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Structural Behavior of Light Weight Ferrocement Walls

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Abstract

This paper presents the experimental results of research to develop ferrocement sandwich panels for use as wall bearing units. The proposed panels are lighter in weight relative to the conventional reinforced concrete panels The sandwich panels consisted of two thin ferrocement layers reinforced with one or two layers of closely spaced galvanized welded wire mesh and expanded steel mesh. The core of the panel was made of light weight brick. Steel wires were used to tie the steel meshes of the two skin layers together and to act as shear connectors to transfer shear between the two ferrocement skin layers. These steel wires were embedded in the mortar joints of the brick. The thickness of the ferrocement skin layer was 10mm when single layer of wire mesh was used and 15mm when two layers of mesh reinforcement were used. Experimental investigation was conducted on the proposed panels. A total of 10 sandwich panels Having the dimensions of 600mm width and 700mm height were tested under compressive loadings until failure. The deformation characteristics and cracking behavior were measured and observed for each wall panel. The results showed that high ultimate and serviceability loads, crack resistance control, high ductility, and good energy absorption properties could be achieved by using the proposed panels. This could be of great construction advantages for both developed and developing counties.

Keywords: Ferrocement; Sandwich Panels; Deformation characteristics; Serviceability load; Ductility
and Energy absorption properties; Cracking pattern; Ultimate loadings.

1. INTRODUCTION

Ferrocement is a construction material that proved to yield superior properties in terms of crack control, impact resistance, and toughness, largely due to the close spacing and uniform dispersion of reinforcement within the material. Many investigators have reported the physical and mechanical properties of this material and numerous test data are available to define its performance criteria for design and construction [1], [2]. Recently, ferrocement has received attention as a potential building material in developing countries, especially for roofing of housing construction [3]. The behavior and strength of wall elements under axial loading were studied by Joshi [4]. Swamy and Spanos [5] presented a proposed method of fabrication of ferrocement slabs by grouping the reinforcement meshes at top and bottom and tying them with skeletal steel to form a rigid cage. The proposed method proved to be effective in obtaining high ultimate strength and better deformation characteristics. Fahmy et al [6] presented the experimental results of first phase of the current research [6]. In that phase, twelve ferrocement sandwich panels and hollow core panels were developed and evaluated for applications in walls, slabs and roofing systems. The sandwich panels were manufactured from two outer ferrocement skins separated by a core of light -weight materials. Two types of core material were investigated, namely; light weight brick and foam concrete. For the hollow cored panels, the core was made of the same mortar matrix as the skin ferrocement layer with three circular holes running along the length of the specimen. The experimental results showed that the behavior of the light brick specimens was superior to that of the foam concrete core specimens. The results also showed that high ultimate and serviceability loads crack resistance control, high ductility, and good energy absorption properties were achieved by using the proposed panels.

Ferrocement is proposed is being used for thin radial gates with high strength, crack resistance, high ductility and energy absorption suitable for irrigation works to replace the commonly used stee1 gales. This paper presents the results of analytical stud y of the strength of a proposed ferrocement radial gate. The cement-sand matrix of the ferrocement composite was designed to achieve high compressive, tensile and flexural strength for the ferrocement radial gates. This was achieved by adding silica fume as replacement percentage of the cement content. The results of an experimental investigation of the effect of silica fume on the strength of the matrix are also included. Replacement of 15% of cement with silica fume proved to be the optimum percentage for water-binder ratio of 0.28. The suitable gate thicknesses for different water heights and waterway widths are also presented in this payer. E.H. Fahmy, Y.B. Shaheen and W.M. El Dessouki, 1995, [8].

Tensile Behavior of Thin Ferrocement Plates presents comprehensive test data on the tensile behavior of ferrocement plates, 12.5mm thick. The main variables investigated were mesh geometry, specific surface, volume fraction, mesh yield strength and skeletal bars. The specimens were specially designed to ensure

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failure in the gage length. The matrix was proportioned for high strength, high workability and high durability with low water to binder ratio, and contained 50% cement replacement with fly ash, Cracking and deformation were monitored throughout the loading range. The results showed that the composite properties of elastic modulus and ultimate strength could be very satisfactorily predicted by a single unique relationship, there was, however, a good correlation between the composite properties of ultimate tensile strength and ultimate flexural strength. The results show that by suitable design of the matrix and the reinforcement, high strength ferrocement sheets with high crack resistance can be developed for a variety of structural applications, Swamy R N and Y B I Shaheen, 1990, [9].

Sandwich wall bearing units presents the experimental results of the second phase of the previously published research to develop ferrocement sandwich wall bearing units. The sandwich panels consisted of two thin ferrocement layers reinforced with one or two layers of closely spaced welded wire mesh. The core of the panel was made of light weight brick. Z-shaped steel bars were used as shear connectors to transfer shear between the two ferrocement skin layers. The shear connectors were tied to the mesh reinforcement of the ferrocement skin layer and were embedded in the mortar joints of the brick. The thickness of the ferrocement skin layer was 10mm when single and double layers of wire mesh was used. The core material was 100 mm thick. Experimental investigation was conducted on a total of 10 sandwich panels. The experimental results showed that the panel thickness, type of steel mesh and the number of reinforcing steel meshes have major impact on the behavior of the panels. The results also showed that all tested panels had high ultimate and serviceability loads, crack resistance control, high ductility, and good energy absorption properties.

2. EXPERIMENTAL PROGRAM

The experimental program was designed to investigate the effect of strengthening light weight wall with ferrocement of wall bearing panels. These parameters are: thickness of the ferrocement layer, type of reinforcing steel mesh, and the number of steel reinforcement meshes in each ferrocement layer were tested under axial compression loadings. Steel reinforcement provided number of the steel layers at each face, and the thickness of the two thin skin layers, as shown in Table 1. Each designation comprised of 5 typical specimens. The width and the height of all specimens were 600mm and 700mm respectively. Different types of steel meshes were used to provide the steel reinforcement in the two thin skin layers at each face of the specimens. These types included welded wire meshes (WWM), expanded steel meshes (ESM). Figure 1 shows welded, expanded meshes, Poly propylene fibers e300, and tensile steel of meshes according to, (Swamy and Shaheen, 1990).

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2.1 Light Weight Brick Core Panels

For this type of panels, a 100mm thick wall was built of this light brick to provide the core material between the two thin skin layers. The outer two skin layers were tied together by 3mm diameter wires to act as shear connectors to transfer the shear between these two layers. These steel wires were embedded inside the mortar of the core wall and were tied to the steel wire mesh of each ferrocement layer. Figure 2 shows ferrocement wall sandwich wall panels and the steel mesh before casting the mortar of the ferrocement skin layers. While Figs. 3 and 4 show reinforcement details of light weight walls.

2.2 Mix Design and Material Properties

The sand-cement mortar of ferrocement consisted of sand, ordinary Portland cement, and silica fume with sand/cement ratio of 2.0. 12% of the cement was replaced by silica fume. The water cement/silica fume ratio used was 0.30. Super plasticizer with ratio of 2.0% by weight of cement/silica fume was used to improve workability. The strength of the ferrocement mortar was

determined by testing 50x50x50mm cubes at 1, 7, and 28 days. The average compressive strength of the ferrocement mortar after 28 days, $(f_{cu})_{ferr}$, was found to be 38 MPa.

