Structural Investigations on Cost Effective Roofing Technology

B.Saikumar[1] N.G.Bhagavan[2] Guru Jawahar[3]
[1]P.G.Student [2]Senior Principal Scientist [3]Professor
[1,2,3]Department of Civil Engineering
[1,3]Annamachrya Institute of Science and Technology, Tirupati. Andhra Pradesh, India [2]CSIR - Structural Engineering Research Centre(CSIR-SERC), Chennai

Abstract— Development of cost effective roofing system built with precast ferrocement elements is discussed. This roofing technology is exclusively designed for innovative / affordable / rapid-built / disaster-resistant SERCular Housing Technology developed by CSIR-SERC. This type of rural house is built of a 2-roomed unit, proposed for Pradhan Mantri Awas Yojana – Garmin (PMAY-G), consisting of each room as a standard 4-meter diameter circular module. For this type of housing, the proposed roofing system is designed to cover over the 4-m. diameter (spanning across the circular walls), with the precast rectangular ferrocement joists reinforced by chicken-wire mesh plus welded mesh and 8-mm rods. The ferrocement planks are used for lateral spanning on the two parallel joists placed at 0.4m spacing. Each of the precast ferrocement elements are designed to weigh less than 200kg, for the ease of manual handling, with-out the necessity of machines / cranes. In-situ screed concrete of 40mm thickness was laid on this roofing system made of precast ferrocement joists and planks, to enable them to act monolithically and for structurally connecting different precast elements. The full-scale / prototype roofing system for 4-m. span with overhang of 0.3m on either end for a total length of 4.6m and 0.8m width, is constructed for load testing. The structural investigations are carried-out on this roofing system by flexure testing, with gradually increasing UDL in the structural testing laboratory of CSIR-SERC. The test procedure is illustrated. Test results are tabulated and the conclusions are drawn. The advantages of this type of precast ferrocement roofing system are described.

Key words: Ferrocement roofing elements; Flexure test; Precast ferrocement joists; Ferrocement planks; Screed; concrete

I. INTRODUCTION

Pradhan Mantri Awas Yojana - Gramin (PMAY-G) is the housing scheme launched by the Government of India, towards the objective of providing affordable housing to rural poor masses. As per PMAY-G minimum plinth area of a rural house should be 25-sq.m. Under the PMAY-G, the monetary assistance offered from government is Rs.1.20 lakhs. The government of India has set the target of building one-crore rural houses within a period of 3-years. Towards the requirements and specifications of PMAY-G, the CSIR-SERC has developed an innovative technology to be adopted in building rural dwelling units with rapid / fast and economical construction technology. This is called as "SERCular Housing Technology". This two roomed house design consists of standard 4-meter diameter circular shaped rooms, built with innovative interlocking earth blocks for walling. These blocks have a special interlocking tongue and groove mechanism. These earth blocks are made of soil-cement mixture. The blocks are curved in shape to the radius of 2 meters. SERCular technology has got fast construction advantages because of its special interlocking mechanism. By mere assemblage, these blocks form a circular shape by itself, maintaining verticality and no skilled labour is needed for masonry works.

Fig. 1: SERCular housing developed for PMAY-G

The circular geometry has got inherent economic and structural advantages. This is because circle needs minimum circumference to cover the given plinth area, when compared to any other shape. It means the circular housing requires minimum walling for given plinth area and hence these houses are economical and affordable. Circular shape of the house being a better aero-dynamic shape, SERCular houses are naturally cyclone resistant. As the circular walling do not contain any seismically failing corners (unlike rectangle wall corners), they are earthquake resistant too.

