bars, the separation of the walls occurred at free edges. This behavior was replaced with tensile cracking for infilled walls frames having anchor bars. As a results it can be concluded that the behavior of the system obviously improved by anchor bars. It is believed that obtained results may provide the guideline for the earthquake codes.

Acknowledgements

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