Axial and Lateral Load performance of reinforced earth-filled wall-panels - an experimental investigation

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Abstract

This paper investigates the behaviour of earth-filled wall panels confined with Galvanised Iron (GI) wire mesh against axial and out-of-plane lateral load.The experimental program includes testing the reduced scale model to examine the earth-filled wall panels confined with GI wire mesh. This experimental research was conducted to study economical and readily available materials for low-cost housing structures and, subsequently, a construction technique. These panels were tested separately for axial load and out-of-plane lateral loads. Many civilizations used earth as a building material in their early days. Many growing nations used Adobe rammed earth and other earth-building techniques because of their self-creation possibilities and affordability. However, the seismic performance of conventional unreinforced earthen homes is very poor, as established in the course of the Bam, Iran 2003, Kashmir, India 2005, and Morocco, 2016 earthquakes. Earthquakes cause great loss of life and property to people in underdeveloped areas with moderate or high seismic activity. Building design is of the many factors influencing the number of fatalities cause during an earthquake. In single story structure, self weight of the structure falling on the occupants is determining factor for the number of fatalities in the event of an earthquake.

Hence, the present study attempts to devise a construction technique for use in affordable earthquake-resistant housing structures.

Keywords: Affordable housing; Wire mesh; Earth-filled wall panel, Earthquake resistant structures, Sustainable construction.

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1. Introduction

Low-income borrowers cannot access home finance due to limited income and the lack of affordable housing options have forced millions of people to live in poorly constructed houses/slum areas/huts in developing and non-developed countries. For example, India is among the largest growing economies globally, putting tremendous pressure on the government to ensure everyone has a roof over their head. The housing inadequacy forced most low-income groups to acquire land and construct their desired houses. The technical group's report on urban shortage (TG-12), Ministry of Housing and Urban Poverty Alleviation, National Buildings Organization, Government of India, 2012, shows that the current housing deficit in India stands at 18.78 million units. Without meaningful intervention, this deficit was slated to double to 38 million units by 2030. Thus, affordable housing is an idea whose time has come, and sooner rather than later, planned sustainable organization would have to be ready by default and not by choice.

In recent times, the trend in many parts of the world has been to build with higher-strength materials such as concrete and masonry instead of lower-strength materials such as earthen materials. Property owners in many developing regions often build low-rise, non-engineered structures, paying little attention to building codes or seismic resistance [9], which was not previously possible with only low-strength earthen materials. However, the non-engineered concrete and masonry buildings are misleading because they seem to be safe and perform well under gravity loads. These buildings are also relatively heavy due to their self-weight, which adds to the deception of safety. However, no consideration is often given to lateral loads, which are the type of loads they will experience during an earthquake.

Reference [20] has developed numerical models of the in-plane behaviour of adobe walls for seismic events. Reference [10] studied adobe bricks under compression to develop a stress-strain equation for eventual modelling, both in load and displacement control. Reference [17] demonstrated various ways to optimize adobe bricks' mechanical strength, both compressive and flexural, using different eco-friendly additives. Reference [18] worked on characterizing adobe bricks already used in a structure. Reference [3] measured the compressive strengths of confined Adobe. A strong earthquake (magnitude 8.4) occurred in Southern Peru and destroyed most adobe houses in the affected region [12]. However, the houses in the region that were reinforced with welded mesh suffered no damage, those were used as shelters.

Adopting the environmentalist catch-phrase of 'think global; act local', they additionally serve as a primary source for the construction today of affordable, energy-efficient, recyclable and sustainable buildings, designed to meet human needs in terms of comfort, health and well-being, and with minimal ecological impact [4]

Most of the previous studies were based only on materials, not on basic structural elements under varying load conditions, static or dynamic, and many were involved in the compression and shear tests on the rammed earth wall components under static loading. The majority of the works in recent years involved compression and shear tests on the rammed earth wall components under static loading as reported by group of researchers [8], [5], [13], [2], [7], [14]. Affordable housing technique for walls with locally available materials like soil is still a distant dream, and no significant work has yet been reported, specifically for a wall.

