Cement-grout filled joints under alternating loads

Bouwkamp, Jack
Stephen, Roy

1968-11-01

REPORT NO.
68-16

STRUCTURES AND MATERIALS RESEARCH
DEPARTMENT OF CIVIL ENGINEERING

CEMENT-GROUT FILLED TUBULAR JOINTS UNDER ALTERNATING LOADS

By
J. G. BOUWKAMP
R. M. STEPHEN

Report to the Sponsors:
Standard Oil Company of
California, San Francisco, California

NOVEMBER 1968

STRUCTURAL ENGINEERING LABORATORY
COLLEGE OF ENGINEERING
UNIVERSITY OF CALIFORNIA
BERKELEY CALIFORNIA

Structures and Materials Research
Department of Civil Engineering
Division of Structural Engineering
and Structural Mechanics

CEMENT-GROUT FILLED TUBULAR JOINTS UNDER ALTERNATING LOADS

A Report of an Investigation

by

J. G. Bouwkamp
Professor of Civil Engineering

and

R. M. Stephen
Senior Development Engineer

to

Standard Oil Company of California
San Francisco, California

College of Engineering
Office of Research Services
University of California
Berkeley, California
November, 1968

TABLE OF CONTENTS

PAGE

LIST OF FIGURES

ACKNOWLEDGEMENT

The work reported herein was conducted in the Structural Research Laboratory, Division of Structural Engineering and Structural Mechanics, Department of Civil Engineering, University of California, Berkeley. The program was co-sponsored by several companies with interest in offshore structures. The United States Steel Corporation, Pittsburgh, Pennsylvania, donated the joint-specimens. The Standard Oil Company of California, San Francisco, acted as industry representative. The research grant was administered by the Office of Research Services, College of Engineering, University of California, Berkeley.

A number of persons contributed to the work described in this report, and the authors wish to thank them. Particularly, the assistance of Mr. E. Serex and the contributions by Messrs. K. T. Rains and A. D. Lawrence of the Laboratory staff are gratefully acknowledged.

The authors also wish to thank Mr. R. A. Nieman, Technical Engineer, Kaiser Cement and Gypsum Corporation, for donating the cement used in the test joints.

I. INTRODUCTION

This report covers the investigation of the fourth and last type of joint studied in the first part of Phase II of the general program on the behavior of tubular joints under alternating loads. The results on the first three joint types were reported earlier.(1) All pipe material used was API Spec. 5L-Grade B.

The objective of this part of the investigation was to determine the fatigue strength, under complete reversals of load, of two Type-I joints with thin-walled column sections as shown in Figure 1. These connections differed from those tested in Phase I because of a cement-grout fill of the column member.

The mix design of the cement-grout used in the specimens was essentially the same as that used by the oil well industry.(2) The mix design for a one cubic foot batch was 47 lb. of API Class G cement, 37 lb of fly ash (Pozmix A),(3) 4.7 gallons of water and 2.5 lb. of calcium chloride.

The grout was pumped into the column section of the specimen and allowed to cure for at least 14 days. During grouting the column section

---

1. Bouwkamp, J. G. and Stephen, R. M., "Tubular Joints Under Alternating Loads," Structures and Materials Research Report No. 67-29, November 1967, Department of Civil Engineering, University of California, Berkeley.

2. Smith, D. K., "Utilization of Fly Ash in the Cementing of Wells," Minerals Processing, August 1967, pp. 22-27.

3. Trade name for fly ash distributed by Halliburton Company.

was in a vertical position with the grout being injected at the lower section of the column. As the grout was completely enclosed in the pipe, no water or other material was used in the curing process.

Prior to grouting, the steel column wall was subjected to an initial precompression load of 140 K or approximately 11 ksi. This load was introduced through four long high-strength bolts placed in the core of the column section and maintained during the grouting and throughout the entire test. Because of the availability of the 1 in. diameter prestressing bolts it was decided only to prestress the steel shell and not the cement core. Contact between core and bolts was prevented by placing the bolts in 2 in. O. D. cardboard tubes.

II. TESTING PROCEDURE

II-1 General

The testing of each of the specimens was carried out in air under alternating load conditions. However, the first of the thin-wall cement-grout filled Type I joints tested was subjected to a series of cyclic, step-wise increased static loads in order to compare the strains for the initial load cycle with those resulting after a limited number of cycles of loading had been applied. This joint was instrumented with six three-element rosettes to determine the material and structure linearity of the composite section at both the initial loading cycle and after several cycles of loading had been applied. The location of these gages is shown in Figure 2.

In order to subject each specimen to the alternating load, the joints were mounted in a special test frame. A dead load stress of 11 ksi was introduced in the column section through a set of four long high-strength prestressing bolts. A more complete description of the test assembly was presented earlier(4) and will not be repeated here.

Due to an improved mounting arrangement, it was possible to improve the fit of the specimen in the test frame considerably. As a result, it was possible to raise for the alternating load studies the cycling speed from about 15 cycles per minute, as applied in Phase I, to about 30 cycles per minute. The alternating loads were applied

---

4. Bouwkamp, J. G., "Tubular Joints Under Static and Alternating Loads," Structures and Materials Research Report No. 66-15, June 1966, Department of Civil Engineering, University of California, Berkeley.

until failure of the joint was observed. Failure was considered the instance of crack initiation.

III. RESULTS OF STATIC TESTS

III-1 General

For the study of the strains in the grout-filled Type I joint, six locations were selected and instrumented--see Figure 2. The maximum load applied to the horizontal branch member was 50 K in either tension or compression. The nominal stress in the diagonal member for a load of 50 K is approximately 28 ksi, or about 1.33 times the commonly allowable stress of 22 ksi. The applied force and the subsequent reactions were superimposed on the precompression of the column member

III-2 Cement-Grout

Control specimens were cast during the grouting of each of the joint specimens in order to determine the compressive strength of the grout at the start of the cyclic tests. Three 4 x 8 inch cylinders and two 3 x 6 inch cylinders were cast for the first joint specimen. These specimens were tested at 15 days of age to determine the compressive strength and modulus of elasticity. The average strength of the three 4 x 8 inch cylinders was 2,380 psi. The average strength of the two 3 x 6 inch cylinders was 2,685 psi. The modulus of elasticity was determined only on the above two 3 x 6 inch cylinders and was found to be 733,000 psi and 800,000 psi, respectively.

For the second joint specimen studied, two 4 x 8 inch grout cylinders were tested. These tests were carried out at 25 days of age. The average compressive strength for these cylinders was 2,960 psi.

III-3 Detailed Test Results

III-3-1 Joint Type I - Thin Wall Cement-Grout Filled

The first loading cycle of 0, -50, 0, +50 and 0 K was carried out step-wise in 10 K load intervals. The residual strains seem to indicate a yielding in the regions of intersection between the branch members and the column section. The complete tabulation of the strain readings under the initial compressive and tensile loading of 50 K is given in Table I. The recorded maximum strains would indicate that residual strains, probably due to welding, must have been present in the joint prior to loading. The maximum strains at gages 15, 16 and 17 indicate a maximum principal stress level of approximately 32 ksi, which is considerably below the earlier recorded yield stress of 48 ksi.(4)

After the first loading cycle, the gages were zero balanced to eliminate the first cycle residual strains and to permit a recording of a complete set of strain data at loads identical to those applied to the specimen during Cycle 1. Subsequently the specimen was subjected to a total of 50 load cycles. Strains were recorded at the 0, -50, 0, +50 and 0 K for cycles No. 3, 5, 10, 15, 20, 25, 30, 40, and 50. Table II shows the extreme strains recorded during the second cycle of loading. Tables III and IV show similar strain readings for the 40th and 50th cycle of loading, respectively. The readings at the end of the 50th cycle show very small residual strains. It should be noted again, however, that the gages had been rebalanced at the end of the first load cycle.

