RIBBED SLAB:
FLOOR: ROOF

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Thin reinforced ribbed slab for floors and roofs

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The paper describes an economical flooring/roofing scheme, suitable for low-cost buildings, developed at Central Building Research Institute, Roorkee. Details of the structural design and method of construction are given. Tests carried out to check the structural soundness of the scheme are explained in the paper. Data on the functional performance of the scheme, such as thermal performance, resistance to impact noise, and fire rating are given. Savings in materials and cost by adopting the technique in place of conventional slabs are given.

Floors and roofs account for about 25 percent of the building cost and consume substantial share of scarce materials like cement and steel. Any saving in these items alone will go a long way in reducing the overall cost of the building. Hence, considerable effort has been put in by Central Building Research Institute, Roorkee to develop economical techniques of construction of floors and roofs. So far, emphasis had been made to develop flooring/roofing schemes with precast units. However, most of the construction works in the country continue to be of traditional insitu type and there is reluctance on the part of site engineers to switch over to precast construction. Hence, an urgent need to develop economical and efficient techniques for insitu type of construction was felt and the thin reinforced ribbed slab scheme described in the paper has been developed with this objective in mind.

Scheme

Thin reinforced ribbed slab consists of reinforced precast ribs, 100mm × 200mm spaced at 1 to 1.5m on centres with 50-mm thick cast insitu flange above, *Fig* 1. It can be used for floors and flat as well as sloping roofs in single and multistoreyed residential and other types of lightly loaded buildings. In case of heavily loaded floors and roofs, the size and reinforcement of the ribs and flange will have to be increased. A conventional finish can be used above the ribbed slab, as requirements may be. Ceiling plaster can be avoided in low cost construction. In situations, where very good finish is called for, the ceiling may be plastered.

Structural design

The structural design is carried out according to the 'limit state method' as given in *Indian Standard Code of practice for plain and reinforced concrete, IS : 456-1978*[1]. The precast ribs are designed to act as rectangular beams during the construction to support the weight of concrete in the flange, the shuttering and the live load of workmen and equipment. The ribs are designed to act as T-beams for the full design loads after the concrete in the flanges has attained strength. The flange is designed as a continuous slab spanning over the ribs. To keep the deflections within permissible limits, the span : depth ratios for the flange and the rib satisfy the relevant requirements of IS : 456-1978. To control flexural cracking, the requirements of spacing for reinforcements as given in IS : 456-1978 have been complied with. To permit monolithic action of precast ribs with the cast insitu flange, stirrups in the ribs are projected into the cast insitu concrete of the flange. To ensure composite action of the flange with precast ribs the relevant provisions of *Indian Standard code of practice for composite construction, IS : 3935-1966,* have been satisfied[2].

Construction

Precasting and erection of ribs : The ribs are precast, preferably in steel moulds over a casting platform. Alternatively, they can be cast in timber moulds. To provide an upward camber to the precast ribs, the moulds are fabricated with a slope of 1 : 350 towards the centre. The casting platform is also provided with the same slope towards the centre. The casting platform and inner sides of the mould are coated with mould oil and the reinforcement cage is kept in position with the required cover. To provide holes in the ribs, 25-mm²

