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ORIGINAL CONTRIBUTION

A Study of Affordable Roofing System Using Ferrocement And Bamboo Cement Panels

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Abstract Structural roofing system contributes substantially to the cost of construction of housing unit in normal situation. In the study undertaken, an attempt is made to reduce the cost of construction by developing an Affordable Roofing System (ARS) consisting of a grid containing primary beams and secondary beams of triangular shape supporting Ferrocement precast infill panels and Bamboo-cement precast infill panels. Precast rectangular infill panels have a shorter dimension of 0.5 m with an aspect ratio of 1.0, 1.5 and 2.1.Panels are designed using cement mortar of compressive strength 7. 5 N/mm^2, wiremesh of yield strength 250 N/mm^2 and bamboo of yield strength 179 N/mm^2.Construction and Demolition waste is used as partial replacement for sand. Expanded Polypropylene Fibres are used for arresting cracks and improving ductility. Primary as well as secondary beams are designed using M20 grade concrete and Fe415 steel. Reliability analysis for the proposed Affordable Roofing System (ARS) and conventional Reinforced Cement Concrete (RCC) roof is performed and compared. The level of structural safety is found to be same for the both roofing systems. Cost analysis is done for the proposed ARS and compared with conventional RCC roof slab. It is found that the proposed Affordable Roofing System is 36.78% economical than conventional reinforced cement concrete roofing system. Further, it is also found that Affordable Roofing System (ARS) made of Bamboo-cement precast infill panels are comparatively more economical than that of Ferrocement precast infill panels.

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Keywords Affordable roofing system · Ferrocement · Bamboo-cement · Construction · And demolition waste · Expanded polypropylene fibres

Abbreviations

ARS	Affordable Roofing System
C&D	Construction and Demolition waste
EPF	Expanded Polypropylene Fibres
RCC	Reinforced Cement Concrete
EWS	Economically Weaker Section

Introduction

Considering the importance of housing in the country as a basic human need, it has been one of the priorites of the Government of India right from the First Five Year plan till date. Due to the rapid growth of the industrial towns, migration of people into the urban areas has increased leading to the necessity of housing to this urban population. 20 million of housing units need to be constructed across the country by 2022 as a part of national mission housing project "Housing for All", where majority is of low-income urban populations. According to this, 95% of housing units are to be provided for the Economically Weaker Section (EWS) of the urban population [1]. In India, households have been categorised into 4 groups based on the annual income ranging from Economically Weaker

Section (EWS) to High Income Group (HIG) including Low Income Group (LIG) and Middle Income Group (MIG) in between. Based on the Government of India (GoI) scheme, the annual income of house-hold and area required for the house are less than INR 3 Lakh per annum (Lpa) and 30 m^2 for EWS, INR 3–6 Lpa and 60 m^2 for LIG and INR ₹6–18 Lpa and upto 150m^2 for MIG [2]. The dream of owning a house particularly for low-income and middle-income families is becoming a difficult reality. Hence, it has become a necessity to adopt cost effective, innovative and environment-friendly housing technologies for the construction of houses and buildings for enabling the common people to construct houses at affordable cost [3].

Roof is defined as the uppermost part of a building envelops which provides protection from the weather conditions in addition to its structural function [4]. The Reinforced cement concrete roofing system substantially contributes to the cost of construction of housing unit. The reduction in the cost of roofing system is considered as a viable option for mass housing system.

Research Significance

The present study aims in developing a cost effective alternative roofing technology by providing a grid work of primary beams and secondary beams of triangular shape on which precast infill rectangular panels rests. Two rectangular panels of size (0.65 m × 0.65 m)and (0.65 m × 1.25 m) made up of Ferrocement precast infill panels and Bamboo-cement precast infill panels were cast. Both the panels have a thickness of 40 mm. The panel size is inclusive of 75 mm bearing on all sides. The Infill panels were analysed and designed as per ultimate load method. The panels were experimentally tested for flexural strength. The percentage cost reduction of both the panels with respect to conventional RCC slab is computed in order to ascertain their affordability.