Commercially produced light weight brick of dimensions 100x200x600mm was used as the core material for the sandwich panel specimens. Variety of the published technical data of this type of brick shows that it has strength of 2-3 MPa, dry unit weight of 400-500 kg/m^3, porosity of 22-30%, and thermal conductivity (K) of 0.27-0.34 W/m^oc. It is worth mentioning that standard compression tests were performed on three units of the used light weight brick and the average compressive strength was found to be 3 MPa.

Different types of steel meshes were used to provide the reinforcement inside the two thin skin layers of each specimen. In the present work, two types of steel meshed were used including: high tensile steel welded wire mesh with 12.5x12.5m opening and average diameter of 0.7 mm, and mild steel type expanded steel mesh. Tensile test was performed on samples of the three steel types. The results showed that the proof stress and the tensile strength of the high tensile steel were 400 MPa and 600 MPa respectively while the proof stress and tensile strength of expanded steel mesh were 250 and 300 MPa respectively. Mild steel bars had yield stress of 238 MPa and tensile strength of 361 MPa. Figs. 3 and 4 show reinforcement details of light weight walls.

2.3 Test Setup

Compression test was performed on each of the test specimens. The compression test setup is shown in Figure 5. Vertical strain was measured on front face at mid-height of the specimen at one location, 200mm gauge length. on the left and right of the centerline (mid-width) of the specimen. Demec points and mechanical strain gauge extensometer were used to record the strain at these locations. Two dial gauges were located in the horizontal front and the other in the horizontal side for measuring displacement for each tested wall panel.

3. Experimental Results

Table 2 summarizes the experimental results of the axial compressive loading of the panels tested. The results includes first crack load, ultimate and serviceability loads, compression stresses for all the tested light walls, ductility ratio and energy absorption properties for all the tested walls. Fig. 6 shows comparison first crack loads of all the tested light walls while Fig.7 emphasizes comparison of serviceability load of tested walls according to CP110. Fig. 8 shows comparison of ultimate loads of all tested light walls. Fig. 9 shows comparison of calculated ductility ratio of all tested light walls. Fig. 10 presents comparison of calculated energy absorption of all tested light weight walls.

Fig. 11 shows load horizontal displacement and vertical compressive strains for tested light weight walls, W1-W3. Fig. 12 shows load horizontal displacement and vertical compressive strains for tested light weight walls, W4-W6. Fig. 13 shows load horizontal displacement and vertical compressive strains for tested light weight walls, W7-W9. Fig. 14 shows load horizontal displacement and vertical compressive strains for tested light weight wall W10.

It is interesting to note that Wall W5 shows higher first crack load reached 120 Kn. and Wall W10 reached higher serviceability load, higher ultimate load and higher energy absorption, while Wall W8 achieved higher ductility ratio

- Ductility ratio

The ductility ratio was calculated as the mid height displacement at the ultimate load to that of the first cracking loads. Walls reinforced with expanded metal mesh and welded steel mesh was given higher ductility ratio compared with wall W1. Fig. 8 shows ductility ratios for all tested light weight walls.

- Energy absorption

The energy absorption was obtained by calculating the area under the load displacement curve for each wall. Walls reinforced with expanded steel mesh were achieved higher energy absorption than control wall W1. Fig. 9 emphasizes energy absorption for all tested slabs. Higher ductility and energy absorption properties are very useful for dynamic applications.

- ***Serviceability load***

The l serviceability load was calculated using the equation according to CP110:
Se_{rvice} load = ($Exc_{remental}$ load - 1.4 D.L)/1.6. Where experimental load is equal to the maximum load reached.

4. Cracking Behavior

Fig. 15 shows cracking patterns of all the tested light weight panels under compression loadings. It is interesting to note that the role of the specific surface area of reinforcing materials and yield stress of the reinforcement in controlling the crack width, the load at crack width, the smaller the opening of mesh used; the smaller; the opening of crack width; the better the result. The obtained results show conclusively that mesh reinforcement is far superior in controlling crack width. It is excellent to notice that is there is no spalling of concrete mortar cover at failure that is predominant.

5. CONCLUSIONS

Based on the results and observations of the experimental investigation presented in this paper, the following conclusions could be drawn:

1. Ferrocement panels show good potential for use in several construction applications as reflected by their relatively high ultimate and serviceability loads, crack resistance control, high ductility, and remarkable energy absorption which are very useful for dynamic applications.
2. Irrespective of sandwich panels are lighter in weight when compared to conventional reinforced concrete construction of the same thickness.
3. For light weight panels subjected to axial compressive loadings the same exhibited higher ultimate loads irrespective of the type of steel mesh employed compared with the conventional reinforced panel.
4. For the same core material, ultimate load, ductility ratio, energy absorption, and deflection were all increased when increasing the volume fraction of reinforcing materials.
5. The overall results demonstrate good performance for the ferrocement panels which can be of true construction merits in both developed and developing countries. Therefore, further research work needs to be conducted as well as through economic feasibility needs to be performed.
6. sound recommendations for applications.

7-It is interesting to note that Wall W5 shows higher first crack load reached 120 Kn. and Wall W10 reached higher serviceability load, higher ultimate load and higher energy absorption, while Wall W8 achieved higher ductility ratio

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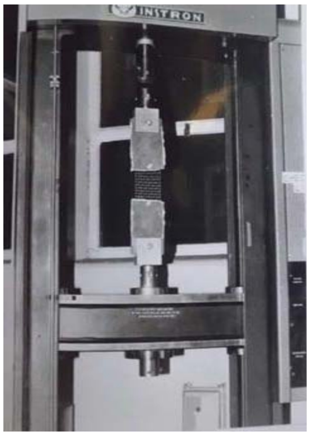


Welded steel mesh Expanded steel mesh

Tensile steel meshes, (Swamy and Shaheen, 1990)

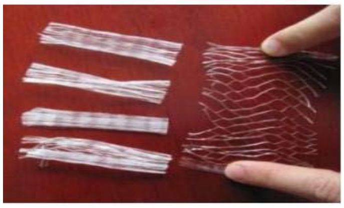


Fig.1 Welded, expanded meshes, Poly propylene fibers e300, and Tensile steel meshes