Tables V and VI give the actual-cumulative-strains for a number of significant strain gages as recorded at 10 K intervals during the first two loading cycles. A plot of these strains versus load--as shown in

Figures 3, 4 and 5 show a basically linear strain response for both the compressive and tensile loads. These plots not only present the load-strain results for the first two cycles, but also indicate the extreme strains after the third and fourth cycles. The results show that an extremely stable load-strain loop seems to develop after the first couple of cycles.

An observation of the graphs in Figures 3, 4 and 5 further indicates that the strains in gages 1 and 6, and 3 and 9, are invariably larger under tension than under compression. This implies that under tension the force transfer between the horizontal branch members and the column wall is more concentrated towards the low point of the line of intersection between this member and the column section than is the case for a compressive load transfer. This is logical because of the expected non-linear influence of the composite column section. Under compression the steel column section will be supported most effectively by the grout core. However, under a tensile load in the horizontal branch member, the beneficial influence of the grout core is basically limited to maintaining the shape of the steel column section wall. Hence the transfer will be concentrated towards the points of maximum column-wall stiffness, or the above noted low-points. The above hypothesis is further supported by the strain readings recorded for gage 12, which shows larger strains when the member is under compression than under tension. The same overall phenomena can be observed from the specific calculated stresses under the two different load applications--see Figures 6 and 7.

Finally to obtain a measure of the strain shift, or structure integrity during the fifty cycles, the strains at gages 1, 6, 3, 9, 12 and 15 are tabulated in Tables VII and VIII. From this tabulation it is clear that after the second cycle, the strain readings become very consistent. This indicates that the joint does not deteriorate after cyclic loading and behaves linearly (although differently under tensile and compressive loads).

IV. RESULTS OF ALTERNATE LOADINGS

IV-1 General

The alternating lateral forces acting on off-shore structures produce alternative web member forces. In these studies, the member forces are represented by alternating loads acting on the joint specimens. These loads are introduced by a double acting hydraulic cylinder with a maximum capacity of ±80 K. For the alternating load tests, the horizontal branch members were subjected to cylinder loads varying between -50 and +50 K. The absolute maximum load in the diagonal under these conditions is 87.5 K, and the nominal stress is approximately 28 ksi.

As was pointed out earlier, all tests in this second phase were carried out under in-air conditions.

IV-2 Detailed Test Results

IV-2-1 Joint Type I Thin Wall Cement-Grout Filled

Two thin walled Type I joints with cement-grout fill were tested under a cyclic loading of ±50 K. The first joint tested developed, after 1400 cycles of loading, a crack in the chord wall at the toe of the weld between the diagonal member and the chord adjacent to the horizontal member. This crack was about 2 1/8 inches in length when noted. A crack in the horizontal member started at 2580 cycles at the toe of the weld on the side of the diagonal member. The propagation of both of these cracks is noted in Figure 8. The test was stopped at 6280 cycles as the chord member crack at the base of the horizontal member was opening about 1/8 inch during each cycle. The crack had penetrated the wall of the chord member and was beginning to tear along this member. Figure 9 shows this crack around the horizontal member between the weld and the chord member.

Two gages, numbers 6 and 9, were monitored during the cycling of the joint to determine the relative retrogression. These are tabulated in Table IX at specific cycles and show that the strains up to about 1500 cycles are relatively constant; thereafter particularly under tension, they show a decrease as the crack propagates.

The second joint tested developed the first crack at 1200 cycles. This crack occurred in the chord wall at the toe of the weld between the chord member and the horizontal member at a point closest to the diagonal member. This crack was about 1/4 inch in length. At 1475 cycles a crack developed in the wall of the horizontal member immediately above the weld between the horizontal member and the chord section, close to where the first crack had started. The first crack in the connection between diagonal member and chord was noted at 1520 cycles and had a length of 1 3/8 inches. This crack occurred in the chord wall at the toe of the weld between the chord and the diagonal at a point closest to the horizontal member. At 3520 cycles a crack in the diagonal member was noted immediately above the weld between this member and the chord member. The location was opposite the first crack indicated in this part of the connection. This crack propagated along the toe of the weld for about 4 inches. At that time the crack began to propagate across the diagonal member perpendicular to the axis of this member. Figure 10 shows the propagation of these cracks during the load cycling. At 6550 cycles, the loading was stopped as the crack in the diagonal member was progressing at the rate of about 1/16 inch per cycle and was opening approximately 1/4 to 3/8 inch during each cycle.

V. CONCLUSIONS AND RECOMMENDATIONS

The static load study on a Type I joint--thin walled and grout filled--indicated that the joint contains considerable residual stresses due to welding. Under the initial loading cycle of ±50 K the diagonal member exhibited some yielding. However, after this initial plastic deformation of the joint, the specimen essentially acted in a linear manner. This behavior was different for a tensile-load transfer between the branch members as compared to a compressive-load transfer. In the tension case the transfer is concentrated towards the low-point of the welds connecting the web tubes to the chord member. For a compressive-load transfer the distribution of the forces between branch and column members seems to be more balanced.

The alternating load studies undertaken in this phase of the project provided additional information as to the alternating-load life of this thin walled joint. It will be recalled that in Phase I the thin walled Type I joint failed within the first 60 cycles of loading. The cement-grout fill therefore increased the overall fatigue life by some 1200 cycles. However, Figure 11 shows that the thin-walled grout filled joints are still significantly inferior to the performance, recorded earlier, for thick-wall Type I joints.(1,4)

TABLE I STRAINS IN TYPE I JOINT
THIN WALL CEMENT-GROUT FILLED

FIRST LOADING CYCLE OF ∓50 K

Gage No.	Strain in Micro in./in.			
	-50 K	0 K	+50 K	0 K
1	-505	-20	+865	+65
2	-40	-10	+125	-60
3	-450	0	+575	+20
4	-200	-15	+330	-10
5	-55	-5	+310	+10
6	-790	-60	+840	-20
7	-370	-45	+390	-30
8	-135	-20	+65	-55
9	-470	-20	+610	+20
10	-405	-20	+460	+20
11	-250	-20	+250	-10
12	-600	+230	+890	+240
13	-360	+160	+730	+210
14	-365	+15	+570	+70
15	+1025	+50	-950	+35
16	-100	-140	-30	-115
17	+550	+15	-490	+15

TABLE II STRAINS IN TYPE I JOINT
THIN WALL CEMENT-GROUT FILLED

SECOND LOADING CYCLE OF ∓50 K LOAD

Gage No.	Strain in Micro in./in.			
	-50 K	0 K	+50 K	0 K
1	-500	0	+860	+30
2	-35	0	+180	+10
3	-440	0	+580	+10
4	-180	0	+360	+10
5	-70	0	+320	+10
6	-770	-40	+920	+30
7	-360	-30	+450	+20
8	-115	0	+140	+30
9	-460	-10	+640	+20
10	-400	-10	+470	+30
11	-245	-10	+280	+20
12	-800	0	+680	+20
13	-520	-10	+550	+20
14	-400	-20	+520	+20
15	+980	+10	-1010	+10
16	+10	-30	+90	0
17	+530	0	-510	+20

