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The Behavior of Infilled Steel Frames under Horizontal Loading

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Abstract: In this study, seven steel frame systems which have different geometries were tested. One bay one story steel frame systems were filled with air-holed brick wall. The steel frames which were tested in the study have different span lenght / height ratios (L/H = 1.00, 1.25, 1.50). Each of the steel frames with different span lenght /height ratio were tested under three different conditions, first the span was empty , in the second condition the span was filled with air holed brick wall and in the third condition the span was filled with air-holed brick wall with plaster. By applying lateral forces, lateral displacements, crack patterns, failure modes and ductility were investigated on the specimens.

***Keywords**: Infilled steel frames, lateral loads, lateral stiffness, air holed brick wall*

Introduction

In order to protect the building structures from the outer affects and make different architectural design of them, their steel frame systems are filled with air-holed brick wall. Although weight of the wall is included in the computations of engineering design of a building as a load on the steel frames, its affects on the behavior of steel frames are eliminated from the computations (Budak, 1997). Both analytical and experimental studies have proved that rigidity and capacity of loading rate of the wall highly affect its energy absorbsion capacity (Yalçın, 1999). Early experimental works on this subject have been started by (Holmes, 1961) and continued by Smith, (1962; 1963; 1967), Smith & Carter, (1969), Ersoy *et al*., (1971), Gülkan and Wasti, (1974), Altın, (1990), Marjani, (1997), Karaduman, (1998; 2005; 2010), Köken, (2003), Kaltakcı et al., (2007, 2008), Nezhad et al., (2013), Lila et al., (2014), Kaltakcı and Koken, (2014), Skafida et al., (2014) also had experimental studies. In this current work, seven steel frame systems which have different span lenght / height ratios (L/H) with filled air-holed brick wall were tested to investigate the behavior of them under lateral loadings. Dimensional affect and lateral rigidity of them have been investigated and resulted based on laboratory experiments.

Materials and Methods

Experimental setup

Unfilled and filled steel frame systems used in current work consist of NPU160 profiles. In the experiments, while span width (L) of frame system was changed at different intervals, its height (H) was kept as a constant. Air-holed brick blocks which have dimensions of 60 x 25 x10 cm were used as a filling material. As air-holed brick blocks were light materials, they have some advantages as to prevent collapsing of a building when an earthquake occurs. Effect of plaster thickness over lateral rigidity is the other parameter used in current study. Dimensions of stell frame system producted by using N160 profile and its properties are seen in Table 1. Their physical and mechanical properties are also shown in Table 2.

Tablo 1. The size and properties of frame samples were made of NPU 160

Sample No	Frame Section (mm)	Infill Thickness t (cm)	Infill Heigt H (cm)	Infill Length L (cm)	Infill	Infill Type
N110	NPU 160	-	100	100	Empth	-
N111	NPU 160	10	100	100	unplastered	G2
N112	NPU 160	10	100	125	unplastered	G2
N113	NPU 160	10	100	150	unplastered	G4
N114	NPU 160	13	100	100	plastered	G2
N115	NPU 160	13	100	125	plastered	G2
N116	NPU 160	13	100	150	plastered	G4

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Table 2. Mechanical and Physical Properties of Infill Material

Material		**G2**	**G4**
Unit weigth	(N/m^3)	5000	6000
Compressive strength	(N/mm^2)	2.5	5.0
Tensile strength	(N/mm^2)	0.25	0.50
Poisson's ratio		0.25	0.25
Elastic Modulus	(N/mm^2)	1500	2050
Dimensions	(cm)	60x25x10	60x25x10

Properties of Plasters

In this experimental study, a special masonry glue was used for building up the wall while mixed plaster was used in plastering. In accordance with TS EN 13914-2:(2007), the volumetric mixing ratios of the mixed plaster was shown in Table 3, the granulometry of rinsed sand in Table 4, and the mechanical properties of the mixed plaster were obtained at the end of 28-day period.

