STATE OF OHIO
DEPARTMENT OF HIGHWAYS

RESEARCH REPORT NO. 1

INVESTIGATION OF THE STRENGTH OF THE CONNECTION BETWEEN A CONCRETE CAP AND THE EMBEDDED END OF A STEEL H-PILE

MURRAY D. SHAFFER, DIRECTOR
FRANK M. WILLIAMS, ASSISTANT CHIEF ENGINEER

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ACKNOWLEDGMENT

Thanks is extended to The Ohio State University and especially to Professor J. R. Shank, Assistant Director of the Engineering Experiment Station, for the use of testing equipment located in the Station.

INVESTIGATION OF THE STRENGTH OF THE CONNECTION BETWEEN A CONCRETE CAP AND THE EMBEDDED END OF A STEEL H-PILE

INTRODUCTION

This investigation was begun late in 1945 by the Ohio Department of Highways with the intention of obtaining information on the strength and behavior of the connection between a concrete cap and the embedded end of a steel H-pile when loaded to failure in a manner to cause the pile to be pressed into the concrete. It had been found that there was a lack of factual data on this subject.

Designs had been based on the assumption that an auxiliary bearing device was required at the top, embedded end of a steel H-pile projecting into a concrete cap or footing, to prevent a high compressive stress per square inch in the concrete bearing directly on the surface of the end of the pile. It was customary to fasten a plate or similar device on the end of the pile, usually welded thereto, to increase the contact area. This practice was similar in Ohio and elsewhere.

The Standard Specifications for Highway Bridges (Fourth Edition, 1944) of the American Association of State Highway Officials required that: 'For piles supporting concrete footings, piers or columns, the piles shall be capped with bearing plates not less than 3/4 inch thick except that in cases where the embedment of the pile in the concrete is 5 feet or more, and the transfer of load is effected through bond and direct bearing, the plates may be omitted. The cap plates may be connected to the pile by either welding or riveting. Where dependence is placed on bond and the piles are encased in thin sections of concrete, they shall be enclosed with 1/4 inch round reinforcing steel. The caps shall have two air holes to prevent pocketing of air while concrete is being poured.'

The 1939 Construction and Material Specifications of the Ohio Department of Highways required that: 'Tops of piles encased in concrete shall be provided with steel bearing plates suitably fastened to the piles so as to avoid displacement of the plate and to provide even bearing on the pile. These plates shall be of such size that the bearing on the footing concrete shall not exceed 1000 pounds per square inch.'

The January 1947 Construction and Material Specifications of the Ohio Department of Highways, which were printed after the first two series of these tests had been completed, make no mention of a plate or other auxiliary bearing device since it was contemplated that the type and size of the bearing device would be called for on the plans.

The January 1946 Specifications for Design of Highway Structures of the Ohio Department of Highways limit the stress per square inch in concrete bearing on the surface of the end of a steel H-pile to 1800 pounds per square inch for Class 'C' concrete (6.3 sacks per cu. yd.) and to 1350 for Class 'E' (5.5 sacks per cu. yd.).

The increased values in the 1946 design specifications (as compared with the previous permissible 1000 for either Class 'C' or Class 'E') were selected as a compromise. Several engineers in the Department believed that a much greater value could be used, such as 2500, and that such a greater value would be conservative since the contact concrete which is subject to high compression is in a confined position (surrounded by concrete not subjected to direct compression) and not at or near the edge of the concrete member as in a conventional test cylinder or as the compression side of a beam. However, since such suggested greater value would have been quite out of line with conventional national practice, it was considered advisable to use lesser increased values in the new design specifications, the preparation of the text of which was completed late in 1945. The greater unit stress suggested, such as 2500, would not usually have obviated the need for an auxiliary bearing device but a lesser area would have been permitted to supplement the top area of the H-pile, and the device could have been of a type that would have interfered much less than the bearing plate with the placing of concrete around the top of the pile.

DESCRIPTION OF TESTS

The bearing capacity of concrete caps or footers for steel H-piles or columns, as reported herein, was studied in four series of tests comprising a total of forty-seven specimens. The series are designated by the letter preceding the test specimen number and a brief description of test designs are given in Table No. I. A detailed description of

each test series follows.

SERIES "A"

Specimens:

The test specimens for the 'A' Series, with A-9 the one exception, consisted of 12 inch lengths of 6" x 6" and 10" x 10" H-piles, with both ends milled to a reasonably accurate surface (±0.001"), embedded approximately 6 inches in a cast concrete block 23-1/2 inches square and 18 inches in depth. Test No. A-9 consisted of a free 12 inch length of 6" x 6" H-piling placed in direct bearing against the side of the undamaged concrete block of Test No. A-8. The 6" x 6" H-pile sections were used in all tests of the 'A' Series except Test No. A-6 where the 10" x 10" H-pile section was used.

Class 'C' concrete (6.3 sacks per cu. yd.) was used in Specimens Nos. A-1 through A-6 inclusive, and Class 'E' concrete (5.5 sacks per cu. yd.) was used in Specimens Nos. A-7 through A-9 inclusive. The sides of the H-pile sections used in Specimens Nos. A-4 and A-5 were greased to reduce the effect of side bond with the concrete and permit the end bearing strength to be measured independently of the side bond strength. The properties of the concrete used in the 'A' Series are given in Table No. II, entitled 'Summary of Concrete Data'. The design of the individual test specimens are illustrated in detail by Figures 1 through 9 inclusive.

Testing Procedure:

A screw type testing machine of 500,000 pound capacity was used to determine the bearing strength of the H-pile specimens of the 'A' Series. The concrete block base of the specimen was set on the weighing platform of the testing machine in a plaster of paris and portland cement cap, covering the entire bottom surface of the concrete block. The compressive load was applied directly to the top machined end surface of the H-pile section through a spherical head compression plate. The load was applied at the rate of 0.052 inches per minute (compression head movement) until failure of the specimen. An Ames dial, reading in thousandths of an inch, was mounted to record the deformation in the pile head by measuring the movement between the machine head and the weighing platform. Applied load readings were recorded for each 0.010 inch head travel of the machine.

SERIES "B"

Specimens:

A total of four specimens was used in the tests of the 'B' Series. Specimens B-1 and B-2 were designed to test only the bond between the sides of a 10" x 10" H-pile and the concrete, and were recessed 6 inches from the underside of the block to the bottom of the H-pile to eliminate end bearing. Specimens B-3 and B-4 were designed to test the end bearing capacity of a 6" x 6" H-pile embedded 9 inches in a plain concrete block 18 inches in depth. The sides of the H-piles were coated with paraffin to eliminate side bond with the concrete.

The specimens of this series were made from Class 'C' concrete (6.3 sacks per cu. yd.), and the properties of the concrete used are given in Table No. II. The design of the individual test specimens are illustrated by Figures 10 and 11.

Testing Procedure:

The specimens were tested in the same machine and at the same load rate as for the 'A' Series. The specimens of this series were supported on the entire bottom edges by a soft wood square frame, 1-1/2 inches thick and 3 inches wide on all sides. The deformations recorded represent the average of two Ames dials, reading to thousandths of an inch, one on each side of the protruding H-pile section and located so as to measure the distance between the traveling head of the testing machine and the top surface of the concrete block. This eliminated the deformation due to the crushing of the wood frame bearing support base.

SERIES "C"

Specimens:

This series of tests comprising a total of twenty-two test specimens were all made from Class 'E' concrete (5.5 sacks per cu. yd.). All H-pile sections employed in this series were 10" x 10" at 49 lbs., and all concrete blocks were 33 inches square. The H-pile sections were suspended in the concrete form by steel clamps supported on the sides of the forms. These clamps were not released until the concrete had completely set (24 hours). The depth of the concrete heads in this series vary from 6 inches to 24 inches, and the embedment of the H-pile sections

varied from 6 inches to 18 inches and such embedment represented from 25 per cent to 100 per cent of the total depth of the concrete head.

Specimens C-5 and C-6 were reinforced with three circular hoops of 3/4 inch round deformed steel bars, and Specimens C-7 and C-8 had a 3/4 inch plate welded to the embedded end of the H-pile to increase the end area in direct bearing against the concrete. All specimens except C-5 and C-6 were plain concrete. Specific test design details applicable to each pair of specimens (consecutive odd and even numbers) are given in Figures 12 through 22 inclusive. The concrete data and method of curing the specimens are given in Table No. II.

Testing Procedure:

A screw type testing machine of 1,000,000 pound capacity was used to determine the bearing strength of all the H-pile specimens of the 'C' Series. Specimens C-1 through C-20 inclusive, were supported on all of the bottom edges by a square steel frame, 1 inch thick (solid) and 2 inches wide, bolted to the weighing platform of the testing machine. The four-edge base support frame is illustrated in Plate 1. Two of the same size edge support bars were placed parallel to the H-pile web in such a manner as to provide support for the concrete block on two opposite sides of the bottom surface of Specimens C-21 and C-22. All specimens of the 'C' Series were set on the steel support bars with a mixture of plaster of paris and portland cement caps. The method of aligning and capping the specimens is illustrated by Plate 2.

The test loads were applied at the rate of 0.0315 inches per minute of machine head travel for all tests of the 'C' Series. Deformation was recorded with two Ames dials placed on opposite sides of the H-pile section, as illustrated in Plate 3, and measured the distance between the moving head of the testing machine and the top of the concrete pile head. The average of these two readings was recorded as the deformation of the specimens. On some of the specimens of this series a third Ames dial was placed to measure the distance between the moving head and the weighing platform of the testing machine.

Specimens:

The specimens of the 'D' Series were identical to the specimens of the 'C' Series in regard to the horizontal dimensions of the concrete head, size of H-pile sections, and the class of concrete used. The H-pile sections were embedded 6 inches in the concrete head of all specimens of this series. Specimens D-1 and D-2 were 18 inches in depth and were reinforced with three circular hoops of 3/4 inch round deformed steel bars. Specimens D-3 and D-4 were 18 inches in depth and had the H-pile end bearing area increased by a 3/4 inch plate, but were not reinforced. Specimens D-5 through D-8 inclusive, were 24 inches in depth and were reinforced with a mat of 1 inch round deformed steel bars spaced on 6 inch centers in both directions of the horizontal plane. The latter pair of specimens were also designed with bearing plate across the embedded end of the H-pile. Specimens D-9 through D-12 inclusive, were 30 inch in depth of plain concrete with only D-11 and D-12 having the additional end bearing plate. Specific test design details applicable to each pair of specimens are illustrated in Figures 23 through 28 inclusive.

The specimens of this series were cast in the normal attitude for pile heads (differing from all previous specimens, where the pile sections were suspended from the top edges of the concrete head form). The pile sections were set in the bottom of a wood form having a depth 6 inches greater than the desired depth of the concrete head. The bottom 6 inches was then filled with thoroughly compacted soil which held the pile section in place while the concrete was placed in the remaining depth of the form. The properties of the concrete used are given in Table No. II.

Testing Procedure:

The method of testing the specimens of this series was identical with that of the 'C' Series, with the four-edge support being used on all specimens.

TABLE NO. I
SUMMARY OF SPECIMENS USED IN
INVESTIGATION OF LOAD BEARING CAPACITY OF
CONCRETE HEADS FOR STEEL H-PILES

SPECIMEN NO.	H-PILE SIZE IN INCHES AND LBS /FT.	DEPTH OF CONCRETE, INCHES	DEPTH PILE EMBEDDED, INCHES	BLOCK SIDE DIMENSION, INCHES	CONCRETE REINFORCING
Series A					
A-1	6x6 AT 15.5	18	6	23-1/2	PLAIN (PRELIM. TEST)
A-2	6x6 AT 15.5	18	6-1/2	23-1/2	PLAIN
A-3	6x6 AT 15.5	18	6-1/2	23-1/2	3 SQ. HOOPS (5/8" Ø BARS)
A-4	6x6 AT 15.5	18	6-1/4	23-1/2	PLAIN
A-5	6x6 AT 15.5	18	6-1/4	23-1/2	3 SQ. HOOPS (5/8" Ø BARS)
A-6	10x10 AT 44.0	18	6-1/2	23-1/2	PLAIN
A-7	6x6 AT 15.5	18	6-1/4	23-1/2	PLAIN
A-8	6x6 AT 15.5	18	6-1/2	23-1/2	3 SQ. HOOPS (5/8" Ø BARS)
A-9	6x6 AT 15.5	23-1/2	0	23-1/2x18	3 SQ. HOOPS (5/8" Ø BARS)
Series B					
B-1 & 2	10x10 AT 49.0	12-1/2	6-1/2(100%)	23-1/2	3 SQ. HOOPS (5/8" Ø BARS)
B-3 & 4	6x6 AT 15.5	18	9	23-1/2	PLAIN
Series C					
C-1 & 2	10x10 AT 49.0	12	6	33	PLAIN
C-3 & 4	10x10 AT 49.0	18	6	33	PLAIN
C-5 & 6	10x10 AT 49.0	18	6	33	3 CIRCULAR HOOPS (3/4" Ø BARS)
C-7 & 8	10x10 AT 49.0	18	6	33	PLAIN (PLATE)
C-9 & 10	10x10 AT 49.0	24	6	33	PLAIN
C-11 & 12	10x10 AT 49.0	18	12	33	PLAIN
C-13 & 14	10x10 AT 49.0	24	18	33	PLAIN
C-15 & 16	10x10 AT 49.0	6	6 (100%)	33	PLAIN
C-17 & 18	10x10 AT 49.0	12	12(100%)	33	PLAIN
C-19 & 20	10x10 AT 49.0	18	18(100%)	33	PLAIN
C-21 & 22	10x10 AT 49.0	18	6	33	PLAIN
Series D					
D-1 & 2	10x10 AT 49.0	18	6	33	3 CIRCULAR HOOPS (3/4" Ø BARS)
D-3 & 4	10x10 AT 49.0	18	6	33	PLAIN (PLATE)
D-5 & 6	10x10 AT 49.0	24	6	33	BAR MAT-6" o.c. (1" Ø BARS)
D-7 & 8	10x10 AT 49.0	24	6	33	BAR MAT-6" o.c. (PLATE)
D-9 & 10	10x10 AT 49.0	30	6	33	PLAIN
D-11 & 12	10x10 AT 49.0	30	6	33	PLAIN (PLATE)

TABLE NO. II

SUMMARY OF CONCRETE DATA*

SERIES	SPECIMEN NOS.	CEMENT FACTOR SACKS	SLUMP INCHES	AIR CONTENT %	CYLINDER TEST NO. TESTS	CYLINDER TEST AGE DAYS	CYLINDER TEST COMPRESSIVE STR.LBS./SQ.IN.
A	1	PRELIMINARY TEST					
A	2 TO 6	6.3	3	3.7	1 1	7 31	3320 4435
A	7 TO 9	5.5	3	4.1	1 1	7 29	2855 4850
B	1 TO 4	6.3	3-1/4	4.2	1 1	7 28	3710 5720
C	11, 12, 13, 15, 17, 18, 19, 20	5.5	2-1/4	2.6	2 2	7 28	3025 4225
C	5, 6, 9, 10, 21, 22	5.5	4	3.1	2 2	7 28	2720 3780
C	1, 2, 3, 4, 7, 8, 14, 16	5.5	3-3/4	2.5	2 2	7 28	2495 4075
D	1, 3, 5, 7, 9, 11	5.5	3	2.3	1 1	28 28	3500 3570
D	2, 4, 6, 8, 10, 12	5.5	3	2.8	1 1	28 28	3740 3670

**See General Notes on Concrete Data*

GENERAL NOTES ON CONCRETE DATA

1. TEST CYLINDERS WERE THE STANDARD 6" X 12" COMPRESSION CYLINDER, CURED IN MOIST ROOM FOR 28 DAYS.
2. ALL CEMENT USED IN CONCRETE WAS AIR ENTRAINING - AIR CONTENT OF CONCRETE SHOWN IN PER CENT BY VOLUME.
3. ALL CONCRETE PILE HEADS, EXCEPT A-1, WERE CURED 7 DAYS WITH WET BURLAP AND 21 DAYS IN LABORATORY AIR AT 70° F. SPECIMEN A-1 CURED 3 DAYS WITH WET BURLAP BEFORE TEST.
4. TEST SPECIMEN GROUPS UNDER SPECIMEN NOS. IN TABLE INDICATE ONE BATCH OF CONCRETE.
5. SERIES 'A' & 'B' CONCRETE MIXED IN A ONE-BAG CAPACITY POWER MIXER AT LABORATORY - SERIES 'C' & 'D' MADE FROM FIVE SEPARATE BATCHES OF 'TRANSIT-MIX' CONCRETE.
6. CONCRETE PLACED IN FORMS AND AROUND H-PILE SECTIONS BY HAND SPADING IN SERIES 'A', 'B' AND 'C' AN AIR VIBRATING TOOL WAS USED IN THE 'D' SERIES.
7. ALL CONCRETE WAS MADE USING NATURAL SAND AND GRAVEL. VINSOL RESIN (NEUTRALIZED, DRY) WAS ADDED TO THE MIX IN THE AMOUNT OF 0.01% BY WEIGHT OF CEMENT.
8. CONCRETE CLASSIFICATION IN ACCORDANCE WITH THE OHIO HIGHWAY DEPARTMENT CONSTRUCTION AND MATERIAL SPECIFICATIONS. CLASS 'C' CONCRETE CONSISTS OF APPROXIMATELY 1:5-1/2 VOLUME MIX AND HAS A MINIMUM ULTIMATE COMPRESSIVE STRENGTH OF 4,000 LBS./SQ. IN. AT 28 DAY AGE. CLASS 'E' CONCRETE CONSISTS OF APPROXIMATELY 1:6-1/2. VOLUME MIX, AND HAS A MINIMUM ULTIMATE COMPRESSIVE STRENGTH OF 3,000 LBS./SQ. IN. AT 28 DAY AGE. STRENGTH DETERMINED BY 1. ABOVE.

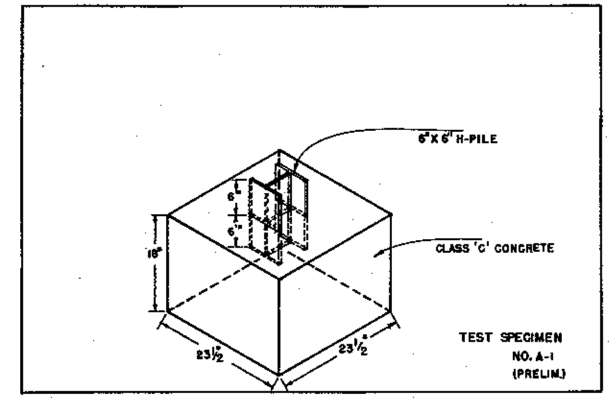


FIGURE 1

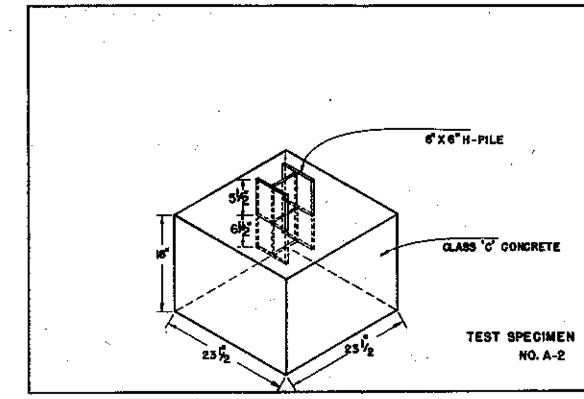
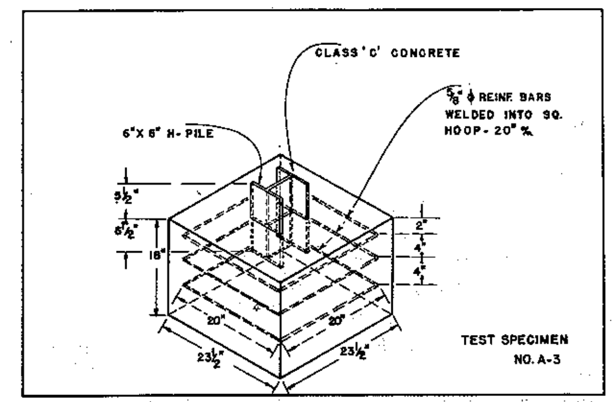


FIGURE 2



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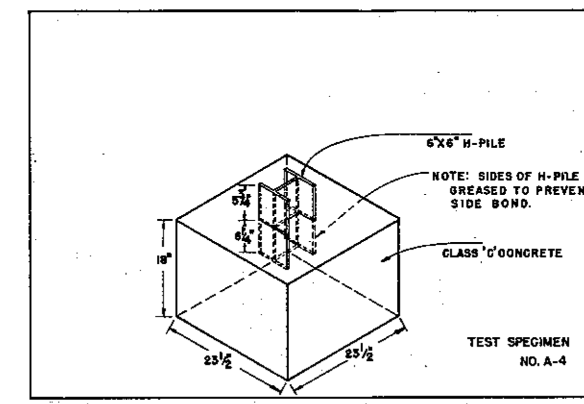

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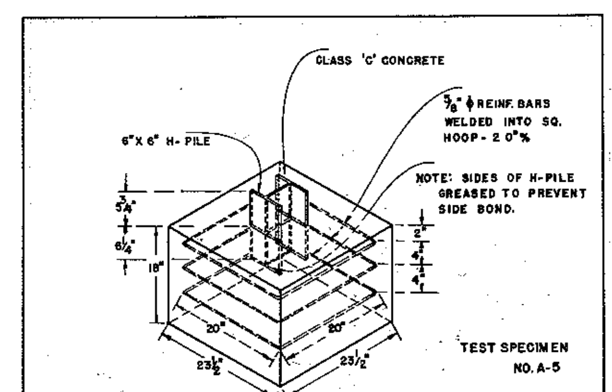

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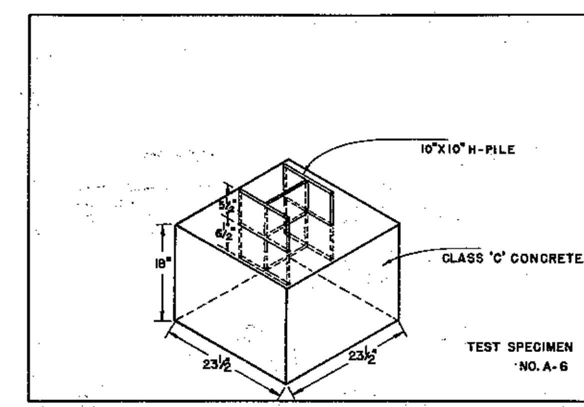

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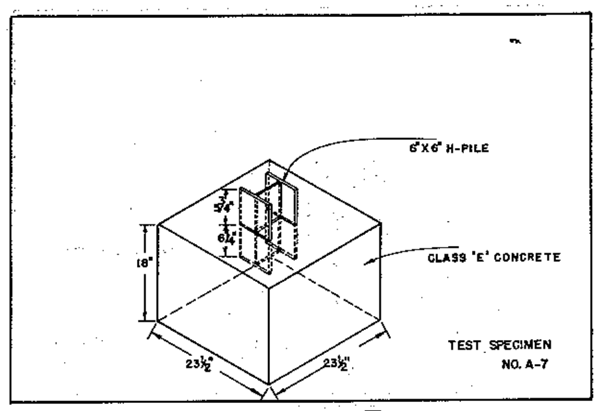

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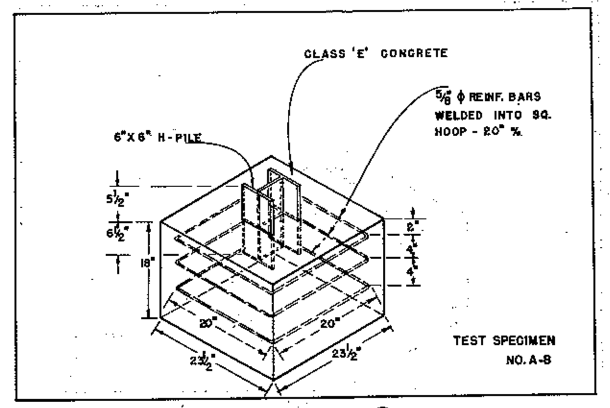

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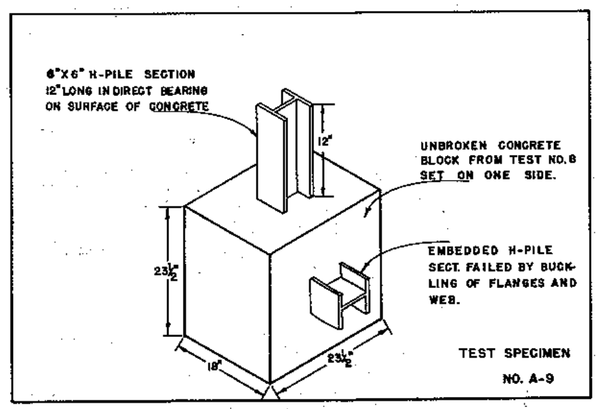

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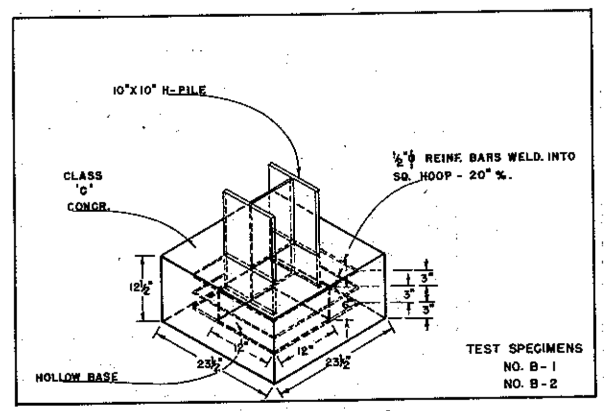

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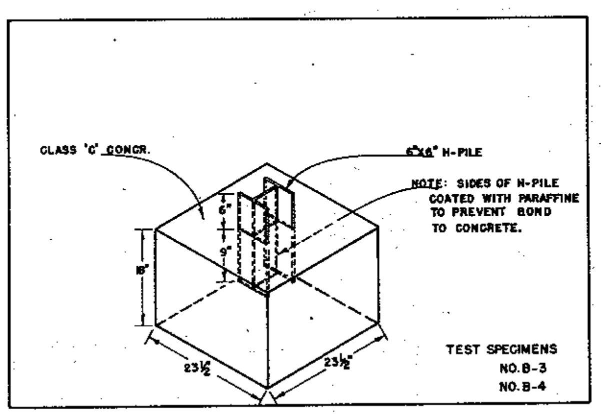

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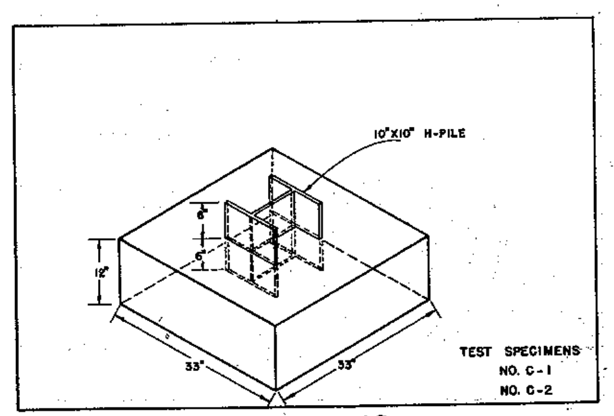

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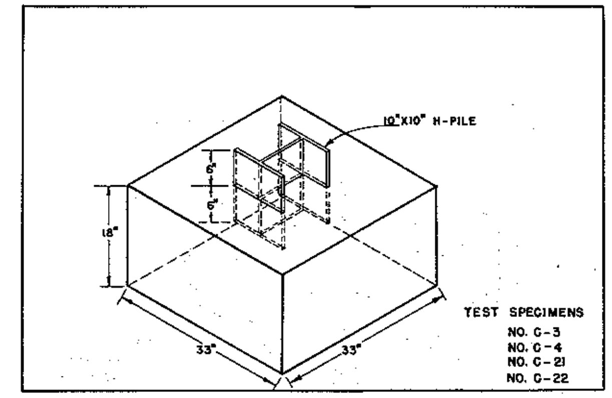

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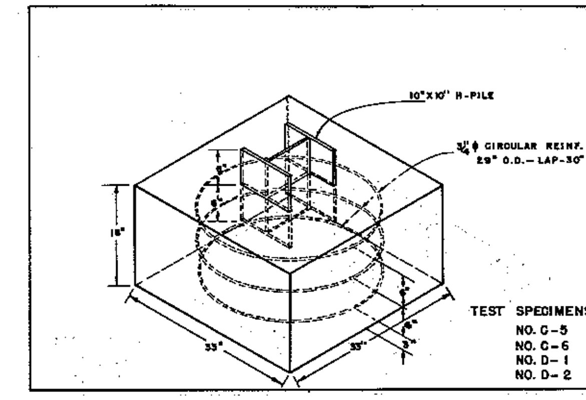

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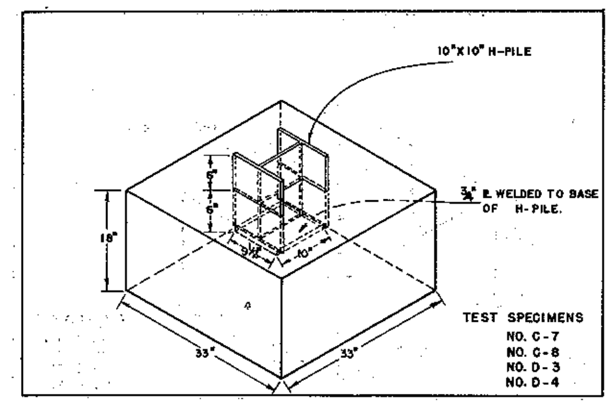

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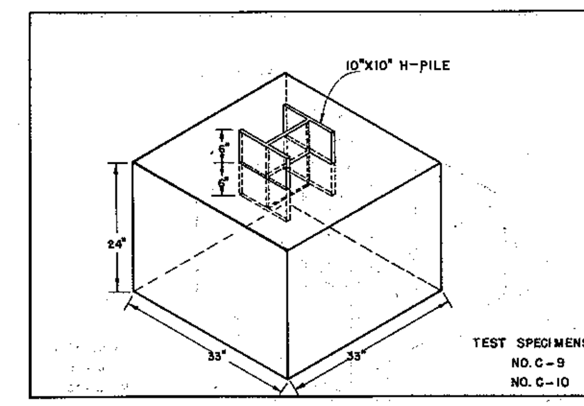

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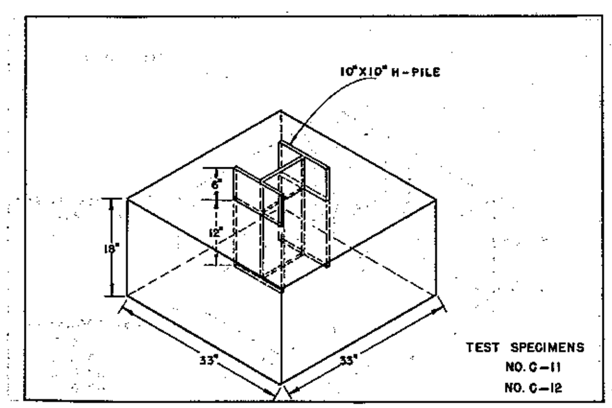

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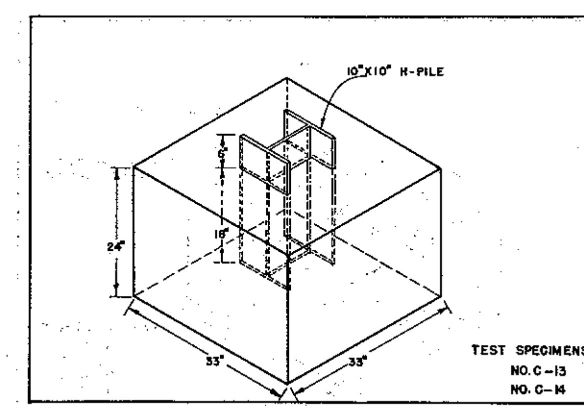

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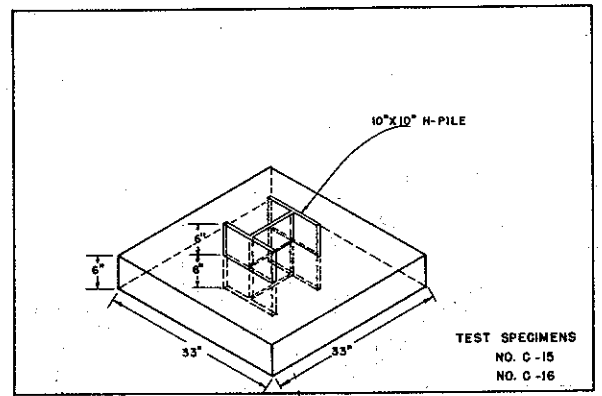

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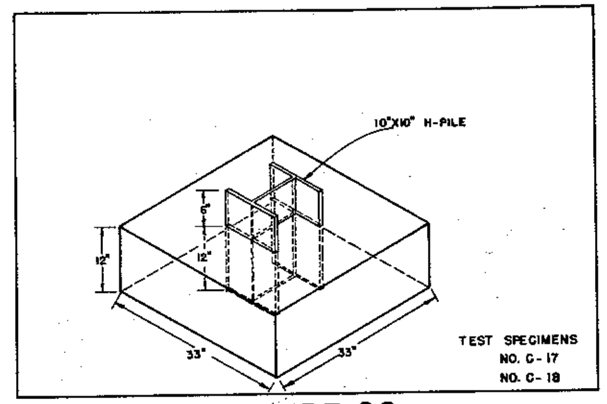

