NOTES ON TESTS OF REINFORCED CONCRETE BEAMS.

BY MAJOR J. MONASH.

PART I.—INTRODUCTION.

The theory and experimental investigation of Reinforced Concrete are at the present time occupying the active attention of engineers all over the world. English and American scientists are beginning to take a belated interest in a subject which has been before the profession in Europe for the past nine or ten years; there these questions have been exhaustively treated, both analytically and experimentally, by Considère, Christophe, Spitzer, Ritter, Von Emperger, and many others whose names will be familiar to those who have access to the technical journals of France, Germany, Austria and Italy. For the past five or six years a series of comprehensively designed experiments have been conducted in Sydney by Prof. Warren, in collaboration with Mr. F. M. Gummow, and the results have been communicated to the Royal Society of New South Wales. Within the past twelve or eighteen months, American investigators have come prominently upon the scene, and the technical publications of America are now replete with records and discussions of experiments dealing with many interesting phases of the subject.

Up to the present, the author has not met with a single published account of systematic experiments originating in Great Britain, although from the great attention which is at last being paid to the matter across the Atlantic, it is to be expected that the serious interest of English engineers will be soon awakened.

The practice of reinforced concrete in Australia dates from 1896, and in Victoria from 1898. Apart from the investigations of Prof. Warren and Mr. Gummow, no scientific work has been done in Australia; it seemed, therefore, that the time had arrived when such work should be undertaken in Victoria. Professor Kernot, Past President of the Institute, courteously consented to supervise this work, and to place the equipment of the Engineering Laboratory of the Melbourne University at the author’s disposal for the purpose.

It was determined to carry out a series of experiments developing the subjects from its elements, until sufficient data had been established to enter upon some of the more difficult and abstruse problems which are involved. The first set of tests was to relate wholly to the question of reinforced concrete in cross bending, the aim being to verify the physical constants presented by foreign writers as a basis for safe practice in the design of beams, or, if necessary, to establish fresh constants for local materials and conditions. It is the
object of this paper to present to the members of this Institute, in a compressed form, the results of the first or elementary set of experiments, in the hope that it will stimulate a discussion which will be fruitful of suggestions for a useful development or modification of further tests which it is contemplated to make hereafter.

The tests were made in December last, and in the period which has elapsed, several very interesting aspects of the question have been opened up in the journals since received, notably in the advance reports of the International Congress at St. Louis, and in the columns of the "Engineering News." Some of these aspects will be referred to later, and it is to be regretted that the observations made during the December tests did not go so far as they might have done in those particular directions.

In view of the fact that, until very recently, almost every word written upon the subject of reinforced concrete has been in some foreign language, the assumption may be pardoned that some, at least, of the members of this Institute would desire a very brief introductory exposition, of the principal characteristics of this form of construction.

In the first place, the term Reinforced Concrete has been chosen (in preference to Concrete Steel) because that title was resolved upon by the St. Louis Congress as being the most accurately descriptive and most generally suitable; and also because it seems to be universally adopted by such text writers as have already written in English. The term is applied only to such a combination of concrete and steel (or iron) wherein the two materials act as a single unit, sharing the stresses between them. Such a definition excludes altogether all those classes of construction where the concrete is used merely as a cover or filling, and in which the stresses are capable of being wholly carried by the steel if the concrete were removed.

The principal physical attributes of these materials and their combination in the form of reinforced concrete which require thorough investigation and determination before sound design can proceed are the following:

A. As to the steel:
   1. Its modulus of elasticity.
   2. Its elastic limit.
   3. Its ultimate tensile strength.
   4. Its ultimate shearing strength.
   5. Its co-efficient of thermal expansion.

B. As to the concrete, of a given composition, and of a given age:
   1. Its modulus of elasticity.
   2. Its elastic limit.
   3. Its ultimate tensile strength.
   4. Its ultimate compressive strength.
   5. Its ultimate shearing strength.
   6. The ultimate outer fibre stress in cross bending on both compression and tension side.
   7. Its co-efficient of thermal expansion.
C. As to the combination:

1. The adhesive resistance against separation of the concrete from the steel.

2. The degree of protection which the concrete affords to the steel against deleterious chemical action.

3. The effect of the steel, if any, upon the elastic limit of the concrete.

It is not purposed to enter upon, nor would the limits of this paper permit of, an adequate treatment of these several subjects. Only some of them are involved in the tests under discussion, and will be referred to as they arise. Some, however, of the fundamental results of past researches are worthy of mention here. The elastic behaviour of concrete is exceptional; unlike steel, it does not obey Hooke’s Law—that is, the deformations are not directly proportional to the stresses. In other words, the modulus of elasticity of any given concrete varies within wide limits, according to the particular stress applied; this is so even within the elastic limit. Now, as is known, the modulus of elasticity of steel is constant within the elastic limit; hence the ratio of the respective moduli of elasticity of the two materials varies as the applied stresses vary. As will presently appear, this ratio is of the utmost importance in any analysis of stresses upon reinforced concrete, and therefore upon its accurate determination for any given set of conditions will depend the complete arithmetical determination of the respective shares of the work performed by the respective materials. For purposes of practical design it would be impossible to make such determinations in every individual case dealt with. It becomes incumbent, therefore, to lay down average standards, just in the same way that average ultimate stresses are habitually laid down for design in ordinary materials.

Proceeding in this way, we may take, as an average modulus of elasticity, $E$ for mild steel $= 30,000,000$ lbs. Authoritative tests to determine the modulus of elasticity for concrete of different mixtures and ages are rapidly accumulating, and the following round values may be taken as fairly typical of results obtained:

Modulus of elasticity of concrete $E'$:—Concrete consisting of 1 part cement, 2 parts sand, and 4 parts screenings, age 1 to 3 months; for compressive stresses not exceeding 600 lbs. per square inch, $E' = 3,000,000$. The same for a concrete of 1:3:6. $E' = 2,000,000$.

As the stresses increase from 600 lbs. up to 2000 lbs. per square inch, the modulus rapidly falls, till it becomes less than one-half of the magnitudes given. For stresses above 2000 lbs. per square inch, determinations of the value of $E'$ are rare, and not well authenticated.

It will thus be seen that the ratio $E$ to $E'$ which is characterised by the symbol “m,” lies between the values 10 to 15, for concrete of ordinary composition up to three months old, within the limits of ordinary working stresses. The choice of this factor must, therefore, be arbitrarily made as lying between 10 and 15, according to circumstances, and the judgment of the designer.

The first difficulty in properly analysing the results of a series
of destructive tests will now become apparent. Destruction of the specimen takes place under stresses far above those for which the value of “m” is reliably known. It is for this reason, chiefly, that the point of failure of such a specimen cannot always be computed with reasonable certainty. Results of tests, which have apparently been discordant, have sometimes been commented upon as indicating a certain unreliability of behaviour in the combination; but, such differences between calculated and actual results have followed almost wholly from the attempt to apply, to the condition of ultimate failure, the calculations proper only for the conditions of safe working stresses.

Before dealing specially with beams, I must refer to some other aspects which have recently come to be enveloped in some degree of doubt. The first relates to the influence of the presence of the steel upon the elastic limit of the concrete. Upon this subject, Considère, a very eminent French engineer, and an ingenious and painstaking laboratory investigator, expounded the doctrine that the presence of the steel in adhesive contact with the concrete greatly increases the elastic limit of the latter; that is to say, that the concrete in a reinforced specimen in tension can elongate without fracture several times more than a similar specimen not reinforced. This doctrine was explained by the circumstance that the presence of the reinforcement prevents the occurrence of the intense local contraction which occurs immediately before fracture, and spreads such contraction more or less uniformly along the reinforcing member. The doctrine was further exemplified by numerous experiments, and accurate extensometric measurements. In addition pieces of concrete were cut out of specimens, in which, while part of same, they had been subjected to actually measured extensions several times greater than they could have suffered without fracture if tested alone; these pieces were then tested in tension, and found to have the normal tensile strengths and extensibility of ordinary non-reinforced concrete.

The doctrine referred to has been accepted and acted upon by every European authority upon the subject for a number of years past, and has only been called in question during the last few months by Prof. Turneaure, of Wisconsin University, and Prof. A. N. Talbot, of the University of Illinois, in the columns of the “Engineering News.”

These experimenters say that their tests and measurements upon similar test specimens do not accord with Considère’s observations, that there is very little difference in the elastic limit of concrete when reinforced and when not reinforced, and that Considère when testing pieces of concrete cut out of the specimens (as already described) must have hit upon pieces which did not happen to contain incipient or developed fractures. While admitting that apparently the concrete exhibited greatly increased extensions without visible fracture, they declare that this is due to the occurrence of numerous very minute fractures or separations not visible to the observer, but whose existence can be indirectly evidenced.