Wall 1

Wall 2

Wall 3

Wall 4

Wall 5

Wall 6

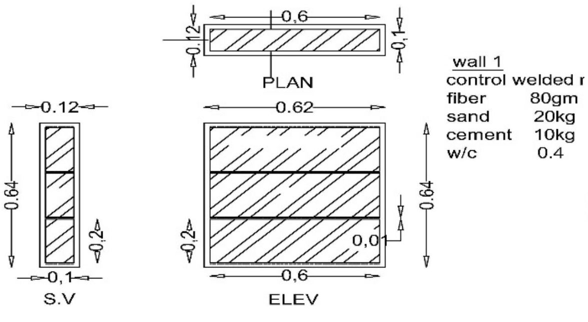
Wall 7

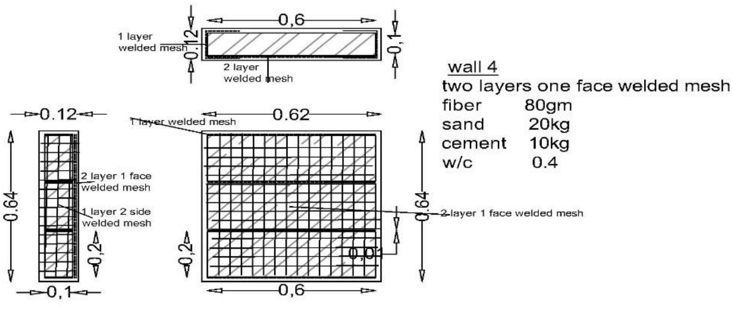
Wall 8

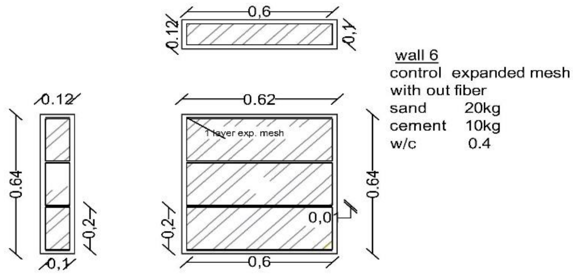
Wall 9

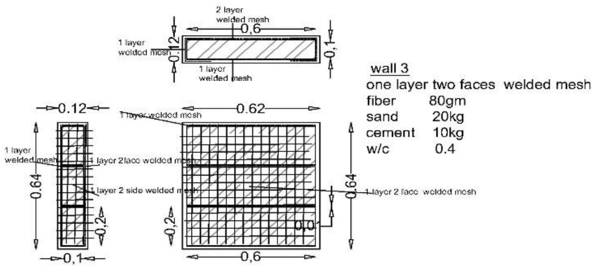
Wall 10

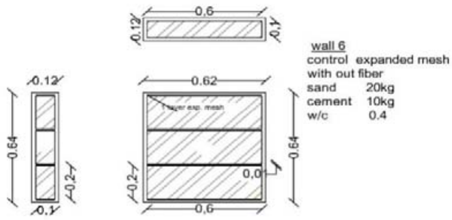
Figure 2: Ferrocement wall sandwich panels.






wall 6
control expanded mesh
with out fiber
sand 20kg
cement 10kg
w/c 0.4
1 layer exp. mesh
0,6
0.62
0.12
0.64
0,2
0,1
0,0


wall 3
one layer two faces welded mesh
fiber 80gm
sand 20kg
cement 10kg
w/c 0.4
2 layer welded mesh
1 layer welded mesh
1 layer 2 face welded mesh
1 layer 2 side welded mesh
0,6
0.62
0.12
0.64
0,2
0,1
0,0


wall 6
control expanded mesh
with out fiber
sand 20kg
cement 10kg
w/c 0.4
0,6
0.62
0.12
0.64
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0,1
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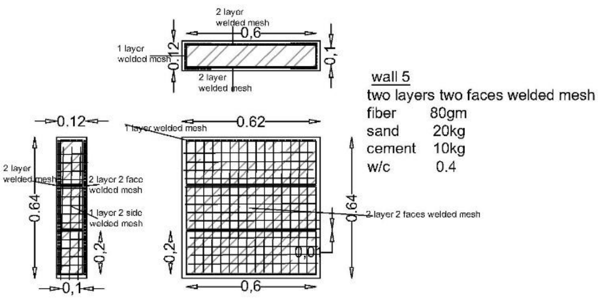
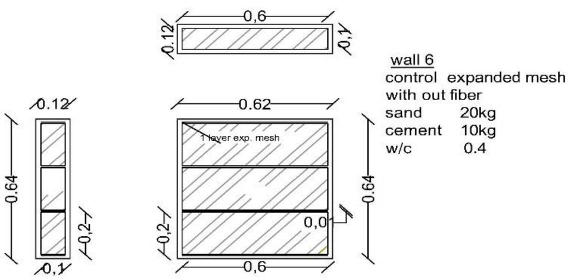
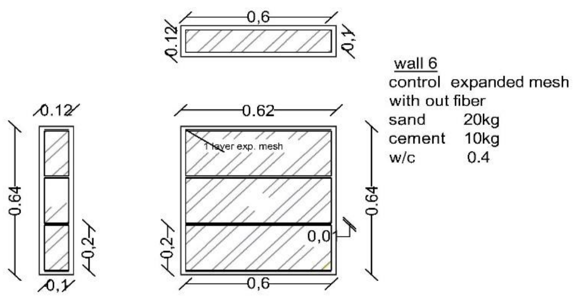

wall 5
two layers two faces welded mesh
fiber 80gm
sand 20kg
cement 10kg
w/c 0.4
2 layer welded mesh
1 layer welded mesh
2 layer 2 face welded mesh
1 layer 2 side welded mesh
2 layer 2 faces welded mesh
0,6
0.62
0.12
0.64
0,2
0,1
0,0


wall 6
control expanded mesh
with out fiber
sand 20kg
cement 10kg
w/c 0.4
1 layer exp. mesh
0,6
0.62
0.12
0.64
0,2
0,1
0,0



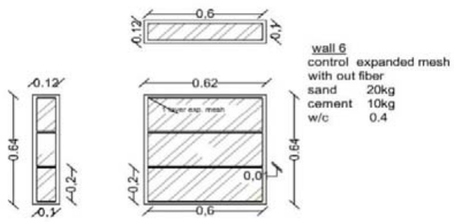
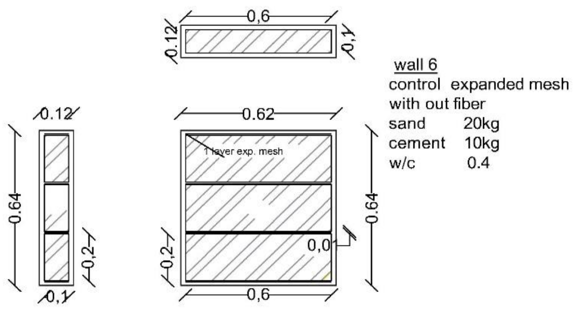


Fig. 3 Reinforcement details of the light weight walls W1-W6.



