Low Cost Earthquake Resistant Ferrocement Small House

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Abstract

The greatest humanitarian challenge faced even today after one year of Kashmir Hazara earthquake is that of providing shelter. Currently on the globe one in seven people live in a slum or refugee camp [1]. The earthquake of October 2005 resulted in a great loss of life and property. This research work is mainly focused on developing a design of small size, low cost and earthquake resistant house. Ferrocement panels are recommended as the main structural elements with lightweight truss roofing system. Earthquake resistance is ensured by analyzing the structure on ETABS for a seismic activity of zone 4. The behavior of structure is found satisfactory under the earthquake loading. An estimate of cost is also presented which shows that it is an economical solution.

Keywords: Earthquake; Low cost house; Ferrocement

1. Introduction

The major earthquake of Oct. 2005 has left a great food for thought for civil engineers to improve the design practice and quality of construction to withstand the natural disasters. Engineers are working at individual and organizational level to meet such challenges. This research work is a part of the same process. A design of simple-to-construct small residential building is presented which has capability to meet the strength and serviceability requirements of a major seismic activity.

Ferrocement, a material recommended by ACI 549R-97, is proposed for this house. Ferrocement performs excellently due to its closely distributed reinforcement. This will be a very economical option for temporary and permanent construction for the years to come. Shortly after the earthquake this design was proposed, keeping in mind the cost efficiency, availability of materials, quick time of fabrication and flexibility of extension and portability.

No level of earthquake preparedness can guarantee that an earthquake will not damage a building [2]. Structures cannot be completely earthquake-proof, but good seismic design will minimize structural damage, and the most importantly, safeguard the lives of the occupants during a major seismic event. Seismic resistance is best achieved by following modern building codes and standards and in large or complex buildings, using the services of a professional structural engineer [3].

2. Ferrocement

Ferrocement is a type of thin wall reinforced concrete commonly constructed of hydraulic cement mortar reinforced with closely spaced layers of continuous and relatively small size wire mesh. The mesh may be made of metallic or other suitable materials [4].

Ferrocement has a very high tensile strength-to-weight ratio and superior cracking behavior in comparison to conventional reinforced concrete. This means that thin ferrocement structures can be made relatively light and watertight. Hence, ferrocement is an attractive material for the construction of prefabricated housing units, boats, barges, and other portable structures [4].

3. Causes of Failure during Earthquake

In majority of cases, it was observed that structures were neither designed by following seismic provisions of code nor the construction was completely carried out accordingly. Size of structural members, especially columns in one direction, was much less than what is recommended by ACI 318 [5]. In some cases the least lateral dimension of column was 4.5″ [114 mm] giving slender column behavior. Materials used for concrete construction and their proportions were well below the required

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Figure 1: Collapsed house in Balakot with heavy roofing.

Figure 3: Corner joint failure of bonded masonry in Bagh

Figure 2: Thick layer of mud collapsed in earthquake

Figure 4: Typical corner joint failure of a house in Bagh

standards. Other construction faults were improper placement of reinforcement, unequal & insufficient concrete cover in same members, poor concrete compaction and substandard formwork etc. Based on all this information, it is concluded that major reason of structural collapse and damage of residential and institutional buildings during 8th October earthquake was the insufficient strength of vertical supporting members including columns, masonry walls, un-reinforced concrete walls and bonded or un-bonded rubble masonry walls (Figures 1, 2, 3 and 4)

4. Features of Proposed House

The principal material for this house is ferrocement. It consists of ferrocement panels (3′-6″ x 10′-6″ each) placed side by side connected with steel plate fixtures using bolts (Figures 5, 6 and 7). Ferrocement is selected because it is recommended by AC I549R-97 as a very good option for making small size houses. Furthermore, all the constituent materials are easily available in Pakistan; the panels are lightweight, which are easy to cast, transport and assemble. The system has been designed with the do-it-yourself concept in mind. As the wall panels are thin therefore some suitable heat insulation sheets can be used to coup up with the wintry conditions of northern Pakistan.