Apart from the respect due to these investigators, prominence is
here given to this issue, because it is at the present moment being very actively discussed in the journal referred to, and the views of these American authorities while contested by other American writers, are being editorially supported. M. Considère has not yet been heard in reply, so that the issue is an open one. Unfortunately it is one which was raised too late to be regarded in the Melbourne tests; in these, the observation of cracks or tension fractures was confined to those which could be visually detected by ordinary means.

The question may not, after all, have any practical bearing upon design. It has been customary in the design of reinforced concrete beams to wholly neglect the tensile strength of the concrete on the tension side. In practice, then, this concrete may behave as it will; if the working loads upon the beam are of sufficient magnitude to induce perceptible cracks in the tensile zone of concrete, this is far from marking the failure of the beam; although for most purposes such a state of stress would mark the overstepping of prudent working limits. But as to "invisible" cracks, if such really occur, it will have to be shown that these have some influence upon other characteristics of the combination; which has not yet been seriously suggested. Nevertheless, the question of the increased extensibility of the concrete on the tension side of a beam necessarily has an important influence upon the purely theoretical analysis of the stresses. For all stages of loading up to the point when some fracture, visible or invisible, has occurred in the tensile zone of concrete, the whole of this zone is acting its part in tension, and the position of the neutral axis must be calculated strictly upon the basis that it does so, but as soon as a stage of loading has been reached, when a crack occurs, the tensile stresses come wholly upon the steel reinforcements, and the neutral axis will assume an entirely different position, by at once moving nearer to the compression side, and thus increasing the effective depth of the beam.

So far as regards observable cracks, experiment exactly agrees with theory, and it is usually upon the occurrence of a visible crack that an entire change takes place in the direction of the stress-strain diagram. It will be gathered from this that the computations to evaluate the ultimate strength of any given beam will have to be made upon the assumption of the entire failure having taken place at some earlier stage of the test of the tensile zone of concrete; in other words, that the neutral axis must be calculated upon the assumption that there is no concrete present below the neutral axis. If, however, the same assumption be applied in computing the stresses in the same beam under any condition of loading short of that which will fracture the concrete, the result will be erroneous, because the neutral axis will be in quite a different place.

There remains but one other fundamental hypothesis with which it is necessary to deal briefly, and this relates to the behaviour of the concrete in the compressive zone of the beam. In a beam of any material which follows Hook's Law, it is customary to assume that any plane cross section will, after bending takes place, still remain a plane cross section or, in other words, that the stress intensities...
upon the compressive zone vary from nil at the neutral axis, in direct proportion to the distance from the neutral axis, to a maximum at the outer "fibre." This is probably not so in the case of concrete, because the compressions, or shortenings of the fibres, are known experimentally not to be in direct proportion to the stress intensities. What particular form any given planar section of the beam will assume when the beam bends, is intimately associated with the abstruse question of shearing stresses, and a further consideration of the point would lead us away into purely hypothetical discussion. It is sufficient for the present purpose to point out that the total stresses upon the compressive zone of the concrete beam (which in the case of a timber beam, for example, would be represented graphically by the triangle OBC in figure 2) would be represented by the outline OAC in figure 1, where OB is the curve, believed to be parabolic, which represents the relation between stress and strain in concrete in compression. The determination of this curve has not yet been satisfactorily established experimentally, except up to the limits of ordinary working stresses. Moreover, to compute the compression area of the beam as a parabolic segment instead of as a triangle would introduce cumbersome exponential computations. The practice has therefore been almost universal, to treat the distribution of stress in the compressive zone as being graphically represented by a triangle. It is apparent that, while this departure from the known properties of concrete is in the direction of safety for the purposes of design, yet it will tend to disturb the attempt to compute, in advance, the ultimate strength of any given beam. It is only by neglecting the complications above referred to, which would be involved in a strict adherence to theoretical ratios, that the equations for the stress distribution in a reinforced concrete beam can be expressed in a form capable of computation by simple arithmetic. This approximate form of treatment is, however, wholly in the direction of safety.

The algebraic statement of such treatment (see Figs. 3 and 4), may be stated thus: Inasmuch as, for any given beam, the values of all the symbols on the right hand side of equation (4) are known, the position of the neutral axis can be at once computed, and from this, by equation (2), can be obtained the effective depth of the beam x, and hence by (3) the moment of resistance. If the value of M be known, then for a beam of width B, the values of h, a, and \( a \) can be calculated for any desired ratio of working stresses \( p \) or \( f \), in the form \( K \sqrt{M} \), where \( K \) is a numerical co-efficient.

PART II.—THE MELBOURNE UNIVERSITY TESTS.

It has already been stated that the principal objects of this, the first series of tests in cross breaking, were, to see whether the results obtained would in a general way confirm, or otherwise, the theories which have been outlined—at any rate in their broad results, if not in the detailed reasoning. It is gratifying to be able to state that they did so to a surprisingly close degree.

From the equations already discussed it will be seen that the strength of the beam depends upon a function of the ratio \( Bh \) over a
that is upon the relative quantities of concrete and steel in the composite structure. Previous practical experience indicated that a suitable value for this was about 100, that is to say, that the steel should be 1 per cent. of the bulk of the whole beam. For purposes of comparison, and to lend point to the conclusions to be drawn hereafter, this "one per cent. reinforcement" will be referred to as "normal" reinforcement. It happens that having regard to the relative cost of steel and concrete, under ordinary conditions, a 1 per cent. reinforcement is about the higher limit of economic design, but the economic aspect is not being at present considered at all.

A set of five beams was made with a 1 per cent. reinforcement, in total thicknesses advancing by inches from 2 to 6 inches. A second set of five beams was made, similar in every respect to the above, but with only \( \frac{1}{2} \) per cent. reinforcement. The object was to determine experimentally whether the respective strengths of any pair of beams of equal thickness would have the relations to each other suggested by theory. A further object was to ensure, by having a sufficient weakness on the tension side, that the ultimate failure would be by failure in tension—i.e., cracking of the concrete, at least in all the beams of the second set, in the event of the beams, or any of them, in the first set, failing in some other manner.

A third set of five beams was made, again similar in all respects to the other two sets, but having 2 per cent. of reinforcement—i.e., much above normal. Apart from the desire to see here also whether theory was verified, the expectation was, in the case of the third set, that owing to the excessive strength of the tension side, some, if not all, of the beams of this set, would ultimately fail in some manner other than by cracking on the tension side, that is either by shear, or by failure on the compression side, or by failure of adhesion.

These being the broad lines on which the experiment was designed, a detailed description of the test specimens, and the manner of testing them can now be proceeded with.

Fifteen specimen beams were manufactured, of reinforced concrete, at Burnley, on September 20th and 21st, 1904. They were all 9 in. wide, of varying depth, and a uniform length of 4 ft. 6 in. Column 4 of the table gives full particulars of the standard and manner of reinforcement.

The concrete consisted of one part of cement (Vic. Portland Cement Co., "Emu" brand), two parts of Port Melbourne sand, and three parts of bluestone screenings up to \( \frac{3}{4} \) in. gauge. The concrete was moulded as (what is known as) a "wet" mixture. The reinforcements consisted of plain mild steel rods, not turned up or swelled or treated at the ends in any way. No reinforcement against shear was provided. After moulding, and upon having sufficiently hardened to be handled, the fifteen specimens were placed in the open, and left subjected to ordinary spring weather conditions for about three months. No special care was used in the manufacture of these specimens, so that the work should be fairly typical of the ordinary results of workshop practice.

These fifteen specimens were tested at the Melbourne University
on December 14th and 15th, 1904, thus averaging 85 days old. They were tested as beams having a net span of 48 inches, by the application of a central concentrated load, distributed uniformly over the width at mid-span. They were placed in the testing machine in such manner that the load was applied horizontally, so that the self load of the specimen was entirely eliminated from consideration. Autographic deflection diagrams were taken of each specimen. In addition, a rough extensometric measurement was taken upon the upper edge of each specimen near the centre, upon a length of 8 in., the extensometer being placed as nearly as possible vertically over the plane of the reinforcements. As a second instrument was not available, no attempt was made to measure the shortening upon the compression side of the neutral axis. It is intended upon a future occasion to devise apparatus for simultaneously measuring the deformations in several planes of the cross section, so that the varying position of the neutral axis may be determined experimentally. From the moment that the stresses were applied, two observers watched the specimen, particularly upon the tension face, for the occurrence of the first crack. The state of loading, and the position, character, and mode of development of the crack were recorded. Any other cracks appearing in the later stages of loading were also similarly noted. For the detection of cracks only ordinary visual means were employed, without the assistance of a microscope; it may be taken for granted that any crack having a width of over .002 in. did not escape observation.