Table 3. Volumetric mix design of mortars

Mortar Type	Used Materials		
	Sand	Cement	Lime slurry
Mortar	8	1	1.5

Table 4. Sieve analysis of Sand

Sieve No	(mm)	0.25	0.5	1	2	4	8
Passed	%	9	23	58	79	95	100

Table 5.Mechanical properties of the mixed plaster

Compressive strength (N/mm^2)		**11.40**
Deflection length of time of Fracture		$1.93x10^{-3}$
Elastic Modulus	(N/mm^2)	5918.825
Dimensions (mm)		70x70x70
Bending Strength	(N/mm^2)	3.416

Experimental Program

The walls constructed within 6 different steel frame systems that their height (H) was kept as a constant while span width (L) of them was changed with different intervals were designed by using air-holed brick materials. Three out of six steel frame systems filled with air-holed brick walls were made by using mixed plaster. Those have been undertaken by lateral loadings up to collapsing phase and their behaivour in these situations were determined. In order to investigate the effects of walls and plasters on the behaviour of steel frame systems, height (H) of the walls was kept as a constant. In the experiments, 7 different steel frame systems which one of them was unfilled while the other ones of them were filled with air-holed brick wall with and without plaster were used. Displacement was measured at increasing load phases. Cracking load and its shape was also determined. Figure 1 shows these lateral loads versus lateral displacements based on experiments conducted in current work.

The Crack Load, Collapse Load, Lateral rigidity and Ductility of Infilled Frames

In this section the effect of infill walls and plaster are studied. The curves given in Figure 1 are divided into three portions as linear elastic portion, cracking portion and collapse portions. The lateral rigidity in linear elastic portion is named as (α_i), Cracking load of infilled wall is given as ($P_ç$), and collapse load is given as (P_k). These are given in Table 6, 7, 8 and 9. Ductility is defined as maximum displacement reached at collapse (Δ_u), over the dispacement at the border of elastic displacement (Δ_y). The Obtained results are given in Table 11.

Lateral Rigidity $\alpha_i = P_H / \delta_H$

P_H : Lateral Load

δ_H : Lateral Displacement

$P_Ç$: Crack Load

P_K : Collapse Load

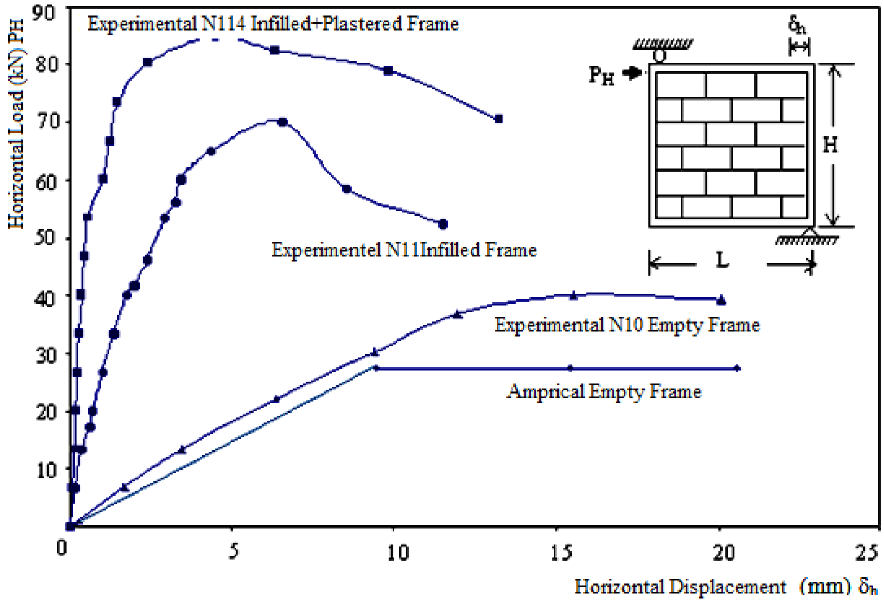

Figure 1. Lateral load-horizontal displacement grafs of the test specimen N110, N111, N114 (L/H=1.00),

Table 6. The ratios of infilled samples for Empty Sample (L/H=1.00)

Sample No	Crack Load (kN)	Collapse Load (kN)	Lateral Rigidity (kN/mm)	Crack Load / Empty	Collapse Load / Empty	Lateral Rigidity / Empty
(1)	(2)	(3)	(4)	(5)	(6)	(7)
N110 –Empty	-	41.35	29.32	-	1.00	1.00
N111-Unplastered	18.13	69.75	378.13	-	1.68	12.89
N114-Plastered	42.18	87.20	980.12	-	2.10	33.42

Table 7. The ratios of infilled samples for Empty Sample (L/H=1.00)

Sample No	Crack Load (kN)	Collapse Load (kN)	Lateral Rigidity (kN/mm)	Crack Load Plastered/ Unplastered	Collapse Load Plastered / Unplastered	Lateral Rigidity Plastered / Unplastered
(1)	(2)	(3)	(4)	(5)	(6)	(7)
N111- Unplastered	18.13	69.75	378.13	1.00	1.00	1.00
N114- Plastered	42.18	87.20	980.12	2.32	1.25	2.59