TABLE III STRAINS IN TYPE I JOINT THIN WALL CEMENT-

40th LOADING CYCLE OF ∓ 50 K LOAD

Gage No.	Strain in Micro in./in.			
	-50 K	0 K	+50 K	0 K
1	-570	-30	+820	0
2	-60	0	+180	0
3	-450	-20	+560	0
4	-200	-10	+340	0
5	-100	-10	+310	0
6	-840	-80	+920	-10
7	-400	-50	+460	0
8	-150	-30	+130	0
9	-520	-50	+460	0
10	-440	-50	+470	0
11	-270	-30	+290	0
12	-720	-30	+660	0
13	-540	-30	+530	0
14	-440	-50	+500	-10
15	+1010	+10	-1020	0
16	0	-40	+80	0
17	+530	-10	-530	0

TABLE IV STRAINS IN TYPE I JOINT THIN WALL CEMENT-GROUT FILLED

50th LOADING CYCLE OF ∓ 50 K Load

Gage No.	Strain in Micro in./in.			
	50 K	0 K	+50 K	0 K
1	-560	-20	+820	+20
2	-50	0	+180	+10
3	-430	-10	+570	+10
4	-190	0	+350	+10
5	-90	0	+310	+10
6	-840	-70	+930	0
7	-400	-40	+470	0
8	-150	-20	+150	+10
9	-520	-40	+640	+10
10	-430	-40	+480	0
11	-260	-20	+290	+10
12	-810	-20	+670	0
13	-540	-20	+540	+10
14	-430	-40	+510	-10
15	+1000	+20	-1020	0
16	+10	-40	+180	0
17	+530	-10	-520	0

TABLE V

STRAINS IN TYPE I JOINT AT SPECIFIC LOCATIONS

FIRST LOADING CYCLE OF ∓50 K

Load Kip	Gage					
	1	6	3	9	12	15
0	0	0	0	0	0	0
-10	-100	-145	-100	-80	-175	+200
-20	-200	-290	-185	-170	-330	+410
-30	-300	-460	-275	-265	-450	+620
-40	-400	-625	-365	-365	-540	+840
-50	-505	-790	-450	-470	-600	+1025
-40	-430	-690	-365	-390	-435	+850
-30	-345	-560	-280	-310	-255	+660
-20	-250	-400	-190	-215	-80	+460
-10	-150	-210	-100	-110	+100	+230
0	-20	-60	0	-20	+230	+50
+10	+130	+160	+90	+130	+345	-185
+20	+290	+340	+205	+250	+485	-385
+30	+480	+500	+330	+365	+620	-590
+40	+675	+650	+450	+480	+750	-780
+50	+865	+840	+575	+610	+890	-950
+40	+750	+660	+480	+500	+750	-785
+30	+590	+470	+360	+370	+600	-580
+20	+420	+300	+235	+255	+450	-370
+10	+225	+140	+120	+135	+320	-150
0	+65	-20	+20	+20	+240	+35

TABLE VI

STRAINS IN TYPE I JOINT AT SPECIFIC LOCATIONS

SECOND LOADING CYCLES OF ∓50 K

Load Kip	Gage					
	1	6	3	9	12	15
0	+65	-20	+20	+240	+240	+35
-10	-25	-170	-65	+90	+90	+235
-20	-145	-350	-160	-160	-90	-400
-30	-245	-520	-250	-260	-260	+655
-40	-345	-655	-330	-350	-420	+845
-50	-435	-790	-420	-440	-560	+1015
-40	-350	-680	-330	-360	-400	+845
-30	-265	-530	-230	-265	-200	+635
-20	-185	-390	-160	-180	-40	+475
-10	-75	-190	-70	-70	+140	+215
0	+65	-60	+20	+10	+240	+45
+10	+235	+160	+130	+150	+380	-195
+20	+425	+320	+260	+270	+510	-405
+30	+605	+510	+380	+400	+650	-615
+40	+755	+700	+490	+530	+780	-785
+50	+925	+900	+600	+660	+920	-975
+40	+795	+700	+500	+530	+770	-795
+30	+645	+510	+390	+410	+620	-595
+20	+465	+330	+270	+280	+480	-375
+10	+285	+170	+150	+170	+350	-145
0	+95	+10	+30	+40	+260	+45

TABLE VII

STRAINS IN TYPE I JOINT AT SPECIFIC LOCATIONS

Cycle	Load Kip	Gage					
		1	6	3	9	12	15
3	0	+95	+10	+30	+40	+260	+45
	-50	-457	-820	-430	-450	-580	+1025
	0	+35	-60	+10	0	+220	+55
	+50	+885	+880	+590	+650	+900	-965
	0	+75	-30	+40	+10	+270	+45
4	-50	-465	-830	-410	-450	-570	+1025
	0	+25	-80	+10	0	+220	+65
	+50	+935	+900	+610	+660	+910	-975
	0	+85	0	+40	+40	+250	+45
5	-50	-465	-830	-410	-460	-560	+1035
	0	+45	-70	+10	0	+230	+65
	+50	+915	+900	+610	+670	+920	-975
	0	+85	0	+40	+40	+270	+45
10	-50	-465	-840	-410	-470	-560	+1035
	0	+65	-90	+30	-10	+240	+65
	+50	+925	+900	+610	+670	+930	-975
	0	+95	-10	+50	+40	+270	+35
15	-50	-465	-850	-400	-480	-550	+1045
	0	+65	-90	+30	-10	+250	+55
	+50	+925	-930	+610	+670	+930	-975
	0	+95	-10	+50	+40	+280	+45

TABLE VIII

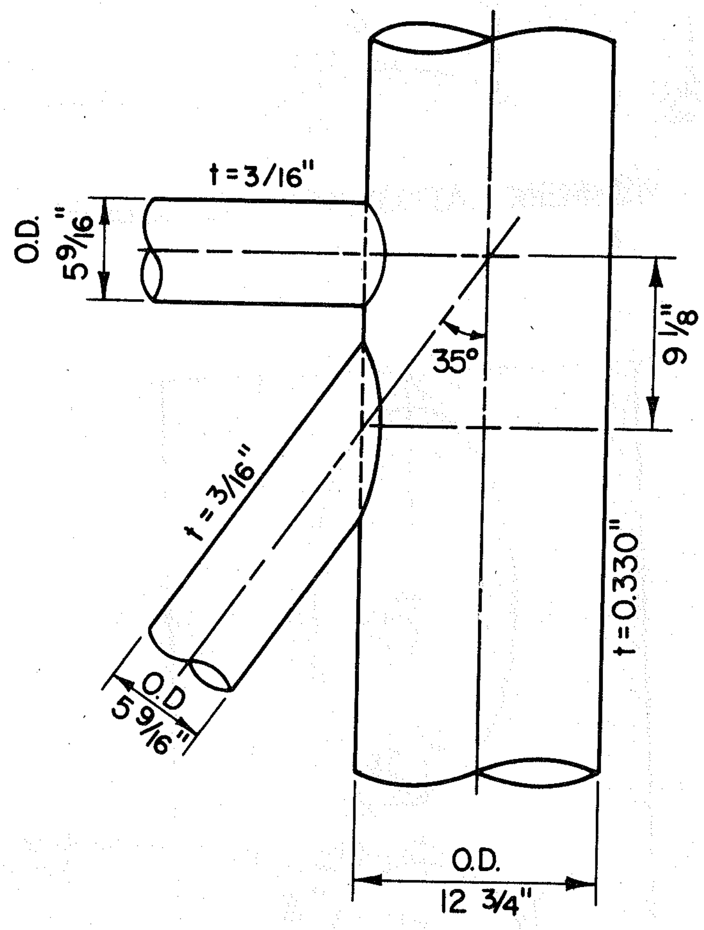
STRAINS IN TYPE I JOINT AT SPECIFIC LOCATIONS