In all the precast components and in the experimental constructions, the Portland Pozzolona Cement (PPC) is utilized. PPC is a kind of blended cement which is produced by inter-grinding of OPC clinker along with gypsum and pozzolonic materials in certain proportions. PPC may also be produced by grinding the OPC clinker, gypsum and pozzolonic materials separately, and mixed thoroughly. Pozzolona is a natural or artificial material containing silica in a reactive form. It may be further discussed as siliceous or siliceous and aluminous material which in itself possesses little, or no cementitious properties but will be in very finely divided form. In the presence of moisture, the pozzolona will chemically react with calcium hydroxide at ordinary temperature to form compounds possessing cementitious properties. It is essential that pozzolana be in a finely divided state as it is only then that silica can combine with calcium hydroxide in the presence of water to form stable calcium silicate which have cementitious properties. The cement used in this experimental investigation is PPC conforming to IS 1489 (part-1) 1991. Portland pozzolona cement of grade 43 from Ultra tech company is used in the study. Table-1 gives the properties of cement used.

s.no	Physical properties of cement	Results
1.	Specific gravity	2.75
2.	Fineness	6.96%
3.	Standard consistency	33.33%
4.	Initial setting time	42 min
5.	Final setting time	343 min

Table 1: physical properties of cement

II. PRECAST FERROCEMENT RECTANGULAR JOISTS

This roofing system consists of longitudinal precast ferrocement joists spanning across the supports / walls, over which precast ferrocement planks are laterally supported and the in-situ screed concrete is placed over the planks. The ferrocement rectangular joists are supported over walls for a span of 4m, with overhang of 0.3m on both ends. These joists are kept parallel at the spacing of 0.4m and the precast ferrocement panels of size 0.8m X 0.6m are laterally placed over the joists. The span of panels between two joists is 0.4m with overhang of 0.2m on either ends, and the width of panel is 0.6m in the direction of joists. Over this combination of longitudinal joists and lateral panels, the in-situ screed concrete for 40mm thickness is placed to enable it to act monolithically.

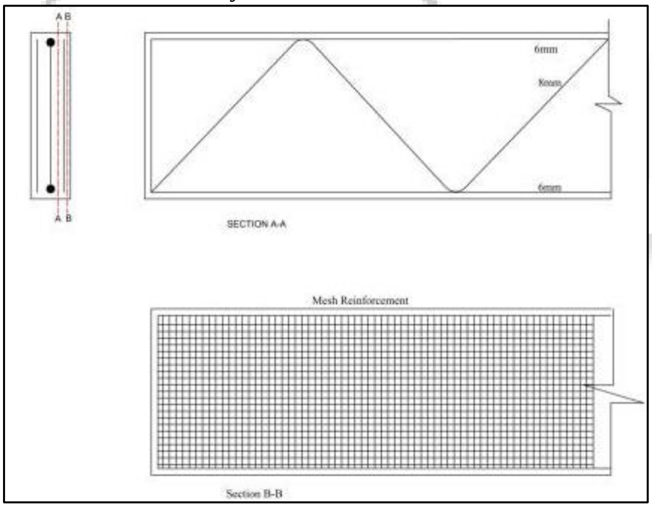

Fig. 2: Reinforcement details of rectangular joists

The size of rectangular joist is 60mm x 250mm and its length is 4.6m. it is continuously supported at effective span of 3850mm. The joist consists two sets of mesh reinforcement and normal steel bar reinforcement. 6-mm diameter steel bars spans at the top and bottom of the beam throughout the length of 4.6m. Zig-zag shear reinforcement is also provided through the length of 4.6m as shown in figure-3.

Fig. 3: shear reinforcement of rectangular joist

Sandwiched mesh reinforcement consisting of one layer of 10-gauge welded mesh with the spacing of 25mm X 25mm wrapped by chicken mesh of 30-gauge, on both sides is provided for the total area of the joist of 4.6m. X 0.25m. Rich cement mortar of ratio 1:3 is used for casting the joist. The joists are cast in horizontal direction, by its thickness.

Fig. 4: Layer by layer casting of rectangular joist

The rectangular wooden mould of 4.6m X 0.25m X 0.06m size is prepared for casting the joists. In this mould 2cm thick cement mortar of 1:3 mix is placed and the first layer of reinforcement containing one layer of weld mesh, wrapped with two layers of wire mesh is placed. Further 2cm thick cement mortar is placed and the second layer of reinforcement is placed as shown in figure-5.

Fig. 5: Middle layer casting with reinforcement

Next 2cm thick cement mortar is placed over it and the third layer of weld mesh wrapped with two layers of wire mesh is placed last, and the final surface finish is made.