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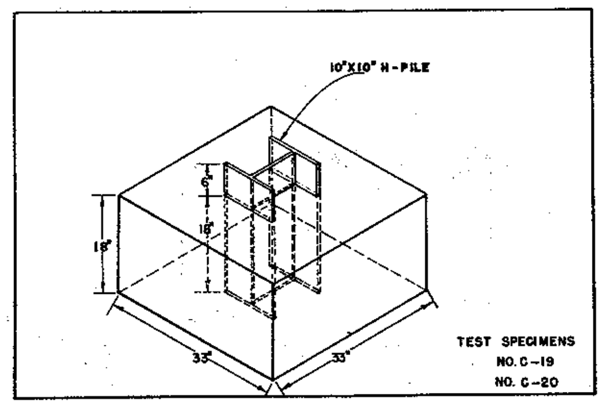

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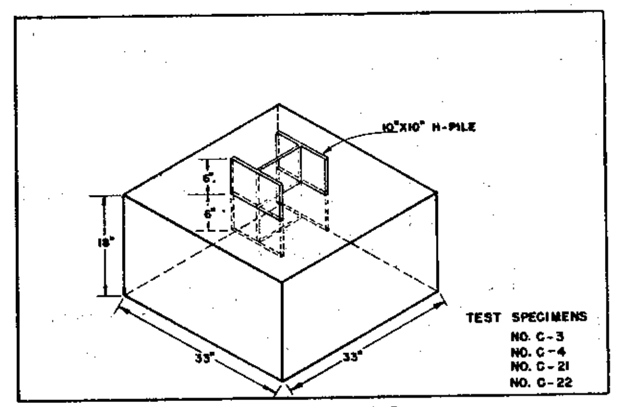


FIGURE 22

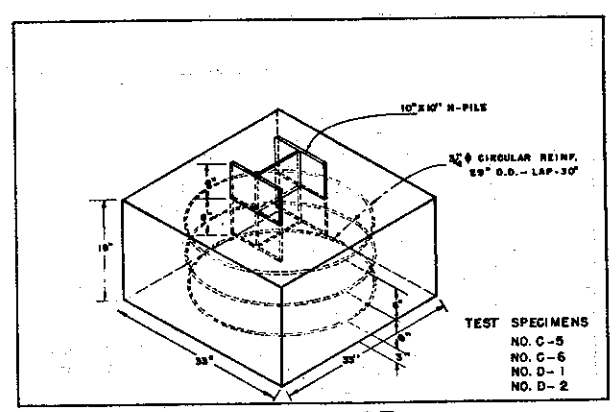


FIGURE 23

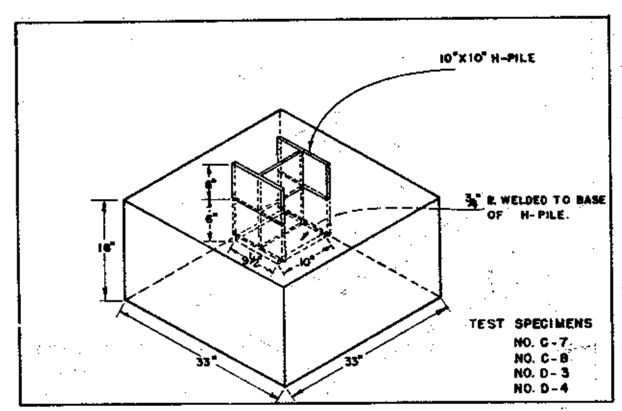
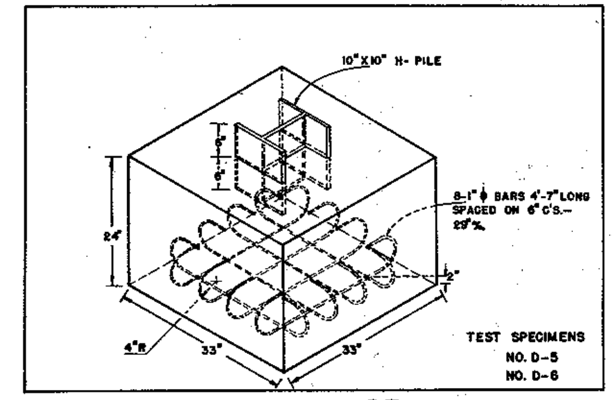


FIGURE 24



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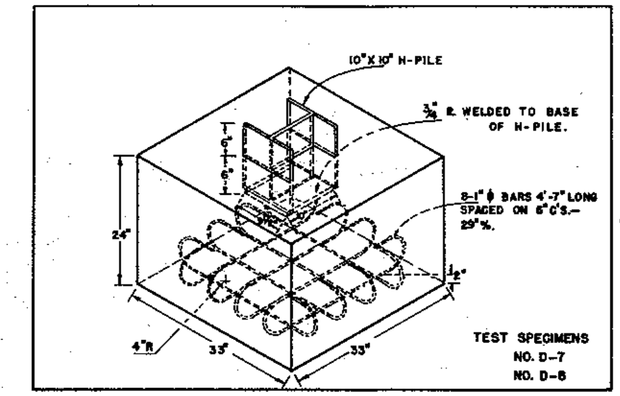

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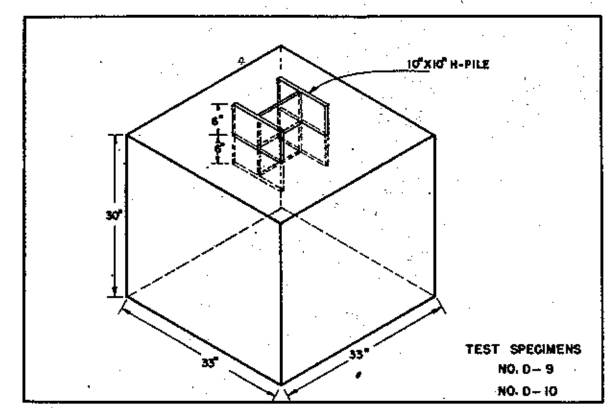

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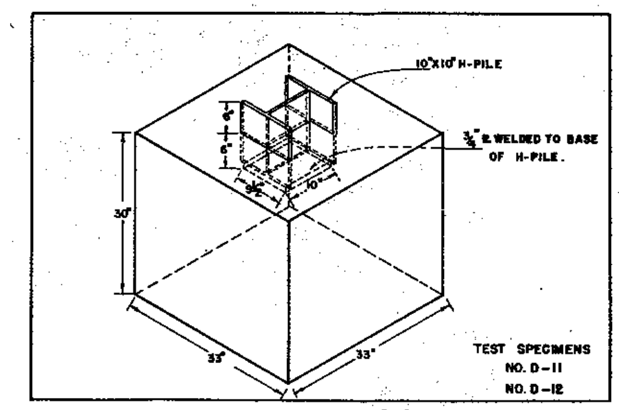


FIGURE 28

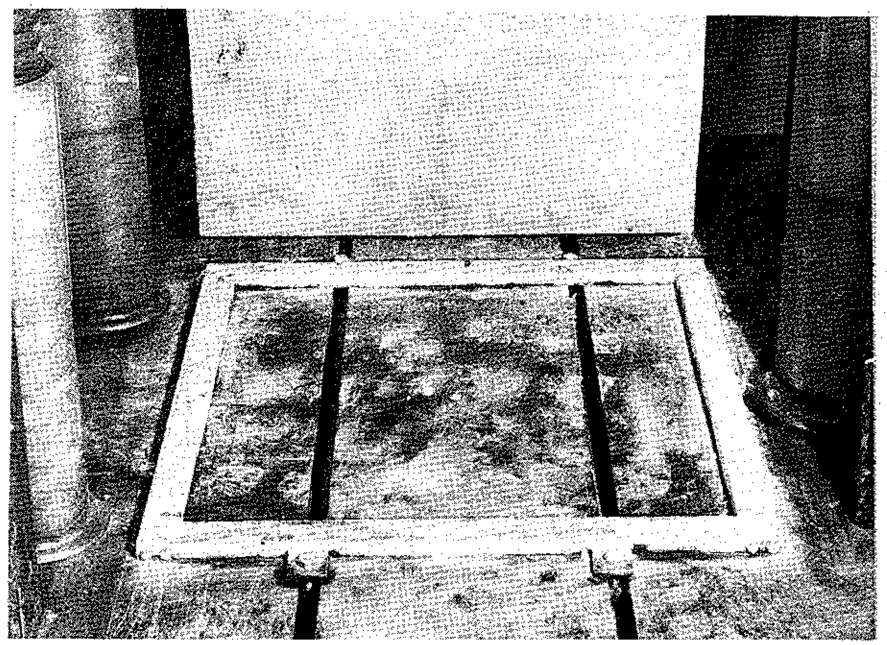


PLATE 1. STEEL SUPPORT RING USED IN SERIES C BOLTED IN PLACE ON WEIGHING PLATFORM OF TESTING MACHINE.

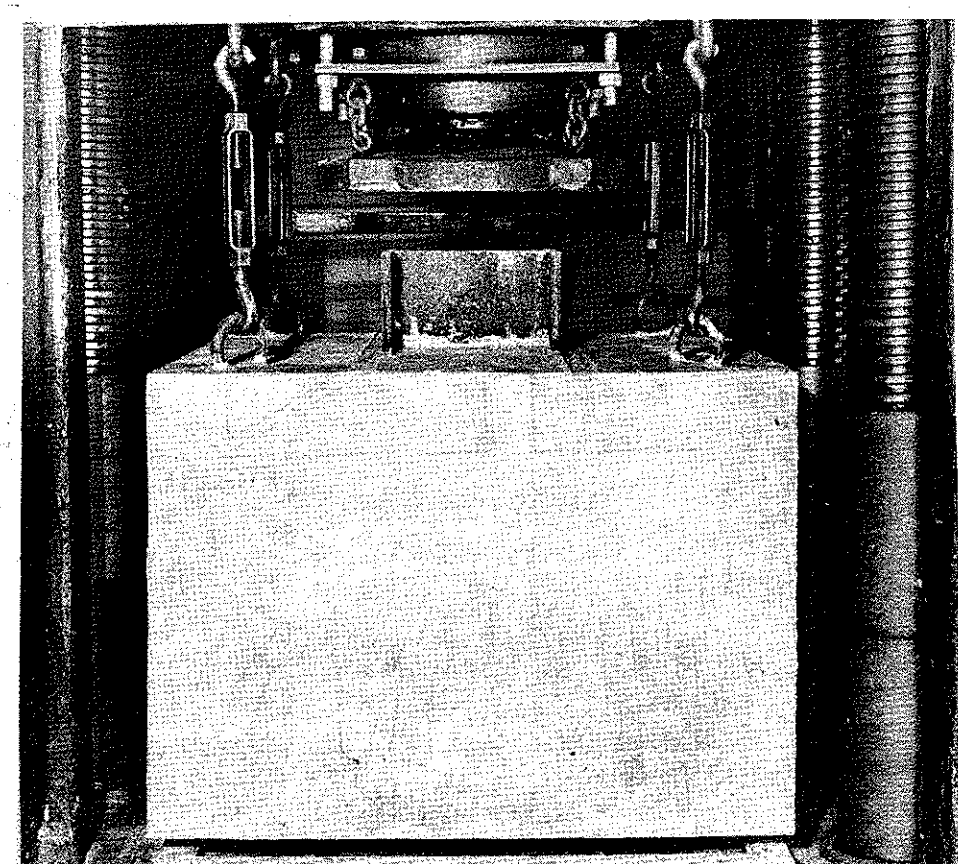


PLATE 2. SERIES C SPECIMEN SUSPENDED ON TURNBUCKLES PEREPARATORY TO ALIGNMENT AND CAPPING.

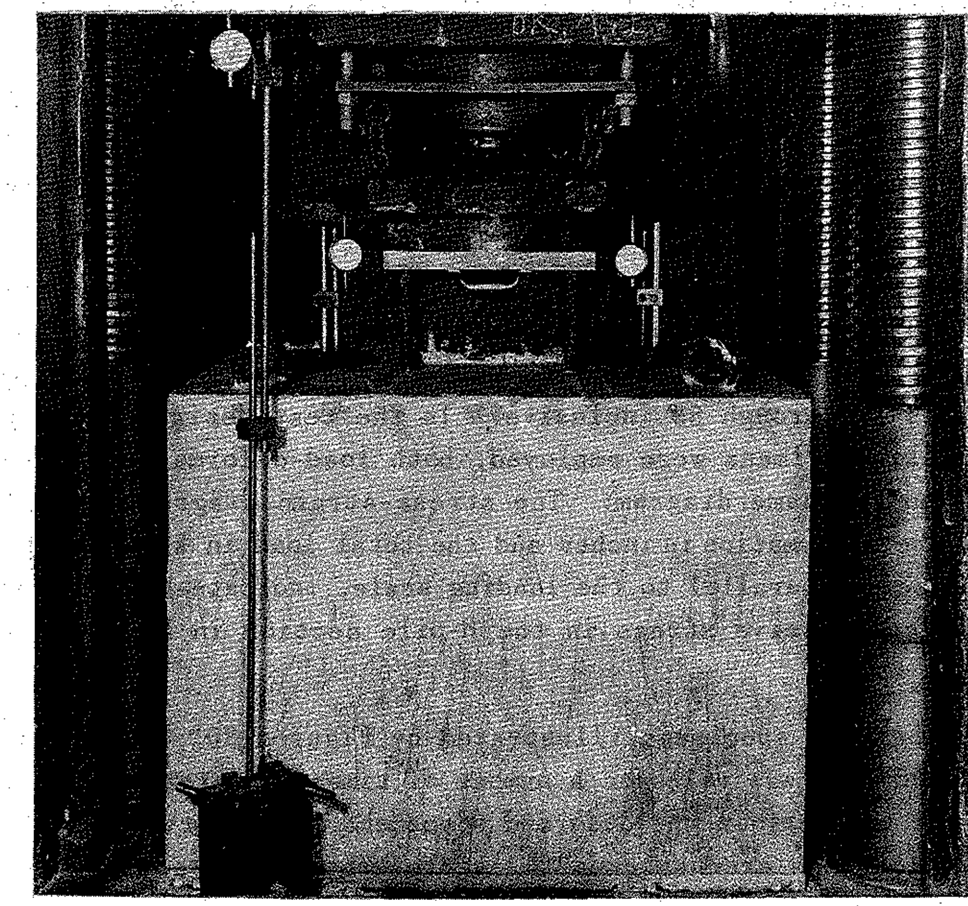


PLATE 3. SERIES C SPECIMEN READY FOR TEST.

RESULTS OF LOAD BEARING TESTS

The maximum total load bearing capacities together with individual specimen design data, for the 'A', 'B', 'C', and 'D' Series of tests, are summarized respectively in Tables Nos. III, IV, V and VI. Unit compressive stress values based on the maximum load and area of the H-pile section are also given. Data applicable to the H-pile sections employed in a series of tests are shown at the bottom of each summary table.

Stress-strain diagrams have been prepared for each test specimen except A-1,,which was the preliminary test, and C-14, which was not tested due to a defective concrete head. These diagrams are illustrated by Figures 29 through 55 inclusive. In the test designs where paired (identical) specimens were employed, both load-deformation curves are plotted on the same diagram. The stress-strain diagrams are plotted to show the deformation in inches and the total load in kips (1000 lbs.). A second scale, parallel to the loading scale, indicates the corresponding unit compressive stress in the H-pile section in kips per square inch.

In the test specimens illustrated by Figures 30, 34, 35 and 36, the applied load was released a number of times to determine the degree of elastic recovery in the deformed specimens. The curves illustrating released loadings are numbered to enable tracing the elastic recovery of the specimens.

In the 'B', 'C', and 'D' Series, Figures 37 to 55 inclusive, where specimen pairs were employed, the individual curves are identified by the test specimen number. In some of the tests of the 'C' Series, and all of the tests of the 'D' Series, the testing machine head-travel is plotted against the applied load and is identified by the letter 'H' after the test specimen number. The curve indicating the penetration of the H-pile section into the concrete head is identified by the letter 'B' after the test specimen number.

The conditions of the test specimens after loading to failure are illustrated in Plates 4 through 43 inclusive. All 6" x 6" H-pile specimens of the 'A' Series are illustrated by Plate 4, as the common failure was by buckling of the H-pile. Plate 5 illustrates the cracked concrete

head of Test A-6. The indentation of the pile section into the concrete surface of Test A-9 is illustrated by Plate 6, and Figure 56 shows the results obtained by surface gage measurements of the indented area. In the 'B', 'C', and 'D' Series, photographic pairs are shown for each specimen tested to enable complete tracing of failure cracks appearing on the surface of the concrete head.

TABLE NO. III
SUMMARY "A" SERIES
SPECIMEN DATA & BEARING TEST RESULTS

Test Specimen No.	Concrete Age At Test, Days	Concrete Head Depth, Inches	Depth H-pile Embedded, Inches	H-pile Size(1), Inches	Concrete Head Type	Base Support Method	Bearing Capacity Ultimate Strength	
							Total Load Kips	Unit (2) Stress lbs./sq. in.
A-1	3	18	6.00	6x6	PLAIN	PRELIM. TEST	178.0	39,000
A-2	31	18	6.50	6x6	PLAIN	SOLID BASE	209.0	45.700
A-3	31	18	6.50	6x6	REINF.	SOLID BASE	194.0	42,500
A-4	31	18	6.25	6x6	PLAIN	SOLID BASE	207.0	45,400
A-5	31	18	6.25	6x6	REINF.	SOLID BASE	191.0	41,800
A-6	27	18	6.25	10x10	PLAIN	SOLID BASE	432.0	33,400
A-7	29	18	6.25	6x6	PLAIN	SOLID BASE	206.0	45,100
A-8	29	18	6.50	6x6	REINF.	SOLID BASE	213.0	46,600
A-9	29	--	0	6x6	.....	SOLID BASE	205.0	44,800

(1) H-Pile Section Data:

Sect. Size in.	Area sq. in.	Depth in.	Flange Width in.	Web Thick. in.	Flange Thick. in.	Wt./lin. ft.	Perimeter Length in.
6x6	4.57	5.990	5.790	0.240	0.270	15.5	35.5
10x10	12.95	9.760	10.098	0.438	0.438	44.0	59.0

(2) Unit stress based on total load and area of H-pile section.

TABLE NO. IV
SUMMARY "B" SERIES
SPECIMEN DATA & BEARING TEST RESULTS

Test Specimen No.	Concrete Age At Test, Days	Concrete Head Depth, Inches	Depth H-pile Embedded, Inches	H-pile Size(1), Inches	Concrete Head Type	Base Support Method	Bearing Capacity Ultimate Strength	
							Total Load Kips	Unit (2) Stress lbs./sq. in.
B-1	28	12-3/4	6.75	10X10	REINF.	WOOD FRAME	119.0	9,180
B-2	28	12-1/4	6.25	10X10	REINF.	WOOD FRAME	106.3	8,220
B-3	28	18	9.00	6X6	PLAIN	WOOD FRAME	117.0	25,600
B-4	28	18	9.25	6X6	PLAIN	WOOD FRAME	100.0	21,880

Notes:

(1) H-pile section data same as given in Table III.
(2) Unit stress based on total load and area of H-pile section.

TABLE NO. V
SUMMARY "C" SERIES
SPECIMEN DATA & BEARING TEST RESULTS

Test Specimen No.	Concrete Age At Test, Days	Concrete Head Depth, Inches	Depth H-pile Embedded, Inches	H-pile Size (1), Inches	Concrete Head Type	Base Support Method	Bearing Capacity Ultimate Strength: Total Load Kips	Unit (2) Stress lbs./sq. in.
C-1	29	12	6	10x10	PLAIN	4-EDGE	100.0	6,950
C-2	29	12	6	10x10	PLAIN	STEEL FRAME	100.0	6,950
C-3	28	18	6	10x10	PLAIN	4-EDGE	220.0	15,300
C-4	28	18	6	10x10	PLAIN	STEEL FRAME	230.0	16,000
C-5	28	18	6	10x10	REINF.	4-EDGE	290.0	20,180
C-6	28	18	6	10x10	REINF.	STEEL FRAME	310.0	21,560
C-7	28	18	6	10x10	PLAIN PLATE	4-EDGE	190.0	13,210
C-8	28	18	6	10x10	PLAIN PLATE	STEEL FRAME	190.0	13,210
C-9	28	24	6	10x10	PLAIN	4-EDGE	450.0	31,300
C-10	28	24	6	10x10	PLAIN	STEEL FRAME	360.0	25,020
C-11	28	18	12	10x10	PLAIN	4-EDGE	280.0	19,470
C-12	28	18	12	10x10	PLAIN	STEEL FRAME	200.0	13,910
C-13	28	24	18	10x10	PLAIN	4-EDGE	390.0	27,150
C-14	28	24	18	10x10	PLAIN	STEEL FRAME	NO TEST	- - - -
C-15	28	6	6	10x10	PLAIN	4-EDGE	40.0	2,780
C-16	29	6	6	10x10	PLAIN	STEEL FRAME	30.0	2,090
C-17	29	12	12	10x10	PLAIN	4-EDGE	110.0	7,660
C-18	29	12	12	10x10	PLAIN	STEEL FRAME	110.0	7,660
C-19	28	18	18	10x10	PLAIN	4-EDGE	160.0	11,130
C-20	29	18	18	10x10	PLAIN	STEEL FRAME	230.0	16,000
C-21	29	18	6	10x10	PLAIN	2-EDGE	140.0	9,740
C-22	28	18	6	10x10	PLAIN	STEEL BARS	130.0	9,040

Notes: (1) H-pile Section Data

Size Inches	Wt. lbs./ft.	Area sq. in.	Depth Inches	Width Inches	Web Inches	Flange Inches	Perimeter Length Inches
10x10	49	14.38	10.00	10.00	0.340	0.558	59.32

All H-pile side surfaces were untreated mill scale with loose rust removed by wire brushing.

(2) Unit stress based on total load and area of H-pile section.

TABLE NO. VI
SUMMARY "D" SERIES
SPECIMEN DATA & BEARING TEST RESULTS

Test Specimen No.	Concrete Age At Test, Days	Concrete Head Depth, Inches	Depth H-pile Embedded, Inches	H-pile Size (1), Inches	Concrete Head Type	Base Support Method	Bearing Capacity Ultimate Strength: Total Load Kips	Unit (2) Stress lbs./sq. in.
D-1	29	18	6	10x10	REINF.	4-EDGE	200.0	13,910
D-2	29	18	6	10x10	REINF.	STEEL FRAME	240.0	16,700
D-3	29	18	6	10x10	PLAIN PLATE	4-EDGE	160.0	11,130
D-4	29	18	6	10x10	PLAIN PLATE	STEEL FRAME	160.0	11,130
D-5	28	24	6	10x10	REINF.	4-EDGE	320.0	22,240
D-6	29	24	6	10x10	REINF.	STEEL FRAME	440.0	30,600
D-7	28	24	6	10x10	REINF. PLATE	4-EDGE	340.0	23,620
D-8	29	24	6	10x10	REINF. PLATE	STEEL FRAME	480.0	33,360
D-9	28	30	6	10x10	PLAIN	4-EDGE	570.0	39,600
D-10	30	30	6	10x10	PLAIN	STEEL FRAME	530.0	36,850
D-11	28	30	6	10x10	PLAIN PLATE	4-EDGE	420.0	29,200
D-12	30	30	6	10x10	PLAIN PLATE	STEEL FRAME	630.0	43,800

NOTES: (1) H-pile section data same as given in Table IV.
(2) Unit stresses based on total load and area of H-pile section.

