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A Study of Affordable Roofing Systems with Composite Slab

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Abstract—Affordable housing is a term used to describe dwelling units whose total housing cost are deemed affordable to a group of people within a specified income range. Structural roofing system contribute substantially to cost of construction of housing unit in normal situation, hence any savings attained in roofing system will reduce the cost of construction of housing unit. In the study undertaken, the roofing system consists of primary beams and secondary beams perpendicular to each other. The infill proposed is a composite slab panel consisting of decking sheets, galvanized iron(G.I) sheets of trapezoidal and corrugated cross section at bottom with a layer of concrete above it. The rectangular composite panelsconsidered in the study have a least width of 0.5m and 0.75m with an aspect ratio varying from 1.00 to 2.00. The rectangular composite panels are designed using M20 grade concrete and reinforcing steel of yield strength 415 N/mm^2. The cost analysis is made for the roofing system and the proposed roofing system indicates a cost reduction 40% when compared to a conventional reinforced concrete (RCC) slab of same size. The weight of the beam systems and the panels are found to be relatively less and can handled easily by two to five masons thus reducing the labour cost. The beam systems and panels are precasted and can be easily placed thus eliminating need of shuttering, leading to faster construction of slab. The proposed roofing system is cost effective with a greater speed of construction compared to conventional roofing system.

Keywords-*Affordable Roofing, Composite Slab, Decking Sheet, Galvanised Iron Sheets.*

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I. INTRODUCTION

Housing affordability has always been a worldwide concern. Affordable roofing is a term used to depict dwelling units whose costs are considered to be “affordable” to a set of people within a given income range. Roofs are the components installed at the top of the buildings to protect the occupants against adverse weather conditions such as temperature changes, solar radiation, rain, snow and wind. Structural floors or roofs do have a considerable impact on the cost of the building in regular conditions. So, any kinds of saving attained in the construction of roofing system substantially reduces the cost of the building unit like other essential parts of buildings, roofs correspond to about 8-11% of the total project cost [1].

According to World Bank 2016 report on poverty in India, 45% are living in lower income range. Government of India launched Pradhan Mantri Awas Yojana (PMAY) in 2015, According to PMAY report Slum dwelling is growing at the rate of 34% for a decade, henceforth there is a need of affordable units. The estimated housing units required by 2022 are 20 million units [2].It is observed that there is an immense societal needs of alternative roofing system. Hence, an attempt is made to explore the realm of alternative roofing system.

Ravindra, et.al., [3] carried out work on affordable roofing system (ARS) consisting of precast roof infill elementssupported on a grid work of precast RCC joist system. The infills panels are rectangular panels with cylindrical/ellipsoidal domed curvature of smaller thickness to have membrane action as well as arching action. It mentions a reduction in cost of 7.5% to 35.4% compared to conventional reinforced concrete (RCC) slab. Panels are lesser in weight and also the time for construction reduced, compared to conventional RCC construction method.Manjunath et.al., [4]studied the experimental behavior of composite concrete slab with profiled steel decking for the determination of the flexural characteristics and bond strength. It is found that use of profile deck sheet reduces 25% by volume of concrete. The ultimate load carrying capacity of composite slab without embossments is 14% more than that of sheets with embossments. Ahmad et.al., [5] carried out experimental investigations to assess the strength of precast roof Slab system comprising of Ferro cement panel system of same thickness is higher compared to similar arrangement of RC beam and sand stone panels. The Ferro cement Slab exhibits ductile failure whereas sand stone roof Slab exhibits brittle failure.Shinde. et al., [6] carried study on affordable housing materials and technology and suggested various materials and techniques for different components of the housing units. They proposed Bamboo Matt corrugated roofing sheets and Micro Concrete Roofing tiles (MCR) for roofing system. The micro concrete roofing tiles were used for sloped roofs. MCR tiles have many advantages of high cost effectiveness, less noise during rains, high durable compared to other roofing materials like Galvanized Iron sheets and mangalore tiles etc. Vivian et.al.,[7] compared the construction cost for the traditional and

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low cost housing technologies by undertaking case studies in India. The construction methods of foundations wall, roofing and lintels are compared. They found thatsavings in construction cost between 22.61% and 26.11% can be achieved by using low cost housing technologies.

