

AN INVESTIGATION OF INSPECTION CRITERIA
FOR
COUNTERSUNK RIVETS

Thesis

by

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In Partial Fulfillment of
The Requirements for the Professional
Degree in Aeronautical Engineering

California Institute of Technology

Pasadena, California

1947

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ACKNOWLEDGEMENT

The author wishes to express his sincere gratitude to Mr. M. A. Miner of Douglas Aircraft Co.; to Mr. Ed Dickerson of North American; to Mr. M. A. Melcon of Lockheed; and to Mr. D. M. Davis of Consolidated Vultee, for making their complete rivet files available, and who have contributed generously their time in conferences.

He wishes to thank his supervising committee of Dr. E. E. Sechler, Prof. R. R. Martel, and Mr. H. L. Martin for helpful suggestions in carrying out this investigation.

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Summary

An investigation was made of the existing flush rivet inspection criteria and inspection methods to establish a norm for commercial flush riveted joints. Studies were made of thirty-four flush riveted joint load deformation curves to obtain their general characteristics and to establish some correlation of yield load as defined in ANC-5 and as defined in Report on Flush Riveted Joint Strength by ARC Rivet and Screw Allowables Subcommittee (Airworthiness Project 12). The specimens corresponding to the load deformation curves were comprised of 18 machine countersunk joints, 12 double dimple joints and four sub-countersunk joints. Within each type of joints the specimen varied in series of sheet material and thickness, rivet material and rivet size.

It is shown that yield load, defined as load giving four percent of rivet diameter joint set, is dependent on d/t ratios, the yield load lowering at increasing d/t values. Also, there are indications that as softer rivet material

is used with a given sheet material, the increasing d/t ratios have less adverse effects.

There could be made no particular correlation of yield load as defined by load at .005" set with any of the varying parameters.

In the case of the double dimple and sub-countersunk joints, no particular conclusions could be reached as the test data was confined to a small range of d/t values.

It was concluded from the countersunk rivet data that permanent set based on rivet diameter is a more reasonable yield criterion than permanent set based on an arbitrary constant.

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Introduction

This is an investigation of the inspection criteria for countersunk rivets. To date, riveting is the primary method of assembling aircraft parts and, as such, the quality of riveting has its effects on the airworthiness of the airplane and its ability to maintain flight under adverse conditions. Flush countersunk riveting must maintain both qualities of strength and aerodynamic smoothness.

There has been a considerable amount of literature compiled by Governmental and other agencies on the strength characteristics and mechanical properties of flush countersunk riveted joints. It is generally conceded that the characteristics of the flush riveted joint result from the interaction of a number of variables in a rather complex relation, and a rational analysis is difficult, if not impossible.

Recently a report has been submitted to the Army Navy Civil Committee by the Aircraft Industries Association in an attempt to change the existing design allowables of the

100° countersunk riveted joint. This report is based on a yield load taken at a permanent set across the joint of .005 inches, instead of at permanent set equal to 4% of the rivet diameter, the latter being the yield point as defined by the Army Navy Civil Committee at the present time.

To approach the problem of this thesis, a survey was made of the existing inspection criteria and inspection methods as used today in the aviation industry. Load deformation curves of thirty-four specimens, consisting of the machine countersunk, double dimple, and sub-countersunk type joints, with varying rivet diameter and sheet thickness were studied to endeavor to correlate the yield points, as defined above, with the varying parameters.

Methods of Approach

It was decided to approach the problem from an industrial stand-point. That is, if any new flush riveting inspection criterion could be set up it should be applicable to flush rivet joints made in the industry on a mass production basis. The various local aircraft factories were approached and conferences were held with their Structural Analysis Engineers.

It was of the general opinion that there is no rational definition of yield point for the flush rivet joint. It was also of general opinion that the simplest method of indication of yield is by permanent set of the joint. As "Quality Control" of aircraft production is an index to the quality of shop workmanship, it was thought advisable to inspect and review the existing aircraft inspection methods and process specifications. Having ascertained, to some degree, the allowable production tolerances, load deformation curves of various flush rivet specimens were obtained from two aircraft companies. These flush rivet specimens were supposedly to have been made by ordinary shop practice, however, it is felt that they, to a degree, possessed higher quality of workmanship because they were specimens, and because they could be easily handled in manufacture.