Literature Review

The performance of the Ferro cement panels was capable of taking loads efficiently under serviceability conditions as been reported in the literature. However, very limited studies have been carried out with respect to bamboo as a reinforcement in the panels of the roofing system. Tam [3], investigated the low cost construction methods for foundation, walling, roofing and lintel. The properties such as strength and durability of the structure, stability, safety and mental satisfaction are factors that assume top priority during cost reduction. He found that, about 26.11% and 22.68% of the construction cost can be saved by using low cost housing technologies as compared with the traditional construction methods with respect to the walling and roofing, respectively [3]. Clarke [5] presented the structural testing results of full scale ferrocement roof system. This comprises of a 9. 0 m wide and 2.5 m high pitched-portal frame of channel-section with bolted steel connections;a 6.10 m hollow-section roof slab in bending and slab-to-frame bolted connections in pullout. He found that the performance of the elements is consistent with the behaviour of the Ferrocement as stated in the literature [5]. Sakthivel and Jagannathan [6]) studied the experimental behaviour of Ferro cement slab with PVC coated weld mesh in comparison with GI coated weld mesh with 1, 2 and 3 layers of mesh. The slabs with PVC coated weld mesh indicate 25% more ductility when compared with GI coated mesh and flexural strength 90% of the GI coated weld mesh [6]. Jeeva Chithambaram and Kumar [7], reported that the ultimate load capacity was three times higher when compared to conventional slabs in their study on the flexural behaviour of bamboo based Ferro cement panels. Terai and Minami [8], concluded that the behaviour of the pullout test with bamboo is almost the same as the plain steel bar but the bond strength with bamboo was higher as compared to that of plain bar. Deshpande and Shirsath [9], reported that flexural strength was 2.5 times higher in double layer bamboo mesh compared to a single layer and 47% higher than single layer conventional wire mesh in a comparative study between bamboo reinforced and conventional Ferrocement panels. Perera and Lewangamage et. al [10] reported that for slabs with bamboo reinforcement only, the load at first crack and maximum load carrying capacity are smaller but higher flexural strength and ductility are observed. When both steel and bamboo reinforcement were used together, the load at first crack and maximum load carrying capacity are found to be higher when compared to the slabs with only steel reinforcement in their experimental investigation on the flexural behaviour of bamboo reinforced concrete slab panels [10]. Ismail et. al [11] in their study concluded that as the percentage of bamboo reinforcement increases the load carrying capacity of slabs increases but the deflection also increases. The literature review suggests the potential of Ferro cement and Bamboo-cement panels being used as slabs [11]. Kathiravan et al. [12] carried out a parametric study on utilization of bamboo in reinforced concrete considering its strength and durability by referring laboratory findings from the available literature. They concluded that bamboo can be used as an alternative for steel by improving its properties through mechanical and chemical treatments [12]. bala et al. [13] studied the energy absorption capacity of bamcrete wall panels made up of bamboo and compared with RCC panel under bullet impact

Fig. 1 Welded mesh reinforcement as well as ferrocement slab

Fig. 2 Bamboo reinforcement as well as casted slab

Table 1 Preliminary test results

Tests	IS code	Parameter	Values
Sieve analysis of M-sand	IS 2386 part 2(1963)	Fineness modulus	2.95
Sieve analysis of C & D waste			2.76
Sieve analysis of M -sand and C & D waste			2.95
Normal consistency of cement	IS 4031 part 4(1988)	Optimum percentage	30%
Marsh cone test	–	Optimum dosage	0.7%
Flow test of cement mortar	IS 4031 part 7(1988)	Flow percentage	61.25%
Flow test of cement mortar with M-sand and C&D waste			98. 75%
Flow test of cement mortar with M-sand, C&D waste and EP fibres			91.25%
Compressive strength of cement mortar[MM 7. 5(1:3 = Cement: sand) without C&D waste and EP fibres]	IS 2250 (1981)	28 days strength	37 N/mm^2 (average of three samples)
Compressive strength of cement mortar [MM 7. 5(1:3 = Cement: sand) with C&D waste and without EP fibres]			42 N/mm^2 (average of three samples)
Compressive strength of cement mortar [MM 7. 5(1:3 = Cement: sand) with C&D waste and EP fibres]			28 N/mm^2 (average of three samples)
Tensile test on bamboo	IS 6874 (1973)	Yield strength	179 N/mm^2