In this study, an attempt is being made to devices a construction technique for wall panel made with earthen materials and confined with GI mesh in affordable earthquake-resistant housing structures. Experimental procedures including casting, loading arrangement for axial load and out-of-plane lateral load testing, and results and discussion have been detailed in subsequent sections.

1.1 Objectives of the present work

1. To modify/alter/device a new technology with the locally available materials for affordable housing in rural India.
2. To cast and test the wall panels to take up the axial and lateral loads.
3. To study the behaviour of these wall panels under the axial and lateral loads.
4. Observe and compare the behaviour of wall panels during the test.
5. Decide the suitability of these wall panels to take up axial and lateral loads.

2 Experimental Program

2.1 Materials used and their properties

2.1.1 Soil

Around 30% of all constructions worldwide have at least one earthen component [1]. Even today earth is still widely used in construction in underdeveloped and developing countries [11]. Main advantage of using soil is the ease of its local availability. In the present studies, soil has been used as a filler for the sandwich panel. Soil has mixed with straw and water in defined proportion and further, hand compacted in layers results in a firm and composed unit. The hand compaction of the soil contributes toward the increase in stiffness and provides better thermal insulation due to its lower density than compressed earth. The soil used in the present experimental studies was tested for sieve analysis and standard proctor test and the coefficient of gradation was 2.48, uniformity coefficient was 19.7, and optimum moisture content was 19 %.

2.1.2 Galvanised Iron (GI) Wire Mesh

GI wire mesh has provided sufficient stiffness to soil. Various openings of GI wire mesh of a diameter of 0.5mmto 2.00 mm were readily available in the market. The wire mesh aperture was selected based on the D_{30} values of the sieve analysis, and D_{30} values for the soil were varying between 1.04 mm to 1.40 mm. The closest available wire mesh with an opening of 8 mm was selected for the present experiments.

2.1.3 Straw

The early use of straw was done by Mesopotamians and Egyptians in 1500 BCE [15]. Straw had reinforced ancient products like boats and pottery. After the removal of chaff and grain, straw is obtained which is one of the byproducts of the agriculture industry. This straw is mixed with the soil to enhance the properties of the hand-compacted soil.

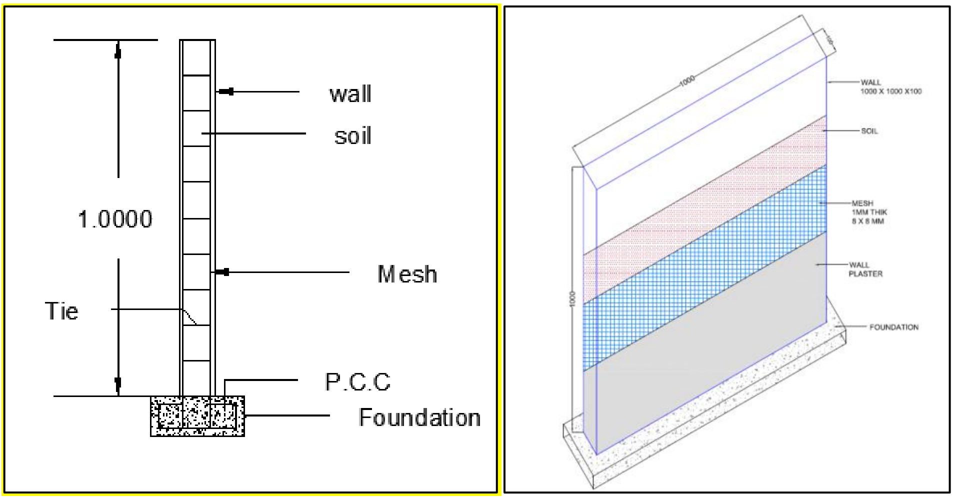
2.1.4 Mortar

Due to its various properties like, non-corrosive, the requirement of no surface treatment, increase in strength with time, less maintenance, and aesthetics look. Cement mortar 1:4 was used here to plaster the assembly of GI wire mesh filled with hand compacted soil and straw.

2.1.5 Plain cement concrete

Plain cement concrete (PCC) of M20 Grade, was used for the foundation of the wall panel. Average compressive strength (for 28 days) of concrete based on the concrete mix design is more than 20 N/mm^2.