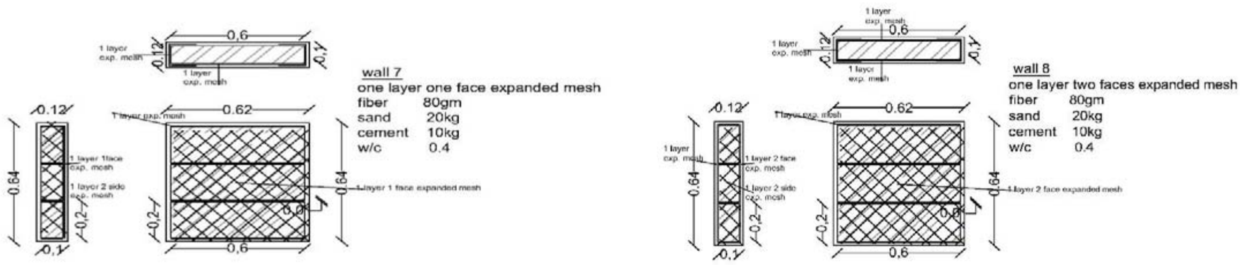


Fig. 4 Reinforcement details of the light weight walls W7-W10

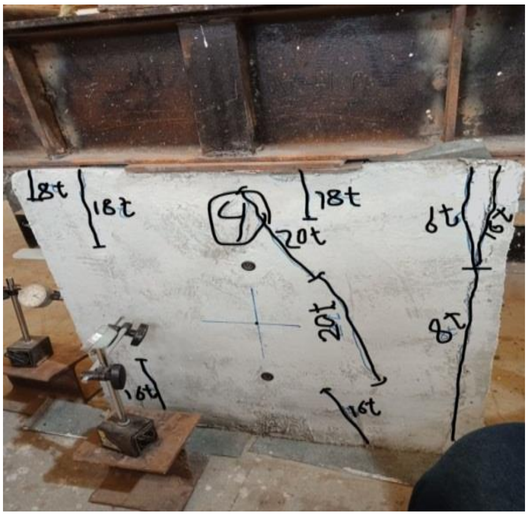


Fig.5 Test set up

Table 1: Designations of ferrocement lightweight walls.

Designations	**No. of Layers of Reinf. at each face**	**Type of Reinforcing Steel**	Vol. fraction%	**Total thickness (mm)**
Wall 1	Without layers	Welded wire mesh (WWM)	**0.509**	120
Wall 2	One layer one face +**U** WWM each face	WWM	**1.019**	120
Wall 3	One layer two faces+**U** WWM each face	WWM	**1.019**	120
Wall 4	Two layers one face+**U** WWM each face	WWM	**1.528**	120
Wall 5	Two layers two faces+**U** WWM each face	WWM	**2.667**	120
Wall 6	Without layers	Expanded Steel Mesh (ESM)	**1.273**	120
Wall 7	One layer one face+**U** E S M each face	(ESM)	**2.548**	120
Wall 8	One layer two faces+**U** E S M each face	(ESM)	**3.822**	120
Wall 9	Two layers one face+**U** E S M each face	(ESM)	**3.822**	120
Wall 10	Two layers two faces+**U** E S M each face	**(ESM)**	**3.822**	**120**

Table 2 First crack, ultimate, serviceability loads, stresses, ductility ratio and energy absorption properties for all tested Walls.

Beam Design .	Vol. fraction%	F.C.L KN	Ultimate .load, KN	stresses, N/mm^2	Service. Load, KN	Def.at F.C.L, mm	Max. defl., mm	Duct. ratio	Energy Absorp. . KN.mm
Wall 1	**0.509**	**40**	**100**	**1.39**	**29.375**	**0.01**	**0.045**	**4.5**	**2.65**
Wall 2	**1.019**	**60**	**140**	**1.95**	**54.375**	**0.1**	**0.18**	**1.8**	**10.6**
Wall 3	**1.019**	**100**	**180**	**2.5**	**79.375**	**0.035**	**0.07**	**2**	**6.5**
Wall 4	**1.528**	**110**	**200**	**2.78**	**91.875**	**0.05**	**0.12**	**2.4**	**13.7**
Wall 5	**2.667**	**120**	**240**	**3.33**	**116.875**	**0.12**	**0.8**	**6.67**	**145.2**
Wall 6	**1.273**	**60**	**120**	**1.67**	**41.875**	**0.02**	**0.07**	**3.5**	**5.2**
Wall 7	**2.548**	**60**	**180**	**2.5**	**79.375**	**0.02**	**0.12**	**6**	**13.5**
Wall 8	**3.822**	**100**	**220**	**3.45**	**104.375**	**0.025**	**0.176**	**7.04**	**25.12**
Wall 9	**3.822**	**100**	**240**	**3.33**	**116.875**	**0.15**	**0.64**	**4.27**	**95.2**
Wall10	**3.822**	**120**	**280**	**3.89**	**141.875**	**0.35**	**1.18**	**3.37**	**185.45**

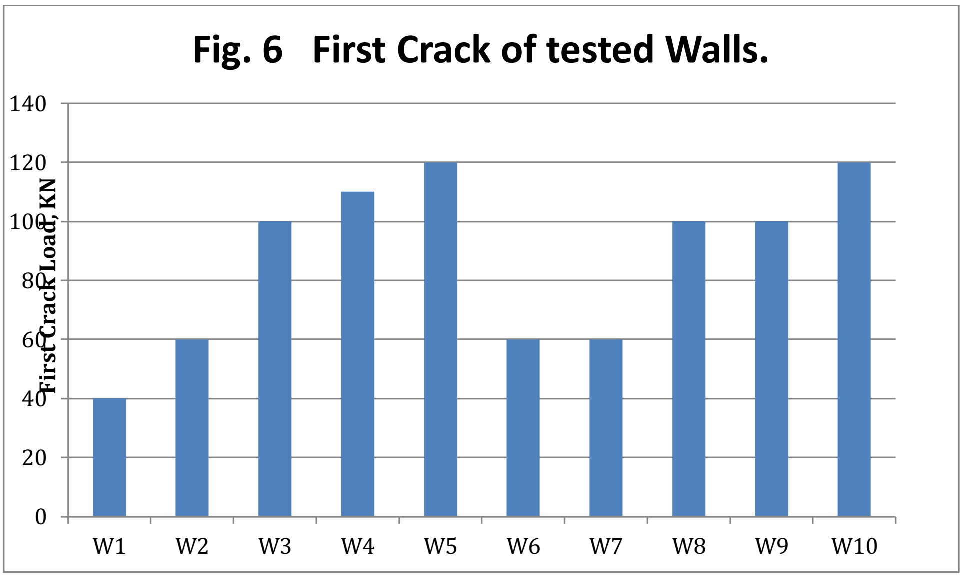


Fig. 6 First Crack of tested Walls.
First Crack Load, KN
140
120
100
80
60
40
20
0
W1
W2
W3
W4
W5
W6
W7
W8
W9
W10

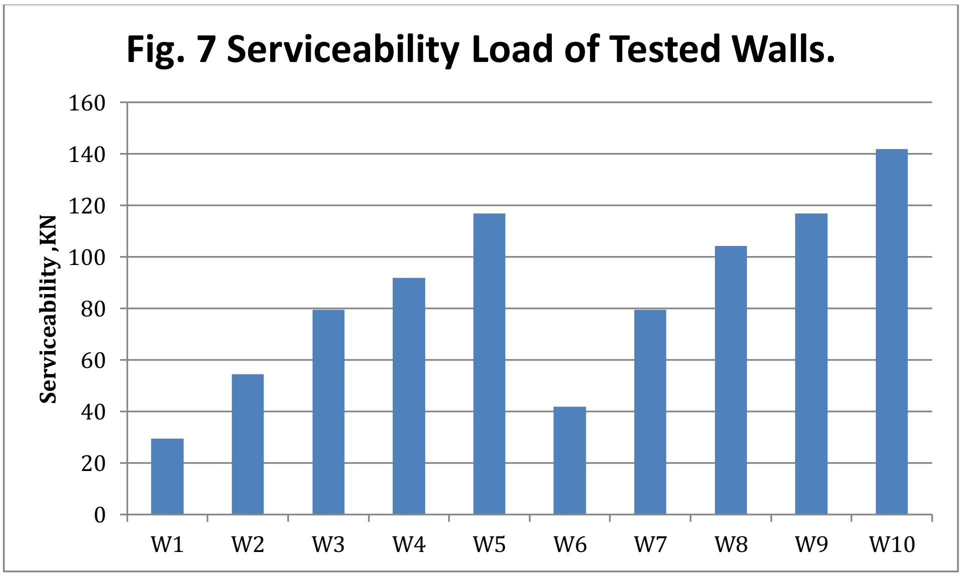


Fig. 7 Serviceability Load of Tested Walls.
Serviceability, KN
160
140
120
100
80
60
40
20
0
W1
W2
W3
W4
W5
W6
W7
W8
W9
W10

