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A composite slab using structural clay units and concrete

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The paper describes the joist and filler block type of construction using structural clay units of a special design. It discusses the size and shape of the clay unit with a brief note on the mechanical composition of the clay used, and the extrusion and the firing methods of manufacture of the clay units. The stress-strain characteristics of individual clay units, and the results of load tests on panels are reported. Analysing the test results, the paper expounds the failure mechanism of the composite slab made up of structural clay units and reinforced concrete, and it is pointed out that ultimate load design can be applied to this case as for reinforced concrete slabs. The economy and merits of this type of slab are also indicated.

A joist and filler type of construction making use of structural clay units with a 3-cm thick deck concrete over the joist and filler assembly has been developed at the Central Building Research Institute in Roorkee, and has been found to be structurally efficient and light ; it has been described at length in a Report of the Central Building Research Institute[1]. Subsequently, attempts have been made to improve upon the shape of the clay units to achieve greater economy in the overall cost, and to reduce the consumption of essential materials such as cement and steel. Maintaining the basic concept of joist and filler construction for ease in handling, transportation, and erection, the shape of the clay unit has been completely modified. The type of clay units adopted, the method of construction, the structural behaviour of the slabs and their method of design are dealt with here.

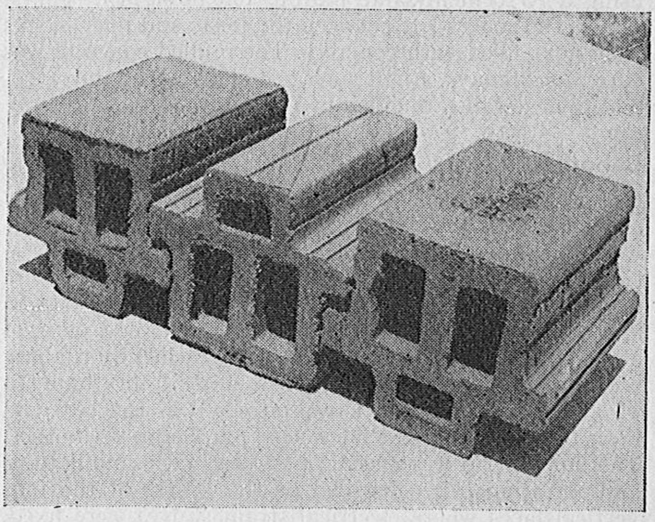

Fig 1 Structural clay units

The clay units

The clay units are 165mm × 150mm × 190mm in overall size, with three rectangular hollows in each, *Fig* 1. The outside faces of the unit have small rectangular serrations in order to afford better adhesion for mortar and concrete. The total volume of voids is about 37·4 per cent. The dimensions of the units are so chosen that the same unit may be used as an element of the joist and also of the filler, and one joist and filler together make up a planning module, 30cm wide.

The structural clay unit is extruded from a brick-making machine with its broader base resting on the cutting table. The extruded product is dried in a covered shed, and fired in a down-draught kiln having a temperature of 1020° to 1030° C. The clay used for extrusion is non-swelling, fairly plastic with a plasticity index of 23 per cent, and free from nodular lime. The mechanical composition of the clay lies within the following range : clay 25 to 30 per cent ; silt 30 to 40 per cent ; and sand 30 to 35 per cent.

Preparation of the test panels

The joist members are prefabricated first. The clay units are placed with their wider bases resting on a casting platform in a row to make up the required length of joist, and the joints are filled in with 1 : 3 cement-sand mortar. Two wooden planks are then placed on either side of the joist along its length and fixed in position by means of mild steel clamps. Reinforcement bars of the required size are placed centrally in the two end spaces, with a cover of 1·2cm, and the space is filled with concrete of the specified strength. This completes the making of the joist, the various stages of prefabrication of joist members being illustrated in *Fig* 2. After curing for about 28 days, the joists are turned upside down, and are ready for handling, transportation and erection.

