SHEAR AND ADHESION IN REINFORCED CONCRETE.

A reader of current engineering literature, or a student of methods appertaining to the uses of cement, need possess no very highly developed faculty for observation to be struck by the fact that reinforced concrete construction has, during the last year or two made enormous strides. The way this comparatively new material has come to the front is really wonderful—though, after all, perhaps it need not be regarded as strange, if we consider how it lends itself to many forms of construction where strength and economy are particularly desired. Like all new things, however, it is liable to abuse. Admirable as it may be for certain purposes, when used by those who really understand its properties and recognise its limits, there is, of course, the danger that it may be employed in a manner quite unsuited to it by those persons not thoroughly competent to undertake the task. Herein lies the great danger of reinforced concrete—the factor of ignorance—which at once introduces grave risks. That there have been numberless structures erected into which reinforced concrete has largely entered, and which have been designed by competent engineers or architects, is well known, and these structures will, we have little doubt, prove satisfactory in every way, and stand the test of time. But what of those in the construction of which the necessary knowledge may have been lacking? The thought is not a pleasant one, and the growing popularity of the material increases the feeling of apprehension. So many factors enter into the problem, and round some of these there is more or less uncertainty—an uncertainty that may be increased vastly by a little carelessness on the part of the workmen who mix the concrete and arrange the reinforcing material, or primarily by ignorance on the part of those who designed the structure. Are these feelings of apprehension justified? We think they are; but whether the element of danger should be magnified till it acts as a check on the use of concrete steel is another matter. Certain risks in such things must always be faced, if any progress is to be made in engineering construction. The point we wish to emphasise is that all work of this kind should be entrusted to men thoroughly competent to carry it out, who have all the latest knowledge with regard to it, so to speak, at their finger-ends.

Time will assuredly teach us many things about this new material, and some of the lessons may be unpleasant. It is always with gratification, therefore, that we notice the carrying-out of carefully conducted experiments by workers in different parts of the world, which have in view the extension of our knowledge of the subject; for with reinforced concrete—more, perhaps, than with most materials—practical investigation is worth a great deal more than theory. In fact, nearly all the knowledge we have about it appears to have been derived from experiments, and the formulæ we use in our calculations are largely empirical.

Points on which engineers have, perhaps, felt particularly in doubt are two that are directly connected with the adhesion between the concrete and the steel; for it is on this adhesion that the value of the material—at any rate, with plain bars—entirely depends. One is the effect that long-continued vibration may have on this adhesion, and the other the risk that may attach to the use of rusty reinforcing material, or the liability of water to obtain access to the steel and cause rust.

Opinions have from time to time been strongly expressed on these subjects, both in Europe and in America, and we need hardly wonder at it; for if the now almost universal belief that there is little or no danger likely to accrue from either rust or vibration should have no sound foundation, the serious trouble that the future has in store for us we hardly like to contemplate.

But are these beliefs without good foundation? With regard to the protective effect of good cement concrete on steel embedded therein, all the evidence and all the experience that engineers have been able, so far, to accumulate, seem to show that, when proper care is exercised in the operation, steel and iron may be encased in cement concrete so as to be completely protected from corrosion. We use the expression "when proper care is exercised" advisedly, for there can be little doubt that if this proper care be lacking, confidence in the reliability of the results must be lacking also. Of course, it may be said that the use of reinforced concrete is of comparatively recent date. Quite true. Still though the time that has elapsed since it began to be recognised as a valuable constructive material has not been long, it has been sufficient to justify engineers in placing faith in it; and if the more conclusive evidence of a long period of time were necessary, it is surely given by the well-established case of a piece of iron embedded in cement for over 2000 years being found perfectly clean when taken out. Again, there is strong evidence to show that oxide of iron cannot exist in contact with cement, and that rusted bars embedded in cement will, in the course of a month or two, be as bright as when new the rust having been deoxidised by the formation of a ferrite of calcium which protects the bars. If it were actually dangerous to embed rusted metal in concrete, reinforced concrete construction would quickly go out of use, for the practical impossibility of putting reinforced rods in concrete without more or less exposure to the weather is manifest.

With regard to the effect of vibration on the adhesion between the steel reinforcement and the concrete there is considerable difference of opinion, and it would appear to be a point on which a series of carefully conducted experiments would be of great value. For probably no amount of theorising will ever settle it satisfactorily. Practical tests will form the only really reliable guide, and we do not know that these have ever been carried out on any extended scale. Such tests would perhaps also do more than anything else to demonstrate the merits or demerits of plain reinforcing bars against special bars of twisted or of corrugated form; for it seems to us that if it can be shown that the former can be thoroughly relied upon when subject to continuous vibration for long periods of time advocates of the latter would lose one of the strongest arguments they have in support of forms of steel possessing a more or less positive bond with the concrete. This subject is one which in certain quarters it is almost dangerous to mention: the feelings of certain makers and advocates of shaped bars running so high as apparently to blind them to a reasonable view of the matter. In fact, to such a length has the matter gone that one firm manufacturing a special form of bar in America has actually, when advertising the material, made the astounding statement that with it adhesion between the concrete and the steel is not necessary. If this opinion were to become general, the sooner reinforced concrete went out of fashion the better.

Great though the advances made in reinforced-concrete construction are, we have by no means yet reached a stage when further experimenting may be looked upon as unnecessary, and we trust that much more work will be undertaken in this direction.

