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Low Cost Ferro cement Single Room House: A Revolutionary change in Construction building of Pakistan

Muhammad Ali Zafar

Abstract - The major earthquake of Oct. 2005 has left a thought for civil engineers to improve the design practice and quality of construction in Pakistan to endure 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 single room house which has the capability to meet the strength and serviceability requirements. Ferrocement, a material recommended by ACI 549R-93 is proposed for this house. This paper attempts to review the literature on ferrocement and brings out the design of Roof Panels/beam and Wall Panels for a single room using ferrocement. The salient features of construction, material properties and techniques of applying cement mortar on to the reinforcing mesh makes it easy and virtually require no expertise to practically construct these Roof panels/beams and wall panels. The tool used for this purpose is ETAB. The idea is generally based on do it yourself (DIY) concept to develop an efficient and economical method for construction of ferrocement room and practically reduce the live losses and damage to infrastructures in case of any seismic activity.

Keywords - Ferrocement, Seismic Activity, Single house construction, reinforcing mesh

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1 INTRODUCTION

The history of ferrocement is an interesting story that goes back to 1848 and many regarded it as the earliest use of reinforced concrete. One such boat was still afloat hundred years later in 1949 and is currently on display in a museum in France. J. L. Lambot built in Southern France, in 1848, a small concrete boat (later he reinforced his boats with iron bars and wire mesh) and in the 1890s the Italian C. Gabellini began to build concrete ships as well. Ferro Cement is the name given by English speaking people to a bowl building method using steel wires covered with a sand cement plaster, patented in 1855 by the French, who called it Ferciment. Ferciment boats built by the French before 1855 are still in existence and one at least is still afloat, effectively supplying the answer to "what happens to the steel and plaster, when the boat is placed in water."

Ferciment boats built by the Italians in the 1940s are still in use and going strong, but they called the method of construction Ferro-Cemento and the New Zealanders who pioneered the amateur construction of Ferro-Cemento boats called it Ferro-Cement. Joseph Louis Lambot constructed several rowing boats, plant pots, seats and other items from a material that he called 'Ferrocement' in a patent which he took out in 1852. The patent reads, in part, as follows: “My invention is a new product that can replace timber (in wood flooring, water containers, plant pots, etc.) that is exposed to damage by water or dampness. The base for the new substance is a metal net of wire, or rods interconnected to form a flexible woven mat.

A composite material consists of a matrix and a reinforcement which act together to form a new material with superior characteristics alone. Ferrocement, a homogeneous composite material, which contains a high percentage of ductile steel wire mesh with a higher surface area to volume ratio in a brittle cement-mortar matrix, enables the matrix to assume the ductile characteristics of the reinforcement. The strength of ferrocement, as in all construction materials is considered as the most valuable property, although in many practical cases other characteristics, such as durability and permeability may in fact be more important. Ferrocement has proved to be durable over long use, exhibits good ductile flexure behaviour and provides reasonably good water tightness properties.

The widespread use of ferrocement has begun only in the last three decades. Thus the state-of-the-art of ferrocement is still in its infancy. Nevertheless, sufficient design information is available and adequate field experience has been acquired to enable safe design and construction of many ferrocement structures some applications of ferrocement appear especially attractive. For industrially developed countries ferrocement seems economical for medium size storage tanks, some types of roof shell construction and wherever the case of forming complicated shapes and the lighter weights of ferrocement can be safely exploited. Corrugated ferrocement sheets have been developed and tested by the Building Research Institute, Colombo, Sri- Lanka. These sheets are developed as a replacement for asbestos cement corrugated sheets, which are widely used as roofing material. It has been reported that ferrocement sheets are less expensive. The ferrocement sheets are so designed that their weight, dimensions and load carrying capacities are similar to those widely used asbestos cement sheets. In addition, it has been observed that ferrocement sheets are more ductile than asbestos cement sheets. Ferrocement is good enough against seismic shocks and its thermal insulation can be increased against extreme weather by providing a special shape, as in our project. The ferrocement displays a series of advantages as compared to reinforced concrete,

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among whom:

1. A wider range of elasticity,
2. Greater resistance to extension,
3. Better behaviour at dynamic stress,
4. Increased value of the breaking effort out of extension,

Ferrocement is commonly used to describe a steel-and-mortar composite material. Essentially a form of reinforced concrete, it exhibits behaviour so different from conventional reinforced concrete in performance, strength, and potential application that it must be classed as a completely separate material. It differs from conventional reinforced concrete in that its reinforcement consists of closely spaced, multiple layers of steel mesh completely impregnated with cement mortar as shown in figure 1.