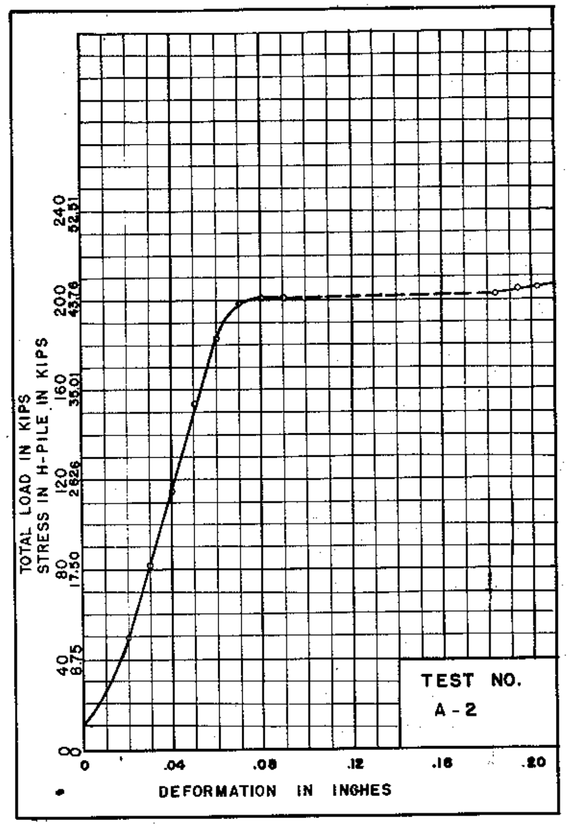


FIGURE 29

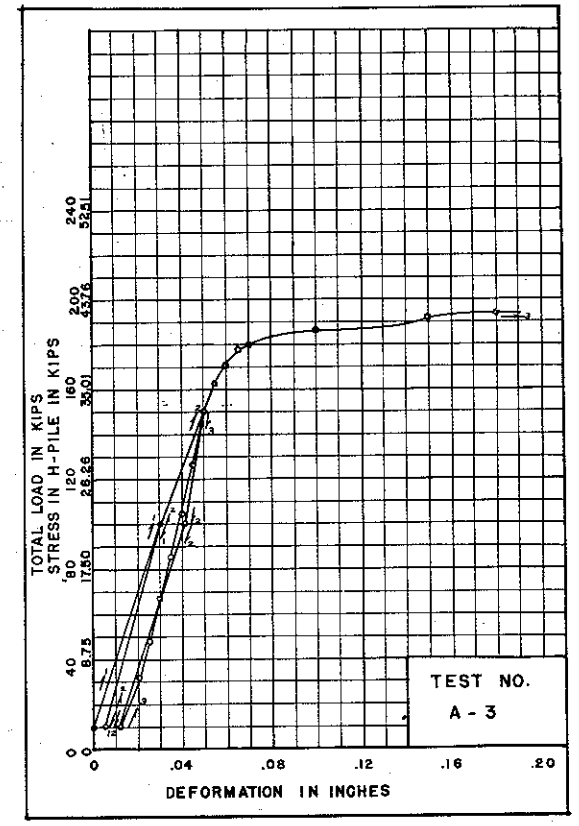


FIGURE 30

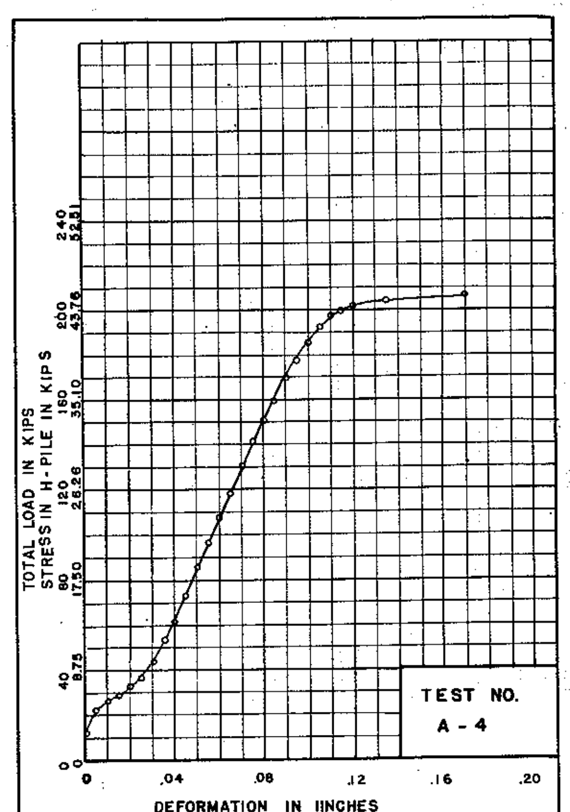


FIGURE 31

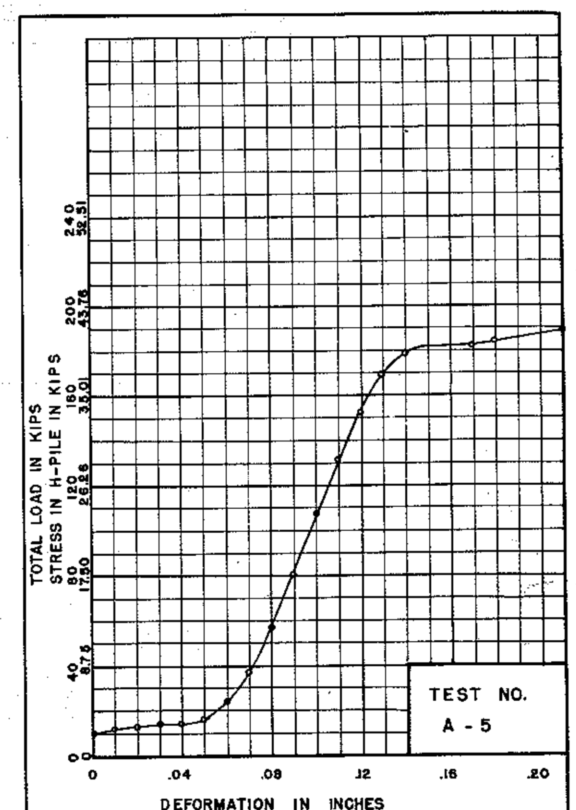


FIGURE 32

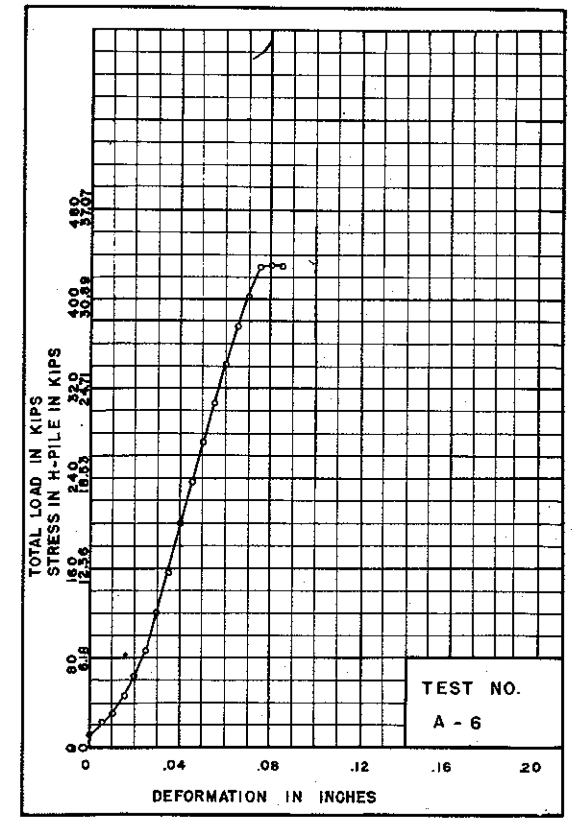


FIGURE 33

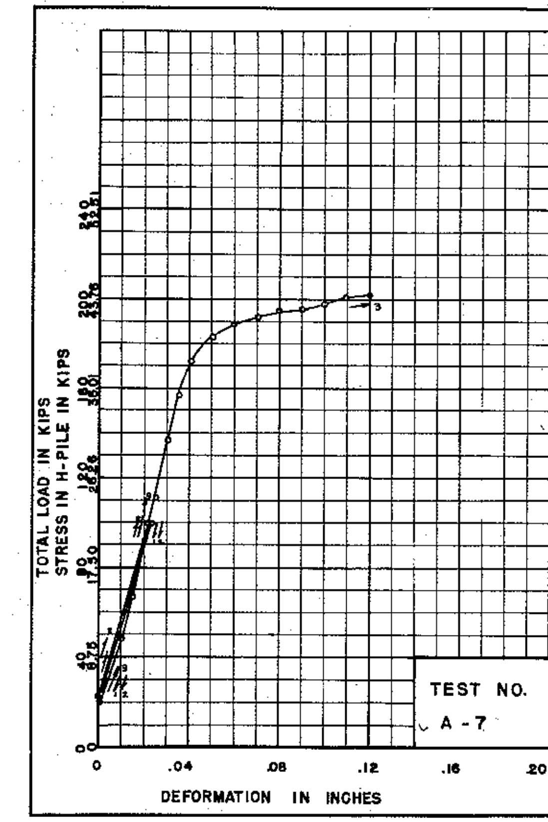


FIGURE 34

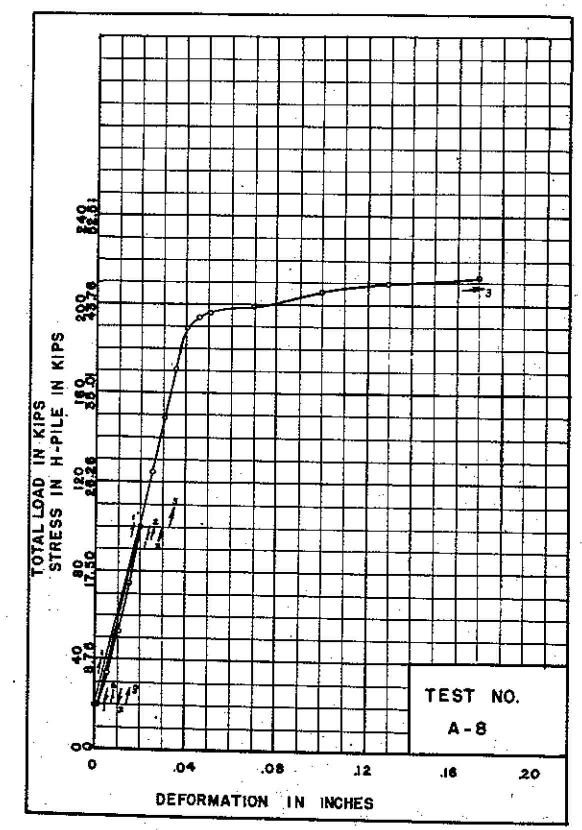


FIGURE 35

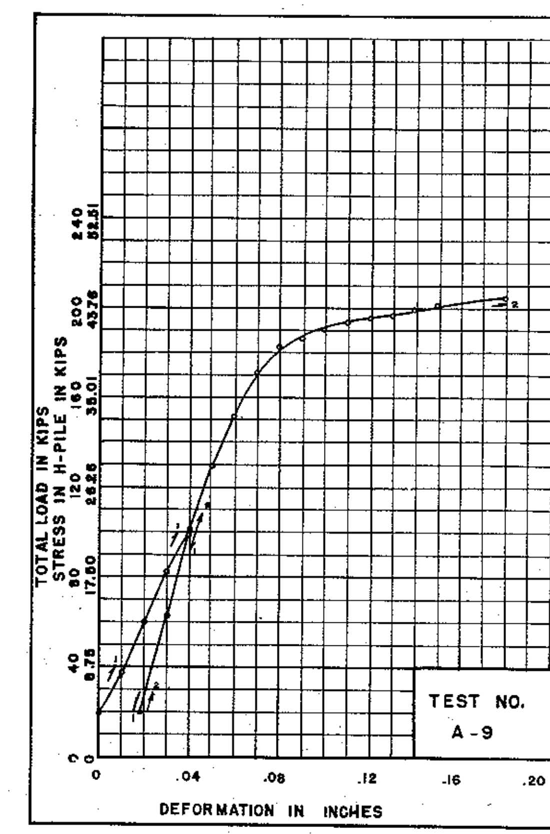


FIGURE 36

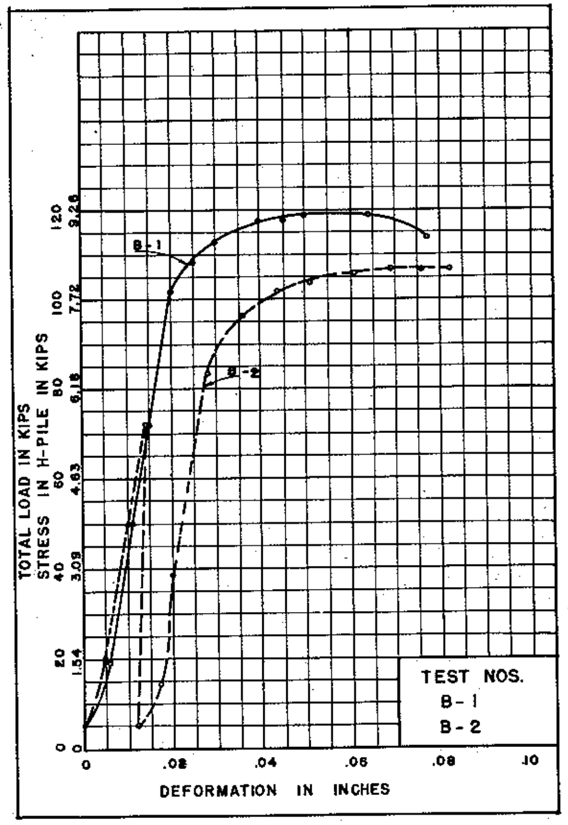


FIGURE 37

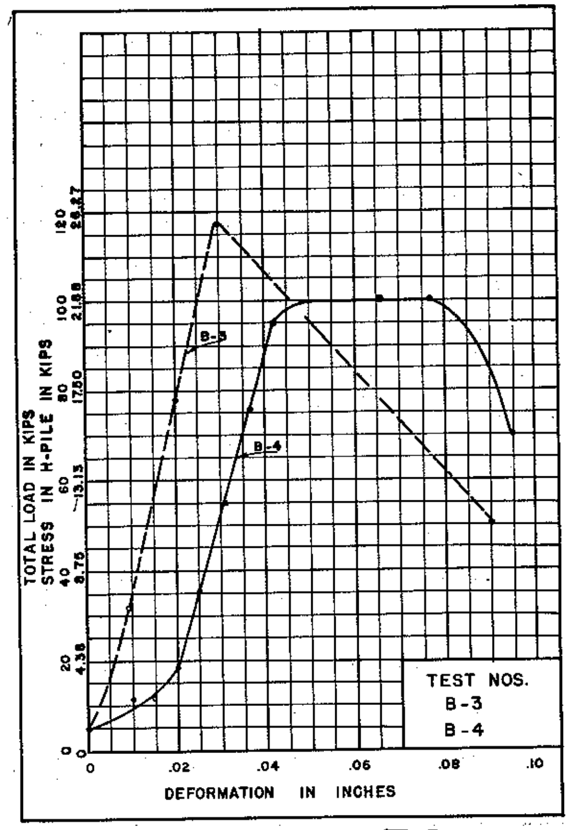


FIGURE 38

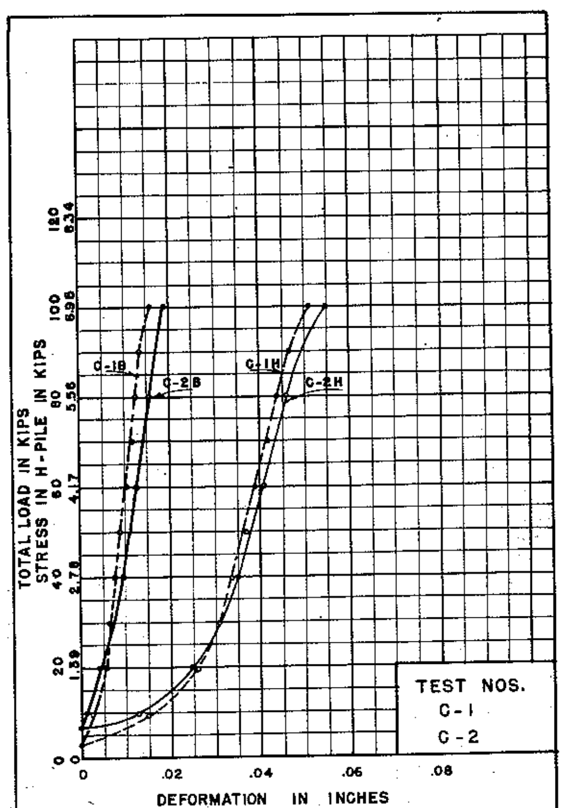


FIGURE 39

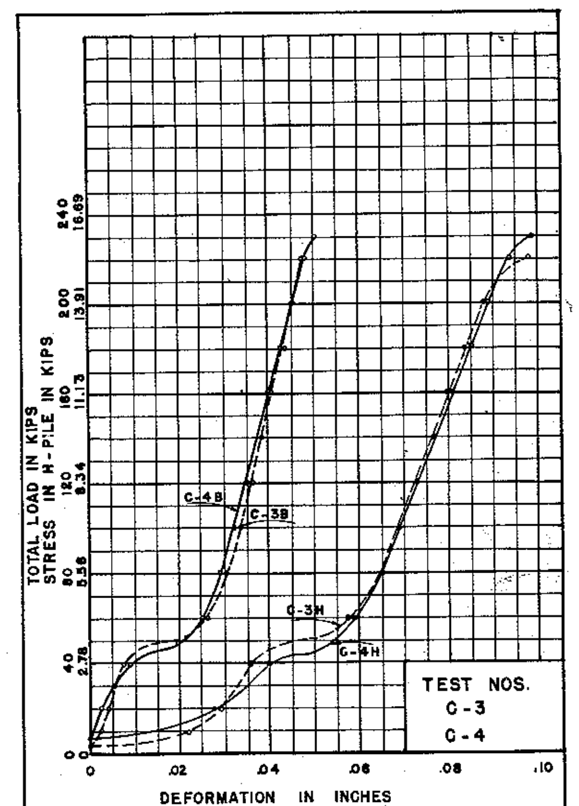


FIGURE 40

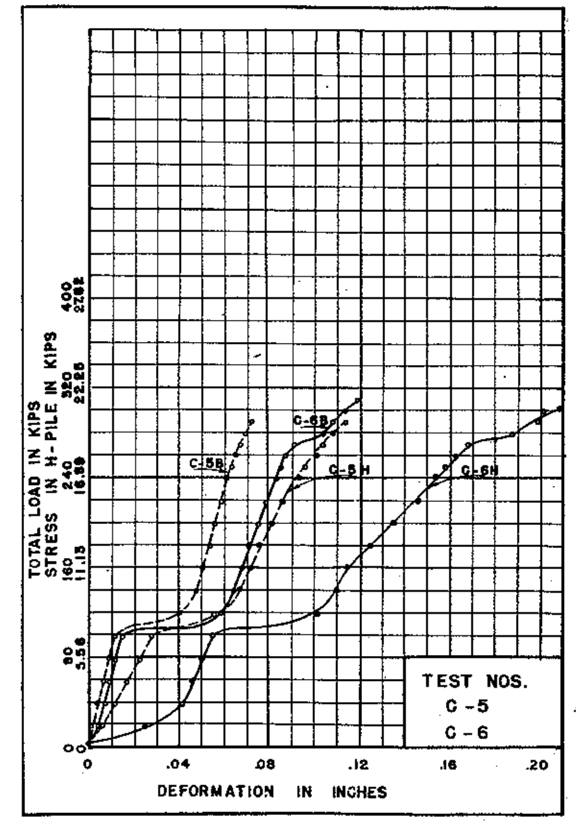


FIGURE 41

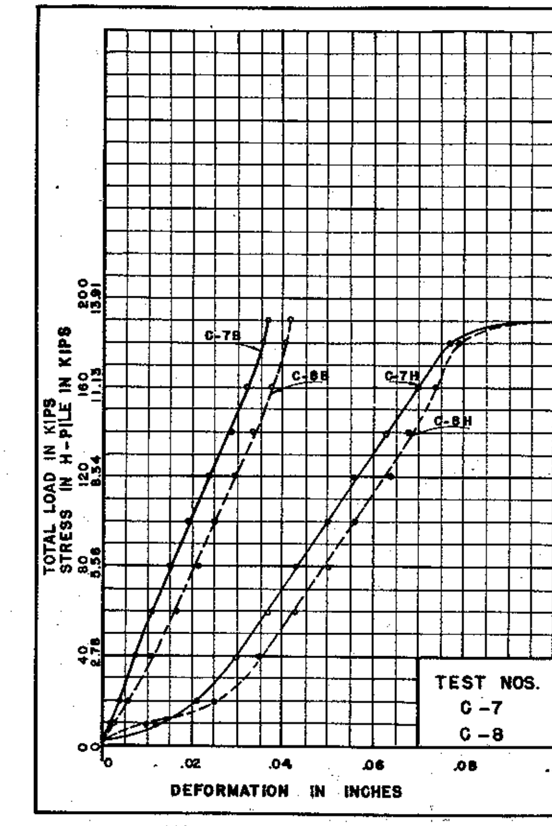


FIGURE 42

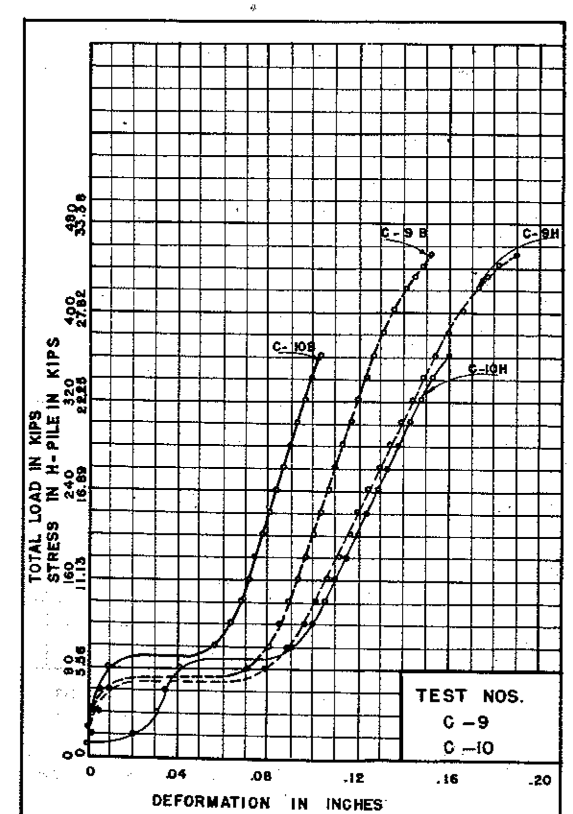


FIGURE 43

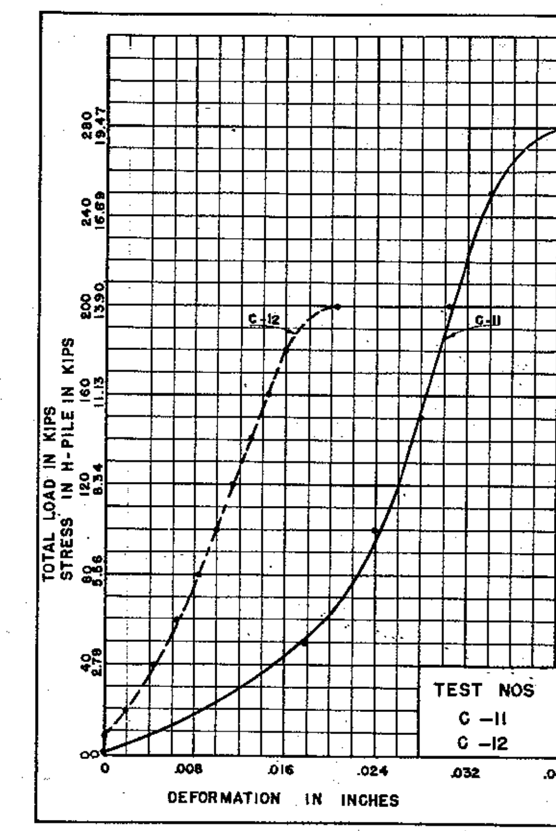


FIGURE 44

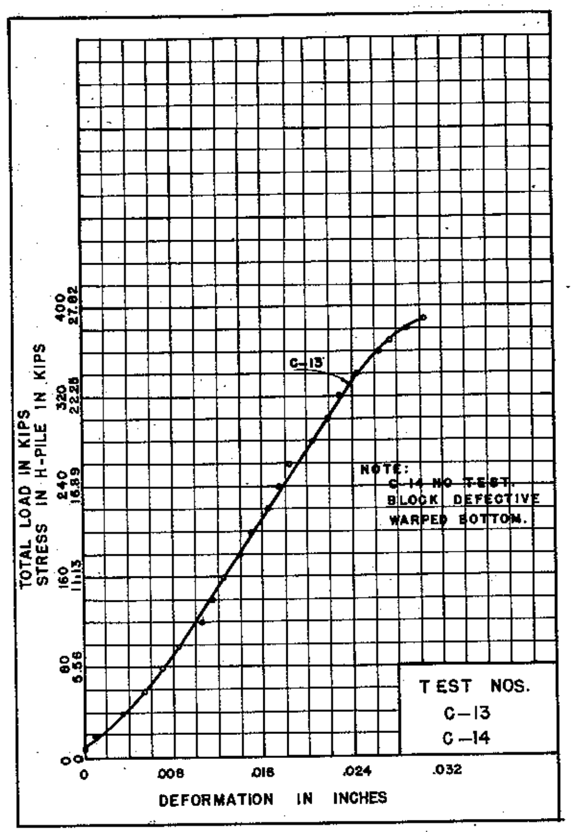


FIGURE 45

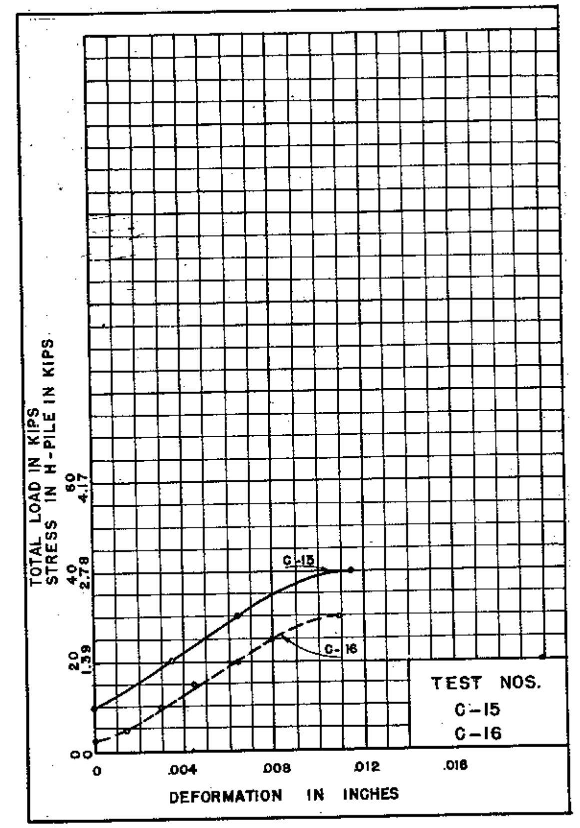


FIGURE 46

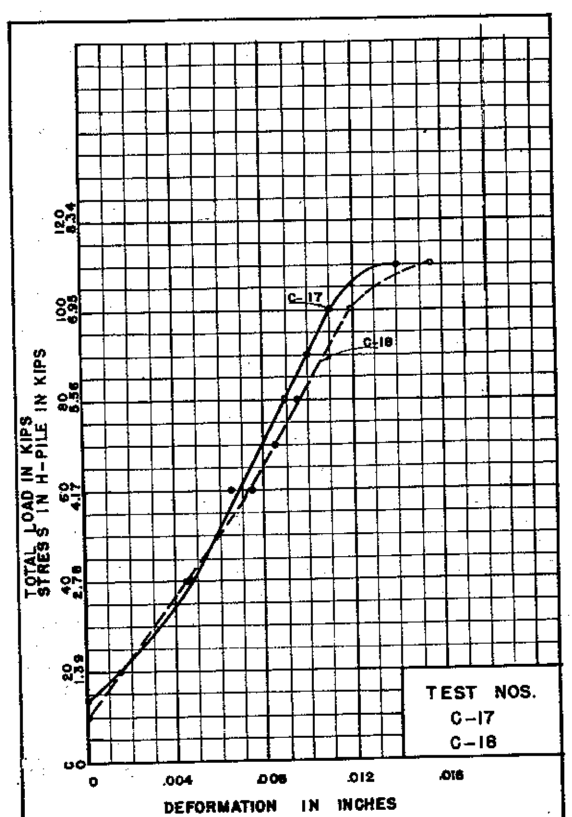


FIGURE 47

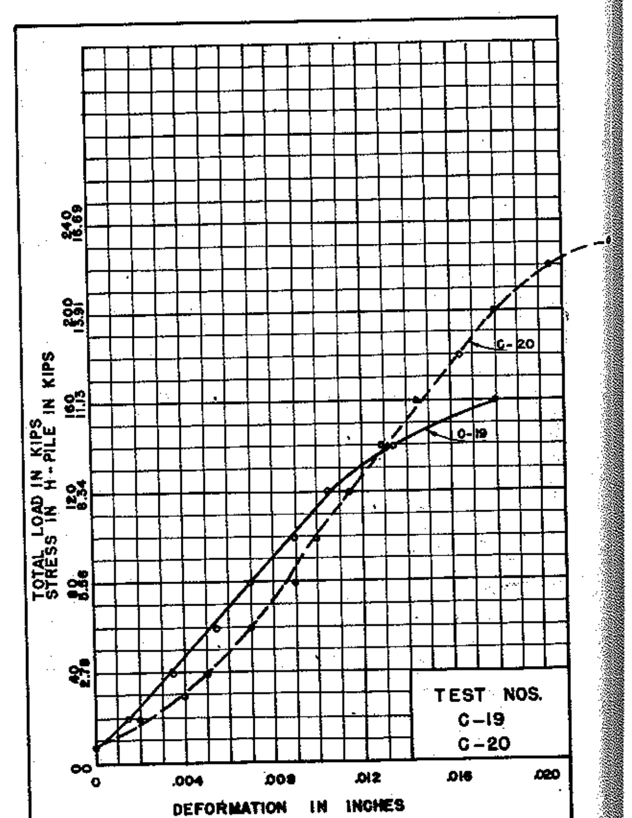


FIGURE 48

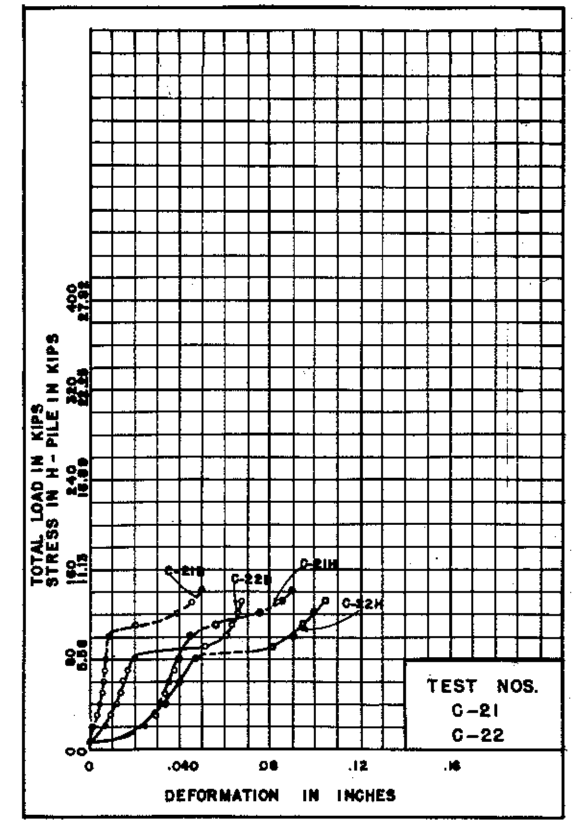


FIGURE 49

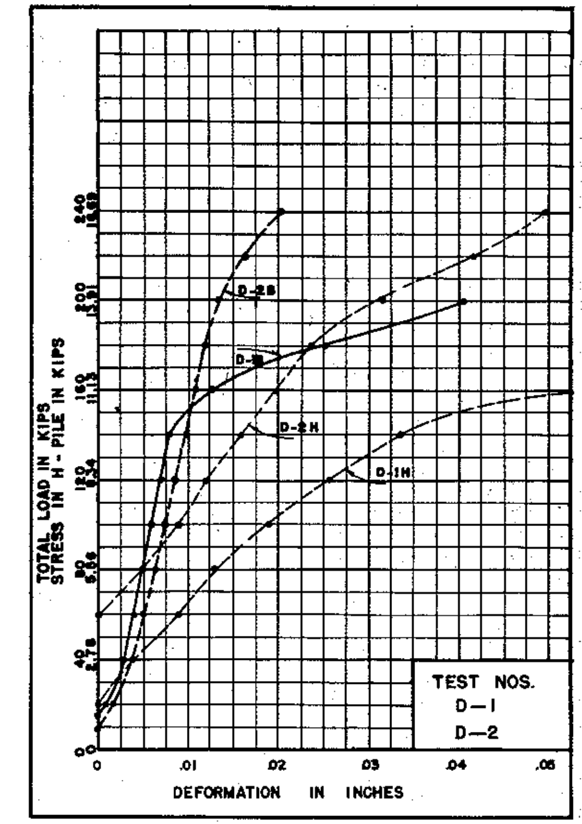


FIGURE 50

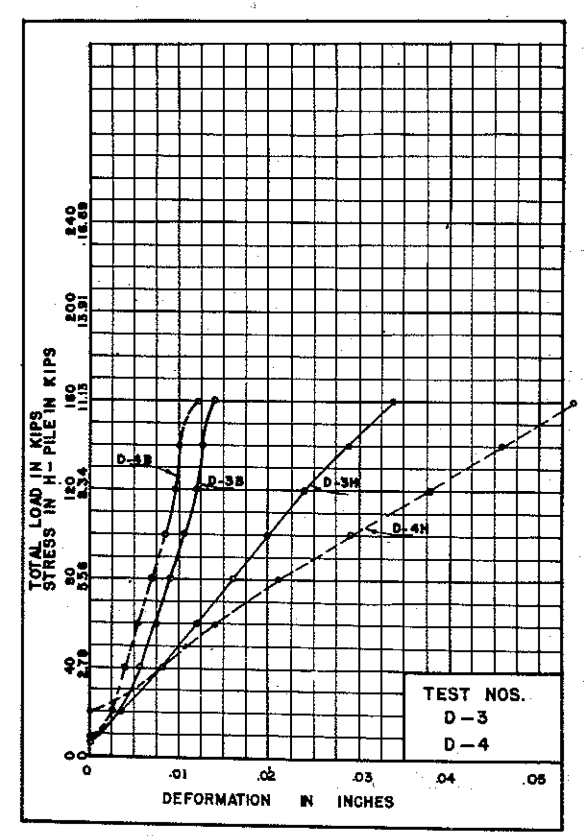


FIGURE 51

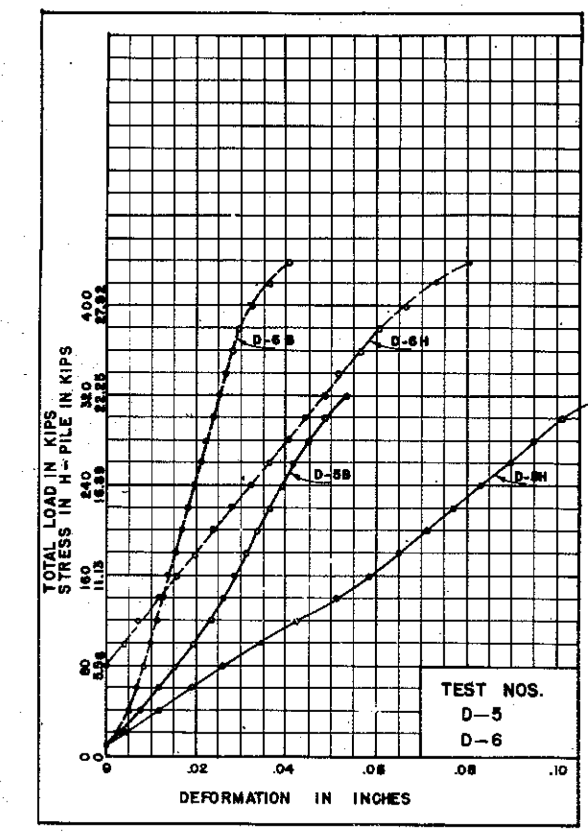


FIGURE 52

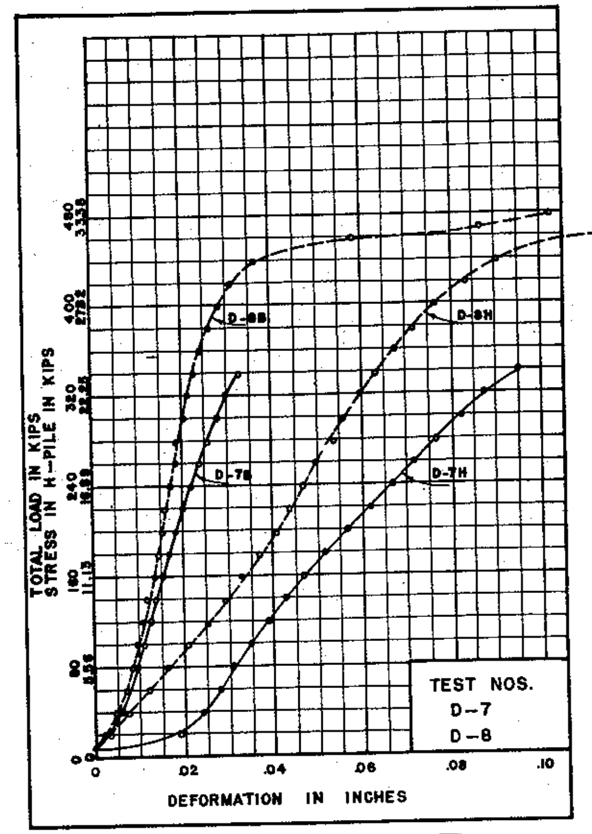


FIGURE 53

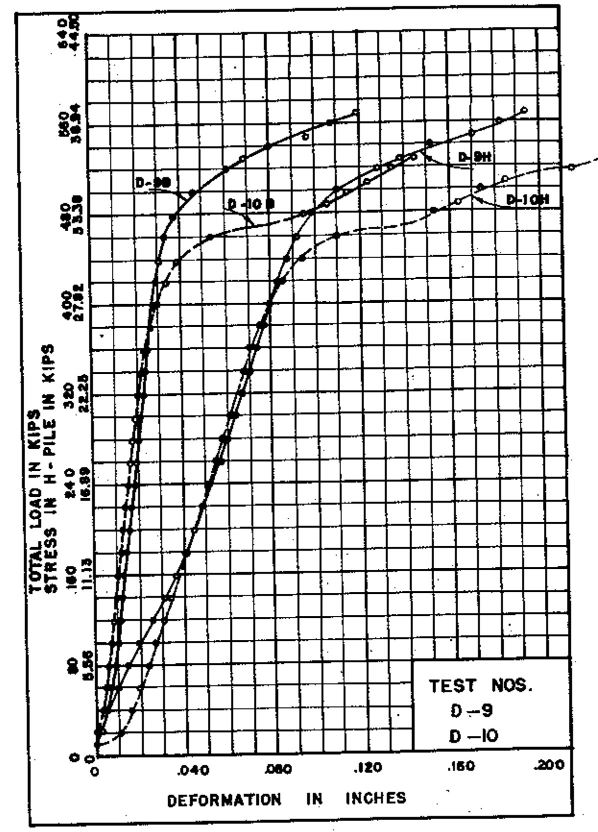


FIGURE 54

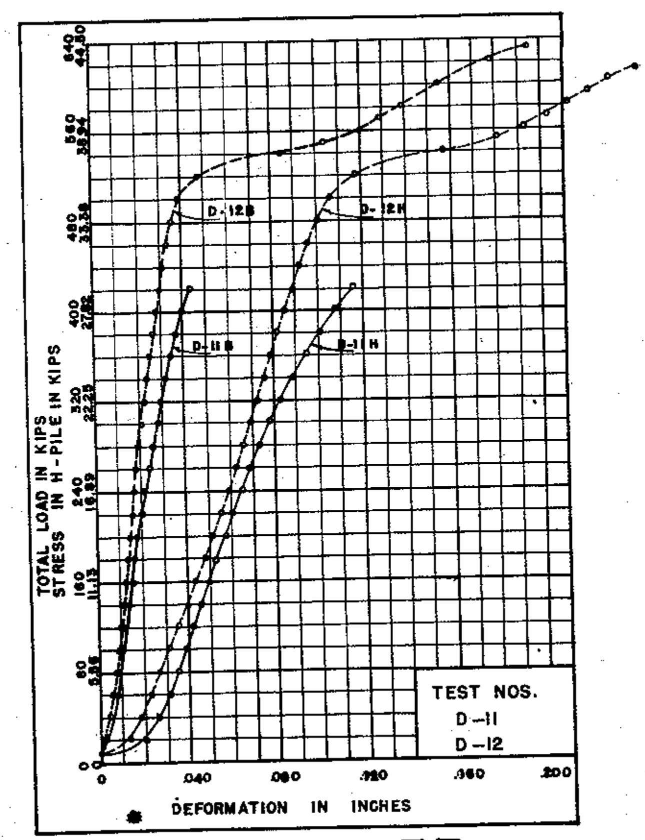


FIGURE 55

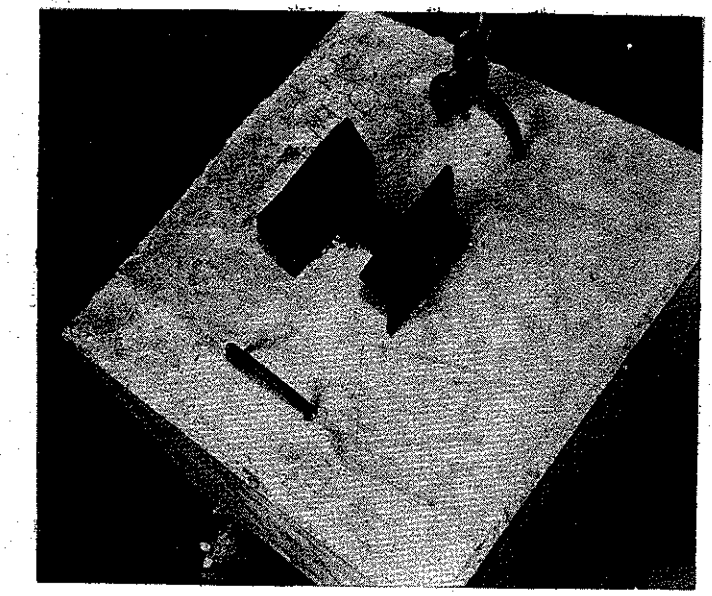


PLATE 4. FAILURE BY BUCKLING IN H-PILE. TYPICAL OF ALL 6" X 6" H-PILE TEST SPECIMENS IN SERIES A.