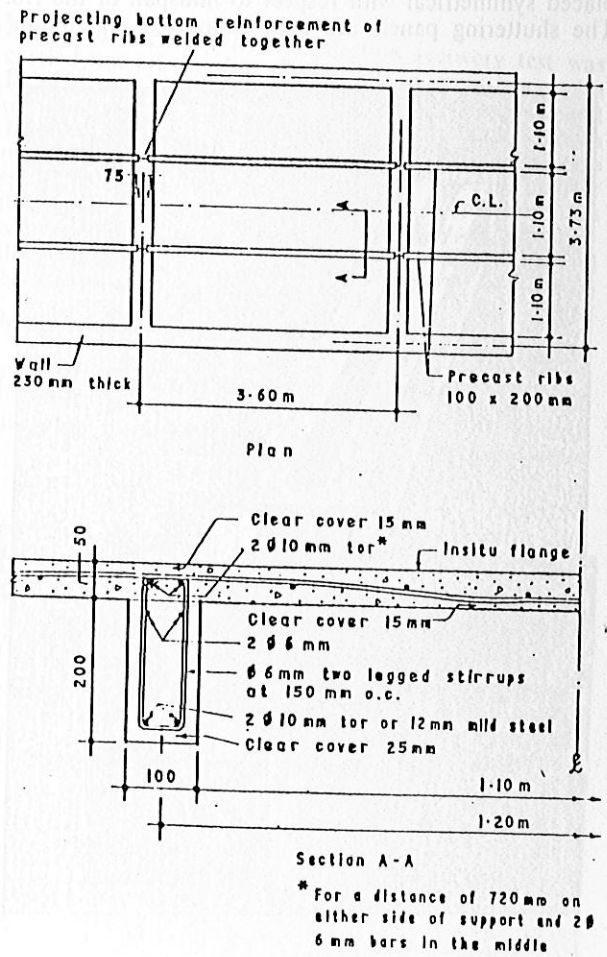

Fig 1 Reinforced ribbed slab

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mild steel hollow box sections are inserted through square holes in the longitudinal members of the mould. The concrete used is of grade M15 with —20-mm graded coarse aggregate. The concrete should be thoroughly compacted by needle vibrator having a 25-mm diameter pin, with the top surface finished rough. When ordinary portland cement is used, about 3 to 4 hours after casting, the rib can be demoulded by sliding the longitudinal pieces of the mould away from the precast rib. The rib should be kept covered with wet gunny bags for 72 hours. Afterwards, it should be slid horizontally on the casting platform to break the bond with the platform and transported to the curing yard or curing tank. After two weeks water curing, the units should be allowed to air dry for another two weeks, before being used in any construction. The precast ribs are to be placed in 115-mm wide recesses left in the wall at the specified spacing, and propped at midspan.

Erection of shuttering for flanges: Simple shuttering panels made of timber framing and plywood panelling covered with GI sheets are used for casting the flange portion, *Figs* 3 and 4. At least 20 reuses can be expected from such shuttering. Alternatively, steel shuttering panels can be used, in which case, the number of reuses will be more. The width of the shuttering panel is kept as the clear distance between the ribs with a clearance of 5mm on both sides. The length of the panels is preferably kept in modules of 300mm; *i.e.* 900, 1200, 1500mm. A combination of these module sizes can be used to suit the span of the room. Even number of panels shall be used in each bay, so that they can be placed symmetrical with respect to midspan of the rib. The shuttering panels are kept supported on 20-mm²