2.2 Specifications of earth panels



(a) Cross section of wall panel (b) Different layers of wall panels

Fig. 1 Test specimen showing cross section and different layers for casting

The cross-section of wall panels selected was 600×600×125 mm for the axial load test and 1000×1000×100 mm for the out-of-plane lateral load test. Earth panel cross-section primarily consists of three layers. The core of the wall panel is of hand compacted earth-straw mixture. This earth-straw mixture is confined with GI wire mesh and on the outer surface of this wall, cement mortar in a 12 mm layer was plastered. The GI wire mesh was first embedded in the PCC of the foundation block. To maintain the width of GI wire mesh in line with the thickness of the wall, GI wire spacers were placed at regular intervals of 0.5 m center to the center along the length and width of the wall panel as shown in Fig. 1.

2.3 Experimental Set up

The experimental set up includes preparing and testing compressed earth panels against axial and out-of-plane lateral load with and without soil infill. For this test two specimens of cross-sections, 600×600×125 mm was prepared, one with only straw filling and the other with hand compacted soil mixed with straw by 10% of the weight of soil. Similarly, another two specimens of cross-section 1000×1000×100 mm were cast for the out-of-plane lateral load test. The cross section of earth filled wall panel with different layers is shown in Fig. 1.

2.3.1 Casting details

First, the formwork of the required size of foundation as per the size of the wall specimen is prepared to receive the GI wire mesh which is embedded in the foundation. Then, the mesh was cut to the required size of the thickness and height of the wall. This GI mesh is tied up with the help of GI wire spacers to maintain the required thickness of the wall. Foundation PCC was placed in the formwork along with GI wire mesh as shown in Fig. 2.

(a) Laying foundation and G.I. Wire mesh (b) Filling layers of earth and straw

(c) Plastered wall panel

Fig. 2 Steps in casting of specimens for wall panels

After curing the foundation PCC for 28 days, the mixture of soil and straw at the required Optimum Moisture Content (OMC) was prepared and placed in layers of 300 mm height along the length of the wall panels. Each layer is hand compacted with temping rod used for concrete cube compaction. Excess soil particles oozing out of the mesh opening were removed.

Table 1. Details of wall panels

Parameters	Specimen No.1	Specimen No.2	Specimen No.3	Specimen No.4
Length (mm)	600	600	1000	1000
Height (mm)	600	600	1000	1000
Thickness (mm)	125	125	100	100

Filler material	Straw	Soil + Straw	Straw	Soil + Straw
Tests performed	Axial load Test		Out of plane lateral load test	

The process continued till the full height of the wall panel is achieved. The top of the wall panel was closed with the same GI wire mesh and additional soil at the top was placed to fill the wall panel with soil and straw mixture. Similarly, the wall panels filled with only straw were prepared. Details of earthen wall panel specimens used in present work are as shown in table 1.

A cement mortar (1:4) of thickness, 12 mm was applied on all sides of the wall including the top as shown in Fig 2. All the panels were cured for 28 days with gunny bags. Different layers of the completely casted panels can be seen in Fig. 2.

2.3.2 Assembly setup for axial load test

For the axial load test, the load is applied using a hydraulic jack of capacity 20 tons. For uniform distribution of the axial load on the wall, a steel plate of 10 mm thickness was placed on the top of the wall. Above this plate, mild steel rods at the spacing of 150 mm center to center were welded and an I section was welded to these rods as shown in Fig 3.

