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A grid scheme for floors and roofs with precast waffle units

S. M. K. Chetty, M. P. Jai Singh and V. K. Jain

The paper describes in detail a grid roofing/flooring scheme using precast open-box type units called waffle units. The elimination of the structural deck concrete normally provided above the units, and the monolithic behaviour of the precast units along with the in situ grid beams are the salient features of the scheme. The load transfer from the units to the grid beams is ensured by the provision of shear keys. The casting and construction techniques, the design of the units, and the tests carried out on individual units and floor assemblies are discussed in the paper.

Conventional methods of construction are often found to be inadequate, slow, and uneconomical to meet the growing demand for houses, offices, schools, factories and other buildings. Prefabrication and industrialisation of building construction will be of tremendous help in solving the problem of shortage of buildings. It is, therefore, surprising that not much effort has been made so far towards the promotion of prefabricated construction in this country. It has been observed that roofs/floors cost about 20 to 25 per cent of the total cost of a building[1]. Any saving obtained by the use of prefabricated roof/floor units, therefore, will go some way towards reducing the total cost of construction. Further, by using precast units the delay at each floor level due to the time needed for providing centering, shuttering, laying reinforcement, etc in the traditional type of construction can be avoided, and the construction above can proceed without delay.

Several schemes are possible for precast roofs and floors. One simple and quick method is by precasting, lifting and placing the complete slab for a room as a single piece. But, this will require the use of heavy lifting equipment, which is not available in the country at present. Considering the type of handling and lifting equipment that can be obtained, it is necessary to keep the size and weight of the elements small so that they may be handled manually, or with improvised light equipment.

With due regard to these aspects, the Central Building Research Institute has developed some roofing/flooring schemes such as precast doubly curved shell roofs, precast doubly curved tile roofs, precast cellular unit roofs and floors, precast cored unit roofs and floors and precast channel unit roofs and floors[2,3,4,5,6]. All these schemes are suitable for one-way spanning slabs. Described in this paper is a two-way grid scheme for roofs and floors using precast units called waffle units, *Figs* 1 and 2. The structural details of the scheme are given in *Fig* 3 ; no deck concrete is provided above the units.

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Salient features

For covering large spans, one method is to provide two-way grid floors with beams running in both directions. They are usually built using removable and reusable timber or steel shuttering. Yet another method is to use open-box cardboard shuttering resting on timber planks or steel forms running in the two perpendicular directions of the grid beams. These cardboard boxes are thrown away after each use. A flat shuttering with expanded polystyrene blocks to create the hollows between the beams is yet another technique. In this case, after removing the shuttering, the polystyrene blocks are extracted by admitting air under pressure into them. Thus, all the in situ schemes for grid construction require shuttering for the entire slab. In the case of longer spans, the cost of shuttering may work out to one-third or even more of the total cost of the slab. To reduce the cost of shuttering and to speed up

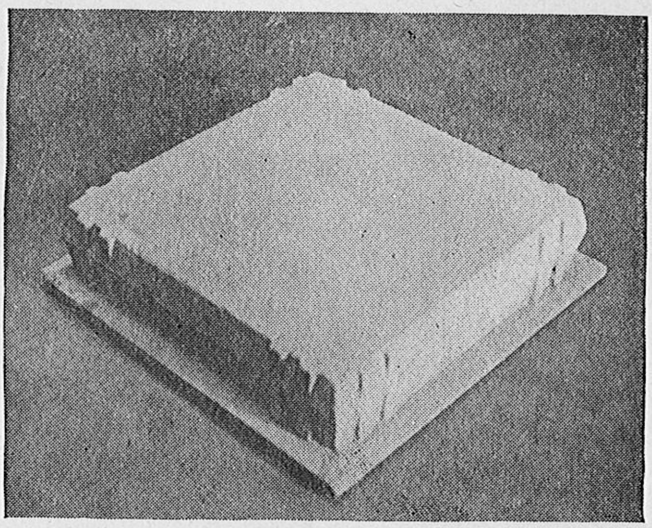

Fig 1 Precast waffle unit

construction, precast schemes have come up. They invariably have open-box type precast concrete units laid in grid pattern with gaps in between. In situ concrete is laid in the joints between the units and above them. Thus the precast boxes act more or less as permanent shuttering, and no structural advantage is taken of them. The in situ concrete laid above the units is designed to take the compressive stresses developed in the slab.