Two types of joints were used, both of single lap type. Type "A" as shown in Fig. 1 was a double row, six rivet joint. Type "B" as shown in Fig. 2 was a single row, three rivet joint. The dimensions of both joints can be seen in the figures.

The test specimens were of aluminum alloy sheeting riveted with 100° countersunk aluminum alloy rivets. The sheet and rivet combinations tested were as tabulated below. The rivet code table on page 14 and 15 will aid in identification. Machine countersunk joint, type "A".

<u>Sheet Material</u>	<u>Sheet Thickness</u>	<u>Rivet</u>
24ST	.051"-.051"	6DH
24ST	.064"-.064"	6DH
24ST	.072"-.072"	6DH
24ST	.081"-.081"	6DH
24ST	.091"-.091"	6DH
75ST	.051"-.051"	6DH
75ST	.064"-.064"	6DH
75ST	.064"-.064"	8DH
75ST	.072"-.072"	8DH
75ST	.081"-.081"	8DH
75ST	.091"-.091"	8DH
75ST	.064"-.064"	8DD
75ST	.072"-.072"	8DD
75ST	.081"-.081"	8DD
75ST	.091"-.091"	8DD

Machine countersunk joint, type "B".

<u>Sheet Material</u>	<u>Sheet Thickness</u>	<u>Rivet</u>
75ST	.064"-.064"	6AD
75ST	.072"-.072"	6AD
75ST	.091"-.091"	6AD

Double dimple joint, type "B".

<u>Sheet Material</u>	<u>Sheet Thickness</u>	<u>Rivet</u>
75ST(Alclad)	.051"-.051"	4AD
75ST(Alclad)	.051"-.051"	4AD
75ST(Alclad)	.051"-.051"	5AD
75ST(Alclad)	.051"-.051"	5AD
75ST(Alclad)	.064"-.064"	5AD
75ST(Alclad)	.064"-.064"	5AD
75ST(Alclad)	.072"-.072"	6AD
75ST(Alclad)	.072"-.072"	6AD
75ST(Alclad)	.063"-.071"	8DD
75ST(Alclad)	.063"-.071"	8DD
75ST(Alclad)	.041"-.093"	8DD
75ST(Alclad)	.082"-.092"	8DD

Sub-countersunk joint, type "B".

<u>Sheet Material</u>	<u>Sheet Thickness</u>	<u>Rivet</u>
75ST(Alclad)	.040"-.102"	4AD
75ST(Alclad)	.040"-.102"	4AD
75ST(Alclad)	.051"-.102"	4AD
75ST(Alclad)	.051"-.102"	4AD

The type "A" specimens were tested on a 50,000 pound capacity Baldwin-Southwark-Emery Hydraulic Test Machine. The type "B" specimens were tested on a 30,000 pound capacity Baldwin-Southwark (Templin Type). The rate of loading was not noted but was in the vicinity of 0.1" to 0.5" ram travel per minute. Movement of the joint lap was automatically recorded by an electric extensometer. It is believed that the loading was accurate within one percent.

The test procedure was to load the specimen to such loads that produced a small permanent joint set, then to unload to approximately zero loading and reload to a higher load to produce more permanent joint set. This was repeated until such time it was thought that the extensometer was endangered. The extensometer was then removed and the load was applied to ultimate.

From the load deformation curves, the load at both .005" joint set, and $\frac{1}{4}$ rivet diameter set was interpolated by lines parallel to the reloading curve. These loads, along with the ultimate, are tabulated in Tables I and II.

In order to make a comparison of the data, it was put into nondimensional parameters. These were taken as the rivet diameter divided by the sheet thickness (d/t) and the yield load divided by the allowable shear load value of the rivet, as taken from ANC-5 (R).