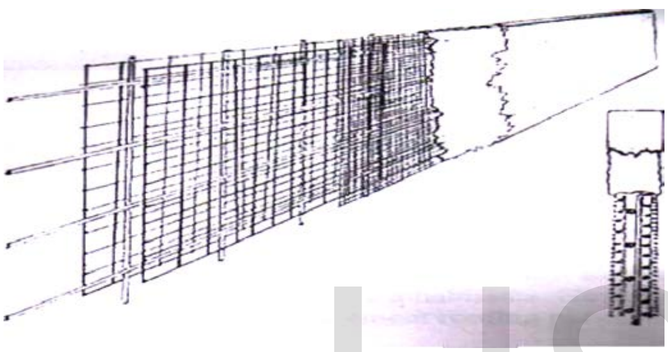

Fig. 1. Ferrocement showing the mesh along with skeleton steel

Ferrocement can be formed into sections less than 1 inch thick with only a fraction of an inch of cover over the outermost mesh layer. Conventional concrete is cast into sections several inches thick with an inch or so of concrete cover over the outermost steel rods. Ferrocement reinforcing can be assembled over a light framework into desired shape and mortared directly in place, even upside down with a thick mortar paste. Conventional concrete must be cast into forms.

Thin panels of ferrocement can be designed to levels of strain or deformation, with complete structural integrity and water tightness, far beyond limits that render conventional concrete useless. Ease of fabrication makes it possible to form compound shapes with simple techniques: with inexpensive materials; and. if necessary, with unskilled labour but supervised. The most extensively used building medium in the world today is concrete and steel combined to make reinforced concrete; familiar uses are in high-rise buildings, highway bridges, and roadways. Yet, the first known example of reinforced concrete was a ferrocement boat. Joseph-Louis Lambofs original French patents on wire-reinforced boats were issued in 1847 not long after the development of Portland cement. This was the birth of reinforced concrete, but subsequent development differed from Lambot's concept. The technology of the period could not accommodate the time effort needed to make mesh of thousands of wires. Instead, large rods were used to make what is now called standard reinforced concrete, and the concept of ferrocement was almost forgotten for a hundred years. Reinforced concrete developed as the material familiar today in fairly massive structures for which formwork to hold the fresh concrete in the wide gaps between reinforcing rods and a fairly thick cover over the rods nearest the surface are required.

Reinforced concrete for boatbuilding reappeared briefly during the First World War, when a shortage of steel plates forced a search for other boatbuilding materials. In the early 1940's, Pier Luigi Nervi resurrected the original ferrocement concept when he observed that reinforcing concrete with layers of wire mesh produced a material possessing the mechanical characteristics of an approximately homogenous material and capable of resisting high impact. Thin slabs of concrete reinforced in this manner proved to be flexible, elastic, and exceptionally strong. After the Second World War, Nervi demonstrated the utility of ferrocement as a boatbuilding material. His firm built the I65-ton motor sailor Irene with a ferrocement hull 1.4 inches (3.6 cms) thick. Weighing 5 percent less than a comparable wood hull, and costing 40 percent less. The Irene proved entirely seaworthy, surviving two serious accidents. Other than simple plastering necessitated by the accidents, the hull required little maintenance.

Ferrocement for Food-Storage Facilities: The need to preserve grain and other food crops in developing countries justifies extensive field trials in the use of ferrocement for silos and storage bins. The existence successful prototypes suggest that little more research is needed, other than techno economic and design studies for given localities. In tropical regions, high temperatures and humidity promote the growth of mild and rot on foodstuffs. Destroy moisture sensitive materials such as bagged cement and fertilizer and also to encourage thermal ultraviolet degradation of many products. Insects, rodents, and birds also take an enormous toll. Perhaps 25 percent · of each year's food crop in the developing world is rendered unfit or unavailable for consumption because of improper handling, storage methods, and facilities. Hundreds of ferrocement boats floating on the world's waterways demonstrate that this material is watertight, and other experience has shown that ferrocement does not readily corrode in the tropical region. Experience in Thailand and Ethiopia has shown that ferrocement grain silos can be built on site very inexpensively, using only one supervisor and unskilled labour. A simplified version of known ferrocement boatbuilding material and techniques was used to build the silos.

