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DYNAMIC AND STATIC TESTS OF PLAIN CONCRETE SPECIMENS, REPORT I

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PREFACE

The funds for this investigation were provided by Army Materiel Command for an in-house research and development project to be designated by the Director, U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Miss. The authorization for the project is contained in a memorandum to the Chief, Concrete Division, from the Director, WES, dated 16 November 1962, subject, "New R and D Work - FY 1963."

This work was conducted by the Concrete Division, WES, under the supervision of Mr. T. B. Kennedy, Chief. Staff members actively concerned with the investigation included Messrs. James M. Polatty, W. O. Tynes, K. L. Saucier, and Pfc. R. L. Lundeen. The investigation was under the direct supervision of Pfc. Lundeen who also prepared this report with assistance in analysis of data from Mr. Saucier.

Director of the WES during the conduct of this investigation and preparation and publication of this report was Col. Alex G. Sutton, Jr., CE. Technical Director was Mr. J. B. Tiffany.

CONTENTS

	Page
PREFACE	iii
SUMMARY	vii
PART I: INTRODUCTION	1
Background	1
Purpose and Scope of Investigation	1
PART II: MATERIALS, MIXTURES, AND TEST SPECIMENS	3
Materials	3
Mixtures	3
Test Specimens	3
Strain Gages	4
PART III: TEST METHODS, APPARATUS, AND PROCEDURES	5
Static Tests	5
Dynamic Tests	7
PART IV: RESULTS	11
Compression Tests	11
Tensile-Splitting Tests	12
Flexure Tests	12
Test Methods	14
PART V: SUMMARY OF RESULTS	15
REFERENCES	16
TABLES 1-5	
PLATES 1-5	
APPENDIX A: METHOD OF TEST FOR STRENGTH OF CYLINDRICAL CONCRETE SPECIMENS LOADED AXIALLY BY IMPACT	A1
APPENDIX B: METHOD OF TEST FOR STRENGTH OF CYLINDRICAL CONCRETE SPECIMENS LOADED DIAMETRALLY BY IMPACT	B1

SUMMARY

The effect of the rate of application of load on the compressive, tensile-splitting, and flexural strengths of specimens from three concrete mixtures having static compressive strengths of approximately 2000, 3000, and 4000 psi, respectively, was investigated. The test specimens were cast as 1-1/2- by 3-in. cylinders, 3- by 6-in. cylinders, and 6- by 6- by 20-in. beams, which were tested in compression, tensile splitting, and flexure, respectively. Dynamic loading of the specimens was accomplished with the rapid-loading MIT-WES gas-operated impact machine. Resistance-wire strain gages were bonded to the concrete specimens used in the compressive and tensile-splitting tests to obtain stress-strain relations. Static tests were made on a hydraulic testing machine.

The compressive, tensile-splitting, and flexural strengths of the concrete were higher under the high rate of loading than under static loading. For all three strength levels, the ratios of dynamic to static strength were approximately 1.36, 1.74, and 4.37 for compressive, tensile-splitting, and flexural strengths, respectively. The ratios of dynamic to static modulus of elasticity obtained in the tensile-splitting and compression tests varied, but generally could be considered as being 1:1.

Reproducible test methods and procedures were developed for determining the dynamic compressive and tensile-splitting strengths of concrete. These methods are given in Appendices A and B.

DYNAMIC AND STATIC TESTS OF PLAIN CONCRETE SPECIMENS

PART I: INTRODUCTION

Background

1. In the field of dynamic testing of concrete specimens a limited amount of work has been done using slow rate-of-loading equipment. In investigations to date of the effect of rate of loading on the compressive strength and elastic properties of concrete,[1,3,4,7,8*] either a weight released at a height to fall on the specimen or a hydraulic testing machine run at full speed has been used to apply the load. Watstein[7,8] attained a maximum stressing rate of 1 psi per 10^{-7} sec using a dropped weight as compared to a rate of 1 psi per 0.5×10^{-7} sec attained in compression testing at the Waterways Experiment Station. This investigation was conducted utilizing a gas-operated impact-hammer apparatus for the purpose of adding to present knowledge on dynamic testing.

2. The value for dynamic compressive strength of concrete f'_{cd} is usually taken as the static compressive strength f'_c multiplied by 1.3. It is believed that this value was developed in tests in which a loading apparatus having a relatively slow rate of loading was used; thus it may not be valid for rapid loading tests. In addition, there is no standard procedure for dynamic testing such as exists for static testing.

Purpose and Scope of Investigation

3. The purposes of this investigation were (a) to develop reproducible test methods and procedures for testing concrete specimens of different strengths at high rates of loading, and (b) to determine the dynamic-static strength and elastic moduli ratios for the different concrete strengths used.

4. The investigation consisted of laboratory tests in which the

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* Raised numbers refer to similarly numbered items in the list of references at the end of text.

WES-modified MIT high rate-of-loading apparatus was used to investigate the compressive, tensile-splitting, and flexural strengths of concrete specimens under dynamic loading, and a hydraulic testing machine was used for static loading. Stress-strain relations were obtained in the compressive and tensile-splitting tests.

PART II: MATERIALS, MIXTURES, AND TEST SPECIMENS

Materials

5. The materials used in the concrete test specimens consisted of type II portland cement manufactured in Alabama, and crushed-limestone fine and coarse aggregates obtained from Tennessee. The air-entraining admixture used was laboratory-stock, neutralized vinsol resin solution.

Mixtures

6. Three concrete mixtures, designed to produce a low-, a medium-, and a high-strength concrete, were proportioned to have a slump of 1-1/2 in. (±1/2 in.) and an air content of 5.0 percent (±0.5 percent). The maximum-size aggregate used was 3/8 in. The mixture proportions are given in table 1. The concrete was mixed in a tilting-drum mixer of 16-cu-ft capacity. Water, coarse aggregate, cement, and fine aggregate were added in that order in the mixer. The concrete was mixed for 2 min, allowed to rest for 3 min, and remixed for 1 min.

Test Specimens

7. Three rounds of each of the three mixtures (low, medium, and high strength) were cast. From each round, 15 of each of the following three types of specimens were cast, twelve for dynamic testing and three for static testing for comparison. The small size of the compression-test specimens was dictated by the limited capacity of the dynamic testing machine.

a. 1-1/2- by 3-in. cylinders for compression tests.

b. 3- by 6-in. cylinders for tensile-splitting tests.

c. 6- by 6- by 20-in. beams for flexural-strength tests.

8. The specimens were consolidated in the molds. The consolidation times used were 5 sec for the 1-1/2- by 3-in. cylinders, and 10 sec for the 3- by 6-in. cylinders using a vibration table (external vibration) with a frequency of 3600 vibrations per min. The 6- by 6- by 20-in. beams were

vibrated internally for 25 sec with a portable, 1-1/2-in.-diameter, flexible-shaft vibrator with a frequency of 6000 vibrations per min.

9. The concrete specimens were moist-cured for 21 days. On the 22d day, the 6- by 6- by 20-in. beams were sawed to a true 20 in.; the ends of the 3- by 6-in. cylinders were sawed smooth to facilitate the applying of strain gages; and the 1-1/2- by 3-in. cylinders were capped with hydrostone on the cast end to obtain a plain surface. The specimens were air-dried for the remainder of the time until tested at 28 days age. In preparation for the strain gages, the surfaces of the concrete cylinders were lightly roughened with fine sandpaper and cleaned with methyl ethyl ketone. Voids in the concrete in the areas where the gages would be attached were filled with hydrostone.

Strain Gages

10. Two SR-4 strain gages were mounted diametrically opposite each other on each compression specimen, and longitudinally opposed to each other on each tensile-splitting specimen. The strain gages had thin paper backs, were mounted on the specimens with a nitrocellulose glue, and wired in series. Each gage was 13/16 of an inch long. The gages had a resistance of 120 ohms (240 ohms when wired in series), and a gage factor of 2.05.

PART III: TEST METHODS, APPARATUS, AND PROCEDURES

Static Tests

Compression

11. Electrical resistance strain gages were used in all static compression tests to provide an indication of the stress-strain relation. A manually operated strain indicator was used to record strain measurements. The specimens were tested in a 30,000-lb Universal testing machine at a rate of approximately 35 psi or 3720 lb per min. Strain readings were taken at load intervals of 750 lb. No attempt was made to obtain the ultimate strain due to the excessive straining rate (readings could not be recorded) near the ultimate strength. A specimen under static test is shown in fig. 1.

