NOTES ON REINFORCED BRICKWORK

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NOTES ON REINFORCED BRICKWORK,

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VOLUME I.

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PREFACE.

These notes are based on experience gained during the construction of the New Capital at Patna, Bihar and Orissa.

I am much indebted to Messrs. Brij Narain, A. K. Datta, Rashid Ahmad and A. Karim, who helped to conduct the experiments carried out and supervise the work done and to Mr. Brij Narain also for much assistance given in the preparation of these notes.

Volume I contains notes and Volume II contains illustrations, experiment tables, comparative tables, plates, curve tables and plans; this arrangement being adopted for facility of reference to any of the latter when reading the letterpress.

A. BREBNER.

SIMLA;
24th August 1922.

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SECTION I.

INTRODUCTION.

Reinforced brickwork construction is in all essential features practically the same as reinforced concrete construction save that brickwork in cement mortar is substituted for cement concrete. The principles of reinforcement are similar and steel is used in various ways where necessary, as in reinforced concrete, to give the requisite strength to the material.

Structures of all descriptions have now for many years been built in reinforced concrete. This form of construction has long passed the experimental stage and at the present time there is scarcely any project which has to be tackled by civil engineers for which it cannot be usefully and economically employed in some way. In India, however, it has not been as extensively used as elsewhere and the reasons for this are not far to seek. In India the price of cement is high as compared with what it is in other countries and the price of bricks, tiles, etc., low, so that in the past it has almost invariably been found when designing, that some other form of construction was cheaper, to all intents and purposes as good, and had the further advantage of being comparatively simple and therefore more easily and cheaply supervised. Another very great obstacle to the substitution of reinforced concrete for other forms of construction in India is undoubtedly the fact that the Indian mason (mistri) and labourer (coolie) cannot be trusted to do good concrete work, unless constantly supervised by an efficient staff, and to arrange for this, more especially in out-of-the-way places is not always feasible. Every one who has experience of reinforced concrete construction in this country knows the great difficulty there always is in getting the labour to understand and put into practice the most elementary principles of good concrete work, not to mention the various troubles connected with the construction of centering and the correct placing of the reinforcement, no matter what detailed drawings may be provided. In reinforced brickwork construction all these difficulties very largely disappear and it will be found almost invariably that the cost of this form of construction is much lower than that of any other form of construction of a more or less permanent nature.

For some years now lintels over ordinary door and window openings have been built of reinforced brickwork—this method of construction being simpler, cheaper, and neater than older methods such as arches and relieving arches, or T and angles with tiles or bricks between them. Partition walls of brickwork in cement suitably reinforced have also been used with certain limitations. It is only recently, however, that reinforced brickwork has been used extensively in other forms of construction, *e.g.*, in floors, roofs, staircases, chhujjas, overhanging cornices of all kinds, bridge-decking, etc.

The system was first introduced early in the construction of the New Capital for Bihar and Orissa at Patna and soon proved so economical and successful from every point of view that the Local Government decided to adopt it where possible, not only throughout the whole of the work on the capital but elsewhere in the province on all new construction. The Government of Bihar and Orissa also brought the system to the notice of the Government of India and the Government of Bengal, and suggested that it would be very suitable for work at New Delhi and elsewhere. As a result of this recommendation reinforced brickwork has been used for roofs and floors in several buildings in Bengal including the large hospital which was recently completed at Dacca. It is being extensively used in Government House, the Secretariats and in all the permanent residences being built for officials of the Government of India at Delhi and has also been largely adopted in works constructed by private enterprise with which Government has had no concern, being used in the following buildings among others :—

Buildings in the new town being constructed by the Tata Iron and Steel Company Limited at Jamshedpur.

The Hindu University at Benares.

Cotton mills, Improvement Trust, and other buildings, at Cawnpore.

The new Allahabad Bank buildings at Patna.

In all nearly 3,000,000 square feet have been laid in the last three years.

The advantages in the main of the system are :—

Advantages over other systems commonly in use.

I. Simplicity of construction.

II. Good, sound and permanent work involving very low repair charges.

III. Fireproof work.

IV. Neat and artistic appearance of the finished work, unlike that of jack arching or other systems in common use.

V. Cool rooms.

VI. Low cost. It is cheaper than any other form of pakka roofing.

I. (1) There is nothing in the construction which cannot be done by an ordinary Indian mistri and, while all the advantages of reinforced concrete work are retained so far as ordinary work is concerned, few of the difficulties inherent in such construction are met with.

(2) No special materials of any kind are required, all that is wanted are :—

(*a*) Bricks,

(*b*) Cement,

(*c*) Sand,

(*d*) Ordinary mild steel rods or bars.

There is, therefore, nothing used which any Indian bricklayer is not well acquainted with, and there are no heavy charges for specially manufactured materials or for freight in bringing the same to work site from the factory.

(3) The centering may be of a rough description provided it is strong. It need not be well finished as is essential in all reinforced concrete work and it can be used repeatedly.

(4) There is no question of stale or half-set material being used as is possible in reinforced concrete work since each mason is given the mortar dry and adds water to it as he proceeds with his work.

(5) The Indian bricklayer can do good brickwork though he cannot do good concrete work, and therefore not only is less supervision required but a less highly trained supervising staff is sufficient. It has been found that ordinary bricklayers quickly become expert and can be trusted to do good and rapid work after a week or ten days' practice.

(6) The reinforcement is inserted as the work proceeds and experience shows that it is not nearly so liable to displacement as it is in reinforced concrete work.

(7) There are not the same transport difficulties to out-of-the-way places as there are in the case of jack arch or T iron and tile roofs since there are no heavy steel sections to handle or carry long distances.

II. (1) There is nothing about the work which can deteriorate or require attention of any kind. The repair charges are therefore very low, in fact, negligible provided the brickwork is efficiently protected from weathering and from damp by cement plaster or something similar. It has also been found that roofs built of reinforced brickwork rarely, if ever, leak. In most cases they have a through cement joint between the bricks which forms as it were, an efficient rainproof course even if the terracing be not sound. Further there are no large steel sections round which cracks are likely to be set up by variation in temperature as frequently happens in forms of roofing in which rolled steel joists are commonly used.

(2) Floors, roofs, etc., can be constructed to take any load.

(3) After the work has set, holes of a fair size can be cut in it without detriment.

III. The work is fireproof. This is more or less obvious, but a reference to experiment 276, table XIX will show exactly what happens when reinforced brickwork is subjected to a fierce heat for many hours.*

IV. One of the main drawbacks to jack arch and T and tile floors and roofs, is their unsightly appearance when viewed from the underside. This is avoided entirely where reinforced brickwork is used. Ordinary sand lime plaster adheres readily to the surface of the bricks and a clean plastered ceiling is therefore easily obtained at a very low cost. This is clearly shown in the photograph of work done in Patna†. What is true of roof and floor slabs is equally true of other work such as cornices, balconies, etc. The whole of the steel reinforcement is completely concealed and no unsightly supporting brackets of any kind are required.

V. When compared with roofs of ordinary T and tile or reinforced concrete, a roof of reinforced brickwork is found to give a cooler room. This is obvious from the fact that it is thicker; as a rule the brickwork in cement is 6″ deep as against 2″ for tiles in tile roofs and about 4″ for concrete in reinforced concrete roofs — the terracing in all cases being the same.

VI. The cost of the work varies not only with the market prices of steel, cement, and bricks, but with varying conditions of design. In most cases it is found that there are several alternatives, any one of which can be adopted, and it is therefore not easy to give definite figures showing the extent of the saving effected by substituting this form of construction for others. In order to get accurate figures, each case must be considered separately. A comparison of the cost of reinforced brickwork and other roofs is given in Section VI. These figures are taken from notes kept of the cost of construction in Patna and may be considered a fair guide.

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* *Vide* photograph, Vol. II, page 22.

† *Vide* photograph, Vol. II, page 17.

SECTION II.

Description of the various forms of Reinforced Brickwork.

The similarity between reinforced brick and reinforced concrete structures has already been referred to. The principles of reinforcement are identical in both, the aim of the designer being to place the reinforcement in such a position that it will take up certain stresses; for this purpose in reinforced brickwork rods are well embedded in the mortar joints of the masonry in suitable positions. Experiments have demonstrated that the steel and the masonry surrounding it act as one compact mass in almost exactly the same way as the concrete and reinforcement in reinforced concrete work.

At first sight it would seem that brickwork could not be a homogeneous mass in the sense that concrete is, and that the regular joints in the work would present planes of weakness along which failure would readily take place. In practice, however, it has been found that this is not so. On the contrary it has been proved that this factor is so insignificant that it can be neglected. It has also been established that there is no reason why reinforced brick structures should not be as successful as reinforced concrete ones of a similar nature, provided ordinary precautions are taken in designing and carrying out the work.

It is now proposed to describe some of the more common uses to which reinforced brickwork can be put.

Reinforced brick slabs.

Reinforced brick slabs are eminently suitable for all kinds of floors, roofs and staircases in buildings and for the decking of bridges. They are simply and quickly constructed and can be designed to carry any load. In practice they are supported either on two sides, four sides, or built in on one side (cantilever).

Slabs constructed of ordinary bricks, which throughout this paper are taken as nominally 10″ × 5″ × 3″, are limited to certain definite depths, namely 3″, 5″, 6″ or combinations of these, *i.e.*, 3″ slabs are made by laying bricks flat, 5″ by laying bricks on edge, and 6″ by laying two courses one upon another in the ordinary manner. A flat course *plus* a brick-on-edge course can be used to make up 8″ slabs, 9″ to 10″ slabs are made of three courses flat while 10″ slabs have also been constructed of bricks on end. Though very satisfactory from the point of view of strength and appearance of the finished work, slabs of greater thickness than 6″ are generally too heavy and expensive for ordinary use.

In referring to the depth of slabs it is usual to give the thickness in terms of brick dimensions neglecting the depth of horizontal mortar joints, *e.g.*, a 6″ slab is made up of two courses of brick laid flat, each therefore 3″ deep *plus* a joint and has an actual depth of 6″ *plus* one joint. A similar convention is used as regards the spacing of reinforcing rods, thus the distance apart specified indicates the brick intervals at which rods should be placed and does not take into consideration the thickness of the mortar joints as will be seen from the sketches in tables I to XX.

(a) Slabs supported on two sides only.

In slabs freely supported on two sides and subjected to transverse loading, the tensile stresses are developed in the lower fibres and therefore the steel is embedded near the lower surface of the slabs. When slabs have their ends fixed, there is tension in the upper fibres near each end and top reinforcement is necessary. Similarly cantilevers and continuous slabs require top reinforcement, the former throughout their length and the latter for some distance on each side of every intermediate support. The amount of reinforcement at top or bottom depends on the amount of bending moment, negative or positive, respectively.

Roof slabs are covered as a rule with lime concrete terracing, and floor slabs with cement concrete artificial stone, commonly called patent stone. It is obvious that the strength of such slabs is considerably increased by this surfacing, once it is set; but it must be borne in mind that this strengthening of the slabs only occurs when surfacing is on the compression side.

In 3″ slabs, the reinforcement can be placed about 5 inches or 10 inches apart, according to the arrangement of the bricks. Figures 1 and 2 show this clearly. The distance apart of reinforcement will vary slightly according to the actual size of bricks, as, in each case, it will be the width or the length of the brick *plus* one mortar joint.

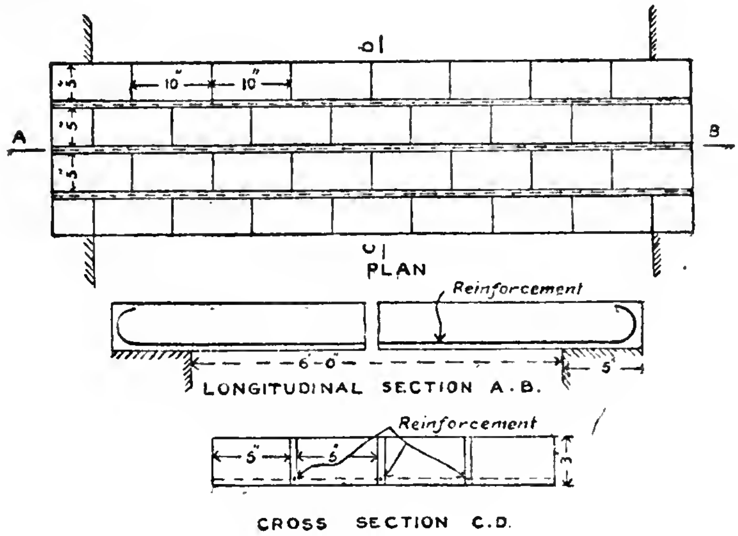

Figure 1.

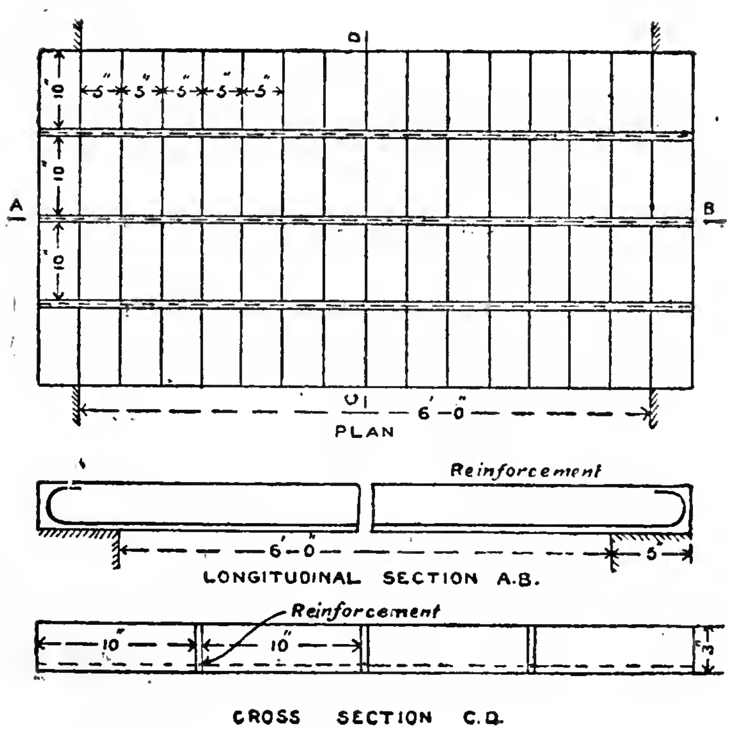

Figure 2.

The reinforcement in 5″ slabs, which consist of bricks on edge, can be placed in any of the ways shown in the cross sections given in figure 3. The arrangements shown in (*a*) and (*b*) are preferable to (*c*) as the reinforcement is more evenly distributed, also since the bricks can be arranged so as to break joint sideways as in sketch (*d*), thereby giving greater uniformity in the brickwork.

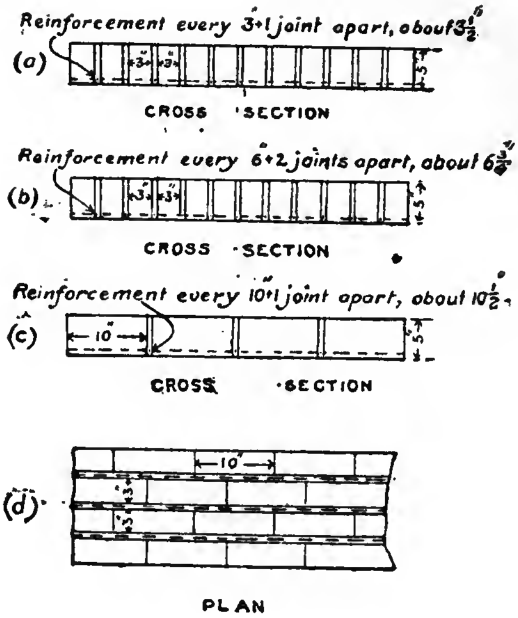

FIGURE 3.

The sketches in figure 4 illustrate various ways in which bricks can be arranged for 6″ slabs. There is a simple break joint between the upper and lower layers and reinforcement can be spaced $5\frac{1}{2}$″ or $10\frac{1}{2}$″ apart (called for the sake of convenience 5″ or 10″) as in the case of 3″ slabs according to requirements.

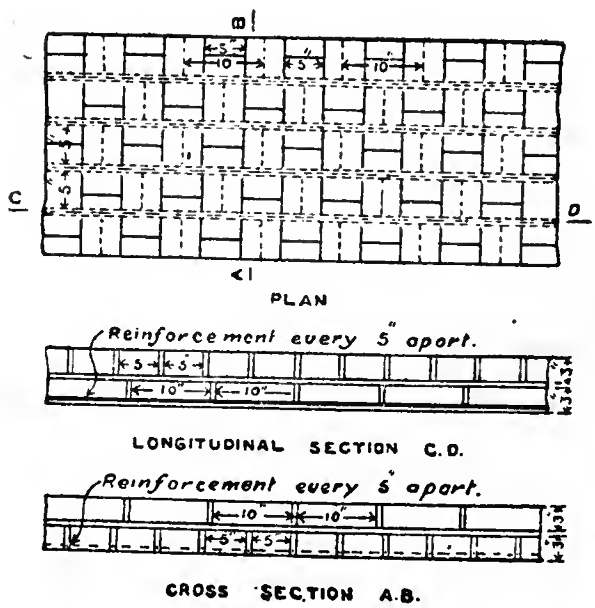

FIGURE 4.

Figure 4 shows bottom reinforcement every 5″ apart, but if it is desired to place it 10″ apart, the arrangement of top and bottom courses can be interchanged. It is desirable, however, to break joint where possible between the top and bottom layers.

Figures 5 and 6 below indicate how 8″ and 9″ slabs may be laid, these in practice will seldom be used except in special circumstances. They are not as a rule economical to construct.

FIGURE 5.

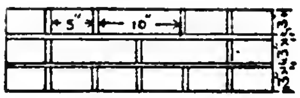

FIGURE 6.

Typical designs for 3″, 5″ and 6″ slabs supported on two sides, as commonly used in roof and floor construction in dwelling houses are given in plate 3, while plate 5 shows a typical design for a slab continuous over two intermediate beams. It will be noticed that some top reinforcement is given in each design, even where the ends are free. This is done to guard against the tendency, which is present in many cases on account of the mortar from the slab sticking to the bearing on the wall, for the slab to act as partly fixed at the supports. When carrying out experiments it was found that, unless precautions of this nature were taken, slabs supposed to be free acted as partially fixed during the earlier stages of the test, and this invariably resulted in the slab cracking at the top near the ends. When top reinforcement is given at the ends it takes up stresses due to this temporary negative bending moment and prevents cracking. The negative bending moment disappears when the load on the span is increased sufficiently to lift the ends of the slab.

Reinforced brick slabs have also been successfully used as decking for road bridges. In such cases not only are the slabs themselves heavily reinforced, but cross reinforcing is desirable so that loads may be distributed as well as possible. Designs which have proved satisfactory in testing are shown in table XIV. Staircases also can be very conveniently constructed in the same way as ordinary floor slabs. A form of construction for these is illustrated in plate 2, figure 8 and plate 8, figures 3 and 4.