The present work under taken consists of Pre-cast composite roof infill panels supported on gird work of precast RCC beam system. The two main components are (i). Composite rectangular roof infill elements using decking sheet and GI sheets of different profiles. (ii). Primary and secondary RCC precast beams grid system.

Scope and Objectives of the Study:
The main objective of the analytical investigation undertaken is to examine the performance of the precast joists and composite panel roofing system. The dimensions of shorter side of rectangular precast panels are 0.5m and 0.75m,with aspect ratio of the panel varied from 1 to 2. A cost analysis of the affordable roofing system and a corresponding RCC conventional Slab of same size is also made. The details of roofing system and composite rectangular panels are shown in Table 1.

Table 1 Parameters considered for the study undertaken

Sl. No.	Composite Rectangular panel Dimension (m)	Aspect Ratio of panel	No. of Panels		Total Size of the ARS Slab (m)
			Along shorter span	Along longer span	
1	0.50 X 0.500	1.00	4	5	2.0 X 2.50
2	0.50 X 0.625	1.25	5	5	2.5 X 2.50
3	0.50 X 0.750	1.50	5	4	2.5 X 3.00
4	0.50 X 0.875	1.75	5	4	2.5 X 3.50
5	0.50 X 1.000	2.00	4	3	2.0 X 3.00
6	0.75 X 0.750	1.00	4	4	3.0 X 3.00
7	0.75 X 0.938	1.25	4	4	3.0 X 3.75
8	0.75 X 1.125	1.50	4	3	3.0 X 3.38
9	0.75 X 1.313	1.75	4	3	3.0 X 3.94
10	0.75 X 1.500	2.00	4	3	3.0 X 4.50

II. METHODOLOGY

In the study undertaken, the Pre-cast composite roof infill panels are supported on a precast RCC joist grid system. The grid system consisting of Primary and secondary beam. The primary beams are spanned along shorter side of slab while secondary beams are spanned between primary beam on brackets.

The composite slab is designed using relevant codes and the joist system consisting of primary beams which are normal to the secondary beams are analysed and designed using Staad-Pro Software. Conventional RCC slabs are designed for the same corresponding size of ARS and a cost comparison is made.
Three different profiles of the sheets considered for the design of composite slab are shown in Fig. 1(a), 1(b) and 1(c)

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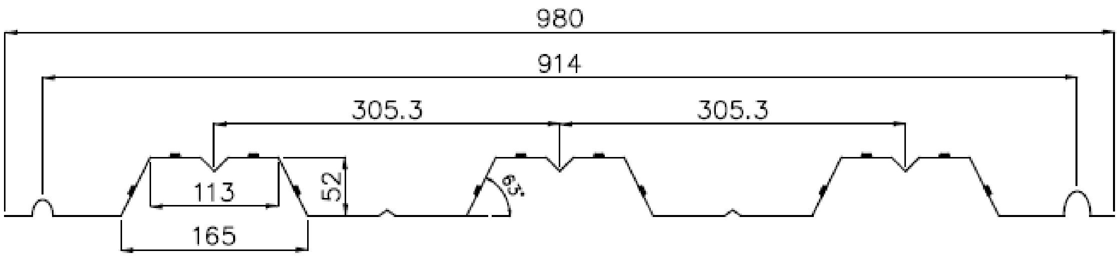

