Three-jack Solution to Obtain a Truly Stable and Symmetric Tensile Concrete Test

by A. Carpinteri and F. Maradei

ABSTRACT—Testing equipment, made up of three orthogonally arranged jacks, which is able to apply a purely tensile load to a concrete specimen is proposed. The secondary flexural stresses are kept under control and constitute a degree of error comparable to the values allowed for normal testing apparatus. When the crack formation tends to produce asymmetry in the system, the counter-reaction intervenes, annulling the load eccentricity. In this way the true tensile properties (strength and fracture energy) of the material may be measured.

Introduction

To determine the tensile strength of concrete, recourse has currently led to indirect methods: the prism bending test and the Brazilian test. The results obtained, however, tend to depart from the actual values obtained from direct testing, as they are determined using the theory of elasticity, on the assumption of a linear elastic behavior and of homogeneous and isotropic material. Concrete is not, however, a homogeneous material and its behavior is anything but perfectly elastic. It is therefore necessary to introduce certain correction terms which take into account these two factors in the results of indirect methods.

It is, on the other hand, certain that only direct testing is able to give the correct information on tensile behavior. Direct testing is difficult to perform in practice and, even though some investigators have already proposed different testing methods, the problem has not yet been solved. These methods, in fact, have for the most part been influenced by the shape of the specimen and do not produce a purely tensile load.[1–10]

In the sequel, we describe a method devised and set up at the Department of Structural Engineering of the Politecnico di Torino. The aim has been to produce a purely tensile load until complete rupture is achieved. The difficulties encountered are set forth and the results obtained are compared with those of similar investigations involving secondary flexural stresses.

Test Specimens and Gripping System

The first problem was that of defining the shape and the size of the test specimens. The shape is linked to the choice of the type of gripping mechanism and to the desirability of creating a preferential fracture zone. The size of the test specimen is limited both by the size of the aggregate used (lower limit) and by the potentialities of the available equipment (upper limit).

In an initial cycle of tests, the approach was to use relatively small aggregates to make it possible to perform experiments on test specimens of varying sizes. The test specimens were flared in the center as shown in Fig. 1. The thickness of all test specimens was 10 cm and was maintained constant for the entire set; the transverse dimension was 0.5—1—2—4 times that of the thickness.

Each test specimen was glued to steel supporting plates in order for it to be attached to the load-bearing system. An epoxy resin-based two-component adhesive was chosen (tensile strength = 50 MPa). This ensures a high adherence both to concrete and to steel. The plates were secured to the lower and upper cross members by a series of bolts. The shape of the test specimen, with cross section of the ends being three times the cross section at which failure was expected, minimized the stress in the glued area.

The testing method has been developed taking into account the following factors.

(1) The general impossibility of making geometrically perfect test specimens, since even if considerable care is taken in their preparation, they inevitably present certain defects in shape.

(2) The extreme difficulty of eliminating centering errors even after introducing hinges in the chain applying tensile force, in which case it is by no means certain that the test specimen is coaxial with the hinges.

(3) Even supposing that centering of the load is performed as exactingly as possible, the development of cracks during the loading phase leads to a new cross-sectional

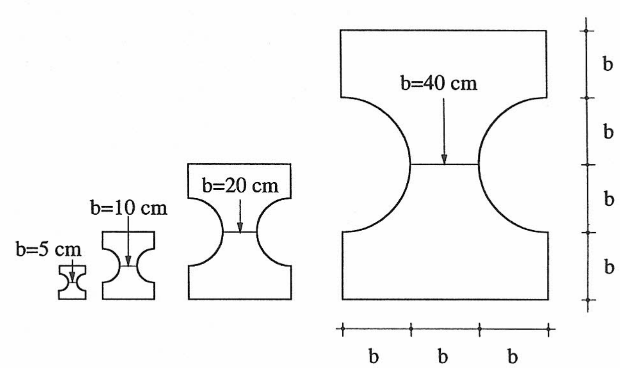

Fig. 1—Four different scales of tensile specimens

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asymmetry and hence produces a bending moment. The application of the load via hinges could eliminate the inconveniences due to defects in the shape and, in part, to centering errors, but not those due to the asymmetry arising during the loading phase. On the other hand, applying the load by means of an extremely stiff structure would make it very difficult to position the test specimen, but would make possible a symmetrical and uniform deformation of the cross section.