III. PRECAST FERROCEMENT PLANKS

Eight precast ferrocement planks of size 80cm x 60cm are cast as shown in figure-6. The rectangular wooden mould of 0.8m X 0.6m X 0.03m size is prepared for casting the planks. These planks are reinforced with sandwiched mesh of 10-gauge welded mesh (with the spacing of 25mm X 25mm) wrapped by chicken mesh of 30-gauge, on both sides is provided. Rich cement mortar of ratio 1:3 is used for casting these 30mm thick precast panels. Sand graded through 1.18mm sieve is used in the cement mortar.

Fig. 6: Precasting of ferrocement planks

IV. Assemblage of Roofing Elements

Two joists are laid parallel over end supports with effective span of 3.85m and with the overhang of 0.3m on each end. The spacing of the joists is set to be 0.4m. On these set of joists, eight precast ferrocement planks are laterally covered for the span of 0.4m with the overhang of 0.2m on either side. It means the parallel joists are put on continuous supports and also the set of precast planks are laid on the continuous supports over the joists. This type of assemblage forms the precast ferrocement roofing system, over which 40mm thick in-situ screed concrete of mix ratio 1:2:3 is placed to enable the roofing system to develop monolithic effect. All the precast components and in-situ concrete elements are cured with wet jute bags for 28 days before testing the whole roofing system for flexural strength.

V. Testing of Precast Roofing System

The roofing system is tested using a hydraulic jack of capacity 100 tons. The load is applied as 8-point locations across the span to simulate uniformly distributed load. Six strain gauges are pasted on the bottom fiber of two joists (three on each joist) at l/3 distance each from both end supports and one at the middle of the joist. One strain gauge is provided at the middle of the ferrocement slab. Three dial gauges are provided at the bottom of planks in the middle line of both the joists, at the distance of l/3 from each support and at the mid span. LVDTs are also placed under the set of joists, at the in between points of already pasted strain gauges.

Fig. 7.a: Testing of precast ferrocement roofing

One dial gauge is also provided at the end of the cantilever projection (in between the two joists) to study the negative deflection of the roofing system. The testing set up of precast ferrocement roofing system is shown in the figure-7.a and 7.b.

Fig. 7.b: Testing of precast ferrocement roofing

The test loading is applied as near uniformly distributed load. The loading is distributed into 8 equal parts, across the span of 4m as shown in figure.7. The hydraulic loading jack with the load cell to measure has been placed at the center of span. The manual hydraulic pack was used to apply the loading.

Fig. 8: Crack pattern above 6-t loadings

As per the test performance on this precast ferrocement roofing system, the following points have been observed:

- The monolithic action of the roofing system is quite effective up to cracking load condition.
- The initial cracking has started at the load level of about 6-tons.
- After the 6-ton. loading, the cracks which have started at the bottom of joists have gradually went-up up to 7.5ton. loading.
- Then at about the loading of 8-ton., the separation cracks have appeared below the precast planks, from the top surface of joists on which planks have been resting.
- The ultimate loading taken by this roofing system for the span of 4-m is 10.21-tons plus the weight of the load distribution steel elements of 0.547-ton.

Fig. 9: Failed specimen, after ultimate loading

The performance of roofing system is quite gradual. As the loading is increasing gradually, the deflections also increased gradually and the cracks started from the bottom-most section with gradual crack propogation in up-ward direction. After ultimate loading, the sagging of the specimen is visually observed. The structural behavior appears to be ductile nature, as the precast components are made of ferrocement. The RCC would have structurally behaved differently, because of brittle nature of the material and sudden failure would have happened. For RCC roofing sudden development of cracks would have taken-place.

This testing has proven that, the overall load capacity of the specimen is more than the expected / calculated service load. Hence this type of precast ferrocement roofing system can be safely and advantageously adopted in real life constructions of housing for moderate spans of about 4-m. lengths. Particularly for affordable housing, this technology suits well. This type of roofing system has got both the economic and engineering advantages, and practically adoptable for rural housing projects.