(ii) Cross reinforced slabs supported on four sides.

Where the area to be covered is square or approximately square—the ratio $\frac{\text{length}}{\text{breadth}}$ should not exceed 1·3—it is best and most economical to run reinforcement both ways and to support the slab on all four sides. When the ratio $\frac{\text{length}}{\text{breadth}}$ is greater than 1·3 it is more economical to reinforce in one direction only. When cross reinforcement is adopted it is obvious that it is impossible to break joint sideways in the bottom course of a 6″ slab, but this is not essential in such cases. A typical design for such a slab, for a roof 16′×15′ clear span, is given in plate 4.

(iii) Cantilevers.

Cantilevers may be made either of slabs ; or stepped, the depth increasing towards the support. Examples of both classes and also an idea of how they can be used for projecting balconies, cornices, and chhujjas are given in plate 8, figures 1 and 2.

Reinforced brick lintels, beams, walls, columns and arches.

Lintels.

Reinforced brickwork is particularly well adapted for the construction of lintels over door and window openings. The brickwork of the lintel can go on without holding up the brickwork of the wall or in any way altering the arrangement of the joints. If in such cases the centering can be conveniently left up for any length of time, the lime masonry sets and will then act along with the cement masonry, thus considerably increasing the strength of the lintel and reducing the amount of steel required. Examples of this class of work are given in plate 7, figures 1 to 4.

Beams. Reinforced brickwork beams are very convenient where the loads to be dealt with are not heavy and where a large number have to be made. Beams for heavier loads such as may be met with in bridges can also be designed, but they are heavy and somewhat clumsy though much less expensive than reinforced concrete beams of similar strength would be. Many such beams, some carrying well over 100 tons, have been built and have proved entirely successful. The results of tests carried out on a 40′ span girder are shown in experiment 160, table XI.*

Ordinary rectangular and T beams of reinforced brick, and of combined reinforced concrete and brick, have been successfully designed in many cases and are easily constructed. In designing such beams ample provision should be made against shearing stresses, and for this both stirrups, and rods inclined near the ends, have proved efficient. Plate 5 gives a typical design of a T beam of reinforced brick only, while plate 6 gives a design for a beam of reinforced brick and concrete combined. It will be noticed that concrete is used only in the lower portion of the beam where most of the reinforcement is located, the reason being that the reinforcement is much more easily arranged and securely packed in concrete than in brickwork in such cases. Except in this position it is not, as a rule, economical to substitute concrete for brickwork.

Embedded rolled steel joists. When reinforced brick slabs run continuous over intermediate rolled steel joist supports, it is possible to connect the joists and the slab rigidly by building the upper flange of the joists a few inches into the slab and casing the rest of the web and lower flange in cement concrete or cement brickwork. If this is done, stirrups, passing round the bottom flange of the joists and having their ends well anchored into the slab, should be provided. When so treated the slab and joist form a sort of T beam. The carrying capacity of the joist is thereby considerably increased, and hence in most cases a lighter section can be used than would otherwise be possible. It will be seen from table XII, experiments 162-163, which give figures of joists so treated, that the loads carried at failure are in each case considerably in excess of the loads at failure carried by a plain joist of the same section, *vide* experiment 161, table XII.

Partition walls. Reinforced brick partition walls are already well known to most engineers as a very useful type of structure. Not only are they light, cheap, and easily constructed, but what is not so commonly known is that they can be made self-supporting with very little extra expenditure. For instance a wall can be constructed in the first floor of a two-storied building without any corresponding supporting wall on the ground floor.† Such a wall is self-supporting and is merely hung from the side walls. It should be designed not so much to carry a load as to stand a lateral thrust and accordingly should have reinforcement near both the faces. When considered from the point of view of the vertical load to be carried, it can be treated as a very deep beam and hence a comparatively small amount of reinforcement in the bottom courses is enough, not only to make it carry its own weight but also that of a roof or floor supported on it. In practice such walls have been made 3″ or 5″ thick, and it is not necessary to make them any thicker. The former have been used successfully up to a 10′ span, and the latter up to a 20′ span. There seems to be no reason why they should not be used on larger spans than these. Care must, however, be taken to see that the shear stresses in such walls are not excessive.

Experiments tend to show that partition walls constructed almost wholly of lime masonry (only the courses containing reinforcement being constructed in cement mortar) are also very successful, *vide* table XIII. In such walls hoop iron is very commonly used as reinforcement, but small round sections may also be used and are probably better. One point to be borne in mind is that the partition walls should be carried well into the side walls, say at least a foot so as to have ample bearing. They should also be bonded into the brickwork of

* *Vide* photograph, Vol. II, page 14.
† *Vide* plans, Nos. 2 and 3, Vol. II.

the side walls. The sketches for experiments 167-172 in Table XIII show how such walls are made and reinforced.*

Longitudinal reinforcement in reinforced brick columns is of little use alone, but when combined with hooping at close intervals it is most efficient. In actual practice reinforced brick columns have not been much used as it has generally been found simpler and not much more expensive to construct either reinforced concrete columns or to provide steel stanchions. The figures shown in Table XVII(*e*), experiments 242-265, are, however, very interesting as showing what can be done. Columns.

Reinforced brick arches have been tried and tested in Patna and found very useful, not because of the fact that reinforcement aids in compression but because it prevents cracking. If there is any bending action due to concentrated or unsymmetrical loading in the arch or to an unequal settlement or yielding in abutments, it is advisable to reinforce symmetrically near the intrados and extrados and combine the reinforcement together at frequent intervals by hoops. The tests given in Table XVIII, experiments 266-269, are of interest in this connection. Arches.

* *Vide* also photographs, Vol II, page 15.

SECTION III.

Practical Execution of Reinforced Brickwork.

In the preceding sections a brief general description of reinforced brickwork has been given and it has been claimed that it is easier and simpler to construct than reinforced concrete work. It is now proposed to give, in as concise a manner as possible, the main points which require careful attention during construction, and to offer suggestions which are likely to be found of practical use in carrying out work.

The main requisites of good reinforced brickwork are:—

I. Sound centering.
II. Good materials.
III. Careful work.

Centering.

As in reinforced concrete work, some form of centering is required on which the work can be constructed and supported, until such time as the mortar has set. Elaborate and expensive centering and shuttering such as is essential in reinforced concrete work is, however, not required. In different localities various suitable materials are available, and it is not proposed therefore to lay down any hard and fast specification. Typical kinds of centering, which have been extensively used with success, are illustrated in Plate 1, figures 1 to 5, and anything of a similar nature will probably be found to serve the purpose equally well.

The simplest type, and that which is most generally used, consists of a platform composed of planking or sheeting at the required level, supported on runners or beams and covered with a thin layer of well-beaten earth finished off with a sprinkling of fine sand.*

It is essential that whatever centering be used it should possess the following properties:—

1. Rigidity.
2. Simplicity of construction, slackening and removal.
3. A smooth surface on which to lay the slab.

Rigidity. The centering must be rigid. By this is meant that it should not sag under the weight of the workmen constructing the slab. It should be tested beforehand by being jumped on, and if there be anything very perceptible in the nature of a "give" about it further stiffening should be provided.

Simplicity of construction and removal. No special difficulties are likely to be met with in erecting centering. The following points should, however, be noted at this stage:—

(*i*) Care must be taken to see that all centering planking is kept clear of the bearings for the slab and rests on cross beams only.

(*ii*) If planks are used they should not be laid too close to each other as they may jam and there may be difficulty in removing them.

(*iii*) All cross beams should be carried on the walls, supported at intervals if necessary by rough timbering (*bullahs*) or temporary dry brick pillars.

(*iv*) Cross beams should rest directly on wedges and not on the supporting walls themselves. This permits of the centering being easily and rapidly struck and removed, and does away with any chance of jarring the finished work.

The length of time for which centering should be left up after construction depends on many conditions, such as the specification of mortar used, the season of the year and the span of the beam or slab. It is therefore not possible to lay down any hard and fast rules on the subject. The practice followed in Patna, as noted below, may be taken as a guide:

(*a*) Centering for ordinary slabs from a minimum of about 5 days in summer to a maximum of about 10 days in winter provided there is no frost.

(*b*) Centering for specially heavily reinforced slabs from 7 days to 15 days.

(*c*) Centering for ordinary beams 10 to 15 days.

(*d*) Centering for important beams carrying heavy loads 28 days.

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* The top surface of the centering should be given a camber as below to allow for initial settlement.
For slabs, about $\frac{1}{12}''$ for every foot of span up to a maximum of $1\frac{1}{4}''$.
For beams about $\frac{1}{16}''$ for every foot of span up to a maximum of $1\frac{1}{2}''$.

R. B. slabs are usually finished with lime concrete terracing for roofs, and patent stone for floors. The terracing may be done after 21 days, but it is better to wait for a month. Patent stone should be done as soon after the R. B. slab is finished as possible, preferably before removing the centering, unless, perhaps, in the case of slabs continuous over beams, where it should be laid as soon after the removal of the centering as possible. This aspect of the question is more fully dealt with on pages 21 and 22. If in the case of continuous slabs supported on intermediate R. S. joists, it be decided to use the joists themselves as supports for centering, care must be taken to see that they are propped up to prevent excessive deflection during construction, otherwise on removal of the load due to centering, the slab may be damaged when each or any joist springs back to its normal position.

Where T beams of R. B. are combined with the R. B. slab, several arrangements of centering are possible, but whatever arrangement is adopted, care must be taken to see that it is possible to remove the slab centering without interfering in any way with that for the beam. This is essential as the slab centering is invariably removed some days before the rib centering.

In constructing R. B. ceilings below tile or other sloping roofs, the centering may be very simply hung from the lower member of the supporting trusses by means of specially constructed clips as shown in Plate 2, figure 6. This method was very successfully employed during the construction of the Secretariat building at Patna where 130,000 square feet of ceiling were laid in a few months.

Suitable centerings for lintels, beams, and staircases, are illustrated in Plate 2. These are perfectly simple and straightforward and require no explanation.

When the time comes to ease and remove centering great care must be taken to see that no jarring of any kind occurs. All wedges should first of all be carefully drawn. This separates the supporting beams and planking from the R. B. construction and readily permits of the removal of centering and supports. In fact all operations in connection with the removal of centering must be gently performed. It is desirable to impress this on everyone connected with the work at the very outset, otherwise accidents may occur and in any case centering is needlessly damaged and destroyed.

Type of surface required.

As has been explained above, the simplest and cheapest way to obtain a smooth surface is by spreading earth to a depth of about 1″ over the planking or sheeting, as the case may be. This is then beaten flat and finished off with a thin sprinkling of fine sand. The earth is required to level up the inequalities in the planking, to help to distribute the weight of the workers and to admit of the requisite camber being given, while the addition of sand gives a smooth surface on which the bricks can be quickly and truly laid and prevents adhesion of the clay to the bricks which would otherwise occur. Care must be taken to see that only a fine sprinkling of sand is given, since, if too much be given, there is always risk of the bricks sinking into it when laid, and in any case mortar may be sucked from the joints, an evil which cannot be over-exaggerated.

Materials.

The materials used in R. B. are :—

(*a*) Bricks,
(*b*) Cement,
(*c*) Sand,
(*d*) Steel reinforcement.

Bricks.

Only the best bricks complying with the usual 1st class specifications should be used in R. B. Hardness is a desirable quality, but brittleness is not, while anything approaching a smooth glaze on the surface, such as is sometimes observed in over-burnt (*jhama*) bricks, is also undesirable as mortar will not adhere well to bricks with such a surface.

The following qualities are also desirable :—

(1) *Low absorption.*—If nothing else is obtainable and porous bricks have to be used working stresses must be correspondingly reduced.

(2) *Freedom from saltpetre.*—Bricks having too much saltpetre are unsuitable for R. B. and should not be used.

It is also advisable to test specimens of the bricks intended to be used in R. B. both in tension and compression.

Tension tests may be carried out by carefully cutting briquettes (similar to cement briquettes used in testing cement and cement mortars) out of the bricks, and testing these in the ordinary manner in a cement-testing machine. Bricks giving a tensile strength of about 200 lbs. per square inch may be accepted with confidence.

For compression tests whole bricks may be tested in a Buckton machine, but such bricks should not have any 'frog' as this would introduce irregularities. If 'frogless' bricks are not available 2″ cubes may be cut out of bricks and tested. A breaking stress of about 1,200 lbs. per square inch or over, indicates sufficiently good bricks. Where a Buckton machine is not available rough and ready tests may be made with a temporary apparatus similar to that illustrated below.

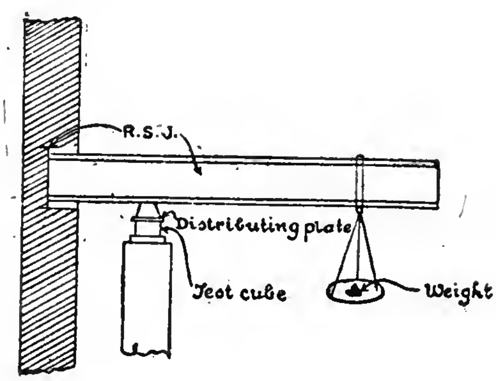


FIGURE 7.

Sand.

Sand should be clean, well graded, *i.e.*, there should be particles of all size from $\frac{3}{16}''$ diameter to the very finest grains, and if possible sharp. Sharpness is not absolutely essential if the grading is good and the sand otherwise sound. It should be free from organic and vegetable matter, and should also be as free from clay and mica as possible. Although some authorities are of opinion that the presence of small quantities of clay actually improves cement mortar, there is always the fear that if too much be allowed the mortar will be weakened.

The presence of mica in the sand is objectionable as a micacious sand requires a greater proportion of cement to produce a mortar equal in strength to mortar made from a sand free from mica and otherwise equally good. Unfortunately, most sands are micacious and the only thing to be done is to determine by actual experiments the proportion in which it has to be mixed with cement to produce a suitable mortar.

Too fine sand should not be used as it requires extra cement to be added to produce good mortar.

Ganges sand which is both very fine and micacious was discarded in Patna in favour of sand dug from pits in the old bed of the river Son. The latter was found to be clean, fairly coarse, sharp and well-graded and entirely free from mica. It gave uniformly satisfactory results.

Cement.

The cement used must comply in every way with the standard cement specification. Both Katni and Bundi cement were used extensively in Patna and gave excellent results. It must also be fresh—any cement which shows signs of staleness should be rejected. Samples of all cement used should be regularly tested.

Mortar.

The mortar used should consist of cement and sand in proportions varying according to the quality of sand available. (Throughout work at Patna the proportions used were 1 of cement to 3 of sand by volume, mixed dry, and it was found that this gave very satisfactory results.) Only enough water should be added to make the mortar of such a consistency that is easily workable, leaves the trowel clean, and can be readily packed round the reinforcement bars.

It will generally be found that 3:1 is a sufficiently rich mixture, but the best proportions should be found by experiment whenever possible. Proportions which ensure that the following results are attained should be adopted :—

(1) Mortar briquettes made in the usual way should give a breaking tensile strength of 150 lbs. per square inch when one week old and not less than 350 lbs. per sq. inch at an age of six months.

(2) Short columns built of single bricks one upon another set in the mortar should have an ultimate breaking stress of not less than 1,200 lbs. per square inch after 28 days.

(3) Adhesion stress between bricks and mortar should not be less than 25 lbs. per square inch. This can be tested by pulling apart bricks, set one upon another crosswise, with a mortar joint between them. For this test the bricks should be well soaked with water before the sample is made, and the sample after being made should be kept under water until the time of test. If the bricks are dry at the time of construction or soon after, the test is unfair.

(4) Bond stress between a round steel rod and mortar should be at least about 400 lbs. per sq. inch of the embedded surface of the rod after 28 days.

It will usually be found that a mortar satisfying the tension test satisfies all other tests.

For beams and other heavily reinforced work, where the bond stress is likely to be high, it may be advisable to use a mortar richer in cement than the mortar used for ordinary slabs where the bond stress is low.

Mixing of mortar at work site.

All mortar used in work must first be thoroughly mixed dry and water should on no account be added except by the masons employed on the work and then only in small quantities. Too great stress cannot be laid on this point. If these precautions be ignored there is every likelihood that stale mortar will be used.

From long experience it has been found that the most suitable method is to have the mortar mixed dry in some central position where this work can be easily supervised, and then have it distributed. If this method be adhered to, each mason need only add water in his iron pan (*karai*) and there is therefore no fear that the mortar will be partially set when used. Needless to say, this method can only be adopted when the sand is really dry. Only clean water should be used.

Steel reinforcement.

Only the best mild steel should be used as reinforcement. As far as possible only steel of circular section should be used. Square sections may also be used but flats or angles should be avoided. If they have to be used care should be taken to see that the bond stresses are kept very low.

In floor and roof slabs no section of greater diameter than $\frac{1}{2}''$ should be used, and as far as possible only small sections such as $\frac{1}{4}''$, $\frac{5}{16}''$ and $\frac{3}{8}''$ should be used. Sections in beams should not be larger than 1″ diameter for main reinforcement and $\frac{1}{2}''$ for shear reinforcement. Hoop iron although unsuitable for slabs and beams is suitable for reinforcing partition walls.

A little rust on the reinforcement is desirable as it ensures good adhesion, but all loose and scaly rust should be removed prior to use. Hoop iron with a bluish glazed surface should not be used; if it has to be, then it should be immersed in water for a few days. This produces rusting and effectively destroys the glaze on the surface.

The ends of all rods should be bent into semi-circular hooks of a diameter at least six times the diameter of the rod itself with a short length of straight rod beyond the bend.

As far as possible overlapping should be avoided by ordering rods of proper lengths, but where this cannot be done and overlapping has to be resorted to, a lap of 50 diameters should be given with proper hooks at the ends and the two rods should be bound with wire along the lap.

Workmanship, etc.

The main points under this heading which require careful attention are :—

(*a*) That all bricks are thoroughly soaked before being used. This hardly requires any comment; dry bricks are sure to suck moisture out of the mortar joints and thus interfere with setting. All bricks should be soaked for at least six hours in a soaking vat before being used.

(*b*) That bricks are properly arranged as they are laid. Where possible, the arrangement should be shown in drawings, but it may be laid down as a general principle that joint should be broken wherever possible as this gives increased strength.

(*c*) That reinforcement is properly arranged. Before starting work all rods should be prepared and bent to the correct lengths and shapes shown in the drawings and where possible laid out *in situ*. If this is done difficulties will be anticipated and cutting and overlapping reduced to a minimum. Rods of the correct length should be used, but where this is not possible overlapping may be resorted to as detailed above. Welding should not be permitted.

