US Army Corps
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STRUCTURES LABORATORY

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WALL ARMOR PULLOUT TESTING

by

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Structures Laboratory

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19. ABSTRACT (Continue on reverse if necessary and identify by block number)

This report is the result of a full-scale pullout test program performed for the purpose of providing comparative data on the pullout resistance of headed stud versus anchor strap designs of wall armor assemblies used in concrete locks. A total of eight wall armor assemblies were fabricated and embedded into concrete specimens during this test program.

Thirteen pullout tests were performed with the two different designs of wall armor assemblies. The anchor strap designs exhibited the highest pullout resistance. Test results indicated that the anchor strap assemblies distributed stress over larger areas of the concrete specimens, thereby resisting greater loadings.

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18. SUBJECT TERMS (Continued).

Anchor straps	Headed studs
Boundaries (failure)	Lockwall armor assemblies
Cracking	Pullout resistance
Deterioration	Rupture
Failure cone	Tensile testing

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PREFACE

The investigation described in this report was conducted for the US Army Engineer District, St. Louis (LMS), by the Concrete Technology Division (CTD) of the Structures Laboratory (SL), US Army Engineer Waterways Experiment Station (WES). Authorization for this investigation was given by DA Form 2544, ED85-35, dated 26 February 1985.

This investigation was performed at WES under the general supervision of Mr. Bryant Mather, Chief, SL; Mr. John M. Scanlon, Jr., Chief, CTD; Mr. Henry Thornton, Chief, Evaluation and Monitoring Unit (E&MU); and under the direct supervision of Mr. Willie E. McDonald, E&MU, principal investigator; and Mr. Edward F. O'Neil III, E&MU, senior advisor. Messrs. Frank W. Dorsey and Dan E. Wilson, E&MU, assisted in preparation of the concrete test specimens and setup of instrumentation. The Welding Shop, Construction Services, at WES fabricated the wall armor assemblies. Messrs. McDonald and O'Neil conducted the pullout tests. Mr. Thomas J. Leicht served as point of contact at LMS and provided helpful insights during the investigation. This report was written by Mr. McDonald with Mr. O'Neil assisting in preparation of the final version.

COL Dwayne G. Lee is the Commander and Director of WES and Dr. Robert W. Whalin is Technical Director.

CONTENTS

CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
degrees (angle)	0.01745329	radians
feet	0.3048	metres
inches	25.4	millimetres
kips (force)	4.448222	kilonewtons
pounds (force)	4.448222	newtons
pounds (force) per square inch	0.006894757	megapascals

WALL ARMOR PULLOUT TESTING

PART I: INTRODUCTION

Background

1. This investigation was authorized by DA Form 2544, No. ED85-35, dated 26 February 1985. The US Army Engineer District, St. Louis (LMS), requested a full-scale pullout test program be conducted by the Waterways Experiment Station (WES), Concrete Technology Division (CTD), for the purpose of providing data to compare the pullout resistance of headed stud versus anchor strap designs of wall armor assemblies. LMS is overseeing the construction of Lock and Dam No. 26 in which wall armor is embedded in lock wall monoliths to prevent damage to the concrete resulting from the impact forces of barges.

2. Presently, wall armor using the anchor strap design is being used. However, the design of wall armor using headed studs provided for more expedient field construction and is less expensive. Therefore, tests were deemed necessary to evaluate the pullout resistance of the headed stud design as compared to the anchor strap design, and to assist in analysis for possible implementation of the headed stud design.

Failure Mode Theory

3. In theory, the failure mode of the wall armor assemblies would be by "pulling out" from the monoliths by barges snagging the ends when passing, and by being caught on the top or bottom when raising or lowering the elevation of the barges in the lock chamber. As a result, testing was desired in which loading to simulate these conditions was concentrated in the respective areas. Also, because the occurrence of deterioration of concrete beneath the wall armor reduces the bonding area of the wall armor assembly, simulation of deterioration was requested to be included in the test program.

4. CTD designed and carried out this test program in support of these efforts.

PART II: ARMOR ASSEMBLIES

Materials

5. A total of eight wall armor assemblies were fabricated and embedded in concrete specimens during the test program. Typical assemblies can be seen in Figure 1, and shop drawings detailing dimensions are given in Plates 1 and 2. A summary of the fabricated assemblies is given in Table 1.

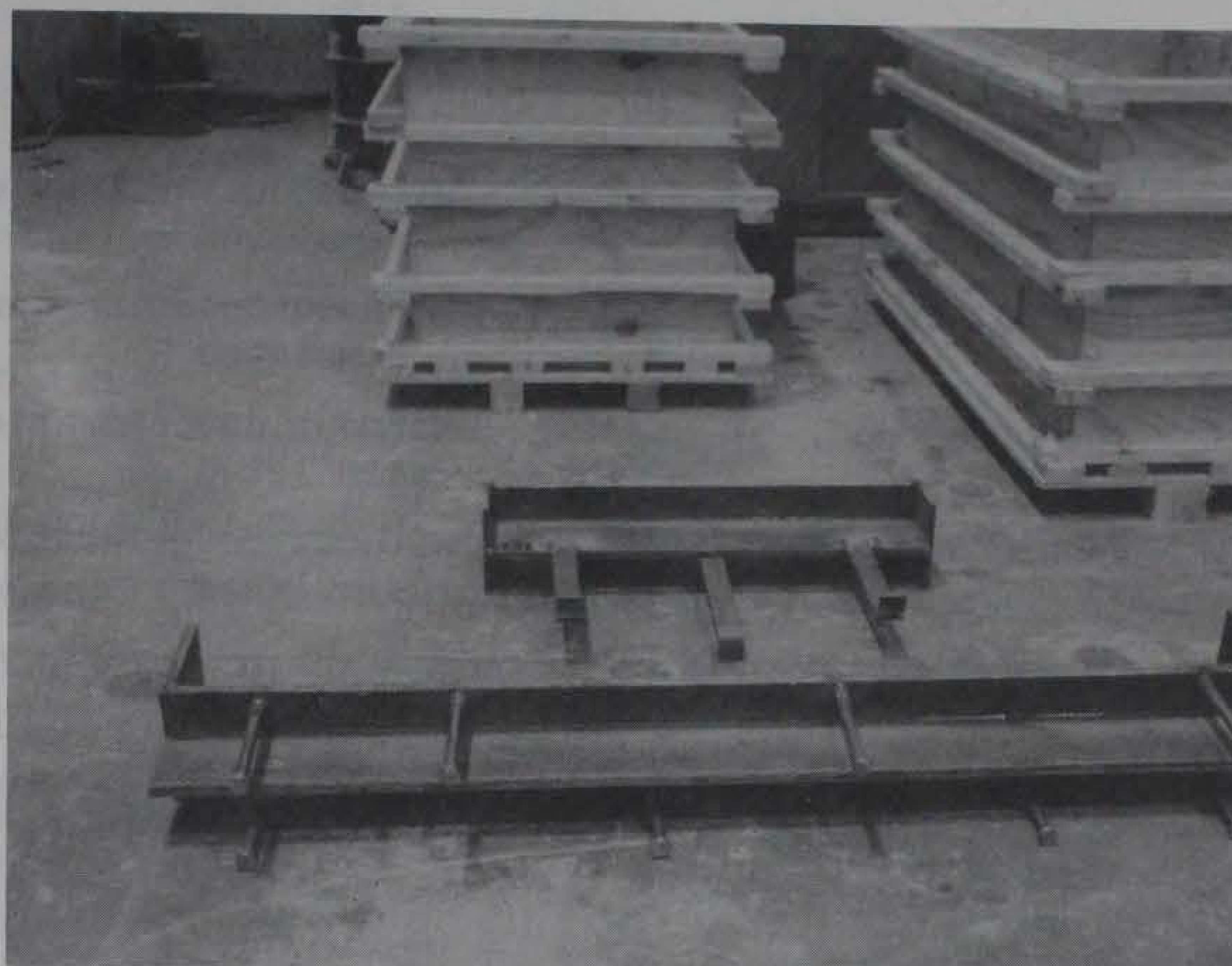

Figure 1. Typical anchor strap and headed stud wall armor assemblies

Deterioration of concrete was simulated in two of the 6-ft* wall armor assemblies by placing 1-in.-thick styrofoam beneath the flange of the wall armor to prevent concrete from filling into this area, and to simulate erosion (Figure 2).

Wall armor with anchor straps

6. There were four anchor strap assemblies fabricated from A36 steel using the design similar to that used in field construction. Two of the four were 6-ft sections, and two were 3-ft sections. The anchor straps measured

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* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 3.

Table 1

Wall Armor Assemblies

Identification	Type	Length, ft	Description	Number of Tests
HS6A	Headed stud	6	Without deterioration simulated	2
HS6B	Headed stud	6	With deterioration simulated	2
AS6A	Anchor strap	6	Without deterioration simulated	2
AS6B	Anchor strap	3	With deterioration simulated	2
HS3A	Headed stud	3	Without deterioration simulated	1
HS3B	Headed stud	3	Without deterioration simulated	1
AS3A	Anchor strap	3	Without deterioration simulated	1
AS3B	Anchor strap	3	Without deterioration simulated	2

Figure 2. Placement of 1-in.-thick styrofoam beneath flange of wall armor to simulate erosion of concrete

1 ft 3-1/2 in. in length, 2 in. in width, and 1/4 in. in thickness. Two inches from their lower ends the straps were bent to a 90-deg angle, and a length 1-1/2 in. at the opposite end was continuously welded to the web of the wall armor. The straps were welded in a staggered pattern along the length of the web 6 in. from each end and 1 ft on center.

Wall armor with headed studs

7. As with the anchor strap assemblies, there were four headed stud assemblies fabricated during the test program. Similarly, two of the four headed stud assemblies were 6-ft sections, and two were 3-ft sections. The headed studs were 3/4-in.-diam steel bars which were 8 in. long. At one end of the headed studs a 1-1/2-in.-diam, 1/2-in.-thick plate was continuously welded. The opposite ends of the headed studs were continuously welded to the flange along the length of the flange in a staggered pattern at 1-ft centers. Two headed studs were positioned on either side of the web 6 in. from each end of the assemblies.

Concrete

8. The concrete used in this test program was supplied by a local ready-mix company. The concrete was requested to provide a compressive strength of 3,000 psi in 28 days. A 1-1/2-in. maximum size limestone aggregate and a 3-in. slump were also specified.

Concrete Specimens

9. Eight concrete specimens were cast during the test program. Four of these specimens measured 2 ft 9-1/2 in. in width, 6 ft in length, and 3 ft in height. The remaining four specimens were similarly dimensioned with the exception of being 4 ft in length. In each specimen wall armor assemblies were embedded such that only the flanges of the wall armor remained exposed as shown in Figure 3. For specimen anchorage to the test floor, four 2-in.-diam steel bars, 12-3/4 in. long, were embedded to a depth of 12 in. in each of the 4-ft-long concrete specimens, 10 in. in height from the bottom of the test blocks. In the 6-ft-long concrete specimens, two 2-in.-diam bars were embedded throughout the width of the test blocks with an overhang of 5-3/4 in. on either side of the test blocks. These were also positioned 10 in. in height from the bottom of the test blocks. These bars are visible in Figure 3. Also, in each 6-ft-long concrete specimen, six No. 8 reinforcement bars were

placed in the tensile zone to resist tensile forces in the lower face of the specimen.

Figure 3. Wall armor assemblies embedded in concrete specimens

PART III: TEST PROCEDURES

Six-foot Wall Armor Assemblies

10. The four 6-ft assemblies were designed such that they could be tested on each end. After one end was tested, the block was rotated and tested on the opposite end. The test program was designed to perform a total of eight pullout tests on the 6-ft assemblies. Steel plate loading lugs, 7-3/4 by 7-3/4 by 3/4 in., with a 1-1/2-in.-diam hold were welded to the top of the flanges at each end to provide for loading attachments. Pullout loading of the wall armor was provided by an Instron 300,000-lb closed-loop hydraulic testing system that was attached to the foot of the actuator and the loading lugs by eyebolt and clevises (Figure 4).