Ferrocement in Food Technology: In view of the properties, availability, ease of manufacture, and reliability of ferrocement. Wide-ranging effort by research organizations to investigate the use of ferrocement to replace steel particularly stainless steel-in manufacturing of some units of basic food processing equipment. Many foods-highly perishable. Irreversibly affected by temperature changes, biological and chemical contaminants are lost to mankind because there are no rural processing plants to preserve, convey, or process food products soon after harvest. Some advantages of ferrocement for food-processing equipment are its:-

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(I) Fabrication from mainly local materials;
(2) Structural strength and reliability.
(3) Ease, economy, and versatility of construction:
(4) Ease of maintenance and repair
(5) Easy-to-transport raw materials.

Ferrocement apparent suitability for processing of fruit and vegetables for preservation, fermentation vats for fish sauces, soy sauce, beer, wine, etc. Storage vats or tanks for fruit juices, vegetable oil, or drinking water. Many other purposes-spray driers for milk. Driers for copra. Cooking stoves or ovens, dairies, free Zing chambers, and slaughterhouses.

Ferrocement for Low-Cost Roofing: Ferrocement may prove a suitable material for low-cost roofing in developing countries. Applied-science laboratories in developing countries and technical assistance agencies should seriously consider this area for field trials and techno-economic studies. Adequate shelter is an essential human need and a roof is the basic element of shelter. But current materials are not meeting the need for roofs. The more-than-80 developing countries in the world suffer from housing shortages resulting from population growth, internal migration. And sometimes from war and natural disaster. For most dwellings in developing countries, a durable roof constitutes the major expense. Roofs made of cheap local materials, such as scrap metal. Thatch, or earth products (sand, mud, rock), are usually unsafe and temporary. A secondary problem is the need for adequate and durable supporting structures. In some areas, scarce wooden supports are weakened by decay and insect attack.

Ferrocement in Disaster Relief: Ferrocement is being used by disaster relief organizations. After fires. Flood, droughts and earthquakes, the needs for food, shelter and public health facilities are urgent. Transportation is often disrupted by destruction of roads, bridges, boats, and airstrips. Supplies of bulky conventional building materials may be stranded outside the disaster area, whereas the basic ingredients of ferrocement may be available on the site or easily transported. The versatility of ferrocement also reduces logistical supply problems: wire mesh. Cement, sand, and water can be substituted for the metal used for roofing such as woods or plastic, shelters and clinics. Asphalt for helipads. Steel for bridges. And so on. Moreover, most ferrocement structures, though built for an emergency: will last long after the emergency is over. Ferrocement could be used at a disaster site for many purposes: Transport facilities. from simple boats to barges, docks, marinas. helipads, and simple floating bridges or short footbridges-as well as road repairs. Food-storage facilities. quickly designed to local needs and quickly built, to preserve emergency food supplies. Emergency shelters such as. For example, the Quonset type of roof, which is easy to erect and highly efficient. Public health facilities, such as latrines and clinics, built with ferrocement roofs and stucco-type walls of the same wire mesh and mortar. To prepare for the use of ferrocement in disaster relief, demonstrations in simulated emergencies could be arranged for national and international relief agencies; and cadres of ferrocement workers could be trained in emergency applications and the supervision of local labourers at the disaster site.

No level of earthquake preparedness can guarantee that an earthquake will not damage a building. 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. This research work is mainly focused on developing a small Single room house. Ferrocement beams and Wall panels are recommended as the main structural elements.

2 LITERATURE REVIEW

There are number of studies on Ferrocement in the Construction industry which have focused on identifying its effectiveness, strength, durability, usability, cost effectiveness, flexibility of use of skilled labor, availability of raw material, its portability, its use as storage facilities, water tank, boat making & vessels and main structural member of the structure (beams and columns). Some of them are given below.