(*d*) That all joints are well filled and all reinforcement well surrounded by mortar. This requires careful attention as workmen unless watched are apt to scamp the work or grout the joints. Both faults are objectionable and apt to lead to trouble unless checked. All reinforcement must be thoroughly surrounded by mortar otherwise slipping and rusting may take place and adhesion, on which the strength of the structure depends, does not develop fully. Care should be taken that the bottom rods in slabs have a real cover of mortar under them and do not touch the centering surface. The mortar used must be fresh and mixed wet only just before using as described above. The importance of this cannot be overestimated.

The masons engaged on the work should when possible squat on a plank and not on the centering itself. Planks should also be laid so that it will never be necessary to walk over newly finished work.

(*e*) That the work after completion is properly looked after and watered. All work should be kept moist by means of wet straw, wet sand, or merely sprinkling water, for the first and part of the next day after finishing. It should then be profusely watered and kept wet until one or two days before the removal of centering. A low mortar wall or *kiari* might be made all round the slab to hold about $\frac{1}{2}''$ depth of water on it. A clear day should be allowed for dry setting before the centering is removed. The work should be kept wet or moist until it is about a month old.

(*f*) As far as possible, each structure should be finished in one operation and in one day, but there will be occasions when this is not possible and in such cases the following hints may be of use:—

(*i*) Ordinary slabs supported on two sides may be left after finishing any layer of reinforcement.

(*ii*) Cross reinforced slabs, *i.e.*, having reinforcement in two directions may, if absolutely necessary, be left somewhere near the middle, that is, when half the slab from one side is laid.

(*iii*) Beams may be left near the centre (section of least shear and maximum bending moment) but as far as possible, these should be finished in one operation and as the size is seldom very large this can nearly always be done. Ordinary T beams with a continuous slab, in which all the shearing action has been provided for in the shape of stirrups, may be left after completing the rib portion provided the stirrups project from the rib almost to the top of the slab. The slab should be built over the rib not later than two days after completion of the rib. In all such cases the work on the remaining part of the structure should be resumed very early, the next day if possible.

(*g*) Careful removal of centering at the correct time and avoidance of shocks when carrying out this part of the work.

This has already been dealt with on page 10 when discussing the removal of centering. But it cannot be too often emphasized that anything in the nature of shocks is bound to be distinctly harmful.

SECTION IV.

Results of Experiments.

When the proposal that R. B. should be used for the floors and roofs of new buildings under construction in Patna, was first put forward by the Executive Engineer, the Local Government were somewhat averse to its acceptance, as they did not consider they were justified in adopting, on a large scale, a system which had not been thoroughly tested. The rapid rise in the cost of rolled steel joists and other steel work, however, left them no alternative but that of stopping work altogether, a course which would have been disastrous in view of the advanced stage which the work had reached. As the preliminary experiments which had been carried out had proved successful and had established beyond doubt the fact that the cost of work done in this system was very considerably less than that of any other in common use, it was decided to introduce it and at the same time to carry out a large number of experiments with a view to testing it thoroughly in every way. Tests, extending over a period of nearly two years, were accordingly made on practically every kind of structure likely to be met with in ordinary building work, and the final results of these are given in detail in Tables I to XX in Volume II. The following are some of the types of structures experimented on—

Types of structures experimented on.

1. Roof and floor slabs of all kinds supported on two sides, generally reinforced in one direction only, with or without covering such as cement concrete, patent stone, terracing, etc.
2. Roof and floor slabs supported on four sides, generally reinforced in both directions.
3. Lintels over doors, windows, etc.
4. Beams.
5. T beams and long-span beams suitable for bridge girders.
6. Brickwork beams reinforced with rolled steel joists.
7. Hanging partition walls with and without door or window openings.
8. Slabs capable of being used over culverts or as decking of road bridges.
9. Columns.
10. Arches.
11. Special experiments.

It was felt from the first that R. B. was a system more or less allied to reinforced concrete, and the investigations therefore ran on somewhat similar lines to investigations made in regard to the latter. Generally speaking, enough steel was embedded in the joints of the brickwork to take the tensile stresses while the brickwork was relied on to take up the compression. Local conditions and the abnormal prices of some of the materials of necessity played a large part in the evolution and development of the practical details.

In Patna the following conditions obtained :—

(1) 1st class bricks suitable for the work cost Rs. 12 per thousand at site.
(2) Very good sand for cement mortar was available practically at the site of the work and cost only about Rs. 2-8-0 per hundred c. ft.
(3) The price of cement varied, but most of it was obtained at Government-controlled rates and cost about Rs. 3 per c. ft. at site. Katni cement was principally used.
(4) The cost of steel rods for reinforcement averaged about Rs. 30 per cwt.

As one of the chief objects in introducing the system was to effect economy, the above conditions influenced the designs and consequently the lines on which the experiments were conducted. The following constructional principles were evolved to ensure economy in cement and steel which were the most expensive items :—

(1) Mortar was made just rich enough in cement to give the requisite safe adhesion with steel as well as brick.
(2) Joints in which there was no reinforcement were made as thin as was consistent with strength and good work.

(3) Reinforcement was, as a rule, placed in the joints between the bricks which therefore naturally ran straight without break. Much brick cutting and consequent use of a large amount of excess mortar was thus avoided. The only exception was in the case of heavily reinforced beams with a lot of steel crowded together near the bottom, where it was found easier and more economical to use concrete instead of brick work on account of the thickness of joints and the extra labour required to fit the bricks in properly, in the latter.

(4) Joints containing reinforcement were only just thick enough to give a sufficient coating of mortar all round the reinforcement rods, $\frac{1}{8}''$ to $\frac{1}{4}''$ depending on the diameter of the reinforcement.

In view of the high price of steel it was found that it often paid to increase the depth of the brickwork slightly and decrease the amount of reinforcement.

The experiments were conducted on the most practical lines possible; in fact with the exception of certain special tests which were carried out with special objects in view, it may be said that all experiments carried out were tests of designs about to be used in construction.

Objects of experiments

The main objects in view were:—

(1) To find the most suitable type of structure and reinforcement for roof and floor slabs, beams, walls, etc., on various spans, and under different conditions of loading and fixing such as are met with in ordinary practice.

(2) To determine the various constants required in analysing the strength of structures, *e.g.*, safe adhesion between mortar and steel rods, between bricks and mortar, the tensile and shearing strength of brickwork, and the compressive strength of brickwork in slabs, columns, beams, etc.

(3) To ascertain if a theory similar to that on which reinforced concrete construction is based could safely be applied to R. B. structures under suitable practical conditions.

(4) To devise safe rules for designing.

(5) To determine the best type of centering for various purposes and the time it should be left in position before being struck.

(6) To determine other practical details essential to the execution of good work, *e.g.*—

(*i*) The camber to be given in structures under transverse stress to allow for initial settlement during construction and immediately after the removal of centering.

(*ii*) The advantages, if any, of introducing bonding in the brickwork.

(*iii*) The best method of overlapping and hooking the ends of reinforcement rods.

(*iv*) Richness, strength and setting properties required in the mortar.

(*v*) The best methods of joining up old to new work.

Before passing on to an examination of results of the tests as tabulated in Tables I to XX, it may be explained that the results of all tests carried out—whatever the result was—are incorporated in these tables. Many of them, more especially those carried out in the early stages when information on the subject was distinctly limited, were not as successful as might have been, but as failures are generally at least as instructive as successes, it has been decided to include the results of all tests made.

Behaviour of a slab gradually loaded to destruction.

An ordinary R. B. slab not too heavily reinforced on being tested to destruction acts as follows:—

For some time the slab remains comparatively stiff and deflections are small. The bending moment couple is resisted, the tension by the steel rods and the brickwork below the neutral axis, and the compression by the brickwork above the neutral axis. This goes on until the appearance of the first minute crack in brickwork which appears after the limiting stresses in tension in the extreme fibres of the brickwork are passed. The position of the neutral axis now rises. As the load increases more minute cracks appear in the brickwork and eventually the stage is reached when practically all the tension is taken up by steel and all the compression by brickwork. The rate of deflection is now more than it was when the brickwork was acting in tension. This stage continues until the steel has reached its yield point and in many cases even much beyond it. The excessive stress tends towards the deformation of the steel, but this is resisted by the adhesion between steel and mortar. Ultimately the stress reaches a point where the adhesion begins to fail. When this occurs there is a sudden increase in the rate of deflection and soon afterwards the slab fails.

The failure in ordinary circumstances is very gradual, the slab sinking down. There is nothing in the nature of a regular collapse. The curve of deflections if drawn accurately will usually be found to be of the shape sketched below :—

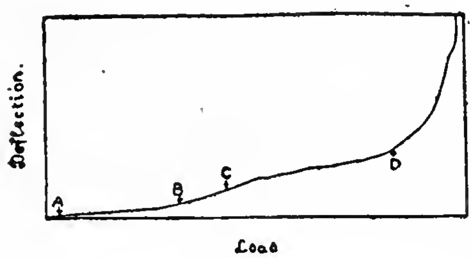


FIGURE 8

The portion of the curve from A to B represents the period before the appearance of first crack, from B to C the period when cracks are appearing, C being the limit after which practically very little tension is being resisted by brickwork. The limit after the yield point of steel has been reached, when the adhesion begins to fail and complete failure is not far off, is shown by the point D. The cracks extend further and further up towards the compression face and nearly reach the top when suddenly the remaining thickness of the brickwork is crushed.

Whether any reinforcement rods are broken or not at failure depends on the nature of the reinforcement and the stresses at which failure occurs. It is found that in most cases where light section rods, say, up to $\frac{5}{16}''$ diameter are used as reinforcement, they are broken at failure—while in cases where larger sections are used the rods are seldom broken. It is also found that the bigger the section of the rod used, the lower the stress in steel at which failure occurs, and *vice versa.* A study of the results given in tables I to XX will make this very clear. The explanation evidently lies in the fact that rods of smaller section have area for area a larger surface in contact with the mortar than heavier rods, and consequently the bond strength is greater. Thus four $\frac{1}{4}''$ diameter rods and one $\frac{1}{2}''$ diameter rod have equal sectional areas, but the former has twice the surface of the latter.

In heavily reinforced slabs failure sometimes occurs through excessive compression in brickwork and not by excessive tension in steel. In such cases failure is apt to be sudden and accompanied by a cracking sound. Small wedge-shaped pieces of brickwork separate from the slabs near the compression surface, and there is usually no marked sudden increase in the rate of deflection.

Failure in slabs seldom occurs on account of shearing or slipping of rods at the ends if the work is good because these stresses are generally very low.

Method of testing.

In the tests made at Patna the loads were applied by piling up bricks, and in some cases sand, on slabs. When the load applied consisted of bricks care was taken to see that bonding did not occur.

Tests of slabs of various kinds.

Tables I to VIII and XIV give results of tests of slabs of all kinds, and also give the calculated stresses at final failure both in masonry and steel. These stresses have been calculated on the assumption that a theory similar to that for reinforced concrete holds good for reinforced brickwork. The modular ratio $\frac{E_s}{E_b}$ for steel and brickwork has been taken as 40 throughout the tables and calculations based on experimental results. In all the tables the loads at failure are shown in lbs. per square foot of the slab and are external loads only. They do not include the weight of the slab. The dead weight has, however, been taken into account in calculating the stresses. Centerings were seldom removed before the sixth day and most of the tests to destruction were carried out at the age of about three weeks.

On removal of centering there was usually a very slight deflection. This varied in amount and had probably something to do with the hardness of brickwork at the time of removal. In heavily reinforced slabs and slabs with patent stone over them there was very little deflection and often none at all. To allow for this settlement some camber was generally given in slabs at the time of construction.

The 'first indication of failure' which is also tabulated is somewhat difficult to define, as failure is very gradual in normal circumstances. It may be considered as the point at which definite signs of distress appear, *e.g.*, sudden increased deflection or many and extensive cracks.

Tests of 3″ slabs.

Table I shows experiments of plain 3″ slabs, supported on two sides. The results obtained are all satisfactory as will be seen from the table. The failures occurred well after the point when the steel had passed its elastic limit. The stresses in steel at failure vary from 46,800 lbs. per square inch to 55,100 lbs. per square inch. It will also be noticed that in experiments 2 and 3 where flat reinforcement was used the failure stress is lower than in case of experiment 1 where round steel was used. Generally speaking, flat bar reinforcement was found not to be so good as round bar, while heavier flat sections were proved to be distinctly unsuitable. The depth to the centre of gravity of steel in 3″ slabs is small, and if big sections of steel are used this is still further reduced. This is a point to be remembered in designing such slabs. The experiments carried out are on an 8′ span, but the loads taken are all low—about 40 lbs. per square foot being the maximum. Such a slab would not do for roofs or floors, but makes a cheap and useful ceiling under a tiled roof. In practice such a slab would only be used for a floor or a roof on spans up to 5′.

Tests of 5″ slabs with free ends.

Table II gives the results of tests of 5″ slabs, supported on two sides. Such slabs have been tried up to 12′ span for floors and roofs but it has been found that unless the ends are well fixed or an inordinate amount of reinforcement is given the deflection in a span of more than 10′ is excessive. The results of the tests are all satisfactory, failure in most cases being due primarily to the steel being stressed well beyond its elastic limit. In these cases the stresses in the slab at failure vary from 43,000 lbs. per square inch in experiment 12 to nearly 79,000 lbs. per square inch in experiments 17 and 18. It will be noticed that the stress is high where the steel section used is light, $\frac{1}{4}$″ diameter round bar for example, and low where the section is heavy—$\frac{7}{16}$″ and $\frac{1}{2}$″ diameter round bar. In experiments 20 and 21 the failure is due to the excessive compressive stress in bricks. It is probable that excessive compression is also partly responsible for failure in experiments 9 to 12. The extreme fibre compressive stresses at failure vary from about 1,100 to about 1,250 lbs. per square inch.

Experiment 23 is a case of a somewhat complex failure. The stress in steel is 50,000 lbs. per square inch which would explain the failure, but the stress in masonry is 2,245 lbs. per square inch which is very high, so that probably the failure is due to both tension in steel and compression in masonry. One unusual factor in this experiment is that the joints were about 2″ thick and were filled not with 3 : 1 cement mortar as usual, but with 1 : 2 : 4 cement concrete. This may explain the high compressive stress taken.

Tests of 5″ slabs with "fixed" ends.

Experiments 27 and 28 were of slabs which had their ends 'fixed', and were reinforced at the top near the ends to take up the tension in upper fibres due to the negative bending moment. The ends were fixed by piling up loads at the ends over the bearings.* The results of these and other experiments referred to later show that it is extremely difficult, if not impossible, to obtain perfect fixing. In all cases the ends lifted slightly before failure.† The actual bending moments at the ends and centre of the span are therefore uncertain.

* *Vide* Photograph, Vol. II, page 6.
† ,, ,, ,, page 5.

External loads at failure of 165 and 151 lbs. per square foot were taken, *vide* experiments 27 and 28 respectively. A comparison of the latter result with that of experiment 13 on a slab containing practically the same amount of reinforcement but with free ends, which took only 25 lbs. per square foot external load at failure demonstrates the great advantage derived by having the ends of a slab even partly fixed.

In 5″ slabs the limit of steel sectional area per foot width of slab after which the failure occurs by crushing of bricks seems to be about ·37 square inch corresponding to about ·75 per cent.

Table III gives tests of 6″ slabs, supported on two sides. This particular type of slab has given the highest results in the matter of strength and should be used in preference to a 5″ slab provided it is not unduly extravagant to do so. **Tests of 6″ slabs with free ends.**

The failure stresses in steel when small sections of reinforcement are used vary from about 60,000 lbs. per square inch to about 80,000 lbs. per square inch. A reference to experiments 2, 3 and 19 will show that where $1'' \times \frac{1}{16}''$ hoop iron is used as reinforcement the fibre stress is a little lower than where a round rod section of about the same area is used. Experiment 32 is on a slab reinforced with hoop iron laid flat and the failure stress in this case is 78,700 lbs. per square inch which proves that hoop iron when laid flat gives better results than when placed vertically in the joints, the reason probably being partly that flat sections when placed vertically show a tendency to buckle sideways when the slab bends thus causing longitudinal cracks.

Experiments 33 to 37, table III were carried out with a view to determining the most efficient method of joining up rods to provide for cases where single rods of adequate length are unobtainable. This is a very important practical problem, as rods of the full length required cannot always be obtained and some form of lapping has to be resorted to. The results of these experiments prove that a lap joint of 40 diameters gives the full strength which would be expected from a whole piece. Experiment 33 with whole rods took 109 lbs. per square foot at failure while 34– with a lap of about 40 diameters and suitable hooks at the ends—took 114 lbs. per square foot. Experiments 35 to 37 give relative strengths of a 40 diameter lap, a weld and a whole piece respectively. Welding, however, cannot be recommended on account of its uncertainty. A lap without hooks is evidently weaker than a whole piece, so that a lap of 40 diameters minimum with hooked ends is obviously the best solution.

These experiments together with two others, are separately tabulated for the sake of comparison in comparative table 5.

Experiment 38 is in some ways a special test. The slab was loaded and unloaded several times, all deflection disappearing each time the load was removed, it was then subjected to load for a period of about 8 months during which it was exposed to all sorts of weather conditions, and was ultimately tested to destruction. The final test, however, gave satisfactory results and the high stress developed in steel, *viz.*, 64,800 lbs. per square inch proves that there was no loss of strength. The same is true of experiment 42.

It will be noted in the case of 6″ slabs, even where heavy sections of steel were used, that the stresses developed in the steel were, usually over 50,000 lbs. per square inch before failure. In experiments 52 to 57 failure is due to excessive compression in masonry. Experiments 52 and 53 give rather low figures for the extreme compression stress at failure, *i.e.*, about 970 lbs. per square inch, but this is explained by the presence of inferior bricks near the centre of span, which shows how important it is that only first-class bricks should be used, more especially where stresses are likely to be severest. Experiments 54 to 57 give compressive stresses at failure varying from about 1,250 lbs. per square inch to about 1,600 lbs. per square inch.

In 6″ slabs if the steel per foot width is about 0·45 square inch or over, corresponding to a percentage of about ·7, failure is in all likelihood primarily due to the crushing of bricks.

Experiments 62 to 67 are on 6″ slabs fixed at the ends. More or less perfect fixing was only obtained in the case of experiment 62; in all other cases it was not perfect and the slabs failed quickly once the fixing was destroyed. All the slabs, however, took very high loads and were very stiff; this although **Tests of 6″ slabs with "fixed" ends.**

showing once more the difficulty of getting perfect fixing, demonstrates the great increase in strength derived by even partially fixing the ends. If therefore moderately good fixing can be relied on, it is possible to use slabs on larger spans than would otherwise be the case.

How easy it is to produce some fixing action is clearly indicated in experiment 63. In this case one of the ends of the slab merely rests on a beam and the other is butted closely against a wall, yet a very considerable fixing action was noticeable and the slab took 126 lbs. per square foot, while an exactly similar slab with free ends, *vide* experiment 58, took only 49 lbs. per square foot. A comparison of the loads taken by similarly reinforced free and fixed slabs, *e.g.*, 58, 61, 62, 64 and 65 further shows clearly the advantage of fixing. Theoretically if the fixing at ends is perfect the B. M. in the centre of the span should be $\frac{wl^2}{24}$ as against $\frac{wl^2}{8}$ in case of free ends, but in practice such a value cannot be adopted with safety.

