# A MODEL OF CALAMITY-RESISTANT RURAL HUT WITH FERRO-CONCRETE THIN SHELL ROOF

**M K Uddin**, BUET, Bangladesh

## Introduction

Bangladesh is a disaster prone country which has been facing perennial problems of natural disasters. In almost every year, the country is hit by different natural calamities such as floods, cyclone, and tidal waves, which sweep away the unstable rural houses. Most houses in the rural areas in Bangladesh are of non-engineered roof construction which have virtually no lateral load resistance mechanism. They can not survive a windy storm of even moderate intensity. The calamities have been causing huge loss of lives and other casualties every year especially due to extreme winds and floods causing massive loss and colossal damage to the economy of the country. Most of the Bangladeshi population lives in rural areas (about 80%) where construction of dwelling houses is made of traditional materials adopting conventional non-engineering methodologies which are not covered in any code. In rural areas, houses are constructed with thatches, leaf, tin, bamboo, corrugated iron sheets etc. with untreated earth base having no foundation. They exhibit little or no resistance to natural calamity. Tin and iron-sheet houses are non-resistant to temperature variation and their cost is getting higher day by day. The thatched houses are vulnerable to destruction to weather and require frequent repair and alteration. Thus maintenance cost is high for these houses. Majority of loss of lives and injury are caused by the collapse of these structures during cyclone, storms and flood. A stronger and safer built environment can protect both lives and livelihood. An improvement to the calamity resistance potential will significantly minimize loss of lives and other causalities. One way of reducing the damages caused by these disasters is to take structural measures through building infrastructures such as rural hut that should be strong enough to withstand disaster of any possible magnitude. Moreover, Bangladesh is facing an alarming situation of population explosion and thus housing problem is emerging horrendously. Durable, constructable and viable low cost house is obviously essential for the rural people.

An alternative to the traditional building materials, ferro-cement and concrete reinforced with wire nets can be used. These are new imputs to the horizon of construction field. The potential uses of these materials especially in shell roofing have long been recognized. In developed countries, ferro-

cement is being used in various types of structures particularly in shell roofing. Thin shells provide strength through form as against through mass: a minimum material is used to maximize structural advantage and economy. Thus shell roofing was chosen for the model house to curtail cost and at the same time rendering higher strength and rigidity of the structure. Cement-plastered bamboo-mat fence was selected as a cheaper and low-cost walling system using local available materials. This paper is based on a research project recently accomplished in Bangladesh University of Engineering & Technology (BUET), Dhaka, wherein attention is focused to develop a hazard-resistant rural hut using thin shell roof of ferro-cement concrete and plastered bamboo-mat as wall. This study is directed towards three objectives: (i) to design and construct a hazard-resistant thin shell roof with pre-cast ferro-concrete elements, (ii) to determine the rigidity of cement-plastered bamboo-mat fence against extreme wind pressure, (iii) to study the economic feasibility of the house.

## Design of Shell Roof

Shell in general does not lend themselves to simple analysis and calculations. Long experience of use, detail analyses have, however, shown that for certain types of forms and loading a simple method of design, based primarily on statical considerations, is often adequate. The design of shell roofing is much more complicated than flat one, as it requires a substantial idealization for detail analysis and finally confirmed by physical model test. In fact, the load bearing capacity of thin curved structure often far exceeds the prediction of the most refined available analysis. Consequently, the shell becomes stronger than even the designer dares to assume. The internal forces which act on an element of doubly curved surfaces are normal forces, shear forces, flexural moments, tortional moments, transverse shear forces. The six equations of equilibrium three for forces and three for moment vectors are clearly not adequate for the determination of the ten unknowns. The problem is statically indeterminate and additional deformation conditions have to be considered. The shell transfers the load tangentially mainly as meridional stress. The vertical load is theoretically insignificant and the moment development in the shell roof slab is far less than the flat one of the same width (Billington, 1965). The detail calculation of shell parameters can be found in Billington (1965).