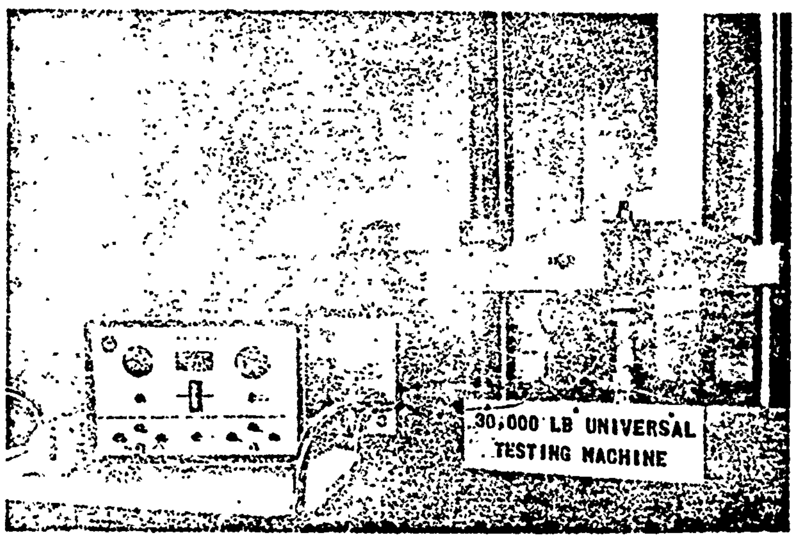

Fig. 1. Static compression test

Tensile splitting*

12. The 3- by 6-in. specimens for tensile splitting were equipped with a pair of gages centered horizontally on the ends of the cylinders. Several positions of gage placement were tried before this position was adopted. The gages again were wired in series to obtain the average strain on the specimen. The strain was recorded on a manually operated

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* The testing procedure that has been referred to as "tensile splitting" has been more recently designated "diametral compression" (A. Rudnick, A. R. Hunter, and F. C. Holden, "An analysis of the diametral-compression test," Materials Research and Standards, vol 3, No. 4 (April 1963), pp 283-388).

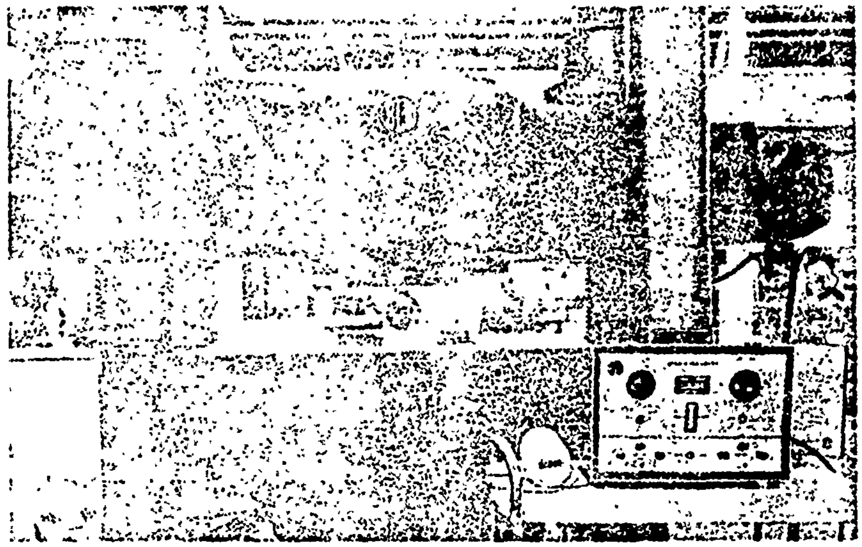

Fig. 2. Static tensile-splitting test

strain indicator with temperature compensating gages wired into a two-arm bridge.

13. The tensile splitting static specimens were tested in a 440,000-lb, Universal hydraulic testing machine according to Test Method CRD-C 77.[6] The specimens were positioned in the testing machine with a 1/8- by 1- by 8-in. piece of plywood placed on the bottom and top of each specimen at the points of contact (see fig. 2). The pieces of plywood were used to eliminate any casting irregularities that might have caused uneven stress distribution on the specimen. The load was applied at a rate of approximately 3 psi per sec or 4250 lb per min. Strain readings were taken at load intervals of 800 lb.

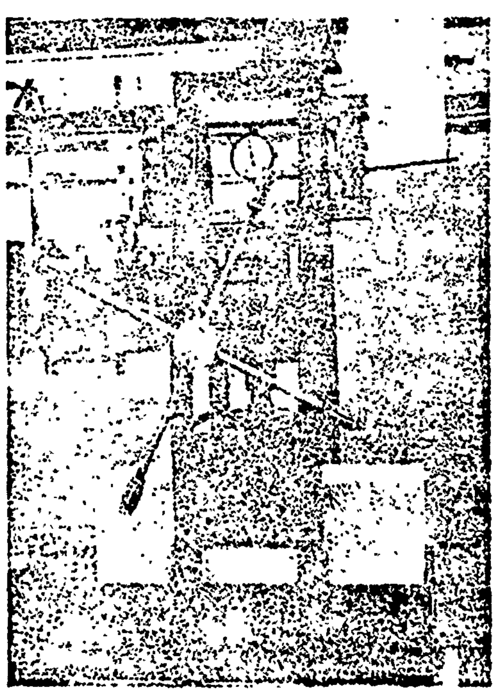

Fig. 3. Static flexure test

Flexure

14. The 6- by 6- by 20-in. beams were tested according to Test Method CRD-C 17-58.[6] The rate of loading was 150 psi or 1200 lb per min. A specimen under static flexural test is shown in fig. 3.

Dynamic Tests

The MIT-WES impact loader

15. Only a brief description of the rapid-loading machine (fig. 4) used for producing dynamic loads will be given in this report. For a more detailed description of the machine the reader is referred to the thesis by Dr. R. J. Hansen.[2]

16. The impact load is produced by a high-pressure, gas-operated, cylinder-piston arrangement. The use of this type of system limits the machine to the production of a single concentrated load. The cylinder-piston arrangement, originally designed to produce a normal working load of 10,000 lb, has been modified to produce a 25,000-lb working load. The stroke of the piston rod in all tests was limited to 1/2 in.

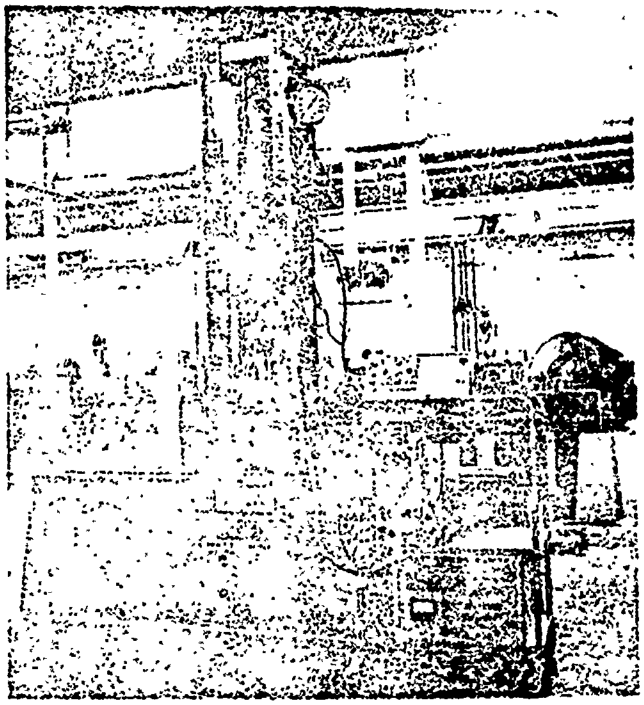

Fig. 4. Impact machine and instrumentation

17. The piston cylinder was made by grinding a standard commercial 4-7/8-in.-ID steel pipe. The original duraluminum piston was replaced with a brass piston. The piston rod was 1 in. in diameter, and was made from neolite steel for additional strength.

18. The piston, piston rod, and load-initiation system were designed so that nitrogen under 1000 psi would drive the piston to the capacity of the machine. Bottled nitrogen was used to provide the required gas pressure as it is a fairly light gas and produces a constant-slope loading pulse which peaked in approximately 1 ms for the tensile-splitting and compression tests. A mechanical trip lever system was used that restrained the piston rod from applying the load to the specimen until it was tripped. The actual tripping operation is initiated by a plunger which pushes the

trip lever at the desired moment by release of a gas-operated solenoid. The load was released by evacuating the gas from the accumulator cylinder above the piston by the use of another solenoid. The total volume of the accumulator cylinder was 982 cu in.

19. The base of the supporting system for the machine and load cell was made heavy and massive to minimize vertical support vibration during testing (see fig. 4).

Instrumentation

20. The instrumentation, also shown in fig. 4, consisted essentially of a 50,000-lb load cell and an oscilloscope modified to provide only one trigger sweep. Initially, an accelerometer was used in conjunction with a load cell to determine the reaction resulting from the impulse applied by the impact machine. The stress-strain relations were recorded on a dual-trace oscilloscope equipped with a camera.

21. The load cell was calibrated statically periodically by loading it with a hydraulic testing machine and relating the corresponding changes in load to the position change of the beam on the oscilloscope. For strain calibration, a known resistance was switched into the strain circuit and the resulting change noted. By use of the gage factor relation the known resistance was equated to a definite value of strain.