Cycle	Load Kip	Gage					
		1	6	3	9	12	15
20	-50	-465	-860	-400	-480	-540	+1045
	0	+75	-90	+30	-10	+250	+55
	+50	+935	+900	+620	+670	+950	-975
	0	+115	-10	+60	+40	+290	+45
25	-50	-455	-860	-390	-480	-530	+1055
	0	+75	-100	+30	-10	+260	+65
	+50	+925	+900	+620	+670	+950	-975
	0	+115	-20	+60	+40	+290	+45
30	-50	-455	-860	-390	-480	-530	+1045
	0	+75	-100	+30	-10	+260	+65
	+50	+925	+900	+610	+670	+950	-975
	0	+105	-30	+50	+30	+290	+45
40	-50	-465	-870	-400	-490	-530	+1055
	0	+75	-110	+30	-20	+260	+55
	+50	+925	+890	+610	+670	+950	-975
	0	+105	-40	+50	+30	+290	+45
50	-50	-455	-870	-410	-490	-520	+1045
	0	+85	-100	+40	+40	+270	+65
	+50	+925	+900	+620	+670	+960	-975
	0	+125	-30	+60	+40	+290	+45

TABLE IX

STRAINS IN TYPE I JOINT
AT GAGE LOCATIONS 6 AND 9
AT VARIOUS LOAD CYCLES

Cycle	Gage			
	6		9	
	Load (Kip)		Load (Kip)	
	-50	+50	-50	+50
50	-840	+930	-520	+640
250	-840	+930	-520	+640
600	-840	+930	-520	+640
1000	-840	+930	-520	+640
1500	-840	+930	-520	+640
2175	-720	+905	-520	+640
3200	-710	+810	-510	+630
3660	-710	+710	-510	+630
4080	-690	+540	-500	+620
4380	-630	+420	-490	+610
4580	-590	+290	-475	+595
4880	-510	+150	-460	+580
5160	-390	+180	-450	+570



THIN-WALL
CEMENT-GROUT FILLED
COLUMN SECTION

FIG. 1 JOINT TYPE 1 (ZERO-ECCENTRICITY)