The whole fifteen specimens were slowly loaded by successive increments of load, until the lever of the testing machine was no longer fully supported. In several cases the downward motion of the lever at the conclusion of the test was very slow, occupying several minutes to fall the 6 inches. It was surmised that this was due to a very slow and gradual drawing of the bars through the concrete owing to failure of adhesion.

Having in view the primary object of these tests, a set of computations was made beforehand for the purpose of forecasting what would be the central breaking load for each specimen. Columns 7 and 8 give an epitome of this computation.

Column 7, or "effective depth," was computed from the fundamental equations (2) and (4). In these equations, the value of "m" or the ratio of the moduli of elasticity of steel and concrete was taken as 10.

Column 8 was computed from equation (3) upon the assumption that the ultimate strength of the beam would be reached when the stress in the steel had reached 50,000 lbs. per square inch. In choosing this, the results of Prof. Warren’s tests were used as a guide. The computation of column 8 was made, however, subject to the important qualification that these would be the ultimate bending moments only if the beams failed in tension, and did not fail at an earlier stage either upon the compression side, or in shear. It will be remembered that the specimens were intentionally not reinforced in shear.

The computed anticipations were handed to Professor Kernot.
before the testing began. Column 10 gives the results of the tests; a comparison of columns 9 and 10 of the table will exhibit a remarkable and satisfactory agreement. In those cases where the difference between the computed and actual results are relatively large, a ready explanation is available.

**Remarks a, b and c:**

In the case of specimens A1, B1, and C1, the total depth of the beam was only 2 in., the intended overall height from loaded surface of beam to plane of reinforcement was therefore only 1 1/2 in. A very slight inaccuracy in the position of the rods would account for a portion of the discrepancy. Moreover, in the case of specimens A1 and B1, the rods used were only 1/4 in. diameter, and had a higher tensile strength and elastic modulus than the general type in the other specimens.

**Remarks d, e and f:**

In the case of specimens C3, C4, and C5, which are the only ones in which the actual fell appreciably below the computed results, the failure did actually take place by crushing on the loaded side, or by shear. As to the remainder, it may be said that the consistency of the results is as great as could be expected in a perfectly homogeneous material. This is emphasised when the wide range of the loading—from 600 lbs. up to 14,000 lbs.—is taken into consideration. The main objects of this set of experiments may therefore be said to have been achieved with complete success, it being established that the behaviour of these reinforced concrete beams followed closely upon the theories which have been propounded. To put these results in a form which may be found to be practically useful, column 18 has been computed to show the safe working limits of span for each of the fifteen designs when used as beams resting freely on two supports, and loaded with 100 lbs. per square foot, taking into account the weight of the beam itself, and allowing a factor of safety of 5.

Subjoined are some interesting deductions from the results at hand:

For many years past it has been usual in civil engineering practice to employ cement concrete wholly for resisting compressive stresses, and, by using it only with a high factor of safety, to stamp it as a somewhat uncertain and unreliable material. Its ultimate strength in compression has been taken as about 2500 lbs. per square inch, and the factor of safety was usually 10, and seldom less than 8; this permitted of working stresses of from 250 to 300 lbs. per square inch. Doubtless, when taking into consideration the character of Portland cement 20 years or more ago, before modern methods of manufacture had been introduced, also the defects possible in the preparation of concrete under ordinary contract conditions, a high degree of conservatism in its use has been justifiable. However, in the present day, Portland cement has become a material of great uniformity and reliability, and standard methods of test are established also in the practice of the modern art of reinforced concrete,
the fabrication of the concrete has been made a special study, and
nowadays the precautions necessary for the production in the field of
a material closely approaching to laboratory perfection are well
understood, chiefly as regards the preparation and proportion of the
matrix, the choice and proportions of the aggregates, the study of
weather conditions, and so on. The fact that the necessity for ex-
cellence of materials for and manufacture of the concrete is so tho-
roughly well recognised is really a guarantee in the direction of
reliability.

The outcome of these considerations has been an entire change of
view in regard to the limits of permissible compressive strength of
concrete. Upon the continent of Europe, where building construction
is carried on under strict police supervision, comprehensive stipula-
tions have been published as regards the use and design of reinforced
concrete, and these freely permit of working stresses of from 450
to 600 lbs. per square inch. These figures are culled from the pub-
lished regulations of upwards of twenty bureaus in Germany, Switzer-
land, France, and Austria. American designers are working upon
the same lines. Now, these figures refer to direct compression, and
even greater values are permitted for the “outer fibre” stress upon the
compression side of reinforced beams. The justification for these
enlarged limits of practice lies partly in the recognition of the fact
that a well-manufactured concrete will have a compressive strength
at one month old of well over 3000 lbs. per square inch, and partly
in the view that owing to increased reliability of fabrication, a factor
of safety of 5 or 6 is very ample.

It will now be interesting to see to what extent the experiments
under discussion justify these higher virtues attributed to cement
when used as the compressive member of a reinforced beam.

The fundamental equations (1) to (4) having received so emphatic
a confirmation, little hesitation need be felt in evaluating by their
means the stress in equation (3). This has, therefore, been worked
out in the table (column 14).

Only two of the specimens—viz., C3 and C4, failed by the crush-
ing of the extreme fibre on the compression side. The whole of the
remainder appear to have withstood the compressive stress intensities
worked out in column 14. Taking even the lesser of the two values
found in the two cases under notice—viz., 4000 lbs. per square inch—
it will be seen that by adopting 500 lbs. per square inch as the safe
working value of $p$, we have a factor of safety of at least 8.

It is quite true that the excessively high values of $p$—computed
for specimens A1, C1, and C2 (in which no compression failure took
place), suggests the possibility of error in the hypotheses upon which
the computation has been made. This may perhaps lie in the direc-
tion which I suggested in the earlier portions of this paper—viz., in
our ignorance of the value of the elastic modulus of concrete under
high compressive stresses. The doubt upon this point is, however,
in character academic only, and does not affect the broad fact that
in the ten beams reinforced to a normal or subnormal extent the
failure took place upon the tension side.

This appears to me to justify the deduction that in beams having
a reinforcement of 1 per cent. or under, the compression side may be left to look after itself, and that its factor of safety will be at least as great as that of the tension side. It is only when excessive reinforcement is introduced that the compressive strength of the concrete becomes a matter of real practical concern.

Column 15 of the table gives the shearing strength in pounds per square inch to which the concrete was actually subjected at the point of failure, although only in one case, that of specimen C5, did the failure take place wholly from shear.

Lastly, column 16 gives the computed actual adhesive resistance of surface of the bars within the concrete against pulling out of, or through the mass, at the moment of failure of the beam. This attribute is merely alluded to in passing, as no special attention was directed to studying this feature, because it is of little moment in this type of rectangular beam, and becomes important only in the design of T beams.

In conclusion, mention may be made of the set of autographic stress deflection diagrams, which show the behaviour of the specimen throughout its test. Many other aspects of interest might be discussed from these diagrams, but these notes have already exceeded their allotted length.

Attention is also directed to the point when the first crack became visible upon the tension side, as tabulated in column 11. In every case the rupture of the tension zone of the concrete occurred when the beam had already been loaded well above half its ultimate load. This point, it is suggested, may probably be the elastic limit of the beam as a whole, and from this it would seem that a factor of safety of four (4) would be sufficient for this class of construction.
### SYMBOLS—

- $E =$ Modulus of Elasticity of Metal.
- $E' =$ do. do. of Concrete.
- $m =$ m.
- $f =$ Stress-intensity upon Metal.
- $p =$ do. do. do. Concrete.
- $a =$ Cross Section of Metal.