Fig 2 Mould for precast rib

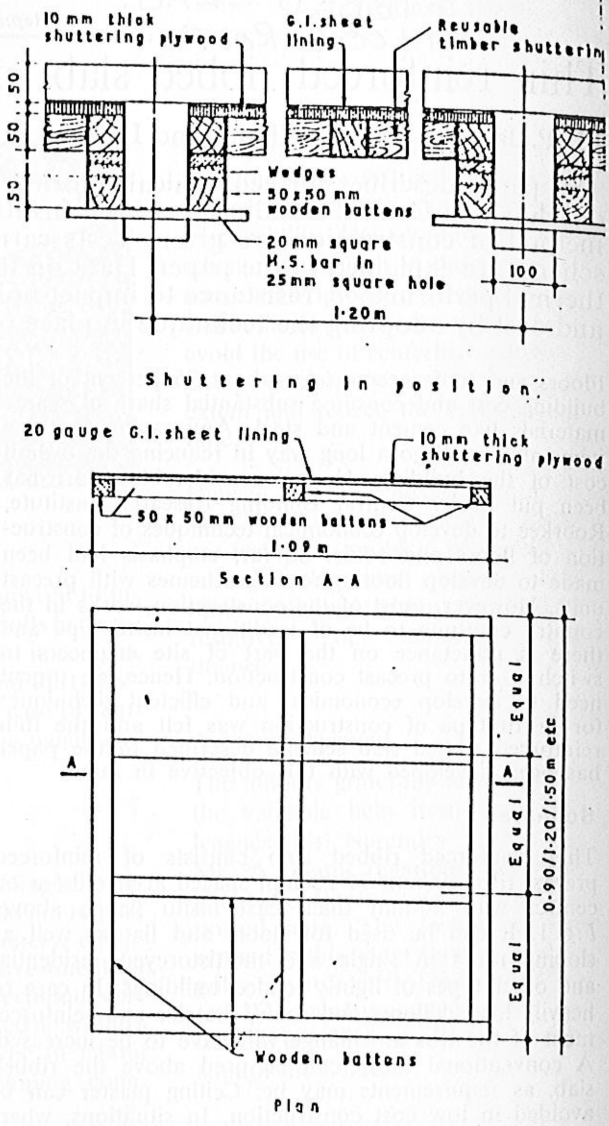

Fig 3 Timber shuttering for thin ribbed slab

mild steel bars projecting out of holes left in the precast ribs, *Fig* 3. As the ribs are designed to act as rectangular beams to take the load of the insitu concrete, shuttering, workmen and equipment during concreting, no props are required in this type of construction. However to keep the adjacent ribs at the same level, a wooden runner is provided at the midspan across the ribs, supported on props, one prop per rib. The shuttering panels are then kept in position and levelled with the help of wedges, with the top surface of the precast ribs in level with the top of the shuttering.

Laying of reinforcement and concreting the flange: Reinforcement of the flanges are laid over the shuttering, *Fig* 1. The specified cover of 15mm to the main reinforcement is ensured by tying the reinforcement to the projecting stirrups of the precast ribs at supports and by keeping cement mortar cover blocks below the main reinforcement bars at midspan. When the ribbed slab construction is done in coastal areas or in any corrosive environment, the concrete cover has to be increased and other precautions taken as suggested in IS : 456-1978[1]. The top surface of the precast ribs shall be given a coating of cement wash with 0.5kg. of cement per m² of area, just before concreting. Concrete of grade M15 with —12-mm graded

..arse aggregate is then laid over the shuttering and ribs and compacted to a thickness of 50mm by a plate vibrator, and the top surface is finished with wooden floats. The concrete is water cured for two weeks by ponding and then allowed to air cure. Three days after casting, the shuttering panels can be removed after first taking out the wedges. The runner across the midspan of the rib and the supporting props shall be removed one week after casting.

Fittings and fixtures: Fanhooks shall preferably be provided in the precast ribs at the time of casting. In case the fan is to be located in the flange portion, the fanhook shall extend over the adjacent ribs and rest over them. Positions of electrical junction boxes and other fittings shall be preplanned and provided in the precast ribs or in the cast insitu flange, as the case may be, at the time of the casting. If concealed wiring is to be adopted, conduits of diameter not exceeding 30mm may be provided above the precast ribs along its length. In the other direction, conduits shall be provided along recess cut in the wall.

Balcony and chajja projections: Short cantilevers such as roof or chajja projections upto 500mm can be provided in the ribbed slab along, or across the direction of the ribs by keeping the flange projected out. The cantilever has to be designed according to normal practice. For larger projections along the direction of the ribs, the ribs have to be designed suitably. They can be precast and kept projecting out. Alternatively, the reinforcement from the precast ribs can be kept projecting out and the cantilever portion of the ribs cast insitu along with the flange. For large cantilever projections across the direction of the ribs, cantilever beams have to be provided.

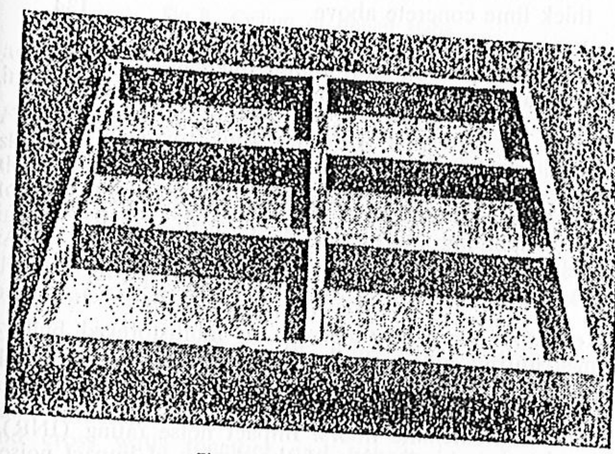

Fig 4 Shuttering panel

Floor and roof treatment: In case of ribbed slab floor, conventional floor finish such as Indian patent stone, can be provided above the slab. In case of flat roofs, lime concrete terracing or mudphuska treatment with tiles above, or any other proven treatment can be provided over the slab, after applying bitumen coating. A slope of at least 1 in 50 shall be provided to the top of the roof treatment. In case of sloping roof, the top of the slab shall be plastered with 12-mm thick 1 : 3, cement : sand mortar with waterproofing additive.