Table 2 Area of longitudinal and transverse reinforcement provided for triangular primary and secondary beams

Sl. No	Dimension, m (base × depth) (Beam type)	Span, m	Moment, kN-m	Longitudinal reinforcement provided, mm^2	Transverse reinforcement, mm^2	Spacing, mm	Suitable for ARS of size in plan (m)
1	0.15 × 0.22 (Primary)	2.6	2.94	101	101 (2 bars of 8 mm)	150	2.75 × 2.75
							2.75 × 3.75
							2.75 × 5.15
2	0.075 × 0.075 (Secondary)	0.65	0.054	101	101 (2 bars of 8 mm)	225	2.75 × 2.75
3	0.075 × 0.075 (secondary)	0.9	0.123	101	101 (2 bars of 8 mm)	225	2.75 × 3.75
4	0.075 × 100 (secondary)	1.25	0.26	101	101 (2 bars of 8 mm)	300	2.75 × 5.15

Fig. 3 Test set-up of one way slab

Fig. 4 Test set-up of two way slab

load. Three different types of panels i. e. single, twin mesh Bamcrete and RCC panel were constructed. Two types of bullet SLR 7. 62 mm and INSAS 5.56 mm were used in this study. They concluded that the twin mesh Bamcrete panel absorb higher energy as compared to RCC panel [13]. Sangma et al. [14] investigated the flexural strength of cob wallettes strengthened with bamboo and steel mesh reinforcement under lateral load. They concluded that bamboo-fibre and steel-fibre reinforcement enhances the ductility property of wallettes, while bamboo and steel reinforced cement stabilised wallettes possess the maximum flexural strength [14]. Sun et al. [15], studied the influence of technological parameters such as strand thickness, strand length and resin content, on the performance of bamboo strand-based structural composite lumber (BSCL) under the mutual function of board density. The results showed that board density and resin content have a significant effect on the water resistance properties of BSCL. In addition, strand length had notable influence on modulus of rupture and shear strength of board with a density of 0.9 g/cm^3.But mechanical properties did not significantly vary with strand thickness and resin content. The mechanical properties of BSCL could be comparable or surpass that of wood or bamboo products [15].

Materials and Methods

The Ferrocement precast infill panels and Bamboo-cement precast infill panels of three different sizes-(0.5 m × 0.5 m), (0.5 m × 0.75 m), (0.5 m × 1.1 m) with aspect ratio 1.0, 1.5 and 2.1, respectively, were adopted for the study. The grid work consists of four bays each in both directions. The outer to outer dimensions of the proposed roofing system works out to be (2.75 m × 2.75 m), (2.75 m × 3.75 m) and (2.75 m × 5.15 m) in plan. The panels of

a Ferrocement slab without C&D waste and EP fibres **b** Ferrocement slab with C&D waste and without EP fibres **c** Ferrocement slab with C&D waste and EP fibres

Fig. 5 Failure pattern of one way Ferrocement slab

a Ferrocement slab without C&D waste and EP fibres **b** Ferrocemnt slab with C&D waste and without EP fibres **c** Ferrocement slab with C&D waste and EP fibres

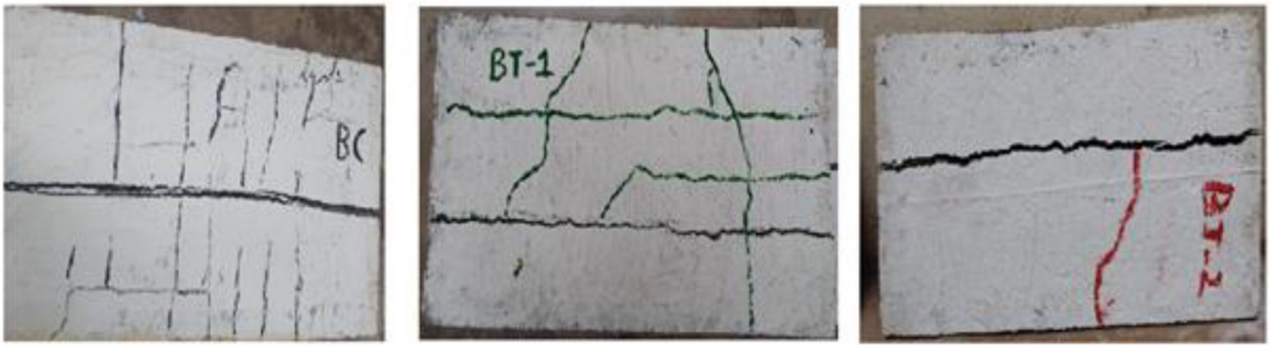
Fig. 6 Failure pattern of two way ferrocement slab