#### Table

<table>
<thead>
<tr>
<th>GROUP</th>
<th>No. of Beams</th>
<th>Overall Thickness</th>
<th>Reinforcing Rods</th>
<th>Actual Net Area of Rods</th>
<th>Approximate Cross Section</th>
<th>Computed Depth</th>
<th>Computed Moment of Resistance for $f = 50,000$ lbs.</th>
<th>Computed Ultimate Load</th>
<th>Actual Ultimate Load</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>2</td>
<td>Four, $\frac{3}{4}$ in. dia.</td>
<td>0.196</td>
<td>1 0.64</td>
<td>10,450</td>
<td>871</td>
<td>1,150</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>3</td>
<td>Two, $\frac{3}{4}$ in. and one $\frac{1}{2}$ in.</td>
<td>0.209</td>
<td>1 0.95</td>
<td>26,250</td>
<td>2,188</td>
<td>2,208</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>4</td>
<td>Three, $\frac{3}{4}$ in. &amp; one $\frac{1}{2}$ in.</td>
<td>0.380</td>
<td>1 2.830</td>
<td>53,750</td>
<td>4,480</td>
<td>4,490</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>5</td>
<td>Four, $\frac{1}{4}$ in.</td>
<td>0.442</td>
<td>1 3.714</td>
<td>82,100</td>
<td>6,842</td>
<td>6,900</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>5</td>
<td>6</td>
<td>Three, $\frac{1}{2}$ in.</td>
<td>0.588</td>
<td>1 4.574</td>
<td>134,500</td>
<td>11,210</td>
<td>10,480</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>2</td>
<td>Two, $\frac{1}{2}$ in.</td>
<td>0.086</td>
<td>$\frac{1}{2}$ 1.107</td>
<td>5,450</td>
<td>454</td>
<td>63</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>3</td>
<td>Three, $\frac{3}{4}$ in.</td>
<td>0.147</td>
<td>$\frac{1}{2}$ 2.019</td>
<td>14,850</td>
<td>1,237</td>
<td>1,594</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>4</td>
<td>Four, $\frac{1}{4}$ in.</td>
<td>0.196</td>
<td>$\frac{1}{2}$ 2.915</td>
<td>28,550</td>
<td>2,380</td>
<td>2,550</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>5</td>
<td>Two, $\frac{1}{4}$ in.</td>
<td>0.222</td>
<td>$\frac{1}{2}$ 3.833</td>
<td>42,150</td>
<td>3,513</td>
<td>3,773</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>5</td>
<td>6</td>
<td>Two, $\frac{1}{2}$ in. and one $\frac{1}{4}$ in.</td>
<td>0.269</td>
<td>$\frac{1}{2}$ 4.750</td>
<td>63,900</td>
<td>5,325</td>
<td>5,390</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>2</td>
<td>Three, $\frac{1}{2}$ in.</td>
<td>0.331</td>
<td>1 1.024</td>
<td>16,950</td>
<td>1,412</td>
<td>1,689</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>3</td>
<td>Three, $\frac{3}{4}$ in.</td>
<td>0.388</td>
<td>1 1.864</td>
<td>34,800</td>
<td>4,567</td>
<td>4,697</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>4</td>
<td>Four, $\frac{1}{4}$ in.</td>
<td>0.785</td>
<td>2 2.993</td>
<td>104,700</td>
<td>8,725</td>
<td>8,775</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>5</td>
<td>Three, $\frac{3}{4}$ in.</td>
<td>0.920</td>
<td>3 3.153</td>
<td>163,600</td>
<td>13,633</td>
<td>12,205</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>5</td>
<td>6</td>
<td>Two, $\frac{3}{8}$ in. and two $\frac{1}{2}$ in.</td>
<td>1.005</td>
<td>2 4.421</td>
<td>221,150</td>
<td>18,430</td>
<td>14,480</td>
<td></td>
</tr>
</tbody>
</table>
### Tabulated Results

#### Fig. 3

![Diagram](image)

#### Fig. 4

![Diagram](image)

**Equations**

\[
\frac{A' A}{C C} = \frac{p}{E} = \frac{f}{f} = \frac{E}{E'} = \frac{p m}{f} = \frac{a}{b} \quad (1)
\]

\[
h = a + b = x + \frac{a}{3} \quad \ldots \quad \ldots \quad (2)
\]

Moment of Resistance \( M = a f x = \frac{B p x}{2} \quad (3) \)

\[a = \frac{m a}{B} \left( I + \sqrt{I + \frac{2 B h}{m a}} \right) \quad \ldots \quad \ldots \quad (4)\]

<table>
<thead>
<tr>
<th>Load when First Crack Appeared</th>
<th>Total Deflection</th>
<th>Remarks</th>
<th>Stress Intensity on Compression Side</th>
<th>Shearing on Concrete</th>
<th>Adhesive Resistance</th>
<th>Weighted Plate per Sq. Ft.</th>
<th>Limit of Span for Load per Sq. Foot</th>
</tr>
</thead>
<tbody>
<tr>
<td>600</td>
<td>0.685</td>
<td>a</td>
<td>5200</td>
<td>60</td>
<td>172</td>
<td>23</td>
<td>11</td>
</tr>
<tr>
<td>1,300</td>
<td>0.515</td>
<td>do.</td>
<td>3530</td>
<td>62</td>
<td>179</td>
<td>34</td>
<td>11</td>
</tr>
<tr>
<td>2,400</td>
<td>0.548</td>
<td>do.</td>
<td>3330</td>
<td>86</td>
<td>180</td>
<td>45</td>
<td>9</td>
</tr>
<tr>
<td>4,400</td>
<td>0.698</td>
<td>do.</td>
<td>3050</td>
<td>103</td>
<td>196</td>
<td>57</td>
<td>7</td>
</tr>
<tr>
<td>6,500</td>
<td>0.415</td>
<td>do.</td>
<td>3030</td>
<td>127</td>
<td>233</td>
<td>68</td>
<td>5</td>
</tr>
<tr>
<td>450</td>
<td>0.600</td>
<td>b</td>
<td>3420</td>
<td>30</td>
<td>175</td>
<td>23</td>
<td>11</td>
</tr>
<tr>
<td>900</td>
<td>0.536</td>
<td>do.</td>
<td>2800</td>
<td>41</td>
<td>157</td>
<td>34</td>
<td>11</td>
</tr>
<tr>
<td>1,500</td>
<td>0.370</td>
<td>do.</td>
<td>2350</td>
<td>50</td>
<td>139</td>
<td>45</td>
<td>9</td>
</tr>
<tr>
<td>2,600</td>
<td>0.255</td>
<td>do.</td>
<td>2110</td>
<td>56</td>
<td>205</td>
<td>57</td>
<td>7</td>
</tr>
<tr>
<td>5,000</td>
<td>0.700</td>
<td>do.</td>
<td>2000</td>
<td>63</td>
<td>178</td>
<td>68</td>
<td>3</td>
</tr>
<tr>
<td>1,000</td>
<td>0.593</td>
<td>c</td>
<td>6220</td>
<td>87</td>
<td>221</td>
<td>23</td>
<td>11</td>
</tr>
<tr>
<td>2,800</td>
<td>0.508</td>
<td>do.</td>
<td>5620</td>
<td>137</td>
<td>262</td>
<td>34</td>
<td>9</td>
</tr>
<tr>
<td>6,000</td>
<td>0.710</td>
<td>d</td>
<td>4000</td>
<td>138</td>
<td>198</td>
<td>45</td>
<td>12</td>
</tr>
<tr>
<td>10,500</td>
<td>0.910</td>
<td>e</td>
<td>4410</td>
<td>190</td>
<td>290</td>
<td>57</td>
<td>8</td>
</tr>
<tr>
<td>13,000</td>
<td>0.500</td>
<td>f</td>
<td>3500</td>
<td>191</td>
<td>259</td>
<td>68</td>
<td>13</td>
</tr>
</tbody>
</table>

- **Remarks:**
  - Mode of Failure: Tension Side, by Crushing, Do. and Shear, By Shear.
  - Lbs = 1000, 1500, 2000, 2500, 3000, 3500, 4000
  - Ft. In. = 4, 7, 11, 9, 7, 5, 3, 4, 11, 9, 11, 12, 8, 13, 6
DISCUSSION.

The President said that the full discussion would take place at a subsequent meeting, but perhaps some member—Professor Kernot, for instance—might desire to make a few remarks.

Professor W. C. Kernot was very pleased to see the way in which Major Monash had developed the subject and carried out the experimental work. He was only too glad to grant the use of the University testing machine for experiments of this nature.

The paper contained a complete scientific investigation, with very interesting comparisons and deductions, and the uniform way in which the results had come out had given him great satisfaction.

Reinforced construction had not developed in Melbourne as it had elsewhere, but he thought the time was coming when it would be more widely used.

He did not know whether the evidence was very clear on the question of the drawing out of the iron bars. Perhaps the point might be dealt with later.

Mr. J. A. Smith said that the author had referred to the anomalous elongation of reinforced as compared with ordinary concrete, and had adverted to the doubts that had arisen as to Considère’s results. He had just received notes of a paper that had very recently been presented to the French Academy by Considère containing data obtained by independent experimentalists, and supporting the previous contention.

Series of similar beams of similar mixture had been prepared, one set reinforced and the other not. The reinforced beams were tested to a load much greater than that causing rupture in a non-reinforced beam, and until the elongation on the tension side exceeded several times that of plain concrete at the time of rupture. Then pieces of concrete cut from between the reinforcing bars were tested, and found to be in no way weakened by their previous extreme elongation.

Considère considered that the failure of other experimenters in repeating his experiments were due to rapid drying, leading to a too great adhesion to the bars before contraction had ceased, thus giving rise to initial microscopic cracks. He had avoided this by covering the specimens and extending the drying over three months.

Perhaps under these circumstances there might even be an initial compression.

The experiments would seem to indicate that with extension the elastic modulus varied towards zero.

Mr. A. G. M. Michell asked whether the symbol E’ used by the author in the equation was Young’s modulus.