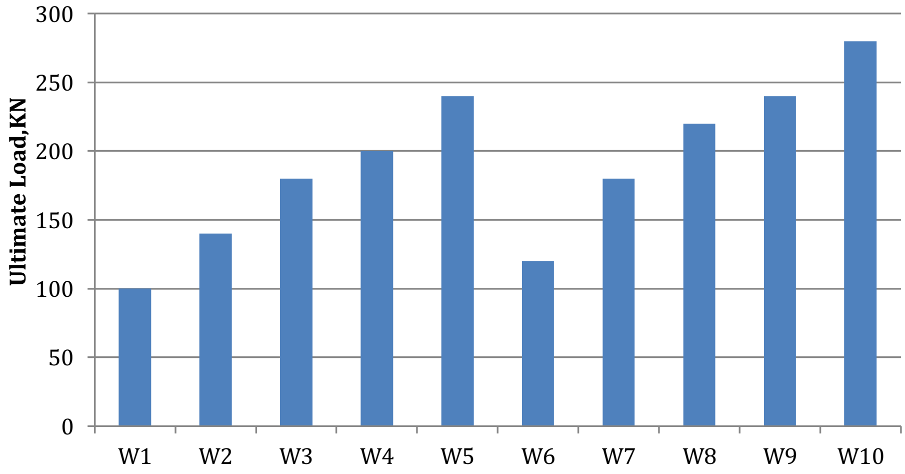


Fig. 8 Ultimate Load of Tested Walls.

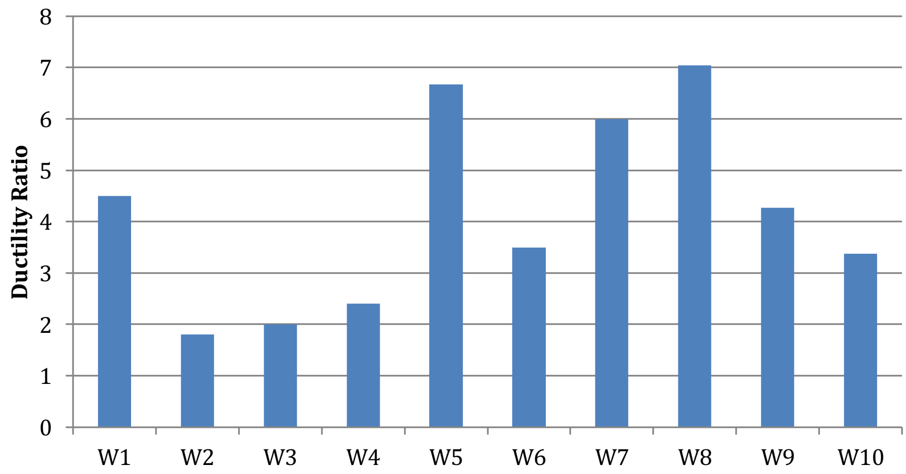
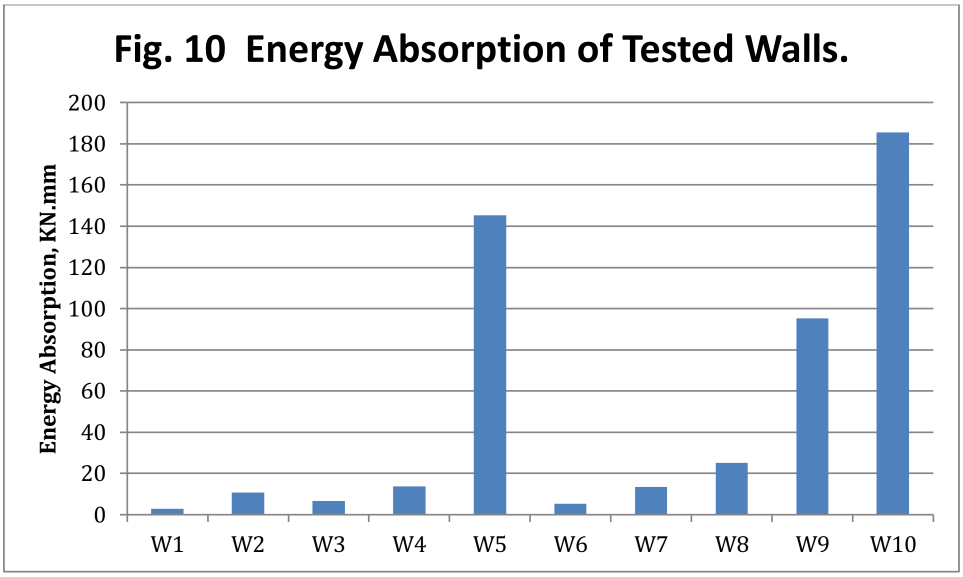
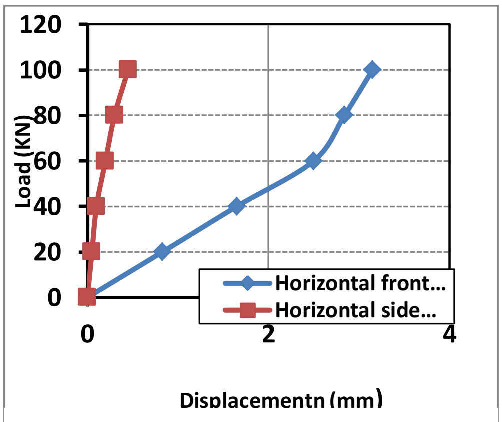
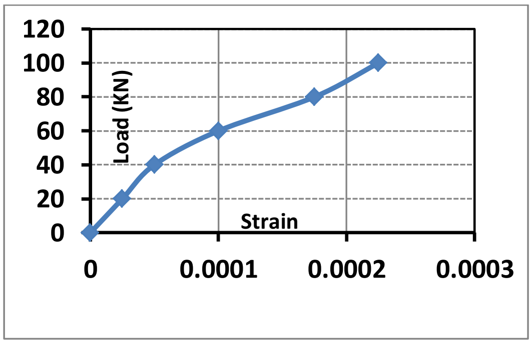


Fig. 9 Ductility Ratio of Tested Walls.