dimensions (0.65mX0.65 m) and (0.65 m × 1.25 m) corresponding to panels of sizes (0.5 m × 0.5 m) and (0.5 m × 1.1 m) were experimentally tested to study one way and two-way behaviour, respectively. The panels are also compared with control panels having neither C&D waste nor Expanded polypropeleyene fibres. Six one way panels and six two way panels were cast. Among six panels, three are of Bamboo-cement precast infill panels, and other three are of Ferrocement precast infill panels. The reinforcement details along with slab cast are depicted in Figs. 1 and 2, respectively.

Among the three Bamboo-cement and three ferro cement panels, one is control panel with no C&D waste,second panel is with C&D waste only, and third panel is composed of C&D waste and EP fibres. Bamboo is coated with bitumen, and M-sand is sprinkled on it to avoid absorption of water and to improve the bonding. Preliminary tests were conducted on materials as per corresponding Indian standard, and the tests results are tabulated in Table 1. The EP fibres were procured from the local vendor, having tensile strength of 4–6 Gpd (as per the manufacturer).

Cement mortar Mix (1:3 = Cement: sand) with water cement ratio of 0.45 (IS 13356:1992) is prepared using C&D waste replacing 20% M-sand. EP fibres are added 1% by volume of cement to arrest cracks and improveductility. In order to improve the wokability of concrete mixes,-plastcizers of 0.7% by weight of cement is used. Correspondingly 10% of reduction in water content is achieved.

Analysis and design of primary and secondary triangular beams are made. Components of proposed ARS like precast panels and triangular beams are analysed for structural reliability. Cost analysis of proposed ARS and conventional RCC slabs are made and then compared.



a Bamboo Cement slab without C&D waste and EP fibres **b** Bamboo Cement slab with C&D waste and without EP fibres **c** Bamboo Cement slab with C&D waste and EP fibres

Fig. 7 Failure pattern of one way bamboo cement slab

a Bamboo Cement slab with C&D waste and without EP fibres **b** Bamboo cement slab with C&D waste and EP fibres

Fig. 8 Failure pattern of two way bamboo cement slab

Design of Precast Panels

Analysis and design of precast panels as well as triangular beams are made. Analysis of precast infill one way and two panels are made in accordance with IS codes. Loads acting on precast panels are in accordance with IS 875:1987(Par-1&2). Loads considered on the slabs are as follows:

a. Mortar density = 21kN/m^3(IS 875:1987, Part 1)
b. Water Proofing Course(WPC) density = 20.4 kN/m^3(IS 875:1987, Part 1)
c. Live load = 1.5kN/m^2 IS 875:1987, Part 2)
d. Self-Weight of slab = 0.04 $\times$ 21 = 0.84 kN/m^2
e. Dead load of WPC = 0.015 $\times$ 20.4 = 0.306 kN/m^2.
f. Total factored load = 4 kN/m^2

Ultimate moment carrying capacity is determined by the equation. This equation is adopted from ultimate load method of design.

$$M_U = f_y \times A_R \times d\left(1 - \frac{0.75 \times f_y \times A_R}{f_{cu} \times b \times d}\right)$$

where f_y = Yield strength of reinforcement, A_R = Area of reinforcement, d = Effective depth of bamboo, f_{cu} = Compressive strength of mortar, b = Breadth of panel.

As per the design of the bamboo-cement panels, bamboo bars of cross-Sect. 4 mm $\times$ 4 mm are provided at 100 mm c/c spacing. Ferro cement panels consist of weld mesh of 3 mm diameter with spacing of 50 mm as reinforcement.

Triangular main beams and secondary beams are of conventional RCC designed using limit state method which supports precast Ferro cement and Bamboo cement panels. The characteristic concrete strength of 20 N/mm^{2}and characteristic yield strength of reinforcement of 415 N/mm^{2}are considered in design.