Major Monash replied that, as already stated in the introductory portion of his paper, E’ was not Young’s modulus, the elastic behaviour of concrete being exceptional.

Further discussion was postponed.
DISCUSSIONS.

NOTES ON REINFORCED CONCRETE BEAMS.

The President said Major Monash's paper on "Reinforced Concrete" was open for discussion.

Major Monash had merited the gratitude of the profession for such a paper as he had submitted to them. It dealt with a subject upon which they had in the past looked with suspicion. The paper was especially valuable, because it explained the results of carefully carried out experiments, and placed them in a very accessible and easily understood form.

He had not had much experience of the material himself. It came before him a couple of years ago in connection with wharf structures, and he was unable to see then that the material so constructed could stand the shocks incidental to mooring heavy vessels alongside the wharf. In Auckland (N.Z.), however, there were in course of construction large and important wharves, which were being built of reinforced concrete, and it would be interesting to learn the results obtained from these structures.

There was no doubt (from the knowledge they now possessed of the material, gathered from American and Continental practice) that for any service whatever reinforced concrete could be thoroughly relied upon for standing any shock which steel material would stand. In relation to the manufacture of the concrete itself, it was mentioned in the paper that the beams were made out of concrete which might be called wet. Did that mean the ordinary pasty consistency?

Were any mechanical appliances used in mixing the concrete; and was the Port Melbourne sand used washed?

He hoped some members had come prepared to discuss this important question, and elicit further information on the subject.

The Secretary read a contribution from Mr. J. T. N Anderson (New Zealand).

"I have no doubt the members of the Institute will have appreciated the able and valuable contribution which Major Monash has made to the records. The scant literature of reinforced concrete will amply illustrate how the advance of public knowledge of a subject is hampered by this divorce, as it were, of the investigating and learned part from the practical construction part of the profession. I trust that Major Monash will continue his very valuable contribution by others of a like nature, and may produce a standard work on the subject.

"From my experience in this particular work, I claim some weight for my views on it, and therefore wish the honour, on this occasion, of adding some of my deductions on the general subject to what has
already been given. I only regret that, being an exceptionally busy man, my contribution must be of the briefest. In introduction, how-
ever, I would record that, in addition to between £35,000 and £40,000 worth of reinforced concrete work which I carried out in collaboration with the author up to the year 1902, here, in New Zealand, I have carried out upwards of £70,000 worth of work in which reinforced concrete has played the principal part. In all this work the greatest care has been taken both in training and weeding out the operatives, and in testing and choosing the materials, because in no engineering con-
structional work with which I am acquainted will trouble and disaster more surely attend any neglect or carelessness in either design, in construction, or in unsuitable material. So great weight do I attach to these latter two factors that practically all the reinforced concrete work I have carried out has been done by day labour under my direct supervision; and of the work mentioned above there have been only two exceptions to this rule. One was a contract of less than £600 value, and the other was a contract for rather larger value, but it had to be cancelled, owing to the contractor not supplying sufficiently skilled operators. The strictest system of testing has always been adopted in these works. For the past two years I have kept a trained assistant constantly employed in testing the materials, and, in addition, I per-
sonally test the finished work, and, where practical, I test some of it to destruction. These are the really instructive tests, which prove not only where the operators are at fault or excel themselves, but also the relative merits of different methods, and new materials, etc. So far as time admitted, I have communicated my most valuable results from time to time to the author of this paper who I understand has con-
firmed and adopted most of the lines of progress on which I have gone, though in several large matters our methods have differed radically.

"Generally speaking, my conclusions from using reinforced concrete in bridges, floors, foundations, joists, pipes, storage tanks, and pipes under pressures which must throw the concrete, irrespective of its iron reinforcement, into a tension of over 70 lbs. per square inch, have been that the use of large-section iron, steel, or copper reinforcement is rad-
ically wrong. I have insufficient time at present to develop this aspect of the question, so I will simply content myself by giving the broad reasons for this result. These are:—

"1st. The failure of the reinforced material, apparently by a passing of the yield point in other material, is nearly always accompanied by more or less shearing between the reinforcement and the concrete. This is due to the surface adhesion of the concrete to the iron failing so soon as the concrete has stretched sufficiently to throw the greater part of the strain on the iron or steel. Now, clearly, the sectional area of the reinforcing material being fixed as some definite ratio of the total area, I generally find 1 per cent. about the best in light work (say, not more than 4½ in. in depth). The best results will be obtained by giving the greatest possible surface to the reinforcing rods. This clearly points to the use of as small diameter rods as possible. I have im-
ported several of the materials constructed by the American companies for reinforcement, and find that most of these are woven out of No. 12
or No. 14 gauge Tinman's wire. It is satisfactory to myself and all
colonial users of Monier material to record that in both the cases of
patent construction companies’ reinforcements which I have imported
and used so far, the cost of the material was more than double the cost
of Monier rods woven by locally-trained workmen, and the distribution
of the material was naturally less advantageous.

"The second reason for the better result with small diameter rods
is that there can be more certainty that the reinforcement will carry its
calculated share of the stresses and strains when placed as nearly as
possible, so as to act homogeneously with the concrete in its layer. This
plainly points to the necessity for spacing the reinforcing rods as close
as is possible. With small rods and fairly fine liquid concrete, it is
quite practicable to space the rods with 1-in. centres. However, in
practice there does not seem to be much need to space closer than can
be got with 3/8 rods in heavy work, or, say, No. 3 rods in ordinary
work. A very important matter in securing the uniform spacing of
the rods is the method and system adopted of connecting the cross or
distributing bars.

"The third point is somewhat similar to the second—namely, that
with the small diameter straight rods, the action of tension causes no
such deformation in the reinforcing material, tending to press against
the concrete, and cause internal adventitious strains on it. With
reference to this, it should be mentioned that the commonest way to
increase the surface hold of large-section reinforcement is by either
making the cross section of irregular shape, or longitudinally the rods
are deformed, or twisted, as in the Ransome reinforcement. All such
devices, I find, precipitate the final distinction of the material apparently
from the tension, causing a torsion, or similar strain, at the surface of
contact with the concrete. This idea, once suggested, can, I have no
doubt, be developed and expressed much better by the author of the
paper and many of the members of the Institute than I can in the few
minutes devoted to it. In confirmation of my views as to the advantage
of the small diameter reinforcement, I would call attention to the fact
established by the experiments recorded in the paper that in every case
the beams reinforced by 1/4-in. bars proved stronger than the calculated
strength, while in every case where the bars were 1/2 in. or 3/8 in., the
strength was markedly below that which had been calculated.

"In connection with my experiments, the deflections up to the yield
point were wonderfully close to calculation, while in most cases where
the yield point had not been passed the tested work almost instantan-
eously (when the load was removed), regained its exact original
shape. In such cases where the loads were put on by weights of 1
cwt. at a time, the deflection and recovery were instantaneous.

"In conclusion, I must emphasise that everything depends on the
uniformity of the material and workmanship. Where confusing and
conflicting results have been obtained, I blame these two factors en-
tirely. Nothing is more calculated to shake one's confidence in theo-
retical investigation than the records of tests on concrete.

"I have puzzled over the records, which fill hundreds of entries in
the log-books of the Melbourne and Sydney University laboratories,
and wondered how it came that so often a 9 to 1 concrete gave better results than a 4 to 1 concrete, and these even when both were apparently made with the same materials. The one lesson which could be learnt from hours of such study was that concrete, with its many different ingredients, was almost as difficult to manage, and as fickle to rely on, as a crowd of human beings. After such records it is most reassuring to find that out of hundreds of tests made in actual work with well-constructed Monier concrete, not 2 per cent. have given less than the calculated yield; and the explanation is that a little skill will soon enable the foreman or inspector to detect and reject the faulty, and that the sound material is as reliable as steel. In fact, my personal experience has been that where there has been any marked departure in the behaviour of the work tested from the theoretical calculation, then there has been some factor omitted in the theory.

"I fear that much which I have said will have been anticipated by other speakers on the same subject. I can only trust that if that is so, those who have less experience will see the importance of the point, and be more particular to avoid reinforced concrete construction, except where sufficiently-trained workmen are available, or the circumstances—as in my case here—are sufficient to warrant specially training the men."

Mr. Geo. Higgins forwarded the subjoined communication, which was read by the Secretary:

"Major Monash's paper has interested me greatly, and contains information of a new and valuable nature, clearly expressed.

"The question of adhesion between concrete and steel rods is one about which I should like to hear something more. It has been recently stated that an ordinary steel rod, of about $\frac{1}{2}$ in. diameter, having one end embedded for about 12 in. in ordinary concrete, would break before it could be pulled out of the concrete, but my recollection of the exact figures is uncertain. Has Major Monash any information bearing on the point?