(4) The use of closed-circuit electronically servocontrolled machines becomes indispensable in order to maintain a constant strain rate, and in order to detect the descending (softening) branch of the load-extension curve, measuring the extension using extensometers directly applied to the test sample.

Single-jack Solution

A first attempt to test the sample was thus made by seeking to center it with the help of a ball joint and only subsequently to stiffen the structure.

The test specimen was fastened to the lower cross member by means of the plates glued to it. Then with the ball joint set in place between the moveable cross member and the jack, the specimen was loaded with a compressive force. Using four electrical extensometers applied to the central zone of the specimen, it was possible to control the eccentricity of the load, which was corrected by varying the position of the ball joint. The operation proved to be very laborious, in that several attempts at loading and unloading were required before a value that could be deemed negligible was achieved.

The jack was connected to the mobile cross member via a steel bar by interposing two ball joints between the securing nuts (Fig. 2). Once the compressive load was centered, the nuts of the connecting bar were tightened so that the action of the ball joint used for centering the load was offset. Only one machine was used, electronically controlled via a closed-circuit servomechanism by measuring the extension detected directly on the test sample. By measuring the strains at four points of the central cross section, it was possible to control the uniformity of the strains.

In this connection we wish to point out that it was found advisable to control the servo-system via the sum of the four measurement signals, both in order to achieve a greater sensitivity of the control system, and because, during the phase of approaching the moveable cross member to the test specimen, which constitutes the most delicate phase of the entire operation, the contact of the cross member with the anchoring plates can occur at any point, thus transmitting to the test specimen an eccentric force. If the system were not sensitive to this force, then it could not even be controlled and would therefore cause the specimen to break even before the start of testing. By summing up the four measurement signals, each extensometer contributes to form the counter-reaction signal of the system, so that, at whatever point of the specimen contact is made, the system reacts appropriately. For this purpose, a specially built operational amplifier was used.

The load-extension curves, obtained using this system on the four points of the cross section, proved to coincide up to the peak load but were highly divergent in the descending branch (Fig. 3). In the light of the experiments carried out in this phase, the system did not prove sufficiently stiff even when appropriate stiffening tie rods were added on the moveable cross member.

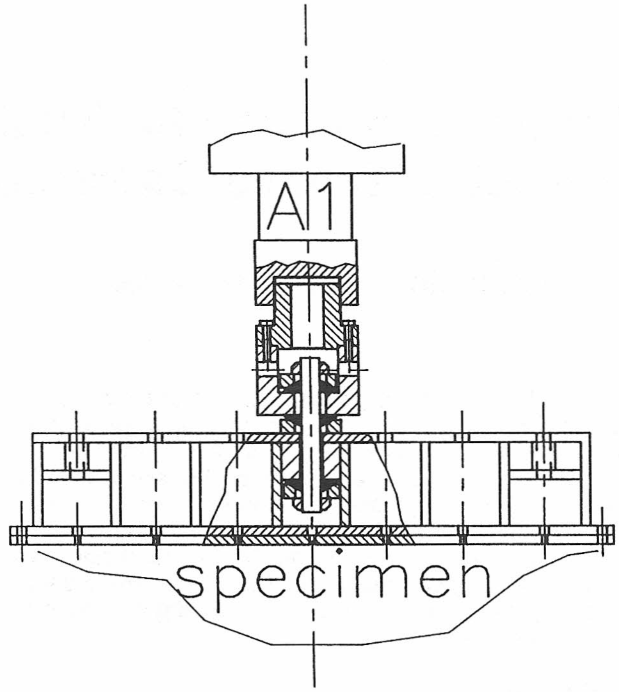


Fig. 2—Connection between jack and cross member via a steel bar and the interpositon of two ball joints