Testing procedures

22. The dynamic test specimens were equipped with the same type of strain gages, mounted and wired in the same way as the static specimens. The testing cap attached to the piston rod consisted of a beveled male surface which fitted into the complementary female surfaces of the different testing heads to provide a rotating ball joint. The different heads are shown in fig. 5 along with the center-point loading, flexure apparatus. A rocking bar was employed on one end of the flexure

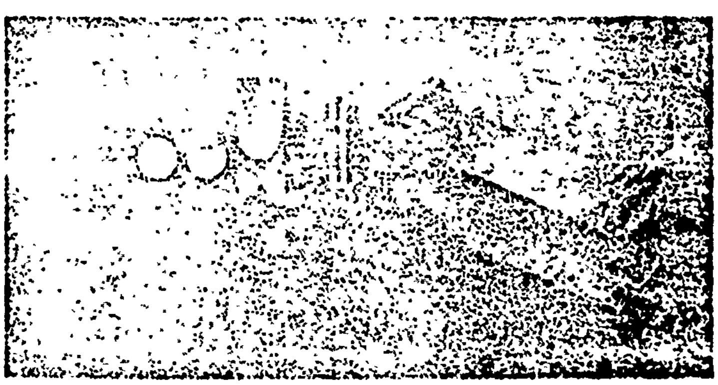

Fig. 5. Testing heads; left to right, testing cap, compression head, tensile-splitting head, flexure head, and flexure apparatus

Fig. 6. Dynamic compression test

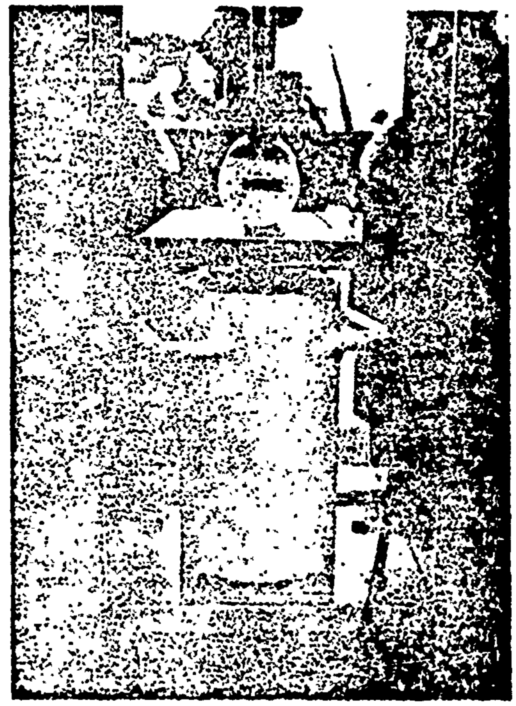

Fig. 7. Dynamic tensile-splitting test

apparatus to compensate for any casting irregularities in the specimens. Dynamic test setups are shown in figs. 6-8.

23. For the test, the trigger of the impact machine was set with a preload of 200 psi. The test specimen was placed on the adjustable plate of the load cell and tightened in place. Next the accumulator pressure was increased to the desired amount. The impact machine was then triggered by the operator, which automatically triggered the single sweep oscilloscope. The camera was tripped by the operator at the same instant the impact loader was triggered.

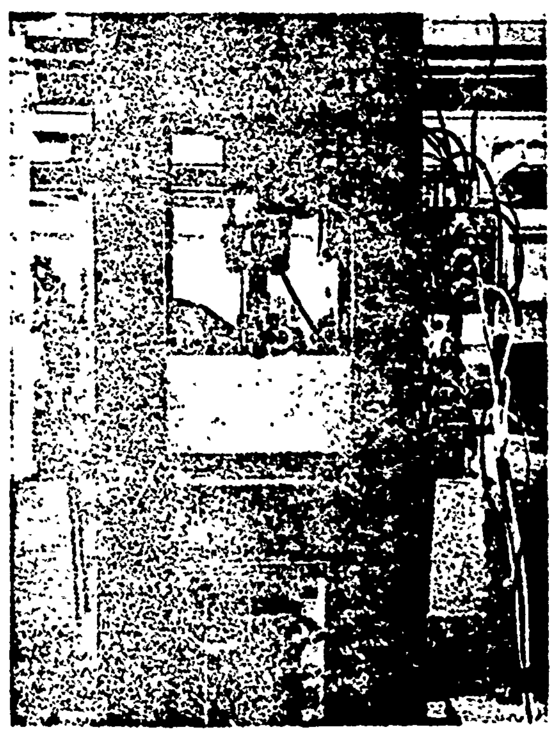

Fig. 8. Dynamic flexure test

Recording and reduction of data

24. The records of the test data were photographed on the screen of the cathode-ray oscilloscope with a 75mm still camera. Typical records of load and strains observed are shown in figs. 9 and 10. Fig. 11 illustrates the recorded load obtained from a flexure specimen. The strain trace is produced by the two strain gages wired in series, and represents the average strain in the specimen. The time base in the photographic records of the oscilloscope was furnished by the oscilloscope grid.

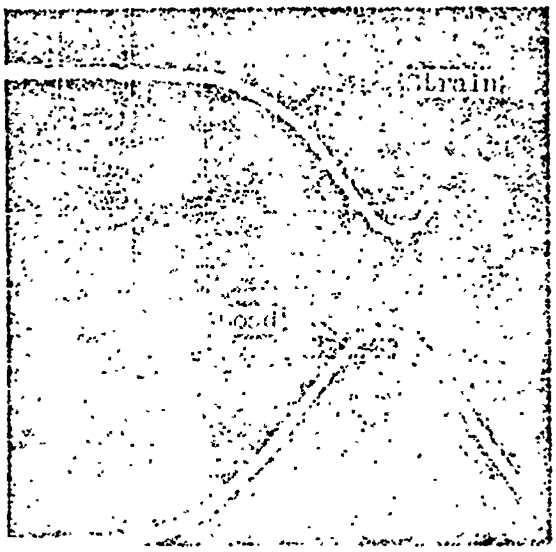

Fig. 9. Dynamic compression-test trace

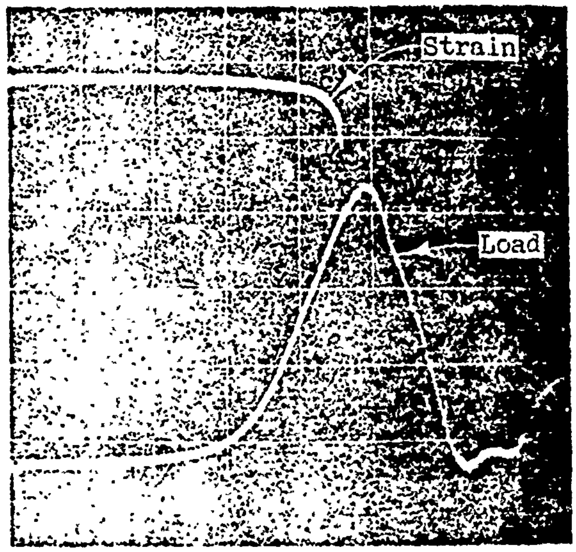

Fig. 10. Dynamic tensile-splitting test trace

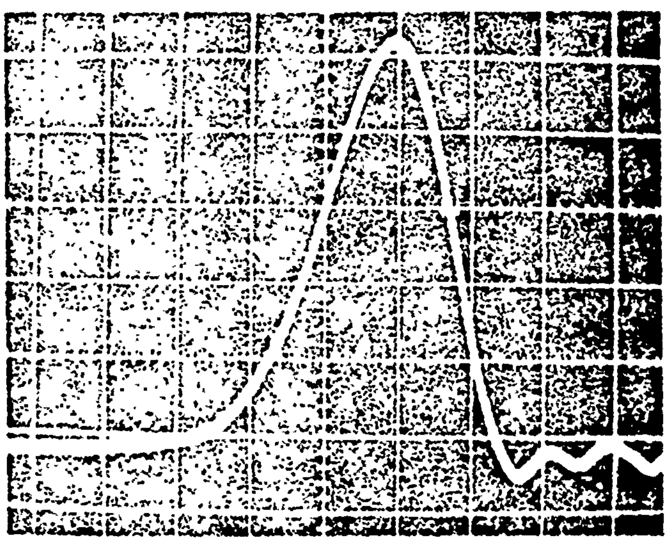

Fig. 11. Dynamic flexure-test load trace

25. The stress-strain data were obtained from the photographs by equating the rise times of the load and strain traces, dividing the two slopes into an equal number of parts with a variable scale, correcting the load to stress, and matching the stress value with the corresponding strain value.

PART IV: RESULTS

Compression Tests

26. The results of the compressive-strength tests on the three strength levels of concrete specimens under static and dynamic loading are given in table 2. Each test value represents the average of three rounds of specimens. The average static compressive strengths were 1960, 2770, and 3920 psi for the low-, medium-, and high-strength mixtures, respectively. The ratios of dynamic to static compressive strengths were 1.37, 1.39, and 1.33, respectively. Table 3 gives the ultimate compressive strength data for each round. Plate 1 shows the relation by round of ultimate static to ultimate dynamic compressive strength. The average load rise time was approximately 0.90 ms for all strength levels.

27. Composite stress-strain curves, both static and dynamic, for each of the three concretes are shown in plate 2. The modulus of the concrete is given as the slope of the secant drawn from the origin to a point on the curve corresponding to a value of 1000 μin. per in. of strain. Use of the secant modulus of elasticity eliminated possible human judgment in determining the modulus by the initial tangent method. It can be seen that the slope of the linear portion of the dynamic stress-strain curves becomes increasingly steeper than the slope of the static curves as the strength of the concrete increases. This is indicated in the ratios of the dynamic to static moduli, which were 0.86, 1.15, and 1.19 for the low-, medium-, and high-strength concrete mixtures, respectively.