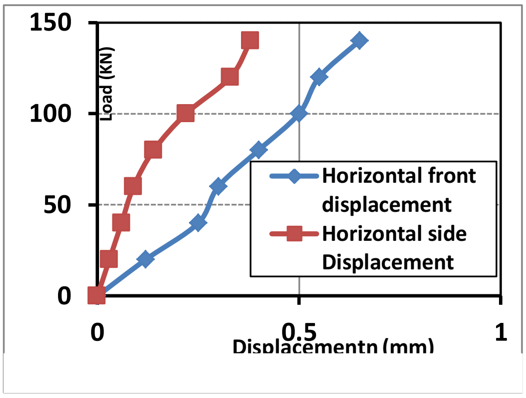


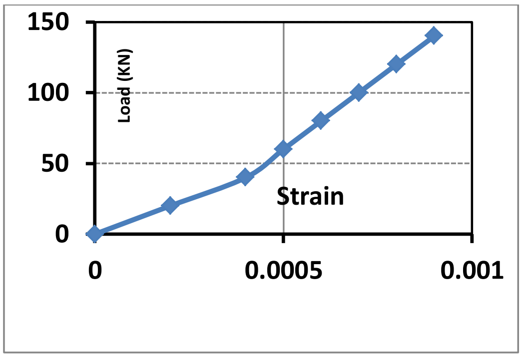
Load horizontal displacement of wall W1



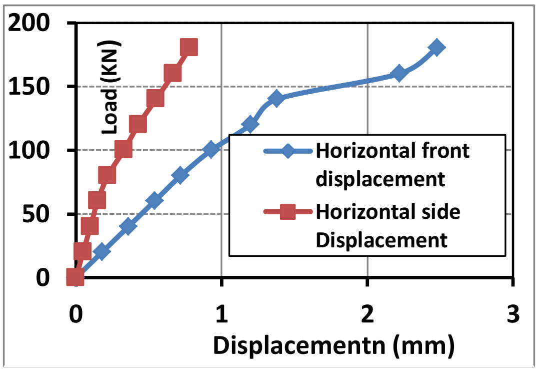
Load vertical strain of wall W1

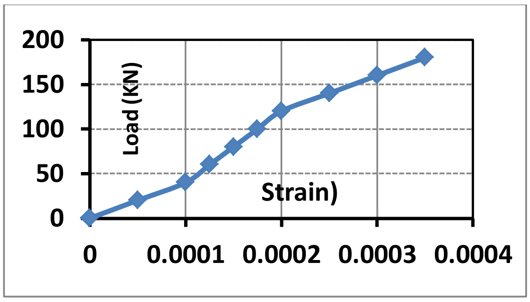
Load horizontal displacements and vertical compressive strains for tested light weight walls W1





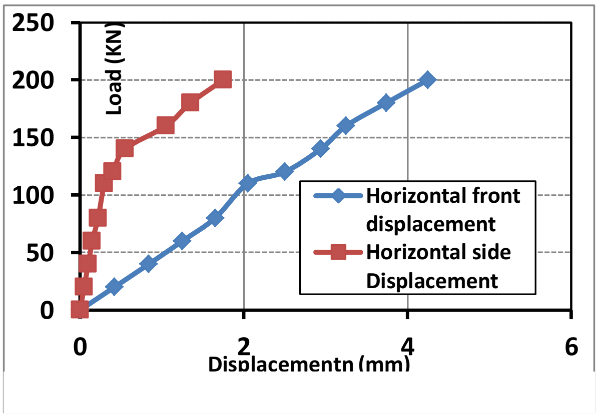
Load horizontal displacement of wall W2
Load vertical strain of wall W2

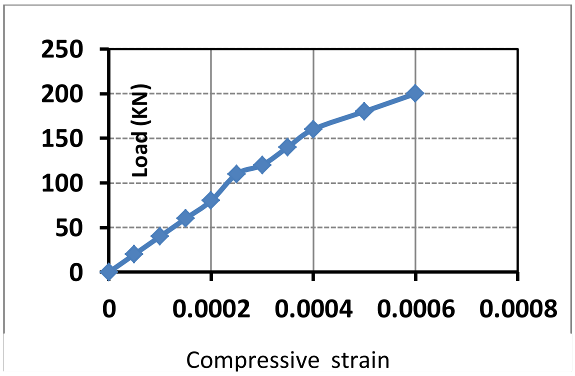




Load horizontal displacement of wall W3
Load vertical strain of wall W3

Fig.11 Load horizontal displacements and vertical compressive strains for tested light weight walls W1-W3.

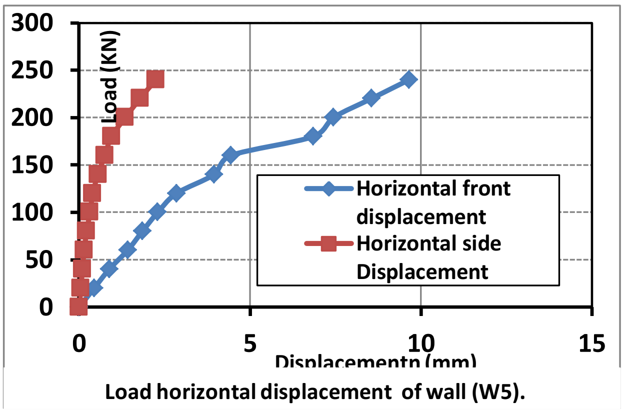


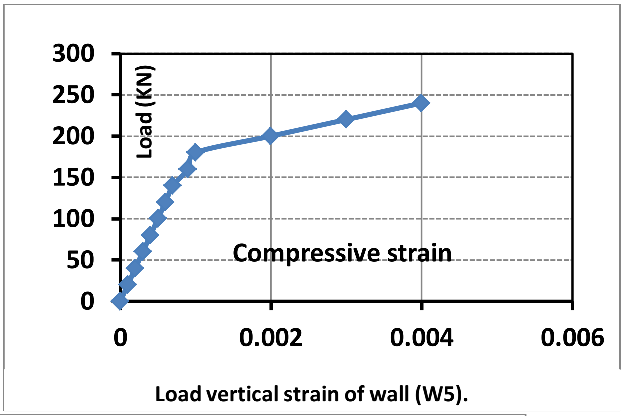


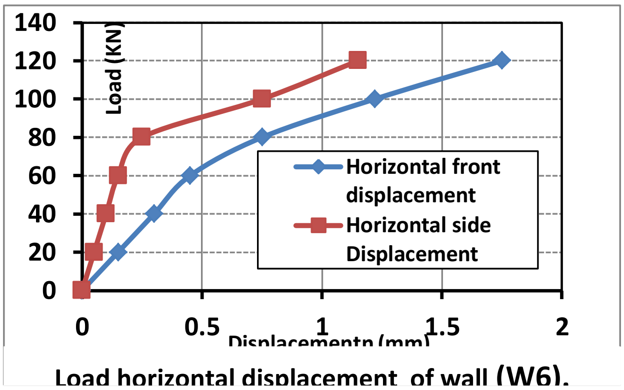
Load horizontal displacement of wall W4

Load vertical strain of wall W4

Load horizontal displacements and vertical compressive strains for tested light weight walls W4