The designed reinforcements provided for beams are shown in Table 2.

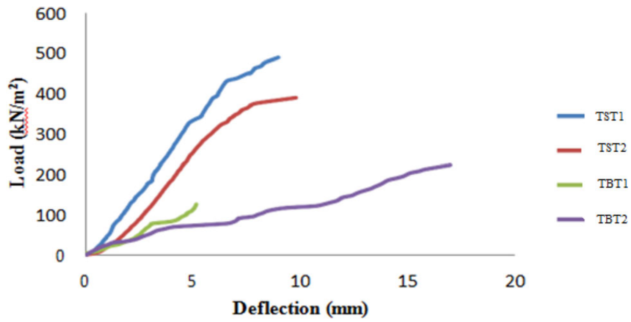


Fig. 9 Comparison of load–deflection of two way bamboo-cement and Ferrocement test panels

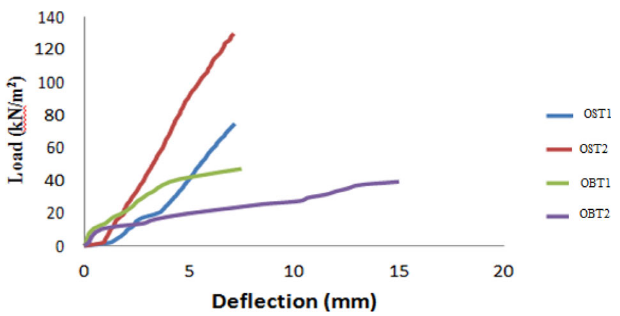


Fig. 10 Comparison of load–deflection of one way bamboo-cement and ferro cement test panels

Results and Discussions

Experimental Results

All the panels were tested in mini test floor having a load capacity of 2000 kN by applying uniformly distributed load, and corresponding deflections were measured. The test setup for one way panel and two way panel is shown in Figs. 3 and 4, respectively.

It is observed that all the slabs failed predominantly by flexure first and then by shear with development of cracks in the centre and the edges of the slabs. Also, no bond slip is observed due to the use of bitumen coated bamboo strips covered with M-sand. The failure pattern of the one way and two way ferrocement slabs are depicted in Figs. 5 and 6, respectively. Figures 7 and 8 represent the failure pattern of the one way and two way bamboo cement slabs.

The variation of load and deflections of the panels is shown in Figs. 9 and 10. Comparison of load–deflection of bamboo-cement and Ferro cement test panels is shown in Figs. 1 and 2, respectively. TST and TBT indicate two way Ferro cement test panel and two way bamboo-cement test panel, respectively. OST and OBT represents one way Ferro cement test panel and one way bamboo-cement test panel, respectively.

The experimental results indicate that the load carrying capacity and flexural strength of Ferro cement panels are greater than that of Bamboo-cement panels. Also, Bamboo-cement panels are able to carry service or working loads satisfactorily without undergoing flexural failure or shear failure.

The theoretical load carrying capability of the panels is obtained from the moment of resistance of the respective panels by adopting ultimate load method. These values are compared with the experimental results as outlined in Table 3. Figures 11, 12, 13, 14 also, represent these comparision graphically.

Ductility index is the ratio of deflection at ultimate load to the deflection at first crack load is evaluated and shown in Table 4. The Ductility Index is found to increase for panels containing EP fibres in both one way and two-way panels. Due to the incorporation of fibres into the cement mortar, the ductility of the panels is increased, and cracks are arrested efficiently. Hence these types of panels can be used for roofing in earthquake prone areas.

