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INSTANTANEOUS DETECTION AND MECHANICAL BEHAVIOR OF MICROCRACKING IN CONCRETE

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SUMMARY

The investigations on microcracking in concrete specimens were made by detecting the elastic waves as signals of cracking by means of a crystal microphone under simple compression, sustained compression and flexure. The cracking occurred at load much less than that generally recognized. Under short time sustained load, cracking signals increase abruptly at 85% of the ultimate load which corresponds to a critical point in creep of concrete.

INTRODUCTION

Safety of structural concrete against failure cannot be realized without a comprehensive knowledge of the nature of inelastic behavior and fracture of concrete. Therefore, one of the most actual relevant problems is to make clear the changes in the inner structure of concrete which determine fundamentally concrete characteristics.

This paper describes the investigations on the mechanical behavior of concrete specimens under simple compression, sustained compression and flexure by utilizing an instantaneous acoustical technique in connection with a directly optical method by means of a microscope.

METHOD OF DETECTION

Remarking the energy transfer at the destruction of molecular bonds in the constituent materials of concrete, it was tried to receive the elastic waves as signals of cracking at its occurence by using an extremely high sensitive crystal microphone on the surface of concrete specimen to explain the relation between microcracking and stress or strain in concrete. The received signals produced by cracking were applied to a synchroscope, giving a visual trace, and fed by a tape recorder. Thus the number and magnitude of signals were confirmed at each stage of loading. The obtained acoustical signals can be clearly distinguished from the scraping and other noises, since the display of the elastic waves on the synchroscope is very similar to the pattern of Bessel's function as shown in Fig. 1 (Ref. 1). The proposed technique, which was first tried by Rüsch (Ref. 2) and different from so-called sonic method (Ref. 3), can successfully catch even the crackings which an optical method fails to detect at early stage of loading.

SIMPLE COMPRESSION TEST

The test specimens of 5 x 5 x 15 cm were cut from Ø10 x 20 cm cylinders and all the sawed surfaces were ground to observe their internal structure, i. e. the location of hardened cement paste and aggregates. By applying load the elastic waves were traced and the number of cracking signals was counted at various steps of loading. The details of testing are shown elsewhere (Ref. 4). The number of signals caused by cracking indicates that cracking of concrete occurs immediately after the first loading, although it has been generally recognized that the minimum cracking load is approximately 30% of the ultimate load (Ref. 5). On the other hand, any new cracks are hardly observed for the following repetitive loads up to the previous exerted load (Fig. 2). The number of signals increases abruptly at applied stresses of the order of 80 to 85% of the ultimate strength. This range of critical load is almost same as the value of 70 to 90% of the ultimate load observed by previous investigators (Ref. 5). According to the optical observations, the cracks at early stage of loading are of so-called bond cracks at the interfaces between coarse aggregates and mortar. Most of them appear around the larger aggregate particles and not many are found around the smaller particles. Thses bond cracks appear parallel to the direction of loading and at the lower side of aggregates. These results agree with the other investigations (Ref. 6, 7).

FLEXURAL TEST

Six plain and three reinforced concrete beams having 15 x 15 cm square section were tested. The reinforcement was of a deformed bar of 16 mm in diameter for each specimen. The beams were subjected to the three-point loading with 45 cm span length. A slice, 2 cm thick, was sawed away from one side of each specimen and then the sawed surface was ground. The microcracks were traced optically on the polished surface by a microscope at each stage of loading. There is no evident difference between plain and reinforced concrete regarding the magnitude of the maximum amplitude of signals. The first cracking of concrete is observed at loading stage much earlier than considered in general; the first signal is caught at about 3 to 6% of the ultimate load for plain concrete beams and 0.5 to 8% for reinforced concrete beams. Thus there is also no evident difference between plain and reinforced concrete with respect to the loading stage where the first microcrack occurs in the interior of concrete (Fig. 3). According to the optical investigations, with increase of load, the isolated microcracks take place successively in the paste near the tension edge of the beams and then bridge over the cracks which occurred previously along the surfaces of aggregates. Theus at the loading stage of 70 to 80% of the ultimate load two or more continuous cracking paths are established near the tension edge. The failure of the specimen occurs suddenly through one of the above-mentioned cracking paths or through a different path appeared newly (Fig. 4, 5). The detailed descriptions can be seen elsewhere (Ref. 8).