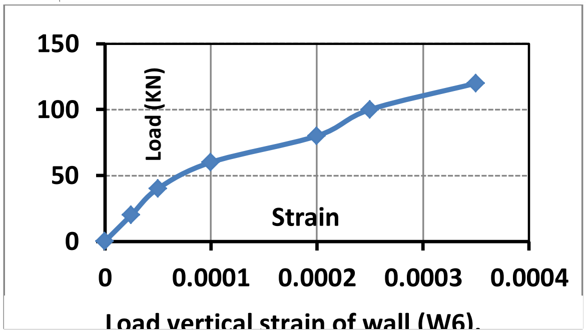
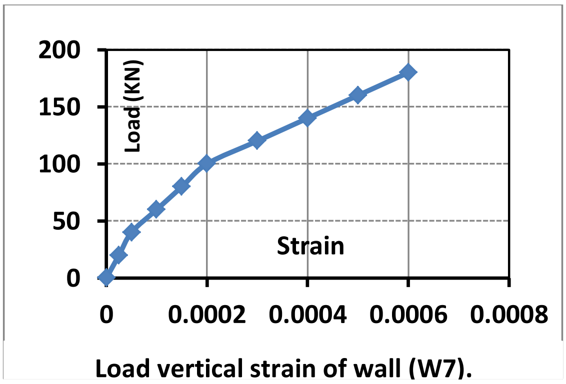


Fig.12 . Load horizontal displacements and vertical compressive strains for tested light weight walls W4-W6.



Load horizontal displacements and vertical compressive strains for tested light weight walls W7

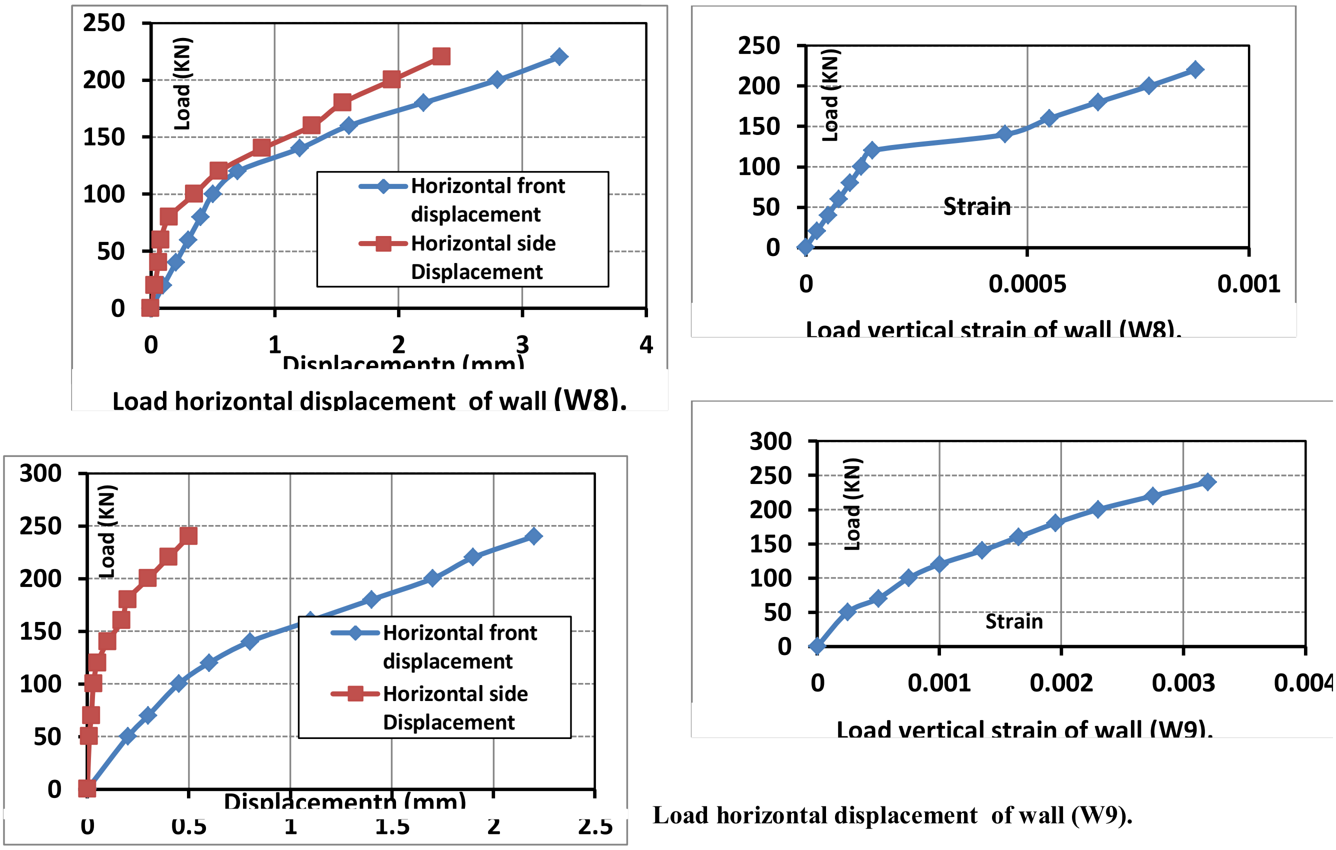


Fig. 13 Load horizontal displacements and vertical compressive strains for tested light weight walls W7-W9.

