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EXPERIMENTAL INVESTIGATIONS ON REINFORCED BRICK SLABS

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EXPERIMENTAL INVESTIGATIONS ON REINFORCED-BRICK SLABS

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ABSTRACT

Reinforced-brick (RB) slabs are commonly used for residential and other buildings in the areas where bricks are available at a lesser cost as compared to stone aggregates. The method of design for such slabs is not fully developed and usually it is based on approximate guidelines given in certain handbooks or only on the experience of the builders. Various methods have been proposed in this paper for the design of RB slabs. Further, nine slab specimens were made and tested in he laboratory for the flexural strength. Comparison is then made between the expected strength according to the proposed design methods and the experimental results. Conclusions are drawn and recommendations regarding the design are presented. The most important finding is that the steel required for the RB slabs may be calculated using the formulas for RC slabs, provided that the bottom steel from the two slab panels at continuous edges is fully lapped. The already present bottom steel on the supports acts as compression reinforcement and the slab, at the continuous edges, may be designed using the doubly reinforced RC formulas and the effective bottom concrete width after adding one-tenth width occupied by bricks.

INTRODUCTION

Traditionally the term "reinforced brick work" was used for cement mortar brickwork reinforced by steel rods embedded in the mortar layers. This type of construction was not found to be satisfactory in the damp localities causing early rusting of steel and deterioration of bricks and mortar. The life of the structures was significantly less (up to 10 to 15 years) in such cases. Recently, RB slam is a term most commonly used for slab having single or group of bricks joined together by concrete ribs having the steel reinforcement with proper cover from the porous bricks and a concrete layer at the top to protect bricks. Used in this way, RB slab behaves more like a special type of waffle slab rather than the traditional RB construction. The strength of the bricks may be ignored and hence low strength bricks having less percentage of slats and porosity may be used to reduce the cost.

In the past, the design of RB slabs was based on the recommendations of the Khanna's handbook (Ref.1) giving very conservative estimate of the steel. Further, this design was originally derived for the traditional brickwork with steel embedded in the mortar. A

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limited literature in available on the experimental investigation of RB slabs to verify their true flexural behaviour and there is a need to perform tests to validate the design o this commonly used type of slabs. In this study, nice specimens of one-way RB slabs were made and tested with the help of reaction frame to determine their flexural strengths and to observe their behaviour during bending. The bond between the concrete and the bricks was especially observed to test whether the bricks are pulled out of the slabs close the ultimate loads. The results are presented in this paper along with the recommended design procedure for the design of such slabs.

COMMON DEFECTS IN ORDINARY RB SLABS AND THEIR REMEDIES

1. The design of such slabs is not based on actual calculations considering the expected loads, geometric dimensions and a verified design procedure. In majority of the cases, the design is either based on recommendations of the Khanna's Handbook or is purely based on judgement of the builder. Using lesser steel than the amount actually required is obviously undesirable. If extra steel is used, it not only makes the construction uneconomical but also can be unsafe in certain situations due to the likelihood of over-reinforced sudden mode of failure without warning.
2. Qualified engineers or sub-engineers are not, generally, employed to supervise reinforced brick construction.
3. The steel is not placed correctly along the depth of the slab, which modifies the effective depth. Some contractors provide steel almost at the mid-depth and thus drastically reduce the effectiveness of steel in resisting the moments. In some cases, negative steel in cantilevers is provided near the bottom of slab, which is similar to having no steel at all. In other cases, no or less cover to the steel in maintained.
4. The bricks are more properly soaked in water before pouring off the concrete. The correct method is to soak all bricks in water up to such a level that these should not be able to absorb more moisture from the poured concrete. Is moisture is sucked from the fresh concrete, the workability of the concrete will be adversely affected. This will result into poor quality of concrete having honeycombing.
5. Manual rodding of he concrete in RB slabs is the only method available for compaction as compared with mechanical vibration used in case of reinforced concrete slabs. Further, concrete in RB work is poured through the gaps in the bricks and the steel. Hence, a little lack of attention during the construction can severely affect the quality of concrete.
6. The width of ribs between the bricks should be sufficient top accommodate the steel with required minimum cover up to the bricks to avoid rusting of steel and for easy pouring of the concrete. Maximum aggregate size must be selected such that concrete may pass through such smaller dimensions. If these conditions are not fulfilled, the quality of RB construction will decrease.
7. The pattern of placement of bricks is also important. Traditionally, the bricks are first joined together by cement mortar to form pairs, which were then replaced on the shuttering to get a stable, regular and organized pattern of bricks. With the new concept of RB slabs with the bricks only used as a filling material, contractors have started to spread the single bricks in an irregular pattern, after placing the steel. This

pattern is unstable, especially when the bricks on edge are used, and the position of bricks changes during pouring of concrete due to working of labour and due to lateral pressure of the fresh concrete. If the bricks are displaced and come closer to the reinforcement, corrosion of steel occurs and the life of such slabs is greatly reduced. There is a need to go back to the traditional methods and the bricks should be joined in-groups by using cement mortar at least three days before placing on he shuttering.