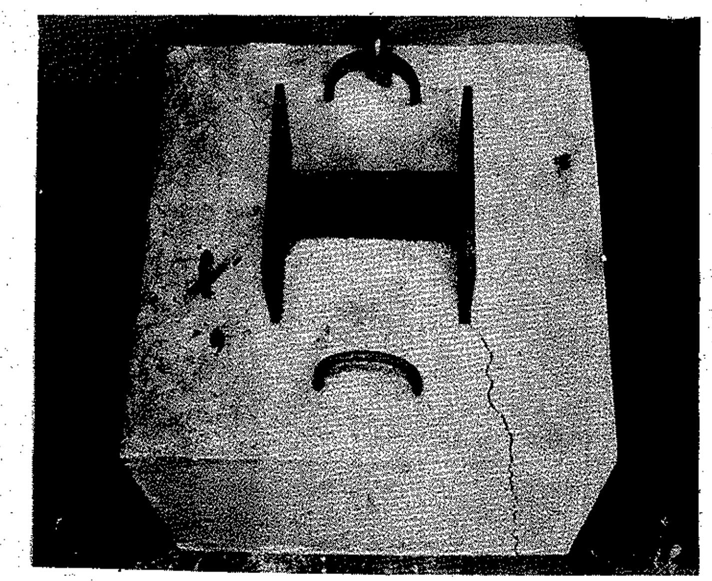
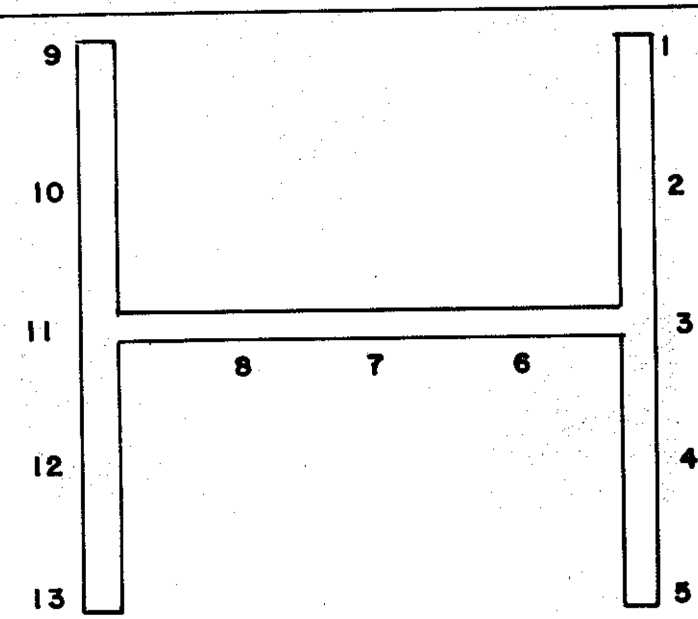


PLATE 5. FAILURE IN CONCRETE BLOCK ON SPECIMEN A-6 WITH 10" X 10" H-PILE.

PENETRATION OF H-PILE IN SURFACE OF CONCRETE BLOCK TEST NO. A-9



MEASUREMENTS BY SURFACE GAGE

READING LOCATION	SURFACE ELEVATIONS				PENETRATION INCHES
	SIDE ELE.	SIDE ELE.	AVE. ELE.	CENT. ELE.	
1	.1749	.1842	.1796	.1399	.0387
2	.2047	.1948	.1996	.1715	.0281
3	.2220	.2069	.2144	.1795	.0349
4	.2302	.2132	.2217	.2045	.0172
5	.2198	.2334	.2266	.2081	.0185
6	.1871	.1933	.1902	.1560	.0342
7	.1480	.1741	.1610	.1179	.0431
8	.1370	.1364	.1367	.1169	.0198
9	.1118	.1220	.1169	.0578	.0591
10	.1342	.1385	.1363	.0950	.0413
11	.1500	.1454	.1477	.1294	.0183
12	.1559	.1555	.1557	.1320	.0237
13	.1865	.1842	.1853	.1670	.0183

AVE. PENETRATION OF H-PILE IN CONCRETE = 0.030 INCHES

FIGURE 56

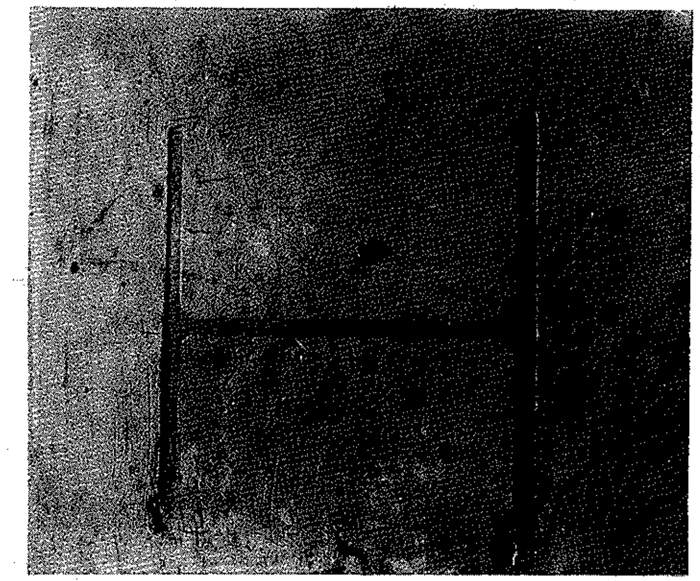


PLATE 6. INDENTATION IN CLASS 'E' (5.5 SACKS/CU.YD.) CONCRETE BLOCK RESULTING FROM 205,000 LB. LOAD ON A 6" X 6" H-PILE.

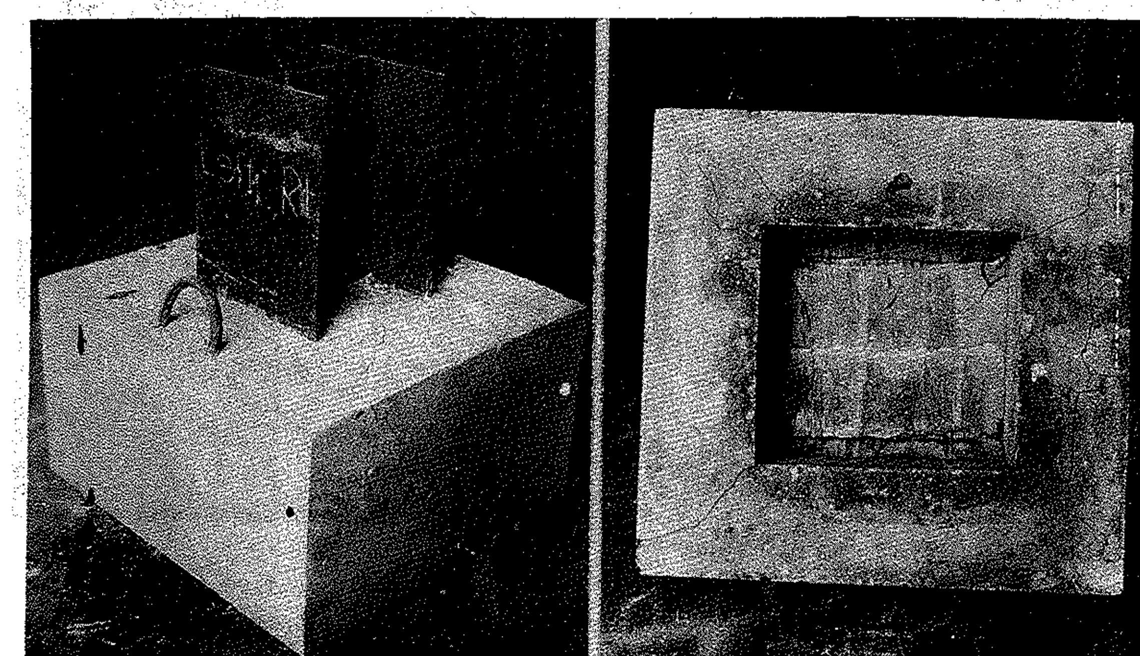


PLATE 7. APPEARANCE OF SPECIMEN B-1 AFTER TESTING.

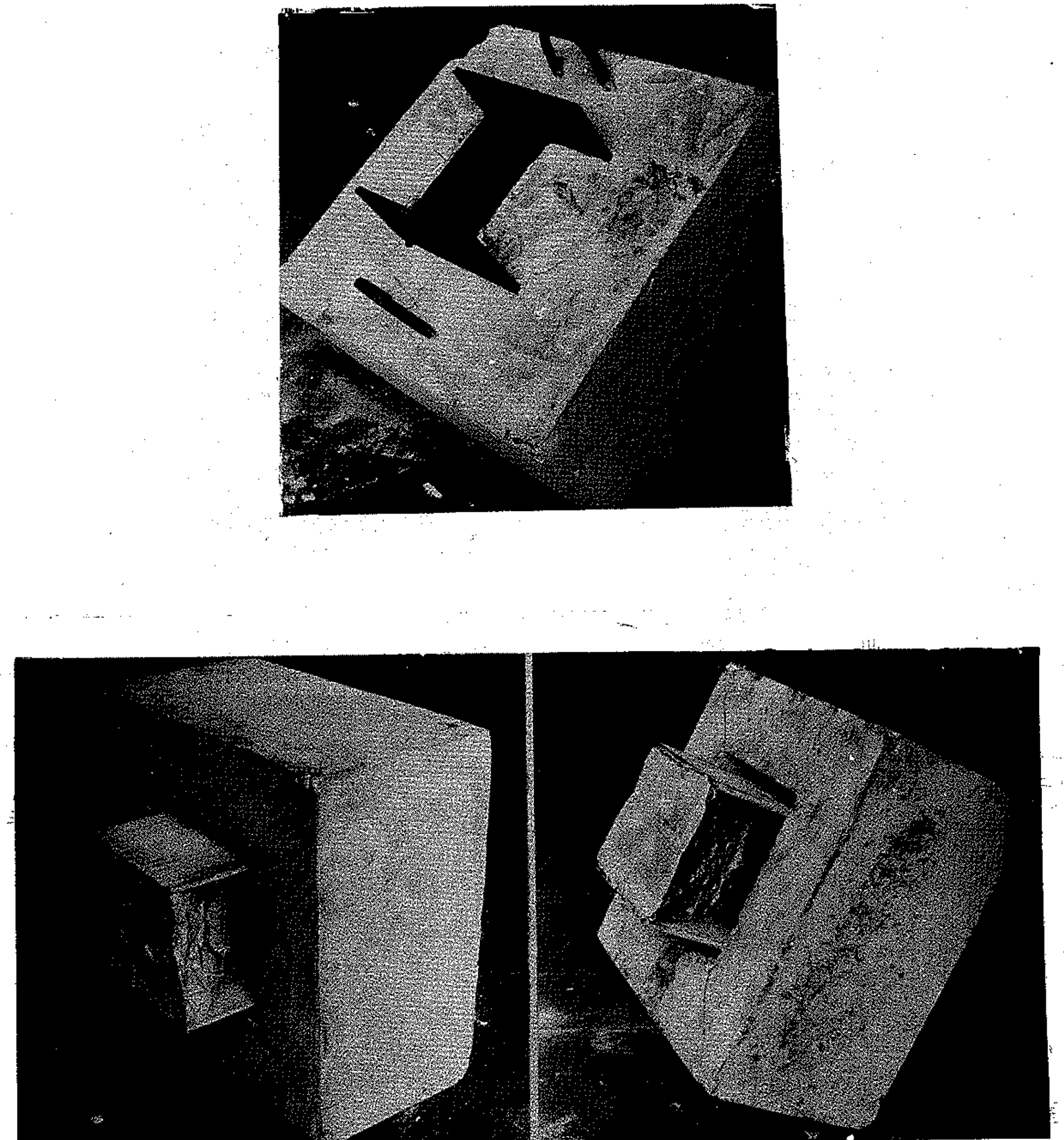


PLATE 8. APPEARANCE OF SPECIMEN B-2 AFTER TESTING.

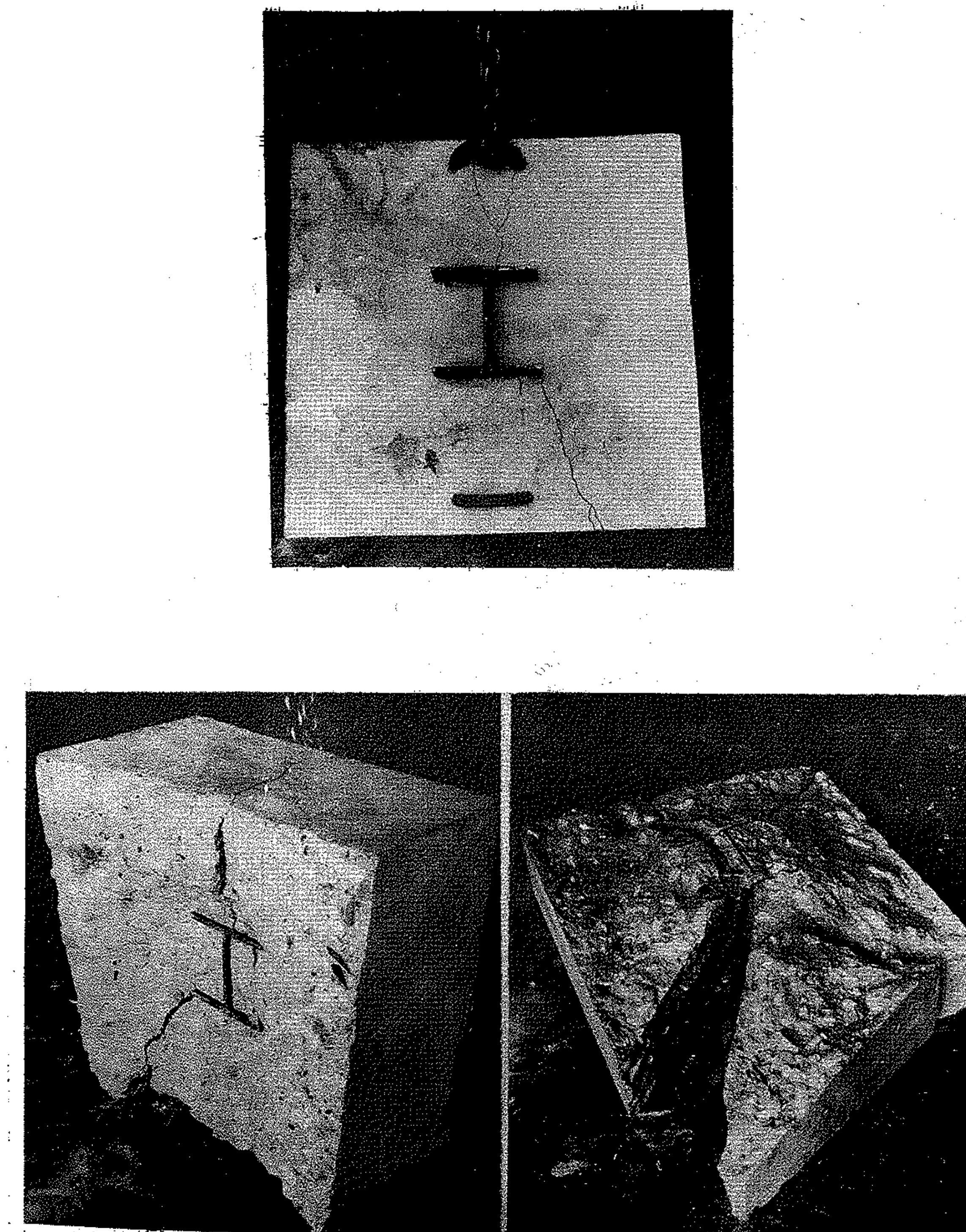


PLATE 9. APPEARANCE OF SPECIMEN B-3 AFTER TESTING.

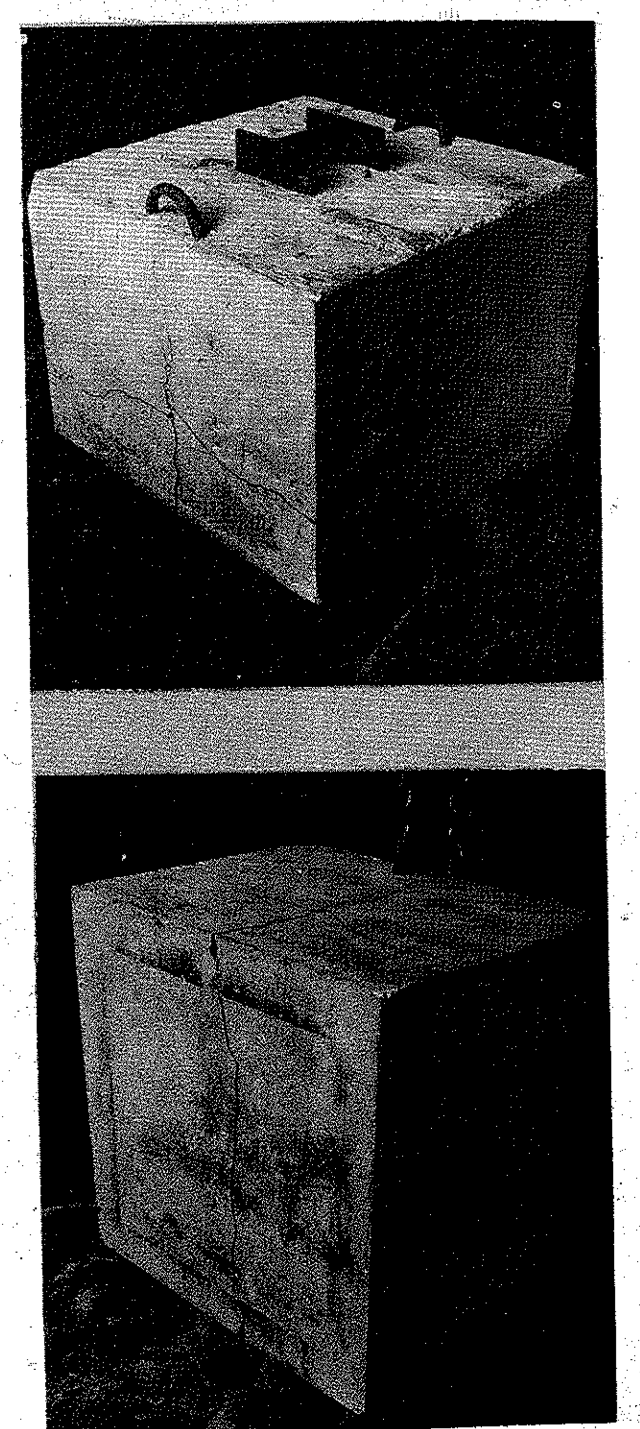


PLATE 10. APPEARANCE OF SPECIMEN B-4 AFTER TESTING.

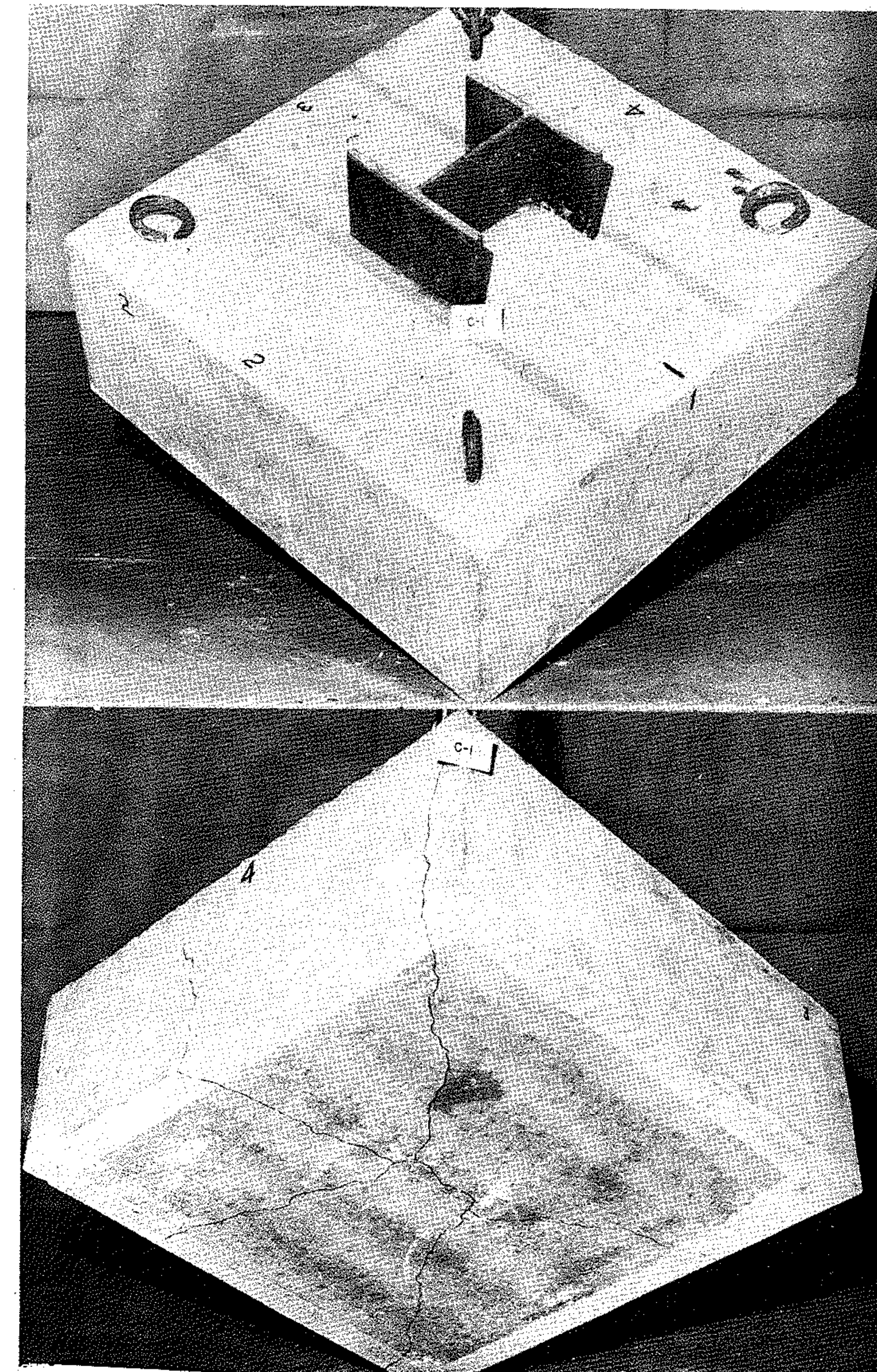


PLATE 11. APPEARANCE OF SPECIMEN C-1 AFTER TESTING.

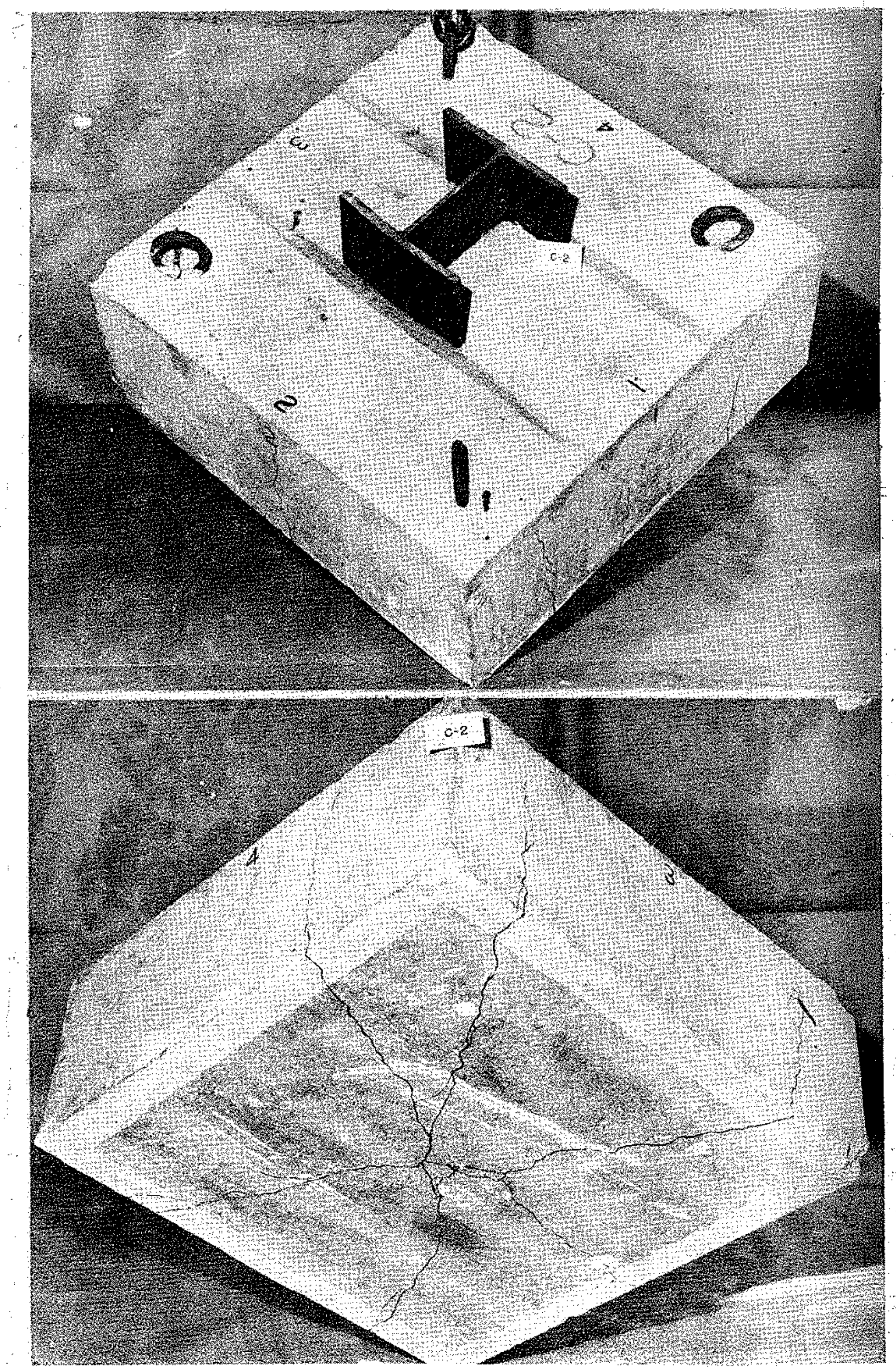


PLATE 12. APPEARANCE OF SPECIMEN C-2 AFTER TESTING.

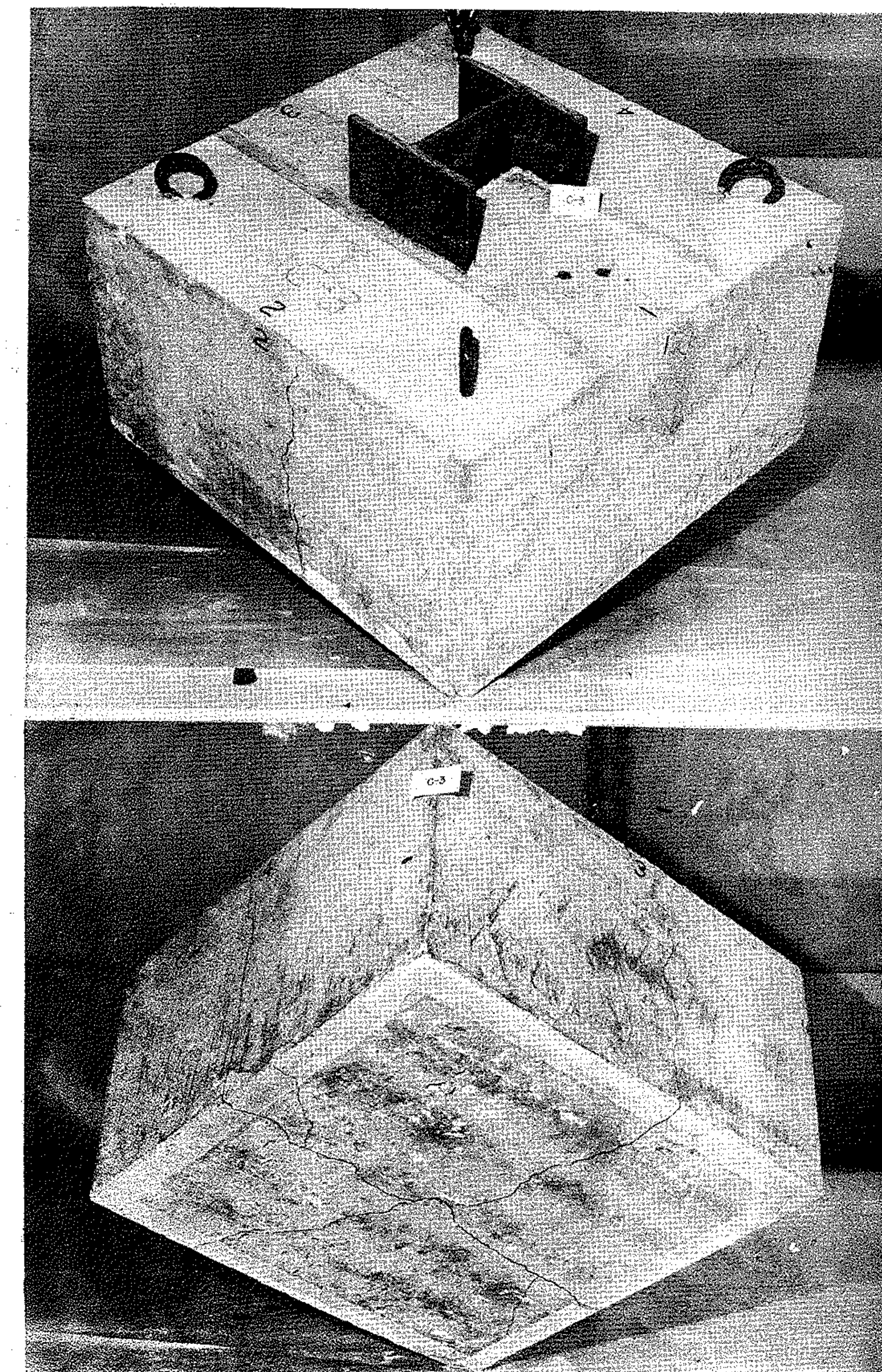


PLATE 13. APPEARANCE OF SPECIMEN C-3 AFTER TESTING.