Alternate construction method

In case, the construction of reinforced ribbed slab floor/roof with precast ribs and ready-made shuttering panels is not possible due to some reason or the other,

Fig 5 Deflection recovery test; dial gauges in position

the construction can be completed with traditional shuttering. In such a case, the ribs need not be designed as rectangular beams to carry the load at the construction stage. They can be designed as T-beams for the final stage of loading. In this case, the depth and reinforcement in the ribs will work out to be less than that of precast rib. However, the cost of shuttering will be more. The overall economy will be less, when the traditional shuttering is used. Hence, only in exceptional cases, where due to extenuating circumstances the use of precast ribs and ready made shuttering panels is not feasible, the use of traditional shuttering is recommended.

Structural tests

Deflection recovery test: Deflection recovery test was carried out on the thin ribbed slab in accordance with IS : 456-1978[1]. Design dead load of 100kg/m² (weight of floor finish) was applied through concrete blocks 72 hours before the start of the test. Dial gauges were used to measure the deflections at midspan and quarter spans below the rib, *Fig* 5. One and a quarter times the superimposed floor load (1.25 × 200 = 250kg/m²) was applied through precast blocks for 24 hours and then released. The measured deflection of 1.7mm 24 hours after loading was less than the specified deflection of $\frac{40l^2}{D}$ = 2.36mm, where l is the effective span in m. and D the overall depth in mm. The slab, therefore, passed the test and there was no need to measure the deflection recovery. The maximum

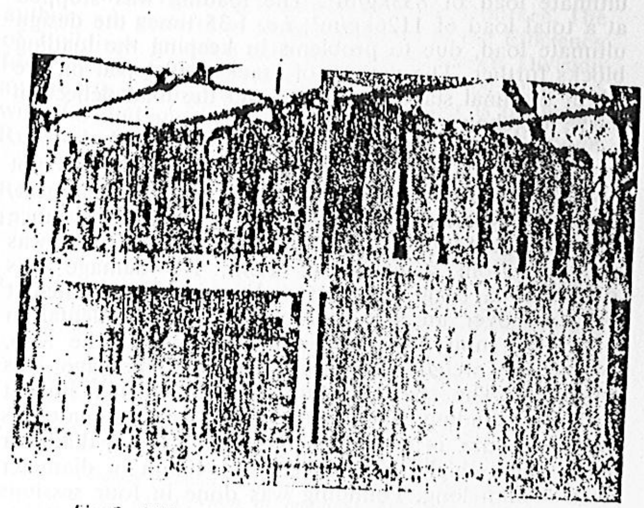

Fig 6 Ultimate load test with load in position

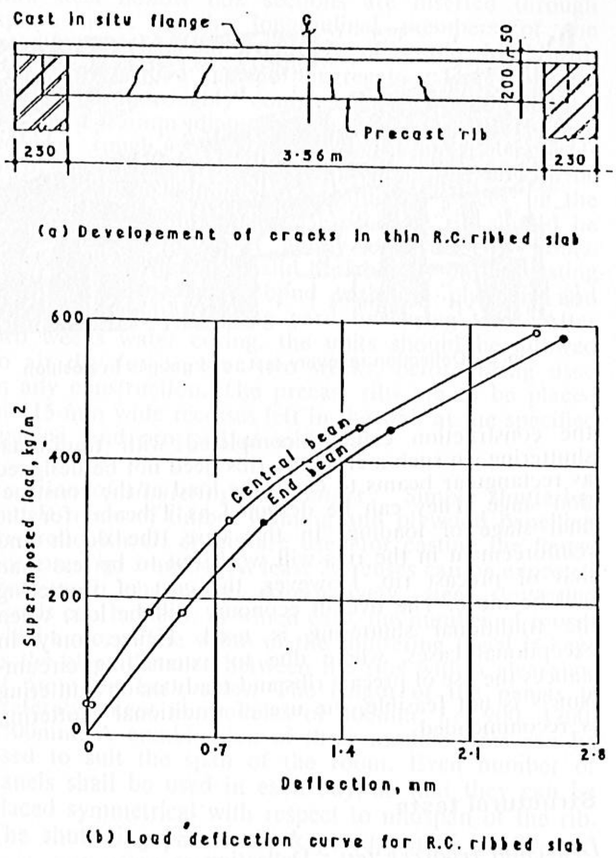

Fig 7 Ultimate load test

measured deflection is only $\frac{1}{2164}$ of the span. The measured deflection of 1.7mm is less than the theoretical deflection of 3.52mm under the imposed load of 250kg/m². No cracks developed during the test.