Fig 2 Different stages of prefabrication of joists

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TABLE 1 Details of test slabs made with structural clay units

Test slab no	*Length,* m	*Effective span,* m	*Breadth,* m	*Mild steel reinforcement*	*Yield strength,* kg/cm²	*Compressive strength of concrete (from test on cubes),* kg/cm²
1	3·85	3·75	0·74	6 bars, 10-mm diameter	4000	153
2	4·14	3·99	0·74	6 bars, 10-mm diameter	4000	153
3	4·30	4·20	0·74	6 bars, 10-mm diameter	4000	153
4	4·26	4·15	0·74	6 bars, 10-mm diameter	4000	153
5	4·14	3·99	0·75	6 bars, 10-mm diameter	4000	153
6	4·35	4·19	0·74	16 bars, 10-mm diameter	3450	150
7	4·16	4·03	1·37	10 bars, 10-mm diameter	4000	150
8	4·315	4·2125	1·38	10 bars, 10-mm diameter	3450	150

For the test panels, the joist members were placed on supports at the required intervals and in the intervening space between two joist members, clay units were placed with the wider bases at the bottom, and using 1 : 3 cement-sand mortar for filling the joints, *Fig* 3. The spaces left between the joists and filler blocks were next filled with concrete. The infilled concrete was cured for 28 days. Eight such test slabs were fabricated, and their details are given in *Table* 1.

Laboratory tests

Compressive strength of clay units and their stress-strain characteristics: Six specimens of structural clay units were tested to determine their stress-strain characteristics and crushing strength. Specimens 1, 2 and 3 were fired at a temperature of 1000°C, and specimens 4, 5 and 6 at 980°C in an electric furnace. The end faces of all the units were prepared plain and levelled by rubbing with emery paper. A mortar pad of 1 : 1 mix and approximately 1·0cm thick was applied on the two end faces to ensure that the faces were parallel to each other. The mortar pad was cured for 28 days. The undulations and serrations were levelled at the centre of the four vertical faces where electrical strain gauges were fixed.

The specimens were tested in a compression testing machine, and the strains were recorded by a strain indicator at intervals of 2·5 tons of applied load, *Fig* 4. The best fitting curve for the sets of stress-strain results has been plotted by the method of least squares, *Fig* 5. The stress-strain equations for the two sets of specimens are given by

$$\varepsilon = 1{\cdot}97\sigma + 3{\cdot}45 \times 10^{-3}\sigma^2,$$ for specimens fired at 1000°C

and $$\varepsilon = 4{\cdot}921\sigma + 3{\cdot}52 \times 10^{-3}\sigma^2,$$ for specimens fired at 980°C

where ε = strain in microns

σ = stress in kg/cm² measured on the net area.

The crushing strengths of the clay unit specimens are given in *Table* 2.

TABLE 2 Crushing strength of structural clay units

Specimen no	*Crushing load,* tonnes	*Net area,* cm²	*Crushing strength,* kg/cm²	*Average crushing strength,* kg/cm²	*Remarks*
1	56		504		
2	78	113·05	702	624	fired at 1000°C
3	74		665		
4	53		477		
5	45	113·05	405	429	fired at 980°C
6	45		405		

In another set of compression tests of clay units, the specimens being obtained from among those fired in the down-draught kiln, the crushing strength was found to vary from 250kg/cm² to 400kg/cm² on the net area. From this, it may be assumed that the clay units which were fired in the electric furnace at 980°C match in properties with the clay units fired in the down-draught kiln. Hence in the discussions that follow, only the properties of the specimens 4, 5 and 6, which were fired at 980°C in an electric furnace, are considered.