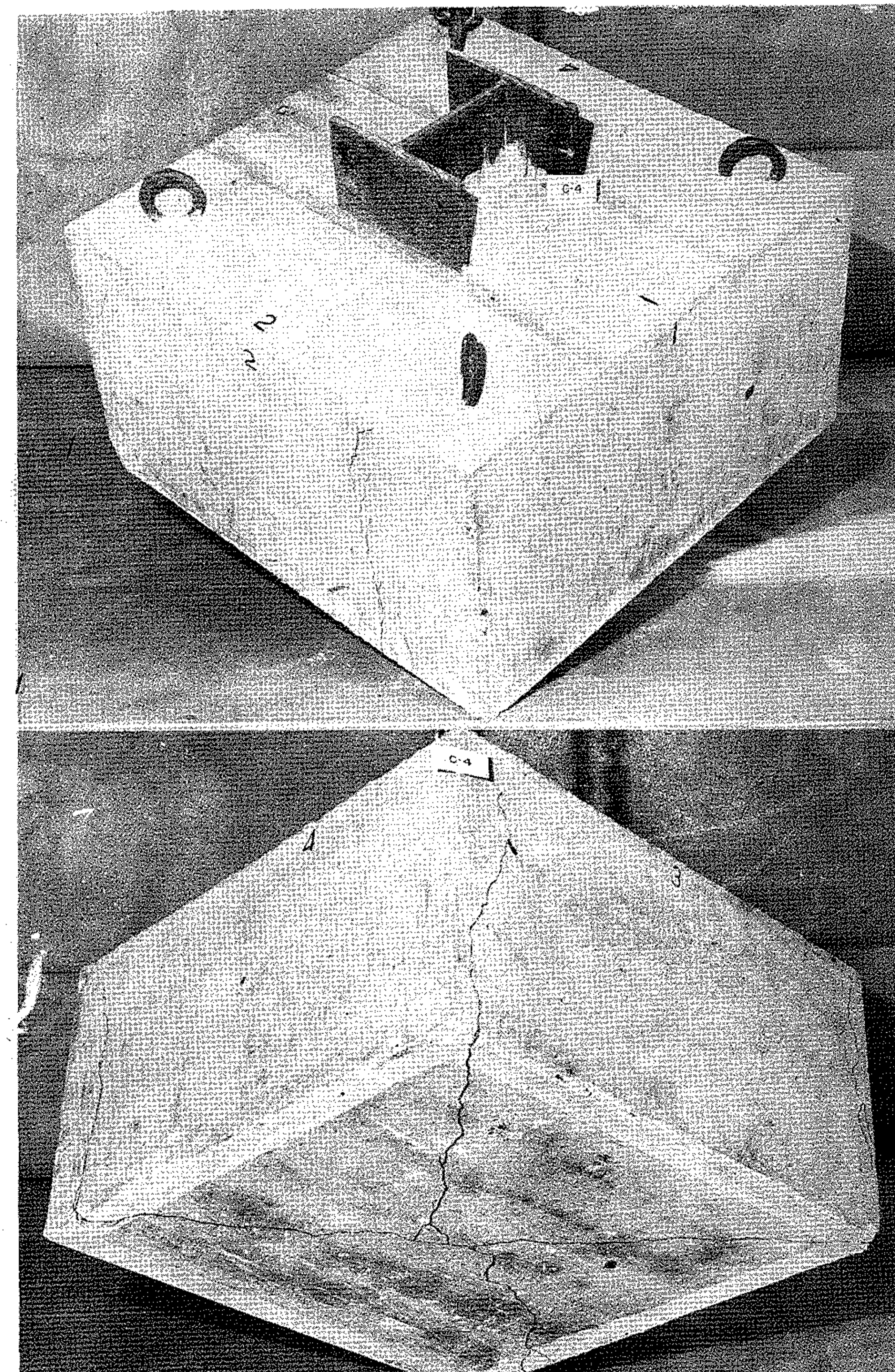


PLATE 14. APPEARANCE OF SPECIMEN C-4 AFTER TESTING

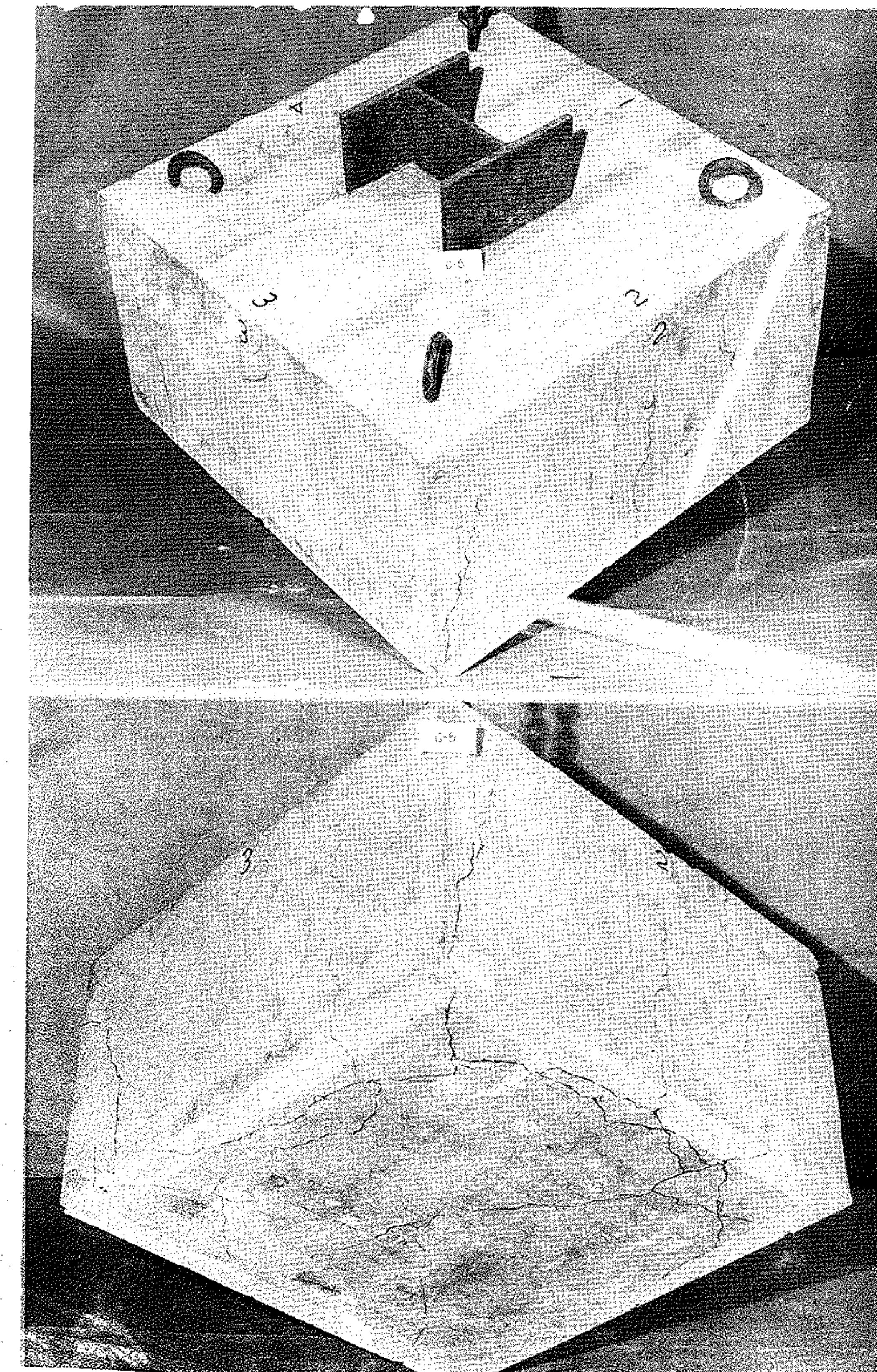


PLATE 15. APPEARANCE OF SPECIMEN C-5 AFTER TESTING

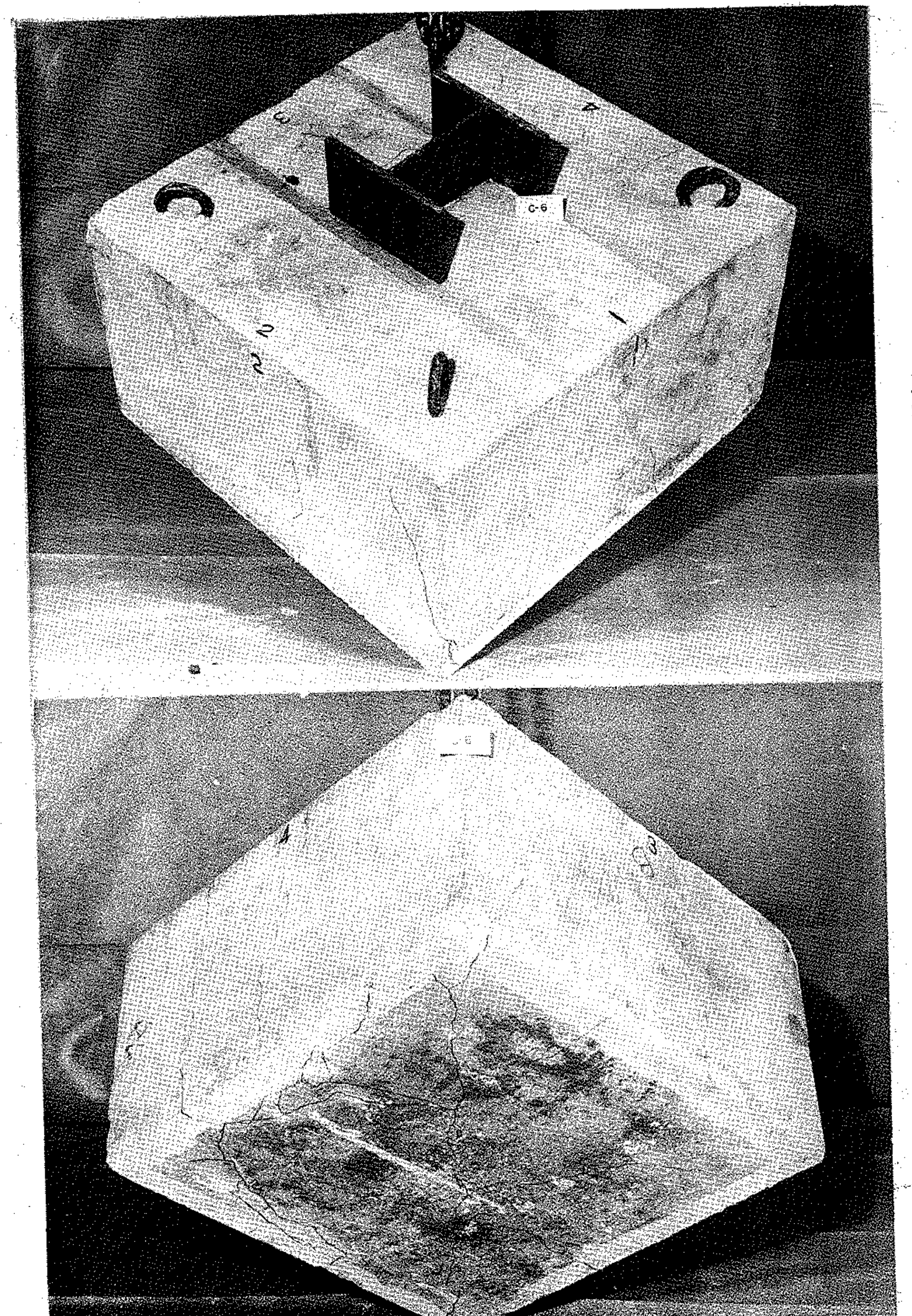


PLATE 16. APPEARANCE OF SPECIMEN C-6 AFTER TESTING.

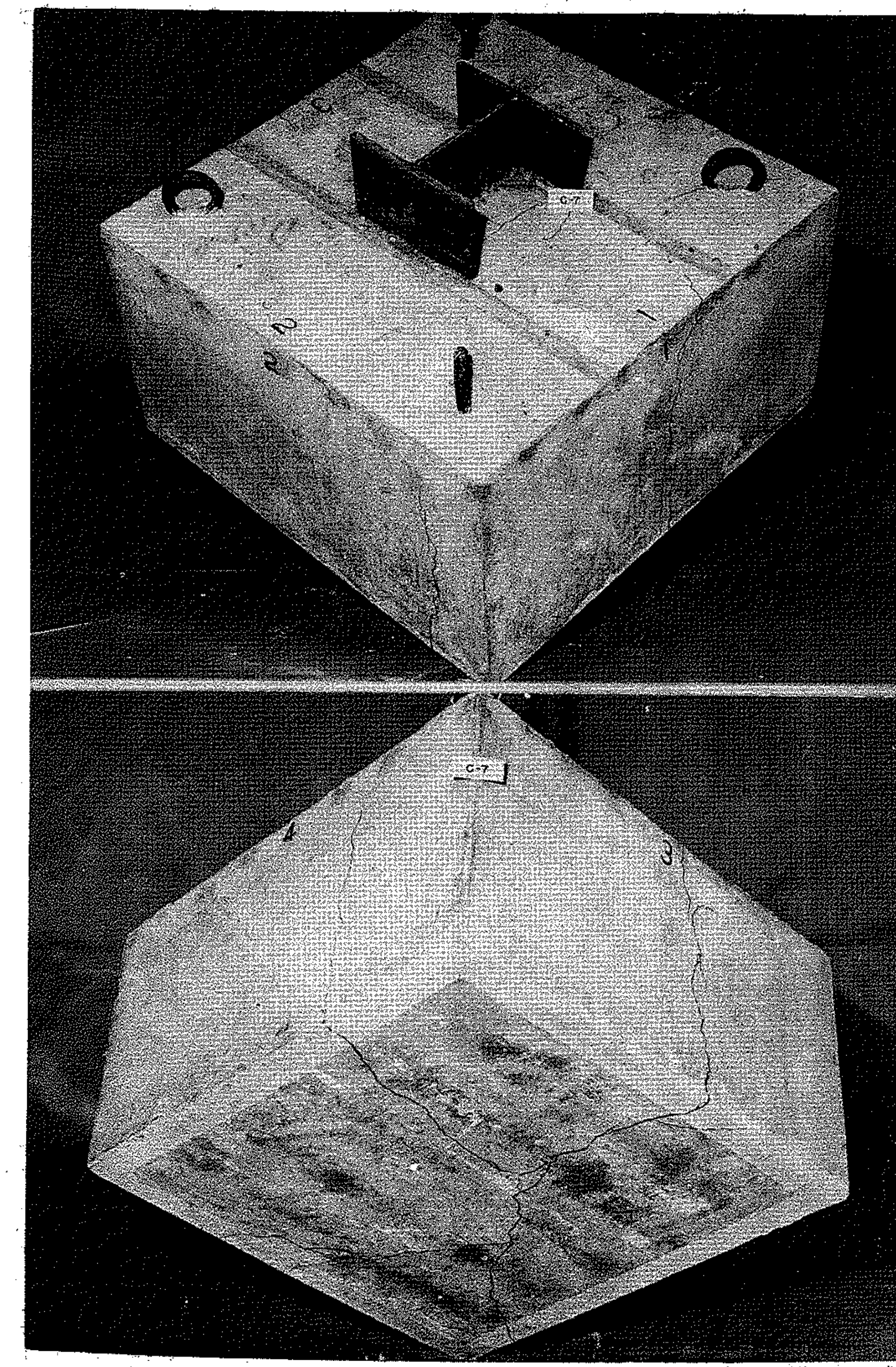


PLATE 17. APPEARANCE OF SPECIMEN C-7 AFTER TESTING.

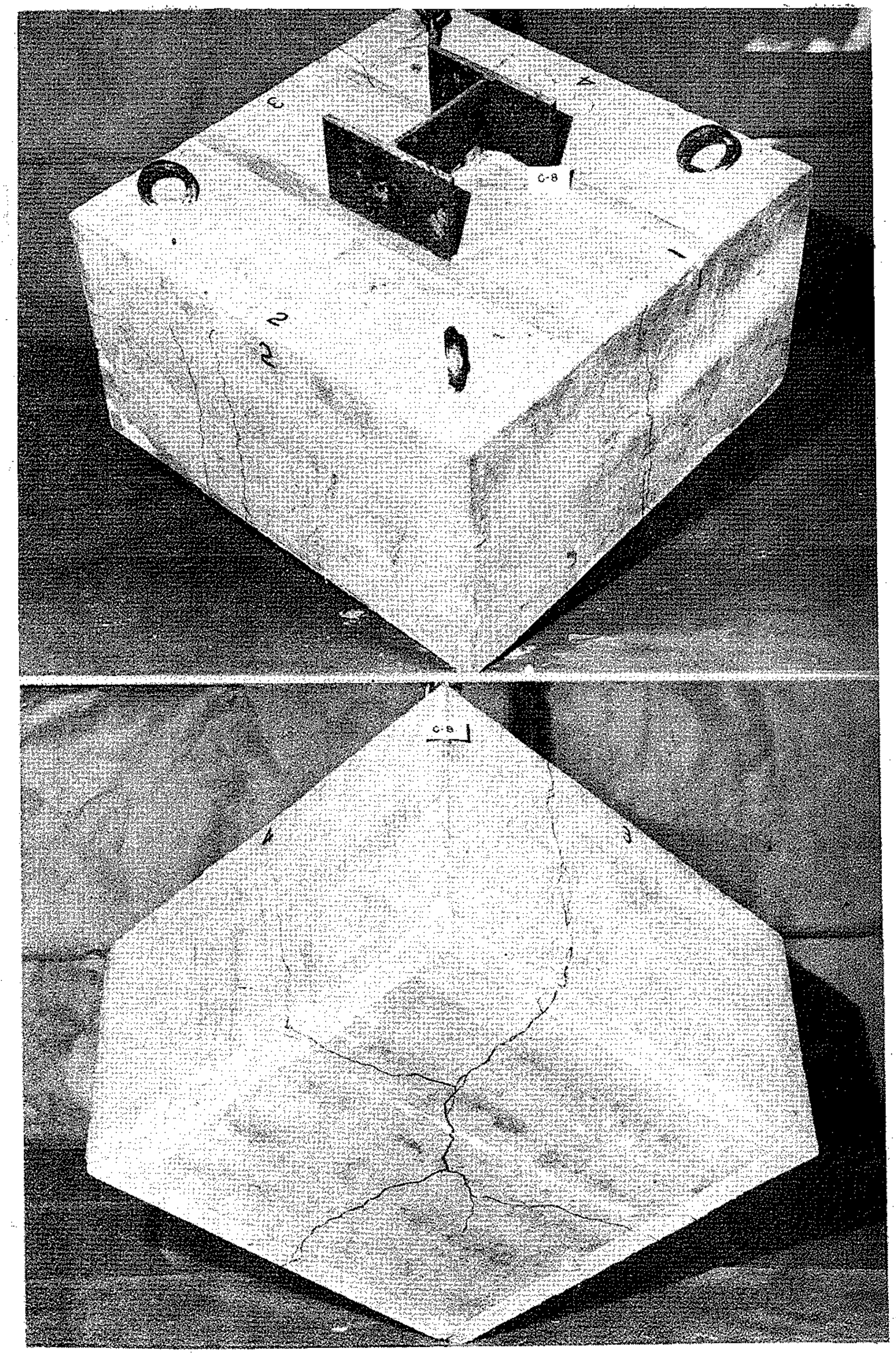


PLATE 18. APPEARANCE OF SPECIMEN C-8 AFTER TESTING.

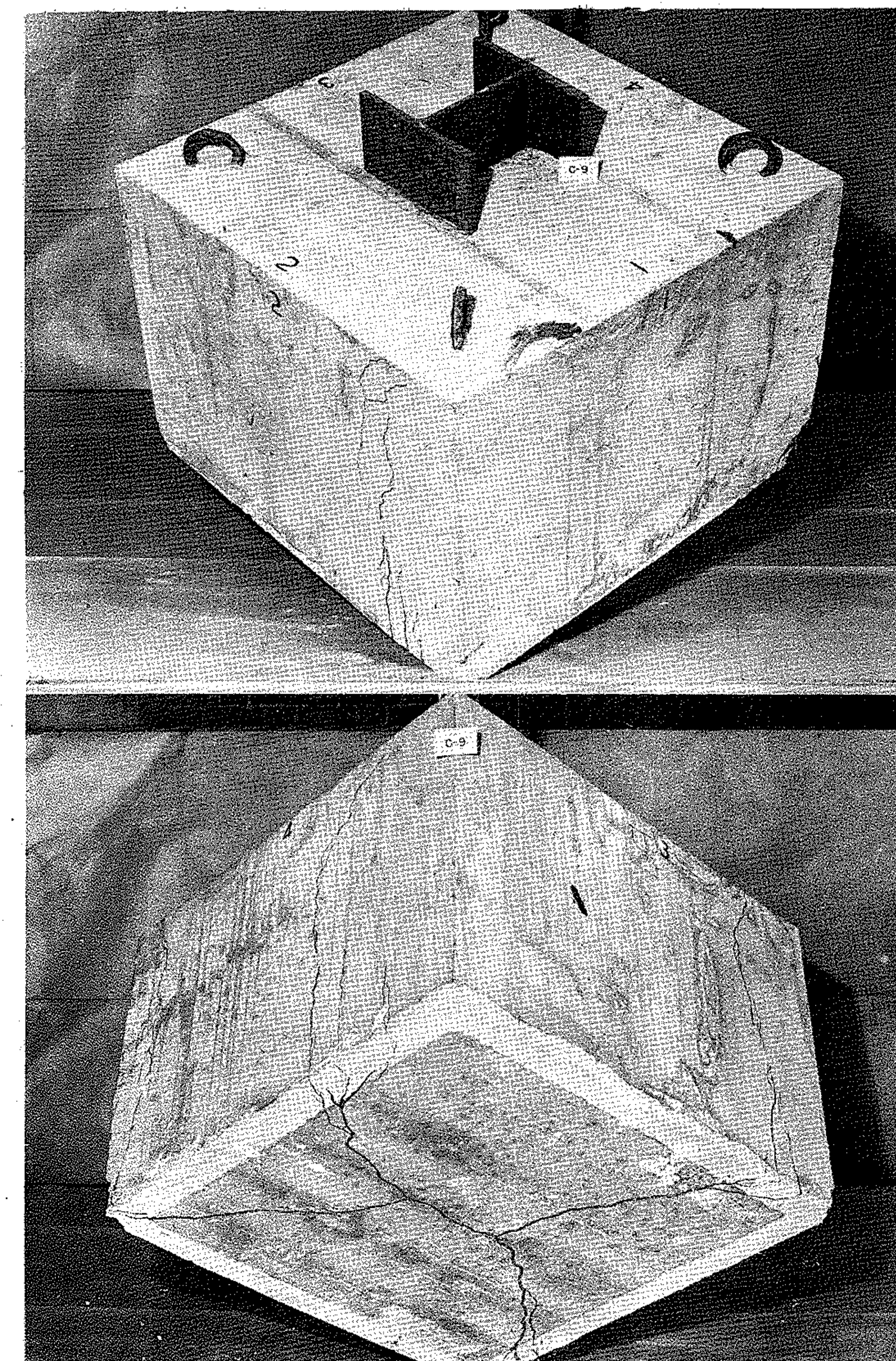


PLATE 19. APPEARANCE OF SPECIMEN C-9 AFTER TESTING.

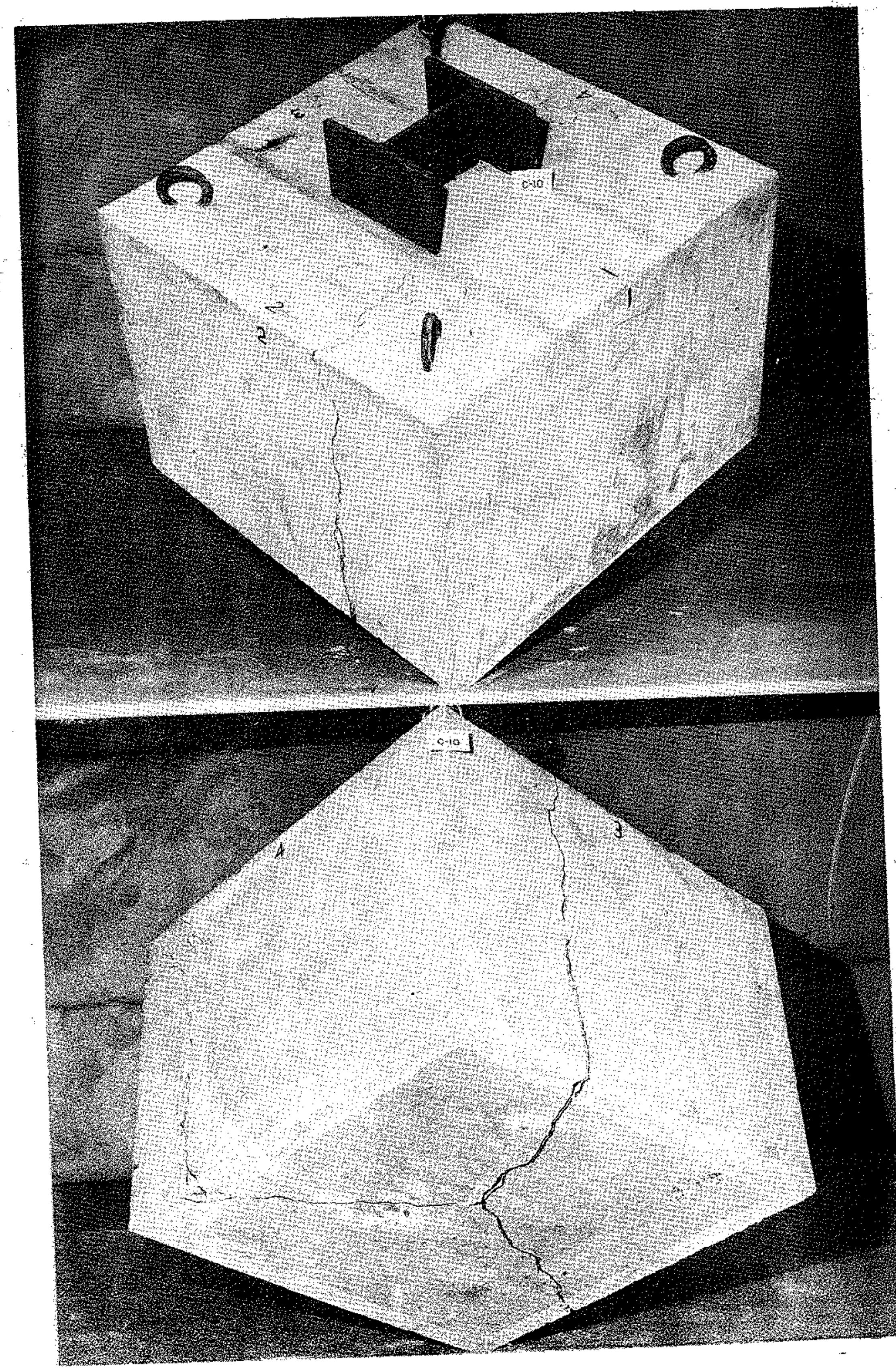


PLATE 20. APPEARANCE OF SPECIMEN C-10 AFTER TESTING.

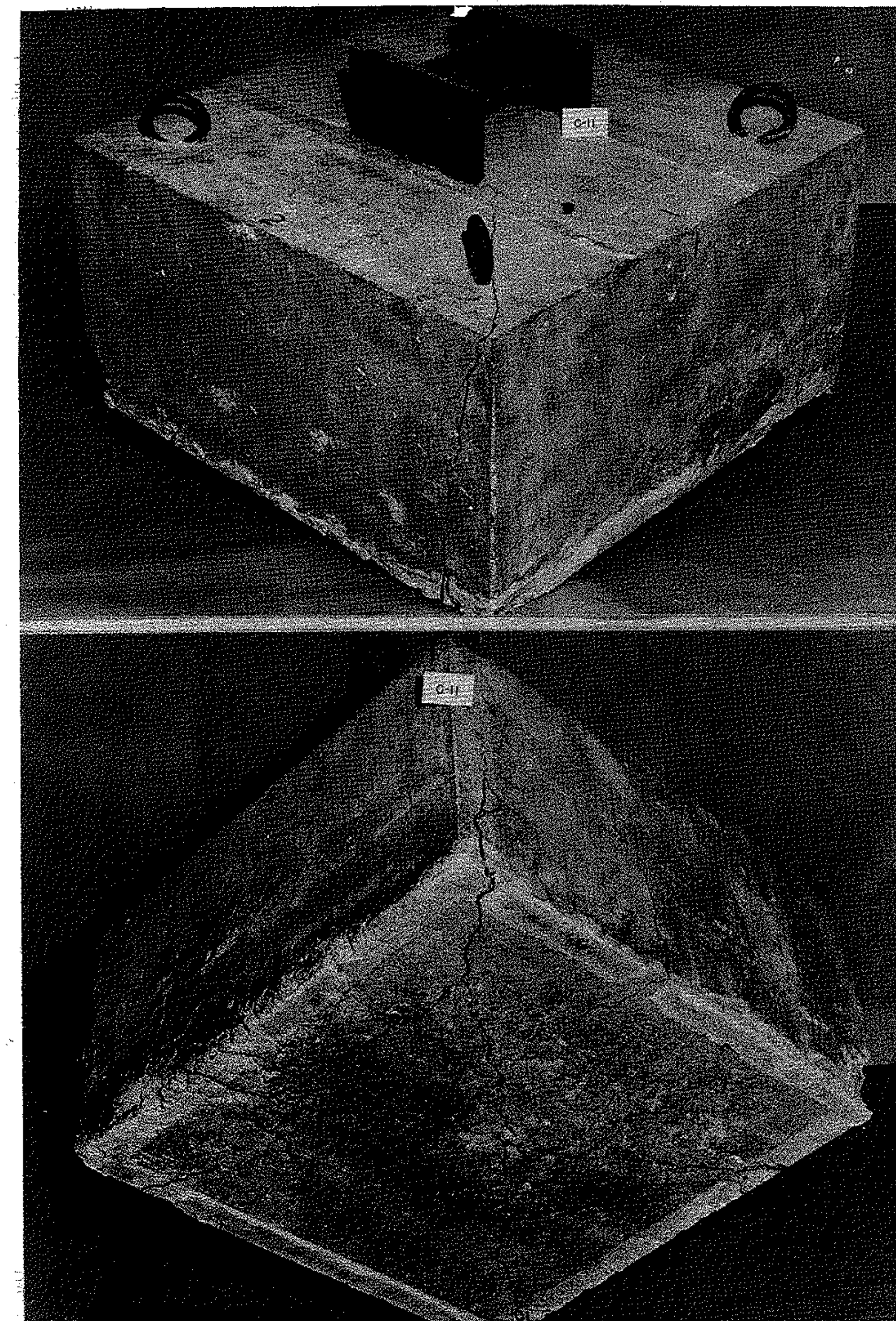


PLATE 21. APPEARANCE OF SPECIMEN C-11 AFTER TESTING.

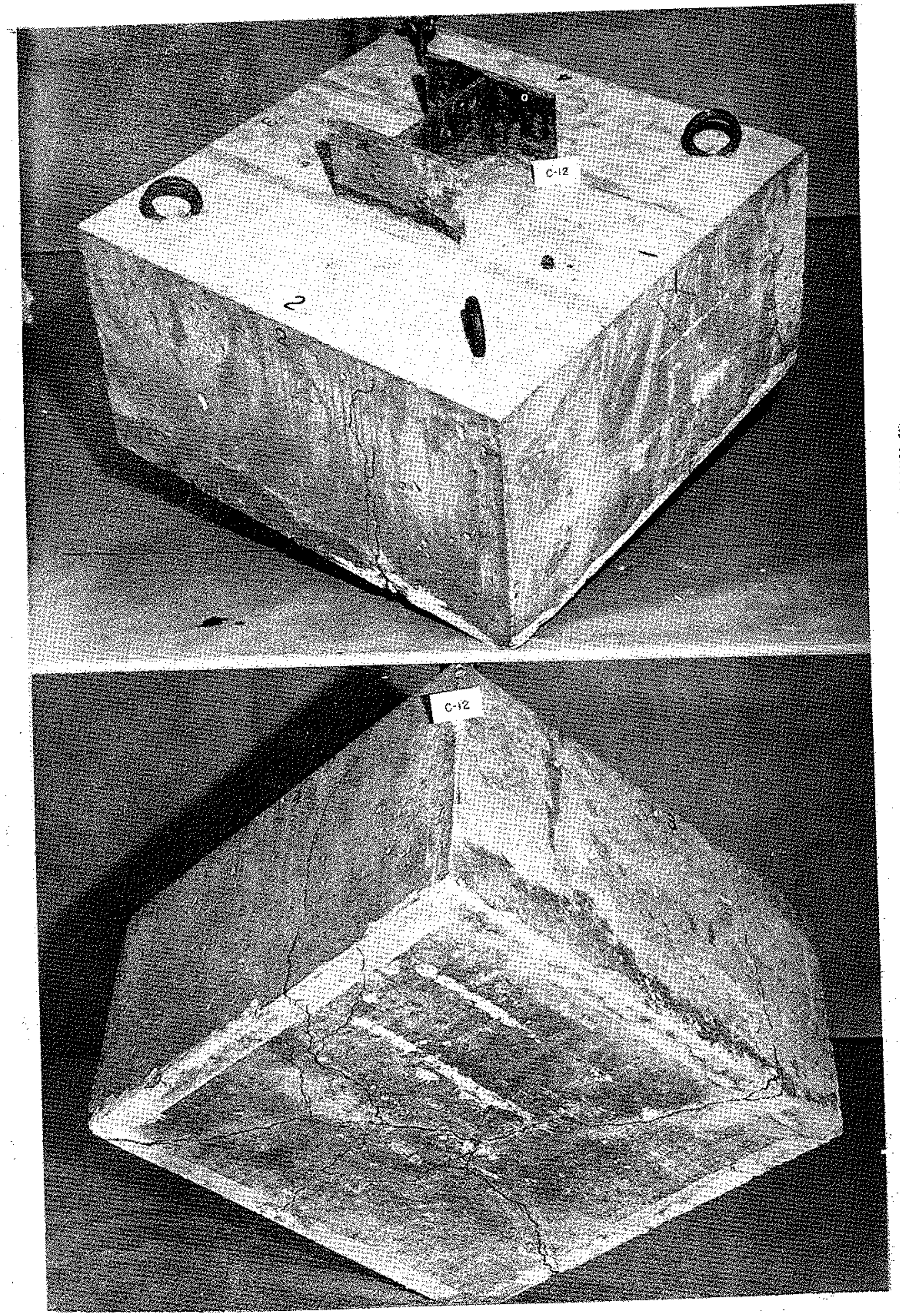


PLATE 22. APPEARANCE OF SPECIMEN C-12 AFTER TESTING.

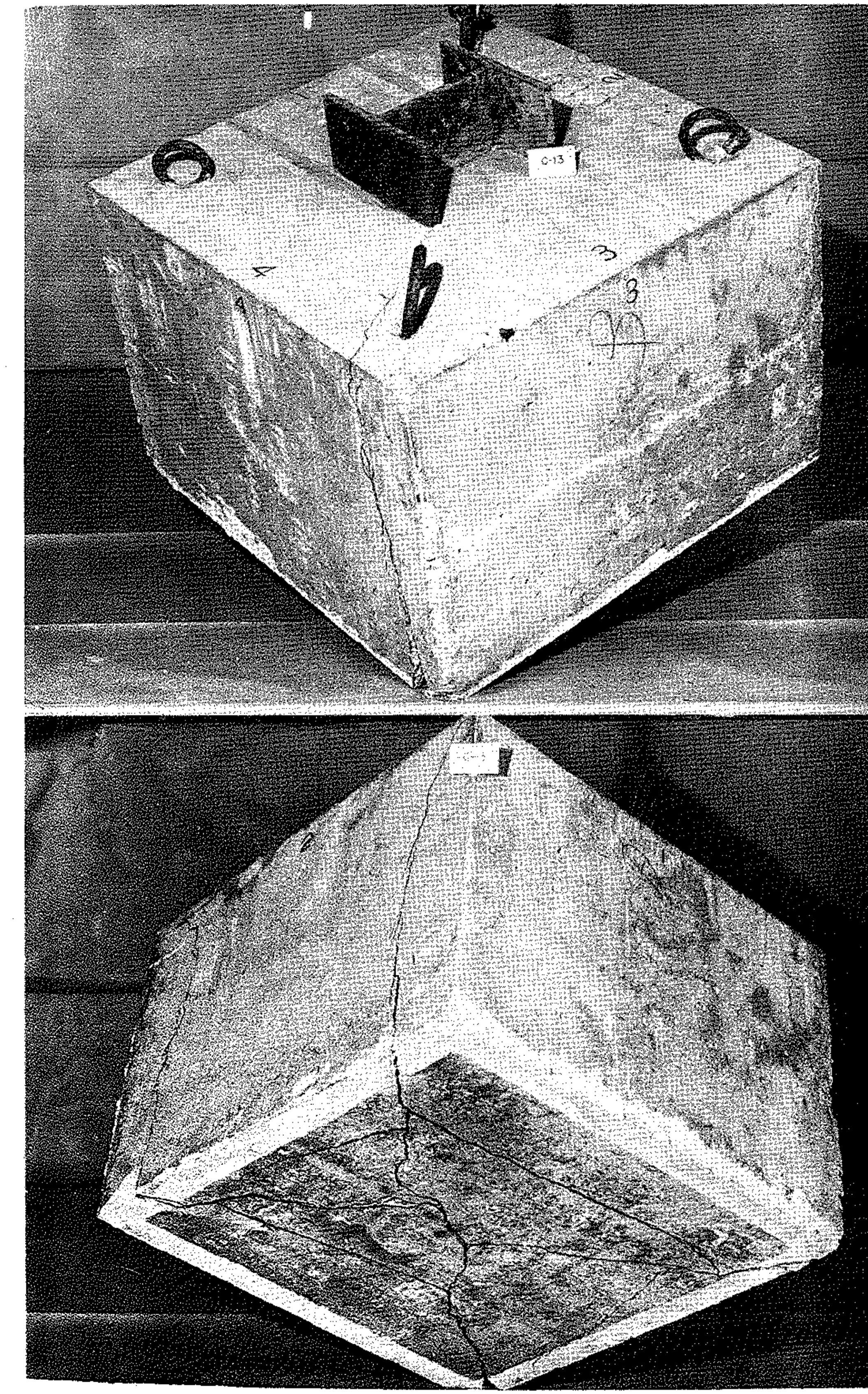


PLATE 23. APPEARANCE OF SPECIMEN C-13 AFTER TESTING.