Results and Discussion

Specifications 1 through 10 show typical "Process Specifications". To date, there is no set of accepted standards governing the exact size of an upset rivet head. Each company or area has its own standards. However, comparison of various company "Process Specifications" show them to be practically the same. Testing methods of rivet upset are either manual or visual, the manual relying on gages, and the visual method relying on experience. Radial cracks in the upset head are dependent primarily on the riveting method, and rivet material. However, the Aluminum Company of America states that even severe cracking has no adverse effects on the static strength, fatigue strength, and resistance to corrosion. During the recent war, because of needed production, the radial crack specification as shown in Specification 2 was accepted by some of the services.

Specifications 6, 7, 8, 9, and 10 show tolerances allowed on the countersunk head. The open countersunk (Specification 6) is unacceptable. This affects both the ultimate and the yield strength of a joint. It has been shown by Ref. 1 that the tightness of a flush rivet joint is an index to its mechanical properties. Specification 7 has to do with the aerodynamic

cleanness of the airplane and would not apply to a high performance airplane as the P-80. Tolerances would be held closer. Ref. 1 has shown that milling the rivet head flush has no serious effect on either the ultimate or the yield load. Specification 8 shows the minimum depth allowance of countersunk heads below skin surface. This condition is an indication that the joint is not tight and again seriously affects the yield and ultimate loads. The depression of rivet head allows the countersunk area to be seen, resulting in what is known as a "shiner". Specification 10 covers sub-dimpling into a machined countersink. North American Aviation is, at present, working on a program to establish a minimum tolerance adjacent to the dimple, as a zero tolerance results in the dimple usually being too small for the countersink.

Figs. 3 through 36 show the load deformation curves of the various specimens. Sheet material and thickness, rivet material and size, type of joint, and type of joint failure are included on each figure in code. The code is explained elsewhere in this report. The load in 1000 pounds is plotted as ordinate against deflection of joint in inches as abscissa. The curves show the ultimate load, the permanent set at various unloadings and the yield load at .005" permanent joint set and 4% rivet diameter joint set.

Examination of Figs. 3 through 20, along with Table I, shows the yield load at the two above yield definitions, increasing with the decreasing of d/t ratios. This is to be expected. The ultimate load also increases generally, with decreasing d/t ratios. This trend fails at d/t ratio of approximately 2.75. However, due to the small amount of test data, this is only an indication.

Figs. 21 through 32 show the load deformation curve for the double dimple joints. A study of Table II shows very good agreement between two similar combinations. However, it was found that there was no particular correlation in the data. This is thought to be due to the very small range of d/t values and general scattering of points. It is interesting to note that the ultimate load divided by the yield load at 4% joint set lies between 1.04 and 1.26, the average value falling at 1.16. Because of the high yield load it is understood that flush rivet double dimple joints are being used in aircraft parts where flushness is not required.

Figs. 33 through 36 are the load deformation curves of the sub-countersunk specimens. Examination will show very good agreement in the ultimate load but inconsistent slip qualities. The inconsistent slip qualities are thought to be contributed to Process Specification No. 10.

Figs. 37 and 38 show the nondimensional (R) values of yield load divided by the allowable shear load value of the rivet, plotted against d/t ratios for the machine countersunk specimens. Fig. 38 seems to indicate that yield load, as defined as 4% rivet diameter joint set, has an approximate straight line variation with the d/t ratios investigated. This is in accordance with Ref. 5, which states that the shear strength of aluminum alloy driven rivet falls off with increasing d/t ratios.

It should be noticed that the line representing 17ST (driven hard) rivets in 24ST sheet, and the line representing 24ST rivets in 75ST are parallel, with a relative steep slope, indicating adverse effects with increasing d/t ratios. The lines representing 17ST(driven hard), 17ST, and Al7ST rivets in 75ST sheet have respectively decreasing slopes, indicating lessening effect of d/t ratio on yield.

Fig. 37 is the same data plotted with "R" being based on yield load at .005" permanent joint set. The correlation of yield load and d/t ratios is not as apparent in this figure. This seems reasonable, inasmuch as the .005" permanent set definition of yield is a purely arbitrary figure, unrelated in any way to the geometry of the joint.

