IMPACT BEHAVIOUR OF POLYPROPYLENE-FIBER-REINFORCED CONCRETE PLATES

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In the present paper the results of impact tests performed on thin precast plates made up with polypropylene fiber reinforced concrete are reported. The experiments were performed by dropping down a steel mass from a fixed height. Parallel to the physical tests numerical simulations were also carried out applying the methods of non-linear fracture mechanics.

INTRODUCTION

The fibers used for the production of fiber-reinforced concrete belong to two main classes: fibers having high elastic modulus and high strength (steel, glass, asbestos, etc...) fall in first class, while those having low elastic modulus and low strength (polypropylene, nylon, polyethylene, etc...) fall in the second one. Laboratory tests showed (Hasaba et al. (1)) that the addition of hard fibers improves the composite behaviour toward both static and dynamic load, while the addition of soft fibers has little effect on the strength to static load but can improve the performance against dynamic load. In account of scarcity of experimental results on the behaviour of plastic-fiber-reinforced concrete a program of experimental tests on polypropylene fiber reinforced concrete elements was started at the University of Rome "La Sapienza" (Calamani et al. (2,3)). In the present paper experi-

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mental and numerical results on the impact behaviour of plates subjected to impact loads are presented.

EXPERIMENTAL PROCEDURES

Outline of tests

Impact loading tests were carried out on square plates made up with polypropylene fiber reinforced concrete. The acceleration of the specimens and the impact load were measured. The number of blows to failure was counted.

Loading method

The experimental setup is shown in Fig. 1. The impact tests were carried out by dropping a spherical steel striker onto the specimen at its center. The mass of the striker was 1 kg and the falling height H = 2 m. These figures were selected to avoid specimen failures at the first blow. The striker was released from its support with null initial speed. After the impact the striker was placed again on its support. The dropping of the striker was repeated until the specimen failed.

Measuring equipment

A dynamic load cell model PCB200B20 was placed on the plates at the impact spot to measure the load time-history. An accelerometer model PCB303A was attached on the top surface of the plates 5 cm away from the impact spot. The outputs of the load cell and the accelerometer were amplified and stored by a digital oscilloscope model HP16531A and transferred to the central computer of the test facility (HP 9000-310) for subsequent analysis.

Specimens

The characteristics of plates may be found in Tab. 1. Four series of plates were tested. They were reinforced with an additional steel mesh (06 15x15 cm) to prevent flexural failure and to assure failure in punching shear.

RESULTS OF EXPERIMENTAL TESTS

The tests results are reported in Tab. 2. For each series of specimens the mean value of the number of blows to failure, along with the total energy W are presented. The measured values of the load time-histo-

TABLE 1 - Specimens characteristics

Series	V_f [%]	S [cm]	B [cm]	E_c [kN/mm^2]	σ_t [N/mm^2]	σ_c [N/mm^2]	G_f [N/mm]
A	0.0	60.0	4.0	29.0	3.89	27.5	19.0
B	0.2	60.0	4.0	21.3	3.51	26.8	32.0
C	0.4	60.0	4.0	20.6	3.39	28.8	58.0
D	0.8	60.0	4.0	22.0	3.78	20.6	72.0

ry, i.e. peak loads and duration of the impact processes are also reported. In Fig. 2 a typical measured time-history of the impact load may be seen.

TABLE 2 - Experimental impact results

Series	No. of blows to failure	W [Nm]	Pmax [kN]	Duration [ms]
A	5.50	107.8	48.70	0.19
B	8.75	171.5	43.20	0.22
C	11.75	230.3	41.40	0.24
D	13.50	264.6	42.60	0.22

NUMERICAL SIMULATION OF EXPERIMENTAL TESTS

Modelling the impact process

This problem may be reduced to a simplified model (C.E.B. (4)) having only two masses M_1 (the target) and M_2 (the striker), a contact spring K_2 between them and another spring K_1 which represents the stiffness of the struck body. In the general case both springs have non-linear stiffness. The system behaviour is described by these equilibrium conditions, where X_1 and X_2 are the mass displacements:

$$M_2\ddot{X}_2 + K_2(X_2 - X_1) = 0$$
$$M_1\ddot{X}_1 - K_2(X_2 - X_1) + K_1(X_1) = 0 \qquad (1)$$

In the limiting case where $X_2 >> X_1$ - the so called soft impact - the term X_1 may be neglected in comparison to X_2 and the previous equations may be decoupled. The kinetic energy of the striking body is totally transferred into strain energy of the struck body. The other limiting case is the hard impact which occurs when the striker is rigid and travels at a moderate speed. In this case its energy is absorbed to a large extent by deformation and fracture of the struck body. The equations (1) no longer may be decoupled. Unfortunately this is the case of our tests.