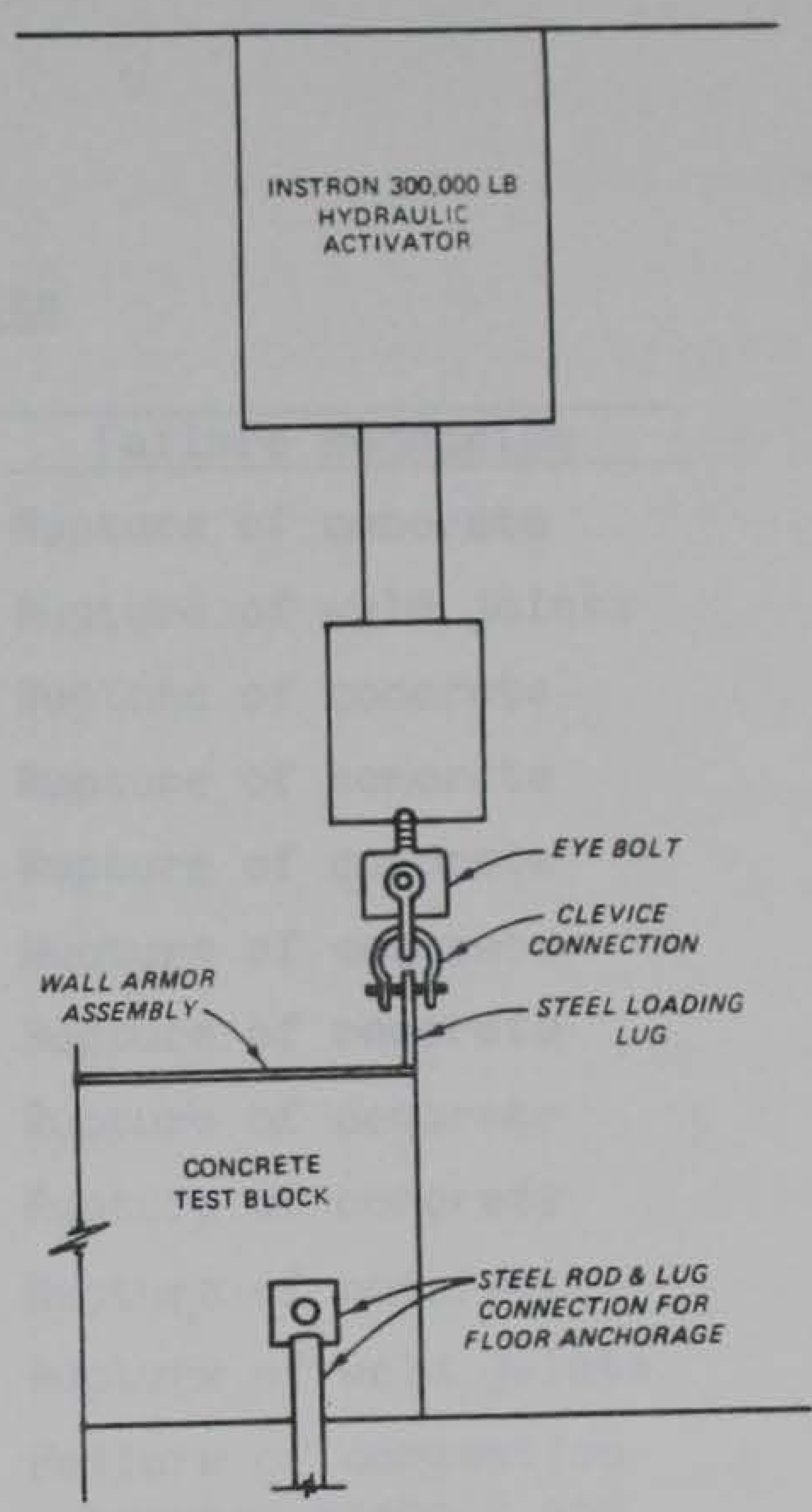

Figure 4. Typical setup for testing of wall armor assemblies

Three-foot Wall Armor Assemblies

11. The four 3-ft assemblies were tested at the center end only for a total of four pullout tests. Loading and attachments were the same as described for the 6-ft assemblies in paragraph 10.

12. The concrete test blocks were secured during testing by means of 7-1/2- by 7-1/2- by 3/4-in. steel plates welded to one end of 2-in.-diam steel rods. Two-inch-diameter holes were cut in the plates to fit on the two-inch steel bars described in paragraph 9. The 2-in.-diam steel rods were threaded on the opposite ends for bolting to the test floor.

13. The wall armor assemblies were pulled from the concrete blocks at a rate of 5,000 lbf per minute. Failure was defined by either pullout of the wall armor or by rupture of the concrete test blocks. A plot of load on the wall armor versus displacement of the actuator foot was recorded on an X-Y plotter for each test.

PART IV: TEST RESULTS

14. Throughout the test program, 13 pullout tests were performed. Of these, nine were successful by definition of failure set forth in paragraph 13. The results of these pullout tests can be seen in Table 2. Two of the three unsuccessful tests were the direct result of failure of weld joints at loadings well below what was expected. After two consecutive pullout tests resulted in weld joint failures, it was decided that 3/4-in.-thick by 4-in.-high steel stiffening members be welded along the top center of the flanges of the remaining 6-ft assemblies to distribute bending stresses over the flanges and thereby reduce the stresses on the weld joints beneath the flange (Figure 5). On the 3-ft assemblies, two stiffeners were welded across the width of the flanges in the center of the wall armor on the remaining assemblies to accomplish the same stress distribution.

Table 2

Pullout Test Results

Identification	Load, lbf	Failure Mechanism
HS6A-1	59,500	Rupture of concrete
HS6A-2	45,000	Rupture of weld joints
HS6B-1	59,700	Rupture of concrete
HS6B-2	62,100	Rupture of concrete
AS6A-1	82,000	Rupture of concrete
AS6A-2	65,000	Rupture of concrete
AS6B-1	76,500	Rupture of concrete
AS6B-2	64,500	Rupture of concrete
HS3A	84,500	Rupture of concrete
HS3B	78,000	Rupture of concrete
AS3A	62,000	Rupture of weld joints
AS3B-1	94,000	Failure of connection between eyebolt and actuator foot
AS3B-2	12,000	Rupture of concrete of anchor bar

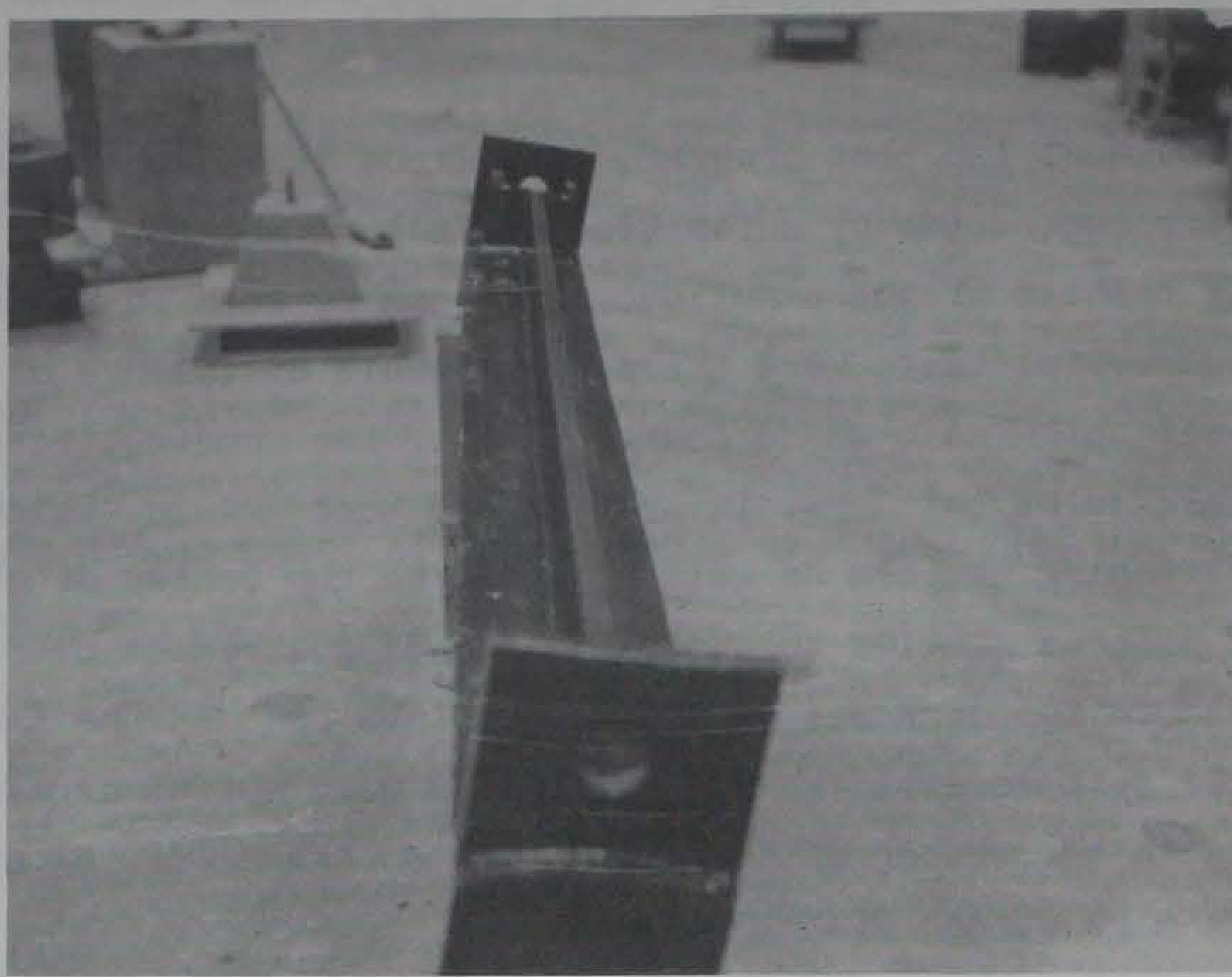

Figure 5. Wall armor assembly with addition of stiffening member

Six-foot Assembly Tests

15. All of the successful tests conducted on the 6-ft assemblies failed first by producing failure cones in the concrete. Photos 1-8 show these failures. Plates 3-10 contain the raw data from the load versus deflection test plots. In the failure of the 6-ft assemblies, concrete rupture was followed by pullout of the wall armor with the exception of assembly AS6B-2. In this assembly, failure near the top surface of the concrete test block was impending (as evident by the presence of failure cracks) when rupture of the concrete occurred at the level of the anchor bar inclusion mentioned in paragraph 9. The loading range and the pattern of the failure cracks were the same as with the other 6-ft anchor strap tests at failure. Therefore, this was also considered a good test. The boundaries of the failure cones for the headed stud assemblies were at a depth close to the depth of the headed studs. For the anchor strap assemblies, the failure plane was very near the top surface of the concrete test blocks. The anchor strap wall armor tests realized the higher pullout resistance with a loading range from 64,000 to 82,000 lbf for an average of 72,000 lbf. The headed stud assemblies provided

a loading range from 59,000 to 62,000 lbf for an average of 60,433 lbf. Test(s) failing by weld joint rupture were not included in computing average values.

Three-foot Assembly Tests

16. Of the tests conducted on the 3-ft assemblies, only the two headed stud assemblies failed in a mode which was expected. Photographs of these failures are given in Photos 9-11. Raw data from load versus deflection test plots can be found in Plates 11-15. As with the 6-ft assemblies, failure of the 3-ft headed stud assemblies was the rupture of the concrete followed by pullout of the wall armor. The failure was across the top and side faces of the concrete at loadings of 84,000 and 78,700 lbf, respectively.

17. Testing of the two 3-ft anchor strap assemblies resulted in the first of the two (AS3A) failing by rupture of the weld joint between the flange and the web of the tee. There were two tests performed on the second of the two assemblies (AS3B). In the first of these two tests, loading of 94,000 lbf was attained when failure of the connection between the eyebolt and the actuator foot interrupted testing. Since no visible damage was apparent to the concrete or to the wall armor, it was retested. The second testing of this assembly resulted in rupture of the concrete in the lower plane at the depth of the anchor bar inclusion at a load of 92,000 lbf. However, failure in a mode similar to that of the 3-ft headed assemblies did not occur.

Concrete Cylinder Tests

18. The 28-day test of the concrete cylinders yielded strengths higher than the requested strength of 3,000 psi. The results can be seen in Table 3. The average 28-day strength of the concrete used in the test program was 4,990 psi.

Discussion

19. The tests performed under this test program were designed to provide relative pullout resistance comparisons between headed stud and anchor strap designs of wall armor under a given set of conditions, and therefore were not intended to be absolute pullout tests. The exception to this is that

Table 3

Concrete Compressive Strengths, 28 days

Batch	Cylinder No.	Compressive Strength, psi
1	5/28/85/1	4,510
	5/28/85/2	4,598
	5/28/85/3	4,704
2	6/3/85/1	4,845
	6/3/85/2	5,110
	6/3/85/3	4,898
3	6/10/85/1	5,376
	6/10/85/2	5,482
	6/10/85/3	5,447
4	6/17/85/1	4,952
	6/17/85/2	4,669
	6/17/85/3	5,235

the first two tests on the 6-ft headed stud assemblies and the first test on the 3-ft headed stud assembly were conducted without the stiffening members which were later added. However, the subsequent tests on the 6-ft headed stud assemblies with stiffeners yielded loading values in the same range as without the stiffening members. Therefore, it is believed that the addition of the stiffening members did not significantly affect the test results.

20. Given the conditions of comparing relative pullout resistance with the 6-ft wall armor, the anchor strap assemblies realized the higher pullout resistance. Using the average loading value on the headed stud assemblies of 60,433 lb as the base, the average loading value of 72,000 lbf on the anchor strap assemblies increased the pullout resistance by 19.1 percent. Also from the test results given in Table 2, the simulation of deterioration had no significant effect on the pullout resistance of the headed stud or the anchor strap wall armor.

21. Given the same conditions with the 3-ft wall armor assemblies as in paragraph 20, the anchor strap wall armor again realized the higher pullout resistance. This is because anchor strap assembly AS3B mentioned in paragraph 17 attained loading up to 94,000 lbf which was significantly larger than loading attained by either of the headed stud assemblies of 84,000 and 78,700 lbf.

22. In the case of both the end and side loading of the anchor strap and headed stud wall armor assemblies, the design of wall armor using anchor straps achieved a significantly higher pullout resistance. This would indicate that, assuming that the tensile strength of the concrete is relatively constant, the anchor strap wall armor distributed the stresses over a larger area of the concrete, and was thereby able to resist greater loadings.