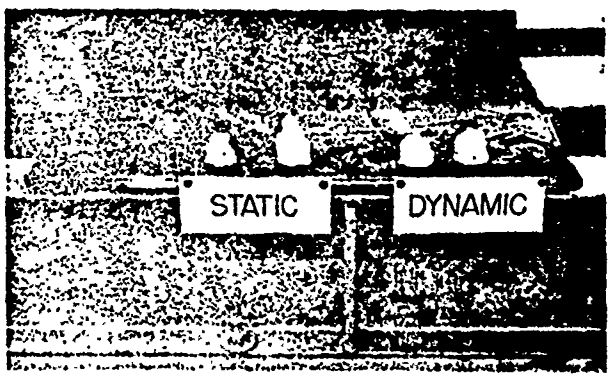

Fig. 12. Static and dynamic specimens after compressive failure

28. There was no significant difference in the manner of failure of the compressive test cylinders in the dynamic and static tests. Fig. 12 shows that both the dynamic and static specimens failed in the characteristic manner of brittle material in a compressive test by developing

cones at the ends which served to split the cylinder.

Tensile-Splitting Tests

29. The average dynamic and static tensile-splitting strengths for the three strength levels are given in table 2. The average static tensile-splitting strengths were 295, 410, and 540 psi for the low-, medium-, and high-strength mixtures, respectively. The ratios of the dynamic to static strength were 1.75 for low, 1.74 for medium, and 1.73 for high strengths, respectively. The average load rise time for all strength levels was about 0.85 ms. The effect of dynamic loading on the tensile-splitting strength of concrete is illustrated in plate 3. Table 4 gives the results of tests of the individual rounds of specimens.

30. The composite stress-strain relations for each strength level are illustrated in plate 4. The curves are identical in pattern with the compressive-strength curves in that the steepness of the slope of the linear portion of the dynamic test curve increases over that of the companion static test curve as concrete strength increases. The moduli of the three strength levels were computed by the secant method using a strain value of 150 μin. per in. The dynamic to static ratios of the moduli for the three strength levels are respectively 0.80, 1.03, and 1.10.

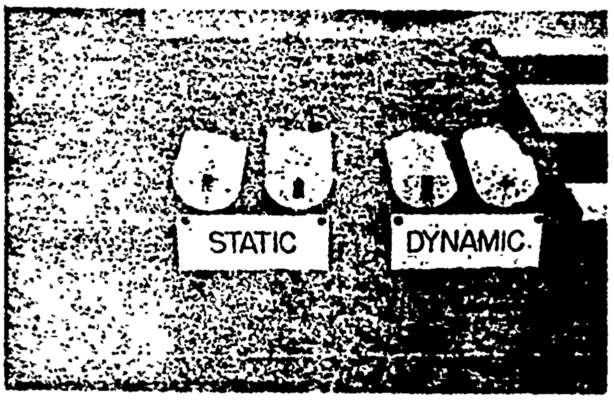

Fig. 13. Static and dynamic specimens after tensile-splitting failure

31. Fig. 13 illustrates the breaks of concrete specimens that underwent static and dynamic tensile-splitting tests. The breaks for both types of loading were clean, even, and passed through the center of the cylinder, all characteristics of a good break.

Flexure Tests

32. Table 5 gives the results of tests on the individual rounds of

the flexural test specimens. Average load rise time for all strength levels was approximately 1.70 ms. The average static flexural strengths, shown in table 2, were 290, 375, and 410 for the low-, medium-, and high-strength levels, respectively, as computed by the following relation:

$$R = \frac{3Pl}{2bd^2}$$

where R = modulus of rupture, psi

P = maximum applied load, lb

l = span length, in.

b = width of specimen, in.

d = depth of specimen, in.

33. As seen in plate 5 and table 2, the dynamic flexural strengths computed from the load cell response by the relation given above were approximately four times greater than the static strengths. It is very doubtful that this is a true value of the relation of static to dynamic flexural strengths. The ratio of dynamic stress to static stress is commonly called the impact factor. The impact factor is dependent on the type of material, the type of loading and, in flexural tests particularly, the type of test apparatus. It has been shown[5] that the impact factor for a suddenly applied load is valid under the following conditions: (a) the proportional limit of the material is not exceeded, and (b) all of the energy supplied by the impacting body is absorbed in stressing the beam. Neither of these conditions existed in these tests. Also, the energy supplied by the machine was surely affected by the test apparatus before the load reaction was recorded on the load cell. Apparently the ratio developed for the flexural strengths was influenced by the aforementioned factors. To obtain valid results from flexural tests of plain concrete beams, a revised test apparatus should be used which has a rigid base and load cells that will measure each reaction individually. Fig. 14 shows the static and dynamic specimens after flexure failure.

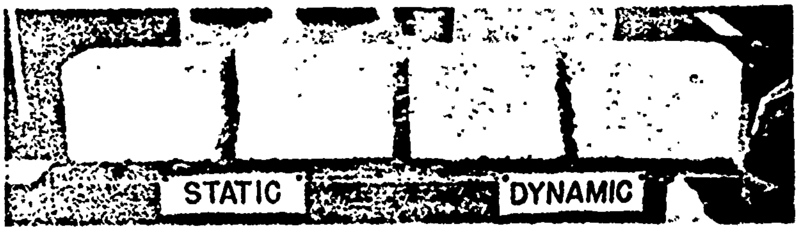

Fig. 14. Static and dynamic specimens after failure in flexure

The breaks shown are characteristic of those encountered throughout the testing.

Test Methods

34. Reproducible test methods and procedures for determining the compressive and tensile-splitting strengths of concrete dynamically were developed and are given in Appendices A and B. Due to the erroneous value attained for the relation of static to dynamic flexural strengths, no test procedures were developed for determining the dynamic flexural strength of concrete.

PART V: SUMMARY OF RESULTS

35. The following results were derived from the tests conducted in this investigation:

a. Compressive strength of specimens of each strength level was higher under the high rate of loading than under the static loading. For all strength levels an average ratio of dynamic to static strengths of 1.36 was obtained.

b. The dynamic tensile-splitting strength of the specimens of each strength level was greater than the static strength; an average ratio of dynamic to static strength of 1.74 was obtained for all strength levels.

c. For all strength levels, the modulus of rupture of the flexure specimens increased by an average ratio of dynamic to static strength of 4.37. However, this value contains several indeterminate factors, and should be considered valid only for the test apparatus used in these tests.

d. The ratio of secant modulus of elasticity of dynamic to static strength from compressive and tensile-splitting specimens increased as strength increased. Values obtained ranged from 0.86 to 1.19 for compressive, and from 0.80 to 1.10 for tensile-splitting strength.

e. Reproducible test methods for determining the compressive and tensile-splitting strengths of concrete dynamically were developed.

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Table 1

Mixture Proportions for Test Concretes

Specimen	Actual Slump in.	Fine Aggregate: Total Aggregate % by vol	Air Content %	Cement Factor bags/cu yd Theoretical	Cement Factor bags/cu yd Actual	Water:Cement Ratio by Weight
			Low-Strength Concrete			
L-1	1-1/2	51	4.9	3.50	3.33	0.95
L-2	1-1/2	51	5.0	3.50	3.33	0.95
L-3	1-1/2	51	5.5	3.50	3.35	0.95
			Medium-Strength Concrete			
M-1	1-1/2	50	5.0	4.00	3.81	0.82
M-2	1-1/2	50	4.5	4.00	3.79	0.82
M-3	1-1/2	50	5.0	4.00	3.81	0.82
			High-Strength Concrete			
H-1	1-1/2	49	4.7	4.50	4.27	0.70
H-2	1-1/2	49	4.7	4.50	4.27	0.70
H-3	1-1/2	49	5.0	4.50	4.28	0.70

Table 2

Summary of Test Results

Test	Low Strength	Medium Strength	High Strength
Compressive strength, psi			
Dynamic (f'_{cd})	2680	3860	5210
Static (f'_c)	1960	2770	3920
f'_{cd}/f'_c	1.37	1.39	1.33
Modulus of elasticity in compression, 10^6 psi			
Dynamic (E_{cd})	1.32	2.33	3.13
Static (E_{cs})	1.53	2.02	2.63
E_{cd}/E_{cs}	0.86	1.15	1.19
Tensile-splitting strength, psi			
Dynamic (f'_{td})	515	715	935
Static (f'_t)	295	410	540
f'_{td}/f'_t	1.75	1.74	1.73
Modulus of elasticity in tensile splitting, 10^6 psi			
Dynamic (E_{td})	1.24	2.00	2.53
Static (E_{ts})	1.55	1.95	2.31
E_{td}/E_{ts}	0.80	1.03	1.10
Modulus of rupture in flexure, psi			
Dynamic (R_d)	1255	1685	1765
Static (R_s)	290	375	410
R_d/R_s	4.33	4.49	4.30

Table 3

Ultimate Compressive Strength Data

Round No.	Static Strength psi*	Static Range psi**	Dynamic Strength psi	Dynamic Range psi	No. Specimens	Avg Rise Time, ms†
L-1	1770	120	2850	440	9	0.77
L-2	2060	230	2790	580	10	0.86
L-3	2040	120	2400	590	12	1.07
M-1	3180	280	4170	880	10	1.02
M-2	2500	250	3190	580	11	0.89
M-3	2630	190	4210	800	10	0.82
H-1	4080	200	4930	1530	11	0.87
H-2	4480	410	5510	1310	10	0.98
H-3	3200	510	5180	1240	9	0.78

* Average of 3 specimens.