Conclusions

It is concluded from the studies made in this investigation that:

1. The aircraft industry, in general, has the same inspection methods and inspection criteria. A compromise must be made between ideal perfection and mass production.
2. The yield load, as defined by load at 4% rivet diameter permanent set, decreases with increasing d/t ratios.
3. The degree of sheet hardness over rivet hardness is a measure of the adverse effect on yield load of increasing d/t ratios. As the ratio of sheet hardness to rivet hardness increases, the effect of increasing d/t ratio becomes less.
4. There seems to be better correlation between yield load and d/t ratio when yield is based on permanent set as a function of rivet diameter, rather than yield based on permanent set taken as a fixed constant.
5. Permanent set based on rivet diameter is a more reasonable yield criterion than permanent set based on an arbitrary constant.

REFERENCES

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3. NACA Technical Note No. 916, November 1943, "The Effect of the Type of Specimen on the Shear Strengths of Driven Rivets" by W. H. Sharp
4. NACA Restricted Bulletin, February 1942, "Mechanical Properties of Flush-Riveted Joints Submitted by Five Airplane Manufacturers" by William Charles Brueggeman
5. NACA Technical Note No. 942, July 1944, "The Shear Strength of Aluminum Alloy Driven Rivets as Affected by Increasing D/t Ratios" by E. C. Hartmann and C. Wescoat

6. ANC 5. Strength of Aircraft Elements, December, 1942, and
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7. NACA Restricted Bulletin 3L01 December 1943, "A Preliminary
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8. NACA Technical Note No. 585, November 1936, "Mechanical
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9. NACA Technical Note No. 165, November 1923, "Tests on
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10. "Riveting Alcoa Aluminum", by Aluminum Company of
America

CODE

In order to reduce the required lettering on the load deflection curves, the following code was devised:

24-5DH-51-AMC-R_S

Reading from left to right;

The first two figures represent the sheet material.

24 - 24ST

75c - 75ST (Alclad)

The next group represents the rivet.

5 - Rivet diameter in $\frac{1}{32}$ " i.e. ($\frac{5}{32}$)

DH - 17ST(driven hard)

D - 17ST

AD - A17ST

DD - 24ST

The next group represents the sheet thickness in $\frac{1}{1000}$ "

In case of two thicknesses of sheet, indicated by 51-64

The next group represents the type of joint.

A - (6 rivet, 2 row lap joint-Fig. 1)

B - (3 rivet, 1 row lap joint-Fig. 2)

MC - Machine Countersunk

DD - Double Dimple

SC - Sub-Countersunk

The last letter indicates the type of joint failure.

- R_s - Rivet in Shear
- R_t - Rivet in Tension
- P - Panel Failure

TABLE I

Machine Countersunk Joint Loading Data

Specimen	d/t	Fu	Py .005	Py 4% d	R .005	R 4% d
24 6DH 51	3.68	4780	2000	2380	.406	.480
24 6DH 64	2.93	6120	2920	3390	.590	.685
24 6DH 72	2.60	6140	3500	3900	.706	.785
24 6DH 81	2.31	6280	3900	4300	.785	.867
24 6DH 91	2.06	6560	4500	4950	.908	1.000
75 6DH 51	3.68	5840	2650	2810	.534	.560
75 6DH 64	2.93	6220	2770	3230	.558	.652
75 8DH 64	3.91	10040	3200	4275	.362	.485
75 8DH 72	3.47	10520	3630	4950	.410	.560
75 8DH 81	3.09	11090	5000	6620	.566	.749
75 8DH 91	2.75	10470	5900	7475	.667	.845
75 8DD 64	3.91	8500	5600	6400	.543	.620
75 8DD 72	3.47	10750	6000	7200	.583	.700
75 8DD 81	3.09	12000	6600	7890	.640	.775
75 8DD 91	2.75	11060	6900	8100	.670	.790
75 6AD 64	2.93	3000	1820	1930	.406	.453
75 6AD 72	2.60	2830	1940	2100	.434	.470
75 6AD 91	2.06	2685	1810	2130	.420	.525