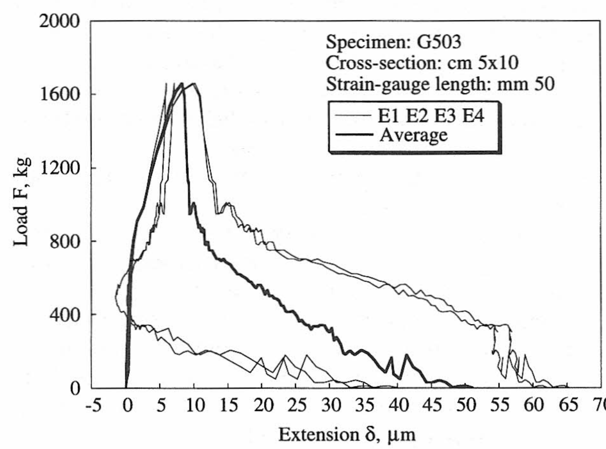
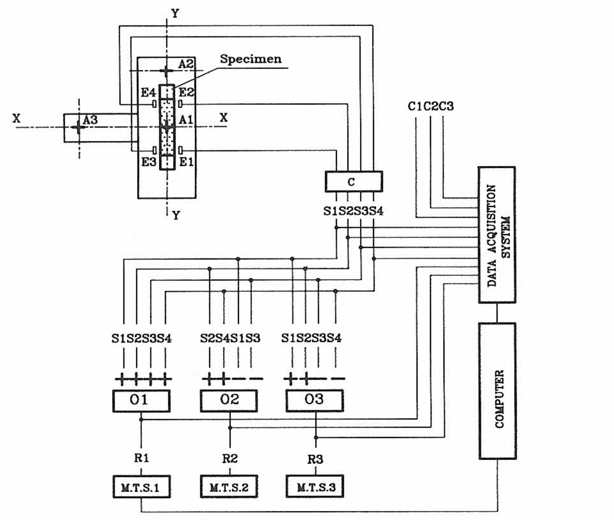


Fig. 3—Load-extension diagrams coming from the four extensometers (single-jack solution)

Three-jack Solution

It thus appeared convenient to seek a testing method to overcome the problem described above. The procedure devised was to use servocontrolled machines to keep also the flexural forces under control along two mutually orthogonal planes. For this purpose it was necessary to have some sort of electrical signal, capable of functioning as a control signal in a counter-reaction system, which was proportional to the bending moment developed on the specimen cross section.

Initially the new counter-reaction signals were obtained by detecting the strains from electrical extensometers set



LEGEND :

E1 E2 E3 E4	Fracture mechanics extensometers
S1 S2 S3 S4	Extensometer output signals
A1	Actuator used to apply tension load
A2	Actuator used to reduce the bending moment in the Y–Y direction
A3	Actuator used to reduce the bending moment in the X–X direction
C	Signal conditioner amplifier
01	Operational amplifier for the addition of the four extensometer output signals
02 03	Operational amplifiers to make other algebraical operations on extensometer output signals
R1=S1+S2+S3+S4	Feed-back signal for actuator A1
R2=(S2+S4)−(S1+S3)	Feed-back signal for actuator A2
R3=(S1+S2)−(S3+S4)	Feed-back signal for actuator A3
C1 C2 C3	A1 A2 A3 actuator output signals

Fig. 4—Counter-reaction electrical system

on two opposite sides of the specimen and connected onto the adjacent sides of the measuring bridge. In this way, two electrical signals were obtained, which were proportional to the difference in the strains and hence proportional to the bending moment acting along a plane passing through the axis of the specimen, each in the direction perpendicular to the faces of the specimen to which the extensometers were attached.