SUSTAINED COMPRESSION TEST

The usual short time compression tests and short time creep tests for about five minutes were made under the various magnitude of sustained load on Ø10 x 20 cm cylinder specimens. Longitudinal and transverse strains in concrete were measured with wire strain gages. Also the elastic waves produced by microcracking were caught by means of a crystal microphone. The stress-deformation curves obtained in the usual compression test show the definite so-called critical points (Fig. 6), i. e. Point U as a maximum volumetric contraction (Ref. 9) and Point L as an abrupt increase of Poisson's ratio (Ref. 10). The stresses corresponding to two kinks of log stress-log strain lines for longitudinal deformation, Point u and l, may also be taken as critical points (Ref. 5). During the first five minutes under short time sustained load, cracking signals are hardly observed at load less than 30% of the ultimate load which nearly corresponds to the critical point l, and increase abruptly as shown in Fig. 7 when the sustained load reaches to about 85% of the ultimate load which corresponds to the critical point U. It should be noted that Point 1 represents possibly the sustained stress under which the occurence of microcracks during creep may start, Point L, the stress at the development of microcracks leading to fatigue failure of concrete, and Point U, the stress at the abrupt increase of cracks under the long time loading. The value of the stress at U lies between 80 to 95% of the ultimate strength while the value of the stress at L between 50 to 70% of the ultimate strength (Ref. 11).

CONCLUDING REMARKS

(1) The cracking signals of elastic waves are received at load much less than 10% of the ultimate load.

(2) The number of signals increases abruptly at applied stresses of the order of 80 to 85% of the ultimate strength.

(3) The similar cracking behavior is investigated in compression tests as well as in flexural tests for plain concrete.

(4) Under short time sustained load, cracking signals are hardly observed at load less than 30% of the ultimate load and increase abruptly at 85% of the ultimate load which correspond to critical points in creep of concrete.

(5) It is again confirmed that the cracks at early stage under short time compressive loading are of bond cracks. Most of them appear parallel to the direction of loading and at the bottom of larger aggregates.

(6) The test results show that the beams could fail by newly appeared cracks rather than the firstly appeared cracking line, although it has been generally considered that plain concrete beams would break down at the very moment of occurence of the first

cracking.

It is clear that the measurement of the elastic waves through specimens during mechanical test offers a powerful tool particularly for studying the mechanical behavior of microcracking and the prediction of the so-called true strength of concrete.

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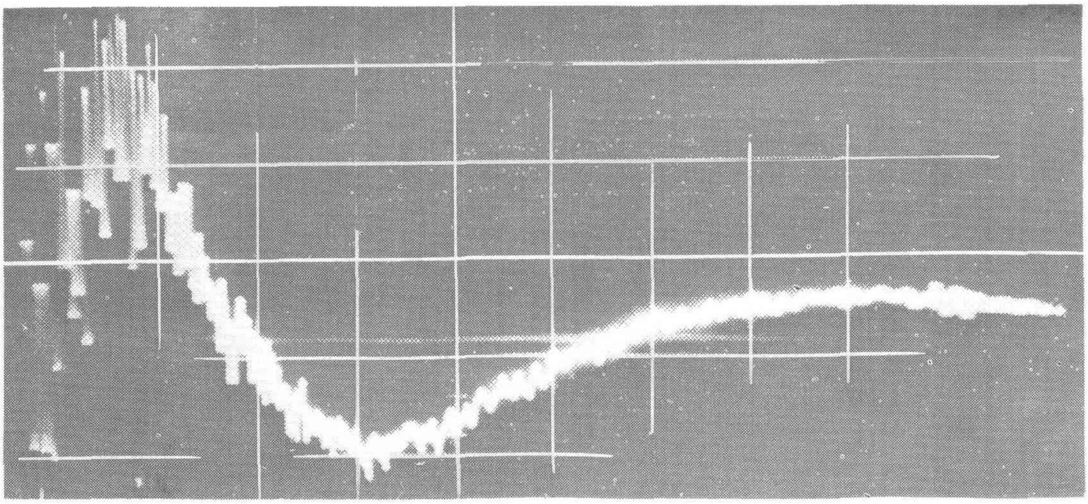
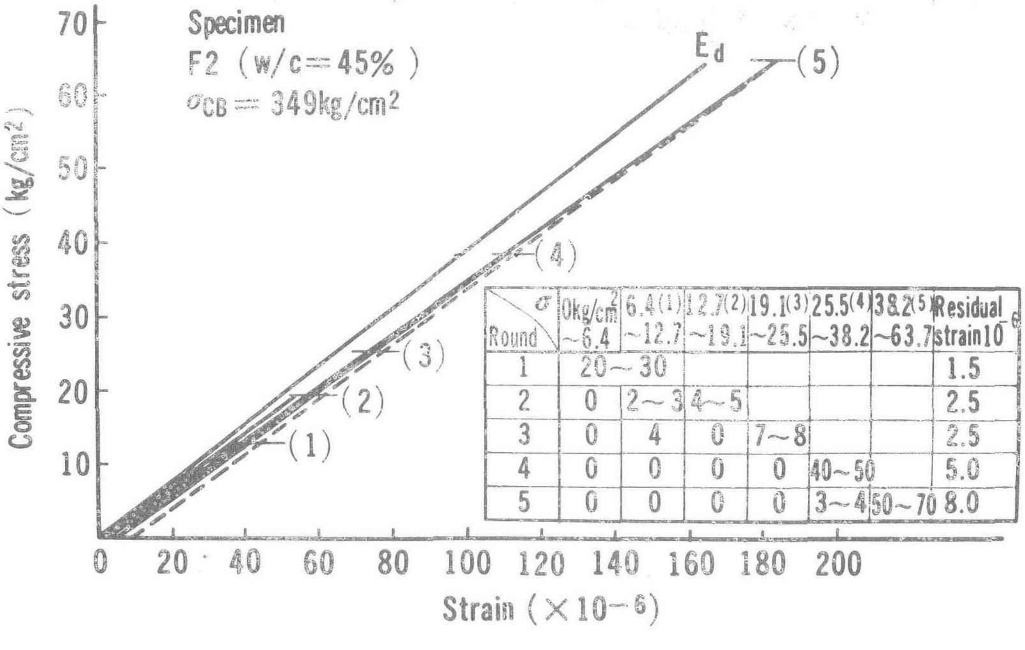