Figure 1(a). Decking sheet

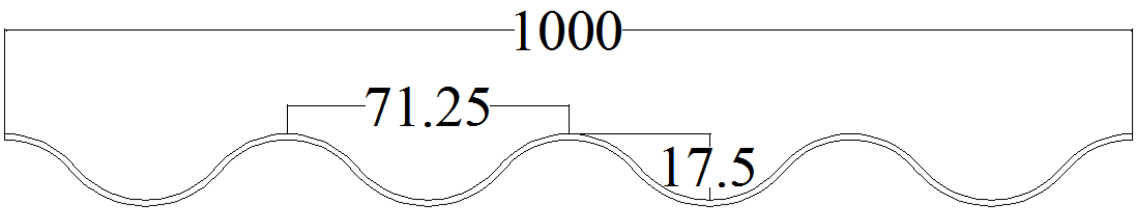

Figure 1(b). GI Corrugated Sheet of 1.6mm thick

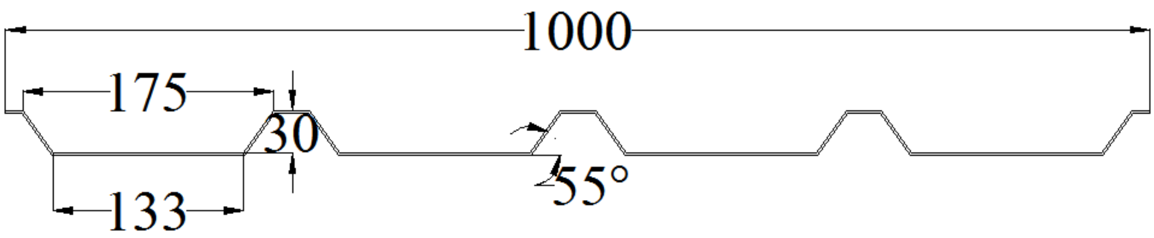

Figure 1(c). GI Trapezoidal Sheet of 1.6mm thick

III. ANALYSIS

The composite slab is analysed for dead and live loads. Dead load includes its self-weight and load from finishes. Density of concrete is considered as 24 kN/m^3. The details are as shown in Table 2.

Table 2 Details of dead loads

Sl. No	Sheet Type	Thickness of Slab (mm)	Dead Load of concrete (kN/m^2)	Dead Load of sheet (kN/m^2)	Floor Finishes (kN/m^2)
1	Decking Sheet	100	1.85	0.023	2.00
2	GI Curved	80	1.71	0.0107	2.00
3	GI Trapezoidal	80	1.56	0.029	2.00

Live load of 1.5 kN/m^2 is considered in accordance to IS 875 (Part 2). Load combination (1.5DL+1.5LL) and (1.0DL+1.0LL) is considered in accordance to IS 456:2000 for limit and serviceability states.

The design of slab is as follows:

Moment, M = $\frac{wl^2}{8}$

Where, w = Total load, kN

L = Span of slab, m

The depth of section is found out using the equation

$$Mu_{lim} = 0.36\,\frac{xu_{max}}{d}\,bd^2 fck\,(1 - 0.42\,\frac{xu_{\max}}{d})$$

Where, fck = Characteristic strength of concrete i.e., 20Mpa

The moment of resistance of the section is found out using the equation

$Mp_{Rd} = N_{cf}(1-0.42X)$

Where,

Tensile Force, $N_{cf} = \frac{Ap \times fy}{\gamma ap}$

Lever arm, $X = \frac{Ncf}{b \times 0.36 \times fck}$

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Ap = Area of the sheet, mm^2
fy = Yield strength of the sheet material, N/mm^2

The moment of resistance of the composite panels considering three different materials i.e., Decking Sheet, GI curved Sheet and GI trapezoidal Sheet are shown in Table 3

Sl. No	Sheet Type	Thickness of Slab (mm)	Moment of Resistance (M_{pRd}) (kN-m)
1	Decking Sheet	100	4.11
2	GI Curved	80	1.5
3	GI Trapezoidal	80	4.2

The beams are analysed by placing primary beams along shorter span and secondary beams along longer span. The primary beams of size 150mm x 150mm for 0.5m span, 150mm x 200mm for 0.75m span and all secondary beams of size 150mm x 150mm is found to be adequate. The analysis of the grid work of beams is performed using STAAD-PRO software and designed in accordance with IS 456-2000.

Brackets are provided on webs of primary beams to support secondary beam. The arrangement of a bracket System is shown in Fig.2. The bracket size is made considering the maximum shearing force transmitted by the secondary beam. The width of the bracket is kept same as the width of the beams, while a bearing length of 80mm was sufficient to ensure the bearing stresses within the permissible limits (0.45fck). Depth of the bracket of 50mm is sufficient to take care of the bending moment generated due to the eccentricity of the reactions of the secondary beam. Limit state adopted for the design of the brackets [8]. Fig.3 shows a primary beam with bracket connection on both the side of it and secondary beams resting over it. A typical reinforcement of secondary beam resting over the brackets of the primary beam is shown in Fig.3. Slot is provided in the bracket and the secondary beam for placing a 10mm bar and grouted with the cement mortar for a depth of25mm.The slot is grouted with cement slurry for better connectivity.