Tests of slabs over 6″ thick.

Table IV contains the results of tests of slabs thicker than 6″. The object in carrying out these tests was to see how far it is feasible to adopt plain slabs for roofs or floors on big spans in cases where it is desirable to have an absolutely flat ceiling. In actual practice they are not likely to be as economical as beams and lighter slabs, and will therefore seldom be used, except possibly in square and approximately square rooms or in residences and offices where appearance is the main consideration.

Experiments 68 and 69 are on slabs 8″ deep made up of one brick on edge and one brick flat, the reinforcement being $\frac{1}{2}''$ diameter rod and $1'' \times \frac{1}{4}''$ flat bar respectively. The results obtained in the case of the round bar are more satisfactory than in the case of the flat, but both have given quite fair results, the steel having passed well beyond the elastic limit before failing.

Experiment 70 on a 9″ slab with a span of 20′ also gives a fair result, the failure again being due to tension in steel. The stress at failure in this case is only about 39,000 lbs. per square inch. This is rather low compared with other results obtained when $\frac{1}{2}''$ diameter rods are used. At the same time it has to be recognised that the brick stress is fairly high, and if this be limited to say, 300 lbs. per square inch, the permissible total load for this slab would be, as the total weight of the slab is 90 lbs. per square foot, $\frac{300}{970}$ (258+90) about 110 lbs. per square foot total, *i.e.*, 110—90=20 lbs. per square foot external load. This would correspond to a steel stress of $\frac{300}{970} \times 38{,}400$ or about 12,000 lbs. per square inch nearly, so that while bricks would be fully stressed the steel would be understressed.

Experiment 71 gives figures of a test of a $16\frac{3}{4}''$ deep slab on a 30′ span. The failure in this case is again due to crushing of bricks. The compressive stress works out to 1,872 lbs. per square inch. Here the dead load alone would ensure a compression stress in the brickwork in the neighbourhood of 350 lbs. per square inch and to ensure the stress in the brickwork being kept within the permissible limits the steel will have to be very much understressed. Another solution would be to deepen the slab, but this would, of course, add considerably to its weight.

9″ slabs (composed of three courses of bricks laid flat reinforced in both directions, *vide* pages 22 and 23) have been extensively used with excellent results in rooms of large span in the new building for the Allahabad Bank recently constructed at Patna.

Although more expensive perhaps than 6″ slabs with beams at intervals, 9″ slabs have undoubted advantages in that :—

(*i*) they give a flat ceiling throughout,

(*ii*) they give a very cool room,

(*iii*) they make an absolutely water-tight roof as there are two through cement mortar joints which prevent any possibility of leakage.

Tests showing the strength of R. B. as compared with R. C.

Comparative table 2 gives detailed results side by side of experiments carried out on similarly reinforced brick and concrete slabs. These prove beyond doubt that both types of structure behave in a similar manner, the only difference being that R. C. slabs are stiffer owing to their higher modulus of elasticity. This is what one would expect. It therefore follows that a theory similar to reinforced concrete theory holds for R. B. structures.

Tests of R. B. slabs supported on two sides covered with 1″ cement concrete artificial stone, usually called patent stone, such as is commonly used in most buildings for floors are given in table V, experiments 72, 73 and 75 to 83. In all these tests the patent stone acted along with the slab and increased its strength immensely. This is only natural as, apart from the fact that the effective depth of the slab is increased, the patent stone acts in compression and as the compressive properties of cement concrete are higher than those of brickwork it adds considerably not only to the strength but to the stiffness of the slab. Tests of R. B. slabs supported on two sides finished with patent stone or lime concrete terracing.

From the R. C. tests which are given side by side with R. B. in comparative table 2 it would appear that when the depth is not too great a R. B. slab with patent stone finishing has exactly the same final strength as a reinforced concrete slab of the same effective depth. A comparison of the results obtained in experiments 79 and 87 shows that a R. B. slab finished with 1″ artificial stone takes 259 lbs. per square foot as against a R. C. slab which takes 260 lbs. per square foot, both having practically the same reinforcement and effective depth. These results are very close, and it is justifiable to infer from them that the strengths are the same. The reason is obvious as in both cases the steel takes the tension, while in the concrete slab all the compression is taken by concrete and in the R. B. and patent stone slab nearly all is taken by the patent stone. A glance at the stresses will show that the failures have all taken place well after the point of elastic limit of the steel and the tests are therefore satisfactory.

In a similar manner lime terrace on a roof, once it has set also increases the strength very much (owing to the increase in effective depth). Results of tests on such slabs are given in table V, experiments 88 to 91. All experiments carried out on slabs finished with lime concrete terracing show that the slab and the terracing act together and not separately as might have been expected. No tendency for the two to separate has ever been noticed.

The results of these experiments as noted above show conclusively that the gain in strength due to patent stone or terrace is very considerable, provided always that the slab is not a continuous one. The following precautions are, however, necessary if this gain is to be made use of in designing :—

(1) Patent stone should be laid along with or soon after the slab and stirrup-shape bindings should be given to join the patent stone to the slab. If the patent stone is done sometime after the slab is constructed there is the possibility of the two separating in course of time.

(2) Terrace takes a long time to set and should be allowed at least three months before it is stressed; even then it is not desirable to count too much on the extra strength. It is better to look on it as increasing the factor of safety. A reference to experiment 91 table V will be of interest in this connection.

Comparative table 3 shows very clearly the advantages of a covering of patent stone or terrace over slabs.

In calculating the stresses in the tables the lever arm of the moment of resistance couple was taken as 0·9 d in case of slabs with patent stone, allowing for a little extra stiffness due to patent stone and 0·8 d in case of terracing, allowing for the softness of the terracing. Even for considerable variations of the modular ratio $\frac{E_s}{E_b}$ or m the variation in the value of the ratio $\frac{a}{d}$ is small. Stresses in concrete slabs are calculated with $m = 15$.

Table VI gives experiments on slabs continuous over supports. The results are all satisfactory except for experiment 96 where large sections of flat iron 2″ × $\frac{1}{4}$″ and $1\frac{1}{2}$″ × $\frac{1}{4}$″ were used as reinforcement. Here failure was not due to excessive tension or compression, but to the disintegrating action of the reinforcement on the slab when subjected to bending. It may here be noted that it was clear to the observer on more than one occasion when tests of slabs reinforced with large flat bar sections were being made, that such sections when stressed tend to buckle and thus introduce a splitting action in the slab and thereafter try as it were to kick the mortar out of the joints and free themselves. For this reason large flat sections are quite unsuitable as reinforcement and should Tests of slabs continuous over supports.

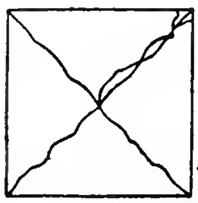
not be used. It will be seen besides from table XVI that their adhesion with mortar is much poorer than that of round bars of a similar area. This is of more importance in case of beams where adhesion stresses are high. In slabs such stresses are as a rule negligible.

Experiments 97 to 100 show that when continuous slabs have patent stone or terracing laid on them before the removal of centering, or when the slab is subjected to heavy loads, the patent stone or terrace tends (as is quite natural owing to the negative bending moment) to crack over the intermediate supports. This shows clearly that for continuous slabs it is best to remove centering before laying patent stone or terracing in such cases, but if this be not done then some reinforcement should be embedded in patent stone or terrace near the top surface over the supports, say, for a distance of $\frac{1}{4}$ span on each side.

Experiment 101 is really a case similar to that of a cantilever bridge. There are end spans of 10′ and a central one of 15′. The slabs of the end spans run into and form a small cantilever in the centre span taking the load of the central slab, the span of which is thus reduced to 10′. This saves reinforcement and would seem to be a possible solution for the roof of a long barrack with verandahs on both sides.

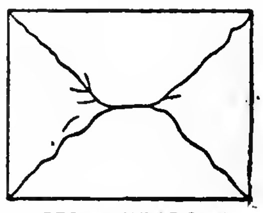
Tests of slabs supported on four sides and reinforced in both directions.

Table VII gives results of tests of a slab supported on all four sides and reinforced in both directions, also results of two experiments, 110 and 111, of slabs which were supported on four sides but had reinforcement only in one direction. These slabs with the exception of the two referred to failed by sagging and at failure exhibited cracks somewhat of the nature shown in figures 9 and 10.



SQUARE SLAB.

FIGURE 9.



RECTANGULAR SLAB.

FIGURE 10.

In all cases when the slab deflected the *corners only* lifted slightly from the bearings.*

The stresses have been calculated on the assumption that the theory adopted by the French Government, which gives the bending moment reduction coefficients as $\frac{r^4}{r^4+2}$ for the short span and $\frac{1}{2r^4+1}$ for the long span in the case of slabs reinforced in both directions is correct; r being the ratio $\frac{\text{long span}}{\text{short span}}$.

In view of the high failure stresses obtained in all these experiments it would appear that the designer is at any rate on the safe side in applying this formula and following French practice. It may also be mentioned that several hundred thousand square feet designed on the above principles have been laid with excellent results.

The fact that only the corners lift when the load is applied would seem to indicate that the effective portion which deflects is approximately circular in case of square slabs and elliptical in case of rectangular slabs. If this is assumed as being correct and it is further inferred that the maximum B. M. in case of a square slab is the same as that in case of a circular slab having a diameter equal to the side of the square, the B. M. given by the above rules for the square agrees exactly with the B. M. given by the ordinary theory for a circular slab.

Experiments 102 and 103 are on 3″ cross reinforced slabs on an 8′ × 8′ room, and 104 to 106 on 5″ slabs up to 20′ × 20′. A comparatively low result is obtained in experiment 106, but in this case it is apparent that the depth was insufficient for the span and therefore the deflection was unduly high, resulting in extensive cracks on the tension side in

* *Vide* photograph, Vol. II, page 8.

brickwork at an early stage. This probably affected the efficiency of steel as tensile reinforcement and caused failure. It may be added that this test was one of the earliest made before much was known about reinforced brickwork. The results of tests 107, 108 and 109, on 6″ cross reinforced slabs are excellent. A comparison between tests 107 and 109 will show that continuity over a support does not interfere with the strength of cross reinforced slabs provided top reinforcement is given over the support. In fact, the strength is increased.

Experiments 110 and 111 show clearly the dangers of omitting to give cross reinforcement when there are supports on four sides. Until the limit of tensile strength of brickwork is reached nothing happens, but as soon as this is passed the slab cracks along the reinforcement and may separate into three parts A, B and C as shown in sketch figure 11, the centre part B acting as an independent slab supported on two sides only. This actually happened in experiment 110.

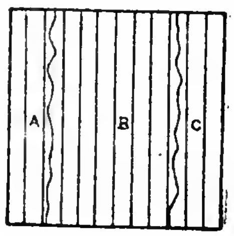


FIGURE 11.

Up to the point where the separation takes place, the strength and stiffness, however, is increased, as a comparison of experiment 110 with experiment 61, and experiment 111 with experiment 18 will show.

The stresses in steel at failure except in the case of experiment 106 are all above 60,000 lbs. per square inch.

Tests of Cantilevers.

Table VIII gives results of tests of cantilevers. These on the whole are not so satisfactory as the results in the case of slabs, the failure stresses being lower. Experiments 119, 121 and 122 are definite cases of early failures, the first on account of imperfectly set mortar and the last two on account of other causes, faulty construction in case of No. 122. Other results are fair, the stresses in steel at failure varying from about 32,000 lbs. per square inch to about 50,000 lbs. per square inch. **Tests of cantilevers.**

Perhaps the lower resisting qualities of the cantilever are due to the comparatively excessive deflection which naturally takes place. This damages the brickwork in tension. Although not recommended as a form of construction for overhanging balconies likely to have to carry loads, it can be used very easily and cheaply for chhujjas and cornices. Balconies if likely to have to sustain heavy loads are best constructed by carrying an ordinary slab over R. S. joists built into the wall.

Experiments 123, 124 and 125 are on " stepped " cantilevers the depth of which increases towards the bearing. These have given good results.

Tests of lintels, beams, walls, etc.

Table IX gives the results of tests of lintels. In experiments 126 and 127 the results are rather low owing to the fact that an insufficient covering of mortar was given to the reinforcement. Experiment 129 is a failure due to the slipping of reinforcement at the ends, thus again showing that with hoop iron and flat bars adhesion is low. **Tests of lintels.**

Experiments 132 to 135 are interesting as showing that brickwork in lime over a lintel combines with the R. B., once it has set, and increases its strength immensely, while experiments 136 and 137 show the dangers of relying too early on the strength of lime mortar as this takes a long time to set.

Tests of R. B. beams.

A comparison of experiment 138 (free ends) with experiments 139, 140 and 141 (butted ends) shows the advantages derived by butting which is partly in the nature of fixing.

Failures of R. B. beams when due to excessive tension in steel or excessive compression in brick are very similar to slab failures. But there are two other ways in which failure may occur in beams :—

(*i*) By diagonal tension due to shear.

(*ii*) By the slipping of reinforcement at ends.

In both of these failure is apt to be sudden, in (1) it is accompanied by the sudden appearance of diagonal cracks near the ends as shown in fig. 12.*

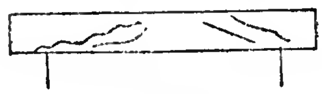


FIGURE 12.

Tests of R. B. rectangular beams.

Table X gives results of tests of rectangular beams. These are all satisfactory, the failure stresses in steel varying from about 50,000 lbs. per square inch upwards.

Experiments 142 and 151 show examples of shear failure, the shear stress in the case of the former being 78 and in the latter 66 lbs. per square inch. There was, however, very little shear reinforcement provided. Tests 146 and 147 are interesting; 147 is of a beam entirely composed of R. C., while 146 is of R. B. with 3″ of concrete near the central portion longitudually about on middle third and to full width. Compressive stresses are high. Both have taken the same external load which indicates that concrete and brickwork act together and also that the laws governing R.B. are the same as those governing R. C.

Tests of T. beams and long-span beams suitable for bridge girders.

Table XI gives results of tests of R. B. T beams and beams made of R. B. which have their main reinforcement embedded in concrete for the sake of convenience, to ensure correct spacing of the reinforcement and in order to avoid wide joints and much cutting which would be inevitable if the reinforcement was laid in brickwork. The results are satisfactory and very instructive.

The failure in experiments 152 and 153 was due to excessive compresion in the brickwork, the stresses, being respectively 1,775 and 1,664 lbs. per square inch The failure in experiment 153 was really a complex one being partly due to shear, the shearing stress being 131 lbs. per square inch. Shear reinforcement was only partially provided.

Experiment 158 shows another case of shear failure, the final shear stress at failure being 133 lbs. per square inch. Here there was very little reinforcement for shear. The failure in experiment 159 was due to tension in brickwork and shear combined. The load it will be noticed was not put on the beam direct but was suspended from R.B. hangers projecting out of the body of the beam, thus causing direct tension stresses in horizontal planes. The shearing stress at failure was 129 lbs. per square inch. If the maximum direct tension stress be added to this it would produce a total tension of about 170 lbs. per square inch.

All the other tests failed primarily on account of tension in steel, the stress varying from about 40,000 lbs. per square inch upwards.

Experiment 160 is of exceptional interest. It is of a girder† on a 40′ span capable of taking heavy loads such as are common on road bridges. This girder was fully reinforced for shear. The failure occurred on account of the tension of steel, but just at failure diagonal tension cracks also appeared, the approximate shearing stress being about 170 lbs. per square inch. In other cases where shear reinforcement was less it may be noted that the failure due to shear occurred at about 130 lbs. per square inch.

Test 154 is of an inverted T beam. This type of construction is sometimes useful where flat ceilings are essential, and the result shows that it may be relied on if proper allowances are made for shear and direct tension.

* *Vide* also photograph of experiment 142, Vol. II, page 11.

† *Vide* also photograph of experiment 160, Vol. II, page 14.

On the whole these experiments show that stirrups are a sound type of reinforcement against shear, and that if reinforcement has been given to take up the whole shear the beam may be relied on to take its full load. The shearing stress must, however, not exceed about 60 lbs. per square inch in the masonry.

Experiments 156 to 158 are all on T beams and the results show that the slab acted along with the rib and that there was no tendency for it to separate even in experiment 158 when there was a definite horizontal joint between the slab and the rib.

Experiments 155, 159 and 160 all had bricks arranged in horizontal courses: there was, however, no tendency towards cleavage. The beam acted as a whole throughout.

Tests of embedded R. S. joists.

Table XII gives the results of tests of R. S. joists embedded in brickwork. Joists are often embedded in masonry or concrete, generally for the sake of appearance but also sometimes to prevent rusting. It is not always realized, however, that if this be done carefully the strength of the joists is increased very materially. For instance, if a slab is continous over a joist it increases the strength of the joist very much if the upper flange is built 2 or 3 inches into the slab, and its bottom flange covered over with cement concrete or brickwork, adequate stirrups being also provided for additional binding. The joist when in conjunction with the slab acts practically as a T beam and its strength is thereby increased considerably.

Experiment 161 gives the deflections of a plain joist under certain loads. The results may be compared with experiments 162 and 163 which have the same section of joists boxed up and built into a slab.* The plain joist takes only 3·39 tons at failure, whereas the structure in experiment 162, takes 9 tons and in experiment 163, 13·65 tons. The load taken on test 162 being less than that in test 163 shows that it is better to box up the whole joist than leave the lower flange unboxed.

Other figures in the same table show the results of embedding joists of larger sections and the loads actually taken when compared with those which could be expected according to R. C. theory, both being tabulated, thus showing clearly that the increase of strength is definite, determinable, and often considerable.

The failures in the ease of the lighter sections, *viz.*, $4'' \times 3''$, *vide* experiments 162 and 163 occur in the ordinary way by tension in steel, but when the section is heavy there is a tendency for separation to occur between the slab and the joist. Stirrups are therefore very necessary.

Tests of R. B. walls.

Table XIII gives the results of tests of R. B. partition walls suspended from main walls. Experiments 167 and 168 are tests on 3″ walls, the rest on 5″ walls. These walls were given reinforcement on both sides to withstand lateral thrusts, but were tested as beams. The failure in most cases is due to shear, the great depth being enough to make the tension in the steel very low. Failure stresses in shear vary from about 60 lbs. per square inch, in experiments 167 and 170 (not reinforced for shear) upwards. Diagonal rods appear to play a considerable part in resisting shear action.

Tests of slabs suitable for bridge decking.

Table XIV gives the results of tests of heavily reinforced slabs suitable for decking for road bridges. They have taken most of the customary road loads and failures have occurred at high stresses. The results are therefore satisfactory.

Tests of lintels, slabs supported on two sides and of slabs supported on four sides, all without reinforcement.

