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Control Tests for Marine Concrete Repair Materials

Essais de contrôle pour matériaux de réparation de béton marin

Kontrollproben für Material für Reparaturen an Meeresbauwerken

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SUMMARY

After a brief description of experimental work in which a large number of damaged concrete slabs and domes were repaired underwater, this paper explains why the existing "standard" slant-shear test is not satisfactory for comparing the effectiveness of repair materials, such as cementitious grouts and epoxy resins. An investigation of alternative control tests for repair materials is introduced, and the findings are summarized.

RÉSUMÉ

Cette communication contient une courte description de certains travaux expérimentaux portant sur la réparation sous-marine d'un grand nombre de dalles et de dômes en béton, lesquels avaient subi des dégâts importants. Une analyse du test standard "slant-shear" montre que ce test est peu fiable pour une étude comparative de l'efficacité des matériaux de réparation tels que des laits de ciment et des résines époxydes. D'autres essais de contrôle des matériaux de réparation sont indiqués.

ZUSAMMENFASSUNG

Nach einer kurzen Beschreibung von experimentellen Arbeiten, bei denen eine Vielzahl von beschädigten Betonplatten unter Wasser repariert wurden, erklärt der Artikel warum der bestehende "standard slant-shear"-Versuch für den Vergleich der Wirksamkeit von Reparaturmaterial wie Zementmilch und Epoxyharzen nicht befriedigend ist. Darauf folgt eine Einführung in die Untersuchung von alternativr Kontrollproben für Reparaturmaterial sowie eine Zusammenfassung der Ergebnisse.

1. INTRODUCTION

The use of concrete in the marine environment, and the subsequent damage of that concrete, has provided some unique maintenance and repair problems.

Concrete has been used successfully for the construction of offshore oil and gas production and storage platforms, support columns for jetties, causeways and bridges, harbour walls, breakwaters, piers and coastal defences. These structures are subject to many forms of damage caused by ship impact, severe wave slam, erosion by sediment laden water, differential settlement caused by scour, corrosion of embedded steel and frost damage.

Where damage occurs to terrestrial structures, access is usually a relatively simple matter, enabling the operator to assess the level of damage, cut back and clean the damaged area and subsequently effect a repair. A wide variety of products are available for the repair of normal land based structures, ranging from low viscosity epoxy resins to lightweight thixotropic mortars. Similarly, a wide variety of repair techniques can be used, these range from crack injection (using resins or cementitious grouts), patching with mortars and gunniting to the casting in-situ of complete new members.

In the marine environment, the range of techniques and materials available is severely limited. Firstly, where the damaged concrete is at significant depth, visibility is limited by the turbidity of the water, the lack of incident light and, often, by encrustations of marine growth; these make visual assessment of the original damage and any subsequent repair very difficult. Secondly, working at depth means that the dexterity of the operator is reduced and the length of time available to effect a repair is limited. Thirdly, the materials used must be compatible with underwater placement. This means that the material chosen must be capable of displacing seawater without being dispersed, must be able to bond to a saturated concrete surface, must be able to set and develop full strength at low temperatures and must provide an impermeable interface between parent concrete and repair material.

Because of the high cost of carrying out underwater repairs, together with the great difficulty of removing an inefficient repair, it is imperative that the repair contractor chooses the correct material for the job. To enable this choice to be made, the contractor requires a control test method that provides comparative information on the different repair materials in a way that is relevant to the manner in which they would be used. This test method would need to be simple to carry out, suitable for site use, and give consistent results.

This paper first describes traditional control tests, such as the slant shear test; then, in the light of extensive experimental work, shows why these are unsatisfactory. A study is reported in which various test methods were investigated with the aim of identifying and recommending one or more that could be usefully employed in both evaluating a repair material and, at the same time, producing results relevant to the behaviour of repaired prototype structures.