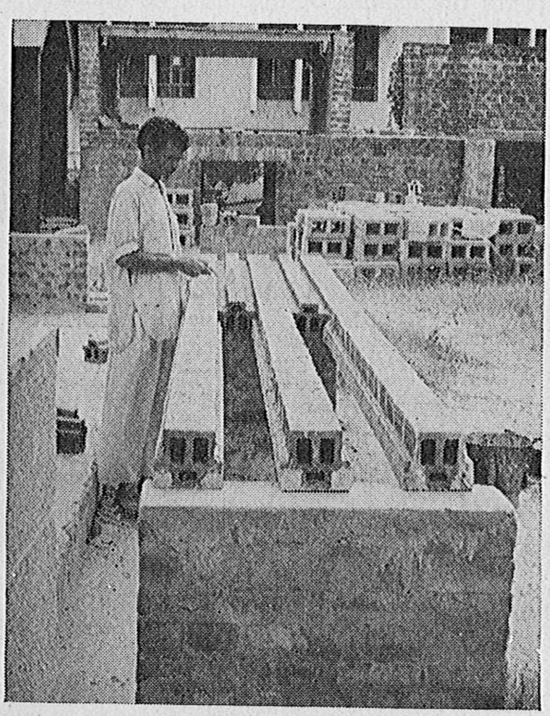

Fig 3 Laying the filler units

Fig 4 Compression test on clay unit

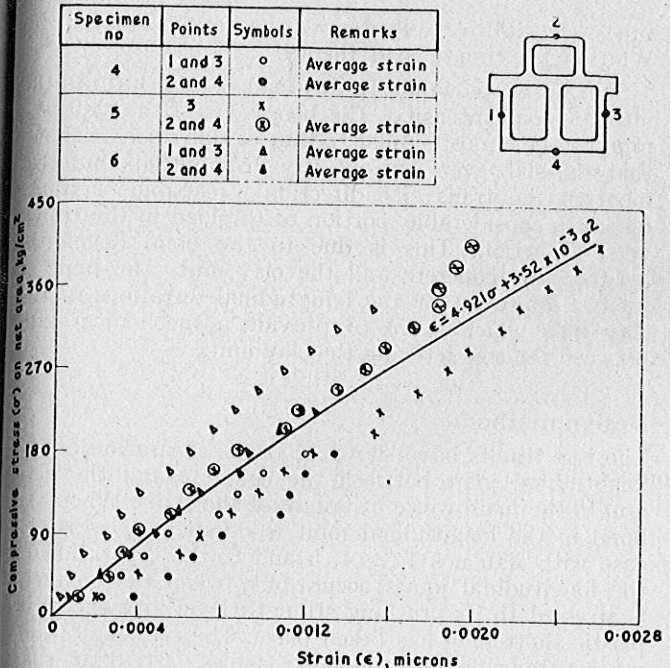

Fig 5 Stress-strain curve for clay unit fired at 980°C

Failure load test of slabs: In order to study the behaviour of the clay unit slabs under load and their ultimate strength characteristics, slab nos 1 to 6 cited in *Table* 1 were tested for the recovery of deflection and failure load.

For recovery of deflection which gave a measure of the stiffness of the slab for the span, the test slabs were subjected to one and a quarter times the superimposed load which the slabs were likely to carry during their lifetime. The same load was maintained for twenty-four hours after which it was removed. The recovery of deflection measured twenty-four hours after the removal of the load was found to vary from 75 to 87 per cent. These tests were carried out in accordance with the requirements laid down in the Indian Standard Code of Practice for Plain and Reinforced Concrete, IS 456 : 1964, and the recovery of deflection for safety should not be less than 75 per cent[2]. All the test slabs were found to meet this requirement satisfactorily.

After the recovery of deflection tests, the slabs were subjected to a failure load test. During the increment of load over the slab, the deflection was measured at mid-span of the three joist members. The deflections in all cases were found to fall well within the specified limit. At about 50 per cent of the failure load the first visible cracks appeared on the slabs, but the cracks were limited to the transverse mortar joints only, *Fig* 6. The failure pattern was almost similar to that of an under-reinforced concrete beam. With increase in the superimposed load, the crack penetrated deep through the joints until, at about 75 to 80 per cent of the failure load, the cracks in the joints bifurcated forming into a Y-shape and extending into the clay unit. At the time of failure, all the test slabs had a large number of wide cracks at the mortar joints associated with large deflections. After failure, some kind of separation of the longitudinal joints between fillers and the joist members was noticed. The failure load and the first crack load for the six slabs along with the deflection recovery per cent are given in *Table* 3.

Discussion of load test results

Referring to *Table* 2, it is seen that each of the clay unit specimens 4, 5, and 6 which were fired at 980°C, was crushed at a stress above 400kg/cm² on the net area. However, the crushing strength of a few other specimens of clay units obtained from kiln firing varied from 250 to 400kg/cm². This shows that the clay units have high compressive strength. The strain just before crushing could not be measured, and hence the excessive plastic shortening of the clay units at that stage could not be determined. But in the case of specimens 5 and 6 for which the strains were measured near the crushing load, the strain was found to be of the order of 0·15 to 0·25 per cent beyond which plastic deformation took place.