Ultimate load test: The thin reinforced ribbed slab of span 3.6m, designed as an inaccessible roof, was subjected to ultimate load test, *Fig* 6. Deflections and strains were measured and development of cracks noted at each stage of loading. The first crack developed at a total load of 848kg/m² which is more than the design working load of 464kg/m² and the design ultimate load of 835kg/m². The loading was stopped at a total load of 1126kg/m²; *i.e.* 1.35 times the design ultimate load, due to problems in keeping the loading blocks further. The pattern of cracks developed on the rib at the final stage of loading and the load deflection curve are shown in *Fig* 7.

Impact load tests: Though codes of practice do not give any procedure for testing slabs against impact, tests were carried out to check the impact resistance of the slab. A gunny bag filled with 40kg of sand was dropped from a height of 1.5m. No damage was observed. A 5-kg weight was dropped from a height of 1.2m over an area of 7cm². Though indentation of about 2mm was noticed at the top of the slab, where the weight struck it, no other damage was observed. The slab was subjected to further impact test by pounding 'haldi', one of the hardest materials used at home, in a 'hamam dasta' of 140mm diameter and 150mm high, with a steel rod 40mm in diameter and 300mm long. Pounding was done in four sessions of 5 minutes each, at the rate of 50 blows per minute from a height 300mm. The top surface and the ceiling of the slab were kept under observation. No cracks or other signs of weakness developed during the test. Only feeble vibrations could be felt by the application of the dynamic load. Hence the reinforced ribbed slab is safe against impact and vibrations normally expected in residential and office buildings.

Functional performance

Thermal performance: The thermal transmittance, *U* value of 50-mm thick reinforced slab with the corresponding value of 100-mm thick slab are given below:

(*i*) 50-mm thick reinforced slab with 100mm average thick mudphuska and 40mm thick brick tiles above	2.01Kcal/hr/°C/m²
(*ii*) 100-mm thick reinforced slab with the same treatment above	1.88Kcal/hr/°C/m²
(*iii*) specified value as per IS : 3792-1978[3]	2.00Kcal/hr/°C/m²

The thermal performance indices (TPI) for the ribbed slab and the conventional slab with the same roof treatment above are given below:

Slab with treatment above	*TPI*
50-mm thick reinforced ribbed slab with 90-mm thick lime concrete above	167
50-mm reinforced ribbed slab with 75-mm thick mudphuska and 50-mm thick brick tiles above	134
100-mm thick reinforced slab with 90-mm thick lime concrete above	134
100-mm thick reinforced slab with 75-mm thick mudphuska and 50-mm thick brick tiles above	110

It can be seen that with the same treatment above, ribbed slab is slightly inferior to a 100-mm thick conventional slab in thermal performance. By an increase in the thickness of mudphuska by 20mm or a corresponding increase in lime concrete, or by white washing the roof top, the same thermal performance can be achieved.

Resistance to impact noise: In multistoreyed buildings, impact noises produced by footwear, movement of furniture, activities in the kitchen, etc., are a source of nuisance and calls for insulation against impact noise in the intermediate floors. Impact noise rating (INR) number is an indication of the degree of impact noise insulation provided by a floor. For comparison, the ratings are given below:

Slab	*INR*
50-mm thick reinforced slab	$\simeq$ 17 db
120-mm thick reinforced slab	$\simeq$ 16 db

It can be seen that the thin slab and the conventional slab have got practically the same impact noise rating. For a satisfactory performance, a rating of +5 db is preferred. In either case, this can be achieved only by sandwiching a layer of resilient material between the structural floor and floor finish.