Fig. 1 Typical oscillogram of cracking signal (horizontal sweep; 2 ms/cm)



σ Round	0kg/cm² ~6.4	6.4(1) ~12.7	12.7(2) ~19.1	19.1(3) ~25.5	25.5(4) ~38.2	38.2(5) ~63.7	Residual strain 10^{-6}
1	20~30						1.5
2	0	2~3	4~5				2.5
3	0	4	0	7~8			2.5
4	0	0	0	0	40~50		5.0
5	0	0	0	0	3~4	50~70	8.0

Fig. 2 Number of cracking signals and stress-strain relation

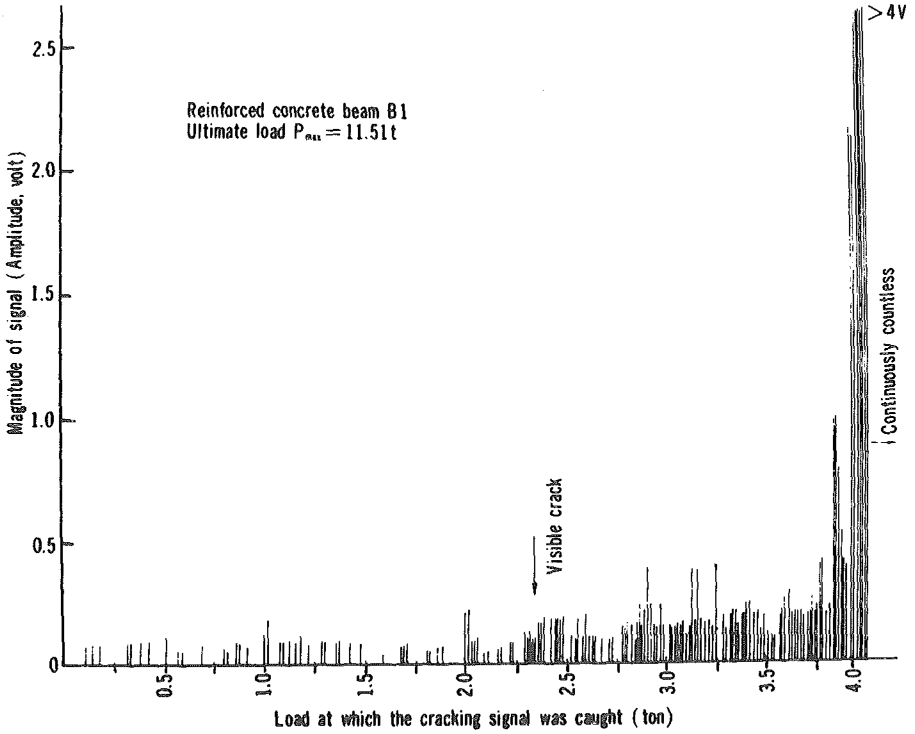


Fig. 3 Magnitude vs. number of cracking signals observed by synchroscope

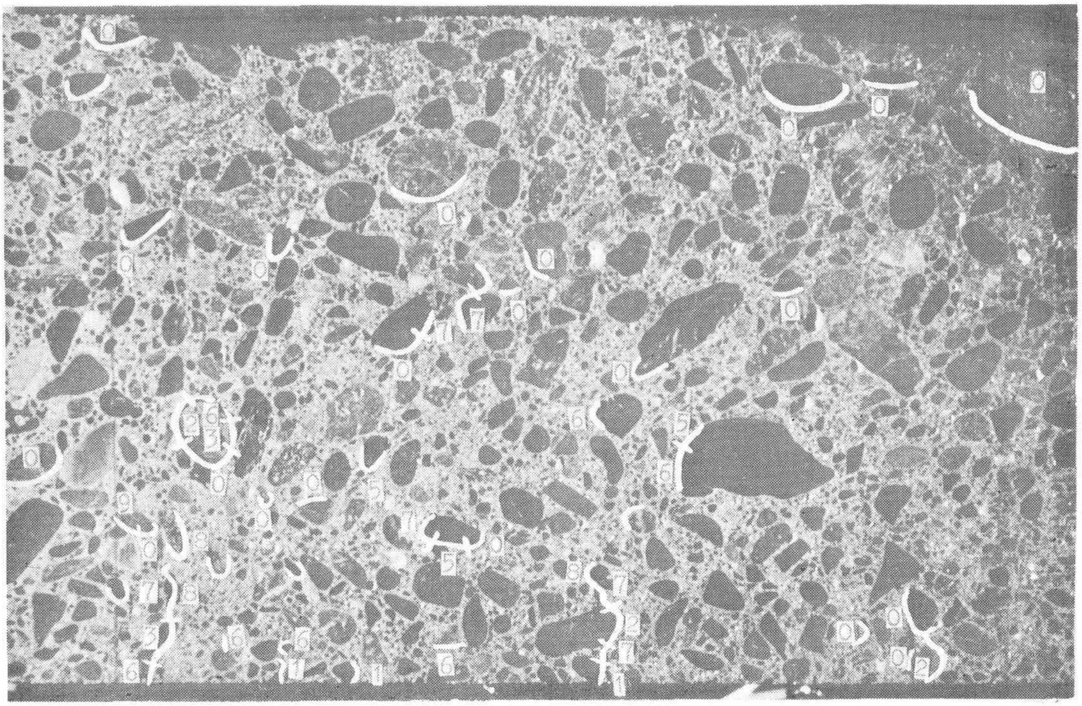


Fig. 4 Cracking process of concrete beam before failure (numerals indicate loading steps with increment of 0.25 tons)