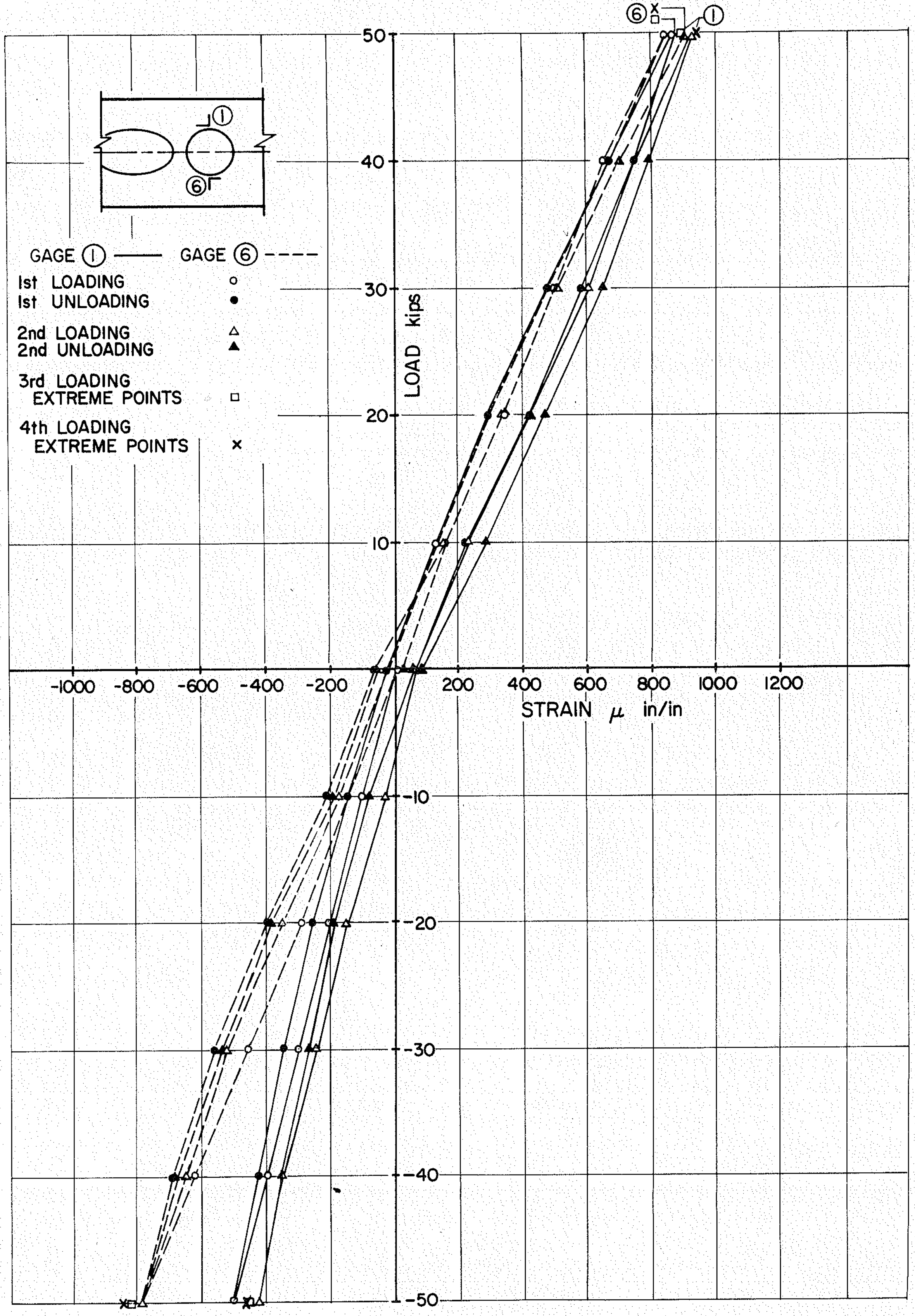


FIG. 3 STRAIN VERSUS LOAD UNDER INITIAL FOUR LOAD CYCLES

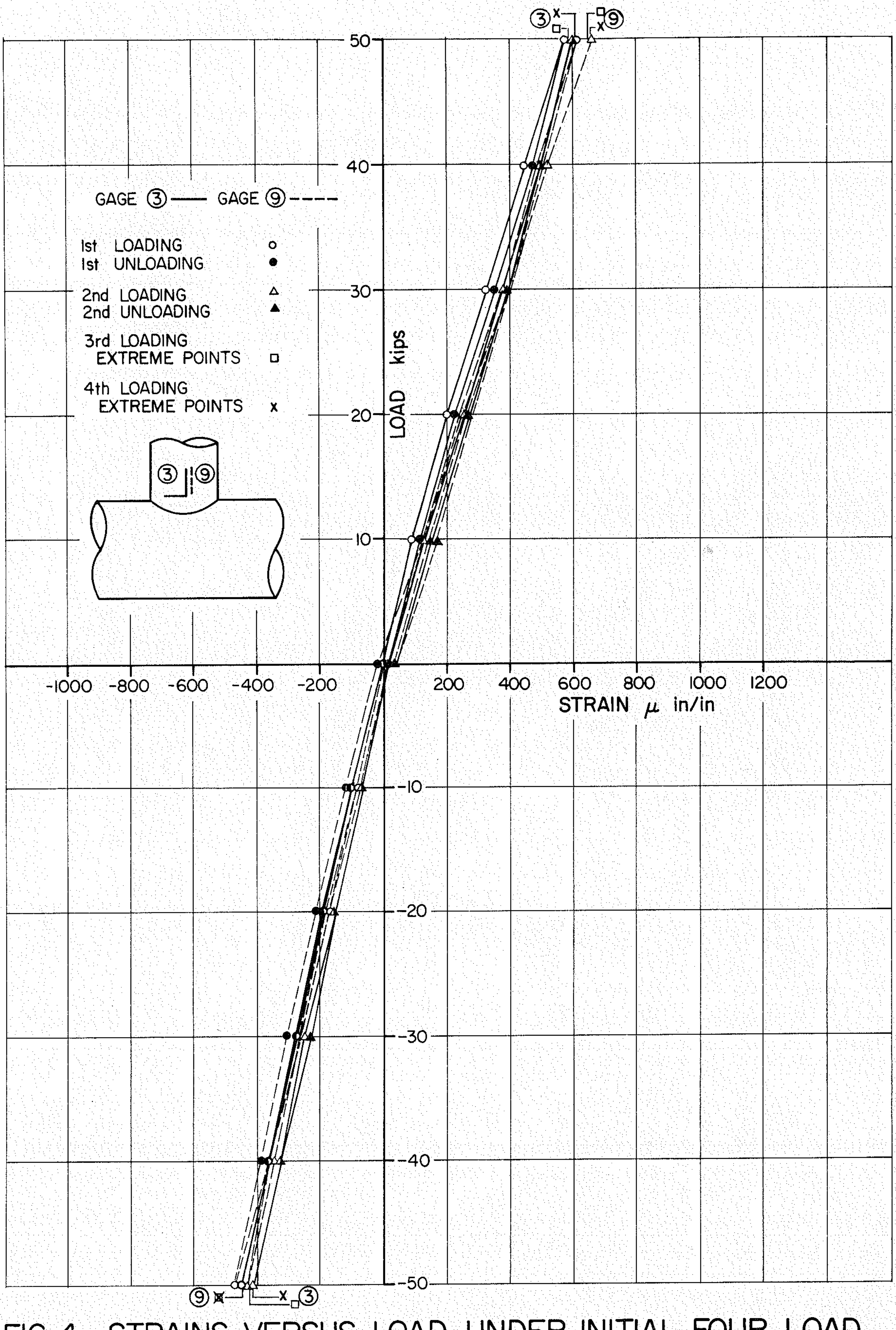


FIG. 4 STRAINS VERSUS LOAD UNDER INITIAL FOUR LOAD CYCLES

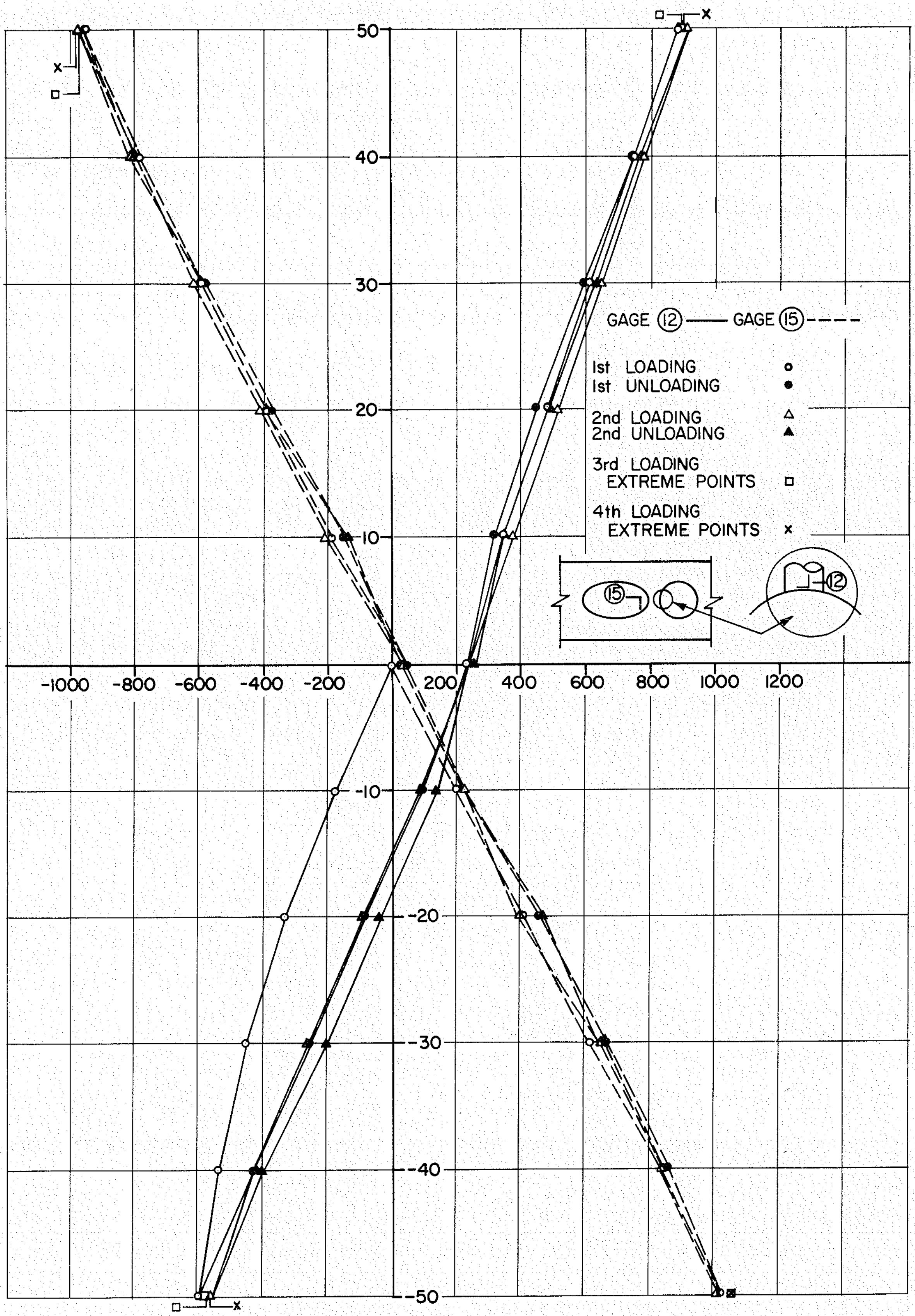