The test proved particularly useful for pinpointing the problems involved in the simultaneous operation of the three servomechanisms employed. It did not, however, prove satisfactory as regards the response curves which still emerged as divergent.

It thus appeared logical to use, for control purposes, the same analogical signals supplied by the four extensometers employed for measuring the strains, carrying out appropriate algebraic operations on them. If ε_1, ε_2, ε_3, ε_4 are the strains of the single measuring points set out as shown in Fig. 4, the strains due to bending moment turn out to be:

$$\text{along the } x \text{ axis: } \varepsilon_x = ((\varepsilon_2 + \varepsilon_4) - (\varepsilon_1 + \varepsilon_3))/2$$

$$\text{along the } y \text{ axis, } \varepsilon_y = ((\varepsilon_1 + \varepsilon_2) - (\varepsilon_3 + \varepsilon_4))/2$$

Figure 4 gives the electrical scheme illustrating the use of analogical amplifiers for performing operations of addition and subtraction of the four extensometer signals and how they are connected up to the three servocontrolled jacks.

Figure 5 depicts the testing scheme, and the photographs of Fig. 6 show the overall setup of the equipment with two different specimens under load.

The central jack was suspended from the contrast structure via a ball joint and was connected again with a ball joint to the moveable cross member. The jack applies the tensile force to the center of the cross member and, as has already been said, the control is achieved by summation of the signals of the four extensometers mounted on the specimen.

The other two jacks are disposed, one at the end of the main cross member, and the other at the end of an auxiliary cross member set perpendicular to the main one. Both jacks generate a couple acting along a principal plane of the specimen.

The test is thus carried out by the central jack imposing an extension on the specimen with a constant rate, while the other two jacks maintain the values ε_x and ε_y equal to zero. Figure 7 presents the load-extension curves obtained with the three-jack method, and it can be seen how they almost coincide up to the point where the load goes to zero in the softening phase.

The test specimen is fastened both to the fixed cross member and to the moveable one by the anchoring plates and by means of bolts. For small-sized test specimens, where the errors in shape are rather limited, the fixed cross member was secured, for convenience of assembly, to the contrast structure. In this case the specimen is set into the base, and the diagram of the bending moment on the specimen, due to the eccentricity of the load, is triangular with a maximum value at the point of constraint. The two side jacks then generate an opposite couple so as to annul the value of the moment in the central zone of the test specimen, which is under controlled deformation. Both glued surfaces are then sites of the residual moment that can lead to the failure of the specimen. In small specimens (5 × 10 and 10 × 10 cm), the failures always occurred at the smallest cross section and hence in the controlled zone, but larger ones sometimes came unstuck from the plates in either the upper or the lower glued zones.

For the specimens having a 20 × 10-cm cross section, it was thus decided to create a hinge underneath the lower cross member, allowing them to turn about the y axis. This same problem, thus overcome in the case of 20 × 10-cm specimens, presented itself again also in the case of the next larger size, 40 × 10 cm. In this latter case the failures were seen to occur even at one or two centimeters' distance from the steel plate, involving the entire concrete specimen.

A close observation of the fracture zone revealed that, over the end areas, the epoxy resin glue had not adhered perfectly even for some dozens of centimeters. Therefore the nonadherent stretch would appear to have acted as a notch, with a concentration of stresses that led to tearing of the sample before the natural tensile strength was reached.

Conclusions

In conclusion, it may be stated that the test carried out using three jacks according to the proposed method makes it possible to apply a purely tensile force, in which the secondary stresses, if kept under control, constitute a degree of error comparable to the values allowed for normal testing apparatus. The method enables a stress-strain curve to be plotted with the descending (softening) branch up to the point where the cross section of the test specimen breaks away.