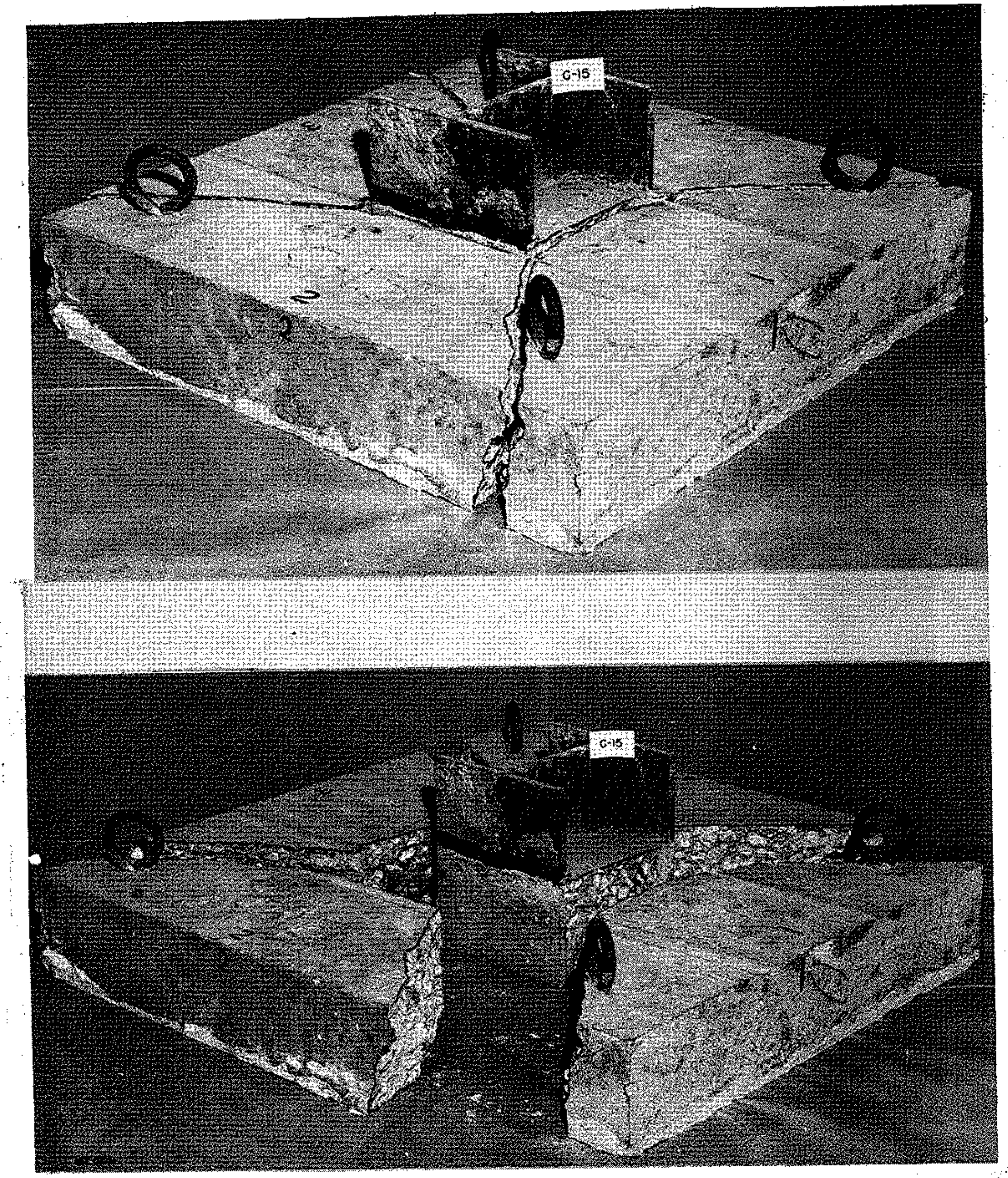


PLATE 24. APPEARANCE OF SPECIMEN C-15 AFTER TESTING.

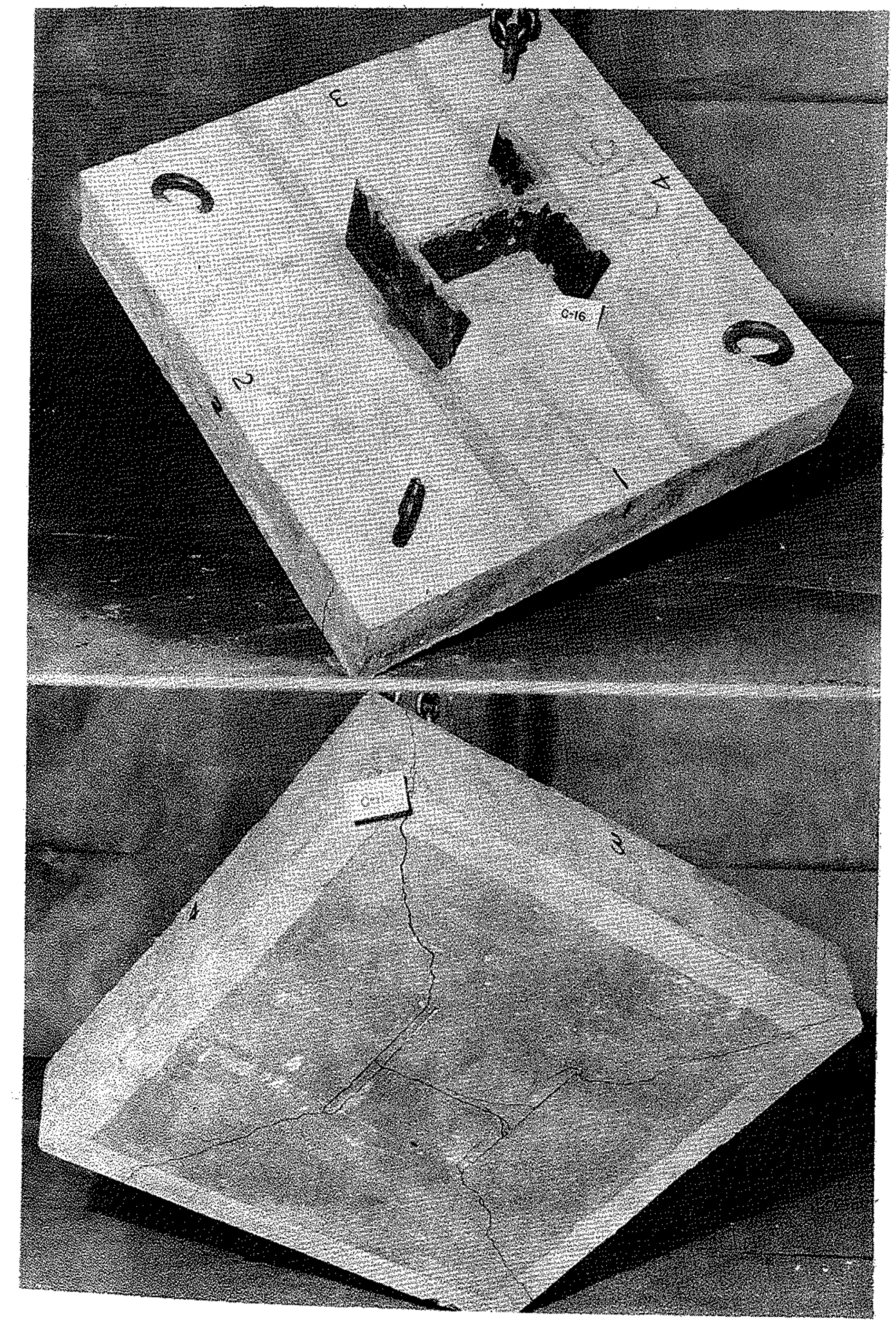


PLATE 25. APPEARANCE OF SPECIMEN C-16 AFTER TESTING.

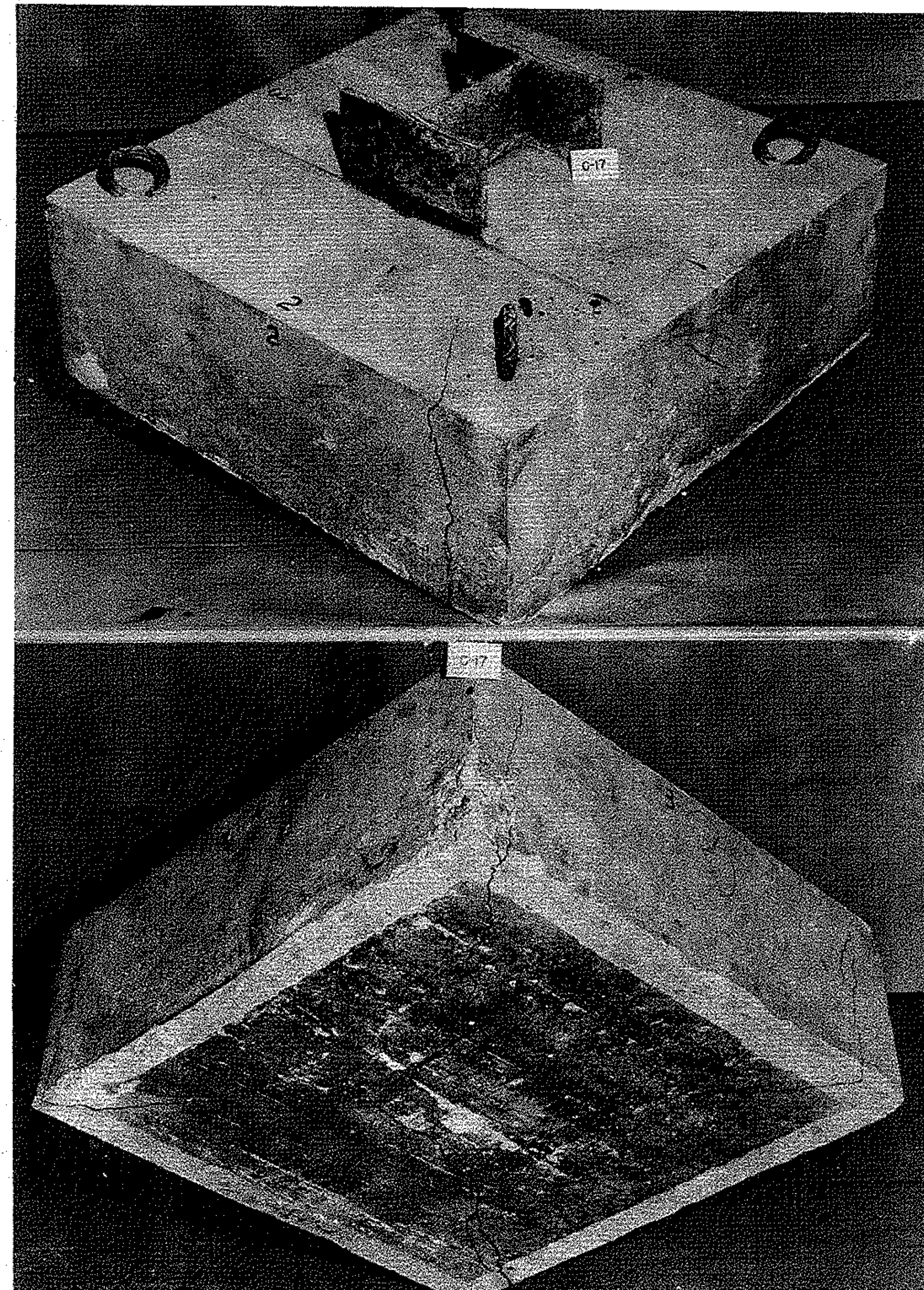


PLATE 26. APPEARANCE OF SPECIMEN C-17 AFTER TESTING.

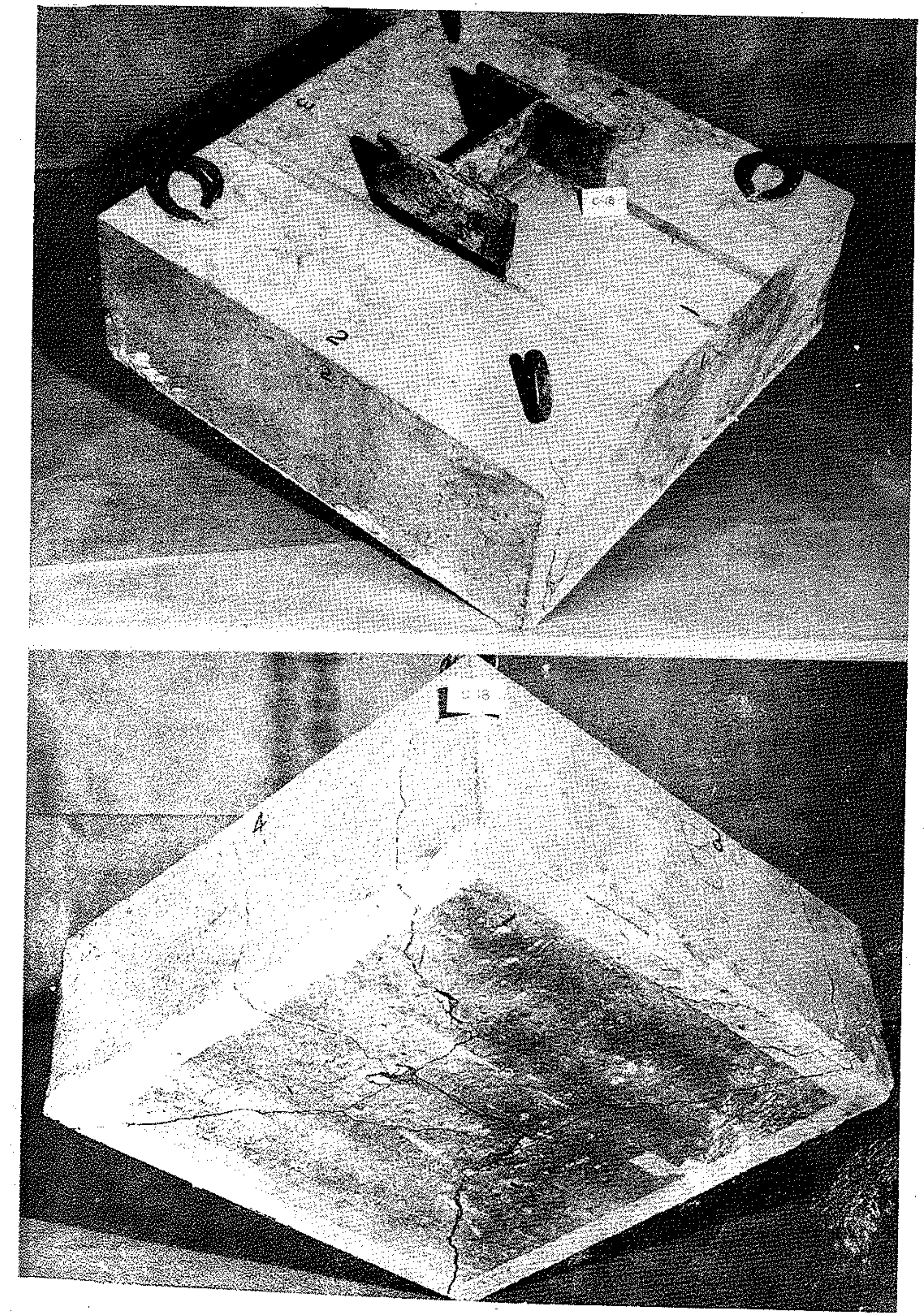


PLATE 27. APPEARANCE OF SPECIMEN C-18 AFTER TESTING

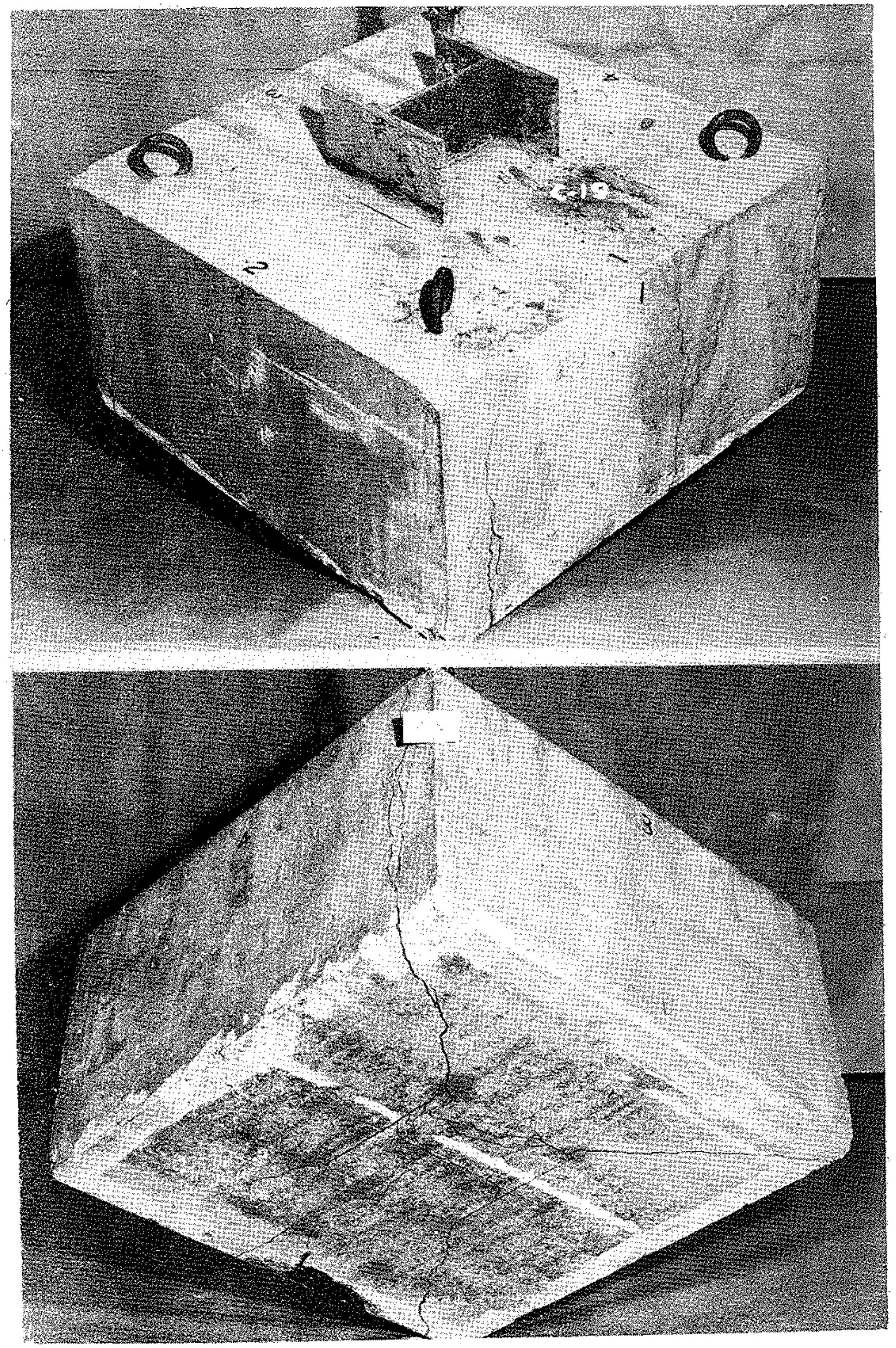


PLATE 28. APPEARANCE OF SPECIMEN C-19 AFTER TESTING.

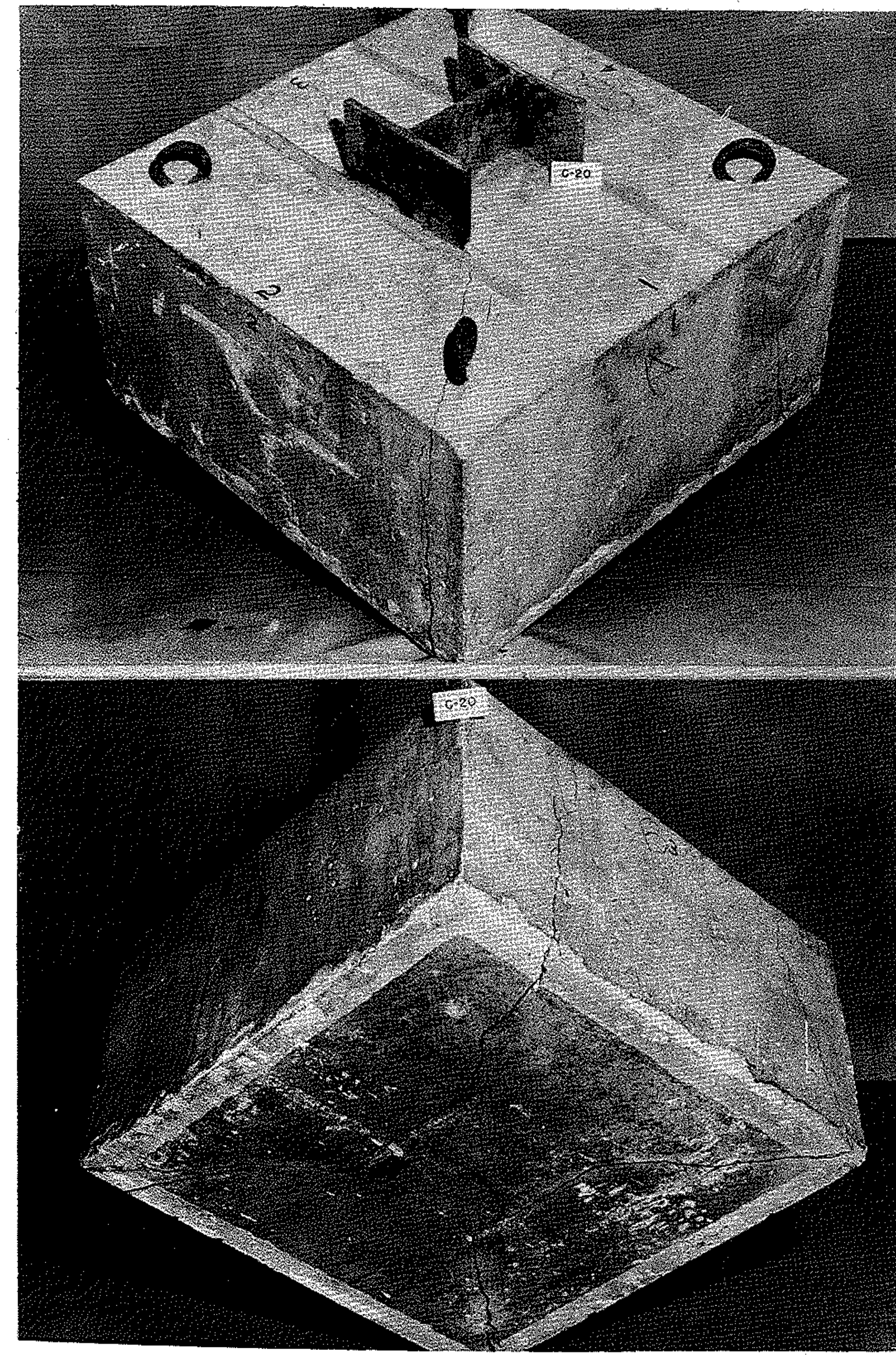


PLATE 29. APPEARANCE OF SPECIMEN C-20 AFTER TESTING.

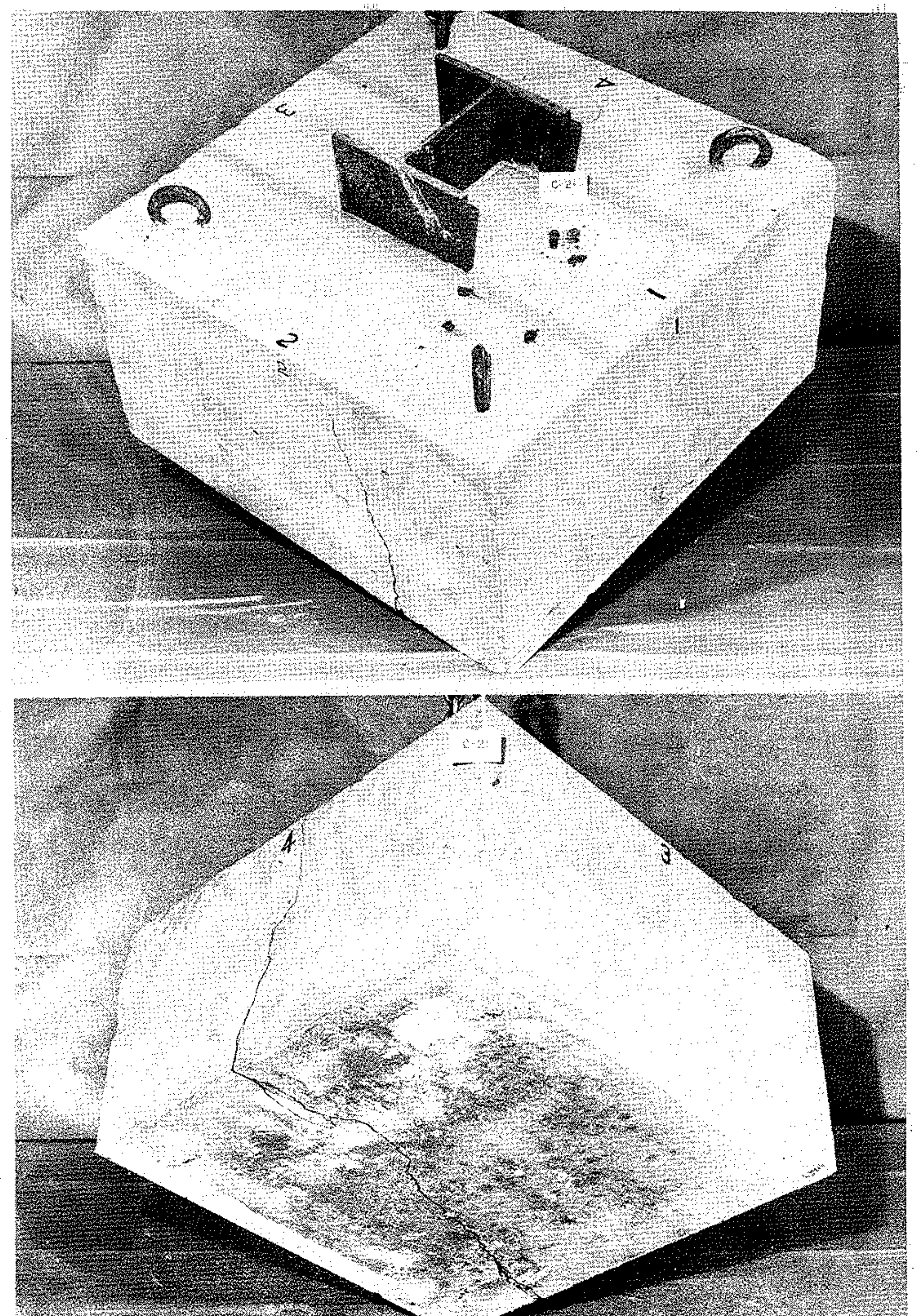


PLATE 30. APPEARANCE OF SPECIMEN C-21 AFTER TESTING.

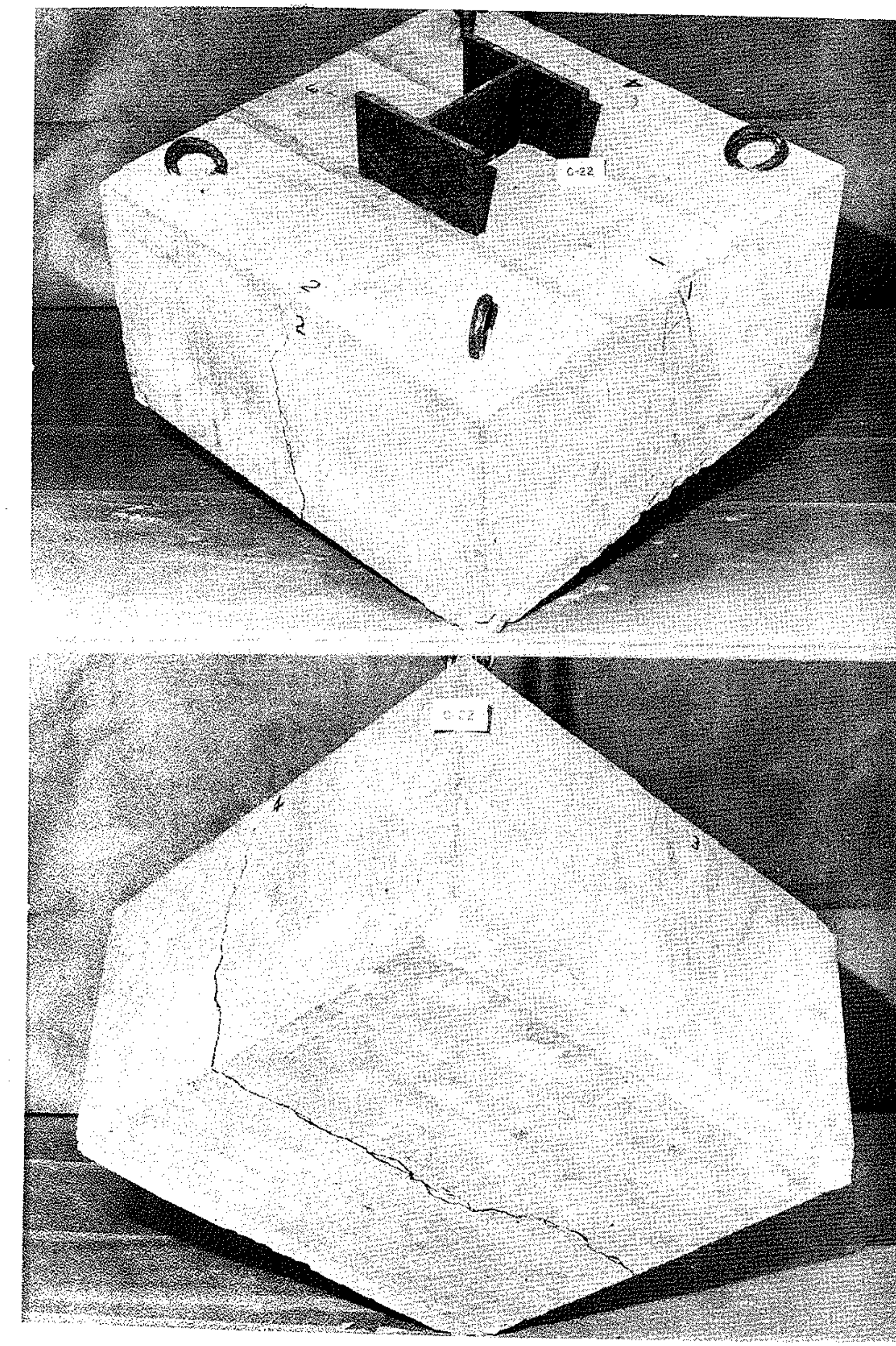


PLATE 31. APPEARANCE OF SPECIMEN C-22 AFTER TESTING.

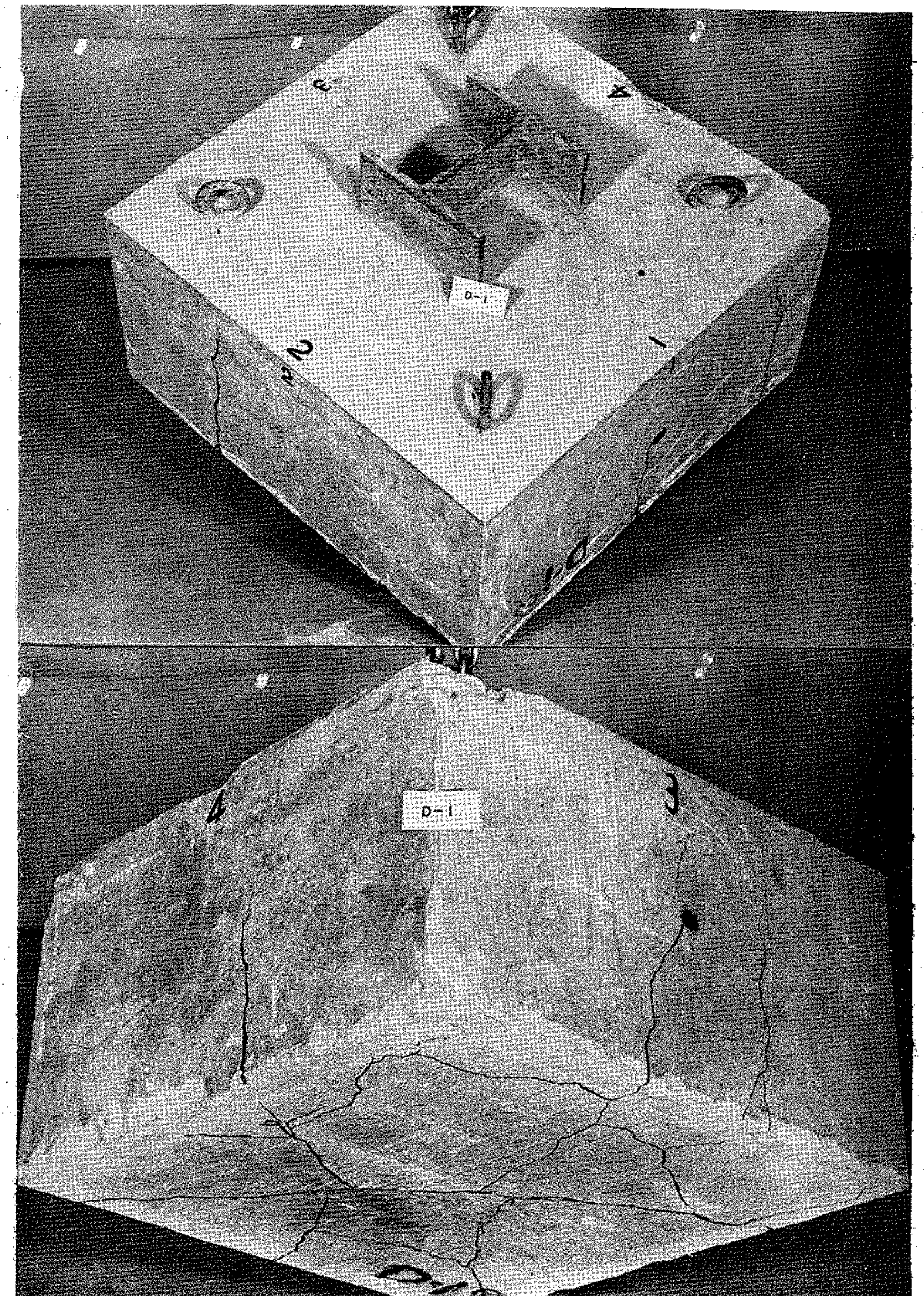


PLATE NO. 32. APPEARANCE OF SPECIMEN D-1 AFTER TESTING.