The slab is a composite construction of concrete and structural clay units. When the slab is under bending, the compression zone of the slab is strained, and as long as there is no separation in the longitudinal joint between the concrete and the clay unit, the strains in the concrete and the clay unit remain the same. The clay unit, in general, is a stronger material than concrete, and for the same strain, the maximum stress at the top fibre of the slab is less in the clay unit than in concrete since the modulus of elasticity of the clay unit is about 10 per cent lower than that of concrete.

In the load test, as the load is increased and the maximum top fibre stress in concrete approaches its crushing strength, excessive plastic flow takes place in concrete, and this separates the longitudinal joint between concrete and clay units. The separation of the longitudinal joints makes the concrete and also the filler clay unit (without any reinforcement) ineffective in carrying compression, and at this stage it is only the joist member which starts carrying the compression. Since the joist members are by themselves incapable of carrying the load, the slab fails. Thus the failure of the slab is due to the separation of the concrete and the

TABLE 3 Results of load test on structural clay unit slabs

Slab no	*Deflection recovery,* per cent	*Load at first crack,* kg	*Load at failure,* kg	*Ratio of load at first crack to failure load*
1	87	2704	4860	0·555
2	76	2292	4646	0·493
3	83	2314	3546	0·652
4	76	2310	4575	0·505
5	75	2908	4932	0·590
6	78	1785	3885	0·460

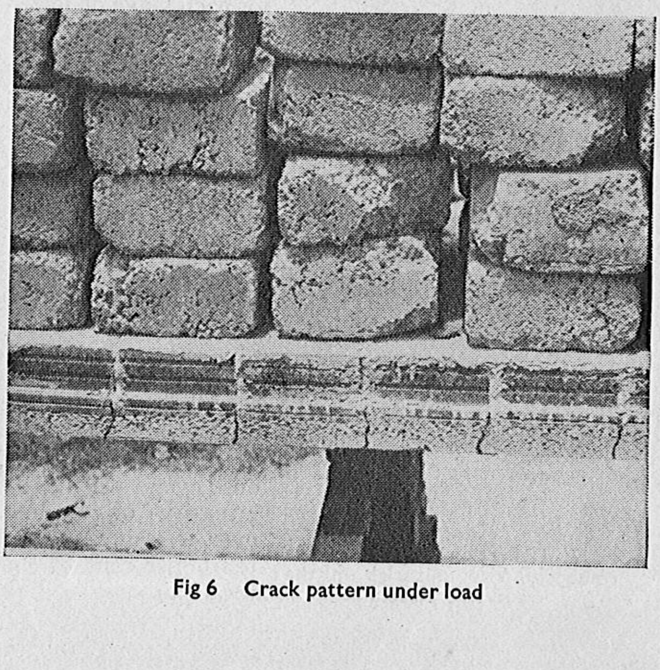

Fig 6 Crack pattern under load

TABLE 4 Results of failure load test on the clay unit slabs

Slab no	Moment due to self-weight of slab, kg m	Failure moment due to super-imposed load, kg m	Total failure moment, kg m	Moment calcu-lated by Whitney's formula, kg m	Ratio of total failure moment to moment by Whitney's formula
1	288	2,080	2,368	2,248	1·055
2	306	2,096	2,402	2,248	1·067
3	322	1,620	1,942	2,248	0·863*
4	318	2,136	2,454	2,248	1·090
5	293	2,240	2,533	2,248	1·125
6	326	1,790	2,116	1,970	1·074

* The early failure of slab no 3 may be due to the improper bond between the concrete and the clay units

clay unit along the longitudinal joints. From the test results of the six slabs tested to failure, it is observed that excepting slab no 3, the failure load moments of all the slabs are comparable to the moment of resistance calculated by Whitney's ultimate load theory taking the strength of concrete as the basis for calculation. The results of failure load tests are given in *Table* 4.

