(Paper No. 3999.)

“Experiments on the Adhesion of Old and New Concrete.”

By HECTOR ST. GEORGE ROBINSON.

IN examining cracks in plain and reinforced concrete structures, usually caused by shrinkage and thermal stresses, the Author has observed the frequency with which such cracks occur in places where concreting has been stopped for some time and then resumed. The difficulty of obtaining good adhesion or bond between new concrete and concrete already set is generally recognized by engineers, and various methods of treating the old surface before laying the new concrete are in vogue.

With the object of terminating a dispute which arose in regard to the responsibility of a contractor for the efficiency of the joints in a fairly large reinforced-concrete structure, the Author carried out a series of experiments as to the relative efficiency of various methods of jointing concrete. The necessity of such tests was occasioned by the limited amount of experimental data available on the subject.

In view of the great difficulty experienced in obtaining reasonably uniform results when fairly large concrete specimens were tested in direct tension, it was decided to test prisms by cross-bending. The apparatus required to carry out this type of test is of an extremely simple description, and it was thus possible to make the tests under natural conditions in the field.

In connection with bending tests, it is important to keep in view the fact that the calculated stress in tension at the extreme edge of a bar of square or rectangular cross-section is much higher than the value obtained in direct tension. In the present case the tensional strength or modulus of rupture is used for comparative purposes only.

For the purpose of the experiments, concrete prisms 30 inches long and 4 inches square were made in timber moulds lined with

zinc. The prisms were tested as simple cantilevers, being fixed at one end and loaded at the other as shown diagrammatically in *Fig. 1*. The distance from the joint to the point of application of the load was 20 inches, and in arriving at the tensile stress at the joint the dead weight of the portion of the prism broken off was included. In testing, the prisms were reversed so that the top or tension side was the underside during moulding. The concrete was of uniform composition throughout and was made in the proportion of 2 cubic feet of crushed Thames ballast, 1 cubic foot of clean Thames sand to 45 lbs. of Portland cement—practically a 4-2-1 mixture by volume. The ballast was mostly crushed flint pebbles, all passing a $\frac{3}{4}$ -inch mesh sieve and being retained on a $\frac{1}{4}$ -inch mesh sieve, the average percentage of voids being 34. The sand was screened from the normal Thames ballast, the grains being $\frac{1}{4}$ -inch and less, and

Fig. 1.

the voids in this case being 31·5 per cent. The cement was to the British Standard specification and was bought in the open market. Its average tensile strength per square inch was as follows:—

Neat, at 1 day	243 lbs.
„ „ 7 days	625 „
„ „ 2 months	768 „

It set initially in 1 hour 25 minutes, the final setting time being 4 hours 30 minutes. In mixing the concrete, 10 per cent. of water was used, based on the total weight of the dry materials. Five sets of prisms were made and the conditions as to mixing and storing were identical.

To arrive at a basis for comparison, a set of six prisms (Series A) were made without joints, these specimens being moulded and tested when 28 days old. In the remainder, division boards of roughly sawn spruce were fixed in the moulds 8 inches from one

end and the first portion of the concrete was placed and well rammed. These short lengths were allowed to harden for 7 days, after which the face against which the new concrete was to be placed was prepared and the prisms completed, care being taken to well ram the new material against the old face. The finished prisms were then allowed to harden for 28 days, after which they were tested.

Four distinct types of joint were investigated. In series B the faces of the 7 days'-old concrete were merely washed and well wetted prior to the imposition of the new material. As these faces had been moulded against a somewhat rough soft-wood board they were fairly open and coarse, and the somewhat high efficiency obtained with these joints is due to this roughness. The faces in series C were roughened with a chisel, all the loose material cleaned away and the surface thoroughly wetted. In series D the faces were prepared first as in series C, and were then washed over several times with a thick wash of semi-liquid neat cement grout, the new concrete being immediately applied. In the last series, E, the faces were thoroughly cleansed with water and treated with hydrochloric acid. After the acid had removed the cement to a sufficient depth to expose the aggregate and thus leave a very rough face, all traces of the acid were removed with stiff brushes and water and the new concrete was then applied.

The results of the tests are tabulated in the Appendix. Prisms A4 and B5 were defective, while prisms D2 and D6 broke outside the joint, therefore these cases have not been included in the Table. All the other specimens broke wholly or partly at the joints. The average efficiency of the various joints in the Table is given in relation to the strength of the unjointed prisms.

While these tests are somewhat limited in scope, it is evident that there is a considerable difference in the strength of the various joints. The value of roughening and grouting is clearly apparent. The joints treated with acid show a high efficiency, but the trouble and care necessary for the successful use of acid, especially where an aggregate of a porous nature is used, is opposed to its adoption in actual practice.

The Paper is accompanied by one diagram, from which the Figure in the text has been prepared, and by the following Appendix.

[APPENDIX.

APPENDIX.

CALCULATED TENSION AT EXTREME EDGE, POUNDS PER SQUARE INCH.

$$f = \frac{M}{z}$$

where f is the stress in pounds per square inch, M the bending moment in inch-pounds, and z the modulus of section.

Series A.		Series B.		Series C.		Series D.		Series E.	
Test No.	Solid Prisms.	Test No.	Face Wetted Only.	Test No.	Face Roughened and Wetted.	Test No.	Face Roughened and Grouted.	Test No.	Face Treated with Acid.
A 1	302	B 1	140	C 1	194	D 1	325	E 1	300
A 2	362	B 2	78	C 2	170	D 2	..	E 2	248
A 3	289	B 3	130	C 3	205	D 3	272	E 3	280
A 4	..	B 4	110	C 4	142	D 4	280	E 4	201
A 5	340	B 5	..	C 5	165	D 5	248	E 5	340
A 6	352	B 6	172	C 6	234	D 6	..	E 6	271
Average .	329	..	126	..	185	..	281.25	..	270
Efficiency .	100 per cent.	..	38.3 per cent.	..	56.2 per cent.	..	85.5 per cent.	..	82 per cent.