2. UNDERWATER REPAIRS OF DAMAGED CONCRETE ELEMENTS

As the result of earlier investigations at Imperial College [1] a collection of concrete slabs and domes existed that had been designed to model the roof members of offshore oil storage vessels. These 1/12 scale models had been subjected to hard impact from a dropped object and exhibited a range of damage, from fine hairline cracking to complete perforation. Certain of these concrete elements were then repaired in a project entitled "Repair and retesting of Concrete Slabs and Domes subject to impact damage" carried out as part of the Concrete Offshore in the Ninety's (COIN) programme[2].

In that project concrete slabs and domes exhibiting an intermediate level of damage were repaired underwater using a variety of repair materials. These materials included epoxy resins of varying viscosities and cementitious grouts, some of which were modified especially for underwater placement. The method of repair was essentially to inject the repair material into the annulus between the displaced cone and the main body of the concrete. (Fig. 1.). The slab or dome was then tested by static loading through a steel platen placed on the repaired area.

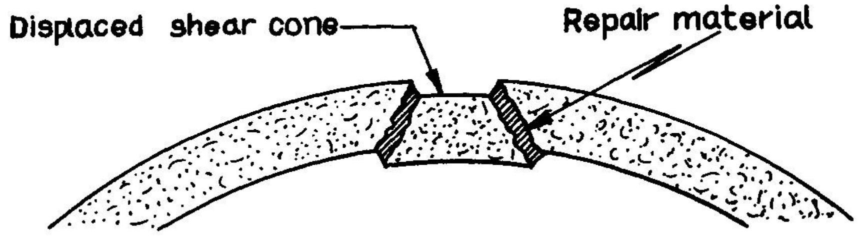

Figure 1. Sectional view of a dome repair

The results allowed a ranking, or scale, of the materials used. In parallel with the large scale repairs, all the materials were tested to BS 6319:Pt4:1984, [3] "the slant shear test for measurement of bond strength." The scale or ranking of materials produced by the slant shear tests did not, however, correlate with the ranking produced by the large scale repairs. As the large scale repairs were considered to be realistic and closely representative of the behaviour of a prototype structure, it was concluded that the slant shear test was not emulating the action of a real repair. These conclusions led to a further study [4] in which a variety of alternative test methods were investigated.

3. INVESTIGATION OF ALTERNATIVE CONTROL TESTS

These included modified slant shear tests, flexural tests and a direct tensile test. The direct tensile test was rejected at an early stage as it was apparent that difficulties in aligning the two ends of the test piece would cause unpredictable stress concentration and, consequently, unreliable results.

The slant shear test method used for epoxy resins was an adaption of the existing British Standard and consisted of testing a resin bonded scarf jointed prism by loading in compression (Fig. 2). A special jig was developed which separated and held the two halves a fixed distance apart and, at the same time, acted as a shutter for the resin injected into the crack.