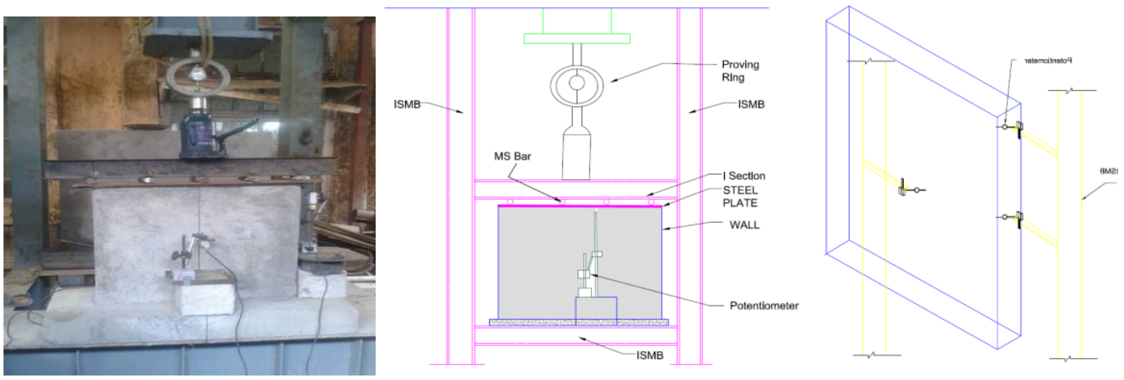


Fig. 3 Assembly setup for axial load test showing loading arrangement and placement of linear potentiometer

The load was applied gradually at the center of the I-section and deflections were measured along linear and lateral directions. The load measurement is done using a proving ring of a capacity of 10 tons. For measurement of deflection, 3 nos of linear potentiometer PM 50 5K MR of ELAP were used. Two potentiometers were placed at the center of length and height on either side of the wall panel and another at the top of the cross-sectional side as shown in Fig 3.

2.3.3 Assembly setup for lateral load test

For the lateral load test, the hydraulic jack was fixed to the loading frame. To avoid overturning, the base of the wall panel was fixed using angles bolted to the base frame. This steel plate was welded to the loading frame and the model is fixed over it by using nuts and bolts. The applied load is measured by proving rings. To apply lateral load uniformly, I section was placed between the wall panel and proving ring at 200 mm from the top of the wall as shown in Fig 4.

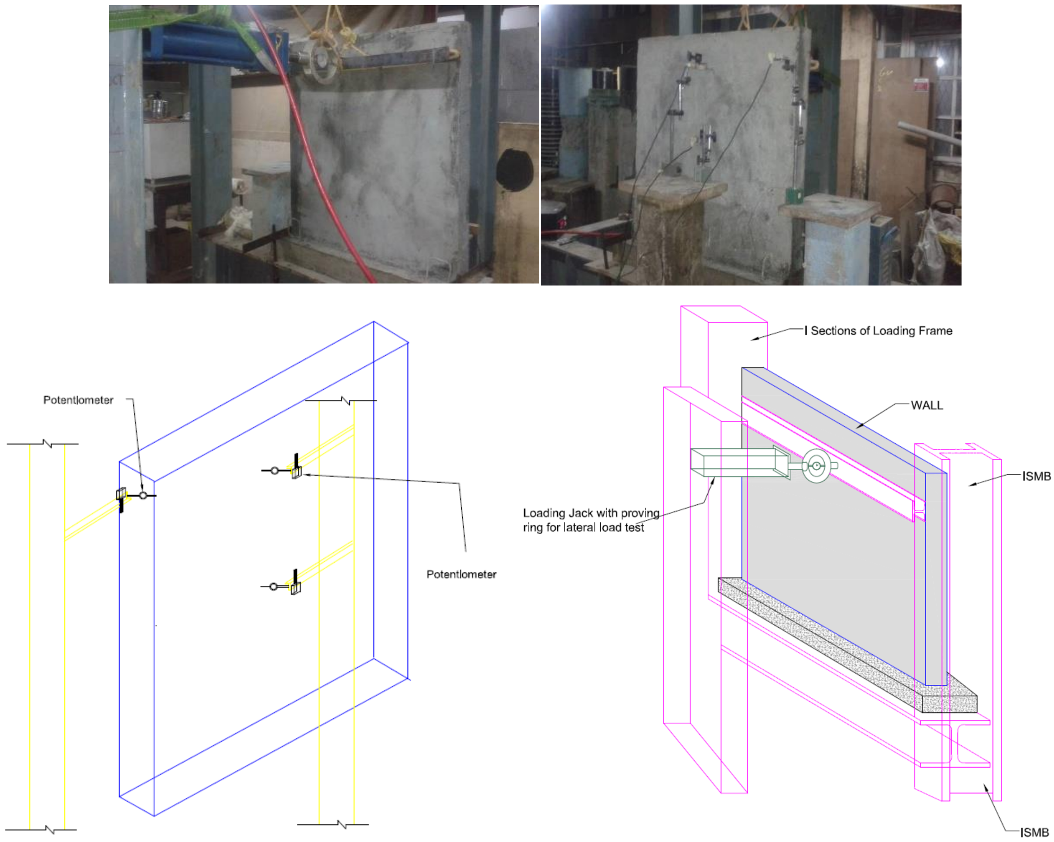


Fig. 4 Assembly setup for lateral load test showing loading arrangement and placement of linear potentiometer