## Low Cost Walling System

In rural Bangladesh, the common walling materials that are normally used are clay, thatches, bamboo, jute-stick, stack of cereals, etc. Some costly and more durable materials such as tin, burnt-clay bricks, metal sheets, corrugated iron sheets, etc, are used by the well-to-do people. Majority of rural population is unable to purchase the costly and durable materials required for a house. Initial investment for cheaper materials are low but in the long run, maintenance cost becomes very high. As for example, using clay wall reinforced with husk or thatches, clay cover on the bamboo-splits, simple bamboo-splits fence, jute-stick fence, fence of thatches etc. are vulnerable to weather or subjected to damage during rainfall, storm, flood, cyclone, etc. The maintenance cost for these walling materials after few years eventually exceeds the purchase price of costly and durable materials. People are aware of this; even then they use these cheaper materials because of its low initial investment and their inability to spend much for costly material at a time. Bamboo is the most widely used natural building material in Bangladesh. It is easily affordable and locally available material. The 1981 Housing Census (BBS 1989) shows that more than 60% of the dwellings in the whole of Bangladesh, and more than 70 percent in rural areas used it. Bamboo has been recognized as a convenient and cheaper building materials in many tropical developing countries around the world. Bamboo is generally available in two varieties, thick-walled and thin-walled. Thick-walled bamboo is used for structural members such as posts, roof rafter and purlins. Thin-walled is split and woven into a variety of stiff mats that are used as wall/fence and sometimes as roof cladding. The expected life of bamboo splits in controlled conditions can be as long as 35 years (IFIC, 1978).

The high cost and scarcity of steel rebars have promoted much research into the feasibility of using bamboo as a substitute of steel in concrete structures. The bamboo has a tensile strength as high as 3.8 kN/m$^2$, modules of elasticity varies from 1.86 to 4.7 GPa and modulus of rigidity varies from 20.48 MPa (Geymayer & Cox, 1970). The load carrying capacity of bamboo-reinforced beam is as high as 43% of the reinforced concrete beam having the same reinforcement ratio (Abedin & Rashid, 1992). Thus bamboo can be used as a potential reinforcing materials for wall. The durability and strength can be enhanced by seasoning or by preservative treatment with coal tar, zinc chloride, sodium floride, etc. The low-cost chemical treatment increases the resistance from decay and weathering enhances the reinforcing properties of Bamboo (Geymayer & Cox, 1970). The problems of bond-volume changes can be overcome by applying melting bitumen to Bamboo strips to form a thin uniform coat resulting in a reduced deformation and greater strength (Janssen, 1987). The bamboo reinforced slab can take more load with greater deflection than the slabs reinforced with mild steel (Mattone, 1990). In the light of above discussions, it can be conceivable that bamboo-splits can be used as reinforcement in an alternative walling system.

## Physical Model

The study was conducted through a physical model. A test house was built for the study at an open site at Joar Shahara, out skirt of Dhaka City. The sectional elevation of the constructed house is shown in Figure 1. The portion ABC (in Figure 1) is the circular thin shell and AD and CE are the flange portion of curved shell. The meridional thrust of circular shell acts as the concentric load on AD or CE and resists the self-weight as transverse load. So, the overall behavior of AD or CE is partly a beam and partly a column. The part AD and CE are nomenclatured as the shell-flange. The radius of shell curves
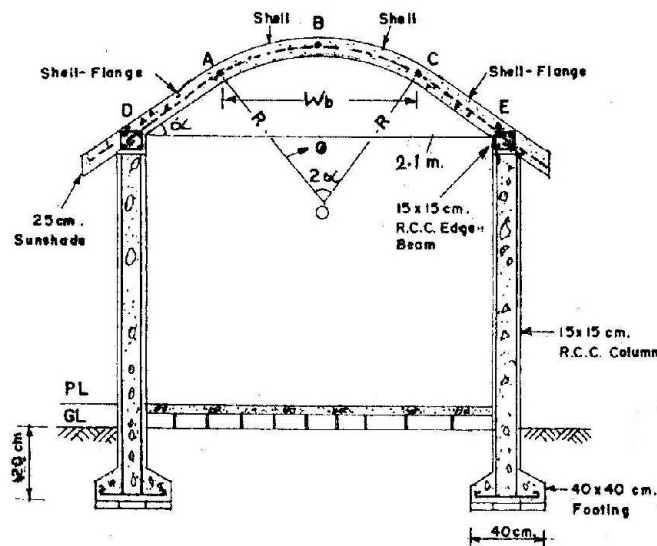