FIG. 5 STRAINS VERSUS LOAD UNDER INITIAL FOUR LOAD CYCLES

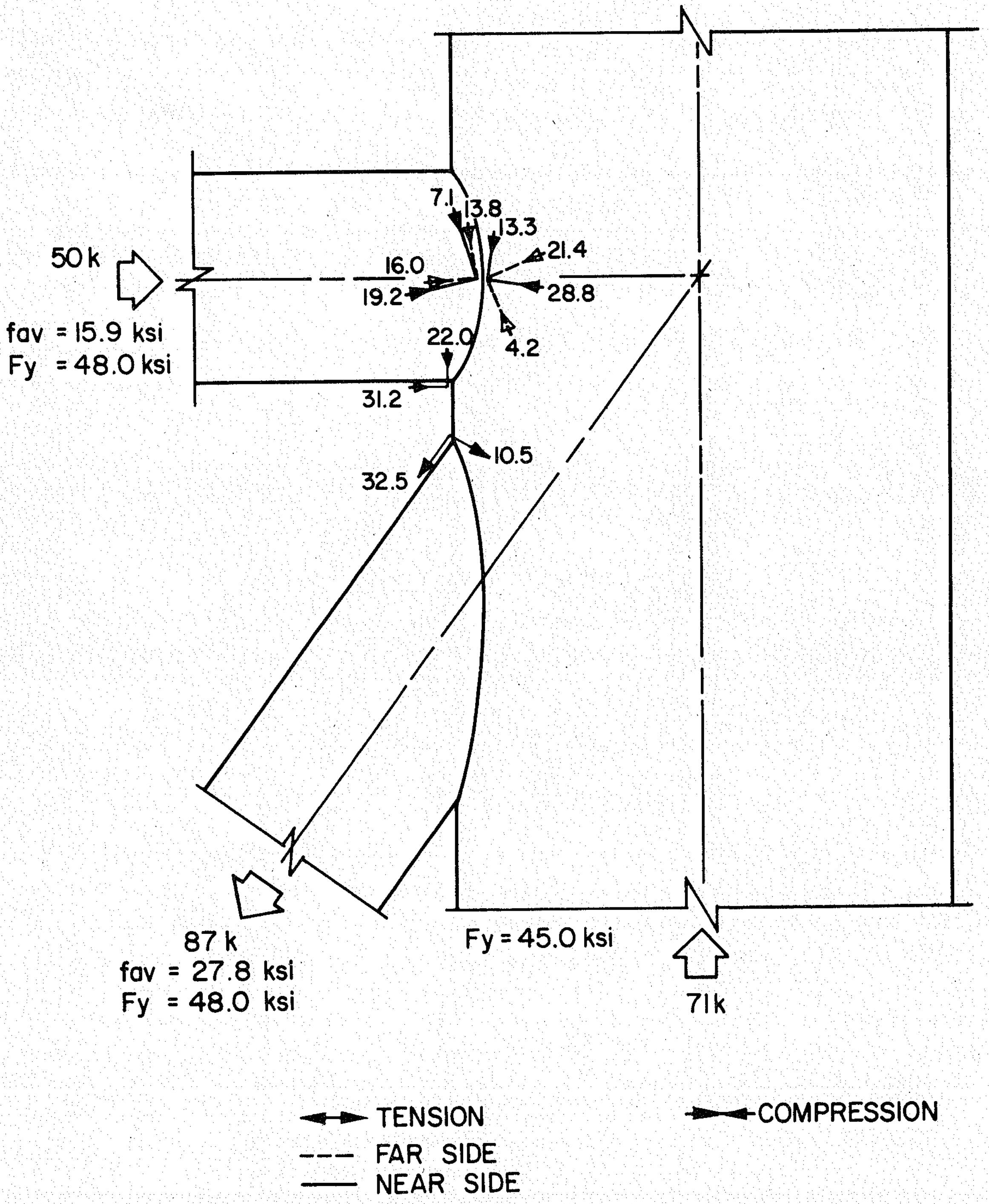


FIG. 6 PRINCIPAL STRESSES - COMPRESSIVE LOAD IN HORIZONTAL MEMBER (5th CYCLE OF LOADING)

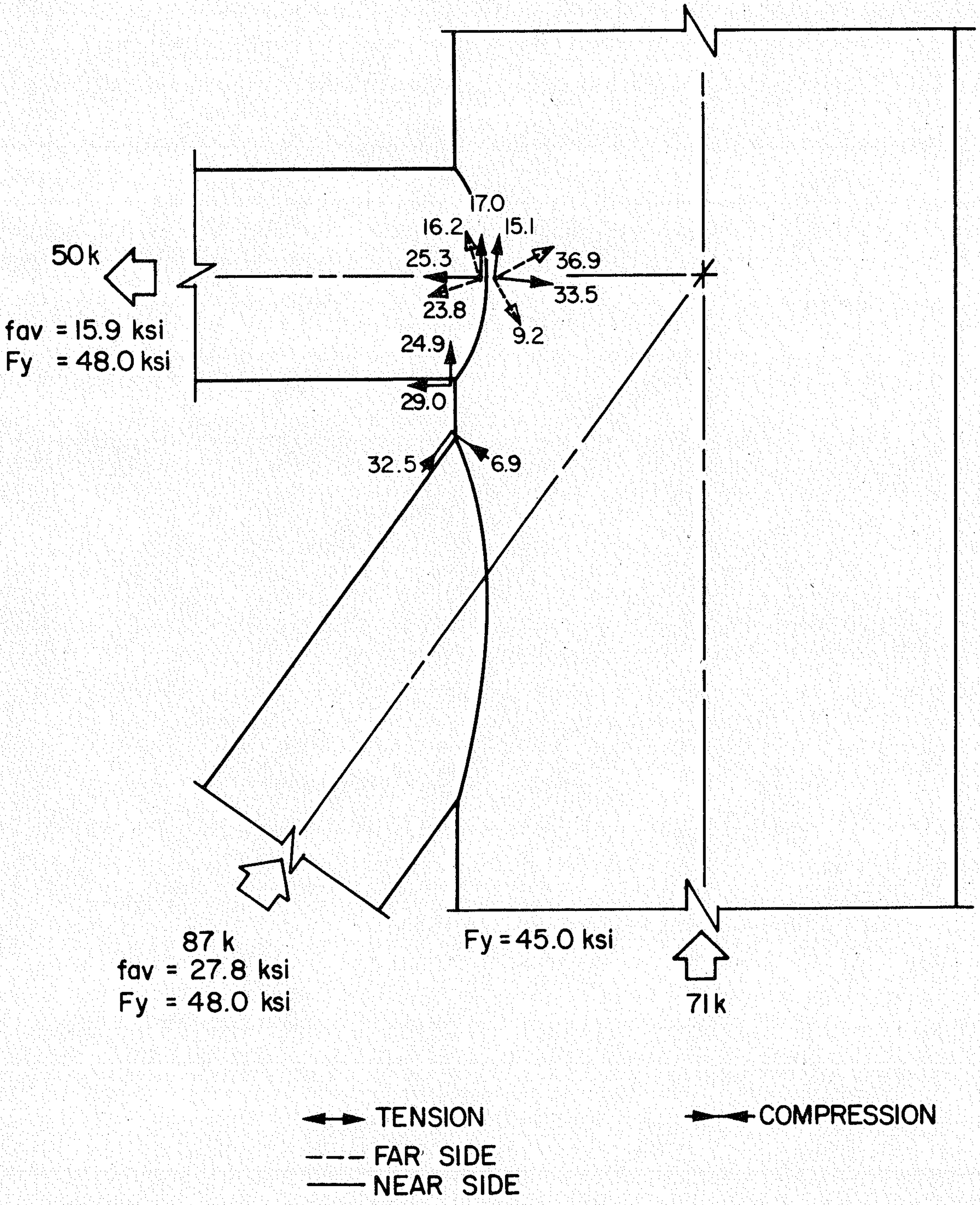
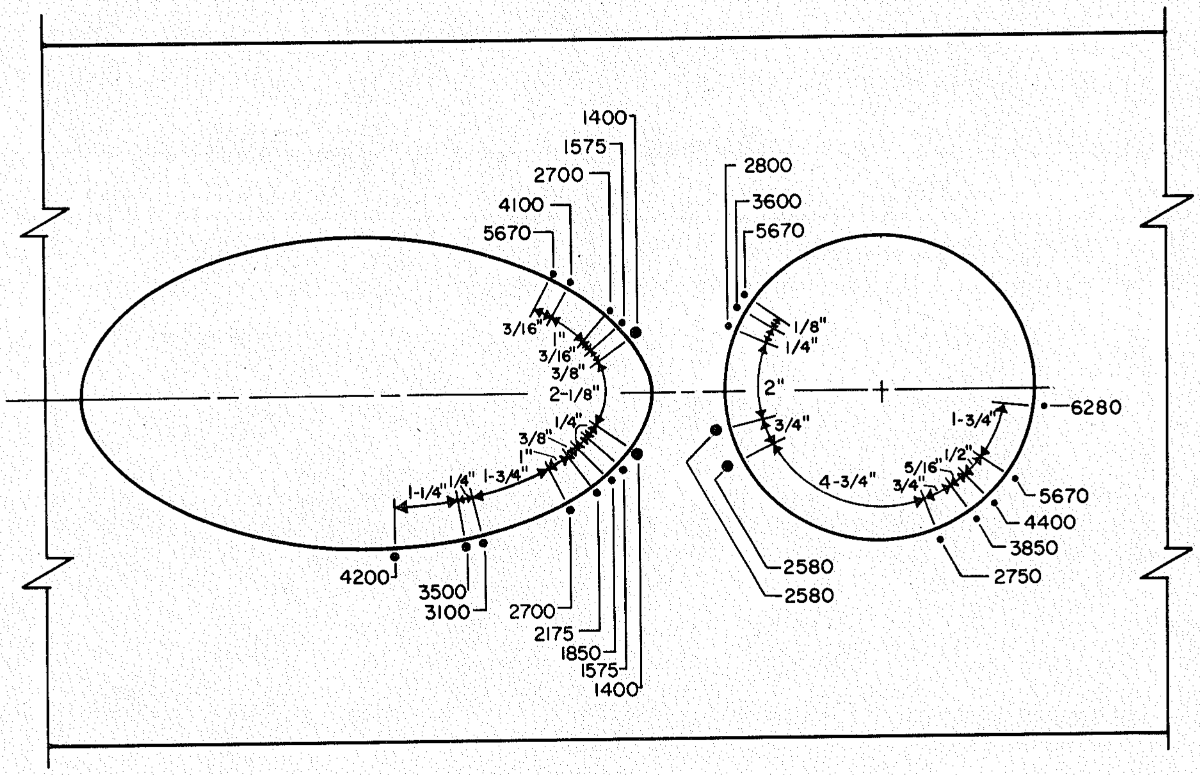