The displacement sensors were placed on the backside of the load application face. For measurement of deflection, 3 nos of linear potentiometer PM 50 5K MR of ELAP were used. One potentiometer was placed at the center of length and height and another 2 were placed at the top center and top of width side as shown in Fig 4.

2.4 Results and Discussion

Results of the test for specimen no. 1, 2 3 and 4 are presented in table 2. Similarly, the graphical representation of load vs deflections for all the specimens is presented in Fig 5 to Fig. 8.

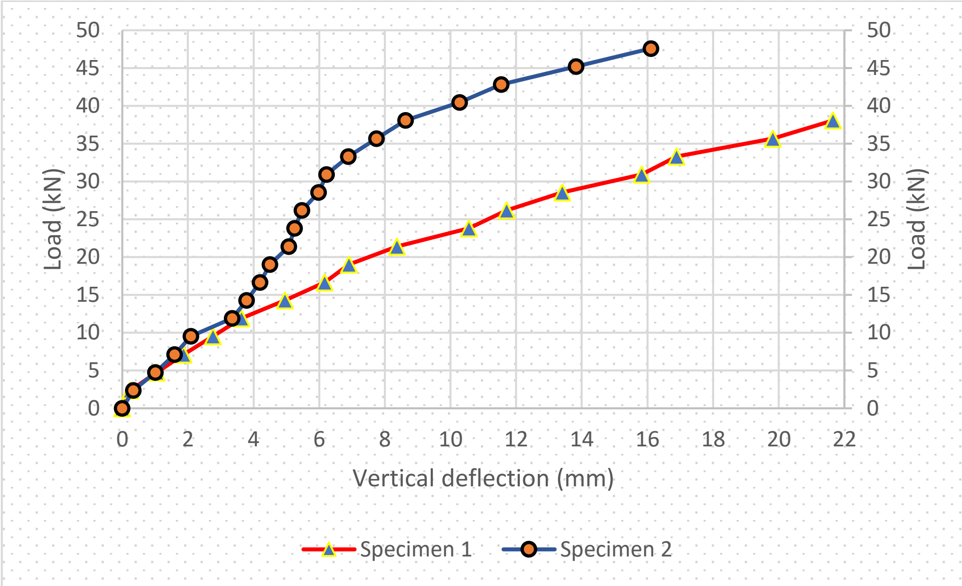


Fig. 5 Load versus Deflection for Axial Load Test

2.4.1 Axial Load Test

Specimen no. 1 and 2 were tested for axial load. For specimen 1, the failure was observed in the mortar at the top of the wall as the mortar started cracking first. The first crack was observed at the load of 21.42 kN and the maximum load applied was 38.08 kN. Maximum vertical deflection of 21.66 mm was observed. Lateral deflection of the specimen has been observed to be 0.52 mm.