S. No.	PARAMETERS	LOAD
1	Loading	UDL
2	Ultimate load as per testing	10.21 t
3	Service load expected	2.11 t
4	Cracking load	6 t
5	Type of failure	Flexure

Table 2: The over-all test results

A. *Super-imposed loads:*

Live load= 2kn/m2=2×0.8×4.6=7.36 KN
Floor finish=1 kn/m2= 1×0.8×4.6=3.68 KN
Total super-imposed load= 7.36 +3.68=11.04 KN

B. *Dead Loads:*

Self-weight of planks=0.8×4.6×0.03×25= 2.76 KN
Self-weight of joist= 0.25×0.06×4.6×25 =1.73 KN
For 2 rectangular joist =1.73×2=3.46 KN
Self-weight screed concrete=0.8×4.6×0.04×23= 3.39 KN
Total Dead Load=2.76+3.46+3.39 =9.61 KN
Total calculated service load= 11.04+9.61=20.65KN

C. *Experimental loads applied on the prototype:*

Ultimate load in tons =10.21x9.8=100.06 KN
Self-weight of loading steel elements=5.37 KN
Total loading taken as per testing=105.43KN
As per the experimental investigations and testing of this roofing system, the overall load capacity of the specimen is more than the expected service load. Hence this type of roofing system is structurally very safe for practical usage in the rural housing projects.

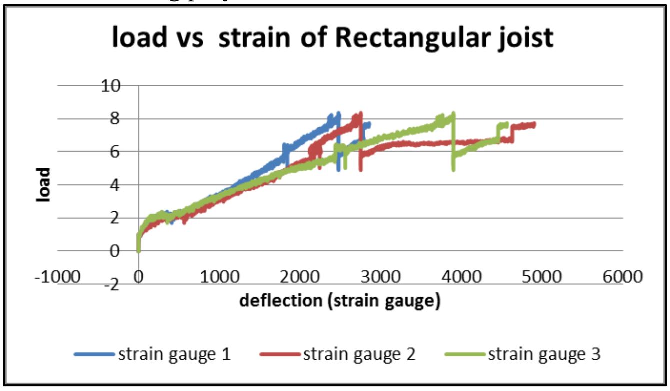

Fig. 10: Graph showing load vs strain

Strain gauge no	Maximum strain µm/m	Location of strain gauge
1	2509	L/3 from support left
2	4749	Mid span
3	2159	L/3 from support right

Table 3: Maximum strain recorded on the roofing assemblage

LVDT no	Maximum deflection (mm)	Location of LVDT
1	29.12	L/3 from support left
2	35.62	Mid span
3	29.24	L/3 from support left

Table 4: Maximum deflection values from LVDT

VI. ADVANTAGES OF PRECAST FERROCEMENT ROOFING SYSTEM

- The structural investigations with the experimental testing on this roofing system has practically proven that this technology is very safe from engineering point of view.
- This roofing technology is easy to adopt for rural constructions, as it requires no special construction machinery.
- This technology doesn't need cranes / handling machinery, as all the precast elements can be manually lifted.
- As the precasting of ferrocement roofing joists and planks can be organised when the walls are being built, the rural housing construction become quite fast and leads to economy.
- This technology consumes very less coarse aggregate as the concrete usage is quite minimum, and that is only for screed concreting.
- As this technology involves precasting, it doesn't require centering and shuttering for roofing construction. Thus it saves 100% money meant for centering work.
- The overall tonnage of steel usage would be less than the conventional RCC roof slabs and the cost of this construction system would be relatively economical.

VII. CONCLUSIONS

Based on the results of this experimental investigation, the following conclusions have been drawn:

- The maximum strain of rectangular joist is 4749 and the maximum deflection is 35.62 mm.
- Crack propagation in the roofing system started at the load of 6-tons.
- The ultimate load failure occurred at the load of 10.21-tons. But the expected service load on this roofing system is only about 2-tons.
- Hence, these experimental investigations prove that, the precast ferrocement roofing system is structurally very safe.
- Also this system can be further optimized to make it more and more economical.

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