FIG. 7 PRINCIPAL STRESSES - TENSILE LOAD IN HORIZONTAL MEMBER (5th CYCLE OF LOADING)



• INDICATES POINT OF CRACK PROGRESSION IN CYCLES

DATE TESTED: 3/7/68 - 3/14/68

FIG. 8 CRACK PROPAGATION IN TYPE I JOINT (THIN WALL CEMENT-GROUT FILLED) LOADED AT ± 50k IN HORIZONTAL MEMBER

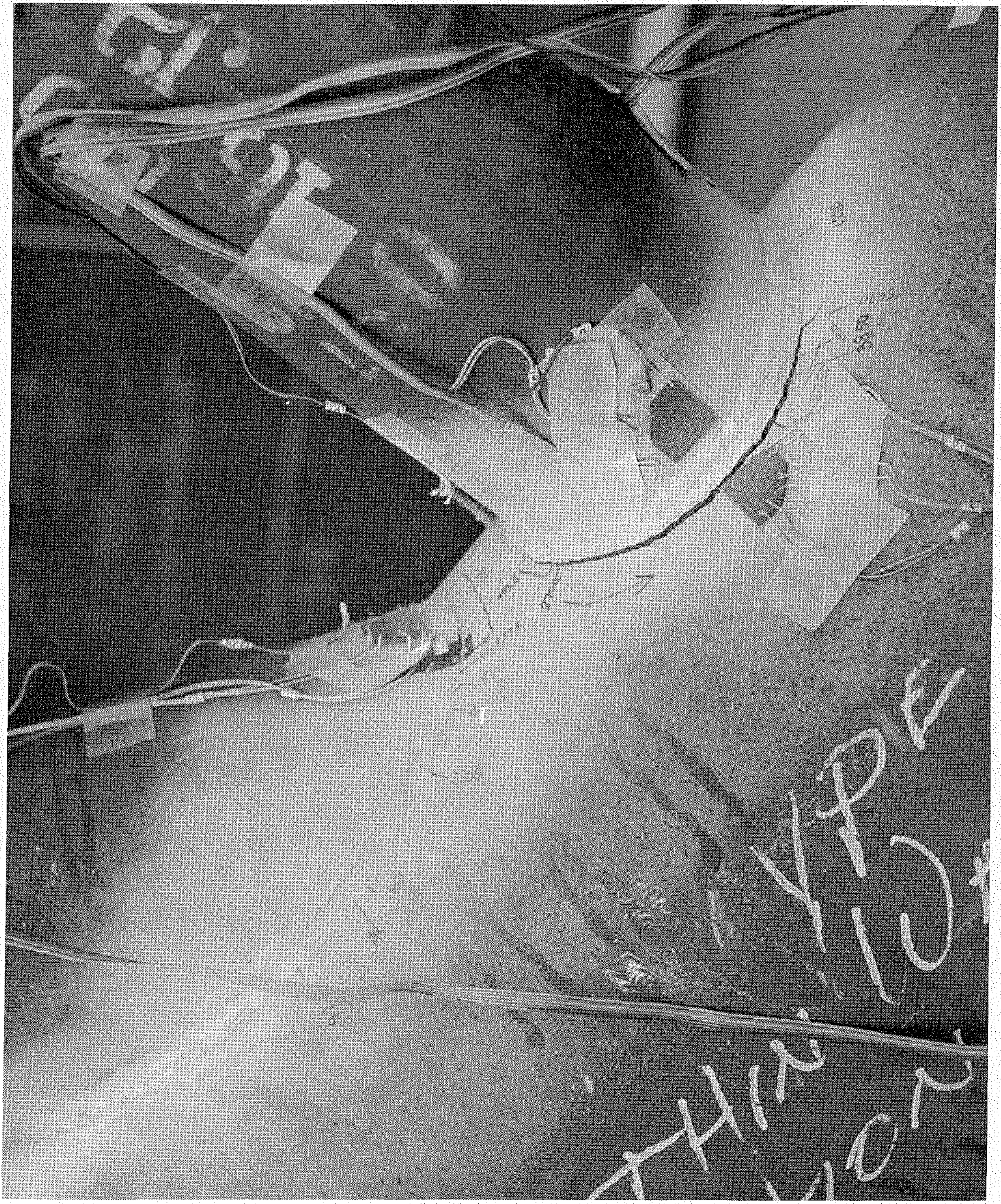
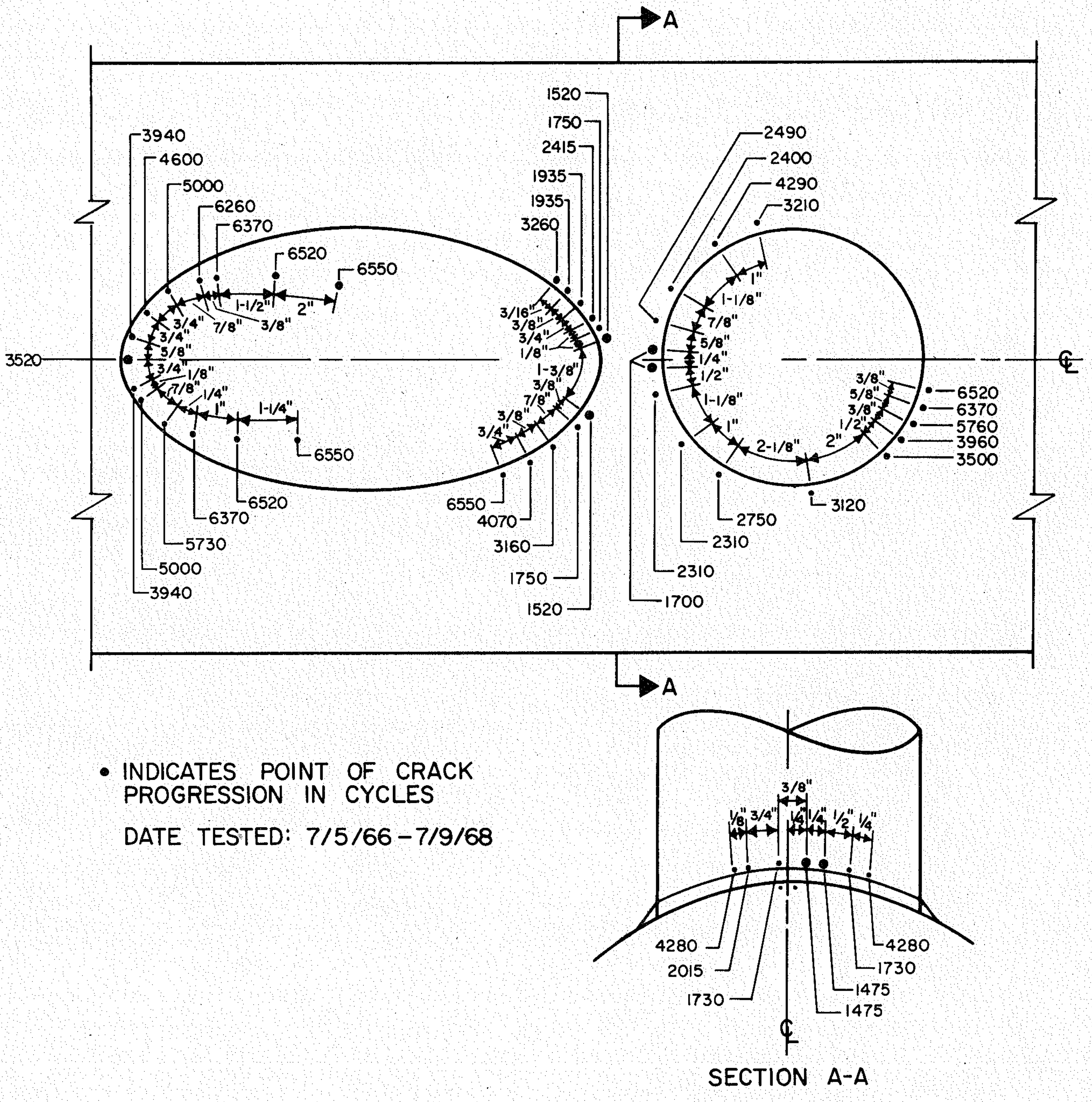