"At the 36th page of the paper it is stated that the rods used may have drawn through the concrete, and (page 39 of the paper) it is stated that the matter is of importance only when designing T beams.

"Is the shearing stress, given in the fifteenth column of the table, the average shearing stress at a section, or the maximum shearing stress at a point in a section?

"In replying to Mr. Michell's question, the author stated that E was not Young's modulus, but in equation (r) I think he assumes it is so.

"I notice that European designers of reinforced concrete structures loop the ends of the rods; some hook the ends together in various ways. I should be glad to have Major Monash's views on this practice."

The President said he was glad to see Mr. Gibson, of Mr. Michell's works at Burnley, present as a visitor. He hoped he would give them the benefit of his thoughts on the subject, as his experience in connection with cement would be most important and useful in this connection.

Mr. John Gibson said that he had had the pleasure of assisting Mr.
Anderson in drawing up the cement specification referred to, and could therefore supply some information on the point.

The tensile strengths specified were somewhat higher than those usually required in this State. Speaking from memory, the minimum tensile strength (average of five briquettes) per square inch at seven days—i.e., one day in air and six days in water—was 500 lbs.; at 28 days—i.e., one in air and 27 in water—600 lbs.; cement gauged with 18 per cent. of water. Sand Tests: Three parts of standardised sand to one part cement, by weight; minimum tensile strength per square inch (average of five briquettes) at three days—i.e., one in air and two in water—90 lbs.; at seven days, 200 lbs.; 28 days, 250 lbs. Tests for Soundness: Pats, 3 in. diameter, \( \frac{1}{2} \) in. thick at centre, thinning towards edges, made up soft, immersed in water at a temperature of 60 degrees to 70 degrees F. when hard, to show no signs of cracking or lifting at the expiration of three days from time of immersion. Similar pats placed in a moist atmosphere at a temperature of 120 degrees F. until hard, then immersed in water having a temperature of 180 degrees F. for at least 48 hours, to show no distortion. Fineness, 92.5 per cent. to pass through a \( \frac{1}{6} \) in. square inch mesh sieve, 72.5 per cent. to pass through a \( \frac{3}{4} \) in. square inch mesh sieve. Specific gravity not less than 3.05.

The following "special" (De Val) test might also be applied:—Briquettes gauged as already specified, immersed in water at 180 degrees F., 24 hours after gauging, and kept therein for seven days, must, at the expiration of that period, show an average minimum breaking strength of at least 80 per cent. of that specified for 28 days at normal temperature. The Monier Pipe Co., at their Burnley-street works and elsewhere, always used cement of this description, principally the brand manufactured by Mr. David Mitchell, which complied with the specification.

Mr. Ritchie, of the Water Supply Department of the Metropolitan Board, said that reinforced concrete had been little used in the operations with which he was directly connected. The use of the Monier pipes had been confined to the sewerage works. As far as he was aware, reinforced concrete had not hitherto been used anywhere for water supply pipes under high pressures. He hoped that some development might take place in this direction; it would be very important. He would be glad if Major Monash could tell them something on this point. Considerable trouble was always experienced in iron or steel pipes owing to the corrosive influences at work both internally and externally, but principally the latter; if reinforced concrete, with its undoubted capacity for resisting such corrosive influences, could be successfully applied to this purpose, it would be a very great advance.

At the invitation of Mr. Gibson he had visited several reinforced concrete works in progress, and found them of much interest. He believed there was a great future for this class of construction; in America it appeared to be adopted very largely indeed. Seeing that reinforced concrete was of recent introduction here, such a highly instructive paper as Major Monash had given was particularly apropos.

He had noticed, when visiting some of the Monier Company's work
at Reilly-street, that particular attention was paid to the mixing of the concrete. The sand and cement were first thoroughly mixed dry prior to incorporation with the screenings. Too often sand, cement, and screenings were heaped together and turned over roughly with a shovel, with the result that there was a partial failure as regards the complete incorporation of the three ingredients. The advance in the use of reinforced concrete construction in America had been marked by a considerable extension of the practice of mixing by machines. The American engineers appeared not only to pay great attention to the thorough mixing of the materials, but also to be adopting the practice of even measuring the water that went into the machines; what they were aiming at was that the whole process of mixing should be a matter of definite proportion. In this connection he had been pleased with the little feature which he had just mentioned as coming under his notice at Reilly-street.

Mr. Mountain said he did not like to give America the whole credit for introducing the machines for mixing. They were used very largely in England and New South Wales.

The President said the machines for mixing the materials had been used extensively, but he had not seen the water measured with anything approaching accuracy.

Mr. T. Hill said he would like some information—if available—from the author regarding the cost of reinforced beams. Did the term "Economic Section" used mean that reinforced concrete in the proportions mentioned—viz., 1 in 100—could compete favourably as regards cost, and enter into competition with the ordinary beams of local blue-stone used in building construction, or could it displace the ordinary wooden railway sleeper?

Frequent mention was made in the engineering journals of the use in the United States of sleepers made by simply embedding a piece of old rail in the middle, and extending the full length of the mass of concrete. The cost of this worked out about double that of an ordinary American oak sleeper; but, on the other hand, the maintenance was practically nil. In one particular case a curve on a main line—with heavy traffic at high speed—the wooden sleepers gave constant trouble, and were replaced with concrete. After one year's wear, the only damage that could be seen was one edge knocked off, probably due to a heavy hammer falling thereon.

The renewal of the wooden sleepers on the Victorian lines was a heavy expense, and they were becoming dearer. If reinforced concrete could be used a considerable saving might be effected.

Mr. J. A. Smith said that, referring to the question raised by the last speaker, he might point out that in the early days of railway evolution the sleepers were—in works intended to be permanent—of stone always. In some instances the blocks were placed transversely; in others they extended longitudinally the whole length of the section.

This practice was discontinued, because experience proved that timber possessed a resilience, which greatly conduced to the longevity of the rails and rolling stock. Those who had ridden on the footplate of a locomotive at high speed over a piece of road laid "too solid"—for
instance, when the sleepers were placed in a rock cutting with insufficient ballast beneath them—would appreciate the destructive impact of the moving mass when the elasticity and cushioning action of the sleepers were unduly limited.

For this reason attempts to utilise sleepers cast from blast furnace slag had failed. Except under special conditions, timber sleepers were adopted by choice, apart from cost. He doubted the general applicability of concrete in this direction.

If embedded rails were used, as suggested, the length of rail in the sleepers would, in the aggregate, exceed the length of track.

One disputed point in the theory of reinforced concrete had interested him very much. He referred to the apparently anomalous behaviour of the concrete element under tensile loading. Considère's contention—alluded to by Major Monash in his paper—was that the introduction of the metallic element enabled the concrete to be extended, without exceeding the elastic limit, to several times the amount to which it could be stretched when not so supported.

This contention seemed almost like a claim of new physical characteristics; but it seemed to him to be hopeless to expect finite quantitative results from such a non-homogeneous material as concrete, where a multitude of microscopic solutions of continuity might exist unobserved.

In an endeavour to arrive at some definite conclusion, he had commenced a series of experiments—unfortunately not yet completed—substituting a homogeneous metal for the concrete, and maintaining the analogy by selecting one (cast iron) giving a much lower numerical extension per unit of tensile load than the reinforcing steel bars.

Compound bars had been so formed, in some cases by casting a strip of cast iron on a strip of steel, in other cases by embedding the steel centrally in a cast bar. The specimens exhibited would show some curious failures arising in the casting. Uncertainty also arose from "chilling;" therefore he was now trying bars of cast iron embedded in a suitably compounded and proportioned fusible sheath, and testing the whole for transverse flexure; this was, in effect, proceeding by a converse process.

He did not care to commit himself to an opinion at present, but he thought, so far, there was reason to think that Considère's contention might receive support; not that there was any new physical characteristic, but a particular arrangement might give rise to interactions which had not yet been fully studied or recorded, and these might tend in the direction specified.

Some of the most recent investigations by independent European experimentalists, dealing with reinforced concrete, also appeared to give corroborative results.

Mr. A. C. Mountain read the following notes:

"It would savour of ingratitude to make no comment, or give no note of appreciation, to a paper such as we have recently had the pleasure of hearing from Major Monash. It is carefully prepared, clearly reasoned out, and is likely to be a valuable reference for engineers who have not hitherto had to do with that class of work. The
chief merit of the paper appears to be its studied moderation and fairness.

"On the eleventh and twelfth pages the very necessary qualifying conditions which must be observed to ensure success with reinforced concrete work are clearly set forth. In a similar way it is explained how the greatly increasing confidence which the engineers of to-day place in Portland cement concrete as contrasted with the doubt of some twenty or thirty years back, has been undoubtedly largely brought about by the superior and more uniform character of Portland cement, particularly in the matter of fine grinding. Indeed, were it not for this knowledge, few engineers would venture to rely upon a composite fabric which, whilst theoretically strong, might easily cause disappointment, either through careless or incompetent workmanship, or through inferiority of the materials used.