Table 8. The ratios of infilled samples for Empty Sample (L/H=1.25)

Sample No	Crack Load (kN)	Collapse Load (kN)	Lateral Rigidity (kN/mm)	Crack Load Plastered/ Unplastered	Collapse Load Plastered/ Unplastered	Lateral Rigidity Plastered/ Unplastered
(1)	(2)	(3)	(4)	(5)	(6)	(7)
N112- Unplastered	35.15	72.01	290.25	1.00	1.00	1.00
N115- Plastered	45.92	98.12	825.38	1.30	1.36	2.84

Table 9. The ratios of infilled samples for Empty Sample (L/H=1.50)

Sample No	Crack Load (kN)	Collapse Load (kN)	Lateral Rigidity (kN/mm)	Crack Load Plastered/ Unplastered	Collapse Load Plastered/ Unplastered	Lateral Rigidity Plastered/ Unplastered
(1)	(2)	(3)	(4)	(5)	(6)	(7)
N113- Unplastered	33.81	86.89	522.16	1.00	1.00	1.00
N116- Plastered	41.02	110.32	866.35	1.21	1.26	1.65

Ductility ($\mu = \Delta_u / \Delta_y$) is described as rate of total displacement can be reached (Δ_u) and the displacement at which the elastic limit is reached (Δ_y).Also ductility is described as the impordad part of strenght of bearing element , system element or used materials can be maintained. In non-lineer behavior.The values related to investigation of ductility wore presented in Table 10.

Tablo 10. Ductilities obtained

Sample	Elastic Displacement Δ_y (mm)	Total Dispalecement Δ_u (mm)	Ductility Ratio $\mu=\Delta_u / \Delta_y$	Infilled Frame Ductility Empty Frame Ductility
N110	11,43	19,90	1,74	1,00
N111	3,84	11,35	2,95	2,37
N112	3,18	13,15	4,13	2,97
N113	2,73	14,12	5,17	3,27
N114	2,55	13,40	5,25	3,01
N115	2,91	13,88	4,76	2,73
N116	3,12	13,18	4,22	2,42

Conclusions

1) For different L/H ratios, experiments have shown that lateral rigidity of a steel frame system has been increased by the addition of air-holed brick walls. Current study has proved that a steel frame system named as N110 with filled by air-holed brick wall with and without plaster has higher lateral rigidity greater than 33,42 and 12,89 times, respectively in comparison with the unfilled ones for L/H=1,00. Besides, for the same L/H ratio, N110 with filled by air-holed brick wall with plaster has higher lateral rigidity greater than 2,59 times in comparison with the N110 with filled by air-holed brick wall without plaster. On the other hand, for L/H ratios which are equal to 1,25 and 1,50, N110 with filled by air-holed brick wall with plaster has higher lateral rigidity greater than 2,84 and 1,65 times, respectively in comparison with the N110 with filled by air-holed brick wall without plaster.
2) Cracks have been highly increased by the use of plaster on the walls. N110 with filled by air-holed brick wall with plaster has higher crack load greater than 2,31 times in comparison with the N110 with filled by air-holed brick wall without plaster for L/H=1,00. Besides, for L/H ratios which are equal to 1,25 and 1,50, N110 with filled by air-holed brick wall with plaster has higher crack load greater than 1,30 and 1,21 times, respectively in comparison with the N110 with filled by air-holed brick wall without plaster.
3) As expected, collapse load has been increased by the use of the walls in the steel frame system. N110 with filled by air-holed brick wall with plaster has higher collapse load greater than 1,15 times in comparison with the N110 with filled by air-holed brick wall for L/H=1,00. Besides, for L/H ratios which are equal to 1,25 and 1,50, N110 with filled by air-holed brick wall with plaster has higher collapse load greater than 1,36 and 1,26 times, respectively in comparison with the N110 with filled by air-holed brick wall without plaster.
4) As to prevent collapsing, filled steel frame systems has more advantages when compared to unfilled ones as indicated in Table 1. Table 1 shows that ductility of filled system is bigger 1,69-3,01 times than an unfilled one.
5) The cracks in filled walls generally observed at the ends of the diagonal of the frame-wall joints. However, the cracks in this reagon do not change the rigidity of the filled frames. It has also been observed that the cracks would continue in load-displacement curves up the diagonal ends.

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