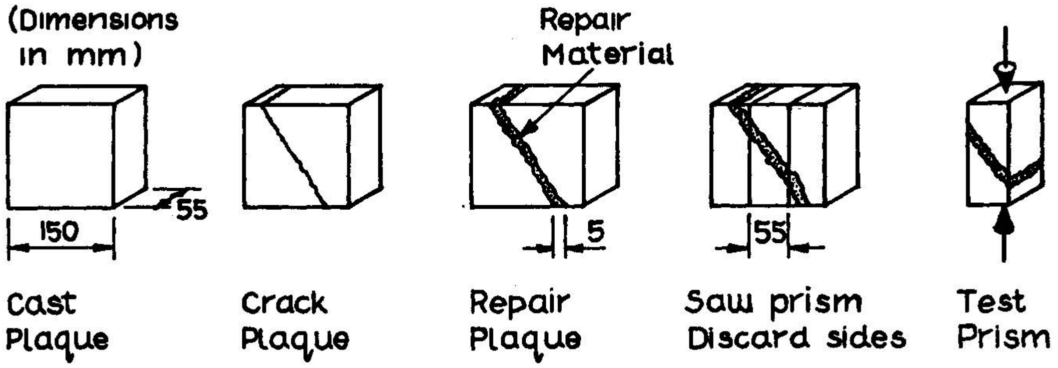

Figure 2 Resin bonded slant shear test method

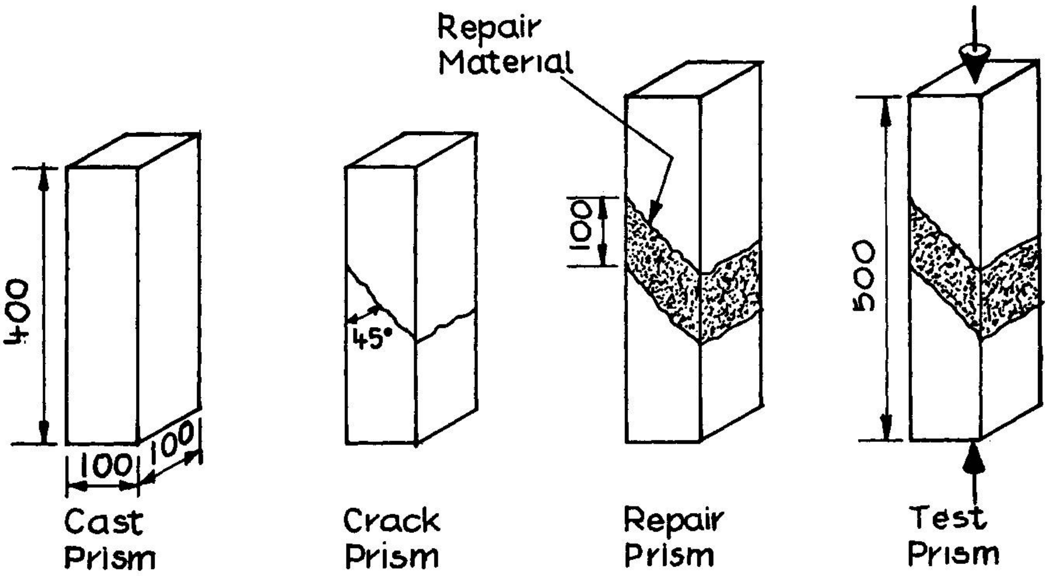

Figure 3 Cementicious grout bonded slant shear test method

The slant shear test method used for cementitious grout was similar in principle in that it also tested a scarf jointed prism in compression (Fig. 3). The test piece in this method was much larger and more robust, and the test was designed to use standard laboratory equipment and moulds.

The two flexural tests consisted of casting a short concrete beam, breaking it by flexural loading, bonding the two halves together and testing by four-point flexural loading (Fig. 4).