"The experiments that have been described and so lucidly demonstrated in the paper are in the line of work in which, no doubt, the usefulness of the material will be most apparent—i.e., that of acting as a beam, and enabling concrete thereby to acquire a tensile strength which it does not in itself possess. I trust this line of investigation will be continued, and that this Institute will be favoured with further information on this interesting subject.

"But, for whatever purpose reinforced concrete may be used, the entire reputation of the blend of metal and stone depends on the fulfilment of the requirements and conditions described by Major Monash during its manufacture, and, therefore, constant and personal vigilance will be obligatory on the makers.

"In dealing with such a composite material, to which, from its nature, ample factors of safety have to be accorded, it would appear almost unnecessary, save for purely theoretical reasons, to elaborate formulae. With a factor of, say, 6, the question of simplifying a calculation by which possibly some slight percentage of error may result, but by which a saving of time and labour may be effected, would not appear to be a matter of serious moment.

"Recent experiments by Professor W. K. Hall, at Purdue University, U.S.A., show that the failure of ordinary reinforced beams in which the concrete is of good quality—either 1·2·4 or 1·3·6—coincides with the point at which the elastic limit of steel is reached. Condron plotted results of a number of experiments to show that the strength of a beam is simply a straight-line function of the amount of steel embedded therein. Tests of about forty beams broken at Purdue University confirm this statement.

"The ultimate strength of the beam is given by the simple formula:

\[
M = B.H^2 \times (55 + 275P)
\]

M—Being moment of resistance in inch-lbs.
B—Being breadth of beam in inches.
H—Being depth of beam in inches.
P—Being percentage of steel based on cross-section of beam.

"This formula is said to be independent of kind or age of the con-
DISCUSSION—REINFORCED CONCRETE.

It appears to give somewhat lower results than does the formula given by the paper. Taking, for instance, at haphazard the case of beam 4 in Group A, the computed moment of resistance of which is shown in the table as being 82,100 inch-lbs., we find that, by the above formula, the result is only 74,250 inch-lbs., calculated on the percentage of steel being 1, as given in the Table. This is between 9 and 10 per cent. less than the result arrived at by Major Monash.

"It would be desirable to know something of the action of beams reinforced by the method adopted in Australia, when called on to resist the action of fire. As beams they would be likely to be employed in large buildings, especially as girders and floors. Are they fire-resisting?"

"The modern Building Acts contain stringent conditions, which must be complied with before any structural material is allowed in new buildings for public use, unless it be proved to be fire-resisting. Apparently reinforced concrete, as made in America, is satisfactory in this respect, as it appears to have passed the demands insisted on as security against fire. I understand that in Germany the Public Works Department has prepared rules and regulations to govern its use. So far, the work done in England with reinforced concrete would appear to be carried out by private companies or individuals, without reference to Government.

"I recently read an interesting description of a typical building of this material built in Cincinnati, Ohio, the walls of which are 8 in. thick, and faced with marble or brick. The floors are supported by reinforced columns spaced about 16 ft. centres. The floors of the upper storeys (5 in. thick, and reinforced with \( \frac{3}{4} \) in. rods) are designed to bear a live load of 60 lbs. per square foot. The whole account is very interesting, and suggestive of great economy of space and material in view of the actual strength developed.

"Before concluding, I may mention, from among the numberless constructions of this material, a few of the most varied and notable types either just completed or in course of erection, as illustrative of the extent to which engineers in Europe and America are now availing themselves of the services of the 'heterogeneous material' which is the subject of this evening's discussion:

"Chatellerault Bridge over the River Vienne, France.—164 ft. central span, two side spans of 131 ft., 21 in. thick at crown of arch, rise 15.75 ft., width 26 ft. Completed.

"Lanesville Bridge, Ohio.—98 arches, the largest 92 ft. span, and 11.50 ft. rise; thickness at crown, 30 in.

"New York Subway.—Largely built with reinforced concrete.

"New Service Reservoir, Antwerp.—Reinforced with expanded metal.

"Jersey City Water Supply Conduit.—Built in loose earth. Thickness of crown, 5 in., and at invert, 6 in.; conduit, 8 ft. 6 in. x 8 ft. 6 in.; reinforcement, longitudinal bars, \( \frac{3}{4} \) in. to \( \frac{1}{2} \) in. diameter, and circular hoops \( \frac{3}{8} \) in. diameter, forming a mesh about 4 in. square.

"Tank at Little Falls, New Jersey.—10 ft. diameter, and 41 ft.
high. Wall, 15 in. at bottom, 10 in. at top. Rings of $\frac{1}{2}$ in. Ransome twisted steel rods placed at about every 2 ft. in centre of wall, and $\frac{3}{4}$-in. diameter vertical rods 5 ft. apart, also set in centre of wall, forming a series of hoops and posts.

“Milford, Ohio.—Stand-pipe, 80 ft. high and $15\frac{1}{2}$ ft. in diameter.

“Southampton, England.—Warehouse, boiler, and engine-house for cold storage.

“Newcastle, England.—Warehouse for Co-operative Society.

“Swansea, England.—Mill and grain silos.

“Dunston-on-Tyne.—6-storey grain stores.

“Manchester Ship Canal’Co.—Transit sheds.

“Simplon Railway Tunnel.—Canal for bringing water from the Rhone, furnishing power (2300 gallons per minute) for driving and lighting the works. 6 ft. 7 in. square in internal section, walls 4 in. thick; has a uniform fall of 1.2 per 1000. Length of canal, 9800 ft.; is supported on ferro-concrete trestles.

“Evidently this material has come to stay.”

Major Monash said he would endeavour to arrange his replies to the various questions which had been raised, under the several heads of theory, practice, and application.

First, as to theory. Mr. G. Higgins had in his letter raised an interesting question as to the adhesion between concrete and steel, and had referred to a statement in the paper that this was a feature which was chiefly of importance in designing T beams. He would point out the reason for that. In a T beam there were the horizontal plate and the vertical rib; the tensile reinforcement had to be concentrated at the bottom of the rib, and there it necessarily appeared in much larger section than it would appear in a continuous plate. In a rib the whole of the concrete below the neutral axis was omitted, except so much as was required to form the rib. That necessarily involved larger sections to give the same cross section area of metal, resulting in a lesser external surface of the bars.

It happened in ordinary plates that the adhesive stress between concrete and steel was so much below the ultimate strength that it could be disregarded; but in designing T beams they had to be careful to see that they had sufficient surface area for adhesion between the concrete and the steel.

With regard to the specific instance given by Mr. Higgins, he doubted the correctness of the figure. On that point he had the result of a comprehensive series of experiments upon adhesion. He had a group of 32 sets of tests. These embodied the adhesive resistance per unit area of bars in various mixtures from 1 to 1 up to 1 to 8 with water from 5 per cent. to 25 per cent.

The resistance of adhesion varied from seven kilogrammes per square centimeter in the lowest case to 49 kilogrammes per square centimeter in the highest case. The weakest adhesion was where the concrete was weakest—i.e., 1 to 8—but that case was outside the limits of practice.

For any particular composition of concrete there was a particular percentage of water which was the best; and, generally speaking,
within reasonable limits, the wetter the concrete the better the adhesion. The best result was obtained from 2 to 1 mortar with 15 per cent. of water. That gave a result of 49 kilogrammes per square centimeter. This was equal to 729 lbs. per square inch. That was an exceptionally high result. The result of many other experiments showed that for good concrete it was safe to take the ultimate adhesive resistance at somewhere between 500 or 600 lbs. per square inch. The American and German building regulations laid down a working limit of 100 lbs. per square inch. The practice here was to work even below that, and to make the working limit at about 50 lbs. per square inch.

In connection with the question of rust, it was advisable that all scaly rust should be knocked off. There was no objection to a discoloured surface. They had used bars of this description, and the result showed that a little rust was not at all a disadvantage. For instance, the Tinman’s wire, which was largely used in pipes, showed no perceptible difference in its behaviour when slightly discoloured by rust. The same point would answer one or two other questions.

The President had inquired regarding the wetness of the concrete. Wet concrete was used for the reason that it was realised that the wetter concrete gave better adhesive results. The practice all over the world was verging towards using wet concrete.

Mr. A. C. Mountain asked if the definition of wet concrete meant a limit of 15 per cent. of water.

Major Monash, continuing, replied that was so. As a matter of fact, 15 per cent. made it apparently very wet indeed. There was no increased tendency to crack on setting. It was not advisable to go beyond 15 per cent. The concrete he had been using was wet in the sense that it could be poured. It would not stand up by itself, it would find its level. This was essential to get perfect adhesion with the metal.