Resistance to rain penetration: Ponding tests carried out on the ribbed slab without any treatment above has shown that it is leakproof. This has also been confirmed by observations on untreated ribbed slab roofs of buildings during the rains. However, for an

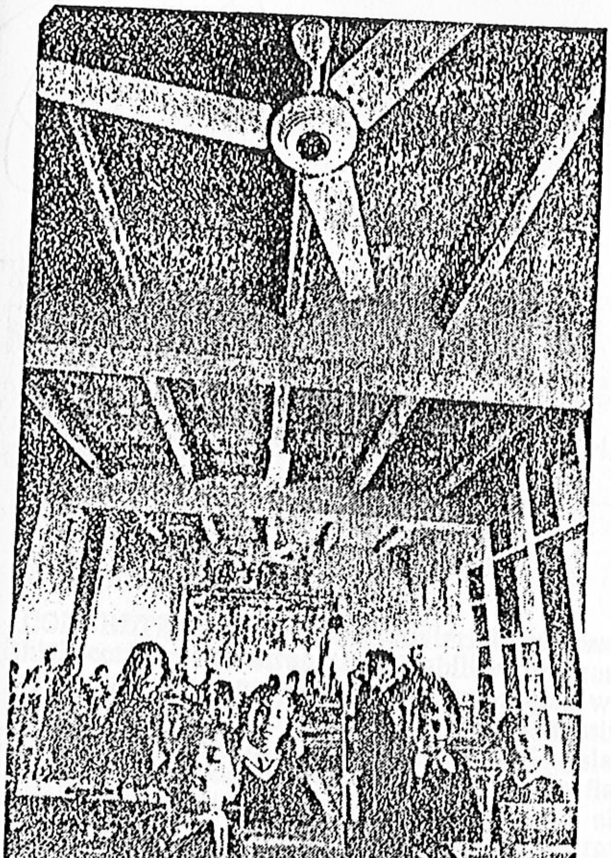

Fig 8 Ceiling of ribbed slabs

added factor of safety against leakage and for thermal insulation, normal roof treatment is recommended.

Fire resistance: Flange of the thin reinforced ribbed slab 1080×1080mm in size, 50mm thick with a 30-mm thick Indian patent stone flooring over it was subjected to fire resistance test in respect of thermal insulation in accordance with *Indian Standard fire resistance test for structures, IS : 3809-1966*. The fire resistance of thin ribbed slab in respect of thermal insulation criteria only was found to be 1 hour and 40 minutes.

Earthquake resistance: In thin reinforced ribbed slabs, the flange portion being insitu with the design reinforcement provides continuity in the two perpendicular directions. Hence, the slab ties the longitudinal and cross walls together and behaves in a similar manner to a cast insitu reinforced slab able to resist forces due to earthquakes and wind. No roof band need to be provided below the ribbed slab roof/floor resting on bearing walls, provided the slabs are made continuous over the whole building, or between crumply sections, if any, and they are given full bearing over the walls. Other strengthening measures such as lintel bands, vertical steel at corners and junctions of walls can be provided in those buildings constructed in seismic zones III, IV, and V as laid down in *Indian Standard code of practice for earthquake resistant design and construction of buildings, IS : 4326-1967*[5].

Savings

The thin reinforced ribbed slab scheme has been used for the roofs of three buildings at the Institute, including a primary school building, *Fig* 8. The structural and functional performance have been found to be satisfactory. Based on the experience gained from experimental constructions, and basic rate of labour and materials required, cost of the construction has been worked out.

For comparing the consumption of materials and cost of construction of ribbed slab with that of conventional reinforced slabs, the structural design of a 3.6 × 3.6-m two-way continuous slab and a one-way simply supported spanning slab of span 3.6m were carried out. The reinforced ribbed slabs were also designed for the above situations. The comparison of consumption of steel, concrete and cost of construction is given in *Table* 1.

TABLE 1 Comparison of materials and cost per m² of floor/roof

Item	*Cement,* bag	*Steel,* kg	*Cost/saving,* percent
Two-way continuous slab			
Conventional slab	0.58	8.5	
Ribbed slab	0.42	6.5	
Saving, percent	27	23	25
One-way simply supported slab			
Conventional slab	0.77	8.6	
Ribbed slab	0.46	6.6	
Saving, percent	40	23	30

Conclusion

It can be seen that the adoption of reinforced ribbed slab scheme in place of conventional reinforced slab will result in a saving of 27 to 40 percent in cement, 23 percent in steel and 25 to 30 percent in total cost. Apart from this, there is saving of 33 to 45 percent in aggregates. The scheme eliminates the use of props to a great extent. Being similar to the conventional construction, it will be easy for the masons and site engineers to adopt, and hence, it will be readily acceptable to them. Thin reinforced ribbed slabs are ideally suited for repetitive type of construction of floors and roofs for low cost houses and other buildings.

Acknowledgement

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