The salient feature of the new scheme developed at the Central Building Research Institute is that the deck concrete above the units is eliminated, and the precast units are made to act as structural components monolithic with in situ beams. The shape of the unit is so chosen that the precast portion acts together with the in situ concrete and ensures load transfer. Details of the shear keys for the load transfer are shown in *Fig* 2. The horizontal shear keys will ensure the vertical transfer of load. The vertical ribs will transfer the horizontal stresses from the unit to the beam and prevent the longitudinal separation of the unit and the in situ concrete. The elimination of the deck concrete has made the two-way grid scheme competitive for smaller spans as well.

Unlike most other schemes of precast construction, where the units span one-way only, in this scheme the loads are distributed on all the four walls or beams on the periphery. Hence there is a uniform distribution of loads on the supporting structures and foundations. All the same the scheme can be applied for oblong rooms and halls also. In such a case, the structure will behave as a one-way slab and the main reinforcement will be provided in the direction of shorter span. This precast grid scheme affords more headroom than a T-beam and slab construction and is also pleasing in appearance.

The units can be square or rectangular, the sides being 60cm to 120cm and the depth according to design. They have a minimum flange thickness of 3cm. There can be three types of waffle units, namely : with bottom flanges on all four sides; with flanges only on two opposite sides ; and without bottom flanges, *Fig* 2. The unit with bottom flanges only on two opposite sides is to be preferred. In this case, shuttering has to be provided only in one direction, and the absence of bottom flange allows extra depth for the placing of

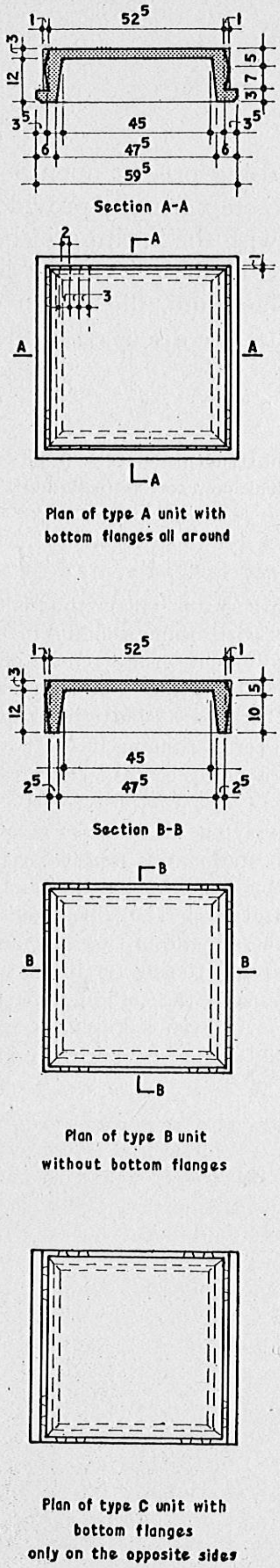

Fig 2 Different types of waffle units

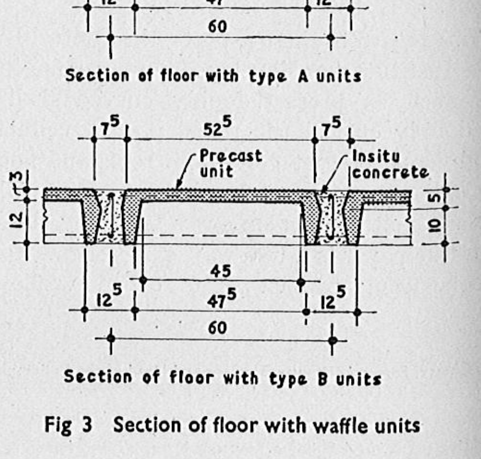

Fig 3 Section of floor with waffle units

reinforcement. A 60-cm square unit, 15cm deep, weighs about 40kg, and can be easily carried as head-load. A 120-cm square unit can be handled by four men. It is thus possible to handle the units manually, and the construction can be carried out without the use of costly and elaborate equipment.