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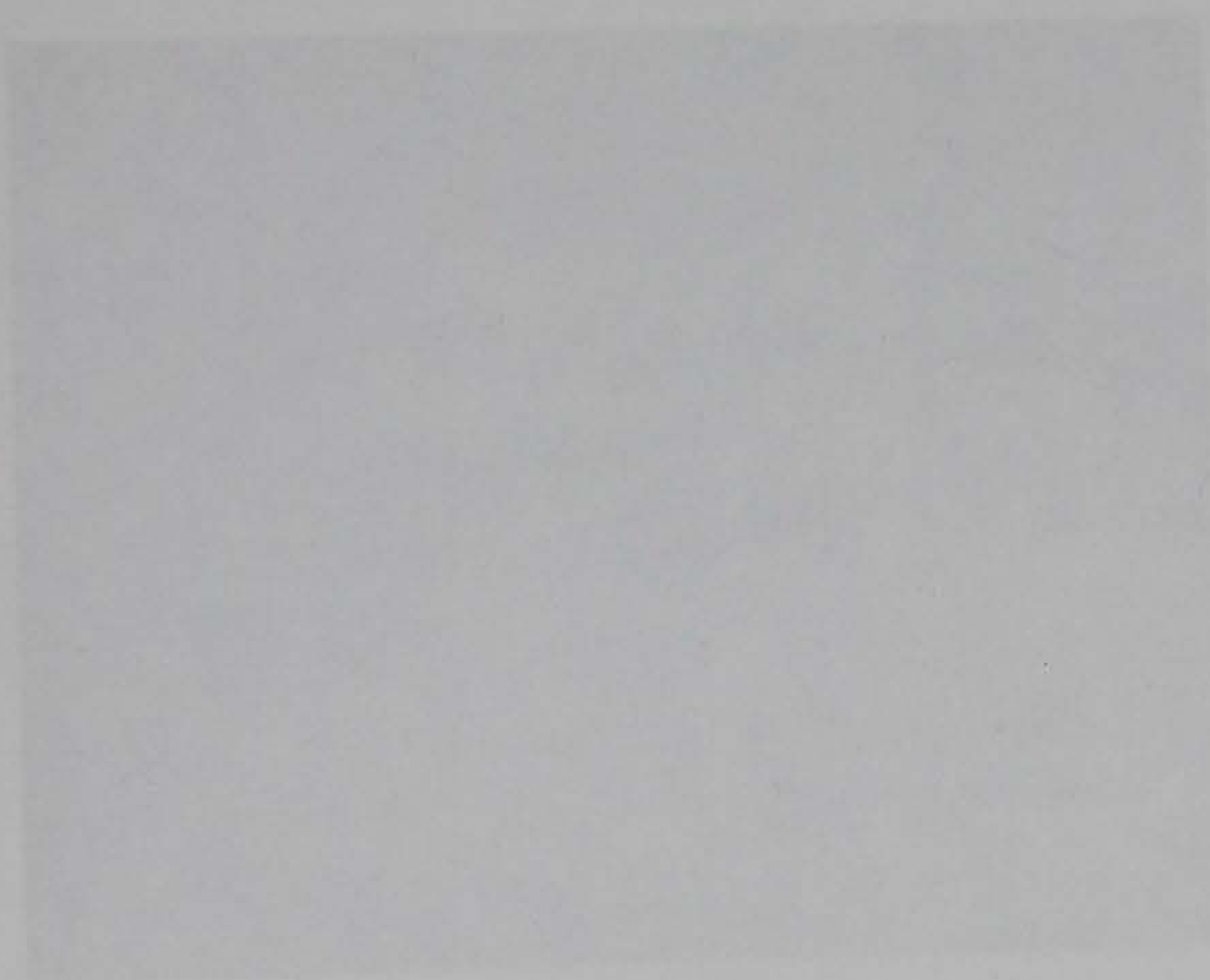

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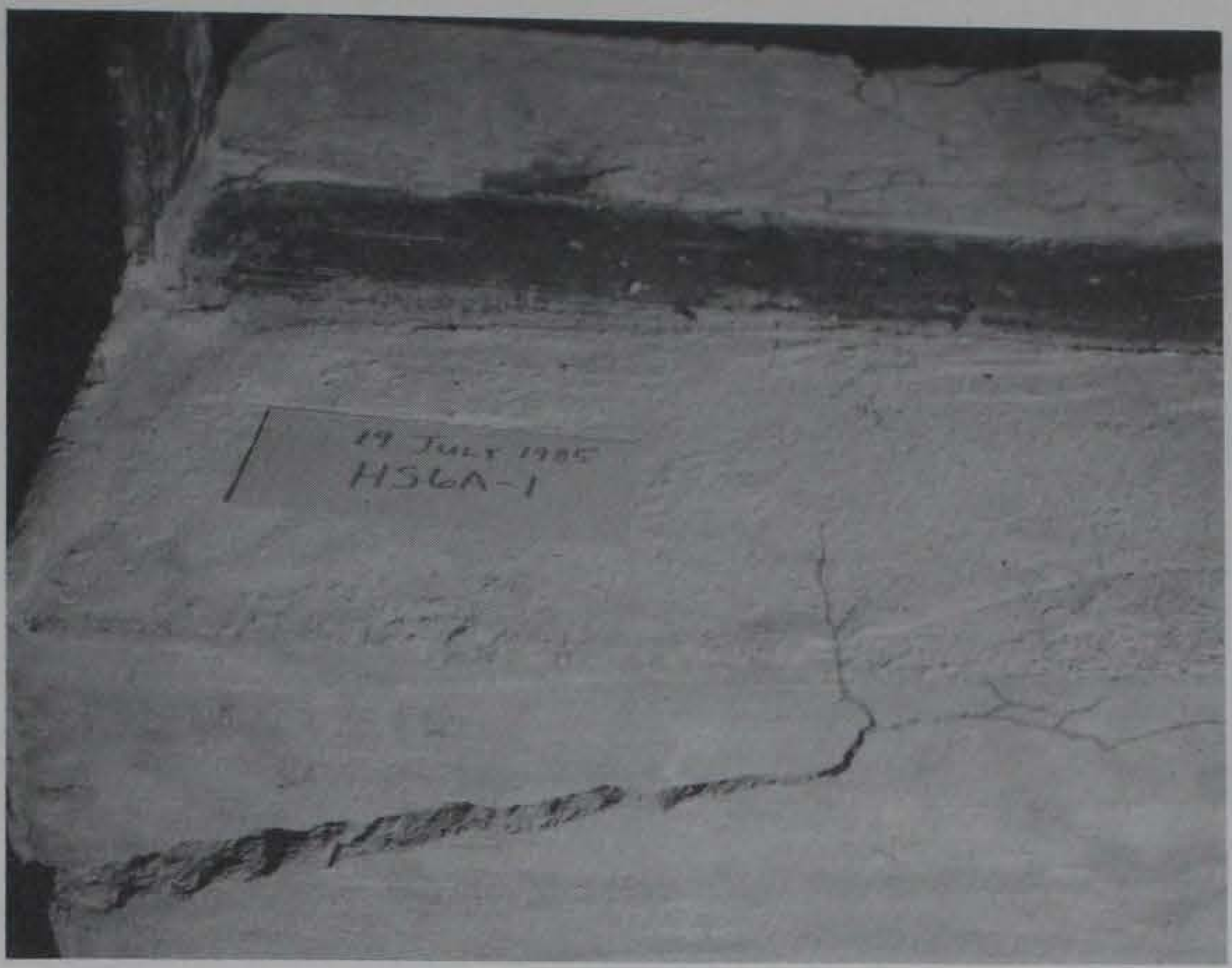