$$R = \frac{P_y}{F(\text{allowable- ANC-5})}$$

TABLE II

Double Dimple Countersunk Joint Loading Data

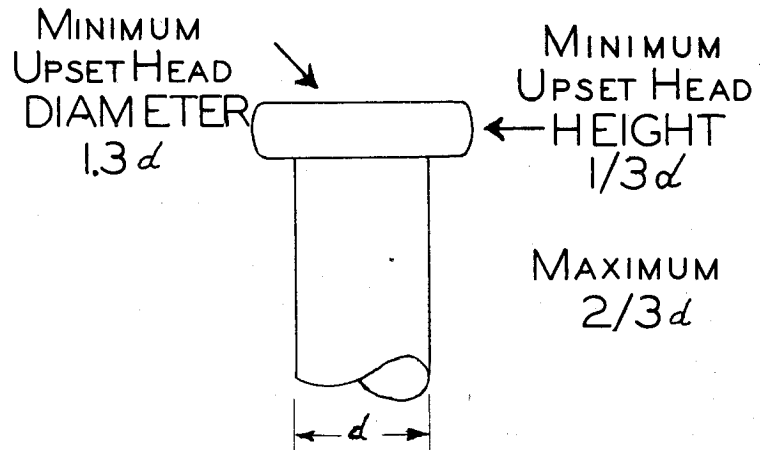
Specimen	d/t	F _u	P _y .005	P _y 4% d	R .005	R 4% d	F _u
							P _y ±% d
75c 4AD 51	2.45	2060	1750	1750	1.50	1.50	1.18
75c 4AD 51	2.45	2095	1750	1750	1.50	1.50	1.20
75c 5AD 51	3.06	2365	2115	2350	1.50	1.51	1.19
75c 5AD 51	3.06	2350	2375	2550	1.53	1.54	1.16
75c 5AD 64	2.44	3040	2500	2625	1.61	1.69	1.16
75c 5AD 64	2.44	3070	2395	2510	1.55	1.62	1.22
75c 6AD 72	2.60	4235	3150	3350	1.41	1.50	1.26
75c 6AD 72	2.60	4510	3340	3600	1.50	1.57	1.20
75c 8DD 33-71	3.46	2300	6250	7125	1.21	1.38	1.16
75c 8DD 63-71	3.43	9225	7350	7950	1.45	1.54	1.15
75c 8DD 41-33	3.57	9585	7833	8835	1.53	1.72	1.08
75c 8DD 32-32	3.57	9675	8417	9375	1.64	1.82	1.04

$$R = \frac{P_y}{P(\text{allowable-ANC-5})}$$

PROCESS SPECIFICATIONS

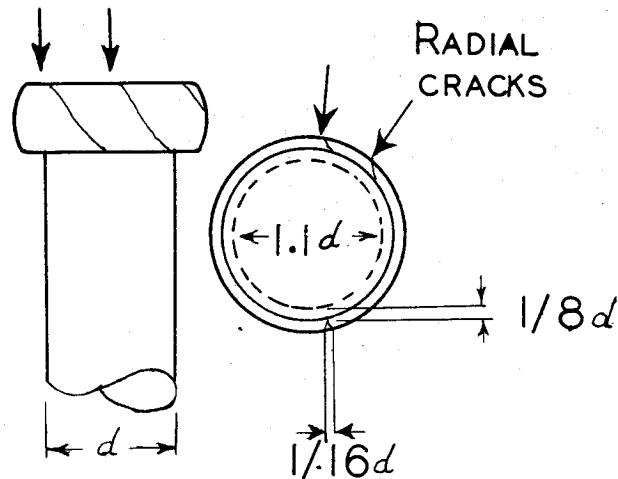
REQUIREMENTS.