Numerical evaluation of the impact force

The time - history of the impact force was evaluated by means of the finite element technique taking into account the non-linear materials behaviour. An axial-symmetrical model was considered and the impact action was assigned by means of initial kinematical conditions at the nodes describing the striker. Fiber-reinforced concrete behaviour was simulated following the smeared crack approach. The computed time - history of load had a total duration of 1.5×10^{-6} s and a maximum level P_{max} = 150.0 kN.

Numerical drop-weight tests

Using the same numerical model the drop-weight test was simulated with reference to the series B specimens. The impact force was applied as a forcing function having triangular shape with a rising time of 1.0×10^{-4} s and P_{max} = 40.0 kN, following the results of the experimental tests. The computed number of blows to failure was 5. The typical damage pattern at failure may be seen in Fig. 3.

CONCLUDING REMARKS

The experimental tests confirmed the favourable effect of the addition of polypropylene fibers toward impact behaviour of concrete plates. The results of numerical model are in good agreement with the experimental ones when the impact is simulated as a forcing function. The direct computation of the impact load with the simulation of the striker-plate interaction led to impact forces far greater than the measured ones. A reliable simulation of the impact process asks for improved material models expecially in the field of high-level pluriaxial compression and for the relation between strength, elastic modulus and strain rate. In the meanwhile the experimental evaluation of the impact forces seems to be the only reliable tool for the assessment of safety against impact and for the calibration of empirical formulae for design purposes.

ACKNOWLEDGEMENTS

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ADDITIONAL SYMBOLS

V_f = fiber content (% by volume).

E_c = Elastic modulus (kN/mm^2).

P_{max} = Maximum impact force (kN).

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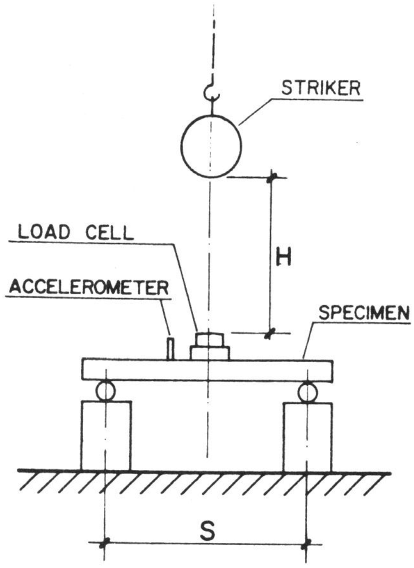

Figure 1 - Setup of the impact test.

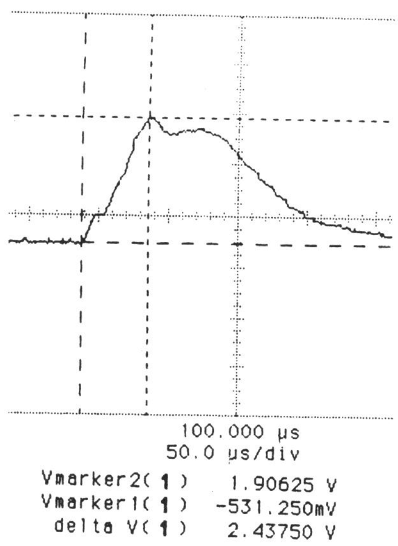

Figure 2 - A typical time history of the impact load.

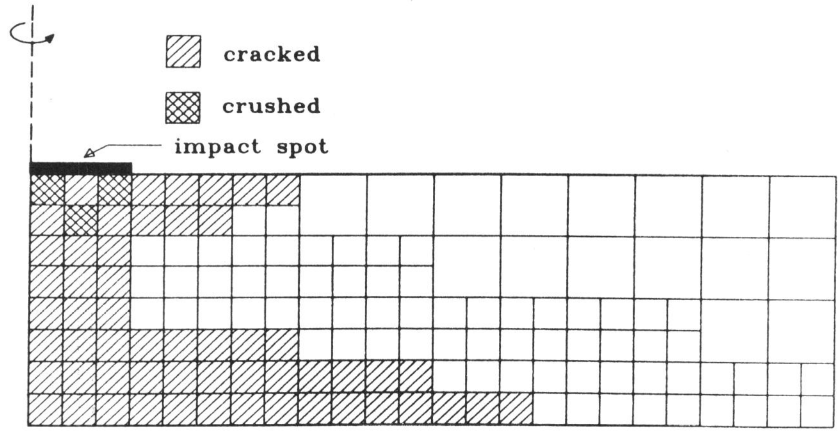

Figure 3 - Numerical model: damage pattern at failure.