Gordon W. Bigg and G. M. Sylvester in 1972 studied about the merits of Ferro-cement as a small vessel hull material. This report attempts to separate fact from fancy to enable the potential designer of Ferro-cement vessels to realistically predict the performance of a Ferro-cement hull. In addition to a basic statement on design philosophy and criteria, the report contains some of the detail associated with the design of a 53 foot fishing vessel for Newfoundland waters. This report must be considered preliminary. As new advances are made in the technology of Ferro-cement it is likely to become rapidly obsolete unless continually brought up-to-date. [1]

Chandrasekhar Rao, T.D.Gunneswara Rao and V.Ramana Rao(2008) conducted an experimental study on the strength and behavioural aspects of voided Ferro cement channel type units for pre cast beams. As these beams are lighter in weight, they find their place in seismic resistant design of structures. Eight channel type Ferro cement units were tested for four points loading. The variable parameter includes the number of layers of wire mesh. The flexural strength of the voided channels was compared with that of solid channels too. The test results indicate that the drop in flexural strength with the voids is very negligible compared to the decrease in the weight of the member. The Moment curvature response of the voided members under flexural loading improved with the post ductility of the member with increase in the number of layers. [2]

Boshra Aboul-Anen1, Ahmed El-Shafey, and Mostafa El-Shami(2009) explained about the composite action between the ferrocement slabs and steel sheeting. This is an important issue that could impact the performance and strength of space trusses. The current paper presents the experimental models of ferrocement slabs with and without steel sheeting and their numerical models using the finite element method. Finite element models were developed to simulate the behavior of the slab through nonlinear response and up to failure, using the ANSYS Package. Additionally, the comparison between the theoretical and experimental models is presented and discussed. [3]

M. A. Saleem and M. Ashraf (2008) conducted the study on earthquake of October 2005 which 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. [4]

Mansur and Paramasivam in 1990 conducted studies on the cracking behavior of Ferrocement elements and predicted the ultimate strength of Ferro cement in flexure using plastic analysis. [5]

Trian Onet, etal have studied on the behavioural aspects of Ferrocement in flexure and reported that Ferro cement elements have better performance under working loads owing to their very small crack widths and improved ductility at post cracking range.[6]

E.Z. Tatsa presented the limit state design philosophy for the design of Ferro cement elements in bending. [7]

D.N.Trikha, conducted analytical and experimental studies on the behavioural aspects of cored Ferro cement slabs, proposed empirical expressions for the estimation of modulus of rupture and effective moment of inertia to estimate the deflections. [8]

S.K. Kaushik performed investigations on behaviour of ferrocement cored plates concluded that these slabs improve the heat and sound insulation properties. Moreover these slabs are lighter in weight there by providing economy for the supporting systems like footings. [9]

P Rathish Kumar, T Oshima, S Mikami in Nov 2004 conducted research on ferrocement confinement of plain and reinforced concrete with application to column retrofitting is presented. [10]

A.B.M Amrul Kaish, Md. Abdul Wahed, Dr. Md. Rabiul Alam investigated the behaviour of ferrocement encased square reinforced concrete columns subjected to monotonically increasing small eccentric load. Three different types of square jacketing techniques have been studied experimentally to find out the effectiveness of ferrocement confinement of RC columns against eccentric loadings. [11]

Abid A. Shah conducted research on load carrying capacity, ductility and serviceability of unreinforced masonry columns can substantially be improved if encased by ferrocement. Parameters such as cement mortar thickness, gage-wire spacing and bond at the interface of ferrocement and brick columns have effects on overall behaviour. Premature failure is possible when bond at the interface of brick masonary column and ferrocement is poor. At higher reinforcement ratio, severe spalling ad delaminating is expected. [12]

Katsuki TAKIGUCHI and Abdullah studied the strengthening method using circular ferrocement jacket to improve the confinement of substandard column which was investigated and compared with control specimens and different strengthening methods. [13]

Based on the literature review, this study would focus on the Design of Roof Panels/beams and wall panels. Its behavior under a major seismic activity so that 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.

3 METHODOLOGY

Based on Literature Review, it is concluded that major reason of structural collapse and damage of residential and institutional buildings during earthquake is the insufficient strength of vertical supporting members including columns, masonry walls, un-reinforced concrete walls and bonded or un-bonded rubble masonry walls. Therefore a house is proposed for which principal material is ferrocement. It consists of ferrocement panels placed side by side connected with steel plate using bolts. 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 (DIY) 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.

Resistance against earthquake is the primary requirement for any structure proposed for Hilly Areas or earthquake prone areas. This wall panels are modelled using ETABS software, and its response under the seismic activity of zone four is checked. Analysis is carried out with forces applied along both the principal directions. Foundation connections are considered as fixed supports and ferrocement is defined as reinforced concrete in ETABS .Stresses in ferrocement panels especially at joints, displacement and sway due to earthquake are carefully noted for various load combinations carried out with earthquake forces applied along both the principal directions.