It is observed that the experimental load carried by the Ferro cement panels is higher than the theoretically

Table 3 Theoretical load and Experimental loads

Slab type		Theoretical load (kN/m^2)	Experimental Load (kN/m^2)
One-way slabs	Bamboo control	49. 487	64.8
	Bamboo test – 1		47. 127
	Bamboo test – 2		39. 273
	Steel control	60.570	204.218
	Steel test – 1		74.618
	Steel test – 2		129. 6
Two-way slabs	Bamboo control	221.121	112.32
	Bamboo test – 1		123.552
	Bamboo test – 2		220.32
	Steel control	309. 704	384.48
	Steel test – 1		488. 16
	Steel test – 2		388. 8

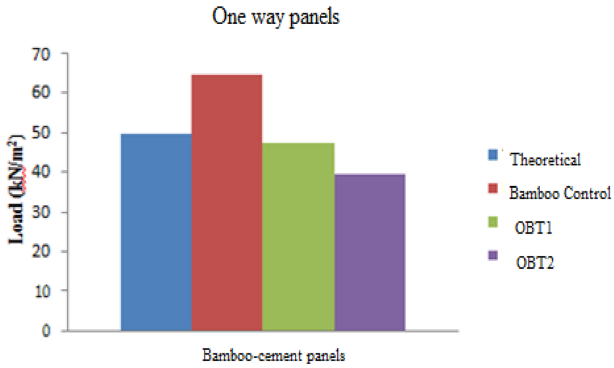


Fig. 11 Comparison of loads of one-way bamboo-cement

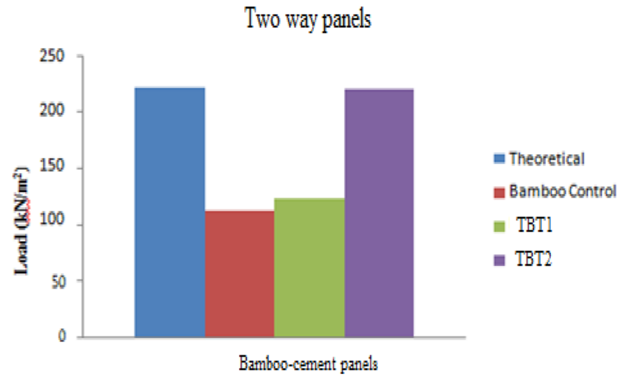


Fig. 13 Comparison of loads of two-way bamboo-cement

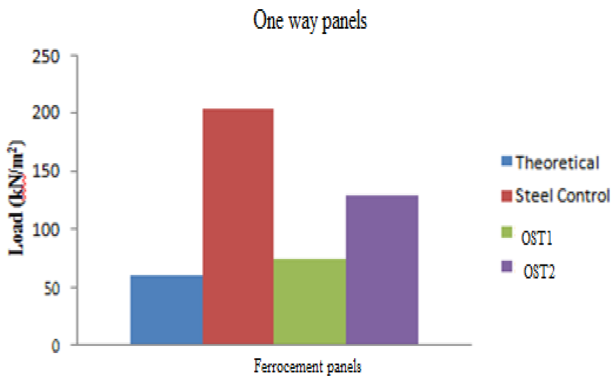


Fig. 12 Comparison of loads of one-way ferro cement panels

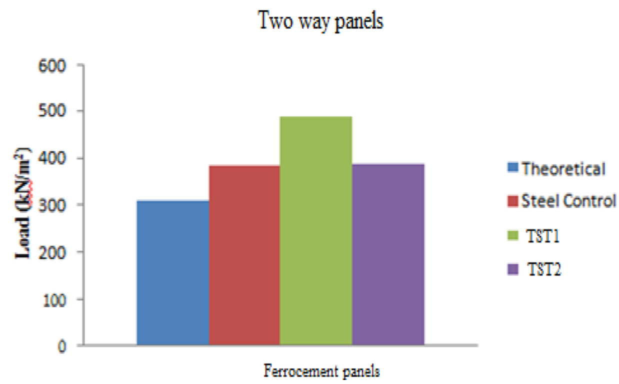


Fig. 14 Comparison of loads of two-way ferrocement panels

calculated loads. The experimental load carrying capacity of Bamboo-cement panels is comparable with theoretical load.

Reliability Analysis

The load carrying capacity(R) of a structure should be greater than load acting on it(S) to ensure structural safety. In overcoming the uncertainties in the design parameters and to ensure the safety of the structure, the smallest value of the strength (R) and the largest value of the load(S) are taken.

Reliability or Risk assessment can be defined as a procedure to incorporate the uncertainties in the parameters in order to ensure the safety of the structure. The performance equation used in the reliability analysisis,

$$M = R - S$$

where M = margin of safety, R = Resistance or Load carrying capacity, S = load effect on structures.