8. If temperature steel is not sufficiently provided on exposed rooks and sunshades without insulation, cracking of the slab may take place. This will lead to a complete failure of the structure.
9. In some cases, negative steel is not provided at the continuous edges of the slab. This reduces the moment strength, increases the deflections and causes the formation of cracks at undefined locations on the top surface. This facilitates percolation of water into the slab and produces deterioration and rusting of the materials.
10. A top concrete layer of 1 to $1^{1}/_{2}$ in should always be provided on the top of the bricks to protect them from moisture. If this layer is not provided, the water may seep into the slab through bricks during rain on top surfaces or during washing of the intermediate floors.
11. The bricks must not have excessive salts and more absorption capacity.
12. The shuttering in case of RB slabs comprises of mud plaster on wooden planks. If this shuttering is not properly constructed, the cement slurry flows out of this shuttering during pouring and causes voids in the concrete.
13. Occasionally, the beams supporting the slab panels are not properly designed and only concealed beams with minimum reinforcement are provided everywhere. Concealed beams are useful for small spans and less loads because of the improved architectural appearance. However, for bigger spans and heavy loads, these beams become very expensive and may produce excessively large deflections. These large beam deflections change the behaviour of the supported slab and may produce excessive bending and cracking.
14. Complete damp proofing is not carried out on the roof surfaces.
15. The pipes for electrification and plumbing are not placed at proper locations and are not handled with care during the construction.
16. The depth of the slab is insufficient producing excessive deflections and cracking.
17. Insufficient or no distribution steel is provided in case of one-way slabs.
18. Water cement ratio and workability are not properly maintained during the construction.
19. Curing is not carried out for the specified minimum time.

BEHAVIOUR OF REINFORCED BRICK SLABS AND POSSIBLE DESIGN APPROACHES

It is well known that reinforced concrete is actually a composite material in which the steel is added to provide tensile strength. This complicates the behaviour of the reinforced concrete and approximating the combined behaviour of the two materials (Ref.3) has developed various design techniques. In case of RB work, one more material is added increasing the complexities of the resulting member. Both concrete and bricks cannot resist tension but can resist compression. The properties of concrete and bricks are completely different from each other. In design, concrete is assumed to crack at a strain equal to a value of 0.003, whereas, bricks starts crushing early but continue to resist more load and the complete failure is defined at a large strain. These two materials interact with each other in the compression zone producing a highly complicated mechanism. Due to these facts, it is difficult to formulate expressions to estimate the exact flexural strength of RB members and certain approximations have to be employed to reach a reasonably simple design technique. The compressive strength provided by the bricks is assumed to be one-tenth of that of concrete. This is supported by the fact that the brick strength is much reliable than concrete. Based on this assumption, following two methods can be evolved to estimate the flexural strength of RB slabs:

Solid Reinforced Concrete Analogy: When RB slabs are subjected to sagging moments and a concrete layer of 1 to 11/2 in. is provided on the top, the neutral axis usually lies within this top concrete layer. This means that the concrete in the ribs and the bricks are all in tension and their strengths must be neglected. In such cases, the RB slab exactly behaves like a solid reinforced concrete slab. The formulae to estimate the flexural strength of RC members are applicable here without any modification. Nevertheless, it is important to note that the concrete strength achieved in case of RB slabs will be much less due to manual compaction, more congestion and lesser control of workability and water-cement ratio.

Reinforced Concrete Ribs Analogy: In cases when the RB slabs with top concrete layer are subjected to hogging moments, the strength of top layer of concrete is wasted due to the presence of tension on this face. A combination of bricks and the ribs of concrete between the bricks at the bottom will be in compression. Neglecting the compressive strength of bricks and the strength of the top concrete layer as mentioned above, only concrete ribs are left to resist compression. However, width of ribs plus one-tenth the width of bricks may be used in calculations in place of the total width of the slab to approximately include the small strength of bricks. The torsional stiffness between the perpendicular ribs is neglected for the simplicity of the calculations.