Photo 1. Wall armor test failure, assembly HS6A-1

Photo 2. Wall armor test failure, assembly HS6A-2

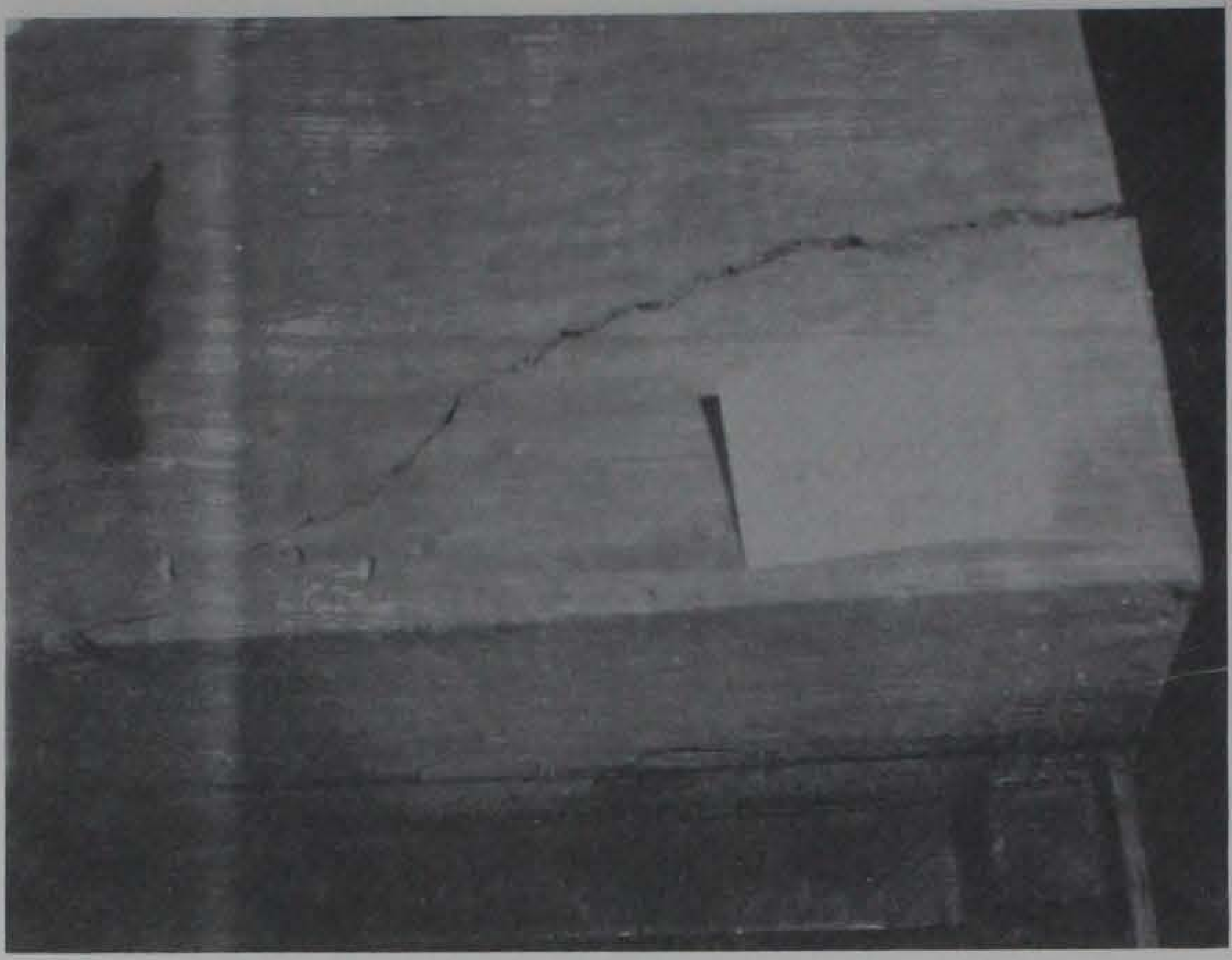


Photo 3. Wall armor test failure, assembly HS6B-1

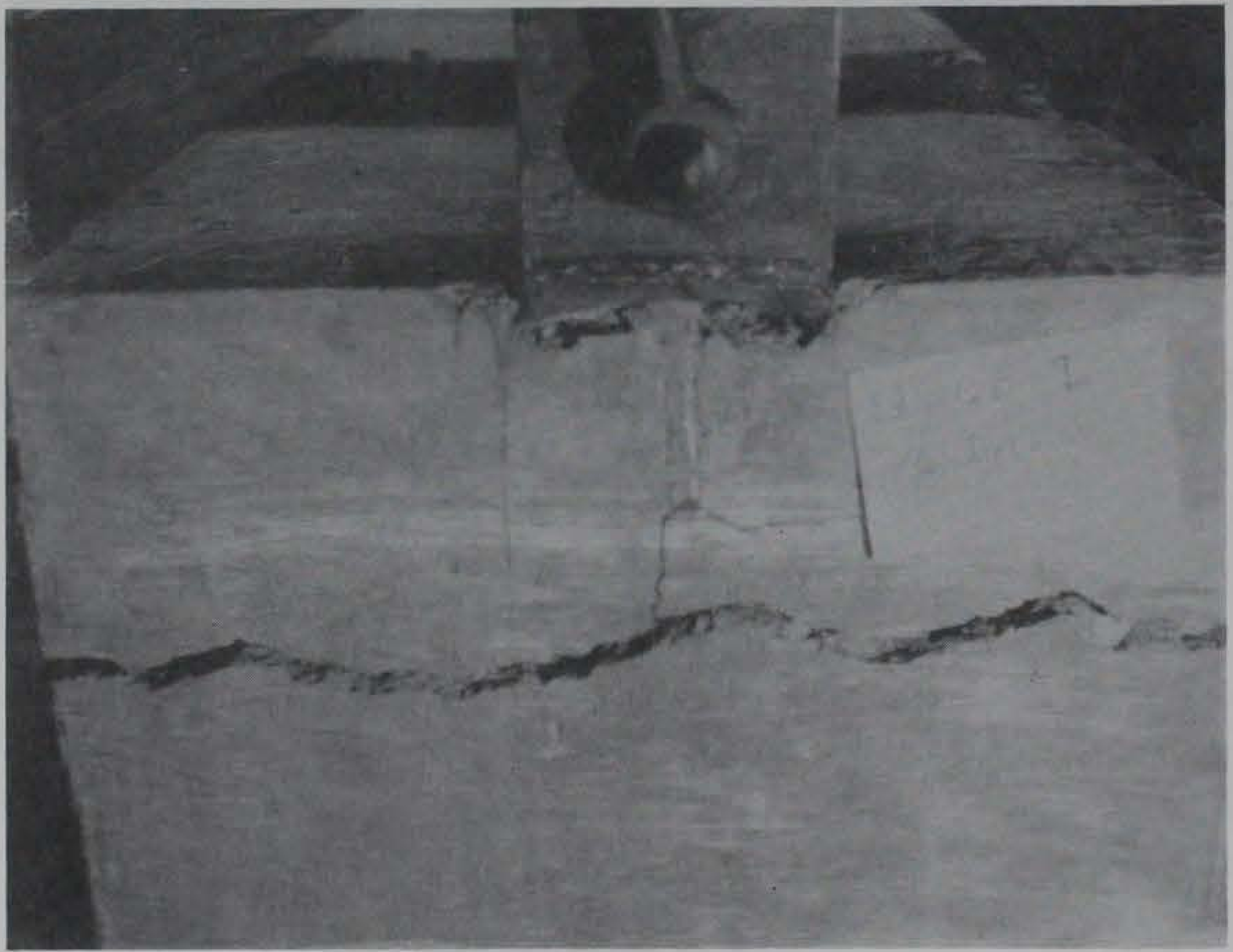


Photo 4. Wall armor test failure, assembly HS6B-2

Photo 5. Wall armor test failure, assembly AS6A-1

Photo 6. Wall armor test failure, assembly AS6A-2

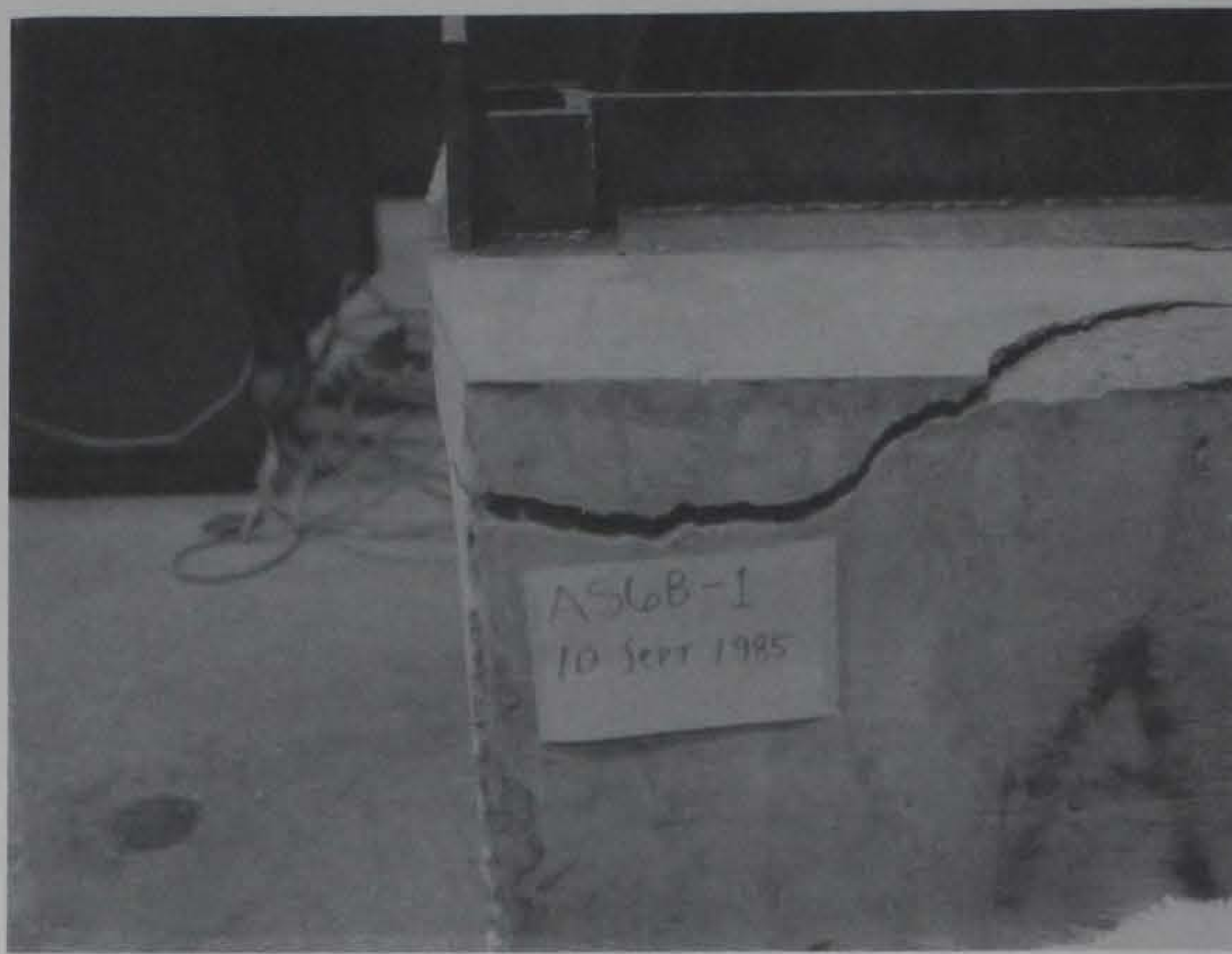


Photo 7. Wall aromor test failure, assembly AS6B-1

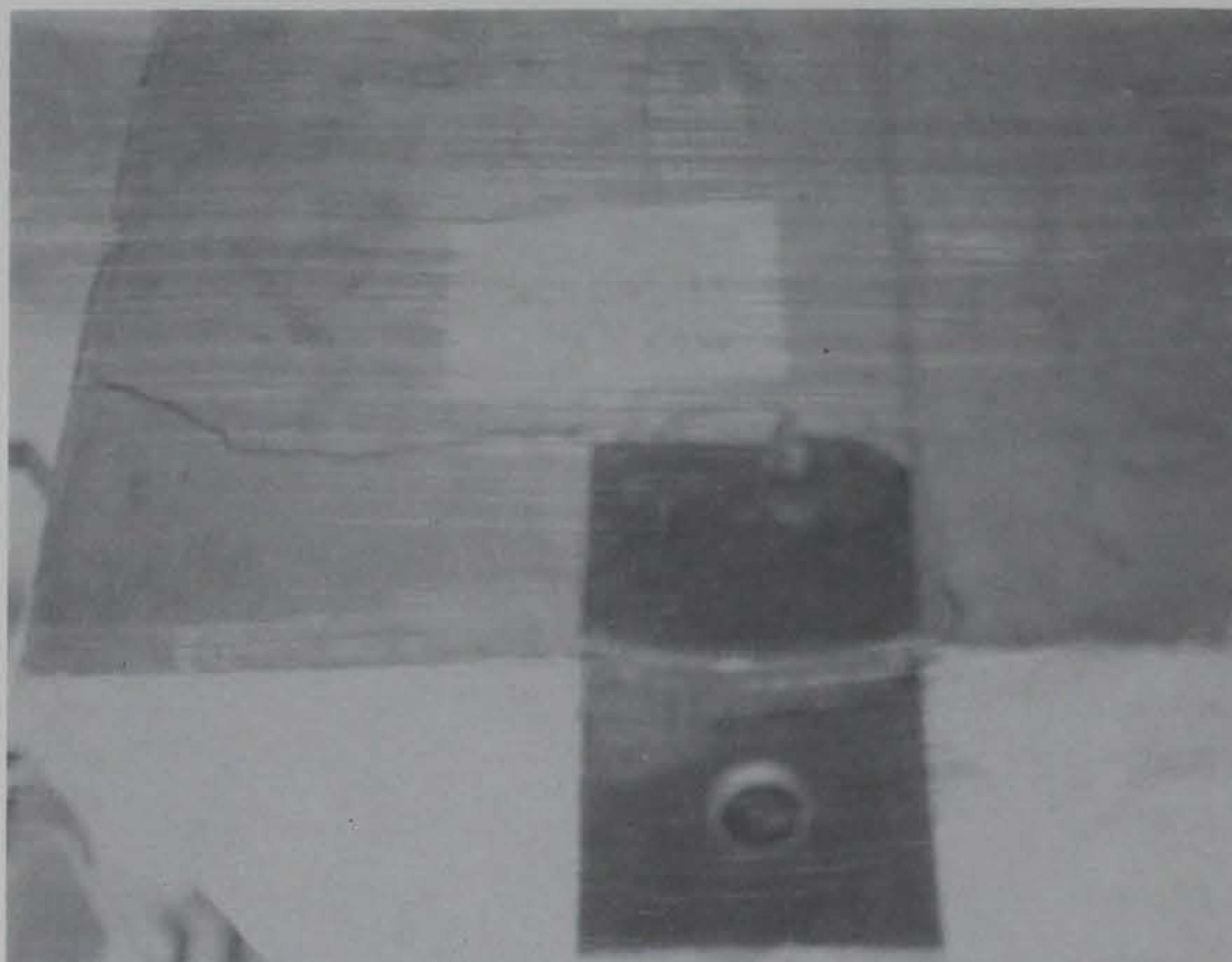


Photo 8. Wall armor test failure, assembly AS6B-2

Photo 9. Wall armor test failure, assembly HS3A

Photo 10. Wall armor test failure, assembly HS3B

Photo 11. Wall armor test failure, assembly AS3A

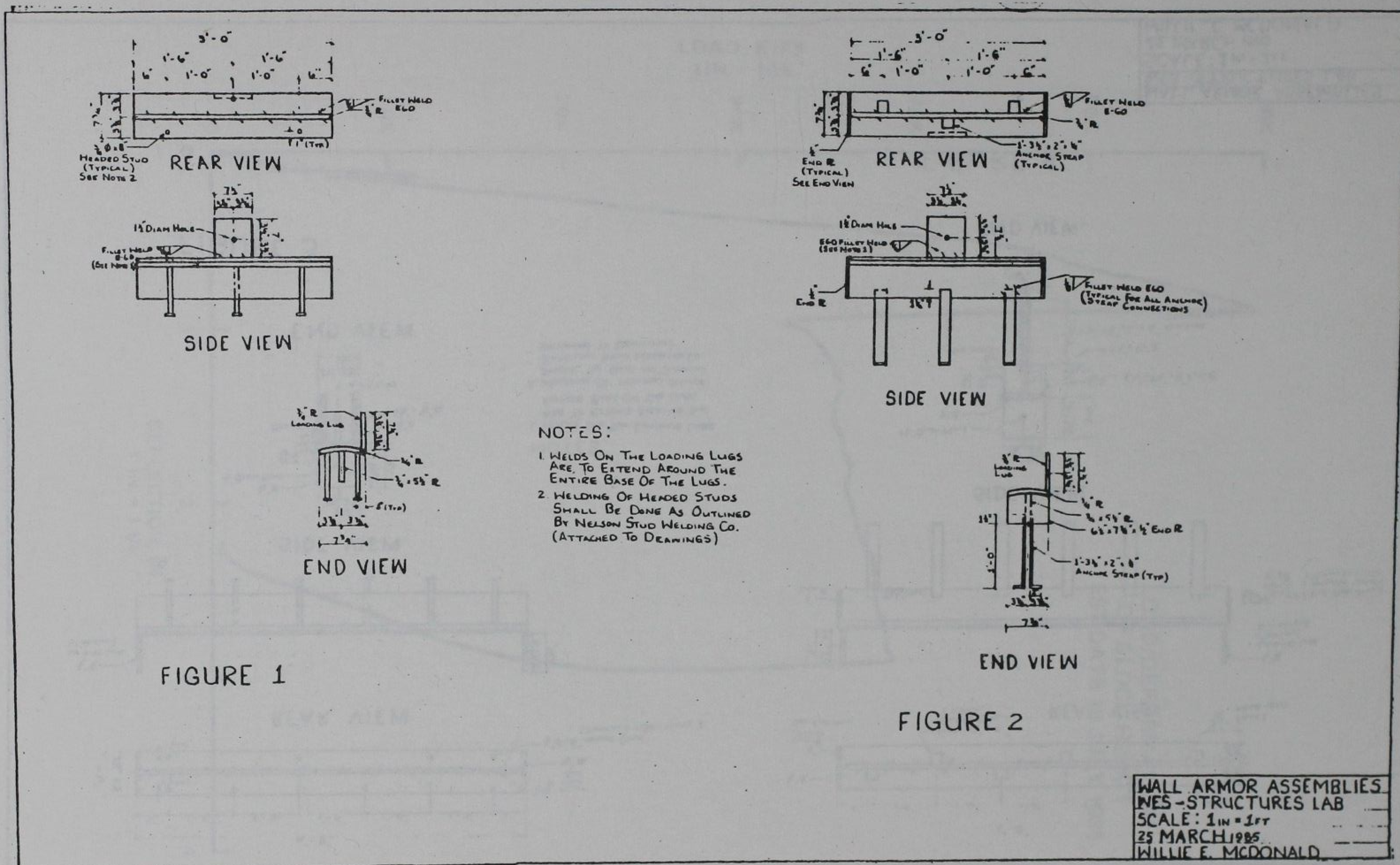
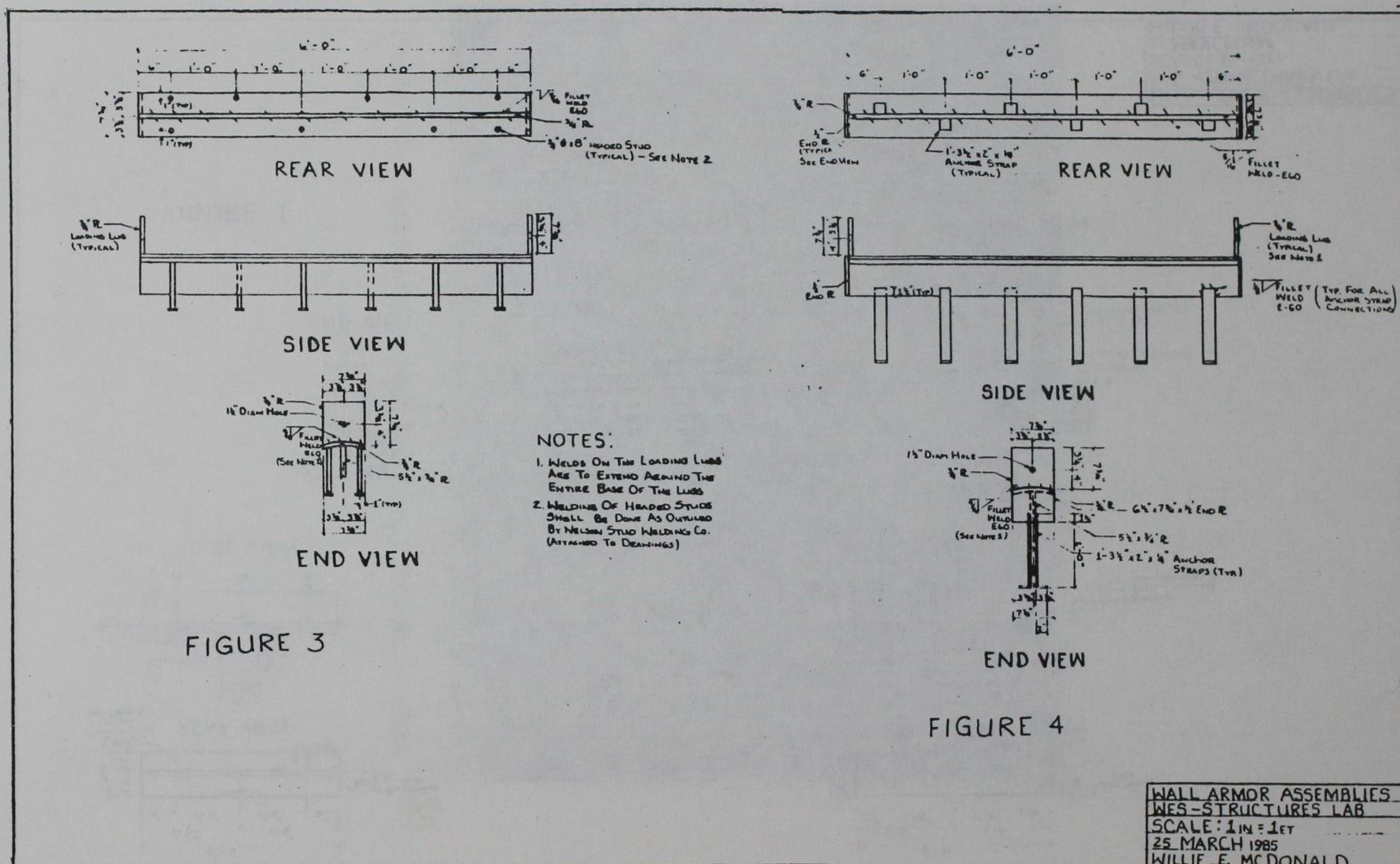