4.1 Resistance against Earthquake

Resistance against earthquake is the primary requirement for any structure proposed for NWFP and Azad Kashmir. This house is modeled using ETABS (Figures 8 and 9), software based on finite element method, and its response under the seismic activity of zone four is checked [6]. Pseudo static analysis is

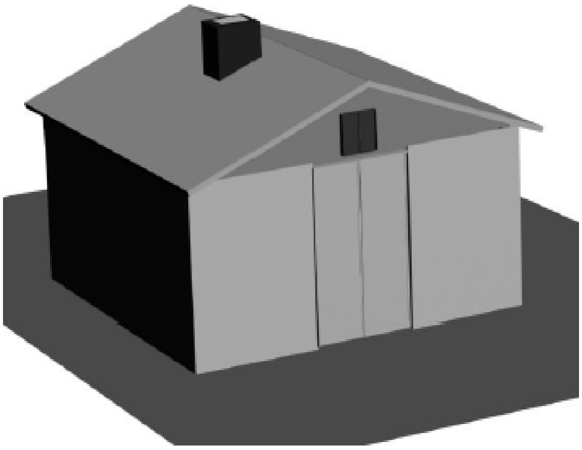

Figure 5: Three dimensional model of finished house

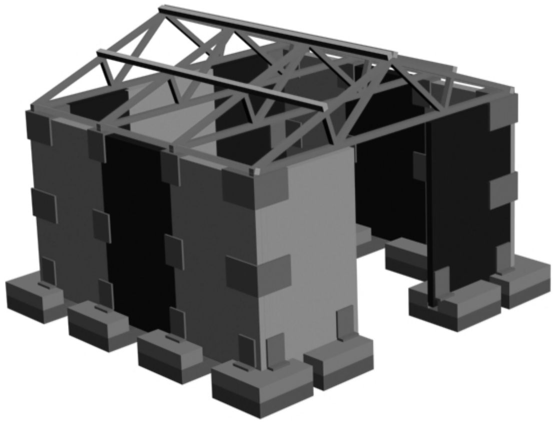

Figure 6: Three dimensional model of inner structure

carried out with earthquake forces applied along both the principal directions. Foundation connections are considered as hinges and ferrocement is defined as reinforced concrete in ETABS [7]. Stresses in ferrocement panels especially at joints, displacement and sway due to earthquake are carefully noted for various load combinations. Some of the important Information related to analysis and design is presented below.

4.1.1 Geometrical Properties

Size of House	= 10′-6″ x 10′-6″ [3.25m x 3.25m]
Panel Size	= 3′-6″ x 10′-6″ [1.10m x 3.25m]
Panel Thickness	= 1″ [25mm]

4.1.2 Parameters for Analysis

Live Load	= 50 psf [250 kg/m^2] (Equivalent to 2 ft thick snow)
Imposed Dead Load	= 20 psf [100 kg/m^2]
Seismic Zone	= 4
Type of Truss Steel	= A36
fc'	= 3 ksi [20 Mpa]
Tensile Strength	= 0.3 ksi [2.0 MPa]
f_y	= 60 ksi [420 Mpa]
Modulus of Elasticity	= 3122 ksi

No test data are available on the shear capacity of Ferrocement slabs in flexure [7].

Load Combination = 1.2D + 1.6L, 0.75(1.4D +1.7L + 1.87E), 1.4D

4.1.3 Analysis Output

Following results are the maximum out of all combinations.

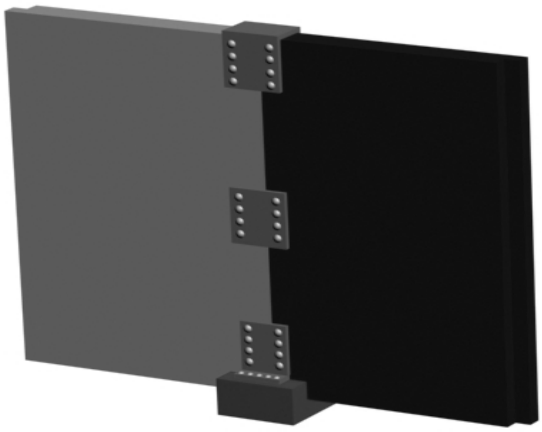

Figure 7: Panels with bolted connection details

Dead Load Reaction	= 0.90 kips [4.00 kN]
Live Load Reaction	= 0.83 kips [3.69 kN]
Compressive Stress in Wall	= 147 psi [1.01 Mpa]
Tensile Stress in Wall	= 120 psi [0.83 Mpa]
Live Load Deflection of Truss Crown	= 0.0222″ [0.56 mm]
Sway under Earthquake	= 0.00178″ [0.045 mm]

Stresses in wall panels are well below than strength of ferrocement. Further, the deflection under gravity loads and sway under earthquake are also minimal.