Table XV gives the results of tests of lintels and slabs without reinforcement tested transversely. They bring out the general fact that by breaking joint in the lower courses the tensile strength of brickwork is increased. The tensile strength of brickwork with straight joints according to the lowest results is about 50 lbs. per square inch after 7 days, but other results give about 120 lbs. per square inch after about three weeks, *vide* experiment 204.

The strength of brickwork with break joints is probably in the neighbourhood of 150 lbs. per square inch on the average, the highest result obtained in these tests is 251 lbs. per square inch after 53 days, *vide* experiment 179, table XV.

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* *Vide* Comparative Table 6, Vol, II.

Experiments 205 to 209 give some interesting results of tests of slabs without reinforcement supported on four sides. These need no comment. When such slabs are tested to destruction they fail suddenly, without much warning, as opposed to reinforced slabs which, when properly reinforced, fail very gradually and give plenty of warning; for this reason, if for no other, non-reinforced slabs are not suitable even for small spans as they might very well collapse during a severe earthquake.

Adhesion tests. Experiments 210 and 211, table XVI, show the extent of adhesion existing ordinarily between bricks and mortar. The results are quite low, the average being about 25 lbs. per square inch.

Experiment 212 gives the tensile strength of bricks tested like cement briquettes, the average is about 171 lbs. per square inch.

Experiment 213 shows the amount of adhesion between steel rods and mortar. This is a most important point and one which deserves close study as the whole action of reinforcement depends upon the existence of this adhesion. The tabulated results show that round rods give better results than flat rods and that 2 : 1 mortar gives slightly better results than 3 : 1 mortar. The adhesion between round bar and 2 : 1 cement mortar is 512 lbs. per square inch at 28 days. In 3 : 1 mortar it is 276 lbs. per square inch at 7 days and 382 lbs. per square inch at 28 days. In the case of flat bar the figures are lower, the adhesion between 2 : 1 mortar being only 143 lbs. per square inch after 28 days.

Compression tests of masonry.

Experiments were carried out, *vide* tables XVII (a) to (e), to determine :—

(1) The compressive strength of bricks alone.

(2) The compressive strength of lime concrete.

(3) The compressive strength of brick masonry in 3 : 1 cement mortar.

(4) The effect of reinforcement on the compressive strength of brickwork.

Only a portion of these tests, those of bricks alone shown in table XVII(a), were carried out at Patna ; most of the others, those shown in tables XVII(b) to (e) were carried out at Sibpur Engineering College, while some were made at Delhi.

From most of the compression tests it appears that failure is generally due to the tensile stresses developed in vertical planes owing to the tendency of the specimen to bulge sideways when compressed. This was proved by the appearance of vertical cracks at failure.

Tests of bricks alone. In Patna the tests were made on small brick cubes about $2'' \times 2'' \times 2''$ cut out of local first class bricks and although the contrivance employed, in the absence of a testing machine, sketched on table XVII(a) was rather crude—the results show a surprising degree of uniformity. The tests give a crushing strength varying from a minimum of about 1,100 to a maximum of about 1,600 lbs. per square inch. The actual average of fourteen tests is 1,331 lbs. per square inch.

Some whole bricks were also sent to Sibpur College and tested there. The results, although good, are not very uniform. This may be on account of the irregularity due to the frog mark on the bricks. Experiment 241, table XVII(d), gives 1,418 lbs. per square inch as the crushing strength while experiments 239 to 241 and 265 give 2,128, 1,497, 1,418 and 838 lbs. per square inch respectively as strength at first sign of cracking and 2,850, 1,900, 1,418, 1,535 at final failure. It must be admitted that 2,850 is unaccountably high while 838 is low.

In the case of cubes tested in experiment 241 it was observed that the first crack appeared at about 85 per cent. of the breaking load. The average crushing strength of fourteen specimens at total failure was 1,331 lbs. per square inch. This would mean an average of $1{,}331 \times \frac{85}{100} = 1{,}130$ lbs. per square inch at first sign of cracking. Combining this result with the above we get an average of 1,172 lbs. per square inch at first sign of cracking.

From these results it would appear that a good first class brick at Patna has an average crushing strength of about 1,170 lbs. per square inch at first sign of cracking and about 1,400 lbs. per square inch at final failure.

Table XVII(a) gives three tests which give an average of 656 lbs. per square inch as the compressive strength of lime concrete at six months. As noted elsewhere, however, lime concrete takes a long time to develop its full strength. **Tests of lime concrete.**

Compressive tests of brickwork in cement mortar give a wide range of results. These are shown in tables XVII (b) to (e). Even similar specimens when tested gave considerably varying results. There is also a considerable variation in the ratio of the loads at first sign of cracking to the final breaking loads. **Tests of brick pillars in cement mortar without reinforcement.**

Tables XVII(b) and XVII(c) give results of tests on brick pillars without reinforcement and as regards these, speaking generally, it may be said that single brick pillars without any vertical joints, *e.g.*, experiments 217, 218, 242 and 243 give the highest results. The average of these is 1,407 lbs. per square inch at final failure at an age of say, from ten weeks to three months and about 1,000 lbs. per square inch at first sign of cracking. The next best results are given by columns which have vertical joints but in which the joints are well broken. Experiments in table XVII(b) give the average strength of such pillars as about 574 lbs. per square inch at the age of twenty days. Experiments 244, 245, 248 and 259, table XVII(c), give the average strength after ten weeks as 936 lbs. per square inch at failure and 701 lbs. per square inch at first sign of cracking. Experiments 224 to 229 in table XVII (c) give the strength of similar pillars at fourteen weeks, and here the averages work out to 1,082 lbs. per square inch at failure and about 629 lbs. per square inch at first sign of cracking. Experiments 230 and 231, table XVII (d), give the compressive strength at the age of five months as about 1,240 lbs. per square inch and about 1,002 lbs. per square inch respectively at failure and first sign of cracking.

Pillars with unbroken joints give the lowest results in compression. Thus experiments 246 and 247 give an average strength of 723 lbs. per square inch at final failure and 481 lbs. per square inch at first sign of cracking.

I is evident from the above that in brick columns the real source of weakness is the continuous vertical joint. The bond between brick and mortar is weak in tension, *vide* experiments Nos. 210 and 211, table XVI, and columns having vertical joints fail earlier owing to the tension developed in vertical planes. When the vertical joint is not continuous the column takes a somewhat larger load because of the fact that the tensile strength of the bricks themselves also comes into play and helps matters.

Experiments 255 to 258, Table XVII(e) give some results of tests of combined brick and cement concrete columns. They do not show any extra strength due to the use of concrete. The explanation of this is again the weakness of the vertical joint where concrete meets brick. The average strength at ten weeks is 868 lbs. per square inch and this is not appreciably higher than the strength of ordinary columns of brick in cement. **Tests of combined brick and concrete columns.**

Tables XVII (d) and (e) give some results of tests of reinforced columns. The reinforcement is of two kinds :— **Tests of reinforced pillars.**

(*i*) Vertical.

(*ii*) Spiral or hoops.

It will be observed that the vertical reinforcement is not of much use and if used alone may even be dangerous on account of its tendency, unless thoroughly bound by hoops to bend outwards under loads and thrust out part of the masonry. A reference to experiments 234 and 236, 253 and 254 will show how harmful such reinforcement can be without adequate hoops.

Horizontal hoops as might be expected are a very good form of reinforcement as the results of experiments 232, 233, 250 to 252, and 260 to 264 all show. They take up the horizontal tensile stress developed and prevent the column from bulging. It will be seen from experiments 251 and 264 that columns so reinforced have stood fairly high stresses even though there is no break joint. Experiments 234 to 237 show that if anything in the nature of a thick paste is applied to the outside of the columns it very soon peels off under stress and its strength cannot be relied upon.

These experiments are enough to determine the safe compressive stress to be allowed in various types of structures.

With a factor of safety of between 3 and 4 the following may be taken :—

Safe compressive stress when the compression is limited to the thickness of one brick	350 to 400 lbs. per square inch.
Safe compressive stress when compression is not limited to one brick	250 lbs. per square inch.

Lime concrete from 60 lbs. at the age of one month to 150 lbs. per square inch at the age of 6 months.

Another constant which it is necessary to ascertain is the modulus of elasticity of brickwork, E_b. Unfortunately no experiments carried out with a view to measuring this directly from compression tests on pillars have so far been successful. Attempts have been made to derive its value from observations of deflections of slabs and beams. From these it would appear that its value is about $\frac{1}{40}$ of the modulus of elasticity for steel, E_s *i.e.*, the ratio $\frac{E_s}{E_b}=40$ at ordinary stresses. It also appears that $\frac{E_s}{E_b}$ is not a constant but varies with the intensity of stress, its value being in the neighbourhood of 60 near the crushing point of brickwork. It is fortunate, however, that this unknown factor does not produce great variation in the value of calculated stresses as far as beams and slabs are concerned. Even a fifty per cent. variation in the value of $\frac{E_s}{E_b}$ does not alter the stresses materially. In any case it does not seem that by adopting the value $m=40$, which appears to hold good for brickwork done at Patna, calculations would be far out.

Tests of reinforced arches.

The results of a few tests carried out of arches are shown in table XVIII. The data obtained are not very valuable from the point of view of determining the effect of reinforcement on an arch, but it shows the great strength of jack arches and even of flat arches in lime mortar. The loads taken are high and yet the failure is due to yielding of abutments, otherwise the loads carried would have been higher still. Reinforcement is however very useful in places where unequal settlement or any other action tending to produce bending moments in the arch is feared.

Special experiments carried out to test certain qualities.

Special tests.

Certain special experiments were carried out to determine certain qualities. These are briefly referred to below as they do not properly fall under any of the headings already discussed.

Table XIX contains tests which are mainly self-explanatory, the following experiments in the table deserve passing mention.

Experiment 271 shows that slabs may be usefully built of a light brickwork slab jointed to ribs of R. B. spaced at short intervals. The composite slab thus formed is lightened considerably by the hollows between ribs.

The application of R. B. walls and roofs as shown by experiment 273 gives an earthquake-proof building.

Some successful methods of waterproofing R. B. slabs are given by experiment 274. Flushing the slab with cement punning just after completion is probably the most efficient. It is essential that the punning should be done at the same time as the construction of the slab, otherwise it may peel off.

Exposure of R. B. slabs to the sun is not harmful, *vide* experiment 275.

Experiment 276 proves that R. B. slabs are fire-proof.

Shocks due to impacts of heavy weights falling on R. B. slabs are not harmful, *vide* experiment 277.

Table XX, experiments 279 to 282, gives some tests which indicate how failures might occur in practice, the features they illustrate are :—

(*a*) Experiment 279 emphasises the dangers of using bad mortar.

(*b*) Failure on account of non-provision of hooks at the end of lap lengths is shown by results of experiment 280.

Experiments 281 and 282 show failures due to bad alternatives for a lap of 50 diameters and hooks at ends.

Conclusions arrived at from experiments.

Summing up the results of experiments, we may say that the following conclusions are justified :—

(*i*) R. B. slabs may be designed according to reinforced concrete theory. In the case of ordinary residences, offices and the barrack type of building commonly met with in India, the limiting stresses may be taken as high as 20,000 lbs. per square inch for steel in tension, and 350 lbs. per square inch for brick in compression reduced to 300 lbs. per square inch in the case of bigger slabs. These stresses should be reduced in the case of buildings which are likely to have any loads out of the ordinary.

(*ii*) Patent stone may be considered to have a strengthening effect if done along with, or soon after, the reinforced brickwork.

(*iii*) Terracing may be considered to have a strengthening effect provided sufficient time is allowed for it to set.

(*iv*) The theory accepted by the French Government which gives the amount of reinforcement, required in cross-reinforced concrete slabs, may be taken as applying to cross-reinforced brick slabs.

(*v*) In cantilevers the stress in steel should not exceed 16,000 lbs. per square inch.

(*vi*) R. B. beams may be designed according to reinforced concrete theory. The limiting stresses should be 16,000 lbs. per square inch for steel in tension, 250 lbs. per square inch for brickwork in compression, 80 to 90 lbs. per square inch for adhesion between steel and mortar, and 60 lbs. per square inch for shear in brickwork.

(*vii*) It is best to combine R. C. with R. B. in the construction of beams. As a rule the lower part of the beam in which the tensile reinforcement is placed should be constructed entirely of concrete.

(*viii*) Embedded rolled steel joists may be designed to take an extreme fibre stress of 16,000 lbs. per square inch, but it is not advisable to use sections greater than 10″ by 5″ in this way. Steel stirrups should always be given.

(*ix*) Partition walls may be designed to carry loads allowing a maximum shear stress of about 20 lbs. per square inch.

(*x*) The value of m may be taken as 40.

(*xi*) Temperature stresses may be neglected in the construction of all ordinary structures. This matter has not yet been fully investigated, but practice shows that the stresses in ordinary work are generally insignificant, provided slabs of a suitable depth are chosen having regard to the span.

SECTION V.

DESIGNS AND CALCULATIONS.

The method adopted for designing is essentially one of trial and error, but some rules have been arrived at as a result of experience from which an approximate section for any ordinary conditions of loading can be quickly found. The design so obtained is then tested by calculating stresses according to the ordinary theory, care being taken to see that they are kept within limits prescribed.

The notation used below and the method of designing adopted follow closely that given by Messrs. Faber and Bowie in their book Reinforced Concrete Design, 2nd edition, 1919.

It is assumed that the reader is conversant with the theory generally accepted for reinforced concrete but if he is not he should refer to that or some other treatise on the subject.

List of Symbols.

l Effective span in feet (of a beam or slab, or projection of a cantilever).

w Total load in lbs. per square foot over a slab.

W Total load in lbs. (over a beam or slab).

f_t Tensile stress in steel in lbs. per square inch.

A_t Area of tensile steel (in a beam in square inches, or area of tensile steel in 12″ width of a R. B. slab in square inches).

d Effective depth, *i.e.*, depth from the extreme compression fibre in brickwork to the centre of gravity of tensile reinforcement.

$B.M.$ Bending moment in inch lbs. of a beam or of 12″ wide strip of a slab.

$M.R.$ Moment of resistance in inch lbs. of a beam, or of 12″ wide strip of a slab.

α Reduction factor for the $B.M.$ on long span of a cross reinforced slab.

β Reduction factor for the $B.M.$ in short span of a cross reinforced slab.

L Long span in feet of a rectangular cross reinforced slab.

B Short span in feet of a rectangular cross reinforced slab.

BM_L Actual $B.M.$ in inch lbs. on 12″ width of slab of a cross reinforced slab on its long span.

BM_B Actual $B.M.$ in inch lbs. on 12″ width of slab of a cross reinforced slab on its short span.

p Percentage of steel in a beam or slab section $=\frac{100A_t}{bd}$.

b_r Width of rib.

b_s Width of slab acting with T beam.

f_a The adhesion between surfaces in units of force per units of area.

r The ratio of long span to short span in a slab supported on four sides and reinforced in both directions.

d_s The thickness of slab in a T beam.

a Arm of couple formed by the compressive and tensile forces in a beam.

$a_,$ The ratio $\frac{a}{d}$.

t The tensile stress intensity.

$t_,$ Ratio of stresses $\frac{t}{c}$.

c Compressive stress intensity in masonry.

n In beams, the distance of the neutral axis from the compression edge of the beam.

$n_,$ The ratio $\frac{n}{d}$.

Method of Designing.

Design of an ordinary slab, for roof or floor, supported on two sides.

In designing a slab supported on two sides the following steps are taken :—

(1) Consider a 12″ wide strip of the slab.

(2) Calculate the total weight in lbs. per sq. ft., w, on the slab. (This will include weight of structure and all external loads).

(3) Calculate the maximum $B.M.$ at the centre of slab in inch lbs.

$$B\ M = \frac{wl^2}{8} \times 12 \text{ for freely supported slabs}$$

$$\text{or } \frac{wl^2}{10} \times 12 \text{ for slightly fixed slabs}$$

$$\text{or } \frac{wl^2}{12} \times 12 \text{ for well fixed slabs (not perfectly fixed slabs).}$$

(4) Calculate the shearing force at ends in lbs.

$$S = \frac{W}{2} = \frac{wl}{2}.$$

(5) Calculate the sectional area of steel required per foot width, A_t from the following :—

$$A_t = \frac{B.\ M.}{20{,}000 \times 85 \times d}.$$

Assuming $d = 2\frac{1}{2}''$ in case of 3″ slabs, $4\frac{1}{2}''$ in case of 5″ slabs and $5\frac{3}{4}''$ in case of 6″ slabs—provide suitable reinforcement near the bottom surface of the slabs allowing a cover of about $\frac{1}{2}''$ so that the area of steel, or A_t, as actually given in 12″ width is approximately equal to A_t as calculated.

At the top of the slab at each end give steel corresponding to an area :—

$\frac{A_t}{4}$ if the ends are free.

$\frac{A_t}{2}$ to $\frac{A_t}{3}$ if the ends are partially fixed (this is a matter of judgment).

A_t to $\frac{A_t}{2}$ if the ends are well fixed (this is a matter of judgment).

We now proceed to test the design and the following steps are taken :—

(*i*) Find $p = \frac{100 \times A_t}{12 \times d}$.

(*ii*) From curve tables II and III find values of a_t and t_t corresponding to this value of p.

(*iii*) Find the tensile stress in steel, f_t, from the following,

$$f_t = \frac{B.\ M.}{A_t \times a_t \times d}$$

This should be about 20,000 lbs per sq. inch. If appreciably greater than this, more steel should be provided.

(*iv*) Find the maximum compressive stress c from $c = \frac{f_t}{t_t}$. This should be less than 350 lbs. per sq. inch; if more, the depth of the slab should be increased.

(*v*) Find s the shearing stress from $s = \frac{\frac{W}{2}}{12 \times a_t \times d}$ this should not exceed 10. If it does, the depth of the slab should be increased or the slab reinforced for shear.

(*vi*) Find the adhesion stress in lbs. per sq. inch, f_a, from

$$f_a = \frac{\frac{W}{2}}{a_t \times d \times \textit{perimeter of rods in 12'' width}}$$

This should not exceed about 80. (It is usually very low.)

Tests (*v*) and (*vi*) are seldom necessary for slabs and are usually omitted.

Freely supported slabs for any loading may also be designed directly from curve tables V, VI and VII.

Design of slab supported on all four sides—reinforced in two directions.

In designing a slab supported on all four sides the following steps are taken :—

(1) Find the ratio $r = \frac{\text{Long span}}{\text{Short span}}$ or $\frac{L}{B}$.

(2) From curve table IV find α the factor for long span corresponding to this value of r and also β the factor for short span.

(3) Find the actual *B. M.* on the long span, BM_L, from the following—

$$BM_L = \frac{wL^2}{8} \times 12 \times \alpha.$$

and the actual BM for short span from

$$BM_B = \frac{wB^2}{8} \times 12 \times \beta.$$

(4) Find A_t for long span from formula,

$$A_t = \frac{BM_L}{20{,}000 \times \cdot 85 \times d}.$$

and for the short span from formula,

$$A_t = \frac{BM_B}{20{,}000 \times \cdot 85 \times d}.$$

(5) Provide steel according to the values of A_t determined in (4) on the long and short spans respectively.