**Figure 1 : Cross-sectional elevation of the model house**

$$R = \frac{1}{2} \, \mathrm{Sin}\, \alpha$$

Where, $W_b$ = Bay width and a = Curvature angle of the shell The slope a is the main design parameter of the thin shell. Because of the construction difficulty i.e., difficulty in concrete casting, it is not suitable to design a shell with a>45°. Steeper slope of roof requires top shuttering form which incurs extra expense. The shell with a<45° is easier in construction but produces higher stresses. Thus the slope should neither be too low for construction economy nor too steep to reduce structural thickness. As a practical compromise, a value of a=35° was used in this study. The other design parameters of shell

section ABC were calculated by shell equation (Billington, 1965). The flange AD or CE was designed according to ACI specification (Winter et. al. 1979). A compromise among the bay width, width of the house, slab thickness and lateral force acting on edge beams was considered for selection of the design components. A computer software based on Finite Element Method 'STAAD IV' was used to find out the stresses and moments for an acceptable design section of the roof shell.

## Design Loads & Roof Details

The design loads were as follows: Dead Load = 1180 N/m², Wind Load = 720 N/m², Weight. of Plastering = 480 N/m². According to ACI Code provisions (ref. Winter et. al., 1979), Equivalent ultimate load=1.4 (Dead Load + Wt. of Plastering) +1.7 (Wind Load)= 3.6 kN/m². The selected thickness of the roof slab are as follows (Figure 1): thickness at the crown of shell (at B) = 3 cm, thickness at the junction of shell and the shell-flange (at A&C) = 4 cm, thickness at the edges of roof (at D&E) = 5 cm. The reinforcement arrangement of the shell roof and the shell flange are shown in Figure 2. The wire (gauge no. 14) mesh of 2.5 cm square was used for netting the reinforcement skeleton. Two wooden-models were made to maintain the geometry of shell and shell-flange for pre-casting. The brick chips (*Khoa*) of 12.5 mm downgraded and sand of Fineness Modulus = 2.18 were used respectively as coarse and fine aggregate. The mixing proportion of concreting was 1:2:3.
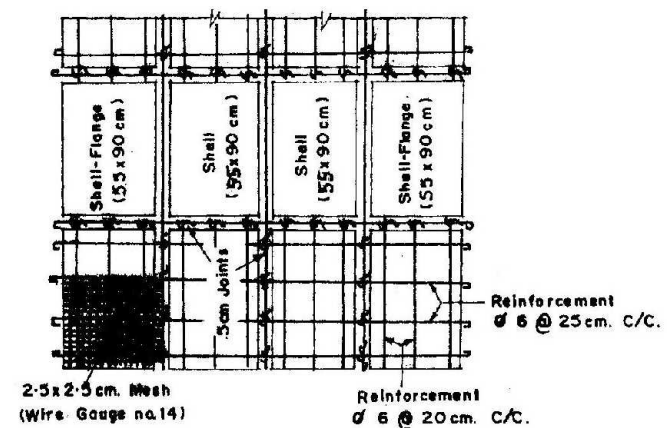