The scheme will lead to the saving of scarce materials such as cement and steel, in addition to saving in cost, the exact amount of saving varying for different spans.

Casting

Details of the mould for casting the units are given in *Fig* 4. The units are cast upside down. The mould is assembled in position first and the bottom concrete is laid to the required thickness. Then the inside box is laid in position and the side concrete is placed and vibrated by means of a plate vibrator. After about an hour's time, depending upon the weather conditions, the inside box is removed, and the inside faces of the units are finished. Twenty-four hours after the casting, the outer frame is dismantled and removed. The units are cured for two weeks storing water in them, or by any other appropriate means. After two weeks of air-curing the units are ready for use in the construction of roof/floor.

Construction

The details of construction will vary somewhat, according to the type of units used. When units without bottom flanges are used, shuttering will be required for the beams in both directions at right angles. Where units with bottom flanges on two sides only or on all the four sides are used, the shuttering for the in situ beam has to be provided only in one direction. The bottom flanges of the units will support the fresh concrete in the other direction. After the walls/beams supporting the grid floor is ready, shuttering is placed in position and the units are arranged above it. Reinforcement is provided as per design in the joint between the units. The in situ concrete is cured with water for a week. The shuttering may be struck, after the concrete has attained sufficient strength. The completed ceiling is shown in *Fig* 5. The flooring/weather-proof course may be laid in the standard manner later.

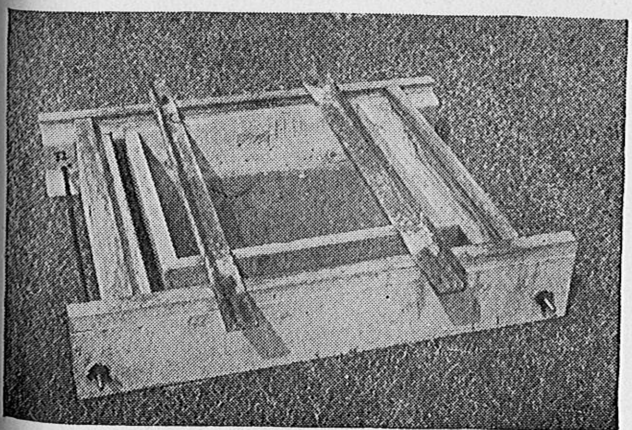

Fig 4 Mould for waffle unit

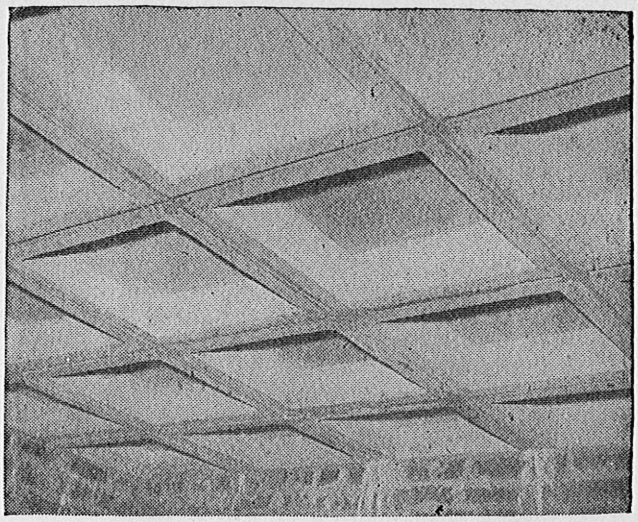

Fig 5 Ceiling of waffle unit floor

Design

The waffle unit roof/floor slab may be analysed by any accepted method for the analysis of grid beams. In the actual design, near midspan, it may be designed as a T-section with the in situ concrete in the joint and the flanges of the precast units taking the compression, and the main reinforcement at the bottom in the joint between the units taking the tension. The support sections may be designed as doubly reinforced. In checking the shear resistance, the width of the grid beams including the precast portion can be considered.