The principal consideration in gauging was a thorough mixing of the aggregates before the water was added. The materials should be passed through sieves, which gave a very thorough incorporation while dry. Every particle of sand should be thoroughly dusted with cement. In the course of manipulation it would be found that the cement sometimes washed off, and laid the stone bare, but there was so much manipulation that any stones so washed might be depended upon to be recoated when put in position.

Mr. Higgins had also raised another interesting point with regard to the shearing stress, to which he would briefly allude. The shearing stress increased from nil at the upper surface of the beam to a maximum at the neutral axis, and then remained so from the neutral axis to the bottom. This was on the hypothesis that the tensile strength of the concrete below the neutral axis was neglected. If the tensile strength were taken into account, he could not say exactly what the resulting curve would be, but there would still be an increase from nil at the top surface to a maximum at the neutral axis. But starting with the hypothesis that the concrete beam to the neutral axis had no work to do, the shearing stress would be nil at the top, a maximum at the neutral axis, and remain so to the bottom.
With reference to a question by Mr. Higgins as to the hooking of ends of the bars, he (the speaker) did not quite understand what particular expedient was referred to. He thought it meant "cogging" the ends of the rods. There was only a practical reason for doing that. It meant that the designer wanted to help the adhesive strength. It was a very cheap thing to do, as the bars could be cogged cold. It was worth while doing it as a matter of practice. The cogging of the end of the bar was merely an additional and cheap safeguard; but he would not pass a design where the adhesive area was deficient merely because the designer had cogged the end of the bars, and was depending on that cogging.

Mr. J. T. N. Anderson had made reference to deformed rods. That subject was discussed in Engineering News, p. 152, of 1905. America was the country of deformed rods, and the writer expressed the opinion that "deformed rods were an unreasoning fad, and that their day would soon be over." There was, and had been for a long time, considerable controversy between advocates of the plain rod and the deformed rod, hinging largely upon the fact that the deformed rod had a very high modulus of elasticity, and the ordinary plain rod of commerce had not. That was a point which still claimed attention. There was no end of patents for deformed bars. Many of them were propounded simply to be different from other devices, and he had books full of the most ridiculous devices of this class, which had been patented.

As to the use of rods of small section, that followed immediately from what had been said about surface area. If they wanted one square inch of surface area, they used a number of bars, with a total cross section area of one inch. Thus, four bars of \(\frac{3}{8}\) in. diameter gave twice the surface of one rod \(\frac{1}{2}\) in. diameter.

In reply to Mr. Mountain, the speaker said he had never found the slightest difficulty in applying the formula he had expressed in the paper. The arithmetic was very simple. The assumptions made were sound, and were based upon an algebraic treatment of the subject. He did not understand any formula which was independent of the age or proportions of the concrete. Everything depended on the elastic modulus and the compression stress the concrete could be entrusted to carry. It was obvious that a 1-4-8 concrete must be very different in its behaviour from a 1-2-4 concrete, and would give totally different results.

The question of increased extensibility was under discussion at present, and as yet there was nothing more which could be said. It had been made clear that there were enormous applications of reinforced concrete works all over the world. There were many critics, but one rarely heard of cases where reinforced concrete plates and beams showed cracks under working conditions, which would necessarily occur if Considère were wrong. He presented this argument for what it was worth. It would be interesting to see whether the Americans made any reply to Considère. He had Considère's latest contribution translated into English, and also in the original French. Considère claimed to have repeated his experiments by the hands of independent men, and to have re-established his first conclusions.

As to the President's question whether any mechanical appliances
were used in mixing, the speaker said that at present there were not in this State. He thought they would be very good things; they were largely used in America, and had been used for many years in England and on the Continent. This was a commercial question, as well as a question of good practice, and unless the bulks to be handled were large it did not pay. Unless they handled at least 40 or 50 cubic yards of concrete per day it would not pay; and, with proper supervision, they could get, at any rate, good results from hand-mixing.

As to whether the Port Melbourne sand was washed, he could not say, but he thought not. They insisted on the sand being of good quality, but did not go in for specially washing it. It was selected sand, and was carefully inspected before being accepted.

It was undoubtedly correct that the great difficulty in reinforced concrete work was that it required such a high degree of care in its execution. But he was not thinking of the same features which Mr. Mountain had in his mind. After all, the danger was not in the gauging and mixing of the materials, which an inspector could keep under control; but the real danger was that people would not recognise that it was a scientifically designed construction, and that when material was designed to go in a certain place it had to go in that place, and not a few inches from it. In a recent number of the Engineering News there was a large photo entitled, "The Failure of a Reinforced Concrete Beam." The letterpress told the story. A very eminent designer had designed a bridge for a private company, and he showed in the cross section four 1-in. bars placed in the orthodox position. The company, instead of calling upon a firm used to that class of work, let the contract by public tender. The contractor, who was a well-known and capable man, but wholly ignorant of this class of work, thought it would be a good idea to distribute the four bars uniformly over the rib, and so he put in two at the top and two at the centre. When he came to remove the temporary supports, of course the structure tumbled down. That was where the real danger lay in connection with reinforced concrete. The men who controlled the execution of the work should thoroughly understand the design of it, and the reasons for following minutely the instructions in the design.

With regard to the cost of sleepers, and sleepers generally, he did not think the elasticity of the sleeper had anything to do with its utility. Reinforced concrete sleepers were used largely in Europe. He thought a great difficulty was in the handling. They were heavy, and received a lot of knocking about. No test had been made here, and he doubted if they would become popular until their special merit had been shown somewhere else. As to the cost, he thought it was going too high to say that reinforced concrete would cost double as much as timber. He thought an increase of 25 per cent. to 30 per cent. would be a fair thing. One difficulty which presented itself to him was that he did not know what standard of cross-breaking strength the Railway Department would lay down.

With reference to Mr. Ritchie's remarks regarding water pipes and pressure, the highest pressure he knew of in this relation was about 110 ft. head. He had read descriptions of higher heads in the Paris
water supply, and there they embedded in the shell of the pipe a very thin sheet of metal. The joints were similarly treated—external joints. But he knew that the ordinary tight pipes, such as we had, were frequently used up to 30 metres head. In Vienna there were about 47 kilometers in pipes 2 ft. diameter, working under 60 ft. head; while he knew of another instance of a length of five miles working under 50 ft. head.

The President had referred to shocks and surface attrition, and wharf work in England. He had some interesting illustrations relating to this work which he would pass round. It was a subject of great importance. Darling Harbour wharf, Pyrmont, Sydney, had recently been pulled to pieces, and rebuilt with reinforced concrete piles, both driven and planted. This was on the eastern side of the Pyrmont bridge. There was a great deal of harbour work done in Sydney and New Zealand with reinforced concrete piles driven with a monkey in the ordinary way.

Mr. Mountain had referred to fire-resistance. There were some very significant instances of large conflagrations where this work proved very satisfactory. He referred to the Baltimore fire in America. A number of independent journals had gone into the matter, and spoke very highly of it.

Mr. Mountain said that was due to the fact that before they allowed any material to be placed in a building, they had it tested and proved to be fire-resisting.

Mr. J. A. Smith asked what authorities were entrusted with the inspection.

Mr. Mountain replied that the police authorities administered the Building Act.

Major Monash, continuing, said he did not address himself to the physical attributes of reinforced concrete. In Berlin the Police Department looked after these matters. Tests were made, and the work was subjected to a heat of about 2000 degrees Fahr. The building referees of the city of Melbourne had given their certificate for the use of reinforced concrete in Melbourne as a fire-resisting medium. They would not have done this had they not been satisfied on the point. He read an extract from *Engineering News* of 25th May, 1905, as follows:

"The increasing use of reinforced concrete in factory-building construction is illustrated in a notable manner by the new works of the United Shoe Machinery Co., which are located at Beverley, Mass., about nineteen miles from Boston. These works consist of ten buildings, comprising two machine shops, each 522 ft. x 62 ft.; a storage and shipping house, 280 ft. x 68 ft.; a forge shop, 200 ft. x 62 ft.; a foundry, 222 ft. x 108 ft.; a power-house, 100 ft. x 90 ft.; two service buildings, each 110 ft. x 80 ft.; and two smaller buildings, all of which are built entirely of reinforced concrete, with the exception of the roofs of the foundry and the forge shop. So far as we know, no manufacturing plant of equal size has hitherto been built of reinforced concrete."

This was very good evidence, and showed the enormous possibility for the future of reinforced concrete.
Library Digitised Collections

Author/s:
Monash, John

Title:
Notes on tests of reinforced concrete beams (Paper & Discussion)

Date:
1906

Persistent Link:
http://hdl.handle.net/11343/24341

File Description:
Notes on tests of reinforced concrete beams (Paper & Discussion)