New method for detecting cracks in concrete using fibre optics

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Research on the use of optical fibres has reached an advanced stage in recent years, especially in telecommunications. The use of optical fibres as detectors of disorder (cracks, damage, etc.), for example in aeronautics, is much more recent. In this article we propose a new application of this method in the field of civil engineering.*

1. INTRODUCTION
The device described here makes it possible, using optical fibres, to detect the formation or propagation of one or more cracks in a material containing a hydraulic binder. It is a very flexible and relatively inexpensive means of investigation for use in studies and research on the fracture behaviour of concretes and for the surveillance of reinforced or prestressed concrete structures (especially the hard-to-reach parts of foundations, offshore structures, and the like).

2. PRINCIPLE OF METHOD
The operation of the device is based on the finding that an optical fibre embedded in a piece of concrete breaks as soon as a crack propagating in the material surrounding it reaches it, and that this break causes an almost complete disappearance of the luminous signal transmitted by the fibre (Fig. 1).

In fact, this breakage occurs only if the cladding protecting the fibre is removed. This can be done by dissolving it in methylene chloride, and done selectively to produce localized 'sensitive' zones along the fibre.

The main difficulty lies in the placement of the fibres. This problem was solved using metal tubes that protect the fibre during preparation operations and are removed when they are completed, before hardening starts.

The method may be used at three levels:

(i) Level 1, mere detection: one or a few fibres are placed so as to 'ring' the zone where cracks are acceptable (in the case of reinforced concrete) or to cross the zone of appearance of critical cracks (in the case of prestressed concrete); the transmitter is a light-emitting diode (LED) and the receiver is a photodiode that may be completed by some alarm or recording arrangement.

(ii) Level 2, locating: squaring a zone with fibres of which the active portions (unclad) are co-ordinated makes it possible, with a multi-channel surveillance system, to obtain information about the number, positions and directions of cracks.

3. EXAMPLE OF RECORDING

Fig. 1 Example of recording made during a bending test of a reinforced concrete joist: there is immediate attenuation of about 90% when the crack reaches the optical fibre (the test is conducted at an imposed strain rate to ensure stable propagation of the crack).

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(iii) Level 3, extensometry: analysis of the backscattered signal by a signal processing device can provide information about deformations along the whole length of the optical fibre [1] and so map the damage to the material.

3. SCOPE OF APPLICATION

The device may be used in all castable materials of which the normal domain of use is limited by the appearance of cracks or of faults that may be treated as kinematic discontinuities. This is the case for materials based on hydraulic binders (mortars, ceramics, concretes) and many other composite materials, provided that they do not impair the active portion of the fibre (unclad), whether during placement or in the longer term.

The technique may be extended to other materials by bonding the fibres to the surface, but is then restricted to the visible portions of the cracks; in the case of materials that shrink when they dry, such as mortar and concrete, the visible cracks are not very representative of the cracks within the material.

Finally, it should be pointed out that the effectiveness of the device will depend essentially on an understanding of the various possible mechanisms of failure; an analysis of these will lead to optimum positioning of the fibres.

4. EQUIPMENT

4.1 The optical fibre

For materials based on hydraulic binders, all mineral fibres (glass or silica) are suitable. However, their sensitivity will depend on their diameter. A device (Fig. 2) may be used to determine, for a given material and given fibre, the crack opening that will break the fibre. As an example, in plain concrete, a common silica fibre having a diameter of 133 to 200 μm breaks at a crack opening of less than 50 μm.

4.2 Placement tubes

The procedure for placing the fibre in the concrete calls for the use of a tube providing temporary protection. This is a metal tube having an inside diameter larger than the diameter of the fibre used, stiff enough to hold the fibre in position during placement.

In reinforced or prestressed concrete, the tube can be attached to the passive reinforcements at regular intervals, so an ordinary 4/2 mm diameter tube is perfectly suitable.

The tube is generally straight so that it can be withdrawn after the material is placed. However, to avoid excessively long transfer lengths, two tubes can be used for a single fibre, one of which, not straight, will be left in place. In this case there must be a coupling sleeve at the end of the fixed tube to prevent shearing of the fibre during the preparation operations.

4.3 The transmitter

This is a light-emitting diode with a support to supply it and align it adequately with the end of the fibre. For level 1 and 2 applications, LEDs of standard quality are adequate and the positioning tolerances are of the order of 10 μm.

4.4 The receiver

This is a photodiode with a support to align it adequately with the fibre. For level 1 and 2 applications, the specifications of the photodiodes and their supports are the same as for the LEDs. The remaining apparatus depends on the type and level of the application: voltmeter, numerical or graphic recorder, threshold detector and alarm, etc.

5. PROCEDURE

5.1 Preparation of optical fibre

The preparation of the fibre involves two operations: cutting the ends and removing the clad. For level 1 and 2 applications, a satisfactory cut surface can be obtained by scratching the fibre with an alumina blade and bending it by hand. For level 3 applications, the manufacturers of optical fibres propose methods of obtaining cut ends of a higher quality.

The clad on ordinary fibres is of epoxy acrylate. It can be removed by dissolving it in methylene chloride. The portion of the fibre that will be in the detection zone is identified and marked, then immersed in a solution of

Fig. 2 Device used to determine, for each type of fibre, the crack opening that will break it. It is a concrete mould (40 cm x 20 cm x 2 cm), in two parts, with a hinge at one end and a micrometer screw at the other; a metal tab serves to initiate a crack in the midplane of the concrete.