** Range is the difference between highest and lowest values recorded.

† Rise time is the time required for the load on the specimen to reach its maximum value from zero load.

Table 4

Tensile-Splitting Test Data

Round No.	Static Strength psi*	Static Range psi	Dynamic Strength psi	Dynamic Range psi	No. Specimens	Avg Rise Time, ms
L-1	290	40	505	120	10	0.85
L-2	280	30	505	185	10	0.75
L-3	315	30	530	65	11	0.98
M-1	415	70	725	100	10	0.80
M-2	375	55	635	110	10	0.86
M-3	435	20	775	115	10	0.98
H-1	555	50	950	245	9	0.92
H-2	520	35	910	160	10	0.84
H-3	535	10	950	330	10	0.72

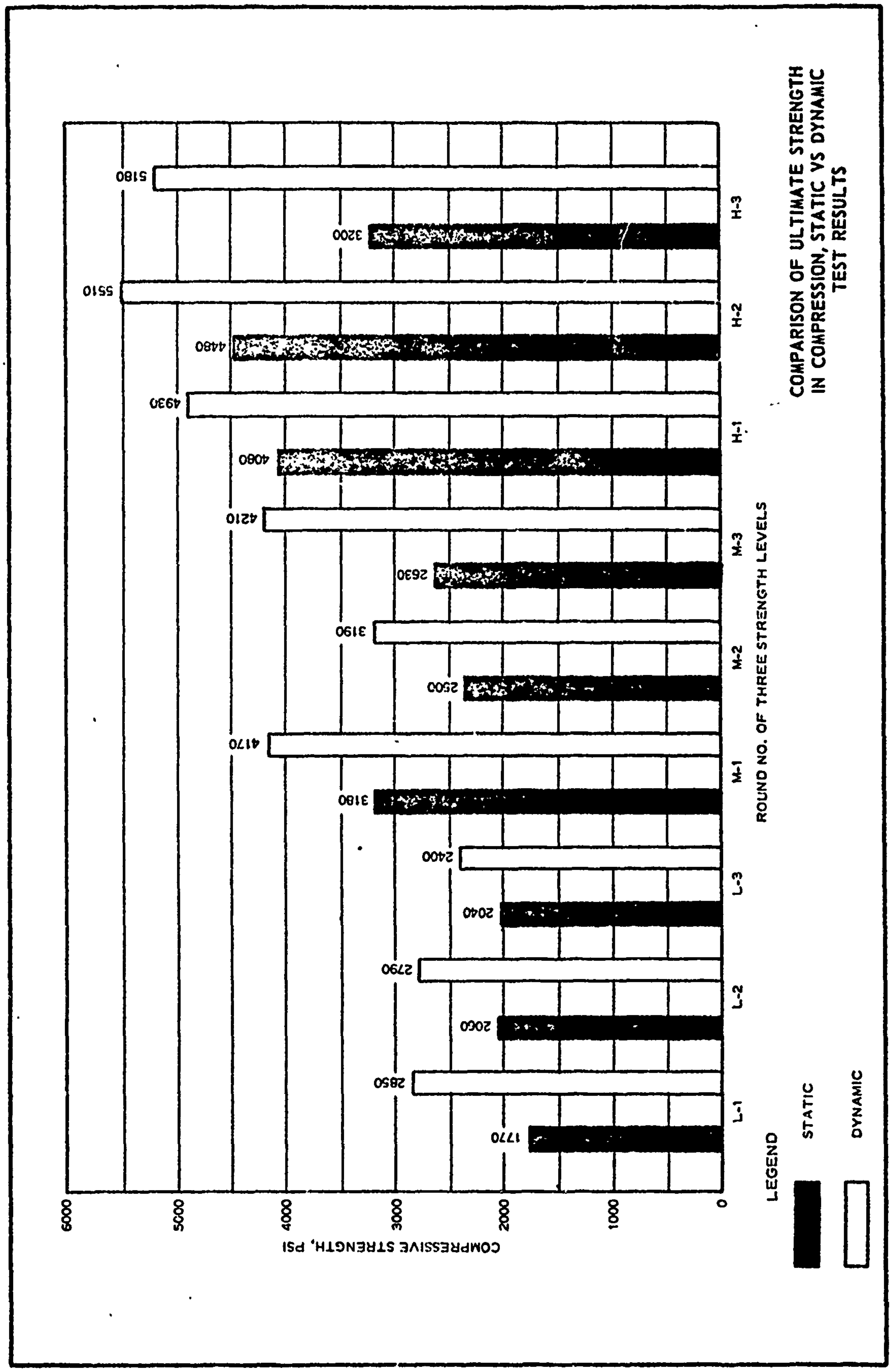
* Average of three tests.

Table 5

Flexural Strength Test Data

Round No.	Static Strength psi*	Static Range psi	Dynamic Strength psi	Dynamic Range psi	Dynamic No. Specimens	Dynamic Avg Rise Time, ms
L-1	285	5	1325	370	10	2.00
L-2	295	25	1270	305	8	1.67
L-3	285	10	1165	305	9	1.89
M-1	365	15	1715	435	11	1.56
M-2	360	25	1740	550	9	1.58
M-3	360	15	1580	655	8	1.54
H-1	435	5	2105	515	10	1.21
H-2	400	15	1800	485	8	1.52
H-3	390	65	1350	215	9	2.25

* Average of three tests.