REAR VIEW
SIDE VIEW
END VIEW
FIGURE 1
REAR VIEW
SIDE VIEW
END VIEW
FIGURE 2
NOTES:
1. WELDS ON THE LOADING LUGS ARE TO EXTEND AROUND THE ENTIRE BASE OF THE LUGS.
2. WELDING OF HEADED STUDS SHALL BE DONE AS OUTLINED BY NELSON STUD WELDING CO. (ATTACHED TO DRAWINGS)
WALL ARMOR ASSEMBLIES
WES - STRUCTURES LAB
SCALE: 1IN = 1FT
25 MARCH 1985
WILLIE E. MCDONALD

PLATE 1

PLATE 2


REAR VIEW
SIDE VIEW
END VIEW
FIGURE 3
NOTES:
1. WELDS ON THE LOADING LUGS ARE TO EXTEND AROUND THE ENTIRE BASE OF THE LUGS
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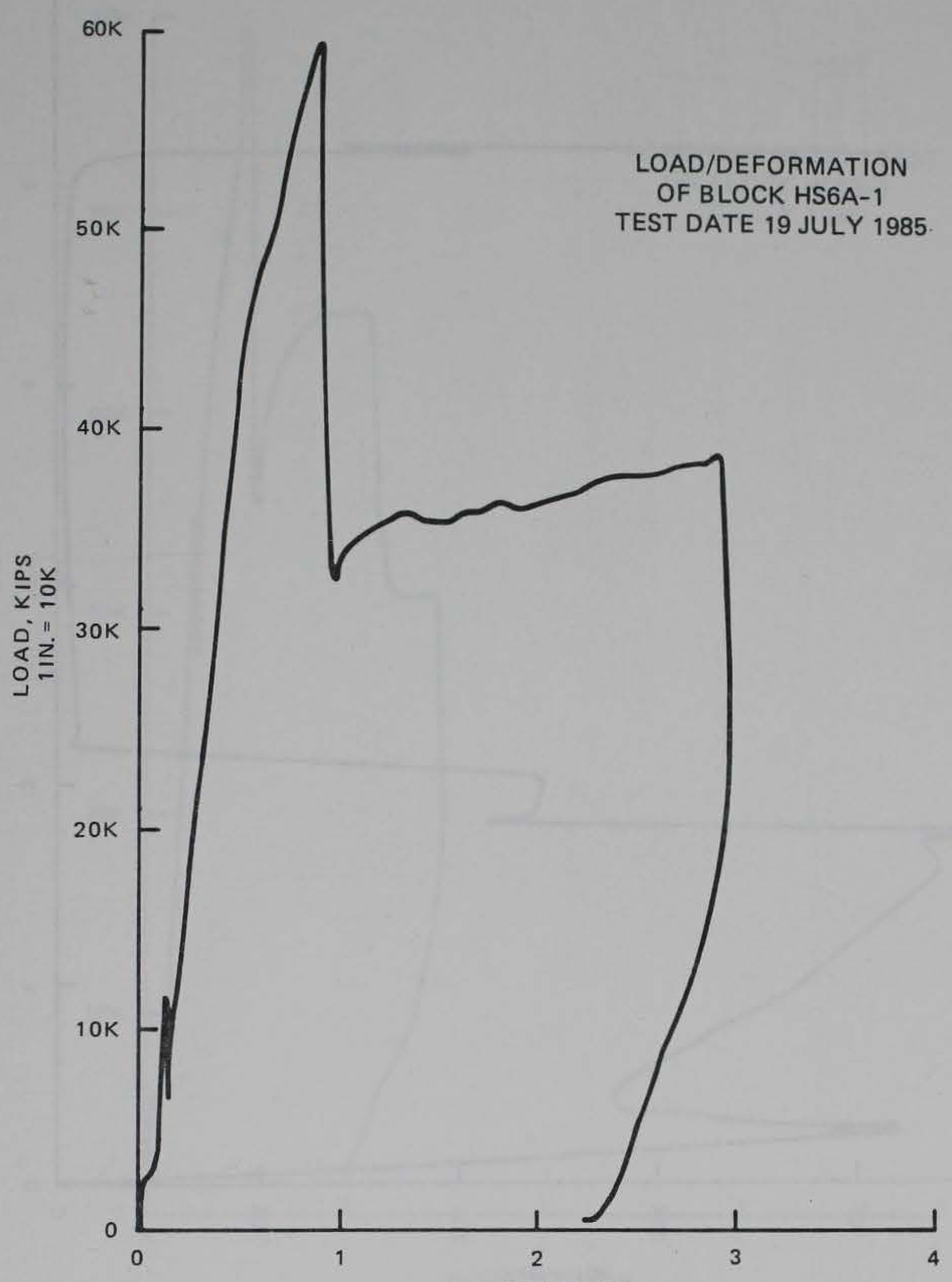
6'-0"
REAR VIEW
SIDE VIEW
END VIEW
FIGURE 4
WALL ARMOR ASSEMBLIES
WES-STRUCTURES LAB
SCALE: 1IN = 1FT
25 MARCH 1985
WILLIE E. MCDONALD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2
3
4
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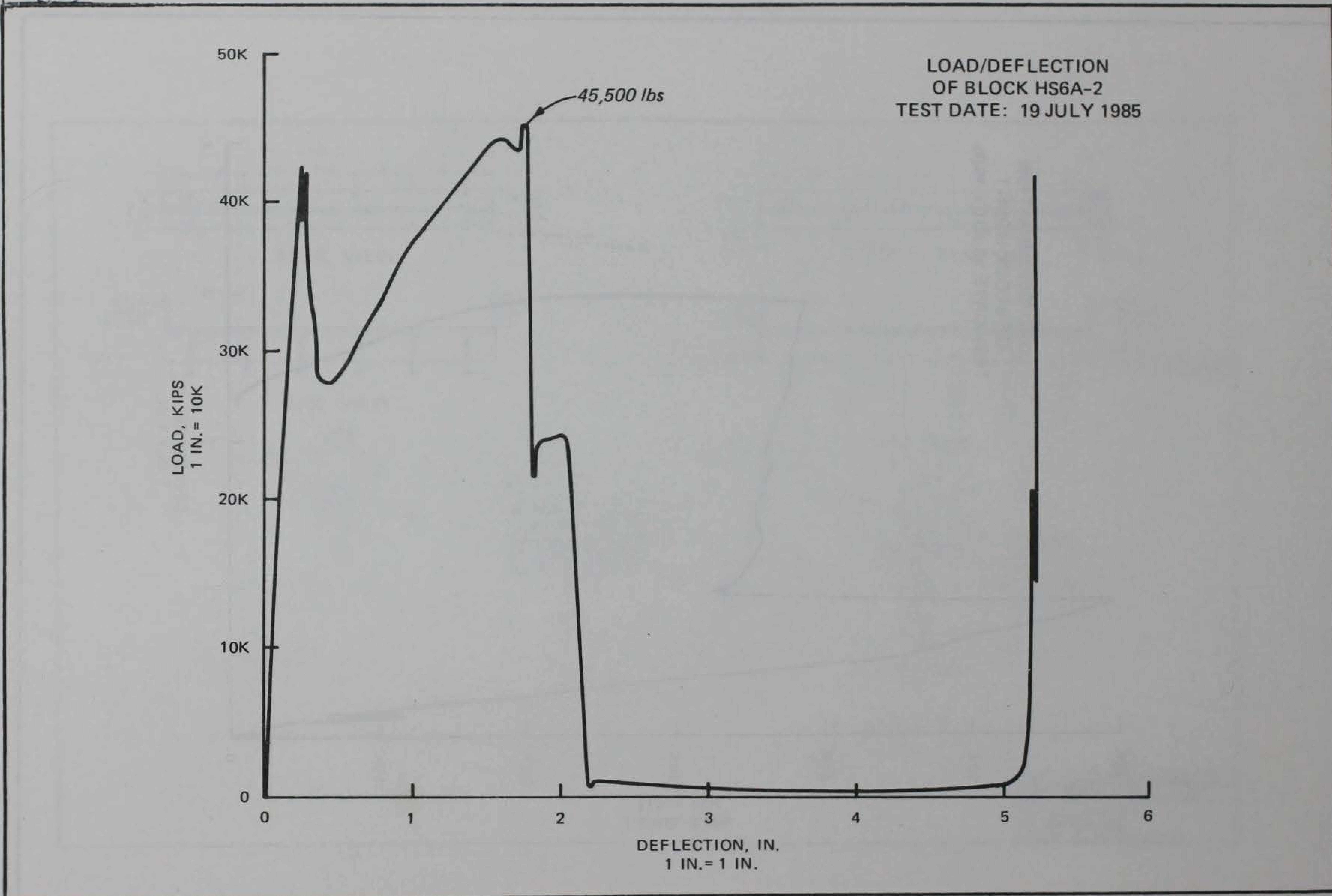
1 IN. = 1 IN.