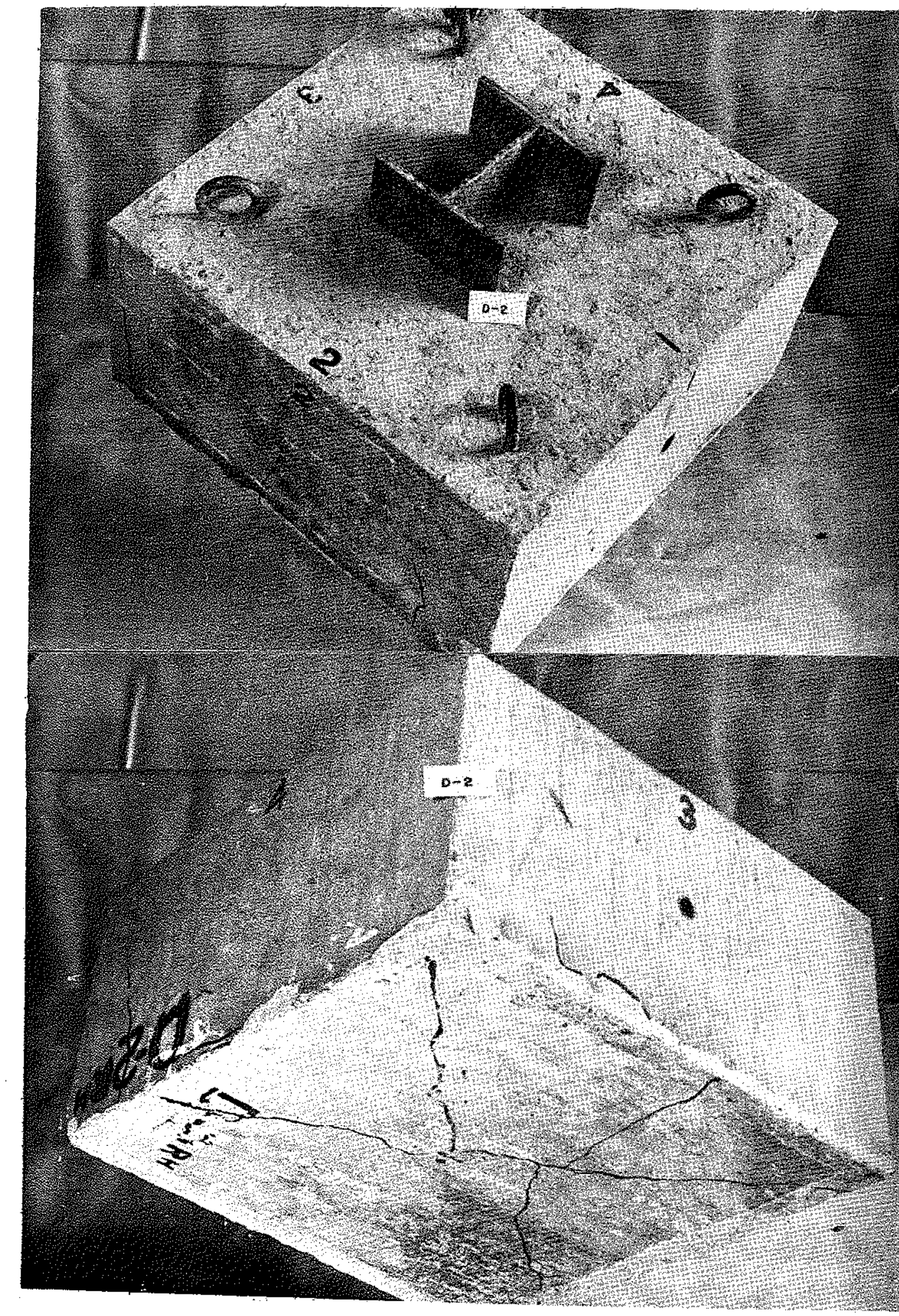


PLATE NO. 33. APPEARANCE OF SPECIMEN D-2 AFTER TESTING.

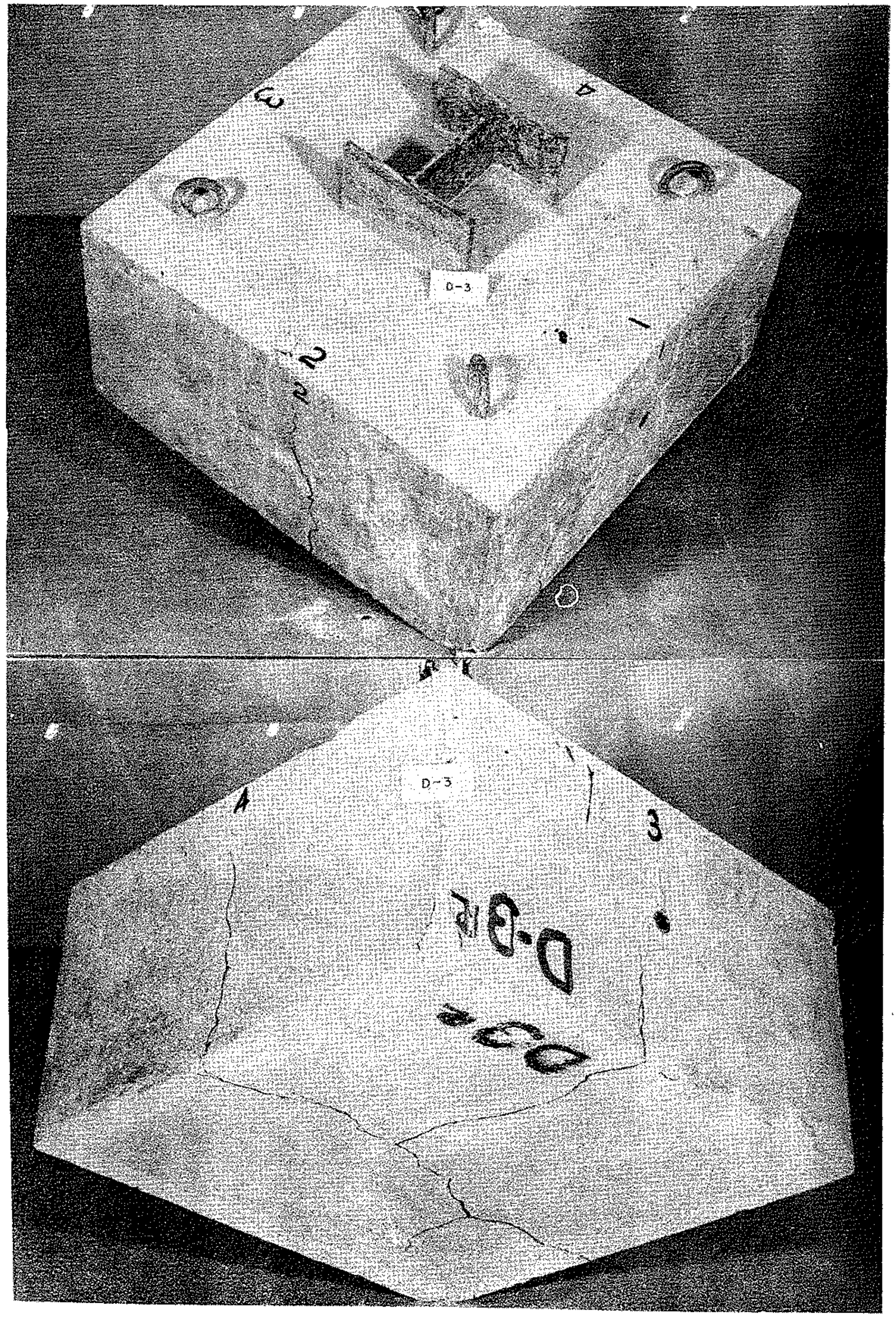


PLATE NO. 34. APPEARANCE OF SPECIMEN D-3 AFTER TESTING.

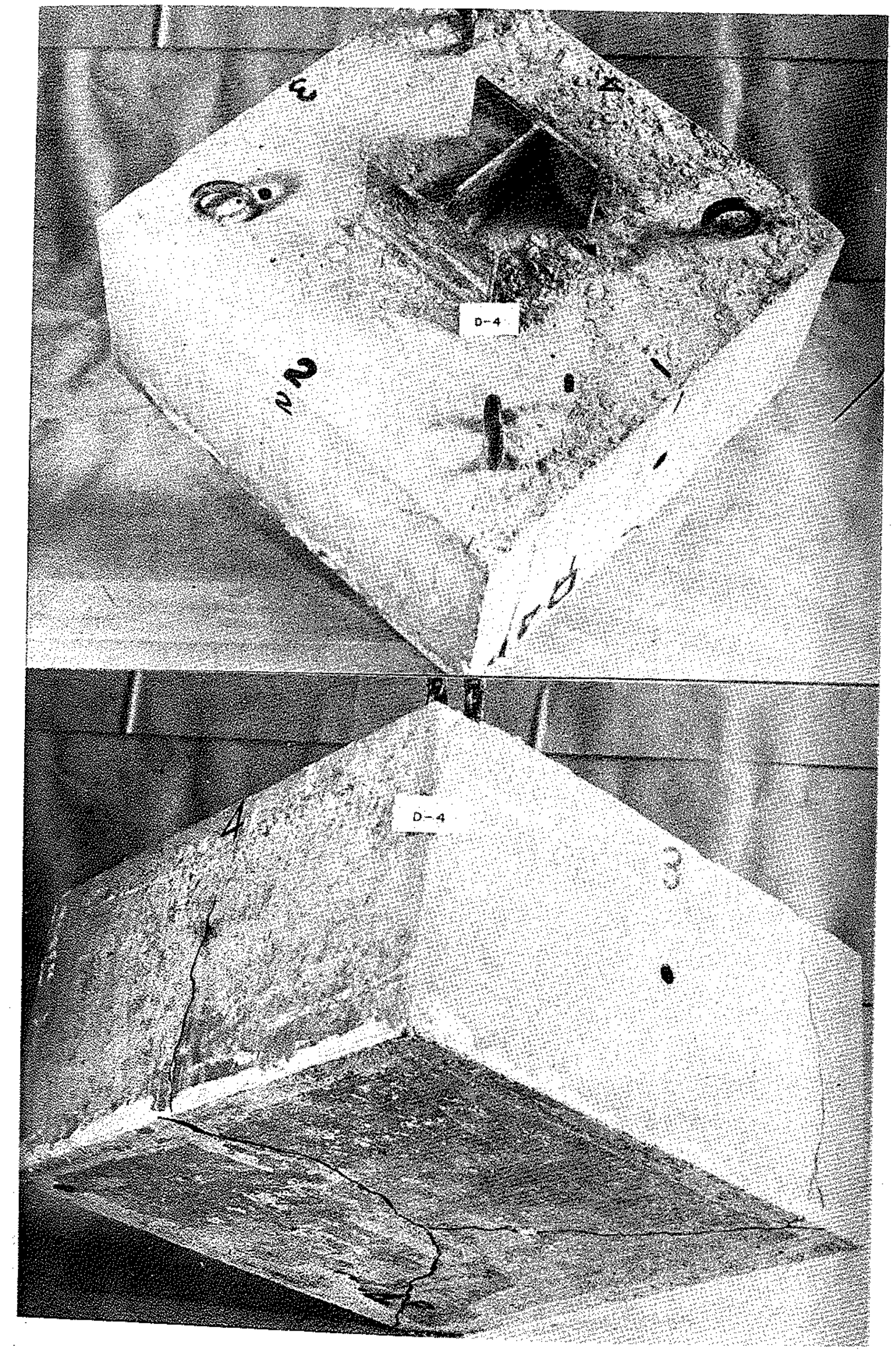


PLATE NO. 35. APPEARANCE OF SPECIMEN D-4 AFTER TESTING.

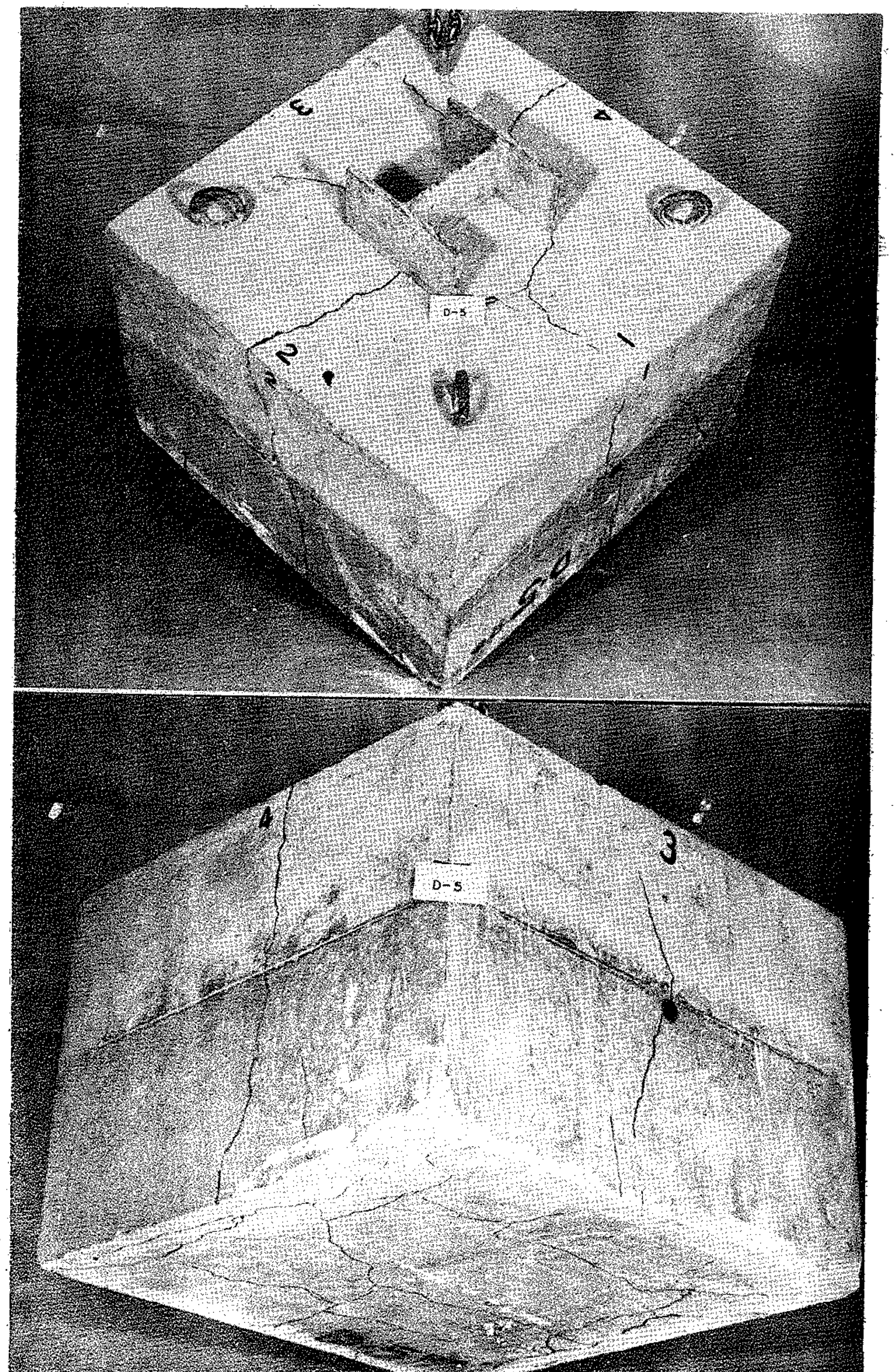


PLATE NO. 36. APPEARANCE OF SPECIMEN D-5 AFTER TESTING.

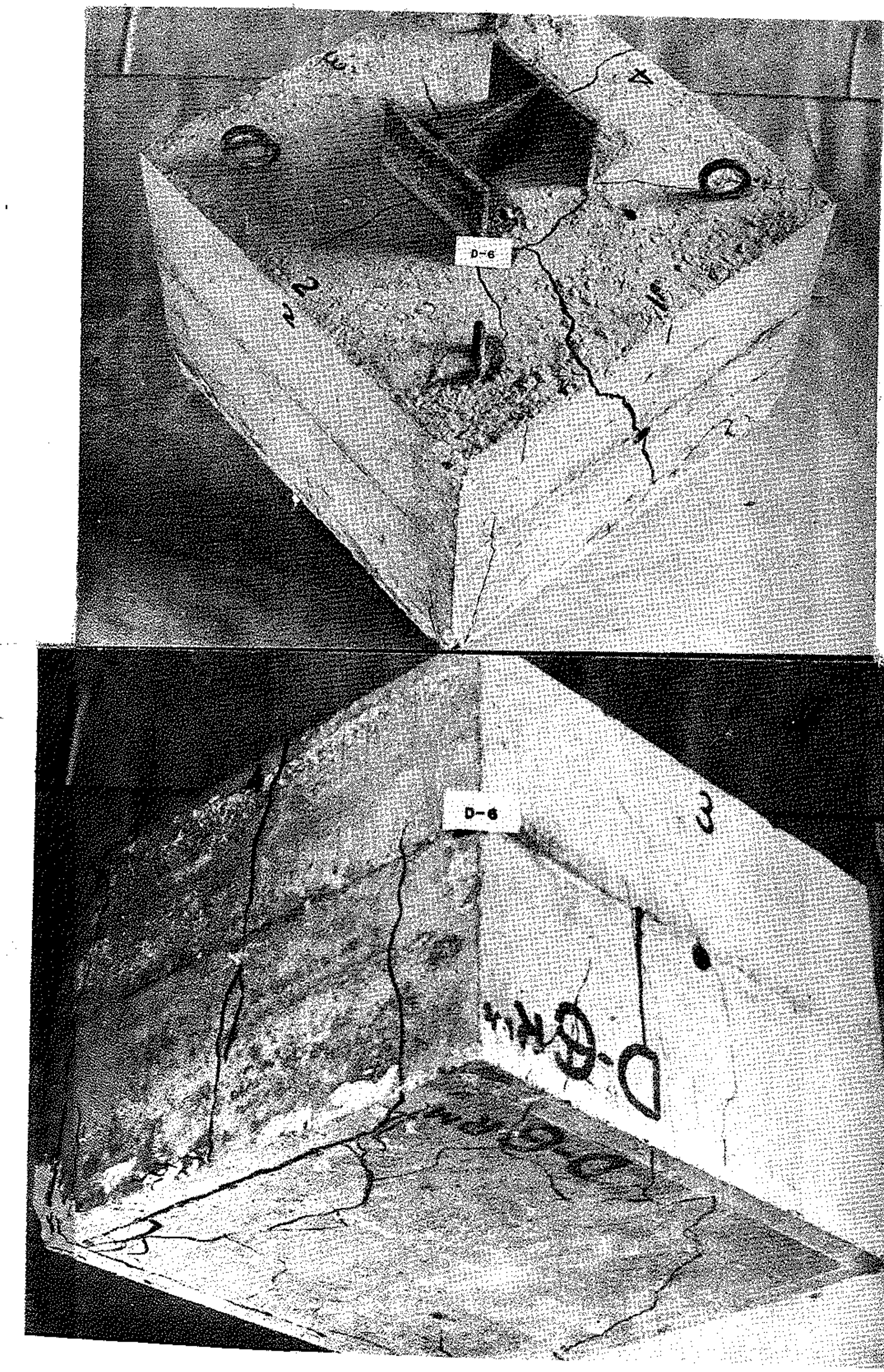


PLATE NO. 37. APPEARANCE OF SPECIMEN D-6 AFTER TESTING.

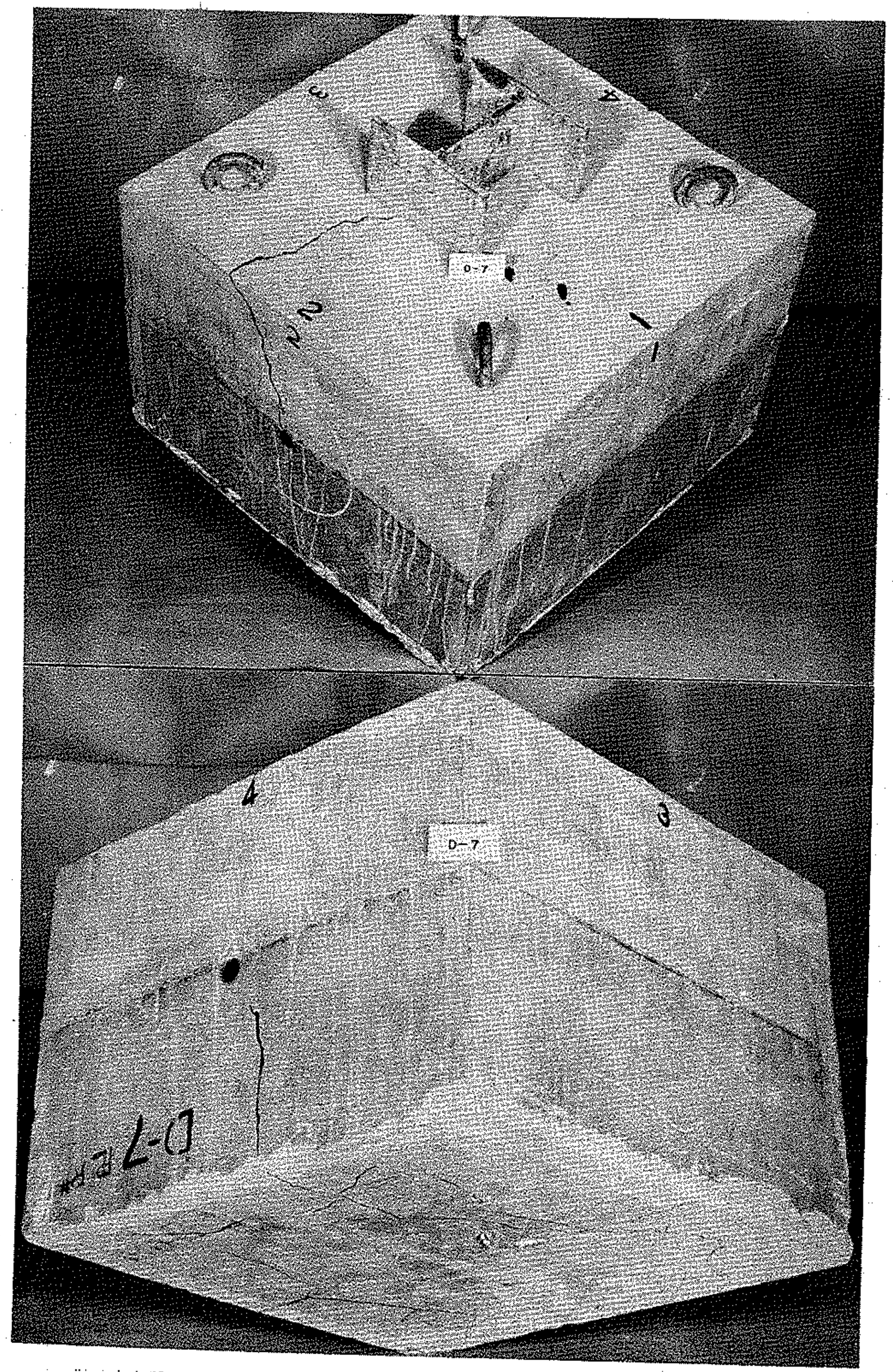


PLATE NO. 38 APPEARANCE OF SPECIMEN D-7 AFTER TESTING.

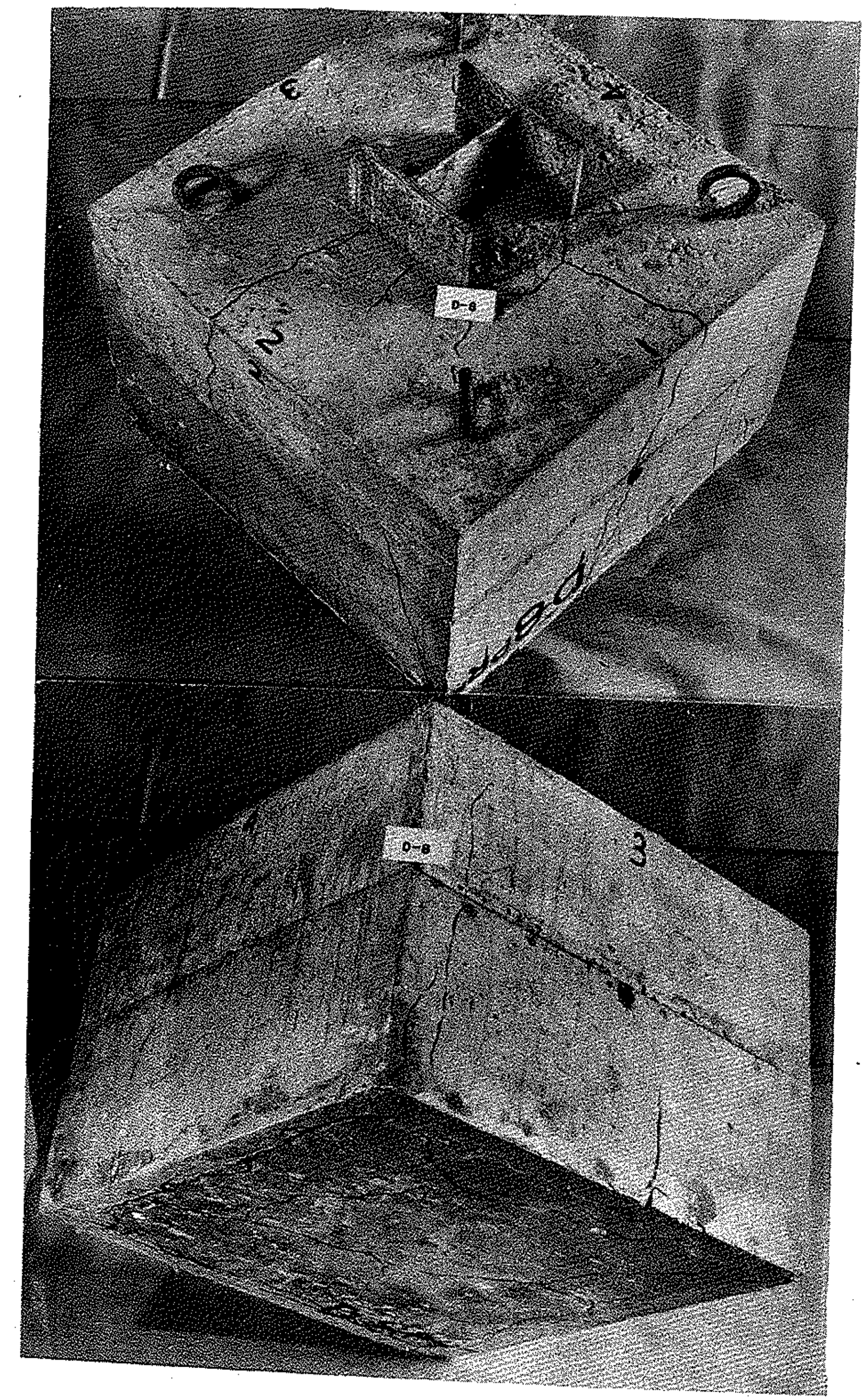


PLATE NO. 39. APPEARANCE OF SPECIMEN D-8 AFTER TESTING.

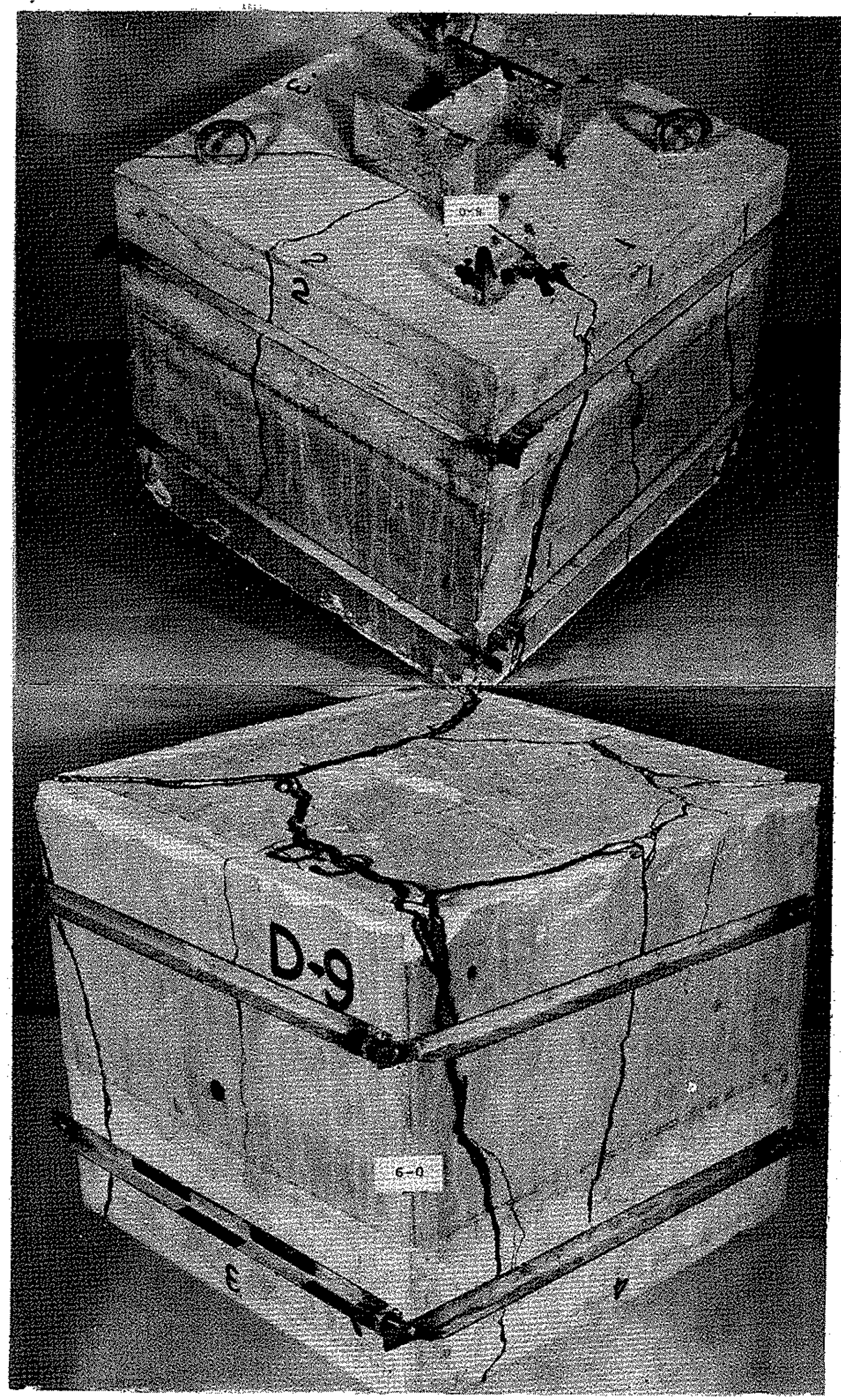


PLATE NO. 40. APPEARANCE OF SPECIMEN D-9 AFTER TESTING.

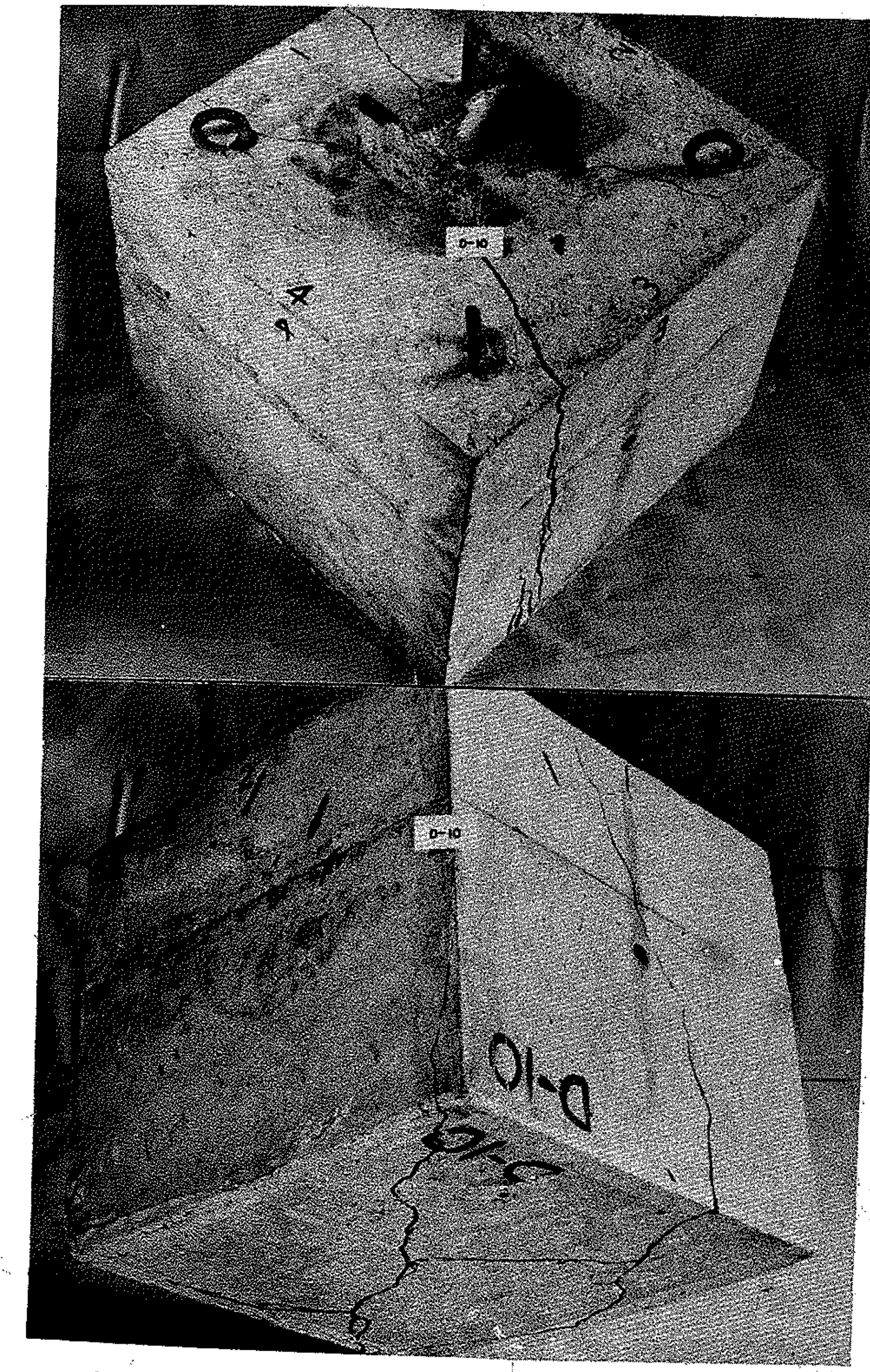


PLATE NO. 41. APPEARANCE OF SPECIMEN D-10 AFTER TESTING.