Partial load tests and discussion of results

Slab nos 7 and 8 were tested to investigate the efficiency of this type of slab in distributing the superimposed load at a point to the neighbouring section in the transverse direction. Such tests were considered necessary since there was no reinforcement in this type of slab in the transverse direction. In the absence of any set test procedure, the load was applied in stages on a width of 60cm in such a way that the centre-line of the load was approximately at the quarter point of the slab width. The deflection at the mid-point of each quarter strip of the slab was measured for each stage of loading. The load deflection characteristics for the partial load test including the disposition of the load on slab no 7 are shown in *Fig* 7. It may be noted that for all stages of loading the deflection is nearer the loaded area, and decreases gradually as the section moves away from the centre of gravity of the load. The deflection curves drawn across the width of the slab are continuous even when the intensity of loading over a uniform strip (43·5 per cent of the total slab area) is 1·8 times the ultimate load intensity as calculated by Whitney's ultimate load theory.

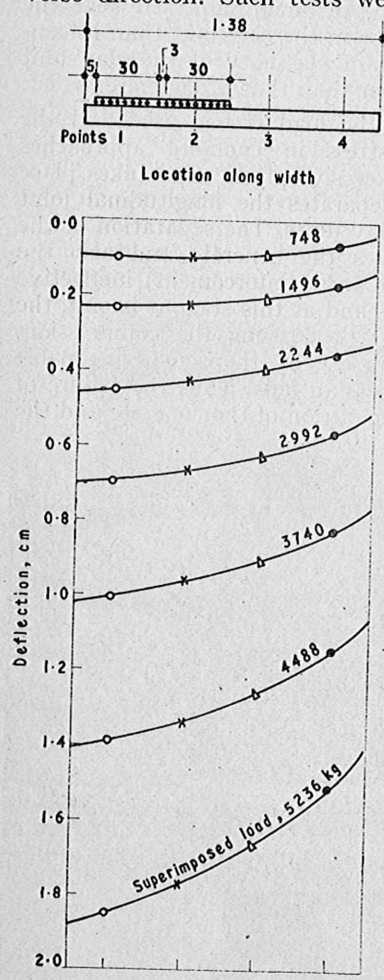

Fig 7 Deflection diagram of the composite clay unit slab in the transverse direction

Slab no 8 was similarly test-loaded to 2·1 times the ultimate load intensity. The behaviour of the slab was found to be almost similar to that of slab no 7. It shows that the slab even without any distribution reinforcement in the transverse direction is capable of transferring a considerable portion of the load in the transverse direction. This is due to the bond developed between the concrete and the clay unit. The bond is further improved by the longitudinal serrations in the clay unit which serve to provide a mechanical grip between the concrete and the clay unit.

Design methods

The test results have shown that the separation of the longitudinal joint between the concrete and the clay unit is the main cause of failure of the slabs. When the bond in the longitudinal joint is satisfactory as is the case with slab nos 1, 2, 4, 5 and 6, the separation of the longitudinal joints occurs only when the concrete is stressed to its crushing strength level and excessive plastic shortening has taken place. The clay unit being much stronger than concrete has less strain at that stage, and this differential strain causes the separation of the joint. Thus the ultimate strength of such slabs can be predicted from the strength of the infill concrete by Whitney's ultimate load theory. For the purpose of design, therefore, the ultimate load formula given in the Indian Standard Code of Practice for Plain and Reinforced Concrete, IS: 456-1964, may be adopted[2].

Conclusions

The tests carried out on the composite slabs made with the clay units indicate that the construction scheme is quite suitable as a substitute for the floor/roof slab. The slab is lighter, its self-weight being about 200 to 210kg/m² as against 240kg/m² for a 10-cm thick reinforced concrete slab. The self-weight of a 3·6-m long joist is about 80kg, and it can be easily handled by four workmen. As it is a joist and filler scheme, the erection of the floor is easy. The word 'filler' is used here only to indicate the construction scheme, the clay units in fact participating in the structural action along with the concrete and not merely serving as filler blocks. This type of slab is superior to the 10-cm thick reinforced concrete slab in thermal behaviour. The slab is likely to be more economical compared to the reinforced concrete slab. On the basis of the prevailing rates in Roorkee, the clay unit slab is estimated to lead to savings of about 10 to 20 per cent in overall cost, 45 per cent in cement, and 25 to 50 per cent in reinforcing steel.

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