**Figure 2 : Thin shell roof: layout of pre-cast roof elements and reinforcement details**

## Structural Configuration

A total of 6 shell elements (each 55 x 90 cm) and 6 shell-flange each (each 55 x90 cm) was cast according to design thickness. The elements were cured by covering with wet sacks and spraying water over it time to time whenever required. The pre-cast element was then arranged according to Figure 3 over the pre-set roof scaffolding. The panels were then connected each other length and breadth wise by the φ6mm steel bar passing through the hooks. The joints were filled up with the concrete having the same proportions (1:2:3) as the panels are made of. Figure 4 is a Photograph showing the layout of roof joints. The house is founded on 4 footings (each 40 cm x 40 cm x 30 cm depth). The footings are at depth of 1.2 m from ground level. The shell load is transferred into four 15 x 15 cm square R.C.C columns through 15 x 15 cm concrete edge beam. Mixing ratio of concrete was 1:2:4. The columns are reinforced with 4φ10 mm steel rebar having stirrup of φ6 mm @ 15 cm c/c. The edge roof beams were reinforced with 2φ10 mm at top and 2φ10 mm at bottom having stirrup @ at 15 cm c/c with gauge no. 8 wire. The roof was extended downward with same rate of increasing slope to act as sunshade, wire mesh of 2.5 cm square were provided on the reinforcement.
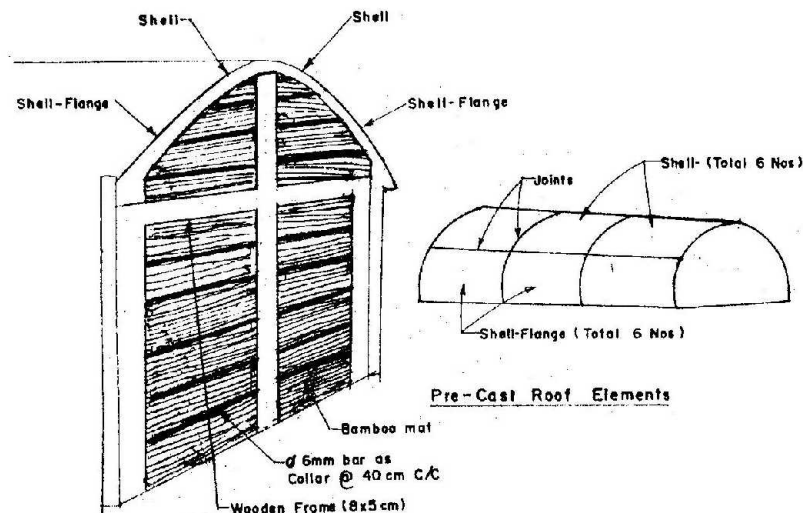


**Figure 3 : Wooden framed bamboo mat walling system and arrangement of pre-cast roof elements**

## Fence Construction

In order to construct fence, culms of thin-walled bamboo (locally called *BORA*) were seasoned under water for four weeks. These were split longitudinally and sized down to rectangular cross section of 10 x 15 mm. The steel bars φ6 mm @ 40 cm c/c were used as collar for reinforcing the bamboo mat. The bamboo-mat was fixed with preset wooden frame from the outer side. The arrangement is shown in Figure 3. The mortar (1:4) prepared with ordinary cement and sand (Fineness Modulus = 2.18) was applied to both sides of bamboo-mat and trimmed with trowel until the fence thickness finished to 5 cm. The photograph of the plastered fence is shown in Figure 4. The constructed fence was cured with water by jute bag for 28 days.
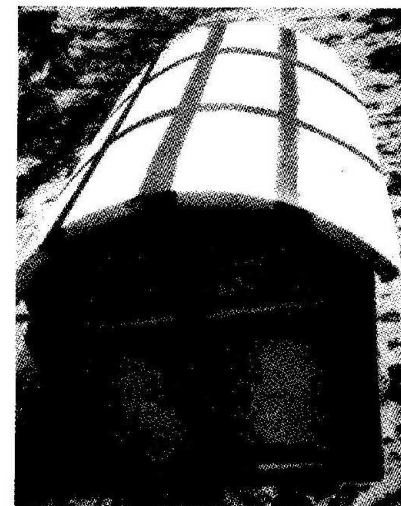