Monte Carlo simulation method is adopted to evaluate the Structural reliability for both proposed affordable roofing system and convention RCC roofing system by determining the Reliability index (β) which in turn helps in evaluating the probability of success and failure.

Margin of safety for one-way precast panels,$M = f_y \times A_{st} \times d\left(1 - \frac{0.75 \times f_y \times A_{st}}{f_{cu} \times b \times d}\right) - W_u L^2/8$.

Margin of safety for Two-way precast panels, $M = f_y \times A_{st} \times d\left(1 - \frac{0.75 \times f_y \times A_{st}}{f_{cu} \times b \times d}\right) - \alpha_x W_u L_x^2$.

Margin of safety for triangular beams,

$$M = \left[f_y \times A_{st} \times \left(d - 4.516\sqrt{\frac{f_y \times A_{st} \times d}{f_{ck} \times b}}\right)\right] - \left[0.5PL + 0.125WL^2\right]$$

Where fcuis mean compressive strength, b is mean breadth, d is mean depth, Wu is mean load, L is mean span, f_y is mean yield strength of reinforcement, A_{st} mean area of reinforcement, αxis short span coefficient mentioned in IS 456.Considering the system component in series then the probability of survival of system is detemined using Eq. (1). The results are given in Table 5. It is found that the level of safety is same for both Affordable roofing system (ARS) and conventional RCC roofing system. Hence the structural safety is same in both the cases.

Table 4 Ductility index

Type of slabs		Deflection at first crack (mm)	Deflection at ultimate load (mm)	Ductility Index	% Increase in ductility index w. r. t control slabs
One way panels	Bamboo control	1.98	7.00	3.535	0
	Bamboo test – 1	1.20	7.50	6.250	76.80
	Bamboo test – 2	1.40	15	10.714	203.08
	Steel control	3.74	11.10	2.968	0
	Steel test – 1	1.95	7.18	3.682	24.06
	Steel test – 2	1.45	7.13	4.917	65.67
Two-Way panels	Bamboo control	2.39	4.70	1.967	0
	Bamboo test – 1	2.78	5.45	1.96	0
	Bamboo test – 2	4.07	17	4.177	112.36
	Steel control	4.21	4.75	1.128	0
	Steel test – 1	2.65	8. 98	3.389	200.45
	Steel test – 2	2.38	9. 80	4.118	265.08

Table 5 Reliability analysis for affordable roofing system and conventional reinforced cement concrete slabs

Sl No	Panel	Slab size, m	ARS Probability of survival of system (Pss)	Conventional RCC slab Probability of survival of system (Pss)
1	Bamboo	0.65 × 0.65	0.999,963,664	0.999,948,608
2	Bamboo	0.65 × 0.9	0.999,963,664	0.999,948,649
3	Bamboo	0.65 × 1.25	0.999,963,664	0.999,948,656
4	Weldmesh	0.65 × 0.65	0.999,963,664	0.999,948,608
5	Weldmesh	0.65 × 0.9	0.999,963,664	0.999,948,649
6	Weldmesh	0.65 × 1.25	0.999,963,664	0.999,948,656

Table 6 Cost comparison between ARS and Conventional RCC slab

Sl. No	Panel	Size of roofing in plan,m	Total Cost/m^2			% cost saving w. r. t RCC slab
			ARS (in Rupees)	RCC slab (in Rupees)	Cost ratio	
1	Bamboo	2.75 × 2.75	1048.6	1649. 3	0.64	36.4
2	Bamboo	2.75 × 3.75	984.42	1637.5	0.60	39.9
3	Bamboo	2.75 × 5.15	912.78	1630	0.56	44.0
4	Weld mesh	2.75 × 2.75	1152.5	1649.3	0.69	30.12
5	Weld mesh	2.75 × 3.75	1087.7	1637.5	0.66	33.57
6	Weld mesh	2.75 × 5.15	1031.8	1630	0.63	36.7
Average						36.78

$$\mathrm{P_{ss}} = \prod_{i=1}^{n} 1 - p(fi). \quad (1)$$

where P_{ss} = probability of success. $p(f_i)$ = Probability of failure. Π = Product symbol.