(6) Test separately for long and short spans as for ordinary slabs, taking the *BM* as BM_L for long span and BM_B for short span.

Design of continuous slabs.

Continuous slabs are designed in the same way as ordinary slabs. When the spans are equal and the loads all uniformly distributed and all supports fairly rigid, the negative *B. M.* over the intermediate supports may be taken as below :—

In case of three spans or more $\frac{wl^2}{10} \times 12$ for supports next to the ends, and $\frac{wl^2}{12} \times 12$ for all others. In case of two spans $\frac{wl^2}{8} \times 12$ for the only intermediate support. If the supports are not quite rigid the B. M_s. are less. When R. B. beams (which are fairly wide in the rib) are used as intermediate supports it is usual to make the clear span from rib to rib equal. This further reduces B. M_s.

The positive *B. M.* in the centre of spans is generally taken as $\frac{wl}{12} \times 12$.

The reinforcement in the centre of the spans should be near the bottom surface of the slab and over the intermediate supports near the top surface. It is usual to provide top reinforcement at the ends to the extent of half of what is provided in the middle of the spans even though the ends are supposed to be free, as it has been found from practice that there is nearly always slight fixing.

If possible the bottom and top reinforcement should be connected to each other.

Design of lintels, rectangular beams, and cantilevers.

Unimportant lintels should be designed in the same way as fixed slabs, and important lintels as fixed beams, full shear reinforcement being provided. The same applies to cantilevers, etc.

Rectangular beams of reinforced brickwork are designed in the same way as T beams, the method for which is detailed below, except that we take b instead of b_s or b_r. Such beams are however seldom used, at any rate for heavy loads.

Design of T beam with slab continuous over it.

In designing a T beam carrying a continuous slab the following steps are taken :—

(1.) Decide upon the thickness of slab to be used, *i.e.*, d_s.

This should be 5″ if the spans are up to about 11′ centre to centre of beams—but 6″ if up to 14′. Spacing of more than 13′ to 14′ is not economical.

(2.) Decide upon the depth of the beam, *viz.*, from top of slab to bottom of rib as far as the centre of gravity of the steel, *i.e.*, *d*. This should be about $\frac{1}{10}$ of span of the beam—but the total depth in inches of beam should be about $d''+2''$ for cover.

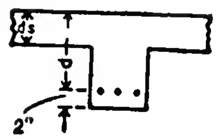


FIGURE 13.

(3.) Assume b_r to be approximately $\frac{1}{10}$ of spacing of T beams.

(4.) Now everything is known, *viz.*,

$l=$ span of beam.
$d=$ depth of beam.
$d_s=$ depth of slab.
$b_r=$ the thickness of the projecting rib.

From this data calculate the total load on the beam$=W$ lbs.

(5.) Calculate $BM=\frac{Wl}{8}\times 12$.

(6.) Calculate S shearing force at end, $S=\frac{W}{2}$.

(7.) Calculate shear stress in brick at end from $\frac{S}{\cdot 85d\times b_r}$; this should not exceed 60 lbs per sq. inch. If it exceeds 60 lbs increase b_r and bring s to below 60.

(8.) If b_r is increased recalculate W as this will also be slightly increased and again find S and satisfy yourself that s is below 60.

(9.) Calculate total shear $S=\left\{\frac{W}{2}\times\frac{l}{2}\right\}\times\frac{1}{2}\times 12$ in one-half of the beam.

(10.) Calculate $A_t=\frac{BM}{16{,}000\times\cdot 85d}$.

(11.) Calculate shear area to be given as stirrups in one-half of the beam.

$$A_s=\frac{S}{11{,}000\times d}$$

Now proceed to test the design as before.

(*i*) Calculate $p=\frac{100A_t}{b_s\times d}$ when $b_s=\frac{l\times 12}{3}$.

(*ii*) From curve tables I to III find $n_{,}$, $a_{,}$ and $t_{,}$ for this value of p.

(*iii*) Calculate $n=n_{,}\,d$, and $a=a_{,}\,d$.

(*iv*) Satisfy yourself that $n=d_s$ or at least is not greater than d_s by more than $\frac{d_s}{4}$. (For explanation of this see p. 39, Vol. I, of Faber and Bowie's Reinforced Concrete Design, 1919, 2nd Edition.)

(*v*) Calculate the stress in steel $f_t=\frac{BM}{A_t\times a}$. This should be about 16,000 lbs. per sq. inch.

(*vi*) Calculate compression stress in brick, c, from $c = \frac{f_t}{t_1}$ which should not exceed 250 lbs. per sq. inch.

(*vii*) Calculate shear stress in brick, $s = \frac{\frac{W}{2}}{a \times b_r}$. This should be below 60 lbs. per sq. inch.

(*viii*) Calculate adhesive stress in steel from $\frac{W}{2}$ × *perimeter of steel in tension reaching the bearing* $\times a$; this should not exceed about 80 to 90 lbs. per sq. inch for round steel and 50 lbs. per sq. inch for flat steel.

Some fully worked out examples of designs are given in the following pages.

EXAMPLES IN DESIGN WITH CALCULATIONS.

Example No. 1.

A slab for a roof 5′ span carrying 4″ beaten lime concrete terracing and subject to 25 lbs. per sq. ft. live load, supported on walls on both sides without any parapets.

The clear span is 5′ and the loads are ordinary and light; therefore a 3″ slab will be suitable.

Design.—Consider a strip of the slab 12″ wide.

The loads are—

(1) Weight of 3″ slab	= 29 lbs. per sq. ft.
(2) Weight of 4″ terracing . . .	= 37 lbs. per sq. ft.
(3) Live load	= 25* lbs. per sq. ft.
w, total load per sq. ft.	= 91 lbs. say 90 lbs.

The ends are free, therefore the maximum *B. M.* in centre of span

$$= \frac{wl^2}{8} \times 12 \text{ inch lbs.}$$
$$= 90 \times 5 \times 5 \times 1{\cdot}5$$
$$= 3{,}375 \text{ inch lbs.}$$

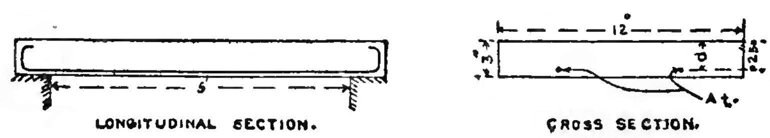


FIGURE 14.

Assume 2·5″ as the effective depth, d, to the centre of steel and let A_t be the area of steel which is required as tensile reinforcement in 12″ width.

Then moment of resistance, *M. R.* $= A_t \times f_t' \times a$

a may be assumed = ·85 d nearly, without much error.

Allowing 20,000 lbs. per sq. inch as the maximum stress in steel

$$M.\ R. = A_t \times 20{,}000 \times {\cdot}85 \times d$$
$$= A_t \times 20{,}000 \times {\cdot}85 \times 2{\cdot}5$$

Equating the maximum bending moment to the moment of resistance, we have $A_t \times 20{,}000 \times {\cdot}85 \times 2{\cdot}5 = 3{,}375$.

$$\therefore A_t = \frac{3{,}375}{20{,}000 \times {\cdot}85 \times 2{\cdot}5}$$
$$= {\cdot}0794 \text{ sq. inch.}$$

---

* This has been found by experiment to be the load of the coolies tamping a roof in the ordinary manner.

In ordinary circumstances a 3″ slab is suitable on spans up to 5′ where the ends are freely supported.

Ditto	5″	ditto	10′	ditto
Ditto	6″	ditto	12	ditto

Now reinforcement can only be arranged after every $5\frac{1}{2}''$ or $10\frac{1}{2}''$, termed for convenience 5″ or 10″, owing to the size of bricks, therefore the area required every $10\frac{1}{2}''$ width is $= \frac{\cdot 0794 \times 10\cdot 5}{12} = \cdot 070$ sq. inch.

From a reference to tables it will be seen that the sectional area of a $\frac{5}{16}''$ diameter rod is ·076 sq. inch.

Hence a rod $\frac{5}{16}''$ diameter spaced every $10\frac{1}{2}''$, *i.e.*, after every brick length, will do.

Some reinforcement say up to $\frac{1}{4}$ of the span may be given at ends at the top to guard against cracks due to possible partial fixing action. For this purpose it will be sufficient to bend up every alternate rod towards the end. Figure 1, plate 3, gives the design.

Mathematical Test of the Design.

Testing the design mathematically we have :—

$$B.\,M. = 3{,}375 \text{ inch lbs. per ft. width.}$$

$$b = 12''$$

$$d = 3'' - \left(\tfrac{3}{8}'' + \tfrac{5}{32}''\right)$$

$$= 3'' - \tfrac{17}{32}'' \text{ or } 2\cdot 5'' \text{ nearly.}$$

$$A_t = \cdot 076 \times \frac{12}{10\cdot 5}$$

$$= \cdot 0868 \text{ sq. inch.}$$

$$p = \frac{100\,A_t}{bd}$$

$$= \frac{100 \times \cdot 076}{12 \times 2\cdot 5}$$

$$= 0\cdot 253.$$

For $p = \cdot 253$ from curve table II we have $a_{,} = 0\cdot 88$.
and from curve table III we have $t_{,} = 72\cdot 0$.

$$\text{Actual stress in steel} = f_t = \frac{BM}{A_t \times a_{,} \times d}.$$

$$= \frac{3375}{\cdot 0868 \times 0\cdot 88 \times 2\cdot 5.}$$

$$= 17{,}676 \text{ lbs. per sq. inch which is safe.}$$

Actual maximum stress in brickwork $= c = \frac{f_t}{t_{,}} = \frac{17{,}676}{72} = 246$ lbs. per sq. inch which is within the safe limit for slabs.

Tests for adhesion and shear may be made as for beams but as the stresses in ordinary cases are very low, such tests are really unnecessary.

Example No. 2.

A slab for a 1st floor, 8′ span carrying 1″ cement concrete (artificial stone) and subject to 56 lbs. per sq. ft. live load.

The clear span is 8′ and the loads ordinary, therefore a 5″ slab (brick on edge) will be suitable.

Design.—Consider a strip 12″ wide.

The loads are :—

(1) Weight of 5″ R.B. slab . .	= 48 lbs. per sq. ft.
(2) Weight of 1″ cement concrete .	= 12 lbs. per sq. ft.
(3) Live load	= 56 lbs. per sq. ft.
w, total load per sq. ft.	= 116 lbs.

The ends will be built into the walls and partially fixed. We may take the positive *B. M.* in the centre as $\frac{wl^2}{10}$ and the negative *B. M.* at the ends $\frac{wl^2}{20}$. (This is a matter of judgment. The positive *B. M.* at the centre may be anything from $\frac{wl^2}{24}$ to $\frac{wl^2}{10}$ according to the efficiency of fixing. It is $\frac{wl^2}{24}$ when the fixing is perfect and about $\frac{wl^2}{10}$ when the fixing is nominal. The negative *B. M.* at the ends is $\frac{wl^2}{12}$ when the fixing is perfect, but practically zero with the fixing nominal.)

The maximum *B. M.* in the centre of the span $= \frac{wl^2}{10} \times 12$ inch lbs.

$$= 116 \times \frac{8 \times 8}{10} \times 12$$

$$= 8{,}909 \text{ inch lbs.}$$

Assume $d = 5'' - \frac{1}{2}'' = 4{\cdot}5''$ and let A_t be as in Example I the tensile steel area necessary in 12″ width.

Then $M.\ R. = A_t \times f_t \times a$

$$= A_t \times 20{,}000 \times {\cdot}85d$$

$$= A_t \times 20{,}000 \times {\cdot}85 \times 4{\cdot}5 \text{ inch lbs.}$$

Equating the maximum bending moment to the moment of resistance, we have

$$A_t \times 20{,}000 \times {\cdot}85 \times 4{\cdot}5 = 8{,}909.$$

$$\therefore A_t = \frac{8{,}909}{20{,}000 \times {\cdot}85 \times 4{\cdot}5} = {\cdot}116 \text{ sq. inch.}$$

Reinforcement can only be put in every 3″, every 6″, or every 10″ apart, therefore the area required every 10″ apart is $= 116 \times \frac{10}{12} = {\cdot}097$ sq. inches. From a reference to tables it will be seen that the area of two rods of $\frac{1}{4}''$ diameter is $2 \times {\cdot}049 = {\cdot}098$ sq. inches, hence two $\frac{1}{4}''$ diameter rods every 10″ apart will do. Half of this may be allowed at the top at ends. This will be near enough as the negative *B. M.* at the ends is half of positive *B. M.* in the mid-span. Also of the two rods at the bottom only one need be carried throughout the full length of the span and bearing, the other one may be a 6″ piece in the centre only. This can be done as the *B.M.* near the ends is very small.

The sketches for this design are given in plate 3, figure 2.

Mathematical Test of the Design.

Testing the design mathematically, we have:—

$B.\ M. = 8{,}909$ inch lbs. per 12″ width.

$b = 12''$

$d = 4{\cdot}4''$ (as actually drawn).

$A_t = {\cdot}098 \times \frac{12}{10} = {\cdot}1176$ sq. inch.

$$p = \frac{100\ A_t}{bd} = \frac{100 \times {\cdot}1176}{12 \times 4{\cdot}2} = {\cdot}223.$$

For $p = {\cdot}223$ from curve tables II and III we have

$a_t = {\cdot}887$

$t_t = 76{\cdot}0$

$$f_t = \frac{B.M.}{A_t \times a_t \times d}$$

$$= \frac{8{,}909}{{\cdot}1176 \times {\cdot}887 \times 4{\cdot}4}$$

$= 19{,}410$ lbs. per sq. inch, which is safe.

$$c = \frac{f_t}{t_t} = \frac{20{,}430}{76}$$

$= 269$ lbs. per sq. inch which is within the safe limit for slabs.

Example No. 3.

A slab for a roof 11′ span carrying 4″ of lime concrete terracing and 25 lbs. per sq. ft. external live load, ends to be treated as free.

The clear span is 11′ and the loads ordinary, a 6″ slab will be suitable.

Design.—Consider a strip 12″ wide.

The loads are—

Weight of 6″ slab	= 58 lbs. per sq. ft.
Weight of 4″ terracing . .	= 37 lbs. per sq. ft.
Live load	= 25 lbs. per sq. ft.
w, total load per sq. ft.	= 120 lbs.

The maximum *B. M.* in the centre of the span$= \frac{wl^2}{8} \times 12$ inch lbs.

$$= \frac{120 \times 11 \times 11 \times 12}{8}$$

= 21,780 inch lbs.

Take $d = 5{\cdot}75''$

Then as before $A_t = \frac{B.M.}{f_t \times a}$

$$= \frac{B.M.}{20{,}000 \times {\cdot}85 \times d}$$

$$= \frac{21{,}780}{20{,}000 \times {\cdot}85 \times 5{\cdot}75}$$

$= {\cdot}223$ sq. inch.

Reinforcement can be put in every $5\frac{1}{2}''$: the reinforcement necessary in $5\frac{1}{2}''$ is ${\cdot}223 \times \frac{5\frac{1}{2}}{12} = {\cdot}102$ sq. inch.

From a reference to tables it will be seen that the area of a $\frac{3}{8}''$ rod is ·11 sq. inch, hence a $\frac{3}{8}''$ diameter rod every $5\frac{1}{2}''$ apart will do. Allow $\frac{1}{4}$ of this at the top at ends, as before.

The sketches for this design are given in plate 3, figure 3.

Mathematical Test of the Design.

Testing the design mathematically we have—

$B.M. = 21{,}780$ inch lbs. per 12″ width.

$b = 12''$

$d = 5{\cdot}7''$ (as drawn).

$A_t = {\cdot}11 \times \frac{12}{5\frac{1}{2}} = {\cdot}24$ sq. inch.

$$p = \frac{100\ A_t}{bd} = \frac{100 \times {\cdot}24}{12 \times 5{\cdot}7} = {\cdot}351$$

For $P = {\cdot}351$ from curve tables II and III we have—

$a_t = {\cdot}865$

$t_t = 58{\cdot}0$

$$f_t = \frac{B.\ M.}{A_t \times a_t \times d}$$

$$= \frac{21{,}780}{{\cdot}24 \times {\cdot}865 \times 5{\cdot}7}$$

= 18,410 lbs. per sq. inch which is safe.

$c = \frac{f_t}{t_t} = \frac{18{,}410}{58} = 318$ lbs. per sq. inch which is also safe.

Example No. 4.

A cross reinforced slab, *i.e.*, a slab reinforced in both directions and supported on all four sides, for the roof of a room 15′×16′ clear, carrying 4″ lime concrete terracing and subject to 25 lbs. per sq. ft. maximum live load.

For such a room a 6″ slab is suitable.

The loads are—

Weight of 6″ slab	= 58 lbs. per sq. ft.
Weight of 4″ terracing . . .	= 37 lbs. per sq. ft.
Live load	= 25 lbs. per sq. ft.
w, total load per sq. ft.	= 120 lbs.

The ratio $\frac{\text{long span}}{\text{short span}} = \frac{L}{B} = \frac{16}{15} = 1{\cdot}067$ nearly.

From curve table IV we get α (the factor for long span) $= 0{\cdot}27$

And β (the factor for short span) $= 0{\cdot}39$

Consider a 12″ wide strip of slab in each direction.

The maximum *B. M.* on long span $= BM_L$

$$= \frac{wL^2}{8} \times 12 \times \alpha \text{ inch lbs.}$$

$$= \frac{120 \times 16 \times 16}{8} \times 12 \times {\cdot}27$$

$$= 12{,}442 \text{ inch lbs.}$$

The maximum *B. M.* on short span $= BM_B$

$$= \frac{wB^2}{8} \times 12 \times \beta \text{ inch lbs.}$$

$$= \frac{120 \times 15 \times 15}{8} \times 12 \times {\cdot}39$$

$$= 15{,}795 \text{ inch lbs.}$$

Assume 5·3″ as the effective depth on the long span and 5·6″ as the effective depth on short span, then

$$A_t \text{ on long span} = \frac{BM_L}{f_t \times a_t \times d}$$

$$= \frac{12{,}442}{20{,}000 \times {\cdot}85 \times 5{\cdot}3}$$

$$= {\cdot}139 \text{ sq. inch.}$$

If reinforcement is placed after every brick, the spacing centre to centre, will be about $10\frac{1}{2}$″.

Reinforcement required in $10\frac{1}{2}$″ width is $\frac{{\cdot}139 \times 10{\cdot}5}{12} = {\cdot}12$ sq. inch, try a $\frac{3}{8}$″ diameter rod the area of which is ·11 sq. inch.

$$A_t \text{ on short span} = \frac{BM_B}{f_t \times a_t \times d}$$

$$= \frac{15{,}795}{20{,}000 \times {\cdot}85 \times 5{\cdot}6}$$

$$= {\cdot}166 \text{ sq. inch.}$$

The joint in this case may be assumed $\frac{3}{4}$″ thick, hence area required in $10\frac{3}{4}$″ is $\cdot166 \times \frac{10{\cdot}75}{12} = {\cdot}149$ sq. inch. Try a $\frac{7}{16}$″ diameter rod, the area of which is ·1503 sq. inch, every $10\frac{3}{4}$″ apart.