COMPARISON OF ULTIMATE STRENGTH IN COMPRESSION, STATIC VS DYNAMIC TEST RESULTS

PLATE I

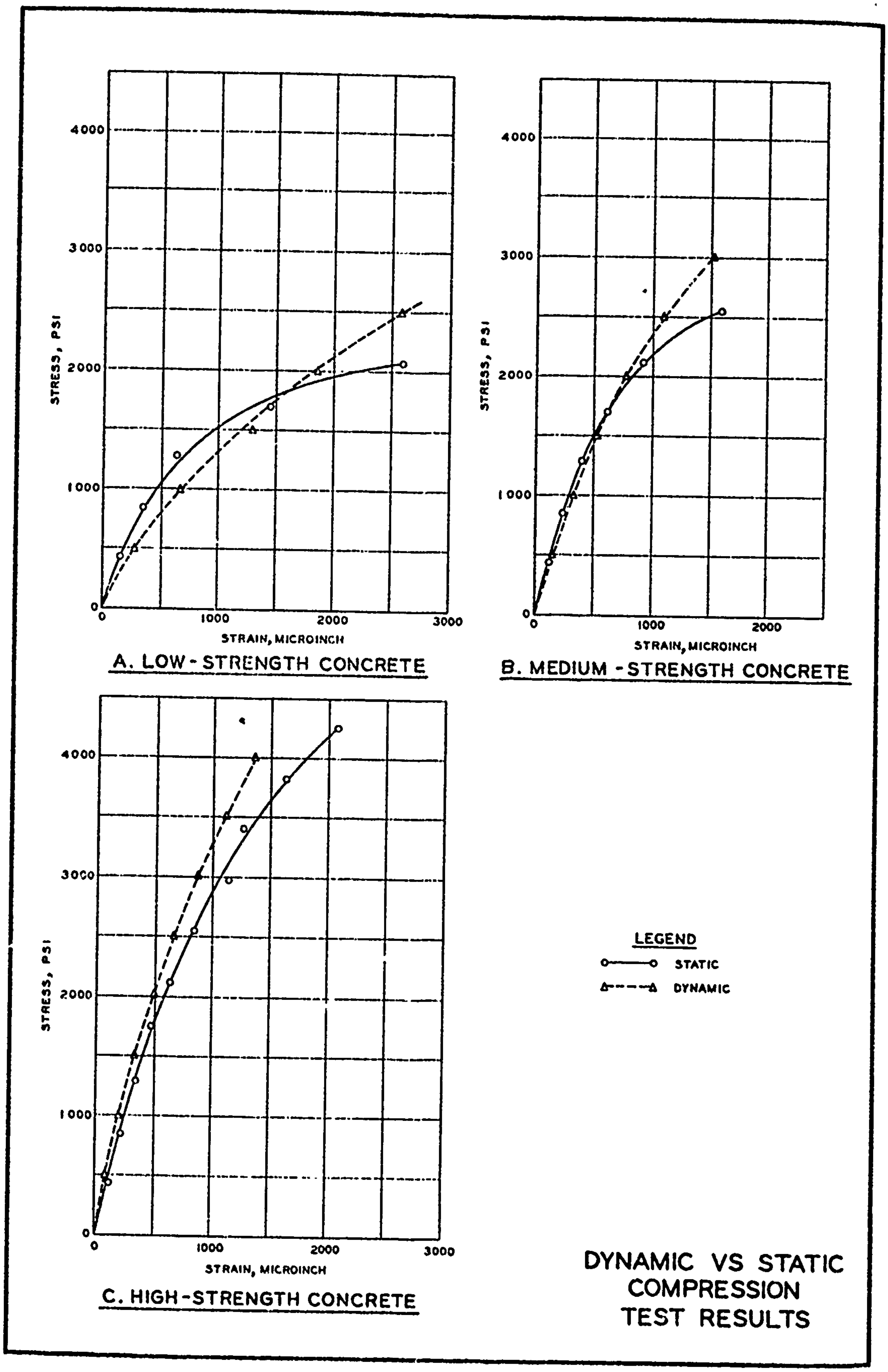
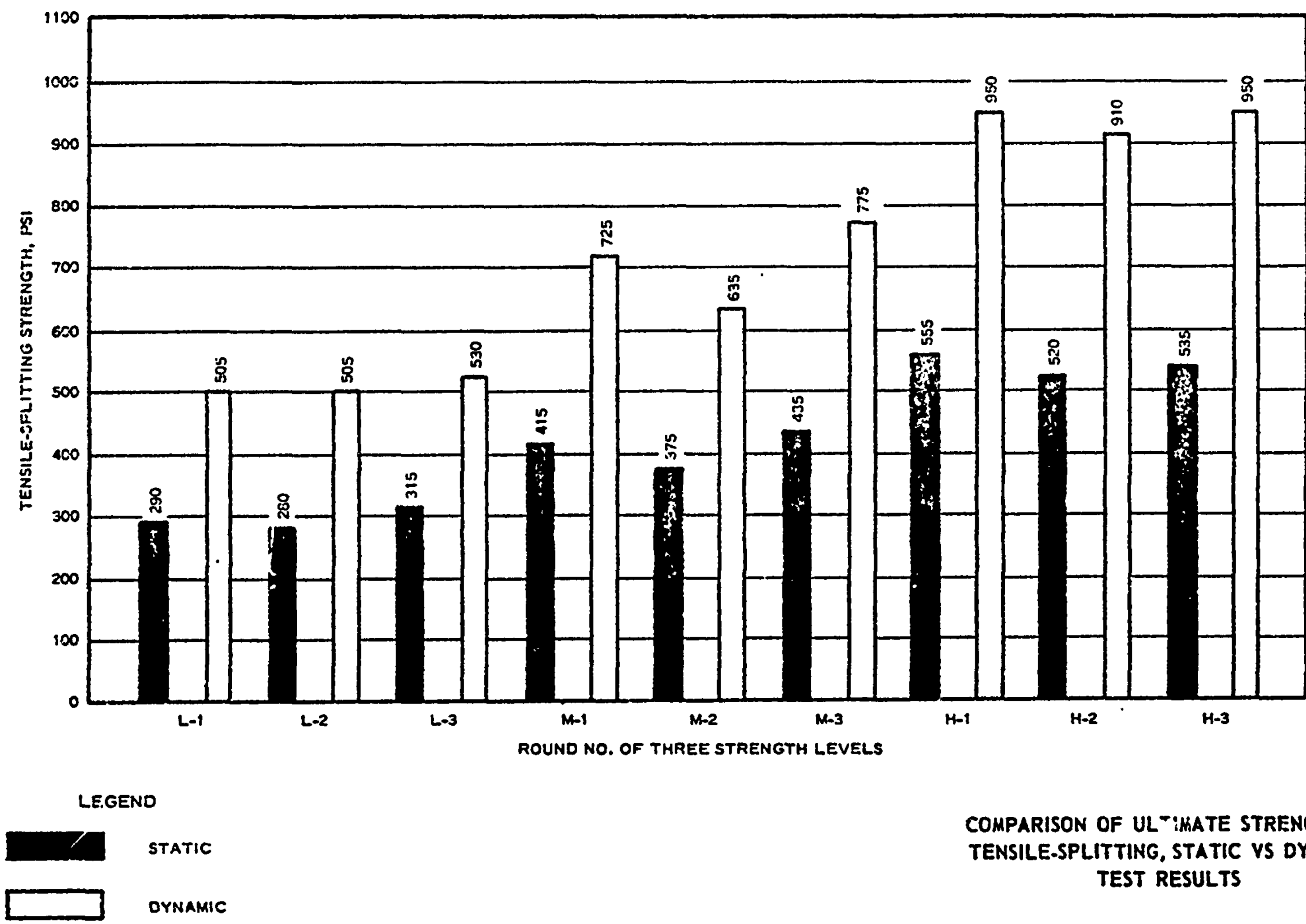
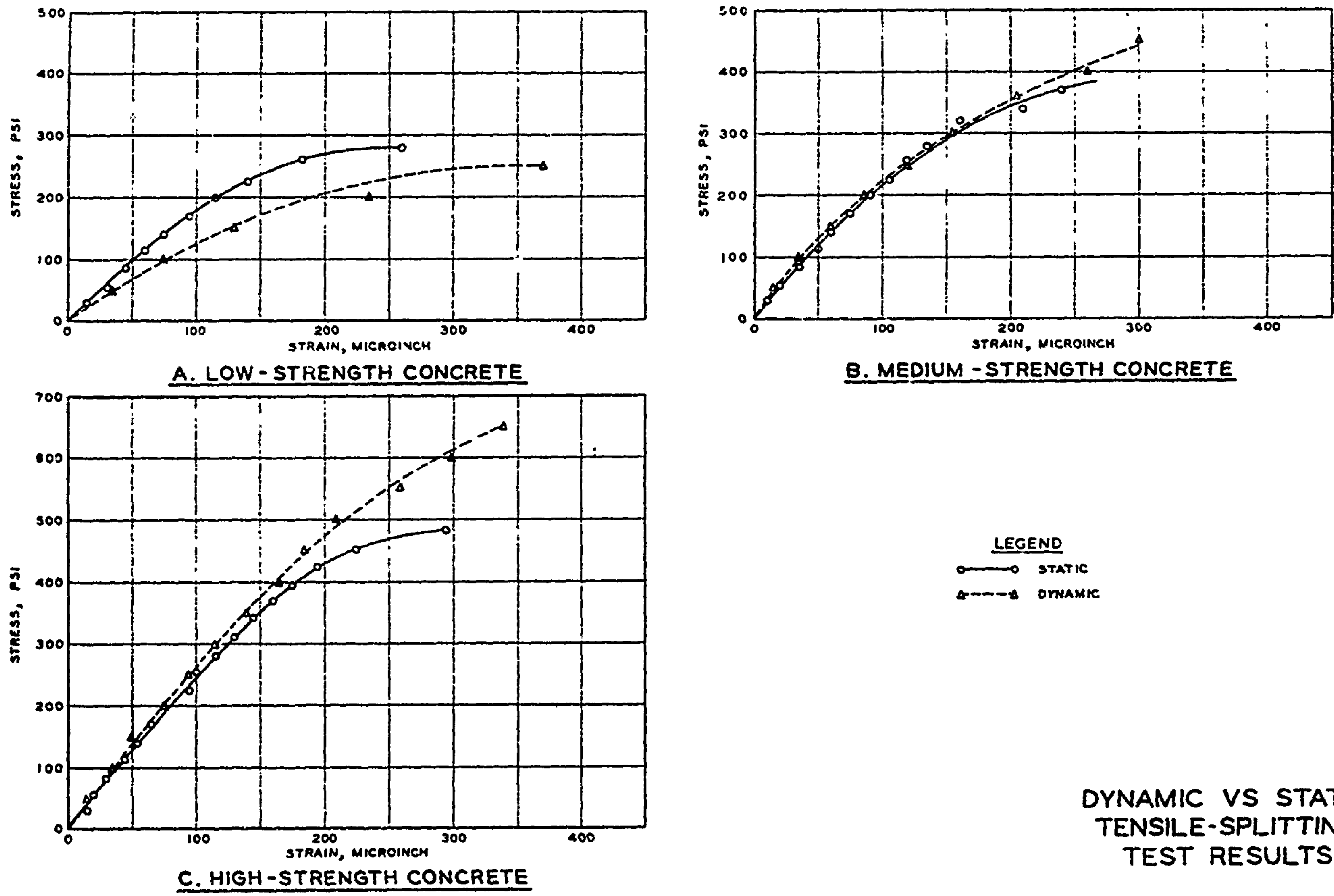

STRESS, PSI
STRAIN, MICROINCH
A. LOW-STRENGTH CONCRETE
B. MEDIUM-STRENGTH CONCRETE
C. HIGH-STRENGTH CONCRETE
LEGEND
STATIC
DYNAMIC
DYNAMIC VS STATIC
COMPRESSION
TEST RESULTS