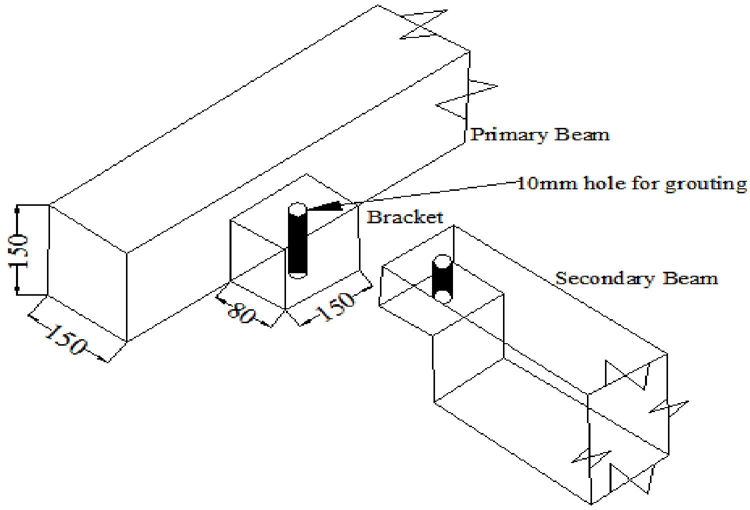

Figure 2. Typical connection between primary and secondary beam

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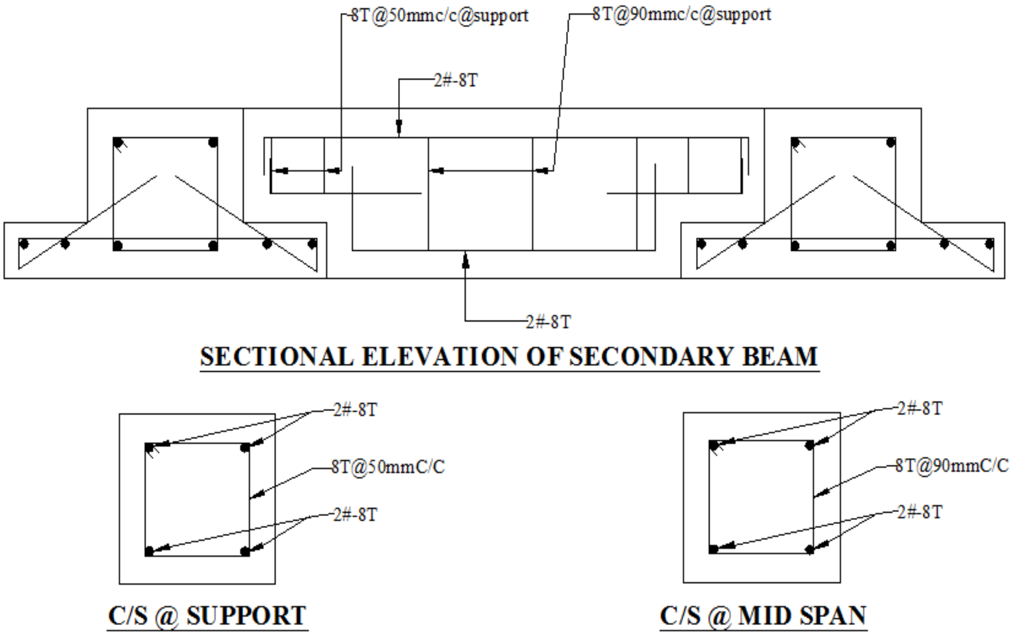

Figure3. Typical reinforcement of secondary beam resting over the brackets of the primary beam

IV. COST ANALYSIS

A study of economy of any technique or process is an important matter and indicates the feasibility of the technique. Cost effectiveness and time of construction are factors in construction, considered after fulfilling the safety and durability requirement. By optimizing the sizes, the quantity of the material required is reduced which in turn contributes to the saving of the materials and money. Cost analysis and comparisons are made for proposed roofing system and normal conventional RCC slab. Conventional RCC slab is designed keeping the size same as that of the affordable roofing slab. Cost of concrete is considered to be Rs 6800/- per cum and the total cost of concrete is calculated. Cost of steel is considered to be Rs 55000/- per ton of steel. Cost for the proposed affordable roofing system and conventional RCC roofing system is shown in Table 4. Similarly, Table 5 shows the weights of Panel, Primary Beam and Secondary Beam in order to achieve the convenience of lifting and placing by limited number of mason.