Tests

Individual units as well as roof/floor assemblies were subjected to static and impact load tests, and were found to be satisfactory. Under static loading, the units were tested as simply supported, resting on all the four edges in one case, and only on the four corners in the other case. A unit under test is shown in *Fig* 6. Even though codes did not specify any tests for impact, as the units would be subjected to such loads in actual practice, it was decided to test the units against impact. A sandbag of 25kg weight was dropped on the units from a height of 1·2m. No damage was observed.

The floor assembly was tested for static loads, as specified in the Indian Standard code, IS: 456-1964. A two-span continuous floor slab with two rooms 3·75 m square having grid beams at 60 cm centres in both directions was subjected to load test. The maximum deflection of the floor at midspan, after twenty-four hours under a test load $1\frac{1}{4}$ times the design live load, and the residual deflection immediately on the removal of the test load were found to be within the permissible limits.

The floor assembly was also subjected to destructive load tests, *Fig* 7. The first cracks appeared at a superimposed load of 440kg/m² or total load of 645kg/m², which gave an overall factor of safety of 1·6 at the first crack. The loading was continued up to 805kg/m², which was more than the total ultimate design load for the floor. The floor could withstand this load without

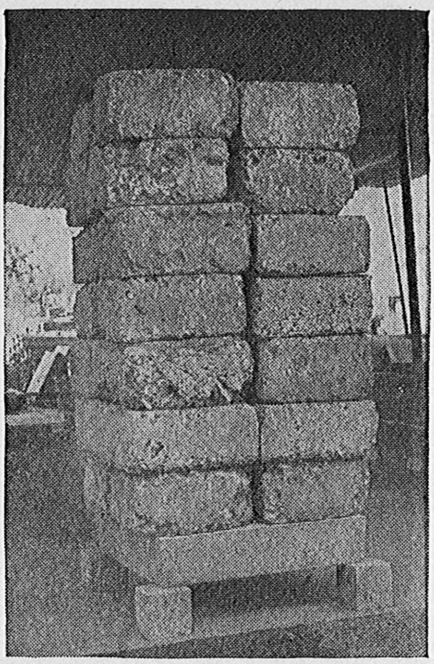

Fig 6 Unit under test

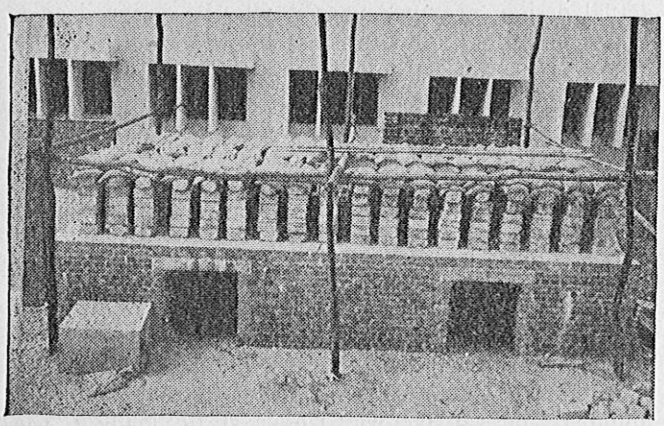

Fig 7 Floor under test

failure or excessive deflection. Due to certain difficulties, further loading of the floor could not be continued.

The pattern of the cracks developed in the waffle unit floor is shown in *Fig* 8. In the ceiling the cracks started

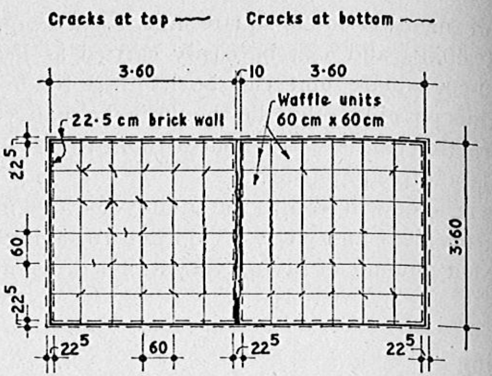

Fig 8 Crack pattern in waffle unit floor under load test

at the lower-most point in the junction of the ribs, and extended towards the flanges. At the top of the floor, the cracks developed above the support. From the crack pattern, it can be observed that under ultimate load the behaviour of the waffle unit floor is in conformity with the yield-line theory for slabs.

Acknowledgment

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