PLATE 2



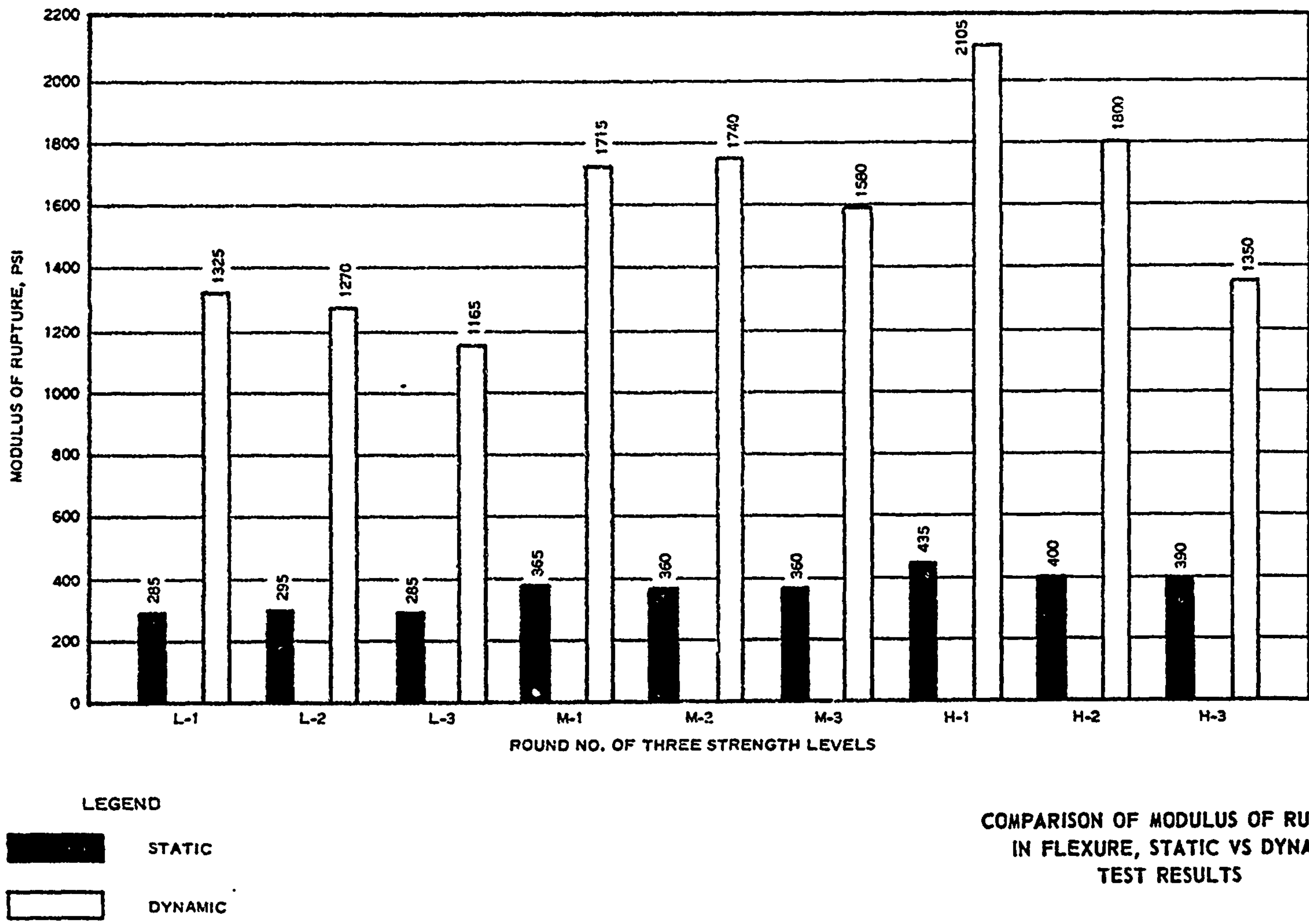
COMPARISON OF ULTIMATE STRENGTH IN TENSILE-SPLITTING, STATIC VS DYNAMIC TEST RESULTS

PLATE 3



DYNAMIC VS STATIC TENSILE-SPLITTING TEST RESULTS

PLATE 4



COMPARISON OF MODULUS OF RUPTURE IN FLEXURE, STATIC VS DYNAMIC TEST RESULTS

APPENDIX A: METHOD OF TEST FOR STRENGTH OF CYLINDRICAL CONCRETE SPECIMENS LOADED AXIALLY BY IMPACT

Scope

1. The method covers the procedures for determining the strength of cylindrical concrete specimens loaded axially by impact.

Apparatus

2. (a) Testing Machine.- The testing machine shall be the WES-MIT rapid-loading impact machine. The machine is equipped with a 50,000-lb load cell, and a testing cap attached to the piston rod consisting of a beveled male surface which is fitted into the complementary female surface of the different testing heads to provide a rotating ball joint. A compression specimen undergoing dynamic testing is shown in Fig. A1. The testing cap and the compressive test head are shown in Fig. A2.

Fig. A1. Compression specimen undergoing dynamic testing

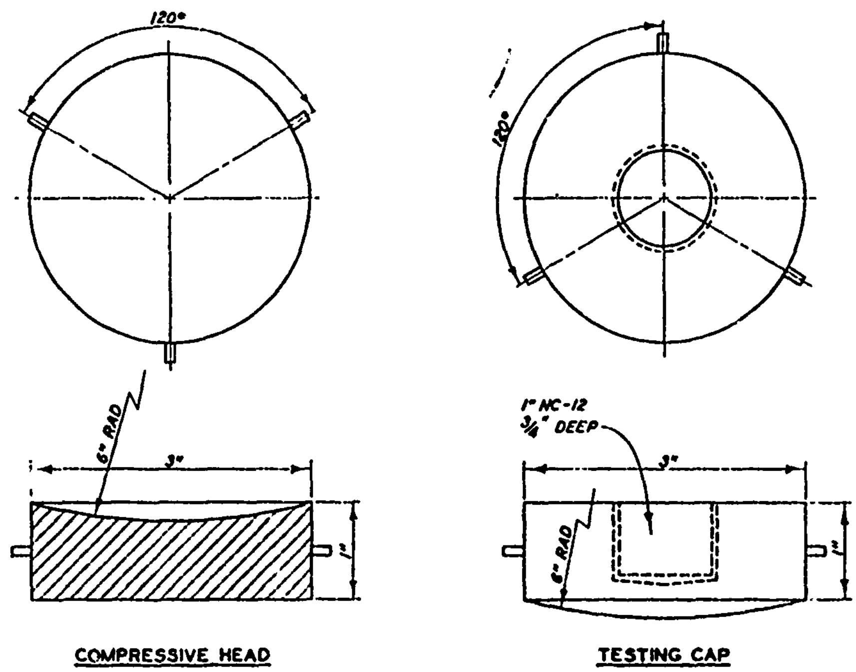


Fig. A2. Sketch of compressive head and testing cap

(b) Recording Equipment.- Recording equipment shall consist of a dual-beam oscilloscope that has been modified to provide a single trigger sweep, on which is mounted a 75mm still camera.

Test Specimen

3. (a) The test specimen shall be cylindrical. Due to the limited capacity of the dynamic testing machine the size of the specimen shall be limited to 1-1/2 by 3 in. Molded cylinders shall be made and stored in accordance with the applicable provision of CRD-C 10, and drilled core specimens shall be taken and moisture-conditioned in accordance with applicable provisions of CRD-C 27. The diameter of the test specimen shall be determined to the nearest 0.01 in. by averaging two diameters measured at right angles to each other at about midheight of the specimen. This average diameter shall be used for calculating the cross-sectional area. The length of the specimen, including caps, shall be measured to the nearest 0.1 in.

(b) Strain Gages.- If stress-strain relations are to be determined, two SR-4 strain gages of type A-3-S6 (nominal length of 1 in.) or equivalent shall be mounted diametrically opposite one another midway between the ends of each compression specimen as illustrated in Fig. A3. The gages shall be wired in series to obtain the average strain on the specimen.

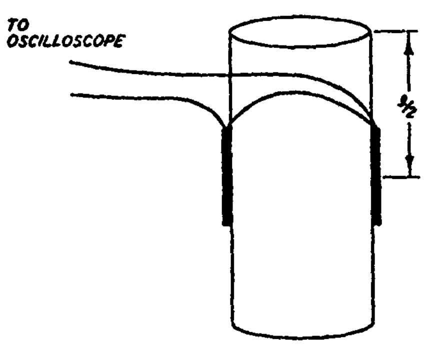


Fig. A3. Position of SR-4 strain gages

Procedure

4. (a) Placing the Specimen.- Place the specimen on the load cell's adjustable bearing plate; carefully align the axis of the specimen with the center of thrust of the beveled, seated compression head.

(b) Application of Load.- First set the trigger on the impact machine; apply a preload of approximately 200 psi to seat the trigger mechanism. Bring the load cell's adjustable bearing plate to bear on the specimen by turning it until tight. As the adjustable plate is brought to bear on the specimen, rotate the movable compression head gently by hand so that uniform seating is obtained. Next increase the accumulator pressure to the required amount to produce failure of the specimen. Then trigger the impact machine, which automatically triggers the single sweep oscilloscope. The camera is tripped at the same instant that the impact loader is triggered. After completion of the test, release the accumulator pressure and reset the trigger mechanism. All tests, the results of which are to be compared, should be conducted using the same accumulator tank pressure.

Calculations

5. The stress-strain data obtained on the photographs are reduced by equating the rise times of the load and strain traces, dividing the two slopes into an equal number of parts with a variable scale, correcting the load to stress, and matching the stress value with the corresponding strain value. The compressive strength of the specimen is determined by dividing the maximum load carried by the specimen during the test by the average cross-sectional area determined as described in Sec. 3; the result is expressed to the nearest 10 psi.

Report

6. The report shall include the following:

(1) Identification number
(2) Diameter, in.
(3) Cross-sectional area, sq in.
(4) Accumulator tank pressure, psi
(5) Load cell scale recorded by oscilloscope, lb per cm
(6) Time scale recorded by oscilloscope, ms per cm
(7) Strain scale recorded by oscilloscope, μin./in. per cm
(8) Type of fracture
(9) Defects in either specimen or caps
(10) Age of specimen

APPENDIX B: METHOD OF TEST FOR STRENGTH OF CYLINDRICAL CONCRETE SPECIMENS LOADED DIAMETRALLY BY IMPACT

Scope

1. The method covers the procedure for determining the strength of cylindrical concrete specimens loaded diametrally by impact.