In addition, the problem of how the specimens are gripped by gluing has partly been overcome. The method has proved

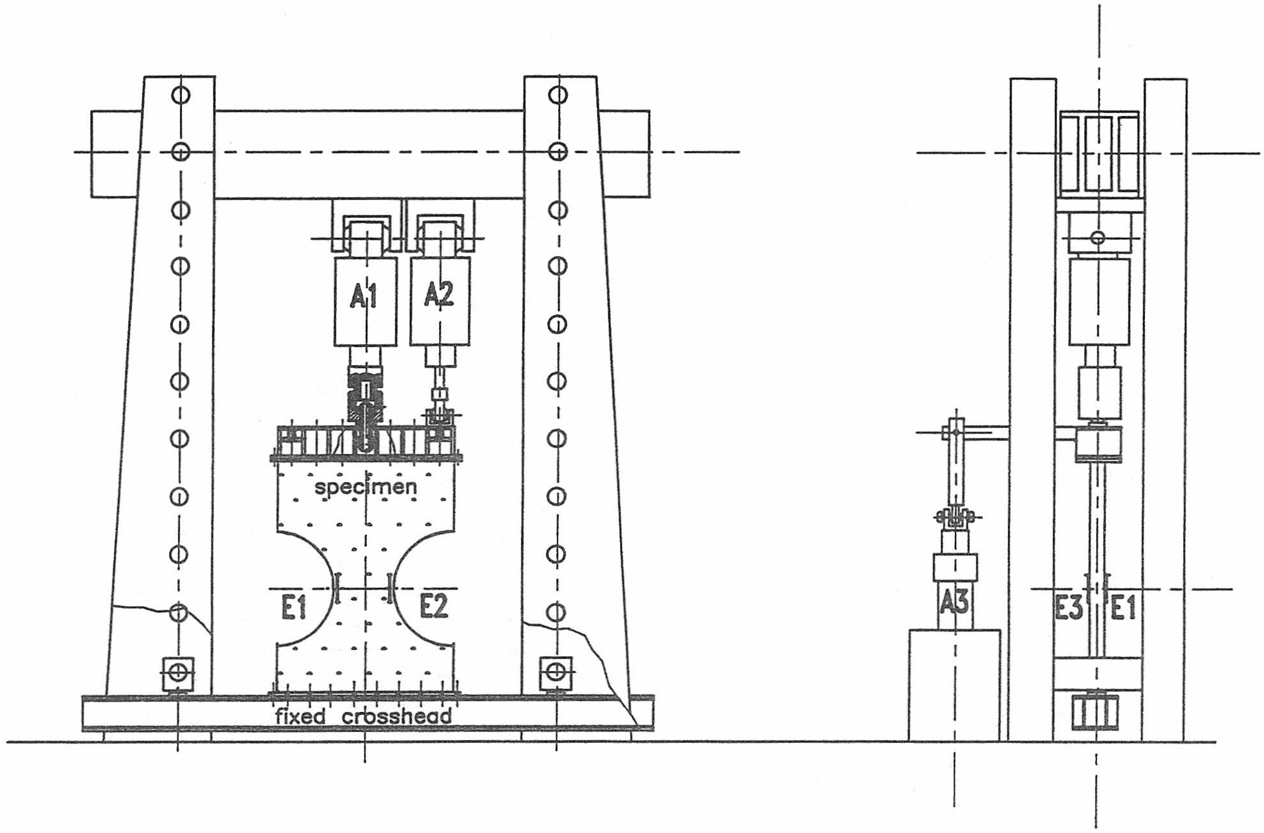
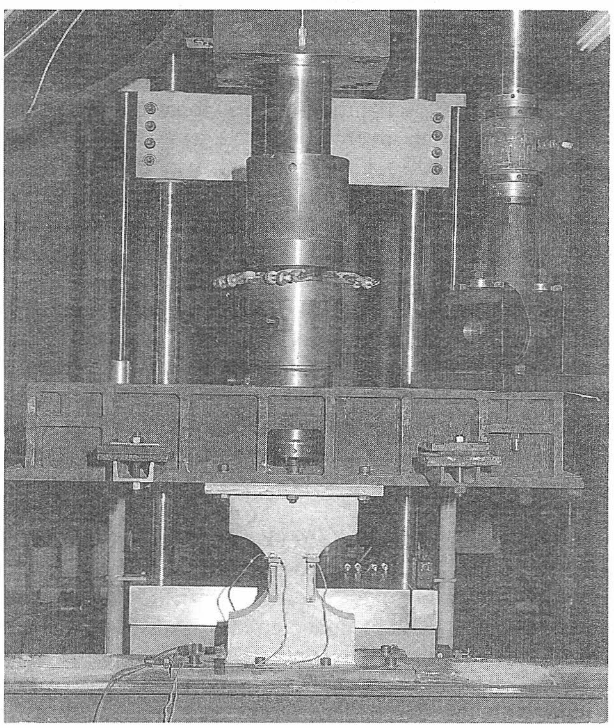
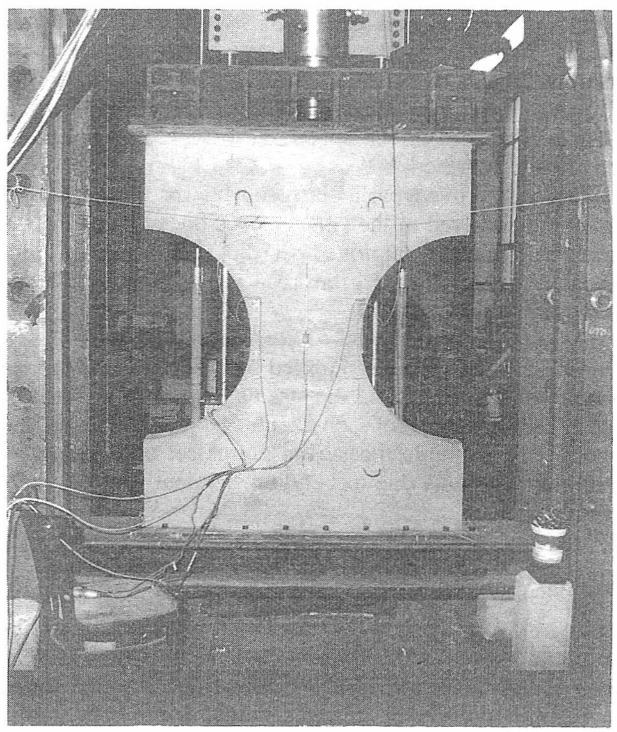