As before a $\frac{1}{4}$″ diameter rod every 10″ apart in both directions may be allowed as top reinforcement at the ends.

Diagrams in plate 4 give the design.

Testing the design mathematically we have :—

for long span, $BM_L = 12{,}442$ inch lbs. per 12″ width.

$$b = 12''$$

$$d = 5{\cdot}4'' \text{ (as drawn).}$$

$$A_t = \frac{{\cdot}11 \times 12}{10\frac{1}{2}} = {\cdot}126 \text{ sq. inch.}$$

$$p = \frac{100A_t}{bd} = \frac{{\cdot}126 \times 100}{12 \times 5{\cdot}4} = {\cdot}194$$

for $p = {\cdot}194$ from curve tables II and III we get

$a_t = {\cdot}892$

and $t_c = 83{\cdot}0$

$$f_t = \frac{BM_L}{A_t \times a_t \times d}$$

$$= \frac{12{,}442}{{\cdot}126 \times {\cdot}892 \times 5{\cdot}4}$$

$= 20{,}500$ lbs. per sq. inch which is near enough to the allowable stress to be accepted.

$c = \dfrac{f_t}{t_r} = 247$ lbs. per sq. inch, which is safe.

For short span—

We have $B.M_B = 15{,}795$ inch lbs.

$b = 12''$

$d = 5{\cdot}7''$ (as drawn).

$A_t = {\cdot}1503 \times \dfrac{12}{10{\cdot}75} = {\cdot}168$ sq. inch.

$p = \dfrac{100\ A_t}{bd} = \dfrac{100 \times {\cdot}168}{12 \times 5{\cdot}7} = {\cdot}246$

for $p = {\cdot}246$ from curve tables II and III we get

$a_r = {\cdot}882$

and $t_r = 72{\cdot}0$

$\therefore f_t = \dfrac{B.M_B}{A_t \times a_r \times d} = \dfrac{15{,}795}{{\cdot}168 \times {\cdot}882 \times 5{\cdot}7} = 18{,}700$ lbs. per sq. inch, which is safe

$c = \dfrac{f_t}{t_r} = \dfrac{18{,}700}{72} = 260$ lbs. per sq. inch, which is also safe.

Example No. 5.

A roof for a room $14' \times 27'$ with two intermediate T beams of R. B. and a slab continuous over these, the roof carrying 4″ lime terracing and subject to 25 lbs. per sq. ft. maximum live load.

Design of Slab.

The spans will be 9′ continuous, hence a 5″ slab is suitable.

Consider a strip 12″ wide.

The loads are—

Weight of 5″ R. B slab	= 48 lbs. per sq. ft.
Weight of 4″ terracing	= 37 lbs. per sq. ft.
Live load	= 25 lbs. per sq. ft.

w, the total load per sq. foot = 110 lbs.

If the spans are all uniformly loaded as will practically be the case, the maximum positive *B. M.* in the end spans will be about $\dfrac{wl^2}{12} \times 12$ inch lbs.—in the centre span much less—and the negative *B. Ms.* over the intermediate T beams will be between $\dfrac{wl^2}{10} \times 12$ and $\dfrac{wl^2}{12} \times 12$ inch lbs. allowing for some settlement in the beams themselves. (It is in most cases safe to take $\dfrac{wl^2}{12} \times 12$.)

We may take $\dfrac{wl^2}{12} \times 12$ inch lbs. in both cases.

The beams for the sake of appearance might be so arranged that the spans, clear of the ribs, are equal. This slight alteration will tend to reduce the *B. M.* in the end spans and increase *B. M.* in the centre span and so will do no harm. The span of slab may be taken as $\dfrac{27'}{3} = 9'$.

$B.\ M. = \dfrac{wl^2}{12} \times 12$

$= 110 \times 9 \times 9$

$= 8{,}910$ inch lbs.

Assume 4·5″ as the effective depth.

Then $A_t = \dfrac{B.\ M.}{f_t \times a_r \times d} = \dfrac{8{,}910}{20{,}000 \times {\cdot}85 \times 4{\cdot}5} = {\cdot}1165$ sq. inch in 12″ width.

Reinforcement can be placed every $3\frac{1}{2}''$ or $10''$ apart.

$\therefore$ A_t required in $10''$ is $\cdot 1165 \times \frac{10}{12} = \cdot 097$ sq. inch.

The area of two rods $\frac{1}{4}''$ diameter is $\cdot 098$ sq inch. Hence these might be used. Top reinforcement over the T beams will have to be continued for $\frac{1}{4}$ of the clear span of the slab on each side of a rib. Top reinforcement at the ends may also be given to the extent of a quarter of that in span.

The sketches for the slab are given in plate 5.

Design of T Beams.

Take depth of beam about $\frac{1}{10}$ of the span, *i.e.*, $1\cdot 4'$ and try a $15\frac{1}{2}''$ deep T beam (including the slab) as it is very easily made by one brick on end under the slab.

For purposes of calculating the weight of the beam assume b_r the width of the rib to be about $\frac{1}{10}$ of spacing of beam, *i.e.*, $11''$, say $12''$. The following are the loads on the beams :—

Slab, terrace, and live load = 110 lbs. per square foot, *vide* page 39 but as the spans are continuous the actual slab load on the beam is—

$110 \times 14 \times 9 \times 1\cdot 1 = 15{,}246$ lbs.

weight of rib $14 \times 125 \times \frac{10}{12} = 1{,}458$ lbs.

W, total load = 16,704 lbs.

say 16,700 lbs.

$\therefore$ maximum shearing force at the ends = 8,350 lbs.

and maximum $B.\ M.$ in the centre (assuming free ends) $= \dfrac{16{,}700 \times 14 \times 12}{8}$

$= 350{,}700$ inch lbs.

Taking effective depth, d = total depth from top of slab to bottom of rib less $2''$, we get—

$$A_t = \frac{B.\ M.}{f_t \times \cdot 85 \times d}$$

$$= \frac{350{,}700}{16{,}000 \times \cdot 85 \times 13\cdot 5}$$

$= 1\cdot 91$ square inches.

Try nine rods $\frac{1}{2}''$ diameter, $A_t = 9 \times \cdot 1963$

$= 1\cdot 767$ square inches.

To take shearing stresses provide enough stirrups to take up all the shear in the beam and turn up three of the tension rods towards each end at 45°.

The total shear in each half span $= \dfrac{8{,}305 \times 7 \times 12}{2}$

$= 350{,}700$ lbs.

$$\therefore\ A_s = \frac{350{,}700}{11{,}000 \times 13\cdot 5}$$

$= 2\cdot 34$ square inches.

Provide fortyeight verticals each $\frac{1}{4}''$ diameter rod in each half span

Then $A_s = 48 \times \cdot 49 = 2\cdot 35$, *i.e.*, eight sets of 3 double stirrups of $\frac{1}{4}''$ round section, to be distributed as far as possible in accordance with ordinary practice. The bricks of the beams might be made to break joint laterally.

The drawings for the design are given in plate 5.

Mathematical Test of the Design of the Slab.

Testing the design of the slab mathematically we have

$$BM = 8{,}910 \text{ inch lbs.}$$
$$b = 12''$$
$$d_s = 4{\cdot}5''$$
$$A_t = {\cdot}097 \times \frac{12}{10{\cdot}3}$$
$$= {\cdot}114 \text{ sq. inch}$$
$$\text{hence } p = \frac{{\cdot}114 \times 100}{12 \times 4{\cdot}5} = {\cdot}211 \text{ square inch}$$

for $p = {\cdot}211$ from curve tables II and III we get

$$a_t = {\cdot}888$$
$$t_i = 80{\cdot}0$$
$$f_t = \frac{B.\ M.}{A_t \times a_i \times d}$$
$$= \frac{8{,}910}{{\cdot}114 \times {\cdot}888 \times 4{\cdot}5}$$
$$= 19{,}560 \text{ lbs. per square inch, which is safe}$$
$$c = {}_{t_i} = \frac{19{,}560}{80} = 224{\cdot}5 \text{ lbs. per square inch, which is safe.}$$

Mathematical Test of the Design of the Beam.

Testing the design of the beam mathematically we get from the actual drawings

$$b_r = 15''$$
$$d = 13{\cdot}5''$$
$$A_t = 1{\cdot}767 \text{ square inches.}$$
$$b_s = \text{assumed } \tfrac{1}{3} \text{ span, } i.e., 56''.$$

Weight of slab
[on the beam] = 15,246 lbs.
Weight of rib = 1,458 lbs.
W, total load = 16,704 lbs., say 16,700 lbs.
Shearing force at ends = 8,350 lbs.
and *B. M.* = 350,700 inch lbs.

$$p = \frac{100\ A_t}{b_s \times d}$$
$$= \frac{100 \times 1{\cdot}767}{56 \times 13{\cdot}5}$$
$$= {\cdot}243$$

from curve table I we get $n_i = {\cdot}355$

$$\therefore n = n_i\, d = {\cdot}355 \times 13{\cdot}5$$
$$= 4{\cdot}8 \text{ nearly.}$$

Hence the neutral axis falls within the slab and all the ordinary rules apply.

$$a = d - \frac{n}{3}$$
$$= 13{\cdot}5 - \frac{4{\cdot}8}{3}$$
$$= 11{\cdot}9$$
$$f_t = \frac{B.\ M.}{A_t \times a_i \times d}$$
$$= \frac{350{,}700}{1{\cdot}767 \times 11{\cdot}9}$$
$$= 16{,}678 \text{ lbs. per square inch, which will do.}$$

from curve table III $t_i = 72{\cdot}0$

$$c = \frac{f_t}{t_i} = \frac{16{,}600}{72} = 230 \text{ lbs. per square inch, which is also safe,}$$
$$f_a = \frac{\textit{Shearing force}}{\textit{perimeter of rods in tension available at end} \times a}$$
$$= \frac{8{,}350}{6 \times 3{\cdot}14 \times \frac{1}{2} \times 11{\cdot}9}$$
$$= 74{\cdot}5 \text{ lbs. per square inch which is safe,}$$
$$s = \frac{\textit{Shearing force}}{b_r \times a}$$
$$= \frac{8{,}350}{15 \times 11{\cdot}9}$$

= 47 lbs. per square inch, which is safe especially as stirrups have been given to take up all shear.

Example No. 6.

A T beam joined to a 6″ continuous slab to carry on 16′ span, a load of 8 tons exclusive of the weight of the rib of the beam.

Take $d = \frac{1}{10}$ of the span $= \frac{16'}{10} = 20''$ say, total depth 22″ approximately. Assume $b_r = 10''$,

then the weight of the rib of the beam $= \frac{10}{12} \times \frac{16}{12} \times 16 \times 120 =$ 2,130 lbs.

Load on beam = 8 tons = 17,920 lbs.

W, total load = 20,050 lbs.

say 20,000 lbs.

∴ Shearing force at each end = 10,000 lbs.

In order that shear stresses may not exceed 60 lbs. per square inch we must have as a limit, *viz.*, $\frac{10{,}000}{\cdot 85\, b\, d} = 60$, or $bd = 196$.

We have assumed $d = 20$ and $b = 10$ ∴ $bd = 200$, which is greater than 196, hence this section will do and our approximations are near enough.

$$B.\,M. \text{ in centre of span } = \frac{Wl}{8} \times 12$$

$$= \frac{20{,}000 \times 16}{8} \times 12$$

$$= 480{,}000 \text{ inch lbs.}$$

$$\therefore A_t = \frac{B.\,M.}{16{,}000 \times \cdot 85 d}$$

$$= \frac{480{,}000}{16{,}000 \times \cdot 85 \times 20}$$

$$= 1{\cdot}765 \text{ square inches.}$$

Give six rods of $\frac{5}{8}''$ diameter each,

then $A_t = 6 \times \cdot 3067 = 1{\cdot}840$ square inches.

$$A_s = \frac{Total\ shear}{11{,}000 \times d}$$

$$= \frac{10{,}000 \times 4 \times 12}{11{,}000 \times 20}$$

$$= \frac{480{,}000}{11{,}000 \times 20}$$

$= 2{\cdot}18$ square inches. Give seven rods of $\frac{5}{16}''$ diameter each, used as quadruple stirrups in each half span.

Then $A_s = 7 \times 4 \times \cdot 0767 = 2{\cdot}148$; bend two rods near each end at 45° to give additional shear strength. For simplicity of construction the bottom 4″ or 5″ should be done in concrete.

Sketches are given in plate 6.

Mathematical Test of the Design.

$B.\,M. = 480{,}000$ inch lbs.

$S.\,F. = 10{,}000$ lbs.

$b_s = \frac{l}{4} = 48''$

$d_r = 20''$

$A_t = 1{\cdot}840$ sq. inches.

$$p = \frac{100\, A_t}{b_s \times d} = \frac{100 \times 1{\cdot}84}{48 \times 20} = \cdot 1917.$$

For $p = \cdot 1917$ from curve table I we get
$n_{,} = \cdot 322$ and $n = 6\cdot 4''$, hence the neutral axis falls just at the bottom surface of the slab (which is about $6\cdot 4''$ deep) and the ordinary theory applies.
From curve tables II and III we have—

$$a_{,} = \cdot 8925$$

$$t_{,} = 84\cdot 0$$

$$f_t = \frac{B.\ M.}{A_t \times a_{,} \times d}$$

$$= \frac{480{,}000}{1\cdot 84 \times \cdot 8925 \times 20}$$

$= 14{,}614$ lbs. per square inch, which is safe,

$c = \frac{f_t}{t_{,}} = \frac{24{,}614}{84} = 174$ lbs. per sq. inch, which is safe,

$$s = \frac{\textit{Shearing force}}{a_{,} \times d \times b_r}$$

$$= \frac{10{,}000}{\cdot 8925 \times 20 \times 10}$$

$= 56$ lbs. per square inch, which is less than 60, and therefore safe, as stirrups have been provided to take up all the shear.

$$f_a = \frac{\textit{Shearing force}}{a_{,}\ d \times \textit{perimeter of the bars in tension at end.}}$$

$$= \frac{10{,}000}{\cdot 8925 \times 20 \times 4 \times \frac{5}{8} \times 3\cdot 14}$$

$= 72$ lbs. per square inch, which is less than 90 lbs. per square inch and therefore safe.

SECTION VI.

COSTS, RATES, COST ANALYSES, ETC.

During the construction of New Patna it was proved conclusively that roofs and floors constructed of reinforced brick are cheaper than those constructed on any other system, for example, jack arch, T and tile, reinforced concrete or any of the tiled roofs of different kinds hitherto in common use.

The saving effected by using it in place of any of these systems was very marked during the war when the price of steel was high. Calculations show, however, that, even if the price of steel again falls to Rs. 10 per cwt. and provided the prices of other materials vary only slightly, roofs and floors built of R. B. would still be cheaper than those built on any other of the systems mentioned above. On the score of cheapness alone, the system will therefore command preference so long as these conditions obtain.

An attempt is made in the following pages to compare the cost of roofs and floors constructed according to different specifications and to illustrate the saving effected by using reinforced brickwork. Except where otherwise stated, the figures given show the cost of work which has been actually constructed in Patna. The buildings chosen are typical of what are met with everywhere throughout India, and, although the cost of work is bound to vary in different localities according to the cost of materials and rates for labour, some idea of the savings resulting from the use of this system can be got from the examples given.

At the time the work was done, the following were the average rates paid for materials:—

	Rs.
First class bricks	12 per 1,000
Cement	3 per cubic foot.
Steel	30 per cwt.
4″ beaten lime concrete terracing (including materials) over roof slabs	15 per 100 s. ft.
1″ cement concrete artificial stone (including materials) over 1st floor slabs	21 per 100 s. ft.

The rates paid to petty contractors allowed 15 per cent. profit on labour. Materials were supplied at cost price by the department.

(I) Example I.

Power House.—Battery room 50′ × 20′.

Corresponding roughly to the usual type of room for class rooms, barracks and hospitals commonly met with in India.

Table of comparative cost in Rs.

	Type of roofing.	Total cost of roof with steel at Rs. per cwt.			Remarks.
		10	30	5C	
		Rs.	Rs.	Rs.	
1	Reinforced brickwork and 4″ terracing.	709	1,143	1,576	
2	Jack arch and 4″ terracing	1,014	2,114	3,414	
3	T and tile and 4″ terracing	1,254	3,008	4,922	
4	Double Allahabad tiles on sal timber trusses.	1,789	1,879	1,946	

(II) Example II.

Small bungalow type, single storey, built for European Registrar. Area of roof 2,634 sq. ft.

Table of comparative cost in Rs.

	Type of roofing.	Total cost of roof with steel at Rs. per cwt.			Remarks.
		10	30	50	
		Rs.	Rs.	Rs.	
1	Reinforced brickwork and 4″ terracing.	1,223	1,529	1,835	
2	Jack arch and 4″ terracing	1,778	3,320	4,852	
3	T and tile and 4″ terracing	2,237	5,185	8,133	Figures marked * are estimated figures, as no work of this kind was actually done when steel cost Rs. 30 per cwt. For purposes of comparison the costs of thatch, tiles, framing, battens, etc., are taken in columns 2 and 3 at the same rate as in column 1, although the prices of these advanced to a certain extent also.
4	Naria tiles on 4″ thatch on bamboo frame carried on sal bullah rafters.	1,870	1,960*	2,050*	
5	Double Allahabad tiling roof on sal truss and rafters and battens.	3,580	3,810*	4,040*	
6	Double Raniganj tiling roof on sal truss and rafters and battens.	3,820	4,050*	4,300*	
7	Red poilite tiling on sal truss, rafters and battens—				
	(a) tiles at pre-war prices	2,850*	3,050*	3,250*	
	(b) tiles at June 1918 prices	3,870*	4,100*	4,430*	

(III) Example III.

Medium sized, double storied house built for Excise Commissioner. Area of roof 3,037 sq. ft.

Table of comparative cost in Rs.

	Type of roofing, and flooring at 1st floor level.	Total cost of roof with steel at Rs. per cwt.			REMARKS.
		10	30	50	
		Rs.	Rs.	Rs.	
	Roofs.				
1	Reinforced brickwork and 4″ terracing.	1,567	2,017	2,467	
2	Jack arch and 4″ terracing . .	2,381	4,579	6,787	
3	T and tile and 4″ terracing .	2,882	6,758	10,634	
	Floors.				
1	Reinforced brickwork finished with 1″ artificial stone.	1,657	2,107	2,557	
2	Jack arch finished with 4″ lime concrete and 1″ artificial stone.	2,907	5,105	7,313	
3	T and tile finished with 4″ lime concrete and 1″ artificial stone.	3,408	7,248	11,160	

(IV). Example IV.