One line along which such experiments might be carried is a further investigation as to how far it is necessary, or advantageous, to use diagonal bars to take the shearing stresses in reinforced concrete. There is much diversity of opinion on the point, and some very interesting and useful tests with regard to it have recently been made in America by Mr. J. J. Harding, and described by him in a paper read before the Western Society of Engineers. The tests were carried out for the Chicago, Milwaukee, and St. Paul Railway Company, who on account of the considerable amount of reinforced-concrete work which they wished to construct, particularly in the covers of flat culverts, desired more information on the subject than they found available at the time. They found that previous tests were fairly in accord, as far as bending-moment failure was concerned but that there was very little reliable information concerning the liability to failure from excessive shearing stresses. Ten different sets of three beams each were made, and the amount of reinforcement used was about 0.75 per cent. of the area of the concrete above the centre of the steel, and Ransome, Johnson, Kahn, as well as plain bars, were used. As the tests were carried out particularly with a view to ascertain the effect of high-unit shearing stresses, the ratio of the distance above the centre of the steel reinforcement to the length of the span was made as large as could be done without going beyond the limits of actual practice. The length of the span was 12 ft., and the beams were all made 12 in. wide. The depth, however was made to vary with the number and size of the bars used. The concrete was made up of 1 part Atlas Portland cement, 2 parts clean sand, and 5 parts crushed limestone of a size less than 2 in. Mortar in the proportion of 1 to 2 of cement and sand was used for the bottom surface of the beams, up to the level of the top of the bars. The beams were kept for about four months before they were broken, and the loading was placed at one-third points, rollers being used at the points of application of the load and at the points of support.

The reinforcing bars were, as we have before stated, of different makes—some plain, and others shaped with a view to assist adhesion. In some of the beams they were placed in a single horizontal row, while in others a double row was tried. Some of the tests were made on beams in which the bars were quite straight, while other beams had some of the bars straight, and the remainder bent up diagonally between the middle third of the length of the beam and the ends, in order to test what assistance these gave to the beam when the shearing stresses were high.

We cannot here give the detailed results of all the tests, though they are very interesting, and seem to show most clearly the advantage gained by diagonal reinforcing bars, particularly where unit shearing stresses are high. We can, however, give briefly the conclusions at which Mr. Harding arrived as the result of his tests They are :—

1. An amount of reinforcement about 0.75 per cent. of the area of the concrete above the steel is as much as can be economically used in beams carrying heavy loads, and subjected to large shearing stresses.

2. At the ends of all large concrete beams diagonal reinforcement should be used in order to develop the full strength of the beam, and also to prevent a sudden failure.

3. The diagonal bars should be brought well up to the top of the beam, and securely anchored against slipping; for instance, by being turned over at the ends.

4. Small bars are preferable to large, for the elastic limit is higher. They give a better distribution of the stresses, and they offer a better opportunity to obtain a satisfactory diagonal reinforcement. They are also much easier to handle and bend on the site.

5. The use of larger bars than 1 in. is objectionable, both for practical and theoretical reasons.

6. The ultimate strength of a reinforced concrete beam is reached when the steel has been stressed up to its elastic limit.

7. The location of the neutral axis varies with the amount of steel and the class of the concrete. With an amount of steel equal to about 0.75 per cent. of the area of the concrete. the distance from the neutral axis to the top of the beam at rupture is about one-third of the distance from the centre of the steel to the top of the beam.

8. After obtaining the approximate location of the neutral axis, it makes little difference whether the distance from the neutral axis to the centre of the compressive area is taken as 3-5 Y, as in the case of the triangular area, or 3-5 Y, as for a parabolic area, the difference in the resulting resisting moment being less than 3 per cent.

In the main, these conclusions have been arrived at by other experiments, and the tests confirm pretty clearly results that have before been obtained. If there is one point, however, that Mr. Harding's experiments bring out very strongly it is that, by using steel of high elastic limit, the ultimate strength of the beam will be raised without any increase in the amount of metal used; but by using a high-elastic-limit steel the shearing stresses are proportionally increased, and the liability to diagonal fracture greater. The shearing stresses must in consequence be well provided for, and diagonal reinforcement introduced; and it is perhaps advisable to provide in all beams of this description, even if their loads are comparatively light, some diagonal reinforcement. Where large loads are concerned, there seems to be no room for doubt that this form of reinforcement is absolutely necessary if we wish to have a reliable form of construction.

Another lesson taught by the experiments to which we have referred is the striking difference with which concrete beams with and without diagonal reinforcement fail. With the former, collapse is a gradual process, warnings of which are given long before final destruction takes place; while the latter failure is sudden, and no indication is given of what is about to happen.

Which form of failure is to be preferred it is quite unnecessary for us to point out. It is this question of the diagonal reinforceing of concrete, or, rather, the omission of it—together with the feeling of uncertainty that there is as to the effect of vibration on the adhesion between the concrete of a beam and the steel that reinforces it—that causes occasional doubts as to the future of the material. Reinforced concrete has been largely used where it is subjected to considerable vibration, and much of the material exists in which no diagonal reinforcement has been introduced. It is probable, however, that in these cases engineers have protected themselves by adopting large factors of safety, and have not run the risk of stressing a material which is not yet fully understood, to the amount which theory might suggest as practicable. Undoubtedly, reinforced concrete has come to stay, to use an expressive colloquialism; but it is possible that there may be failures unless designers keep well in mind the limitations of their present knowledge. Just as our reliance on steel has grown by painstaking experiments, so must our confidence in reinforced concrete proceed by slow degrees.

We have no wish to take a pessimistic view of the matter, but it is better to call attention to the subject, in order that precautions may be adopted, before the necessity for them is forced upon us in unpleasant ways. Further experimental tests on reinforced concrete are required, in order that we may have doubtful points made clear; and one of the most important of these points is the effect (if there be any effect) that continued vibration, when