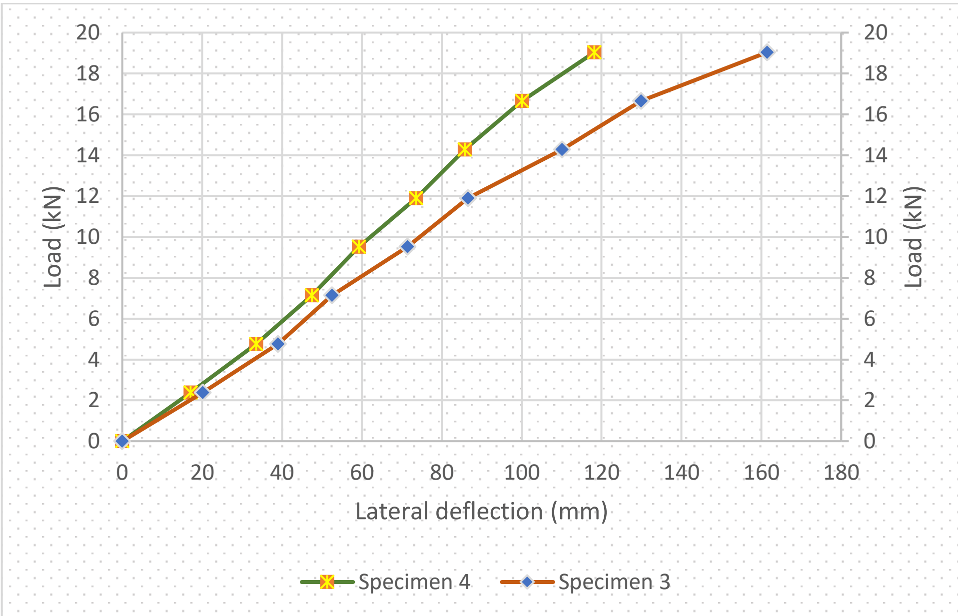


Fig. 6 Load versus Deflection for Lateral Load Test

For specimen 2, the failure was observed in the top portion of the wall as the mortar at the sides of the wall panel, started cracking as shown in fig. 8. The first crack was observed at the load of 40.46 kN and the maximum load applied was 47.6 kN. Maximum vertical deflection of 16.11 mm was observed. Lateral deflection of the specimen has been observed to be 1.48 mm.

The stress strain behavior of specimen no. 2 under compressive load observed to be linear and elastic in nature.

Table 2. Results of test specimen

Axial Load test		
Parameter	**Specimen 1**	**Specimen 2**
Load (kN) at first crack	21.42	40.46
Load (kN) at failure	38.08	47.60
Maximum vertical deflection (mm)	21.66	16.11
Out of plane lateral Load test		
Parameter	**Specimen 3**	**Specimen 4**
Load (kN) at first crack	9.52	14.28
Load (kN) at failure	19.04	19.04
Maximum lateral deflection (mm)	161.49	118.23

2.4.2 Lateral Load Test

Specimen no. 3 and 4 were tested for lateral load. For the panel, without soil infill i.e., specimen 3, the lateral deflection at the top was 161.49 mm. The soil infill panel started to crack at the load of 9.52 kN in shear, at the bottom, but the panel continued to take the maximum load till 19.04 kN with increased deflections and the mortar started to crack and disintegrate.

Fig. 7 Initiation of cracks in the wall at bottom

Fig. 8 Final failure of wall panels at maximum load

For specimen no. 4, wall panel with soil infill, the lateral deflection at the top was 118.23mm, at the maximum load of 19.04 kN. The failure was observed in the bottom portion of the wall as the mortar at the sides of the wall panel, started cracking as shown in Fig. 7.

3. Concluding Remarks

- The load carrying capacity of soil in-filled panel is 25 % higher as compared to the panel without soil infill and can be increased with improved compaction of infill soil.
- It can be inferred that the soil infill panel is better at resisting axial loads due to the compacted soil infill. The infill imparts rigidity and GI mesh imparts the confinement and ductility.
- In lateral load test the soil infill panel started to crack in shear at the bottom, but the panel continued to take load with increased deflections, till the mortar started to crack and disintegrate.
- For the panel without soil infill the deflections were quite large i.e 161.49 mmeven for smaller load of 19.04 kN and failed quite early with huge deflection of 161.49 mm in lateral load test. Whereas the soil infill panels show the defelction of 118.23 mm for the sae load of 19.04 kN. Stress strain relationship of compressive stress and strain for specimen no. 2 is elastic in nature and the sample did not disentegrate even after the final load of 47.60 kN.
- With the improvement in compaction of infill soil and its properties, these wall panels can be used in single story houses with aesthetics of safety and performance under gravity and lateral loads.
- Improtant to note in all the test is the monolithic behavior of the entire wall panels. Non of the wall panels disintegrated into the pieces.

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