PLATE 3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5
6
DEFLECTION, IN.
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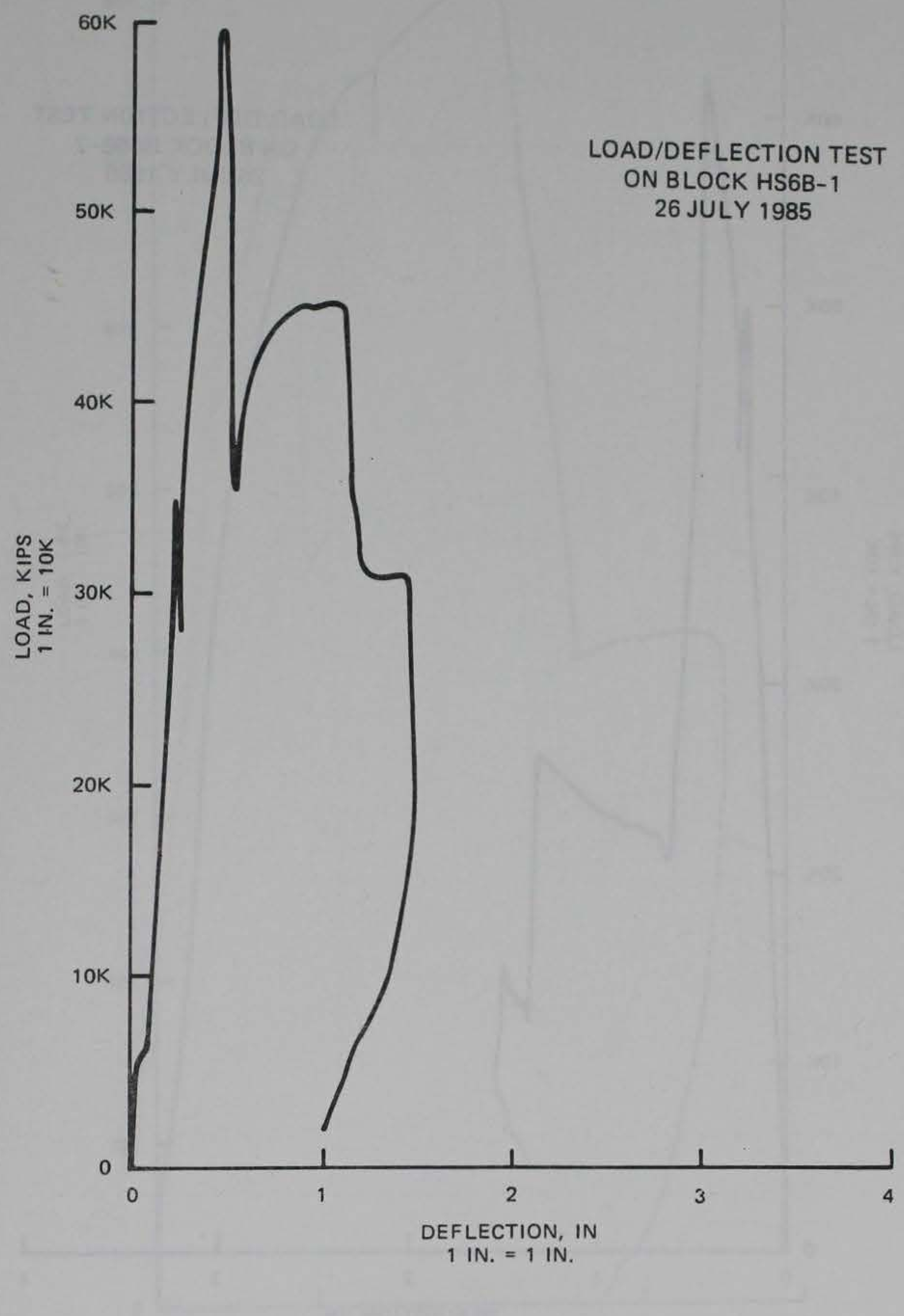
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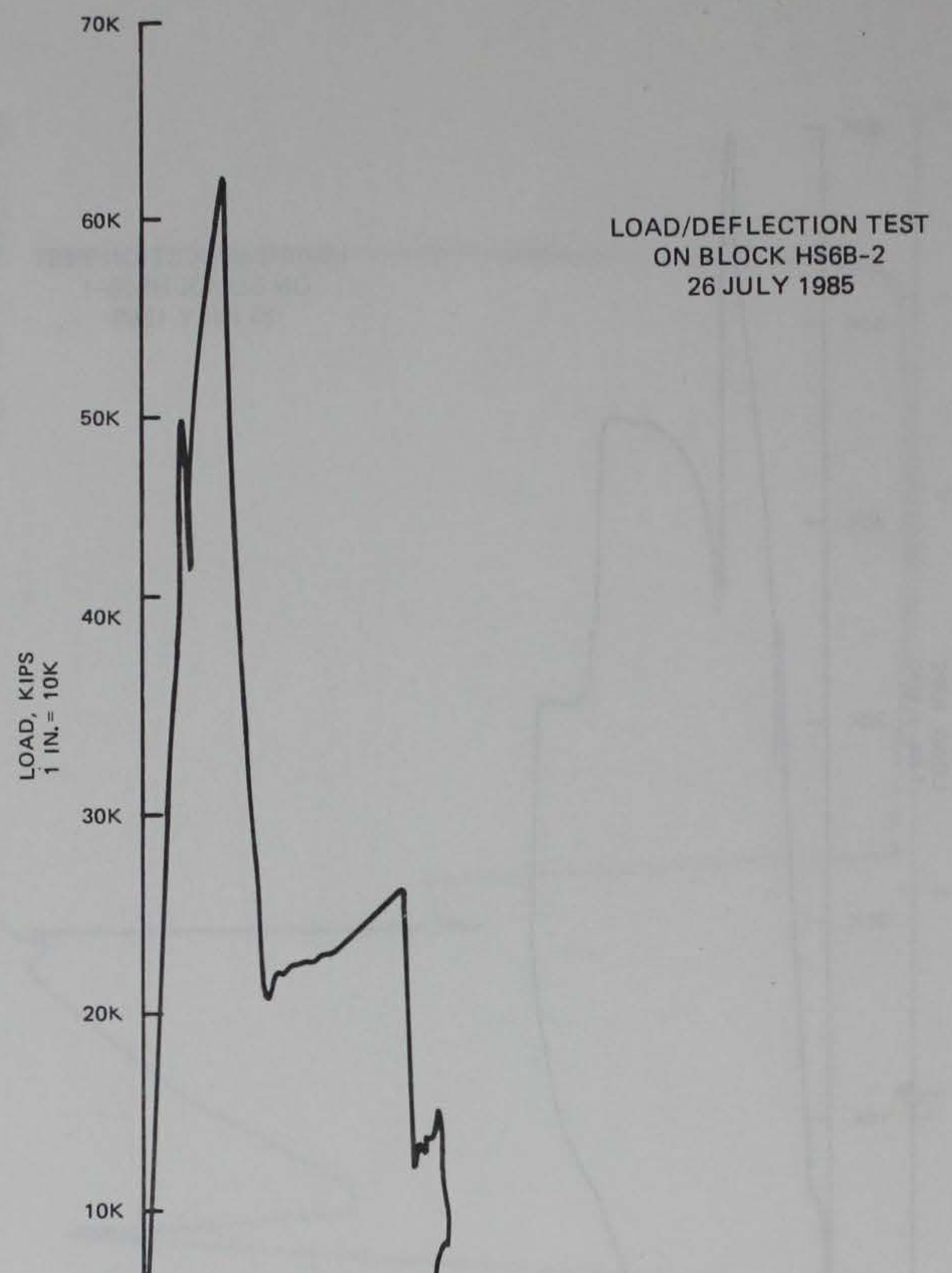
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DEFLECTION, IN
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PLATE 6

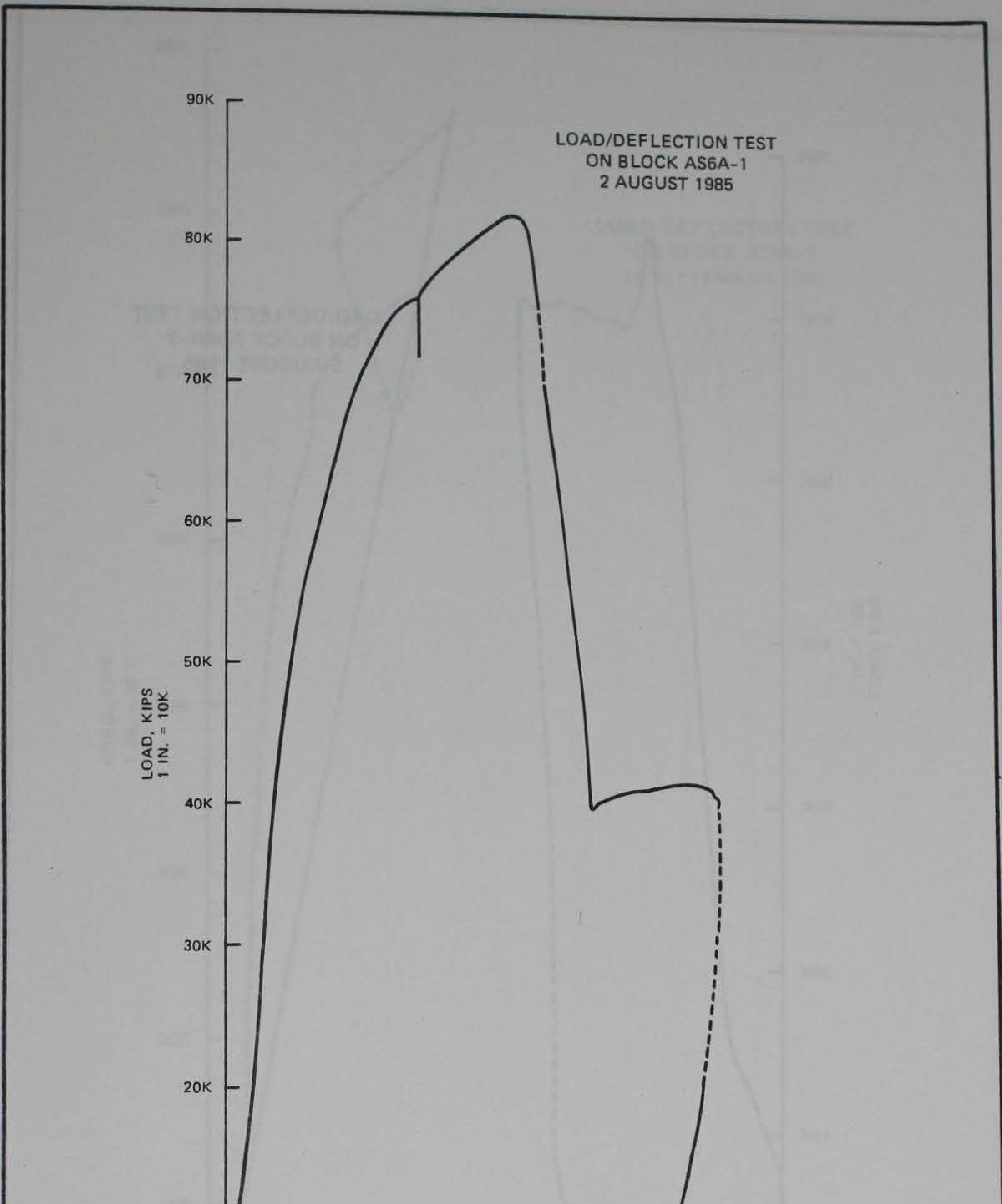

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PLATE 7

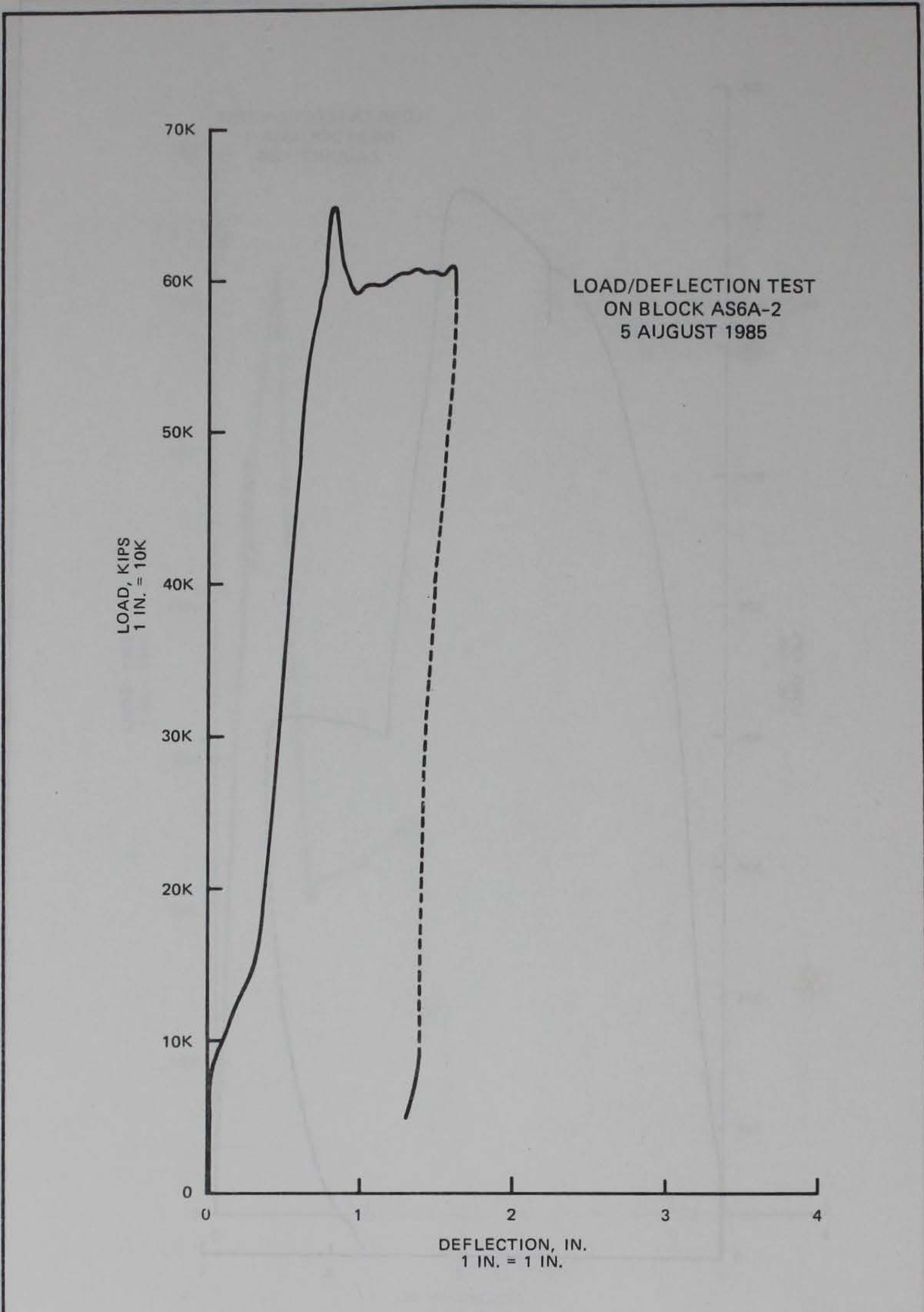
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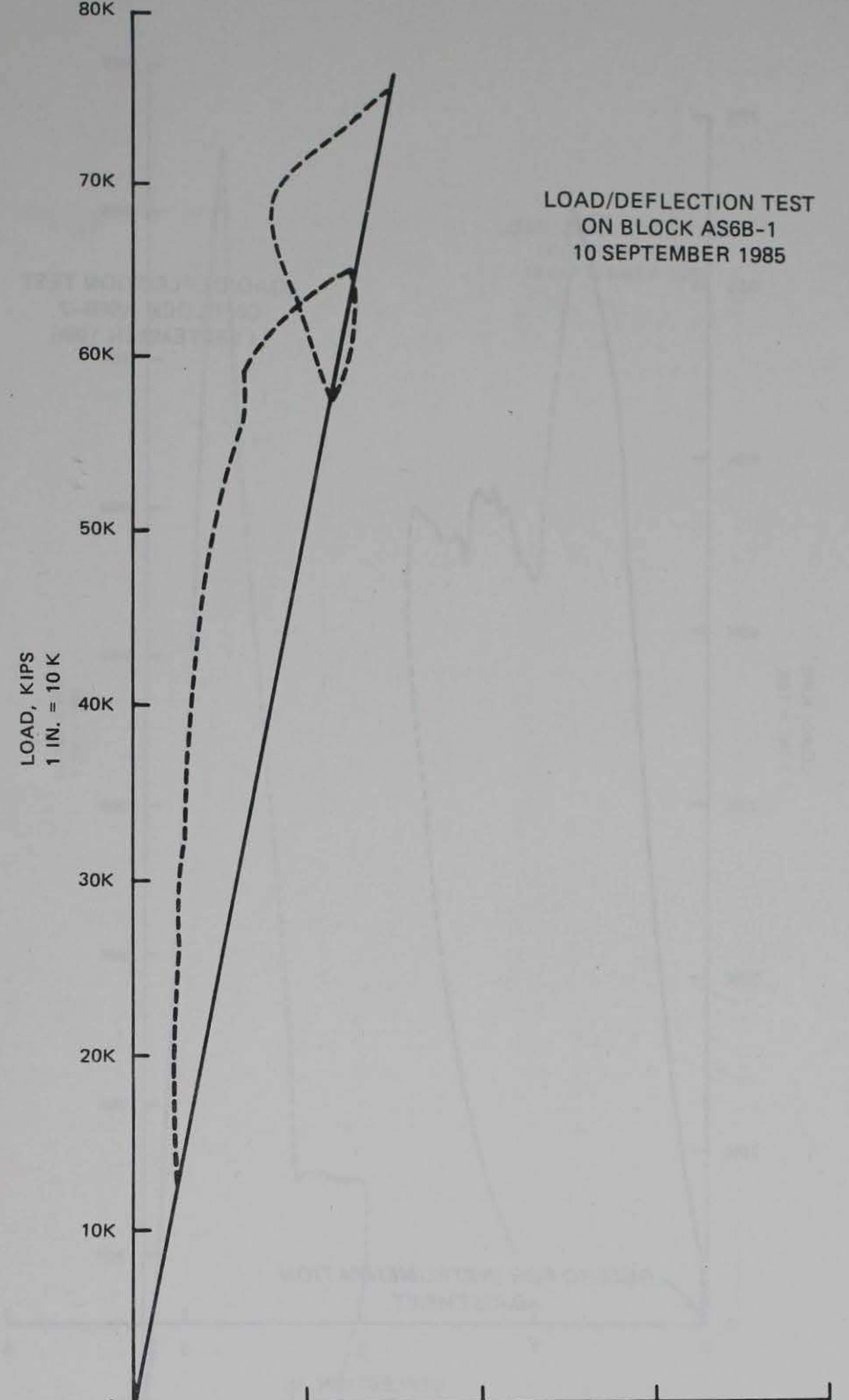
PLATE 8