Large sized, double storied house for Hon'ble Member of Executive Council. Roof area 7,529 sq. ft.

Table of comparative cost in Rs.

	Type of roofing, and flooring at 1st floor level.	Total cost of roof or floor with steel at Rs. per cwt.			REMARKS.
		10	30	50	
		Rs.	Rs.	Rs.	
	Roofs.				
1	Reinforced brickwork and 4″ terracing.	3,054	3,830	4,606	
2	Jack arch and 4″ terracing . .	4,181	8,248	12,313	
3	T and tile and 4″ terracing .	5,494	13,228	20,958	
	Floors.				
1	Reinforced brickwork finished with 1″ artificial stone.	3,396	4,056	4,716	
2	Jack arch finished with 4″ concrete and 1″ artificial stone.	5,218	9,285	13,350	
3	T and tile finished with 4″ concrete and 1″ artificial stone.	6,531	14,765	21,995	

(V). Example V.

Comparison of costs of roofs of various sized square rooms commonly met with in practice.

Table of comparative cost in Rs.

	Size of room.	TOTAL COST OF ROOF, STEEL AT Rs. 10 PER CWT.			TOTAL COST OF ROOF, STEEL AT Rs. 30 PER CWT.			TOTAL COST OF ROOF, STEEL AT Rs. 50 PER CWT.		
		R. B. and 4″ terrace.	J. A. and 4″ terrace.	T and tile and 4″ terrace.	R. B. and 4″ terrace.	J. A. and 4″ terrace.	T and tile and 4″ terrace.	R. B. and 4″ terrace.	J. A. and 4″ terrace.	T and tile and 4″ terrace.
		Rs.	Rs.	Rs.	Rs.	Rs.	Rs.	Rs.	Rs.	Rs.
1	8′ × 8′ ..	24	46	51	29	86	113	34	126	175
2	12′ × 12′ .	81	97	117	104	173	266	127	250	411
3	14′ × 14′ .	107	155	194	138	308	450	168	462	706
4	16′ × 16′ .	147	224	276	202	466	653	257	708	1,030
5	18′ × 18′ .	188	317	388	265	688	941	341	1,058	1,496
6	20′ × 20′ .	255	381	469	400	821	1,137	545	1,261	1,805

The very large saving effected by using R. B. construction will be evident from the above figures.

For convenience of reference the information tabulated above is given in graphical form at the end of this section. (Comparative figures for R. C. roofs have not been worked out in these cases but it was found from comparisons which were made in other work that reinforced concrete work cost roughly three times what reinforced brickwork did when steel cost Rs. 12 a cwt. and cement Rs. 10 a barrel.)

Analysis showing in detail the cost of R. B. at Patna.

Rates for materials and labour vary so much from day to day and also for different localities that it is of little use giving all the cost figures in greater detail. Analyses of rates for various types of R. B. are given on pages 48 to 50 which will, however, enable engineers who wish to make use of the system, to work out costs and fix fair rates for similar work in any locality.

For the sake of convenience, the analyses, which show in detail the cost of R. B. at Patna, are divided as follows:—

(i) Cost of centering.

(ii) Cost of the brickwork portion of the structure.

(iii) Cost of steel reinforcement.

(i) and (ii) do not vary very much and are given on pages 48 to 50.

(iii) obviously varies with the design adopted and has to be calculated in each particular case from the drawings, cost tables of this are therefore not given.

COST STATEMENT I.

Cost of centering per 100 sq. ft.

Based on cost of 10,029 sq. ft. of centering erected and dismantled at Patna showing quantities of material and labour required and cost per each 100 sq. ft.

Details and items.	Quantity.		Rate.		Amount.	Total.	Remarks.
	Unit.	Nos.	Cost in Rs.	Per			
					Rs.	Rs.	
1. Materials—							
(i) rough planks . .	sq. ft.	120	·02*	sq. ft.	2·40		* Price of planks being about 3 annas per sq. ft., 10 per cent. depreciation allowed.
(ii) bricks or wedges under cross beams . . .	nos.	12	·012	each	0·14		
(iii) earth and sand used as top dressing . . .	c. ft.	16	5·00	%₀ c. ft.	0·08		
			Total	materials		2·62	
2. Labour for erection—							
(i) making holes in walls							
1/8 mason . . .	nos.	1/8	0·75	each	0·094		
1/8 coolie . . .	”	1/8	0·375	”	0·047		
(ii) hoisting cross beams—coolies . . .	nos.	1/2	0·375	”	0·198		This table gives the cost per 100 sq. ft. of the types of centering most commonly used, namely, ordinary planking supported on runners as shown in Plate I. Other types can more easily be used in places but the figures given may safely be taken as a guide when the area to be done is fairly large. If the area be small, the cost will necessarily be slightly higher, but when the area to be done is large, planks can be used from 20 to 30 times if carefully handled and the cost will be lower in proportion. Centering for R. B. need not be nearly so well finished as centering for R. C. and therefore may be used much oftener.
(iii) spreading planks and earth of the platform and stopping chinks with grass—coolies. . .	”	3/4	0·375	”	0·281		
(iv) finishing top surface and giving camber—							
mason	”	1/8	0·75	”	0·094		
coolie	”	1/16	0·375	”	0·023		
		Total	labour	for erection		0·737	
3. Labour for removal of centering—							
(i) putting cross bamboos in proper places and striking wedges—							
mason	”	1/16	0·75	each	0·047		
coolies	”	1/8	0·375	”	0·047		
(ii) removing planks—coolies . . .	”	2	0·375	”	0·750		
(iii) scraping and patching up voids, if any—							
mason	”	1/4	0·75	”	0·187		
coolie	”	1/4	0·375	”	0·094		
(iv) cleaning floor—coolie . . .	”	1/8	0·375	”	0·047		
	Total	labour, etc.,		for removal		1·172	
4. Miscellaneous—							
(i) making good damage to walls, etc. . .	lump sum . . .				0·40		
(ii) other petty items .	lump sum . . .				0·10		
			Total .		...	0·5	
	Grand Total					5·029, say Rs. 5 per % sq. ft.	

COST STATEMENT II.

COST OF R. B. SLABS PER 100 SQ. FT.

This table shows the cost of the brickwork portion of the slab omitting the cost of reinforcement which varies with conditions of span, loading, etc.

Materials.	Rate.	Unit.	3″ Quantity.	3″ Cost.	5″ Quantity.	5″ Cost.	6″ Quantity.	6″ Cost.	8″ Quantity.	8″ Cost.	9″ Quantity.	9″ Cost.
	Rs. A.			Rs.		Rs.		Rs.		Rs.		Rs.
1. bricks	12 0	%₀	270	3·24	450	5·4	550	6·6	700	8·4	830	10·0
2. cement	3 0	c. ft	1·6	4·8	3	9·0	4·2	12·6	5·0	15·0	6 to 6·2	18·6
3. sand	3 0	% c. ft.	5·0	·15	9	·3	13	·4	15	·4	19	.6
(a) Total materials	...		...	8·19	...	14·7	...	19·6	...	23·8	...	29·2
4. Labour—												
head mason	1 0	Day	·05	·05	·10	·10	·15	·15	·20	·20	·30	·30
mason	0 12	„	·6	·45	1·00	·75	1·50	1·13	2·00	1·50	2·50	1·88
coolies carriers	0 6	„	1·2	·45	1·80	·67	2·70	1·01	3·50	1·31	4·50	1·69
„ mixers	0 6	„	·2	·07	·33	·13	·50	·19	·66	·26	·83	·31
„ brick wetters	0 5	„	·2	·06	·33	·10	·50	·16	·66	·21	·83	·26
bhistis	0 10	„	·5	·31	·75	·46	1·00	·62	1·00	·62	1·00	·62
(b) Total labour	...	...	...	1·39	...	2·21	...	3·26	...	4·10	...	5·06
5. centering, erecting, dismantling, etc.	...	...	...	4·00	...	5·00	...	5·00	...	5·00	...	5·00
6. scraping, cleaning, etc.	...	...	...	·25	...	·25	...	·25	...	·25	...	·25
7. filling holes, etc.	...	...	...	·5	...	·5	...	·5	...	·5	...	·5
(c) Total 5, 6 and 7	...	...	...	4·75	...	5·75	...	5·75	...	5·75	...	5·75
Total Cost (a) + (b) + (c)	...	...	...	14·33	...	22·66	...	28·61	...	33·65	...	40·01

NOTES—

(1) One bag Katni cement = 2·1 c. ft.

(2) Bricks = 10″ × 5″ × 3″ each (no allowance for wastage is made in the above figures.)

(3) Mortar 3 : 1 = 3·5 c. ft. mixed dry = 2·7 c. ft. mixed wet.

COST STATEMENT III.

Cost of R. B. lintels and beams per 100 c. ft.

This table shows the cost of lintels and beams omitting the cost of reinforcement which varies with conditions of span, etc.

Details and items.	Rate.	Unit.	3″ and 5″ lintels.		6″ lintels.		9½″ lintels.		10″ lintels.		Beams.	
			Q.	C.	Q.	C.	Q.	C.	Q.	C.	Q.	C.
	Rs. A. P.			Rs.		Rs.		Rs.		Rs.		Rs.
1. Materials—												
bricks	12 0 0	%	1,100	13·2	1,050	12·6	1,030	12·2	1,010	12·1	1,000	12·0
cement	3 0 0	c. ft.	7·0	21·0	7·75	23·3	8·25	24·8	9·5 to 11·25	33·8	12·0	36·0
sand	3 0 0	%c. ft.	21·0	·6	22·25	·7	24·75	·7	30·0	·9	36	1·1
Total materials	...	...	...	34·8	...	36·6	...	37·7	...	46·8	...	49·1
2. Labour—												
head mason	1 0 0	Day	·2	·2	·2	·2	·3	·3	·4	·4	1·0	1·0
mason	0 12 0	„	2·4	1·8	2·8	2·10	3·0	2·25	3·5	2·63	5·0	3·75
coolies carriers	0 6 0	„	4·8	1·8	5·0	1·87	5·0	1·87	5·0	1·87	5·0	1·87
„ mixers	0 6 0	„	·8	·3	1·0	·38	1·0	·38	1·0	·38	1·0	·38
„ brick wetters	0 5 0	„	·8	·25	1·0	·31	1·0	·31	1·0	·31	1·0	·31
bhisti	0 10 0	„	·5	·31	1·0	·62	1·0	·62	1·0	·62	1·0	·62
Total labour	...	...	...	4·66	...	5·48	...	5·73	...	6·21	...	7·93
3. Centering, erecting, dismantling and cleaning.	...	...	...	6·0	...	6·0	...	6·0	...	6·0	...	12·0
Total cost per 100 c. ft.	...	...	...	45·46	...	48·08	...	49·43	...	59·01	...	69·03

EXAMPLE I.

Power House. Battery room 50 × 20, corresponding roughly to usual type of room for barracks & hospitals commonly met with in India

EXAMPLE II.

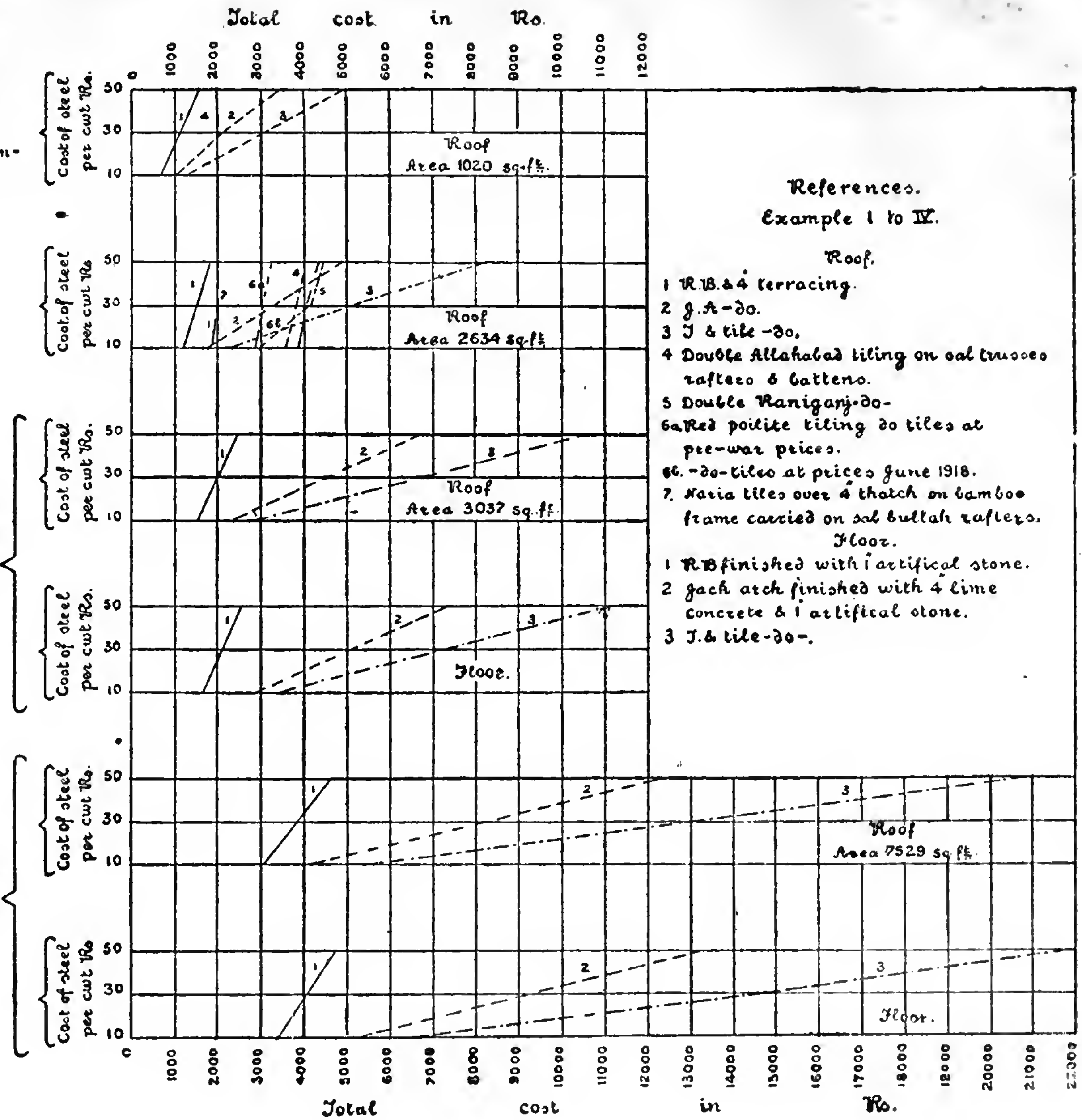
Small bungalow type, single story, built for European Registrar.

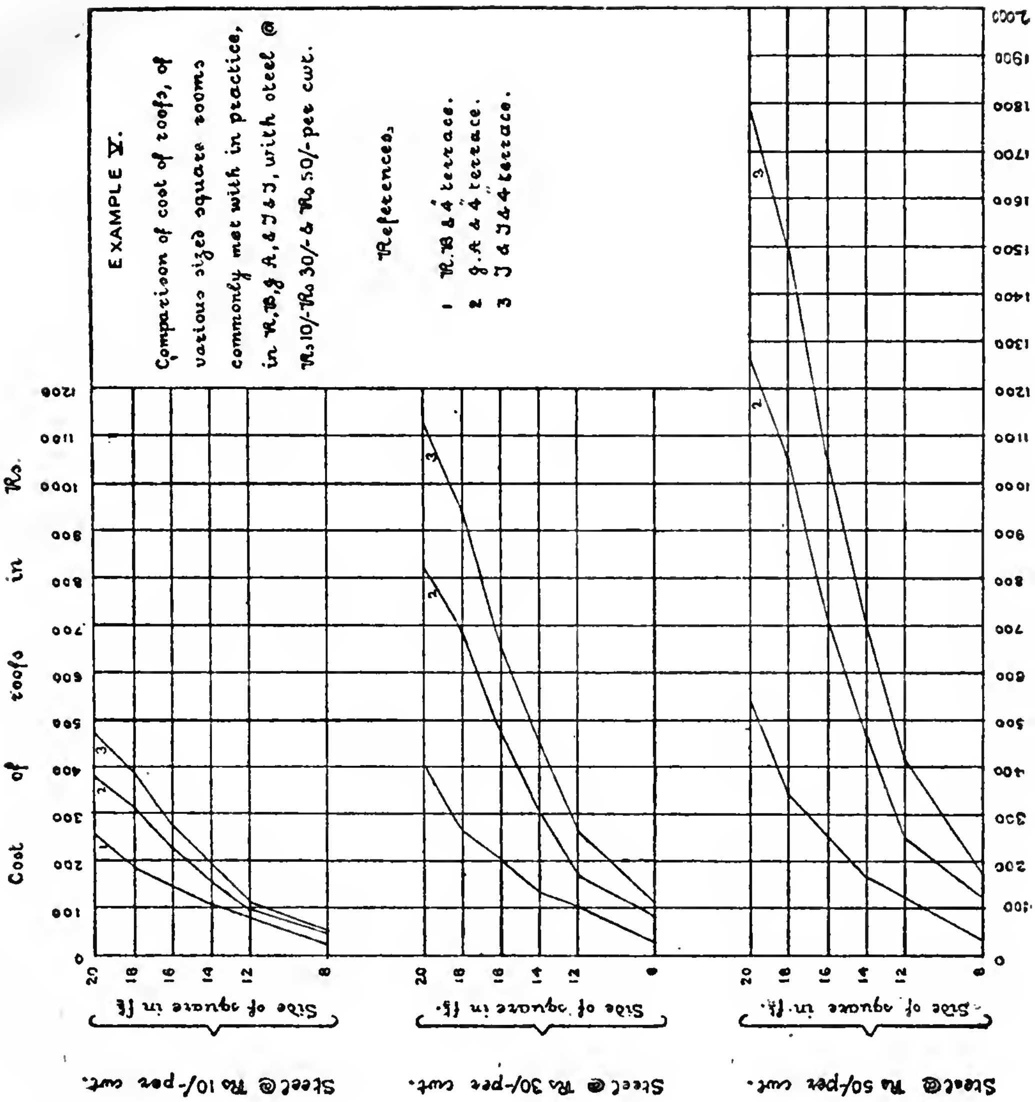
EXAMPLE III.

Medium sized, double storied house built for Excise Commissioner.

EXAMPLE IV.

Large sized, double storied house for Hon'ble Member of Executive Council.




EXAMPLE V.
Comparison of cost of roofs, of various sized square rooms commonly met with in practice, in R.B.& A., & J & J, with steel @ Rs.10/- Rs 30/- & Rs 50/-per cwt.
References.
1 R.B & 4" terrace.
2 J.A & 4" terrace.
3 J & J & 4" terrace.
Cost of roofs in Rs.
Side of square in ft.
Steel @ Rs 10/-per cwt.
Steel @ Rs 30/-per cwt.
Steel @ Rs 50/-per cwt.

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Notes on reinforced
brickwork.