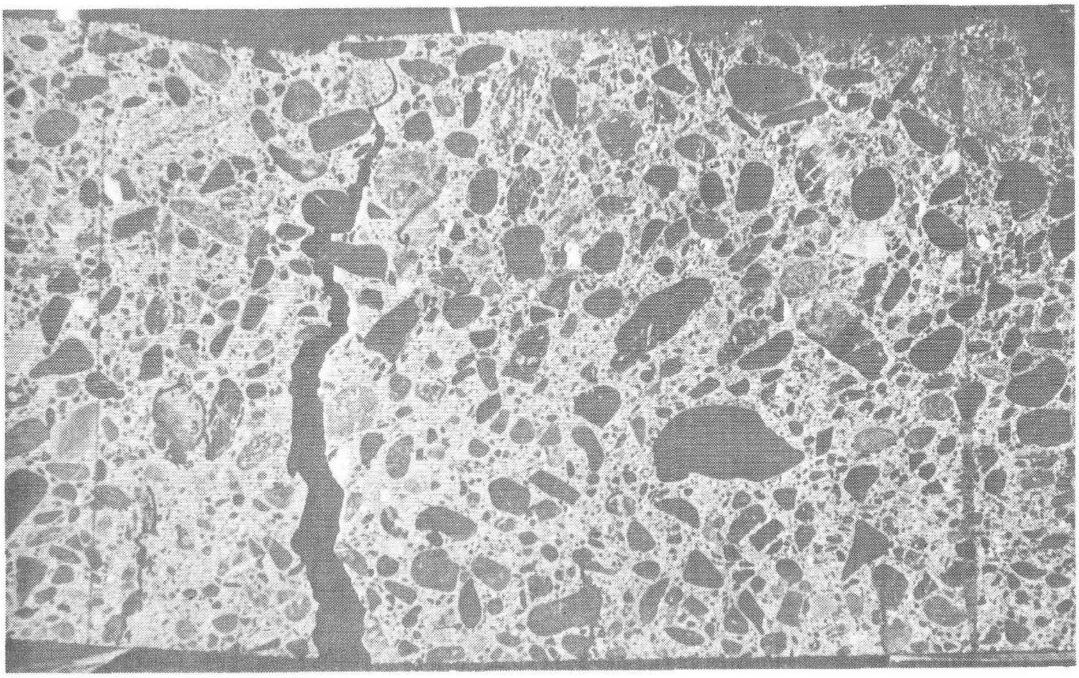


Fig. 5 Crack of concrete beam after failure at load, 2.415 tons

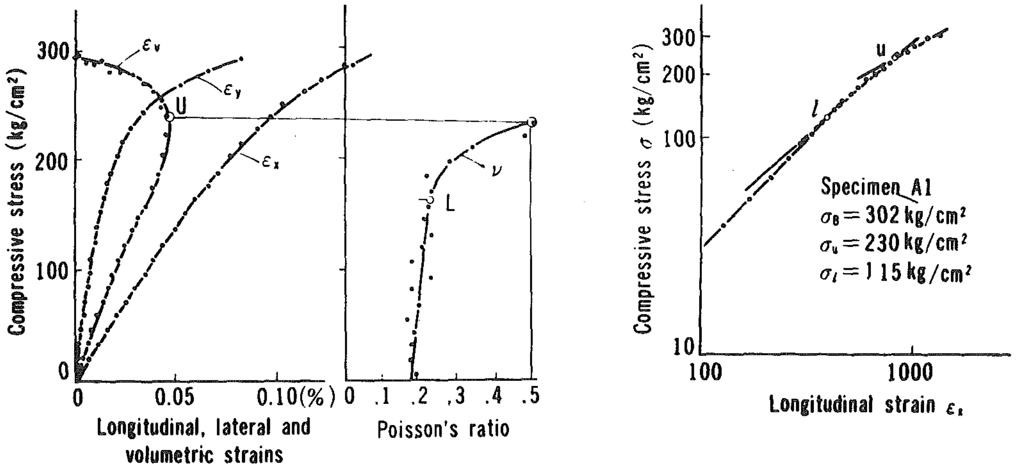