Apparatus

2. (a) Testing Machine.- The testing machine shall be the WES-MIT rapid-loading impact machine. The machine is equipped with a 50,000-lb load cell, and a testing cap attached to the piston rod consisting of a beveled male surface which is fitted into the complementary female surface of the different testing heads to provide a rotating ball joint. A tensile-splitting specimen undergoing dynamic testing is shown in Fig. B1. The testing cap and the tensile-splitting test head are shown in Fig. B2.

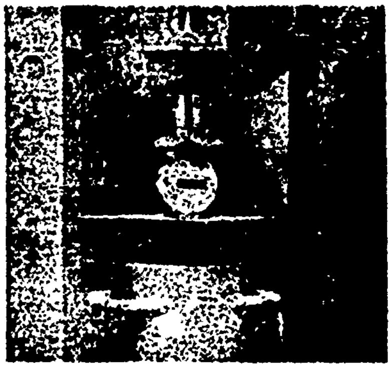


Fig. B1. Tensile-splitting specimen undergoing dynamic testing

(b) Recording Equipment.- Recording equipment shall consist of a dual-beam oscilloscope that has been modified to provide a single trigger sweep, on which is mounted a 75mm still camera.

(c) Bearing Strips.- Strips of nominal 1/8-in.-thick, hand-tempered pressed wood approximately 1 in. in width and of a length slightly greater than the length of the specimen shall be provided for placing between the specimen and load cell's adjustable plate on the bottom, and between the specimen and tensile-splitting head on the top.

Test Specimen

3. (a) The test specimen shall be cylindrical. The ratio of length to diameter shall be 2 whenever possible, but in no case shall the ratio be less than 1 or greater than 2. Molded cylinders shall be made and stored in accordance with the applicable provision of CRD-C 10, and drilled cores shall be taken and moisture-conditioned in accordance with applicable provisions of CRD-C 27. Specimens shall have a diameter not greater than 3 in. due to the capacity of the machine.

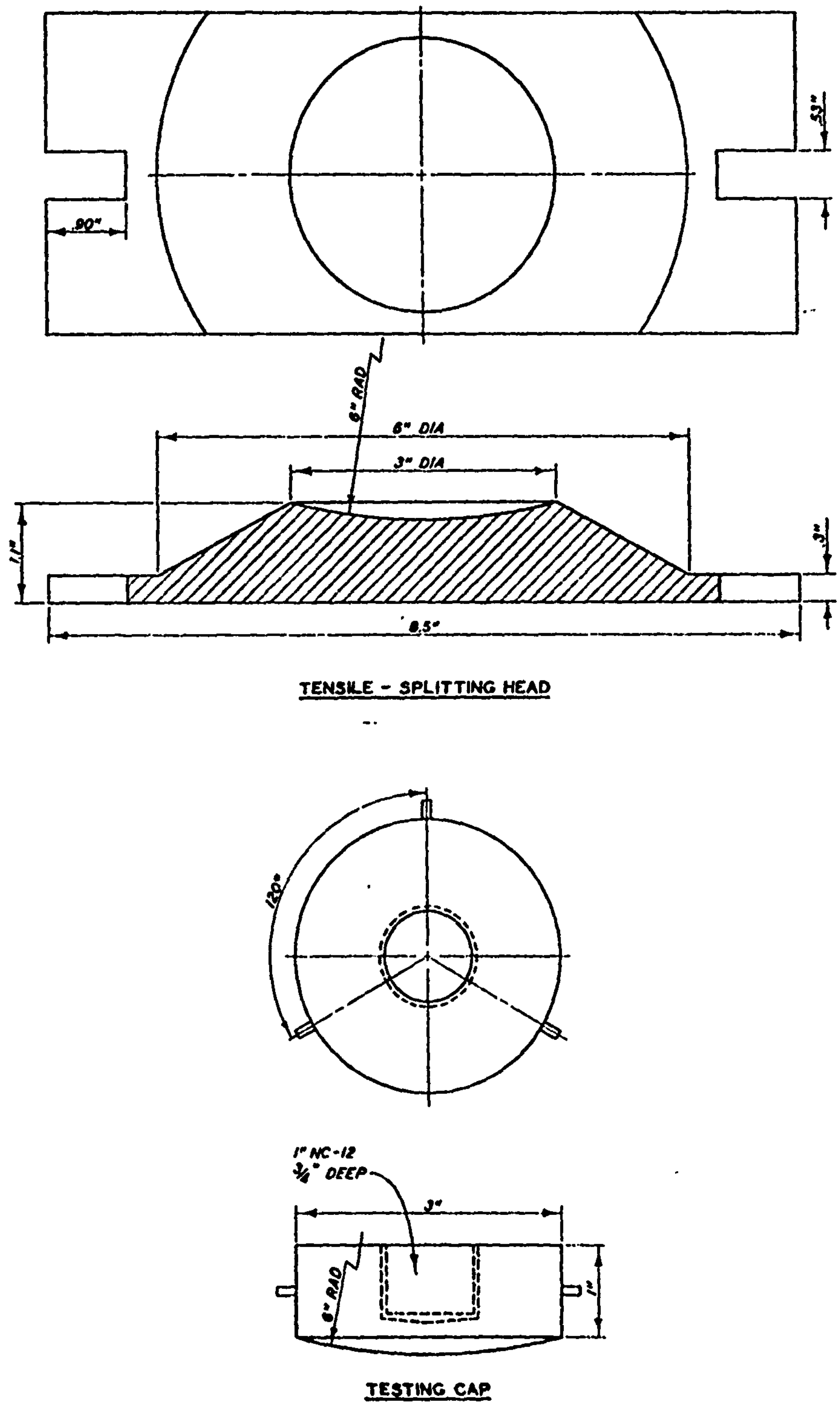


Fig. B2. Sketch showing tensile-splitting head and testing cap

(b) The line of contact between the specimen and each bearing strip shall be straight and free of any projections or depressions higher or deeper than 0.01 in. When the line of contact is not straight or contains projections or depressions having heights or depths greater than 0.01 in., the specimen shall be ground or capped so as to produce bearing lines meeting these requirements. When capping is employed, the caps shall be as thin as practicable and shall be formed of high-strength gypsum plaster, and a capping device as shown in CRD-C 77 for tensile splitting shall be used.

(c) Strain Gages.- If stress-strain relations are to be determined, two SR-4 strain gages of type A-3-S6 (nominal length of 1 in.) or equivalent shall be mounted by centering the gages horizontally on the ends of the cylinder as illustrated in Fig. B3. The gages shall be wired in series to obtain the average strain on the specimen.

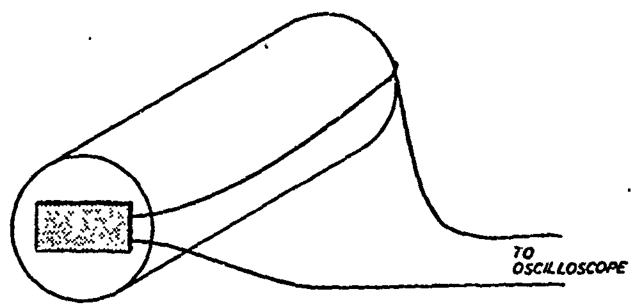


Fig. B3. Sketch showing position of strain gages

Procedure

4. (a) Marking.- Draw a line along the vertical diameter of each end of the specimen. These lines shall be in the axial plane.

(b) Positioning.- Place one of the bearing strips across the center of the load cell plate. Then place the specimen on the bearing strip in such a position that the diametrical lines on the ends of the specimen are vertical and centered over the bearing strips. Place second bearing strip on the upper axial element of the cylinder so that diametrical lines intersect its center. Position the assembly, including the specimen and two bearing strips, so that the projection of the selected axial plane intersects the center of the tensile-splitting head and the center of the specimen is beneath the center of the beveled testing cap (Fig. B1). Bearing strips shall be used in all cases regardless of the methods which may have been used to prepare the bearing lines on the test specimen.

(c) Application of Load.- First set the trigger on the impact machine; apply a preload of approximately 200 psi to seat the trigger mechanism. Bring the load cell's adjustable bearing plate to bear on the specimen by turning it until tight; next increase the accumulator pressure to the required amount to produce failure of the specimen. Then trigger the impact machine which automatically triggers the single sweep oscilloscope. Trip the camera at the same instant that the impact loader is triggered. After completion of the test, release the accumulator pressure and reset the trigger mechanism. All tests, the results of which are to be compared, should be conducted using the same accumulator tank pressure.

Calculations

5. The stress-strain data obtained on the photographs are reduced by equating the rise times of the load and strain traces, dividing the two slopes into an equal number of parts with a variable scale, correcting the load to stress, and matching the stress value with the corresponding strain value. The tensile-splitting strength of the specimen is calculated as follows:

$$T = \frac{2P}{\pi t d}$$

where:

T = tensile splitting strength, psi

P = maximum applied load indicated by the load trace, lb

t = length, in.

d = diameter, in.

The results shall be expressed to the nearest 5 psi.

Report

6. The report shall include the following:

(1) Indentification number

(2) Diameter and length of specimen, in.

(3) Accumulator tank pressure, psi

(4) Load cell scale recorded by oscilloscope, lb per cm

(5) Time scale recorded by oscilloscope, ms per cm

(6) Strain scale recorded by oscilloscope, μin./in. per cm

(7) Type of fracture

(8) Defects in either specimens or caps

(9) Age of specimen