**Figure 4 : Photograph showing plastered bamboo fence and layout of roof panels joints**

## Rigidity Test of Bamboo-Fence

In order to determine the rigidity of bamboo-fence against applied load, a test specimen of fence element 90 x 35 x 5 cm were used. The test specimen was cured for 28 days. The fence element of 90 cm length weighed 340 N. The equivalent self weight of test slab was 378 N/m length. The model fence slab was tested for flexural rigidity against line load as shown in Figure 5. The load is substantially converted to wind pressure by simple mathematical calculation as follows:
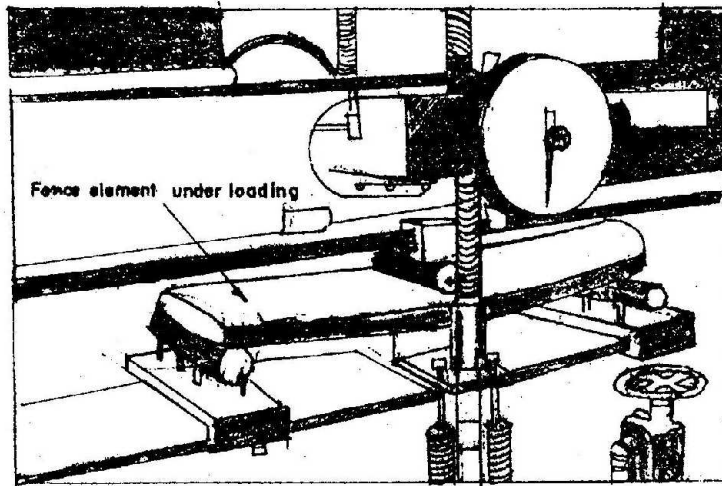
**Figure 5 : Load test arrangement for rigidity test of plastered bamboo mat fence**

If a slab of length L fails at line load P then the bending moment,

$$M_p = PL/4 \qquad (1)$$

For a simply supported beam loaded with uniformly distributed load, $w_u$, the bending moment,

$$M_w = 0.125 w_u L^2 \qquad (2)$$

Equating both the failure moment of (1) and (2), i.e., $M_w = M_p$, then,

$$w_u = 2P/L \quad \text{per unit length.}$$

The load $w_u$ combining with $w_s$ (self of the slab) acts as the load bearing capacity q per unit length of the slab as $q = w_u + w_s$. If b is the width of slab then ultimate bearing stress,

$$q_u = q/b \qquad (3)$$

The wind pressure that acts at right angles to the wind stream (for an air of density 0.0764 lb/ft³) can be found using the following equation ($W_p$ is the wind pressure in lb/ft² and V is the wind speed in miles/hour)(Barre & Sammet, 1963):

$$W_p = 0.00256 \ V^2 \qquad (4)$$

Equating $q_u = W_p$ in equating (3) and (4).

$$V = 145.32 \ q_u \qquad (5)$$

where V = wind speed, km/hr and $q_u$ = bearing stress, kN/m²

The speed obtained from equation (5) is the required wind speed at which the slab collapses. $q_u$ value at failure can be obtained from the test. For flexural test, the test slab was placed over two rollers at 82 cm apart. The line load was applied at mid span of the slab through roller. Figure 5 shows the testing arrangement. The slab was failed at 952 N line load. The photographic view of the completed built up house is shown in Figure 6.



**Figure 6 : photographic view of the completed built up house**

**Analysis and Results**

Computer program based on finite element analysis STAAD IV was run to find out design values of moment and forces developed in different sections of the shell; these values are presented in Table 1.