Geometrical Properties

Size of House = 10′-6″ x 10′-6″
Panel Size = 1′-6″ x 10′-6″
Panel Thickness = 8″
Roof Panels = 6″
Parameters for Analysis
Live Load = 50 psf [250 kg/m2]
(Equivalent to 2 ft thick snow)
Imposed Dead Load = 20 psf [100 kg/m2]
Seismic Zone = 4
fc' = 3 ksi [20 Mpa]
fy = 60 ksi [420 Mpa]
Modulus of Elasticity = 3122 ksi

No test data are available on the shear capacity of

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Ferrocement slabs in flexure.4

4 RESULTS & ANALYSIS

4.1 Design of Ferrocement Roof Panels/Beams

The ferrocement beams / roofing panels are taken of sizes as 1" thick, 18" wide with 6" rib's depth and 10' length. Total thickness including insulating material would become 6". The roofing panel and its x-sec is shown in the figure 2

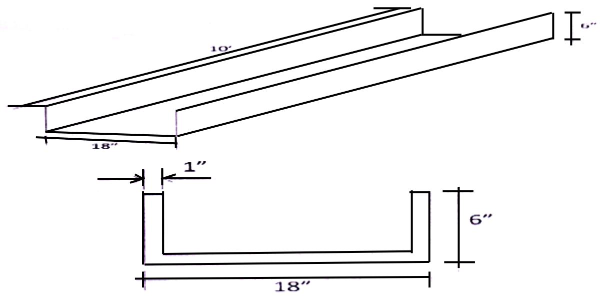

Fig. 2. Roof Panels/ Beam

4.2 Sand Selection

Sand is the only aggregate that is used in ferrocement and it occupies substantial volume of mortar. The grading of the sand particles is important. On the other hand, compressive strength, which is primarily dependent on the mortar characteristics, is sensitive to varying types of sand. Samples from different sites were analyzed to meet the requirement of ACI 549.1R-93.

4.3 Mesh Reinforcement

Steel mesh is the primary mesh reinforcement for ferrocement. Steel meshes for ferrocement include different type of meshes. Welded square wire mesh was selected to be used in the construction of Panels. The wires are made up of low to medium tensile strength steel and are much stiff than hexagonal wire mesh. It can be molded more easily to conform to the desired curves of the structure, producing much fair cracks. Welded square wire mesh has the possibility of weak spots at intersections resulting from inadequate welding during the manufacturing of the mesh. The mesh opening of welded

Properties of meshes

Welded square
Wire spacing = 0.5 in
Wire diameter = 0.035 in gage # 20
$V_f = 0.409\%$
$f'_c = 5000$ psi
$b = 18$ in
$h = 1$ in
$d'' = 0.15$ in
$f_y = 40$ ksi
$E_r = 30{,}000$ ksi
$\eta = 0.50$

Calculate β_1, V_f and Asi

$$\beta_1 = 0.85 - \frac{0.05(5000-4000)}{1000} \quad (f'_c > 4000 \text{ psi})$$

$$= 0.80 \geq 0.65$$

$$V_n = 0.409 \text{ / layer}$$

$$Asi = \eta V_n A_c$$

$$= 0.50\ (0.409/\ 100)\ (18)\ (1) \quad = 0.0368 \text{ in}^2$$

square wire mesh used in panels was 0.5 inch.

4.4 Design Computation

4.5 Design of Wall Panels

Design of wall panels was carried on ETABS. The ferrocement wall Panels are taken of sizes as 7" thick including insulating material, 18" wide with 6" rib's depth and 10' length. The complete arrangement is taken as one single unit to be analyzed