SELECTION OF TEST SPECIMENS

The objective of the present study was to observe the combined behaviour of concrete and bricks in compression. This can only be achieved when the compression side is fully stressed at the ultimate loads. Accordingly, it was decided to make slab specimens having steel equal to or greater than the balanced steel ratio calculated using the solid RC slab analogy. In reality, the steel ratios for reinforced concrete slabs seldom exceed 35% of the balanced steel ratio. One-way slab specimens were made which were consistent with the coefficient method of slab design. After using the moment coefficients, the two perpendicular slab strips are designed independently as one-way slabs. Other considerations in the selection of the specimen slabs were as under:

1. Uniformly distributed load was replaced by two line loads acting within the simply supported spans. This does not affect the results when the moment capacity is to be checked without consideration of shear failure.
2. Width of the specimens was decided depending on two factors. Firstly, the width should be large enough to truly represent the brick and concrete rib pattern for the actual slabs. Secondly, the size should not be so large to have handling and testing problems.
3. Length of the specimens and the line load positions in the loading arrangement were decided in such a way that shear failure does not occur prior to the flexure failure. The selected specimens have steel ratios in excess or ordinary beams, which may lead to shear failure, if smaller length specimens are used.
4. Thickness of the specimens was varied to test different brick patterns and orientations within the slabs.
5. Negative bending specimens were planned to be tested in positive bending by turning the samples upside down. This does not affect the results except the minor difference due to self-weight.
6. Sufficient amount of distribution steel, satisfying the RC Code requirements, was provided in the transverse direction.

The details of the selected specimens are given in Table 1.

Specimen No.	Width (in.)	Length (in)	Span (in)	Thickness (in)	Bricks Orientation	Brick Dimension Along the Slab (in)	Main Steel Provided	f_c' (ksi)	f_y (fsi)
1	16.5	83	80	4.5	Single flat	4.5	3 - #6	2.26	70
2	16.5	83	80	4.5	Single flat	4.5	3 - #6 (top)	2.26	70
3	19	83	80	4.5	Single on edge	3	2- #6, inner ribs 2 - #4, outer ribs	2.26	53
4	19	98.5	94.5	6	Single on edge	3	2 - #6, inner ribs 2 - #4, outer ribs	1.8	6
5	19.5	98.5	96.8	6	Double on edge	6	3 -#6	1.8	60
6	19.5	98.5	96.8	6	Double on edge	6	3 - #6 (top)	1.8	60
7	19	88	84	5.5	Single flat	4.5	2 - #7, inner ribs 2 - #7. Outer ribs	1.8	55
8	19	86.2	82.2	5.5	Double on edge	6	1 - #8, inner ribs 2 - #7, Outer ribs	1.8	61
9	19	86.2	82.2	5.5	Double on edge	6	1- #8, inner ribs 2 - #7, outer ribs (both on top)	1.8	61

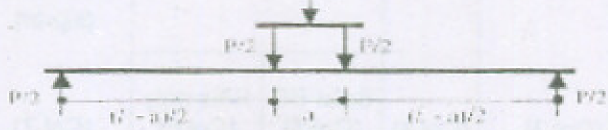
Table 1. Details Of the Selected Specimens.

Notes- Rib width for = 2.5 in. for specimens 1 to 6 ; 1.375 in. for specimen 7 & 2,5 in. (inner) and 2.25 in. (outer) for specimen 8 and 9.

- Specimens 2, 6 and 9 are for negative bending with steel on top.

TEST PROCEDURE AND RESULTS

The samples were tested as simply supported one-way slabs by providing line-roller and line-hinge supports along the two edges. The load is applied vertically downwards through reaction frame and press jack. For negative bending, the specimens were placed upside down on the supports but the load was again applied downwards. The load was measured using a calibrated pressure cell and was distributed on the slabs in the form of two equal and symmetrically places line loads. The distance these line loads, *a*, is shown in Figure 1, and its values are given in Table 2. The slabs were tied by loose rope during the test to avoid mishaps in case of sudden failure. The position of loads and the supports are shown in figure. 1 and the testing arrangement is shown in Figure.2