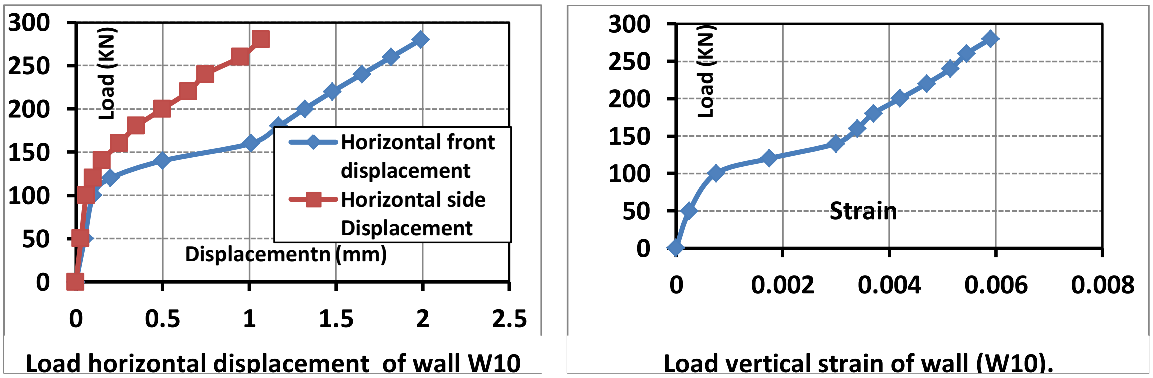
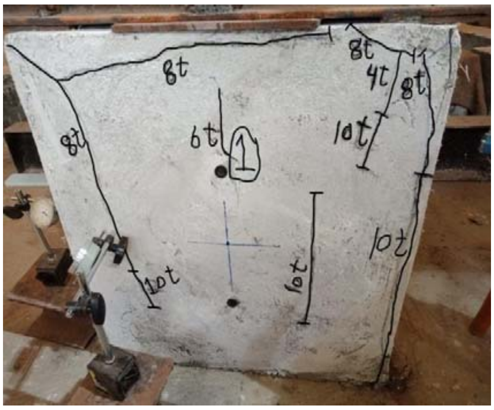
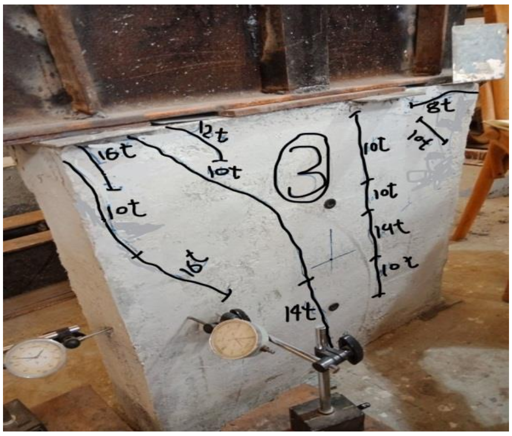
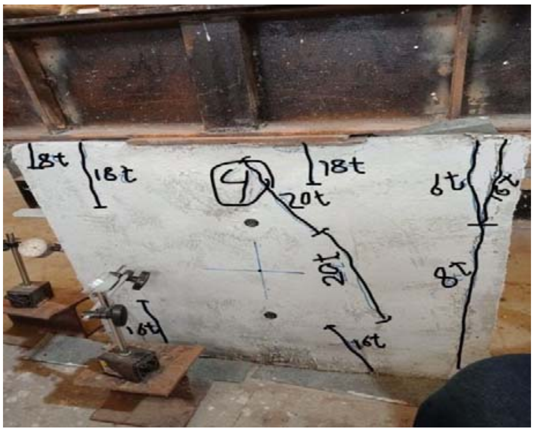
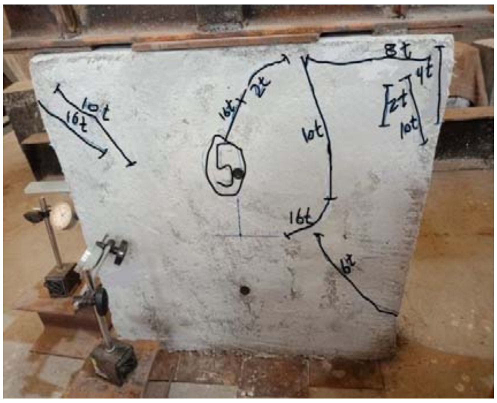


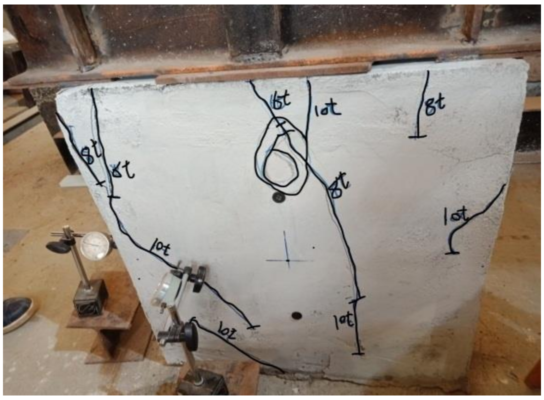
Fig. 14 Load horizontal displacements and vertical compressive strains for tested light weight wall W10.











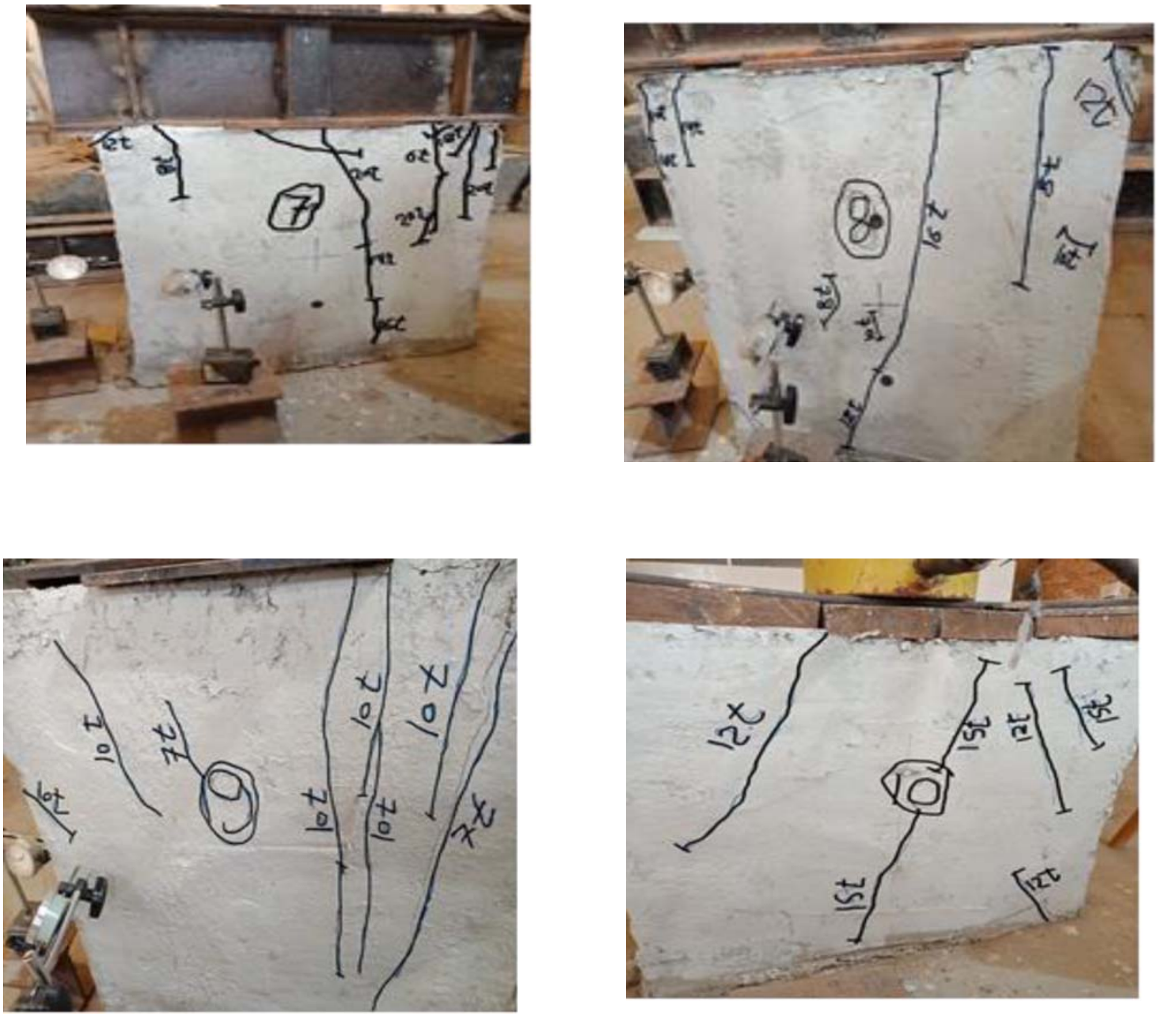


Fig. 15 Cracking patterns of all the tested light weight panels under compressive.