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30K
20K
10K
0
LOAD, KIPS
1 IN. = 10 K
0
1
2
3
4
DEFLECTION, IN
1 IN. = 1 IN.

PLATE 9

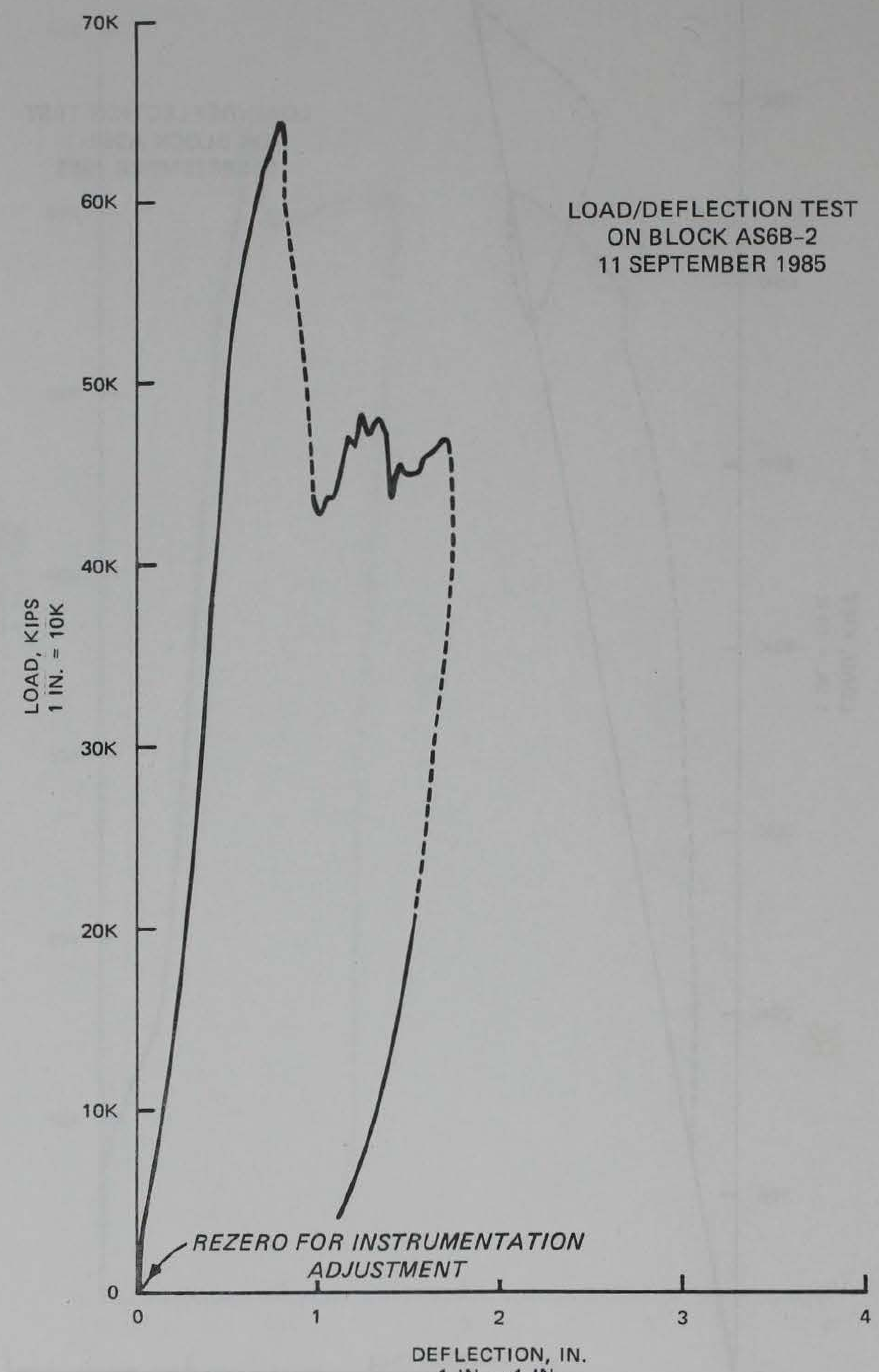
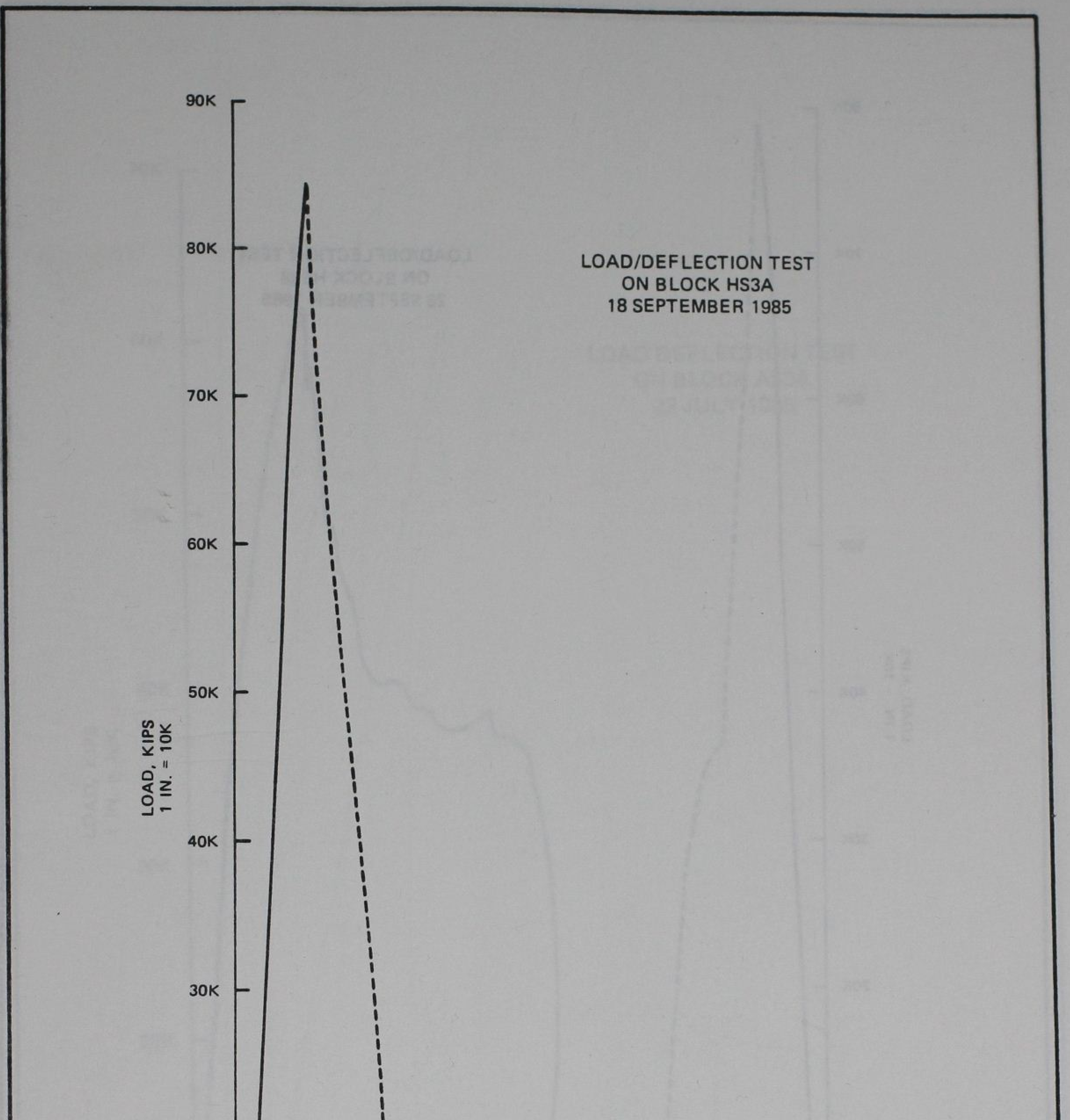

LOAD/DEFLECTION TEST
ON BLOCK AS6B-2
11 SEPTEMBER 1985
70K
60K
50K
40K
30K
20K
10K
0
LOAD, KIPS
1 IN. = 10K
REZERO FOR INSTRUMENTATION
ADJUSTMENT
0
1
2
3
4
DEFLECTION, IN.
1 IN. = 1 IN.

PLATE 10


LOAD/DEFLECTION TEST
ON BLOCK HS3A
18 SEPTEMBER 1985
LOAD, KIPS
1 IN. = 10K
90K
80K
70K
60K
50K
40K
30K
20K
10K
0
1
2
3
4
DEFLECTION, IN.
1 IN. = 1 IN.