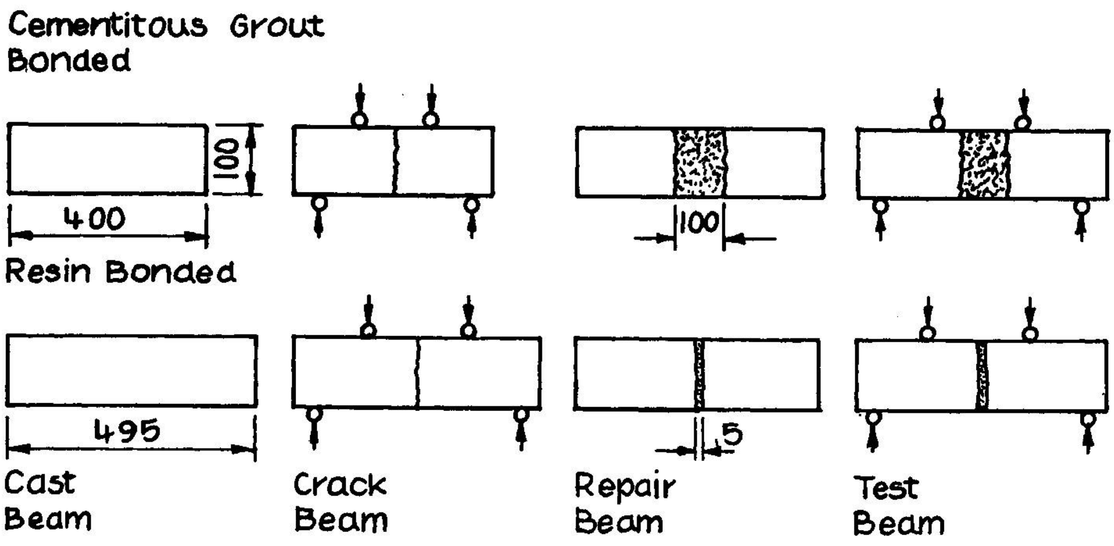

Figure 4 Flexural tests

The results of all these tests were assessed for consistency, ease of use and how they compared with the results obtained during the large scale slab and dome repairs.

4. CONCLUSIONS

For a number of reasons, it was concluded that the slant shear tests were not satisfactory. Firstly, the BS slant shear test was cumbersome to use and it proved impossible to inject some of the higher viscosity resins into the hairline crack demanded by the standard, although this problem was overcome in the modified tests where the crack width was fixed at 5mm. Secondly, it was felt that the slant shear test was not testing the repair material in the same mode in which it would be used real life. The slant shear test tests the ability of a thin layer of repair material to transmit compressive stress from one piece of concrete to another. Bond appears to have very little effect on this ability. Of far greater importance is the elastic modulus of the repair material and the roughness or interlock of the two concrete faces. In the tests reported here, where the repair material was of similar elastic modulus to the concrete (for example, in the cementitious grouts), then the compressive strength of the repaired prism was similar to the compressive strength of either the grout or the parent concrete, whichever was the weaker. Where the repair material was of a lower elastic modulus (for example, epoxy resin), then the distortion and stress concentrations in the resin caused failure of the repaired prism in the concrete adjacent to the repaired interface at loads lower than those found in plain concrete prisms.

Thus, the slant shear test, in it's present form, is of limited use as a test of bond and merely gives a of measure of the elastic modulus or compressive strength of the repair material. Both of these properties can be better tested by other existing methods. What is needed is some form tensile test. However, direct tensile tests are impractical and so a flexural test which is simple to use, gives reproducible results and can be used for all types of repair material is proposed by the authors.

5. RECOMMENDED TEST METHOD

This flexural test would give a severe test of the bonding power of a repair material and would test the bond in a mode that is likely to be encountered by a repaired prototype structure. The test is based on the flexural tests described above and consists of casting a short beam of concrete, of a mix design as similar as possible to the marine structures being repaired, breaking that beam in a controlled manner, separating the two halves to a fixed distance, filling the gap with the repair material and, after curing, testing the resulting composite beam by four point flexural loading (Fig. 5).

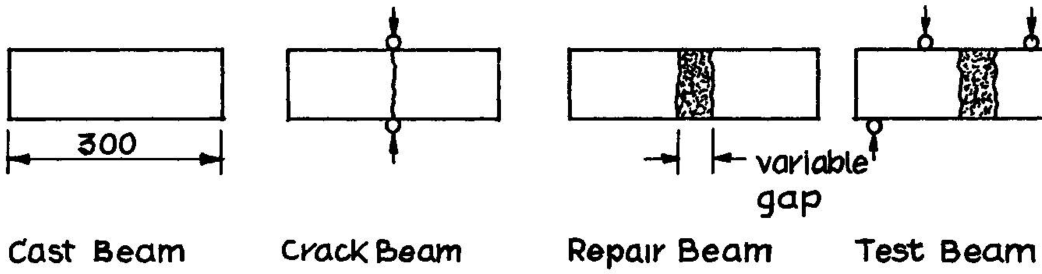

Figure 5 Recommended flexural test for resin or cementicious bonded beams

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