igure 1. Load and Support Positions

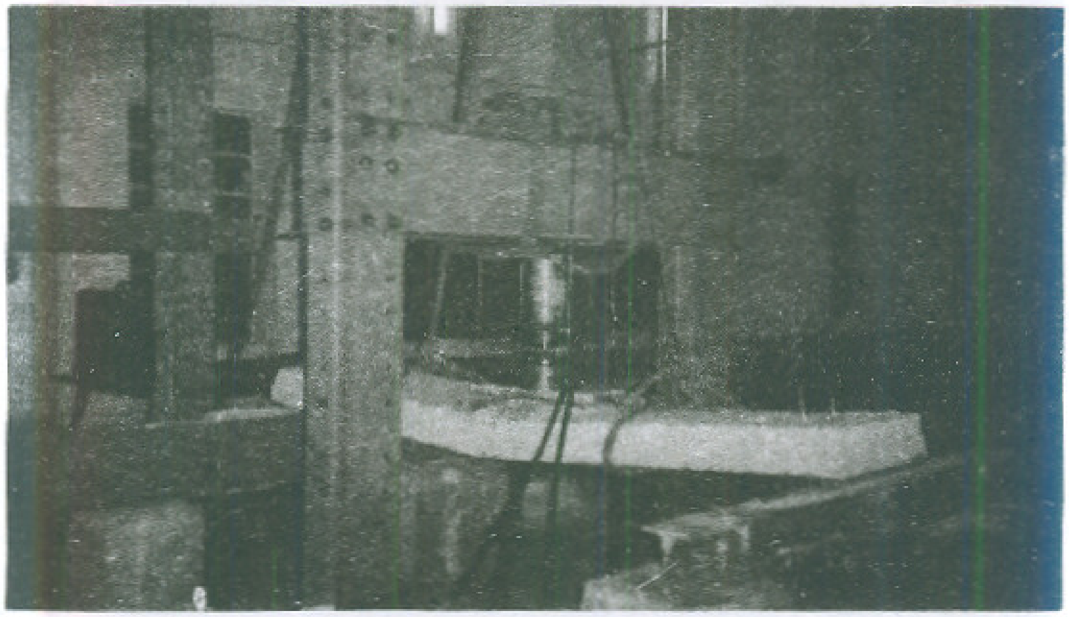


Figure 2. Photograph Showing Testing Arrangement

The theoretical flexural capacities using the solid RC and RC ribs analogies along with the experimental flexural capacities are listed in Table 2. The nominal moment resistance has been calculated just at the balanced failure. The ratios between the experimental and theoretical results are also given. Specimens 7 and 8 were observed to have a considerable honeycombing at the bottom around the steel and hence, these failed prematurely at lesser loads due to bond failure. This was obvious from appearance of large longitudinal cracks in horizontal plane around the main reinforcement. All other slab panels tested for sagging moments provided resistive moments in excess of those theoretically expected considering solid RC slab behaviour. For he slab panels tested for hogging moments, the results were higher than the theoretically expected solid RC results but lesser than the corresponding results for panels tested in sagging conditions.

Slab No. (Col 1)	Total Load (lbs) (Col 2)	Effective Span "l" (in). (Col 3)	Distance 'a' (in) (Col 4)	Theoretical Resistive Moment (kip-in)		Experimental Resistive Moment (kip-in) (Col 7)	Ratio of Col 7 w.r.t (Col 5 or Col 6)	
				Solid RC (Col 5)	Ribs only (Col 6)		Solid RC (Col 8)	Ribs only (Col 8)
1	9040	80	9	103.8	52.8	160.5	1.55	N.A
2	8380	80	9	103.8	52.8	148.7	1.43	2.82
3	8820	80	9	119.5	68.6	156.6	1.31	N.A
4	14460	94.5	12	190.9	109.5	298.2	1.56	N.A
5	11790	96.8	12	195.9	87.4	249.9	1.28	N.A
6	9790	96.8	12	195.9	87.4	207.5	1.06	2.37
7	5740	84	12	151	54.4	103.3	0.68	N.A
8	8050	82.2	12	147.2	63.5	141.3	0.96	N.A
9	9920	82.2	12	147.2	63.5	174.1	1.18	2.74

Table 2. Theoretical and Experimental Results for the Selected Specimens.

CONCLUSIONS AND RECOMMENDATIONS

It has been observed from the comparison of the theoretical and experimental results of the slab specimens that, for the positive moments, the RB slabs having the top concrete layer may be analyzed by using the solid RC slab methods. For negative moments, the RC ribs analogy gives a conservative estimate of strength and is not recommended to be used. However, this analogy reveals that actually the slab at the continuous ends may become over-reinforced if full negative steel is used. Three solutions are possible to overcome this problem. The first method is to consider flexural strength as 75% of the solid RC strength and to increase the overall depth of the slab to avoid the over-reinforced behaviour in area around the supports. This option will be expensive and is not recommended. The second and better method is to use the already present bottom steel on the supports as compression reinforcement and then design the slab at the continuous edges using the doubly reinforced RC ribs analogy. It is hoped that this treatment will give flexural strength close to the solid RC method, however, the bottom steel is to be properly lapped at the supports. The third suggestion may be to provide a strip of RC without bricks extending one foot from edge of each support.

It is observed, during the testing, that the bond between the concrete and the bricks does not break due to crushing load. In practice, the separation of bricks and concrete may tae place due to excessive moisture in case of faulty construction. Further, it is observed that if the compaction of concrete is not of the desired quality, the bond between the steel and the concrete may fail causing premature failure of the slabs. For two-way continuous slabs, it is recommended to use the moment coefficients given by Zahid and Ashraf (Ref.2), which are close to BS8110, in place of the ACI 1963 coefficients.

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