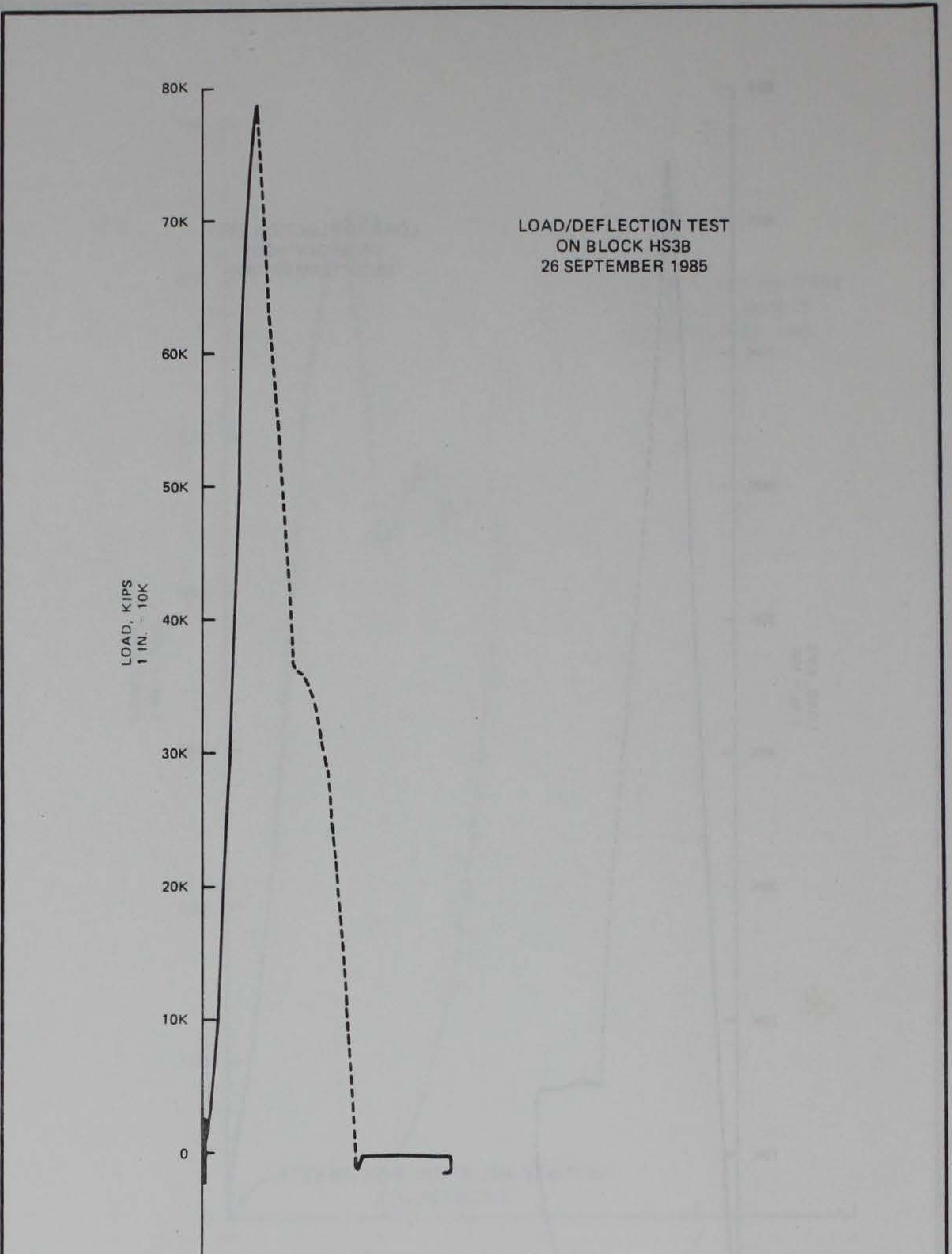
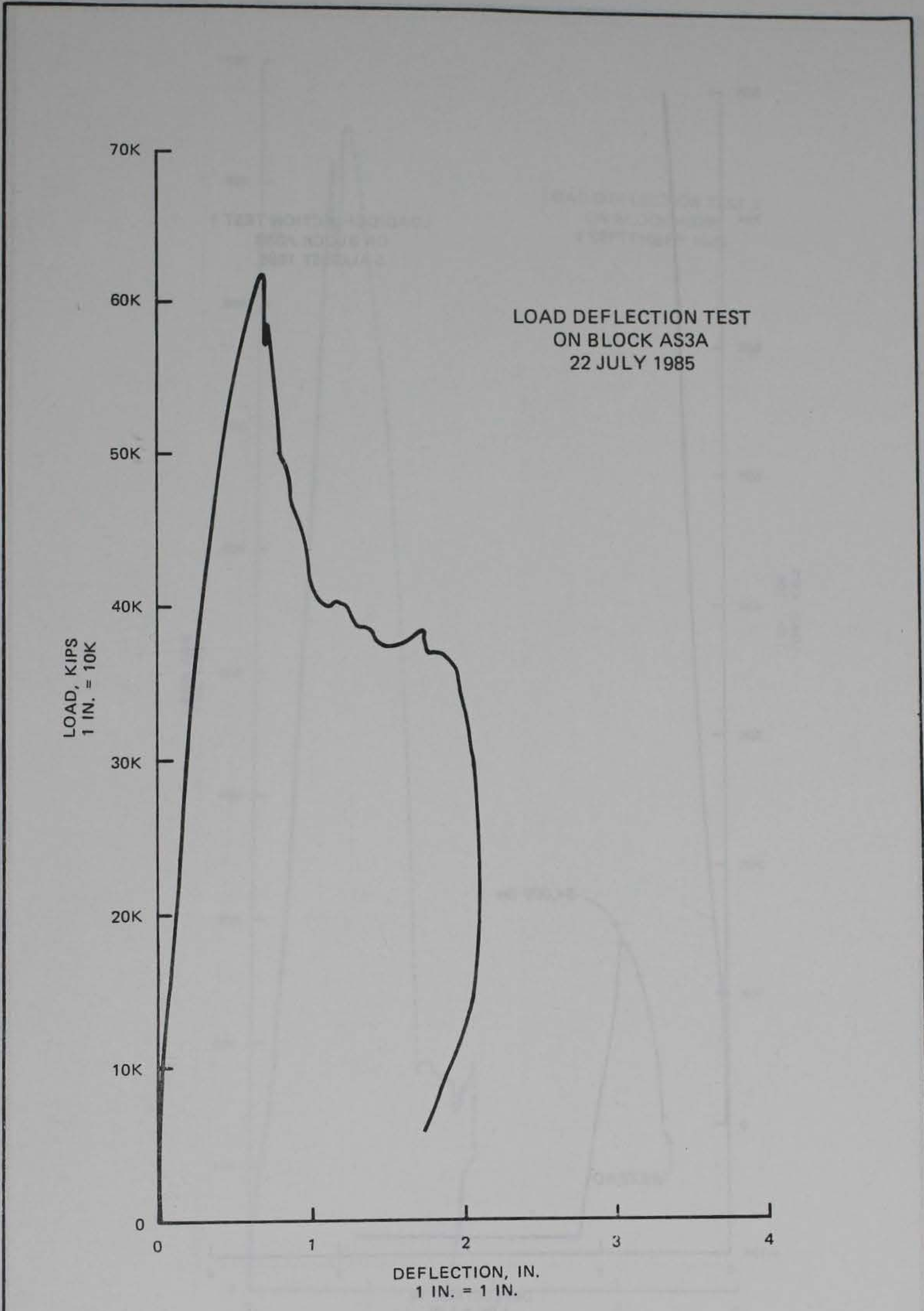

LOAD/DEFLECTION TEST
ON BLOCK HS3B
26 SEPTEMBER 1985
LOAD, KIPS
1 IN. = 10K
80K
70K
60K
50K
40K
30K
20K
10K
0
-1
0
1
2
3
4
DEFLECTION, IN.
1 IN. = 1 IN.

PLATE 12



LOAD DEFLECTION TEST
ON BLOCK AS3A
22 JULY 1985
70K
60K
50K
40K
30K
20K
10K
0
LOAD, KIPS
1 IN. = 10K
0
1
2
3
4
DEFLECTION, IN.
1 IN. = 1 IN.

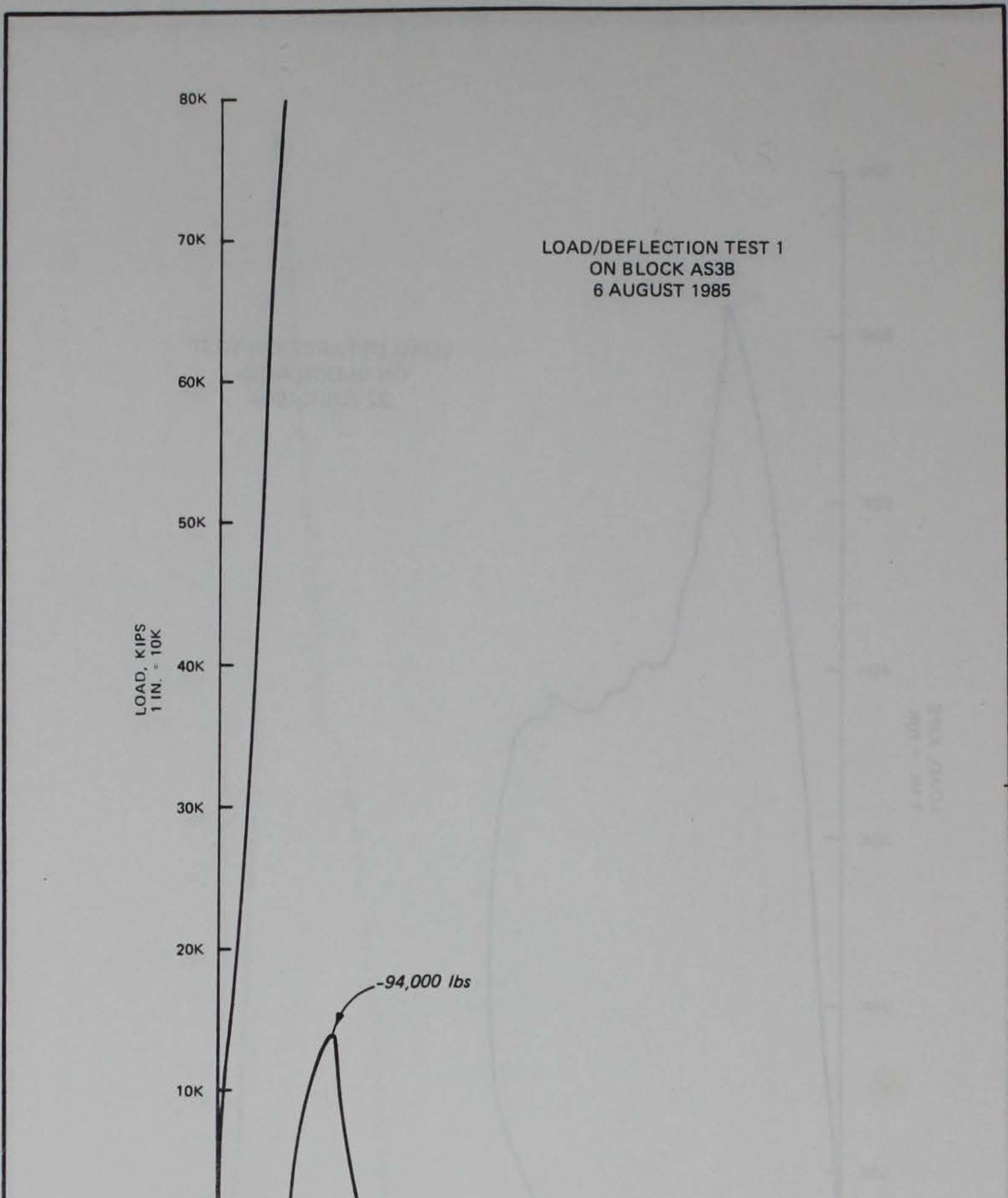

LOAD/DEFLECTION TEST 1
ON BLOCK AS3B
6 AUGUST 1985
80K
70K
60K
50K
40K
30K
20K
10K
0
−10K
LOAD, KIPS
1 IN. = 10K
-94,000 lbs
REZERO
0
1
2
3
4
DEFLECTION, IN
1 IN. = 1 IN.

PLATE 14

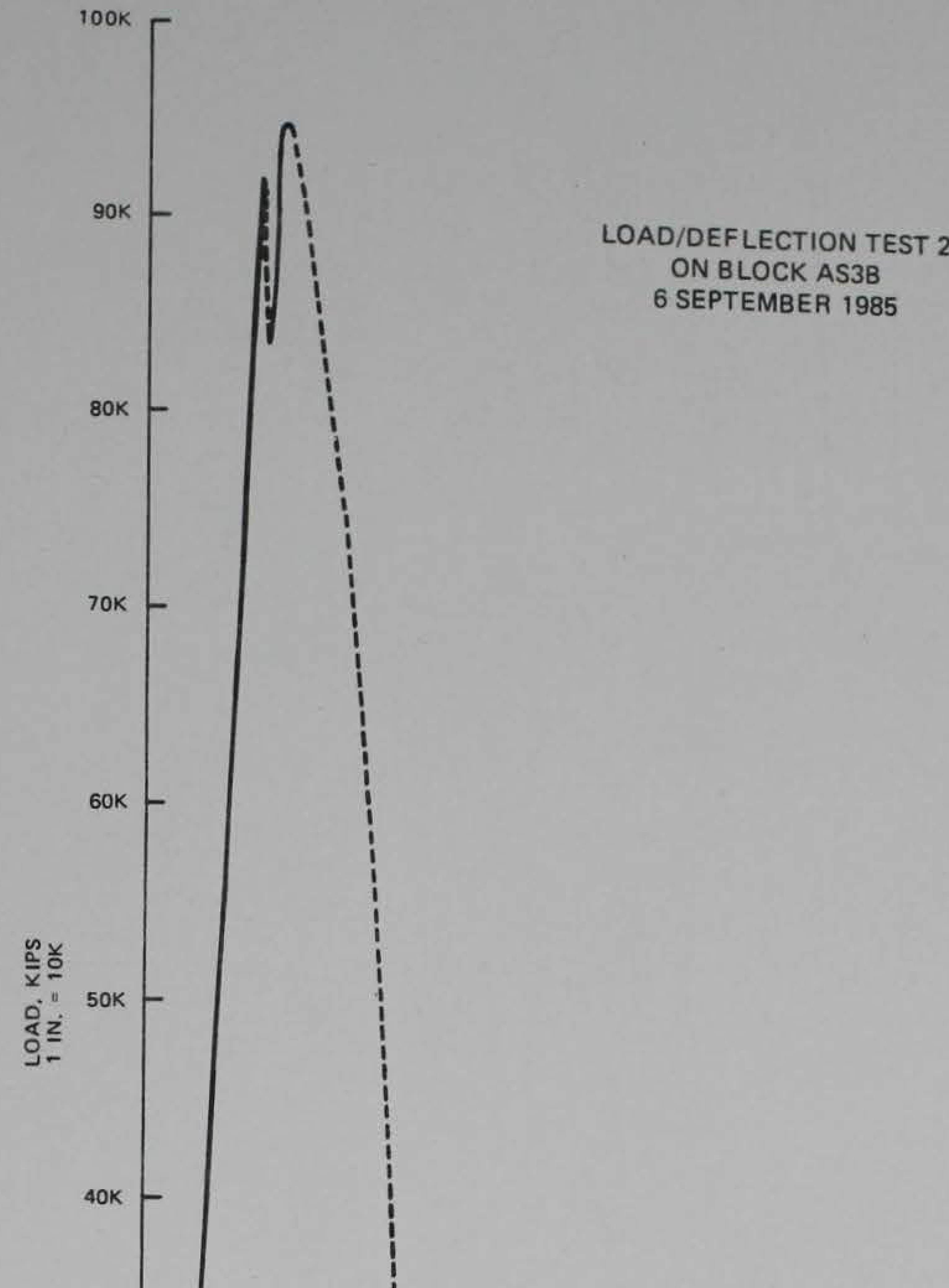

100K
90K
80K
70K
60K
50K
40K
30K
20K
10K
0
LOAD, KIPS
1 IN. = 10K
LOAD/DEFLECTION TEST 2
ON BLOCK AS3B
6 SEPTEMBER 1985
0
1
2
3
4
DEFLECTION, IN.
1 IN. = 1 IN.

PLATE 15