d'' = clear cover = determined from geometry of panel

d_b = dia of fiber

$$d_1 = d'' + ½\, d_b$$

$$= 0.115 + ½(0.035)$$

$$= 0.1325$$

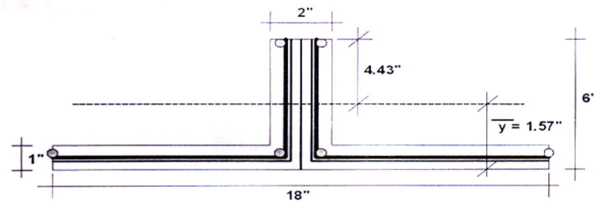

Fig 7.3 X-sec with one layer of mesh

$$A\bar{y} = (18)*(1)*(1/2) + (5)*(2)*(3.5)$$

$$\bar{y} = \frac{(18)(1)(1/2) + (5)(2)(3.5)}{(18)(1) + (5)\ (2)} = 1.57 \text{ in}$$

$$\varepsilon_y = 40 / 30{,}000 = 0.0013$$

$$\varepsilon_{cu} = 0.003$$

in ETABS. The roofing panel and its x-sec is shown in the figure 3.

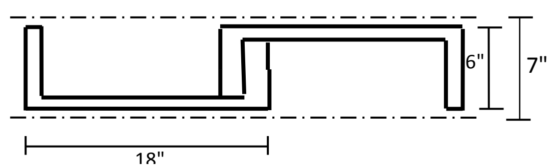

Fig. 3. Wall Panels for the Room showing thickness with plastering

Wall Panels and Roof panels/Beams are considered monolithically for analysis purpose. Universal Building Code (UBC) was taken as standard for analyzing the model room. The Parameter for type of sand, SD was used; Seismic Zone 4 was selected for analyzing the drift caused in the Single Room along both major axis. The Calculated story drift using M shall not exceed 0.025 times the story height for structures having a fundamental period of less than 0.7 second. For structures having a fundamental period of 0.7 second or greater, the calculated story drift shall not exceed 0.020 times the story height. In our case at point A for Earthquake forces on X axis drift is .00000384 which is less than the 0.25. Similarly On point A for earthquake force on Y axis drift is 0.0000049 which is less than .025 thereby meaning that the Drifts produced on the top of panel is less to cause the failure of the structure.

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4.6 Cost Calculation

TABLE 1
SHOWING MATERIAL COST

Serial No	Item Name	Unit	No	Unit	Total
1	Cement	Bag	15	450/-	4500/-
2	Sand	CubicFt	45	23/-	900/-
3	SteelWire Mesh	Sq Ft	800	24/-	6400/-
Total			20500/-		

5 CONCLUSION

Based on the analysis and experience it is 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.

6 RECOMMENDATIONS

There is a need to test a model of the proposed house on shake table to observe its performance during earthquake. When constructed on slope Seismic behaviour should also be evaluated both analytically and experimentally. This is a non-funded research.

REFRENCES

[1] www.Architectureforhumanity.com/accessed 10th Feb. 2007

[2] www.hud.gov/accessed 10th Feb. 2007

[3] www.forintek.ca/accessed 12th Feb. 2007

[4] State-of-the-Art Report on Ferrocement ACI 549R-97, ACI Committee 549, American Concrete Institute, Farmington Hills, MI, USA, (1997), 15-35.

[5] Building Code Requirements for Structural Concrete ACI 318-05, ACI Committee 318, American Concrete Institute, Farmington Hills, MI, USA, (2005), 237-241.

[6] Uniform Building Code, ICBO, CA, USA, 2(1997) 1605-1617.

[7] Guide for the Design: Construction and Repair of Ferrocement ACI 549.1R-93, ACI Committee 549, American Concrete Institute, Farmington Hills, MI, USA, (1993) 27-37.

[8] International Journal of Recent Trends in Engineering, Vol. 1, No. 6, May 2009

[9] Ferrocement utilisation for rehabilitation of buildings Phd Thesis

[10] Low Cost Earthquake Resistant Ferrocement Small House .Pak. J. Engg. & Appl. Sci. Vol. 2 Jan 2008

[11] International Journal of Mechanics and Solids ISSN 0973-1881 Volume 3 Number 2 (2008) pp. 195–203 Research India Publications http://www.ripublication.com/ijms.htm

[12] Ferrocement: Application inDevelopingCountries
A Report of an Ad Hoc Panel of the
Advisory Committee on Technological Innovation. Board on Science and Technology for International Development. NATIONAL ACADEMY OF SCIENCES
Washington. D.C. February 1973

[13] Abdullah & Katsuki Takiguchi, (2003), "An Investigation into Behaviour and strength of Reinforced Conc rete Columns Strenthened with Ferrocement Jackets. Cement & Concrete Composites, 25:233-242.