4.1.4. Design output

Angle Sections for Truss, Purlins & Braces	=L 2″x2″x1/8″ [L 51x51x3.2]

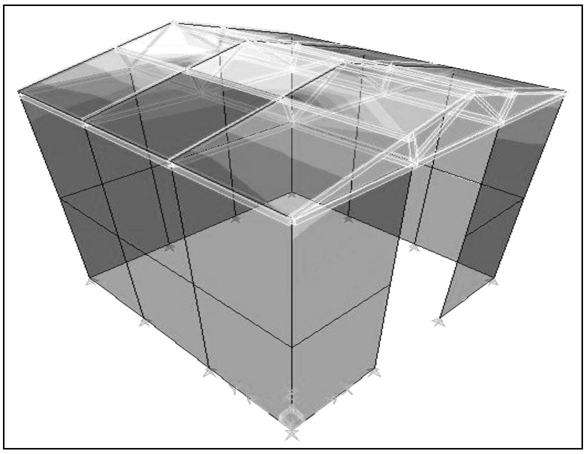

Figure 8: Three dimensional view of ETABS model.

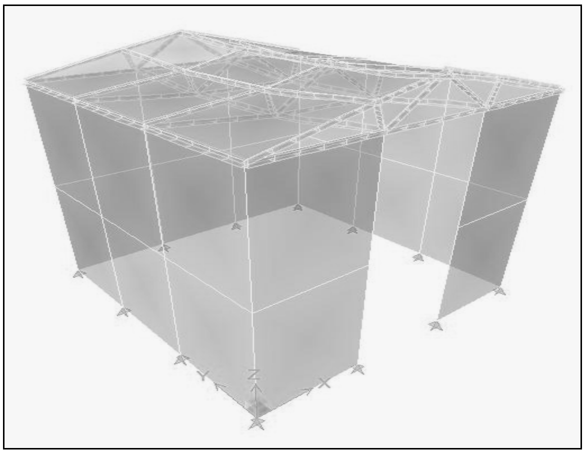

Figure 9: Deformed shape of ETABS model.

Vertical Steel Ratio
Required For Panels = 0.0012 (minimum) [5]

Horizontal Steel Ratio
Required For Panels = 0.002 (minimum) [5]

The vertical steel is 1/16″ or 1.5mm wire @ 4″ c/c & @ 3″ c/c for horizontal steel. Such a small spacing proves that thin wire mesh (grating) can be used for the wall panels, which is in fact ferrocement.

4.2 Flexibility of Extension

Flexibility of extension and ease of alteration are two of the important features. Although this house is proposed as a single room but the design has flexibility to add kitchen, bathroom and stores etc. Adding more and more panels at the suitable location makes the extension very simple. This small unit can be extended to build a field hospital, combined residence, messing facility and a warehouse etc.

4.3 Light Roofing System

One of the major causes of damage during earthquake was heavy roofs. Mud layer of one to two feet was used to be placed on weak walls to avoid the severe cold during chilling winters (Figures 1 and 2). During earthquake the weak vertical supports could not survive and came down with thick layer of mud, burying everything under it. Lightweight roofs are better than heavier ones because they:

- Generate lesser forces
- Cause less damage if they fall.

The roof system of this proposed house consists of GI corrugated sheets with simply supported lightweight trusses consisting of single angles (Figure 10). Every truss is strongly coupled with panels by bolted steel fixtures. Braces connecting bottom cords of consecutive trusses and the purlins ensure the space truss behavior. Wooden trusses, which have been in common use, are deliberately avoided as they are comparatively heavier and cause more damage to life and property in case of collapse.