Fig. 5—Testing scheme with the three-jack solution



(a)



(b)

Fig. 6—Overall setup of the equipment with two different specimens under load: (a) 5 × 10 cm; (b) 40 × 10 cm

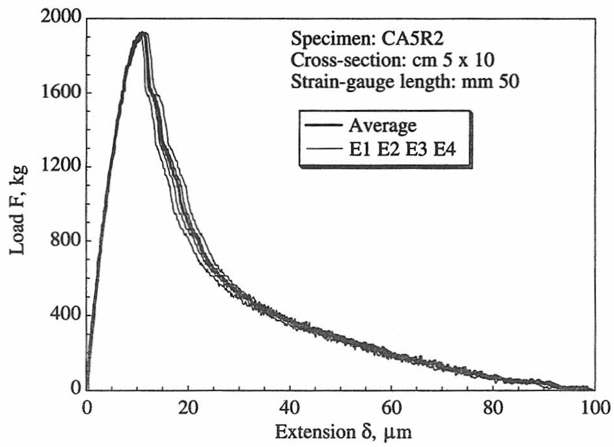


Fig. 7—Load-extension diagrams coming from the four extensometers (three-jack solution)

effective for test specimens of up to 20 × 10 cm. For larger-sized test specimens (40 × 10 cm), the problem of how they can be gripped in place has been only partially solved.

Acknowledgments

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