Cost Analysis

The cost estimates of the proposed affordable roofing system (including cost of primarybeams, secondary beams and infill precast panels) and conventional roofing system (including cost of concrete, shuttering, water proofing coat and reinforcement) is carriedout and expressed in total cost per m^2. This cost analysis is as per schedule of rates, Public Works Department, Karnataka, 2018–2019. The results are given in Table 6. The proposed Affordable roofing system is found to be 36.78% more economical than conventional RCC roofing system. Weight of precast panels is less than 80 kg and can be lifted by two or three masons. Hence the cost of the labour also reduces.

Conclusions

1. Compared to conventional reinforced cement concrete slab system of same size in plan, the proposed affordable roofing system resulted in 36.78% of cost reduction.
2. The Precast panels being comparatively lighter can be lifted easily by not more than 3 masons, thus reducing the labour cost and erection time.
3. The level of structural safety is same for both proposed affordable roofing system and conventional Reinforced cement concrete roofing system.

Declarations

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

References

1. A. Bras, C. Ravijanya, V. de Sande, M. Riley, R.V. Ralegaonkar, Sustainable and affordable prefab housing systems with minimal whole life energy use. J. Build. Eng. **19**, 134–141 (2018)
2. Ministry of Housing and Urban Poverty Alleviation Government of India, Pradhan mantriawasyojana - housing for all (urban) - credit linked subsidy scheme, 2017, 1–62 (2017). http://mhupa.gov.in/pmay/repository/01_MAY_Guidelines_English.pdf
3. V.W.Y. Tam, Cost effectiveness of using low cost housingtechnologies in construction. Proc. Eng. **14**, 156–160 (2011)
4. I.K.B. Najima, O.T. Fadhil, Assessing and improving the thermal performance of reinforcedconcrete-based roofing systems in Iraq. Energy Build. **89**, 213–221 (2015)
5. R.P. Clarke, Study of full-scale elements of a ferrocement roof system for Caribbean application. Constr. Build. Mater. **24**, 221–229 (2010)
6. P.B. Sakthivel, A. Jagannathan, Study on flexural behavior of ferrocement slabs reinforced with PVC-coated weld mesh. Int. J. Eng. Res. Dev. **1**(12), 50–57 (2012)
7. J. Chithambaram, S. Kumar, Flexural behavior of bamboo based ferrocement slab panels with flyash. Construct. Build. Mater. **134**, 641–648 (2017)
8. M. Terai, K. Minami, Research and development on bamboo reinforced concrete structure. In 15th World Conference on Earthquake Engineering (2012)
9. N. Deshpande, M. Shirsath, Comparative study between bamboo reinforced and conventional ferrocement panels. Int. J. Res. Publ. Eng. Technol. **2**(7), 2454–7875 (2016)
10. P. Jude, L. Chamindalal, Experimental investigation on flexural behaviour of bamboo reinforced concrete slab panels. IESL Anual Trans. pp. 125–131 (2015)
11. R. Ismail, Y. C. Bon, N. A. Joolkeepri, I. S. Ishak, Strength Behavior of Bamboo-Reinforced Concrete Slabs. In International Conference on Concrete Engineering and Technology, (2018)
12. N. S. Kathiravan, R. M. Kumar, P. Jaya Kumar, J. Kumaraguru, V. Jayanthi, State of art of review on bamboo reinforced concrete, Mater. Today Proc. (2020)
13. A. Bala, S. Gupta, K.P. Paradeshi, A.K. Dash, Behavior of bamboo wall panel under bullet impact load. Mater. Today Proc. **32**(4), 904–909 (2020). https://doi.org/10.1016/j.matpr.2020.04.673
14. S. Sangma, D.D. Tripura, Flexural strength of cob wallettes reinforced with bamboo and steel mesh. Construct. Build. Mater. **272**, 121662 (2021). https://doi.org/10.1016/j.conbuildmat.2020.121662
15. Y. Sun, W. Yu, X. Wei, L. Ge, Z. Guo, Y. Zhang, Bamboo strand-based structural composite lumber: Influence of technological parameters on physico-mechanical properties". Construct. Build. Mater. **271**, 121795 (2021). https://doi.org/10.1016/j.conbuildmat.2020.121795