Fig. 6 Typical critical points

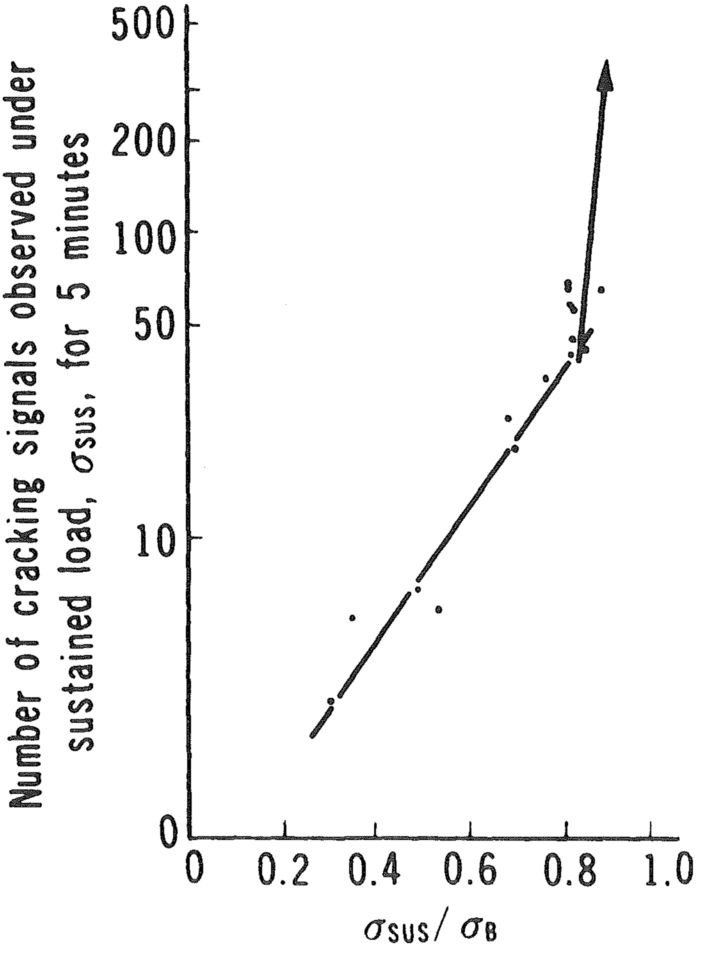


Fig. 7 Number of cracking signals vs. sustained load