Table 4 Cost Comparison of ARS and Conventional RCC Slab

SL. NO	Slab Size, m	Conventional Slab, Cost per Sqm, (Rs)	ARS Slab, Cost Per Sqm (Rs)			Cost Ratio = $\frac{\text{Cost of ARS Slab}}{\text{Cost of Conventional Slab}}$		
			DS	*GIC*	*GIT*	*DS*	*GIC*	*GIT*
1	2.0 X 2.5	2599	1353	1217	1295	0.521	0.469	0.499
2	2.5 X 2.5	2578	1353	1217	1295	0.525	0.473	0.503
3	2.5 X 3.0	2565	1363	1219	1299	0.532	0.476	0.507
4	2.5 X 3.5	2555	1352	1220	1301	0.530	0.478	0.510
5	2.0 X 3.0	2585	1363	1219	1299	0.528	0.472	0.503
6	3.0 X 3.0	2745	1362	1219	1299	0.497	0.445	0.474
7	3.0 X 3.75	2729	1356	1220	1298	0.497	0.448	0.476
8	3.0 X 3.38	2736	1356	1216	1295	0.496	0.445	0.474
9	3.0 X 3.94	2726	1358	1216	1302	0.499	0.447	0.478
10	3.8 X 4.5	2890	1360	1216	1300	0.471	0.421	0.450

Table 5 Weight of ARS Slab

Sl. No	Slab Size, m	Panel Size, (L_x x L_y x T) m	Primary Beam, (B x D x L) m	Secondary Beam, (B x D x L) m	Weight, Kg		Weight of Panels, Kg		
					Primary Beam	*Secondary Beam*	*DS*	*GIC*	*GIT*
1	2.5 X 2	0.5 x0.5 x 0.1	0.15 x 0.15 x 2	0.15 x 0.15 x 0.5	122.5	31	48	63	48
2	2.5 X 2.5	0.5x0.625x0.1	0.15x0.1 x 2.5	0.15x0.15x 0.625	155	38.5	60	78	60
3	2.5 X 3	0.5x0.75 x 0.1	0.15x0.15x 2.5	0.15 x0.15 x 0.75	155	46	72	94	72
4	2.5 X 3.5	0.5x0.875x0.1	0.15x0.15x 2.5	0.15x0.15x 0.875	155	54	84	110	84
5	2 X 3	0.5 x 1 x 0.1	0.15 x 0.15 x 2	0.15 x 0.15 x 1	124.5	61	96	125.5	96
6	3 X 3	0.75x0.75x0.1	0.15 x 0.2 x 3	0.15 x 0.15x 0.75	243	46	108	141	108
7	3 X 3.75	0.75x0.9 x 0.1	0.15 x 0.2 x 3	0.15 x 0.15x 0.94	243	57.5	135	177	135
8	3 X 3.38	0.75x1.12x0.1	0.15 x 0.2 x 3	0.15x0.15x 1.125	245	69	162	211	162
9	3 X 3.94	0.75x1.31x0.1	0.15 x 0.2 x 3	0.15x0.15x 1.312	245	80	188	247	188
10	3 X 4.5	0.75x1.5 x 0.1	0.15 x 0.2 x 3	0.15 x 0.15 x 1.5	247	91	216	282	216

V. CONCLUSION

Based on the analytical investigations carried out in the work undertaken the following conclusions are drawn.

- The affordable roofing system proposed proves to be a strong alternative to the conventional RCC roofing system.
- The cost ratio of atleast 42.1% is achieved in the affordable roofing systems when compared to the RCC roofing system, which advocates the adoption of this technology in low cost housing projects.
- The alternative roofing system proposed has a pleasing aesthetic appearance. It requires no plastering work and false roofing work can be avoided which reduces the cost of the roofing unit.
- As no Shuttering work is involved in the composite Slab, its cost is reduced.
- The decking sheet acts as a tensile reinforcement hence minimum reinforcing steel is required in slab.
- The composite panel and beams weighs lesser and can easily be handled by two to five masons.Thus reduces labor cost and can be erected in a very short period of time.

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