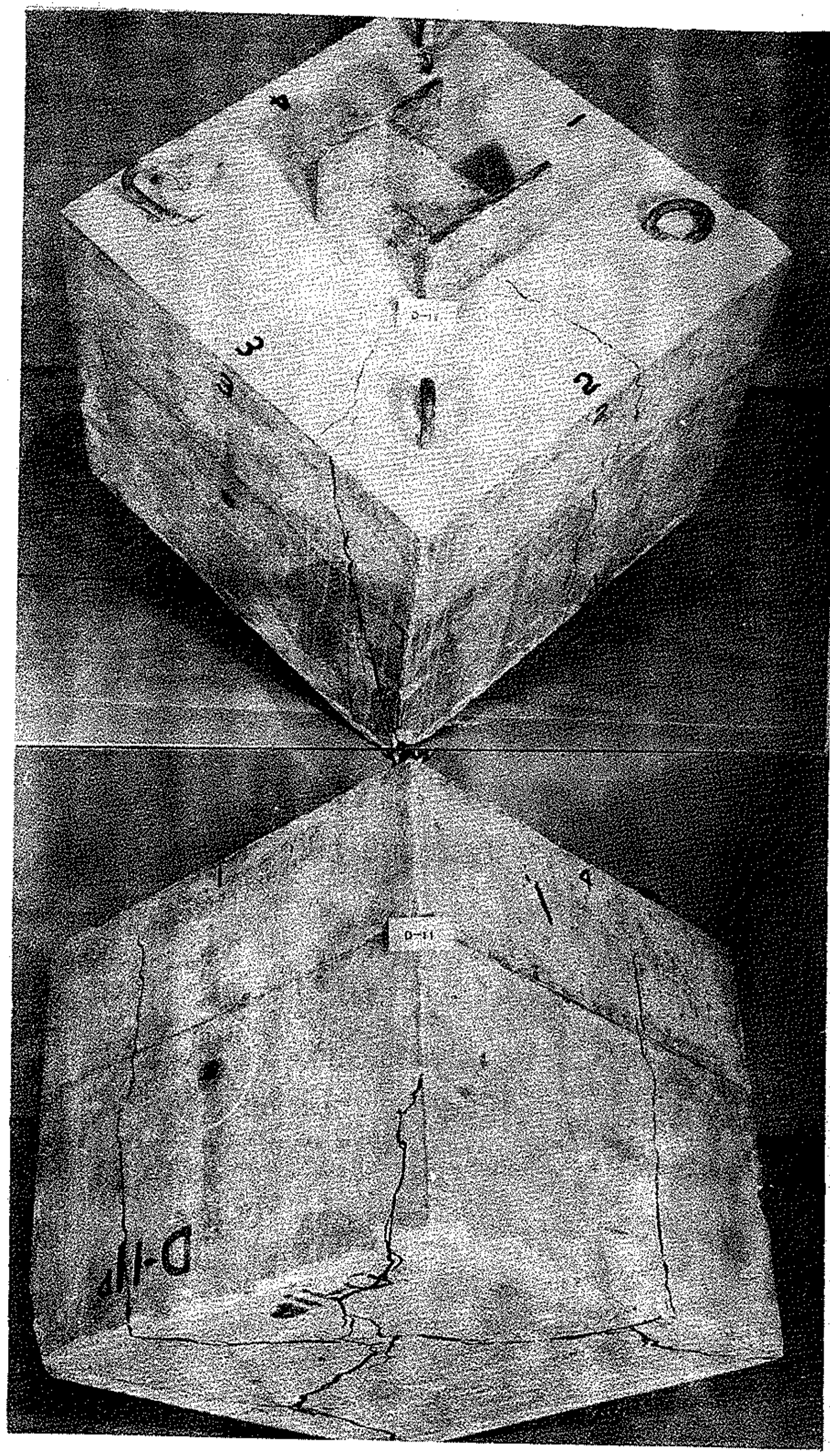


PLATE NO. 42. APPEARANCE OF SPECIMEN D-11 AFTER TESTING.

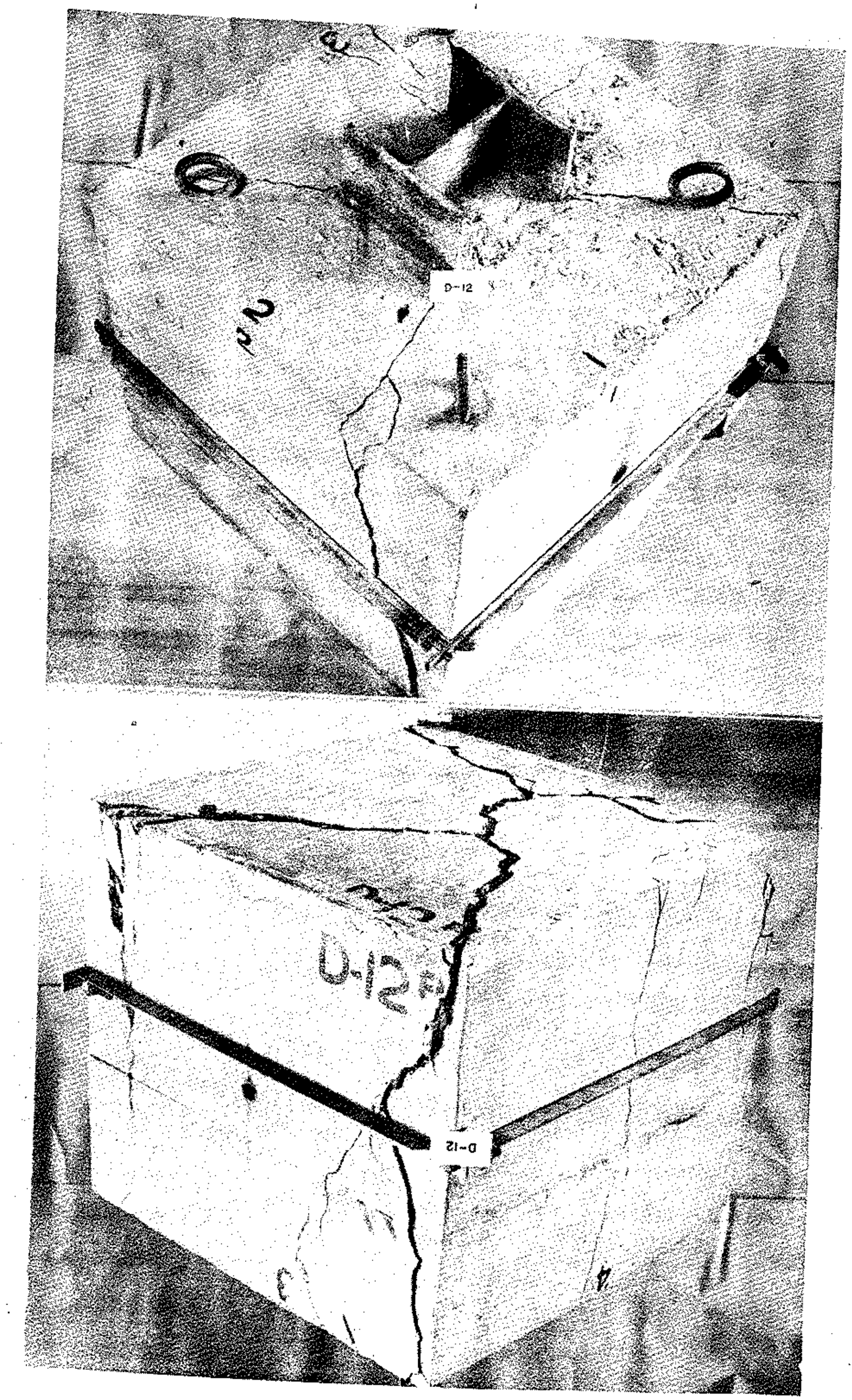


PLATE NO. 43. APPEARANCE OF SPECIMEN D-12 AFTER TESTING.

PLATE NO. 44. CLOSE-UP VIEW OF SPECIMEN D-12 AFTER TESTING.

DISCUSSION OF RESULTS

GENERAL

In the plain concrete specimens failure at the ultimate loading was rapid and complete, whereas in the reinforced concrete specimens failure was gradual with many small tension cracks appearing before the ultimate loading was reached.

Since the determination of a proper working stress is based mainly on the greatest load reached within the elastic limit of the materials rather than on the ultimate load at complete failure, the elastic limit for each of the specimens has been determined from the stress-strain diagrams (Figures 29 to 55) and recorded in Table VII together with the net permanent deformation.

SERIES "A"

From Series 'A' it can be seen that there need be no concern regarding the compression stress in the concrete in contact with the H-shaped surface at the end of a steel H-pile. Its ultimate strength is shown to be greater than the compressive ultimate strength of the steel H-pile itself and is so great that even with a generous factor of safety it would permit a working capacity for the pile of a greater magnitude than would usually be entertained. Even in Test A-9 in which there was no embedment whatever the average permanent indentation due to an extreme force of more than 35,000 lbs. per square inch (the maximum elastic as per Table VII) was only 0.03 inch despite imperfect seating of the free 12 inch length of H-pile on the concrete surface.

Test A-6 (10" x 10" H, 23 1/2" square block) indicated that when a force greater than 400,000 lbs. (the maximum elastic as per Table VII) is delivered to the concrete at the end of the pile (compared with the maximum of 188,000 lbs. for the 6" x 6" H-piles and the same size of block) the transverse tension created in the block is greater than the enclosing concrete can resist, and the block cracked. This was not quite a fair test since the 23 1/2 inch square block was disproportionately small for the 10" x 10" size of H-pile for which the spacing in a structure is generally at least 36 inches. However, this test disclosed the probable general character of failure of the concrete in contact with a pile.

TABLE NO. VII
SUMMARY OF MAXIMUM ELASTIC
LOAD-DEFORMATION DATA

Specimen No.	Elastic Limit Bearing Capacity			Failure of Specimen in Pile or Concrete	
	Total Load Kips(1)	Unit Stress(2) lbs./sq.in.	Net (3) Deformation Inches	at Elastic Limit	at Ultimate Strength
A-1	PRELIMINARY TEST			CONC.(4)	---
A-2	184.0	40,250	.057	STEEL(5)	STEEL
A-3	158.0	34,600	.040	STEEL	STEEL
A-4	160.0	35,000	.072	STEEL	STEEL
A-5	160.0	35,000	.067	STEEL	STEEL
A-6	400.0	30,900	.056	CONC.	---
A-7	160.0	35,000	.036	STEEL	STEEL
A-8	188.0	41,100	.042	STEEL	STEEL
A-9	160.0	35,000	.069	CONC.	STEEL
B-1	101.0	7,800	.018	BOND(6)	CONC.
B-2	85.0	6,550	.016	BOND	CONC.
B-3	117.0	25,600	.027	CONC.	---
B-4	95.0	20,800	.027	CONC.	---
C-1	95.0	6,610	.011	CONC.	---
C-2	100.0	6,950	.016	CONC.	---
C-3	220.0	15,300	.025	CONC.	---
C-4	220.0	15,300	.029	CONC.	---
C-5	252.0	17,500	.035	CONC.	---
C-6	248.0	17,250	.046	CONC.	---
C-7	170.0	11,800	.036	CONC.	---
C-8	170.0	11,800	.036	CONC.	---
C-9	380.0	26,400	.064	CONC.	---
C-10	360.0	25,000	.058	CONC.	---
C-11	250.00	17,350	.016	CONC.	---
C-12	180.0	12,500	.014	CONC.	---
C-13	344.0	23,900	.022	CONC.	---
C-14	NO TEST				---
C-15	30.0	2,100	.009	CONC.	---
C-16	25.0	1,700	.007	CONC.	---
C-17	100.0	6,950	.010	CONC.	---
C-18	100.0	6,950	.012	CONC.	---
C-19	120.0	8,350	.011	CONC.	---
C-20	200.0	13,900	.016	CONC.	---
C-21	NO ELASTIC ACTION INDICATED				
C-22	NO ELASTIC ACTION INDICATED				
D-1	140.0	9,750	.007	CONC.	---
D-2	180.0	12,500	.010	CONC.	---
D-3	120.0	8,350	.009	CONC.	---
D-4	120.0	8,350	.009	CONC.	---
D-5	260.0	18,100	.034	CONC.	---
D-6	360.0	25,000	.025	CONC.	---
D-7	320.0	22,200	.030	CONC.	---
D-8	360.0	25,000	.020	CONC.	---
D-9	440.0	30,600	.026	STEEL	CONC.
D-10	380.0	26,400	.023	STEEL	CONC.
D-11	300.0	20,900	.026	CONC.	---
D-12	360.0	25,000	.021	STEEL	CONC.

Notes:
(1) Total bearing load at elastic limit.
(2) Unit stress in H-pile section at elastic limits of pile head assembly.
(3) Deformation value derived from stress-strain diagram by projecting the elastic (straight) line downward to zero loading and adding algebraically the origin correction to the deformation at the elastic limit.
(4) Indicates failure in the concrete head.
(5) Indicates compression yield failure in H-pile section.
(6) Indicates failure in concrete bond to sides of steel H-pile.

The recorded net deformations (Table VII) appear large due to the manner of measurement employed. Deformations in the testing machine, the plaster of paris cap, the concrete block and the 12 inch length of H-pile are included as well as the penetration of the H-pile into the block. It was discovered that on the earlier tests of Series 'A' insufficient time was allowed for setting of the plaster of paris cap. This excessive deformation was revealed on Test A-3 in which a considerable amount of permanent deformation was measured after released loadings within the elastic range. This condition of the plaster of paris cap was corrected on Tests A-7 and A-8 for which the elastic recovery was nearly perfect.

The average net permanent deformation, taken from Table VII, for Tests A-2, A-3, A-4, A-5, A-7, and A-8 for an average maximum stress (within the elastic range) of approximately 170,000 lbs.,(37,000 lbs. per sq. in.) is 0.052 inch. Since this includes deformation in the plaster of paris cap, etc., besides the penetration of the pile into the concrete and since the comparable net deformation for Test A-9 (Table VII) is 0.069 inch compared with an actually measured indentation of 0.030 inch for a stress of more than 160,000 lbs., (35,000 lbs. per sq. in.), the average permanent indentation for A-2, A-3, A-4, A-5, A-7, and A-8 may plausibly be estimated as approximately 0.02 inch. As the greatest working load on an H-pile would rarely cause a working unit stress greater than say 7,000 lbs., it appears that the indentation of the concrete may be regarded as negligible for such a working stress multiplied by a factor of safety of 2 or 3.

The behavior of Specimens A-4 and A-5, which had greased sides is not sufficiently unique to provide definite information. This is to be expected since the steel piles of these specimens failed by buckling, like the other 6" x 6" before the concrete block strength was fully taxed and therefore the maximum load at failure for these tests is similar to that of the others. The same is the case with reference to those specimens of which the blocks were equipped with hoop reinforcement.

The results of Test A-9 indicate that the depth of embedment is not important insofar as stress under compressive force is concerned, since on this test there was no embedment. This seems to be borne out by subsequent tests (Series C and D) in which the depth of embedment varied. Transverse encirclement by other concrete of the concrete directly subjected to compressive force appears more important than the depth of embedment.

Although Series 'A' provides definite assurance that there need be no concern regarding the strength of the concrete in immediate contact with the end surface of the pile and shows that this concrete is less apt to fail than the pile section itself, it does indicate in Test A-6 that cracking of the block may occur if the pile section is relatively large with reference to the block.

The 6" x 6" size of H-pile was used because of the belief that a small-scale test would be satisfactory. It was thought that a 6" x 6" H would bear approximately the same relationship to a 23 1/2 inch spacing that a regularly used 10" x 10" H bears to the usual spacing. However, the test results indicated the desirability of testing a full-scale size such as 10" x 10".

The concrete blocks in this series of tests were supported over their entire lower area. This was originally considered satisfactory since only the behavior of the compression contact area of the concrete at the end of the pile was to be checked. However, since compressive stress on the H area was found not critical and since it seemed probable that the delivery of a great force to the concrete immediately around and beyond the embedded H-pile would cause a punching-out tendency as well as cracking and splitting, it appeared desirable to undertake additional tests in which the blocks would be supported only along their edges so as to permit deflection of the block and punching-out.

SERIES "B"

The four tests of Series 'B' were of exploratory character and for that reason the 23 1/2 inch size of block was continued.

Specimens B-1 and B-2 were designed to determine the strength of the bond between the sides of the embedded portion of the pile and the concrete. The computed unit stress at failure, considering the area of all of the embedded side surfaces of the H-pile, was 299 lbs. per sq. in. for Specimen B-1 and 288 lbs. per sq. in. for Specimen B-2. However, such a designation is merely nominal since the bond failure between the flanges was only partially along the contact surface between the H-pile and the concrete. Plate 8 shows the diagonal-tension break which occurred between the flanges, approximately along a plane at 45 degrees with the web of the pile. Substantially all of the concrete at the extreme end of the embedded portion of the H-pile remained in place and a substantial portion of all of the contact of the embedded web and the concrete remained intact. This is considered an important disclosure because it seems reasonable to expect a tendency for the break to occur at the edges of the H flanges rather than along the inner surfaces of the flanges and along the surfaces is approximately twice as great as the area of contact of concrete-against-concrete along the edges of the flanges. In view of this and since the diagonal break left the concrete between the flanges at the extreme end of the embedded portion intact, there would seem to be no useful service performed by placing a steel plate against the end surface of the pile.

In Tests B-3 and B-4 the plain concrete blocks failed due to the punching action causing diagonal-tension breaks extending from the edge of the end of the pile to the four side surfaces of the blocks.

SERIES "C"

In Series 'C' the 33 inch square concrete blocks in connection with 10" x 10" H piles provide a consistent balance and full-scale size. A 36 inch size could not be used since the space on the weighing platform of the 1,000,000 lb. testing machine used would not accommodate more than a 33 inch square size.

By providing edge support only for the blocks they were permitted to deflect and opportunity was given for punching-out of the concrete beyond the end of the pile. In this respect and also because of their larger size they should be regarded as more typical and representative specimens than those of Series 'A'. However, the fully-supported blocks of Series 'A' were hardly more misleading in one direction than the edge supported blocks of Series 'C' were in the opposite direction. The latter behaved as unreinforced slabs supported on four sides and constituted a more severe condition than would be encountered in a typical concrete cap or footing into which piles project. At any rate, since the disclosures are nevertheless favorable, one can believe that the strength in actual cases would be very great.

The failure due to slab action is quite clearly shown by comparing Tests C-15 and C-16, in which the concrete block is only 6 inches thick and has 6 inch (100%) embedment of the 10" x 10" pile, with Tests B-1 and B-2. The average tctal load at failure for the former (Table V) was 35,000 lbs., and for the latter (Table IV) was 112,700 lbs. As the area of contact between the steel and concrete was only 8 per cent greater for the latter than for the former, the great difference must be credited to the difference in slab properties and behavior of the specimens. Specimens B-1 and B-2 averaged 12 1/2 inches thick and were 23 1/2 inches square. Specimens C-15 and C-16 were only 6 inches thick and had a much greater span on account of the 33 inch square size. Even in Tests B-1 and B-2 slab action probably combined with punching shear to cause failure, but at any rate it appears to be clearly shown that slab action was the major cause of failure in Tests C-15 and C-16, and that the bond resistance to punching-out was in fact not actually determined.

Failure of the specimens partially due to slab action is also evident in Tests C-1, C-2, C-17, and C-18 for which the blocks were 12 inches thick. For these the average ultimate load at failure (Table V) was 105,000 lbs., compared with 112,700 lbs., average (Table IV) for B-1 and B-2. Even though the latter specimens were cored-out for half their thickness at the middle, they (because of their lesser slab span) required a greater force to cause failure.

Although similar proof of slab action's contribution to failure is not available for the 18 inch and 24 inch thick blocks of Series 'C', it is reasonable to believe that slab action would plav a part also as the thickness increases, although to a proportionately lesser degree. It will be found from Table V that the average load at failure is 35,000 lbs. for the specimens with 6 inch thick blocks, 105,000 for the 12 inch, 230,000 for the 18 inch (exclusive of C-21 and C-22 which were supported on only two sides), and 400,000 for the 24 inch. The strength per inch ot thickness increases steadily and consistently as the thickness increases, which seems to show that as the block becomes thicker (and of more nearly natural and full-scale size) its thickness is better able to cope with the slab action problem and to work more effectively in resisting stresses due solely to the punching-through

tendency of the pile.

This discussion of slab action has been with the object of pointing out this important complicating influence in Series 'C'. In a bridge cap or footing the area pertaining to each pile would not be, even remotely, so seriously subjected to local beam action and such beam action as does occur in a cap or footing is taken care of by adequate thickness of concrete and amount of reinforcing steel. The strength of the connection between the embedded end of the pile and the concrete is, therefore, believed to be definitely greater than shown by Series 'C' - far greater than indicated where the block is as thin as 6 inches and also greater where the block is as thick as 24 inches. In attempting to correct the ultra-favorable condition of full support for the block as used in Series 'A', an unfavorable condition was created.

It will be found that this series of tests seems to indicate that it does not matter how much a pile is embedded in a given thickness of block. The strength seems to be substantially the same. In the case of the 12 inch thick blocks the average ultimate load for those specimens with 6 inch embedment (Table V) was 100,000 lbs., and those with 12 inch (100%) embedment 110,000 lbs. In the case of the 18 inch thick blocks the average ultimate load for those specimens (exclusive of C-5, C-6, C-21, and C-22) with 6 inch embedment was 239,000 lbs., for those with 12 inch embedment 240,000 lbs., and for those with 18 inch (100%) embedment 195,000 lbs. In the case of the 24 inch thick blocks the average ultimate load for those with 6 inch embedment is 405,000 lbs., and the ultimate for the one with 18 inch embedment is 390,000 lbs.

Blocks as thin as 6 inches were included among the specimens in order to be able to check the behavior of this extremely light size and to facilitate the plotting of behavior over a wide range of sizes.

A comparison of Tests C-7 and C-8 with Tests C-3 and C-4 indicates that a bearing plate on the end of a pile does not increase the strength of the connection. This is plausible in the light of the disclosure on Tests B-1 and B-2 that the concrete between the flanges tends to adhere to the web and flanges, and the break occurs near the edges of the flanges. This is also borne out by an examination of the broken test specimens of Series 'C' although this behavior was complicated by the simultaneous tendency of the thinner blocks to fail largely due to slab action. A comparison of Tests C-7 and C-8 with Tests C-3 and C-4 in fact indicates a weakening of the connection because of the bearing plate. This is possible since the plate interferes with the placing of the concrete.

On inspection of the deformation curves for Series 'C' (Figures 39 to 49) one finds a break in the curve early in the loading on Tests C-3, C-4, C-5, C-6, C-9, C-10, C-21, and C-22 but not on the others. It is believed that these breaks are associated with the method of placing the concrete and supporting of the H-pile. Since the concrete was placed with the H-pile projecting into it from above and held by a clamp supported from the top of the forms and since the clamp was not released until after the concrete had set, it is possible that shrinkage and settling of the concrete caused the concrete to settle slightly away from the end surface of the pile. If this is true, the pile in the early loading would be supported by bond only and after bond failure would move slightly until end compression contact was made. This shrinkage and settling conjecture appears justified since the tests on which the break in the deformation curve occurred all had a depth of concrete below the embedded end of the pile of 12 inches or 18 inches whereas those on which such a break did not occur all have a comparable depth of 6 inches or zero inches, except Tests C-7 and C-8 for which this depth was 12 inches. As specimens C-7 and C-8 were equipped with bearing plates it seems plausible that the presence of the plate may have prevented such settlement of concrete as occurred on the others of similar depth. The average load at the beginning of bond failure on Tests C-3, C-4, C-5, C-6, C-9, C-10, C-21, and C-22 is approximately 75,000 lbs. On Tests B-1 and B-2 it is approximately 95,000 lbs. The lesser average force required in the Series 'C' tests may have been due to expansion of the wetted form sides having raised the clamps and moved the H-piles slightly, thus weakening the bond. (On Series 'B' and 'A' the clamps were released before setting began.) The average deformation for these tests of Series 'C' was 0.011 inch compared with an equivalent of approximately 0.019 inch for Tests B-1 and B-2. It seems clear that on these tests of Series 'C' the force was at first resisted by bond until the bond was broken and end bearing began.

SERIES "D"

The twelve tests of Series 'D' were intended as a supplement to

Series 'C'.

Since the position of the H-pile during the placing of concrete for these specimens was to be like that in actual construction and would avoid the suspected settling-away discussed under Series 'C', it was intended that Tests D-1 and D-2 be compared with Tests C-3, C-4, C-5, C-6, C-21, and C-22, and that Tests D-5 and D-6 be compared with Tests C-9 and C-10, to determine if this change in method of specimen construction would avoid the break in the deformation curve which occurred on the comparable Series 'C' tests. No such break in the curve occurred on any of the Series 'D' tests.

Specimens D-1 and D-2 also were intended to provide a greater number of tests of circular-reinforced blocks of this size, previously covered by only Specimens C-5 and C-6. The influence of circular reinforcing steel is indicated by a comparison of Tests C-5, C-6, D-1, and D-2 (18 inch thick block, 6 inch embedment) in which the blocks were so reinforced, and Tests C-3, C-4, C-7, C-8, D-3, and D-4, for which the blocks were similar but without such reinforcement. The average ultimate load (from Tables V and VI) was 260,000 lbs. for the former and 192,000 lbs. for the latter. This improvement of the strength because of such reinforcing is as would be expected.

Specimens D-3 and D-4 were intended to supplement Specimens C-7 and C-8 (18 inch thick blocks, 6 inch embedment) in representing bearing plates. Since an important purpose of these tests was to determine the degree of need for auxiliary bearing devices for H-piles, it was realized that bearing plates had not been incorporated in a sufficient number of specimens to conclusively determine the difference in strength between specimens with and without such plates. Therefore, bearing plates were also incorporated in Specimens D-7 and D-8 (24 inch thick blocks, 6 inch embedment and slab reinforcing), and Specimens D-5 and D-6 were prepared to provide the same type and size without such plates. Also, Specimens D-11 and D-12 (30 inch thick blocks, 6 inch embedment) included plates, and D-9 and D-10 were of the same type and size without plates. The average ultimate load (Tables V and VI) for C-7, C-8, D-3, and D-4 (with plates, 18 inch block, 6 inch embedment) was 175,000 lbs., and for C-3 and C-4 (the same without plates) it was 225,000 lbs. For D-7 and D-8 (with plates, 24 inch

LOAD CARRYING CAPACITY OF 10" H PILE HEADS

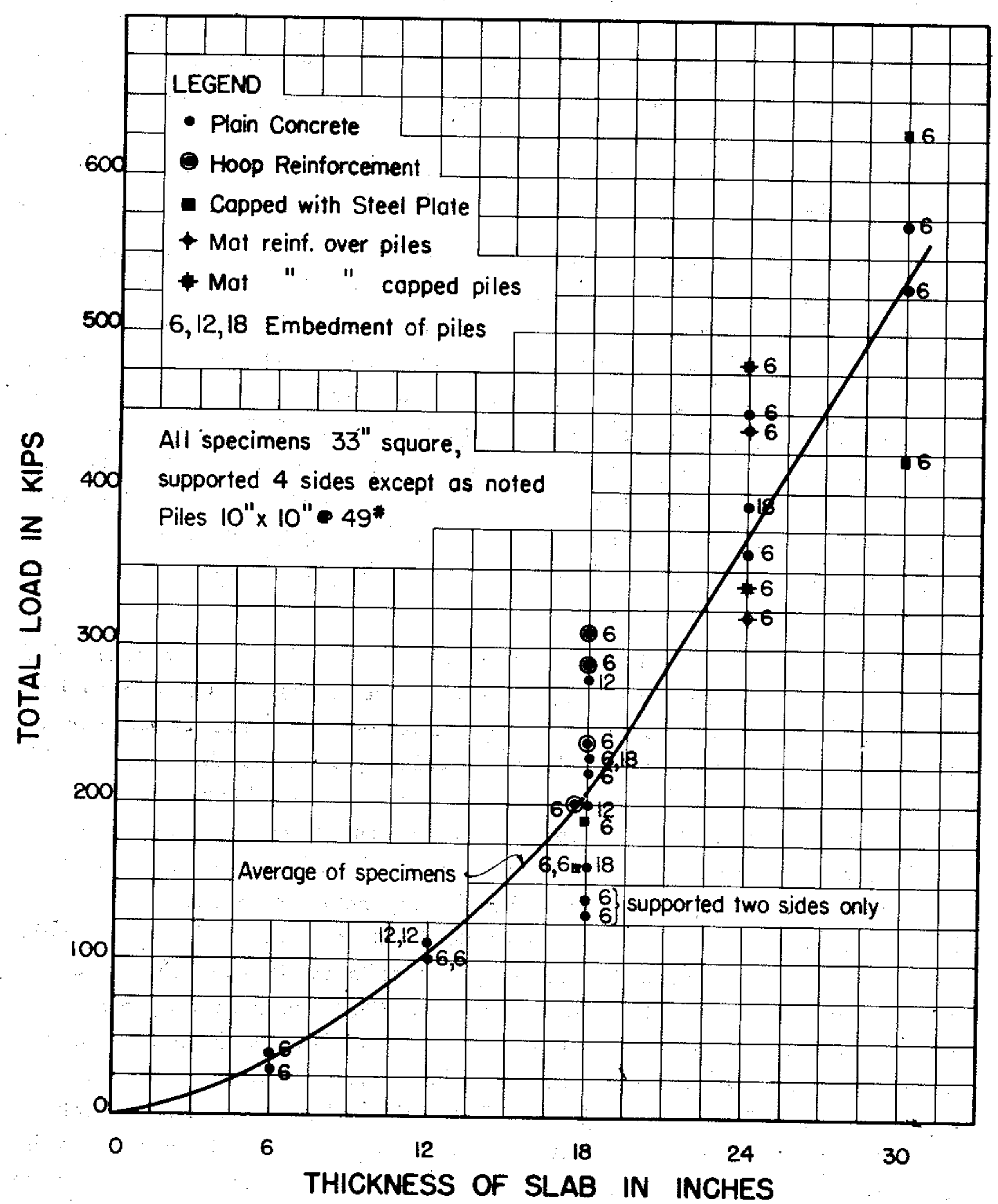


FIGURE 57

block, slab reinforcing) the average ultimate load (Table VI) was 410,000 lbs., and for D-5 and D-6 (the same without plates) it was 380,000 lbs. For D-11 and D-12 (with plates, 30 inch block) it was 525,000 lbs., and for D-9 and D-10 (the same without plates) it was 550,000 lbs. From these comparisons it can be seen that such plates do not add to the strength of the connection.

In view of the complications in Series 'C' because of slab action, Specimens D-5, D-6, D-7, and D-8 (24 inch thick blocks) were equipped with two-way reinforcing bars in the bottom of the blocks (as set in the testing machine), intended to insure against failure due to slab action. It was thought (but not desired) that such bars would also resist the punching-out forces and it was expected that these specimens would break at a much greater force than the comparable specimens of Series 'C'. However, the average ultimate load (Table VI) for tests D-5, D-6, D-7, and D-8 (with such reinforcing) was 395,000 lbs., and for Tests C-9 and C-10 (without reinforcing) (Table V) was 405,000 lbs.

The 30 inch thick blocks (Specimens D-9, D-10, D-11, and D-12) were provided to introduce a thickness more nearly comparable with that of a conventional footing. The ultimate load was very great (Table VI), averaging 538,000 lbs., and the failure of the steel piles (which began to buckle) and of the concrete blocks was nearly simultaneous.

Figure 57 shows how the load at failure increased steadily, for Series 'C' and Series 'D', as the thickness of the blocks increased. Although this is as one would expect it to be, yet it is interesting to note how a smooth curve passes through the center of each group of equal thickness.

CONCLUSION

Although the reader may disagree with the discussion regarding the interpretation of some of the phenomena observed, the evidence is believed conclusive that where the top of a steel H-pile is embedded in a concrete cap or footing, if the pile itself is of adequate section and the concrete member is of adequate size and arrangement and properly reinforced for the pile reactions, there need be no concern regarding the strength of the connection for compressive force, and it is unnecessary to provide a bearing plate or other auxiliary bearing device at the top of the pile.