**Table 1 : Computer results for moment and forces developed on shell**

| φ (From shell edge) | Moment, $M_p$ (N-m/m) | Meridional Stress, Nφ (kN/m) |
|---|---|---|
| $0^0$ | $0^0$ | $0^0$ |
| $5^0$ | 2.95 | 0.56 |
| $10^0$ | 27.9 | 2.02 |
| $15^0$ | 65.6 | 3.97 |
| $20^0$ | 103.2 | 5.65 |
| $25^0$ | 132.1 | 6.79 |
| $30^0$ | 141.2 | 7.15 |
| $35^0$ | 149.9 | 8.65 |

The maximum values of moment, Mj and meridional stress, Nj were found to be 149.9 N-m/m and 8.65 kN/m respectively. The monent Mj was so less that the reinforcement requirement for this value was even less than minimum quantity provided according to ACI Code provisions (Winter et. al., 1979). The bending moment for line load P in accordance to Equation (1), $M_p = 195.16$ N-m and its corresponding uniformly distributed load, $w_u = 2322$ N/m. The self weight of the fence is 378 N/m length. Hence the total load applied on the slab, $q = w_u + w_s = 2700$ N/m. The ultimate bearing capacity of slab according to Equation (3), $q_u = 7.714$ kN/m$^2$. The wind speed equivalent to $q_u$ as calculated by Equation (5) is V = 404 km/hr. Hence to refer that a wind speed of 300 km/hr is taken as the most devastating value which corresponds to cautionary signal no. 10 of meteorological forecast. Thus the slab has safety factor $= \frac{404}{300} = 1.35$ with respect to most devastating wind speed. Although the wall slab was tested as a simply supported member but in practical situation, it is fixed at all sides by wooden frames. A part of the wind pressure is resisted by the frame, which acts as end moment bearing member reducing moment at mid-span of the slab. Thus the bamboo-wall slab can be considered safe at wind speed higher than the most devastating one. Moreover, the bonding capacity between the bamboo with cement mortar can be increased using bamboo-splits of smaller cross-sections.

## Cost of Analysis

The breakdown of the cost (as per market price, September, 2000) of the house is shown below. The unit construction cost of the house without fence is Tk. 1686/m² on 2.1 x 2.6 m plinth section. Cost of the fence is Tk. 524/m² of the fence.

### A. Cost analysis of the house (without fence) at 2.1 x 2.6 m plinth section

|  |  |  | Taka |
|---|---|---|---|
| 1. | Cement: | 6 bags @ Tk. 260/bag | 1560 |
| 2. | Sand (F.M = 2.12): | 0.65/m³ @ Tk. 240/m³ | 156 |
| 3. | Khoa (12.5 mm down graded) | 0.80 m³ @ Tk. 1100/m³ | 880 |
| 4. | Steel bar (f6 mm): | 32 kg @ Tk. 20/kg | 640 |
| 5. | Steel bar (f10 mm): | 26 kg @ Tk. 19/kg | 494 |
| 6. | Wire gauge no. 8: | 3 kg @ Tk. 35/kg | 105 |
| 7. | Wire mesh (1m width, | 2.54 cm square, gauge no. 14): 10 rm. @ Tk. 70/rm | 700 |
| 8. | Floor Brick: | 180 Nos. @ Tk. 3.20/piece | 576 |
| 9. | Plinth sand: | 1.6 m³ @ Tk. 120/m³ | 192 |
| 10. | Mason : | 6 man-day @ Tk. 200/man-day | 1200 |
| 11. | Labour : | 12 man-day @ Tk. 100/man-day | 1200 |
| 12. | White wash + labour: | Lump sum | 300 |
| 13. | Material for wooden mould and labour: | Lump sum | 600 |
| 14. | Bamboo mat door:Lump sum | | 600 |

| Total cost except fence = | Tk. 9203 |
|---|---|
| Unit cost per m² | Tk. 1686 |