4.4. Joint Details

Most of the masonry and frame structures failed from the joints therefore special attention is paid on joint details. The steel fixtures shown in Figure 11 will be used to make strong joints

4.5. Foundations

Total service load reaction is 1.73 kips [7.69 kN] which yields a foundation size of 11″ x 11″ [280mm x 280mm] for a net allowable bearing capacity of one tons/ft^2 [100 kPa] Foundation is proposed as 12″ x 12″ [300mm x 300mm] pre-cast ferrocement block with 6″ [150mm] total thickness (Figure 12). It has a 3” [75mm] deep grove to accommodate ferrocement panels. Foundation depth

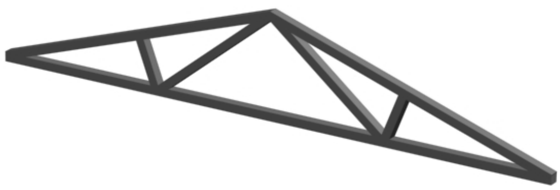

Figure 10: Truss used for roofing system.

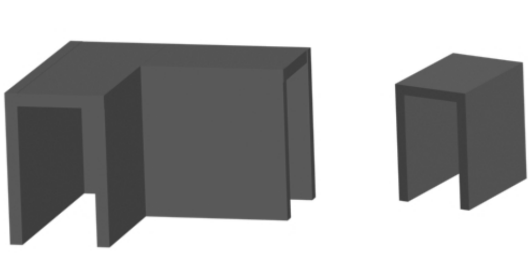

Figure 11: Joint fixtures

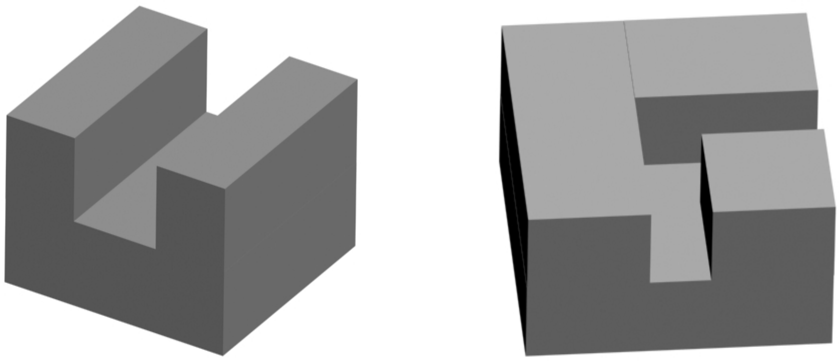

Figure 12: Side and corner foundation blocks

is proposed as 2ft [600mm]. The connection between foundation blocks and panels is developed by bolted angle section both at inner and outer side. Blocks are so sized that a single person can easily lift and transport it to the required place.

4.6. Openings

Doors can be located at any desired position. It is just a matter of removing one panel and the door opening is ready. Panels with windows and ventilators can also be cast but it is recommended to have ventilators in roof.

5. Tentative Cost

Table 1 presents the tentative cost of structural elements of proposed house.

It can be confidently said that cost will not cross rupees 30,000/-, which means it is rupees 275/- per square foot. The cost can also be quoted as rupees 2,850/- per foot length with a width of 10′-6″ [3.25m]. As stated previously, this structure can be easily extended so the approximate cost for any size can be easily calculated.

6. Conclusions

- Based on the analysis and experience it can be confidently stated that this type of structure will not only be suitable for temporary use but for permanent construction as well.

- Its behavior under a major seismic activity is satisfactory. It can bear the shock with little or no damage. Catastrophic failure will be avoided in any case thus minimizing the loss of life and property.

7. Recommendation for Future Research

- There is a need to test a model of the proposed house on shake table to better observe its performance during earthquake.
- Seismic behavior when constructed on slope should also be evaluated both analytically and experimentally.

Table 1: Estimated cost of proposed house

Serial #	Item Name	Unit	No.	Unit Rate	Total Cost
1	Cement	Bag	15	300/-	4500/-
2	Sand	ft^3	45	20/-	900/-
3	Steel Wire Mesh	ft^2	800	8/-	6400/-
4	Angle Sections	kg	145	60/-	8700/-
				Total	20500/-
40% additional for connections and labour					8200/-
Grand Total					28700/-

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