FIG. 9 PHOTOGRAPH OF CRACK AROUND HORIZONTAL MEMBER



• INDICATES POINT OF CRACK PROGRESSION IN CYCLES

DATE TESTED: 7/5/66 - 7/9/68

FIG. 10 CRACK PROPAGATION IN TYPE I JOINT (THIN WALL CEMENT-GROUT FILLED) LOADED AT ± 50k IN HORIZONTAL MEMBER

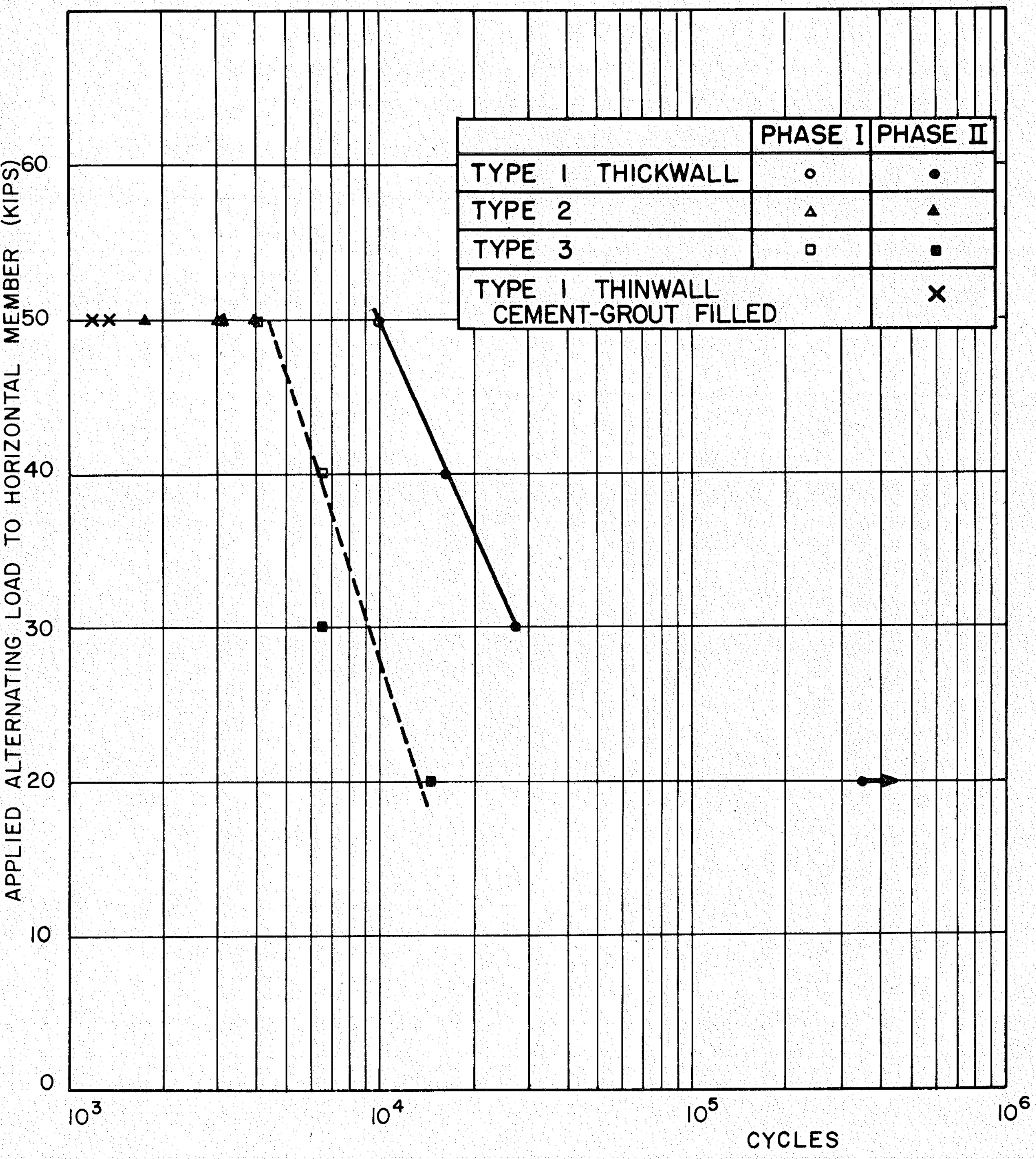


FIG. 11 ALTERNATING LOAD LIFE OF FOUR TYPES OF TUBULAR CONNECTIONS