### B. Cost analysis of bamhoo-mat fence with an area 2.1 x 1.5 = 3.15 m²

|  |  |  | Taka |
|---|---|---|---|
| 1. | Bamboo: | 1.75 nos. @ Tk. 80/no. | 140 |
| 2. | Cement: | 0.9 bag @ Tk. 260/bag | 234 |
| 3. | Sand (F.M=2.12): | 0.3 m³ @ Tk. 240/m³ | 72 |
| 4. | Labour (splitting & mat preparation): | 1.75 nos. @ Tk. 100 | 175 |
| 5. | Wooden frame + Carpenter: | Lump sum | 400 |
| 6. | Steel bar for collar (f 6mm): | 3.5 kg @ Tk. 20/kg | 70 |
| 7. | Mason: | 1.2 man-day @ Tk. 200/man-day | 240 |
| 8. | Labour: | 1.2 man-day @ Tk 100/man-day | 120 |
| 9. | White wash + painting + labour: | Lump sum | 200 |

| Total Cost for test fence slab: | Tk. 1651 |
|---|---|
| Unit cost per m² | Tk. 524 |

The overall projected unit construction cost of the house considering all boundary fence of 17.1 m² was found to be Tk. 3327 per m². This cost is about 60% of the rate of Public Works Department (1997) for the semi-pucca house of timber trussed tin-roofing.

# Conclusion

A model for low-cost rural hut with shell roof and bamboo-mat walling system is presented in the paper. The research study demonstrated that the use of thin shell roof render higher rigidity of the structure and requires less constructional material; thus curtails construction cost significantly and can be used as a good substitution of tin or other type of roofing usually used in rural areas. It was shown by physical model and analysis that the wooden framed cement-plastered bamboo-mat fences can be used as a substitution of tin, brick or wood fence in the cyclone-prone areas where wind of high velocity is the principal devastating agent. Laboratory test showed that the model's bamboo-plastered walling system can withstand wind velocity up to 404 km/hour which is far beyond the speed usually referred during cautionary signal no. 10 of weather forecast (corresponding wind speed of 300 km/hr); thus rendering factor of safety $= 1.35$ with respect to cautionary signal 10. Economic feasibility analysis revealed that the construction cost of the house was in the order of Tk. $3327/m^2$ which is about 60% of the rate of PWD of semi-pucca of timber-trussed tin roofing. The paper describes the simple techniques adopted for material preparation, pre-casting of roof elements, bamboo-mat fabrication, cement plastering etc., which can be easily disseminated among rural people. Thus the technique and the methodology of construction of such rural hut is quite feasible in rural Bangladesh and can be a solution to non-engineered unstable and vulnerable houses in the rural and calamity-prone areas of Bangladesh.

# References

Abedin, M.Z. and Rashid, M.A. (1992). Design, construction and stability study of concrete shell roof, Bangladesh Journal of Agril. Sciences, 19(2):323-328.

Billngton, D.P. (1965). 'Thin shell concrete structure' McGrow Hill, New York IT publications Ltd., London, UK, 13 (4): 5-7.

Barre, H.J. and. Sammet, L.L. (1963). 'Farm Structure', John Willy and Sons, New York.

Geymayer, H.G. and Cox, F.B. (1970). 'Bamboo reinforced concrete', ACI J. Title no. 67-51: 841-846.

IFIC (1978). 'International Ferrocement Information Centre', Ferrocement Booklet No. 2, Asian Institute of Technology, Thailand.

Janssen, J.J., (1987). 'Using bamboo as a reinforcement', Appropriate Technology, IT publications Ltd., London, UK, 14(2); 12-13.

Mattone, R. (1990). 'Ferrocement prefabrication-self-help for low-cost housing', Journal of Ferrocement, 20(2): 143-148.

Public Works Department (1997). 'PWD Schedule of Rates' Public Works Department, Bangladesh.

Winter, G., Urquahart, L.C.O., Rourke, C.H., and Nilson, A.H., (1979). 'Design of Concrete Structure', Tata McGrow Hill Publishing Company Ltd., New Delhi.