1. Dimensions of the formed shop head

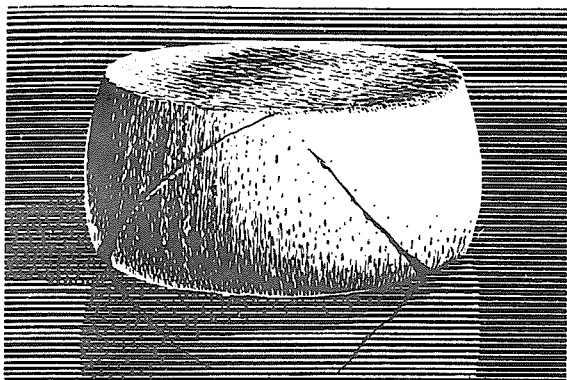


Rivet Size	Minimum Upset Head Diameter $1.3d$		Minimum Upset Head Height $1/3d$		Maximum Upset Head Height $2/3d$	
	Decimal	Fract.	Decimal	Fract.	Decimal	Fract.
$5/32$	0.122	$1/8$	0.031	$1/32$	0.062	$1/16$
$1/8$	0.163	$5/32$	0.042	$3/64$	0.083	$5/64$
$5/32$	0.203	$13/64$	0.052	$1/16$	0.104	$7/64$
$3/16$	0.243	$1/4$	0.063	$1/16$	0.125	$1/8$
$1/4$	0.325	$21/64$	0.083	$3/32$	0.167	$11/64$
$5/16$	0.405	$13/32$	0.104	$1/8$	0.208	$13/64$
$3/8$	0.487	$31/64$	0.135	$1/8$	0.250	$1/4$

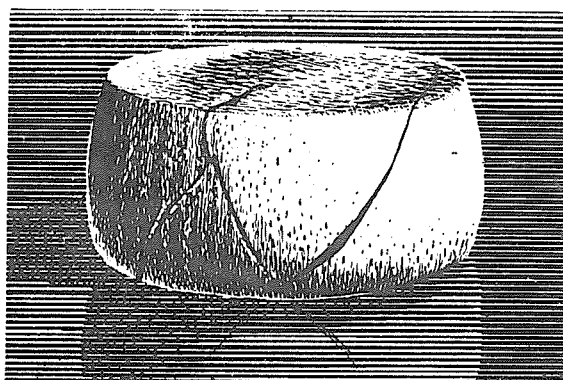
2. Rivets containing radial shear cracks in shop heads are acceptable provided the maximum depth of any crack does not exceed one-eighth ($1/8$) of the nominal shank diameter and the maximum width of any crack does not exceed one-sixteenth ($1/16$) of the nominal shank diameter. However, rivets containing two or more intersecting cracks, or cracks which cause a piece of the rivet to chip off or to be a potential cause for chipping, are rejectable. In addition, rivets containing cracks in the head running in an approximately radial direction are acceptable provided the cracks do not extend within a circle concentric with and one and one-tenth (1.1) times the nominal shank diameter.



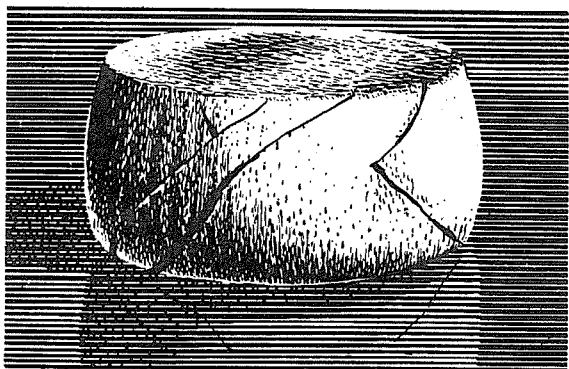
Rivet Size	Minimum Area Crack Free		Max. Depth Of Cracks	Max. Width Of Cracks
	$1.1 d$	Fraction		
d	$1.1 d$	Fraction	$1/8 d$	$1/16 d$
3/32	.103	7/64	.012	.006
1/8	.138	9/64	.016	.008
5/32	.172	11/64	.020	.010
3/16	.206	13/64	.023	.012
1/4	.275	9/32	.031	.016
5/16	.343	11/32	.039	.020
3/8	.413	13/32	.047	.023



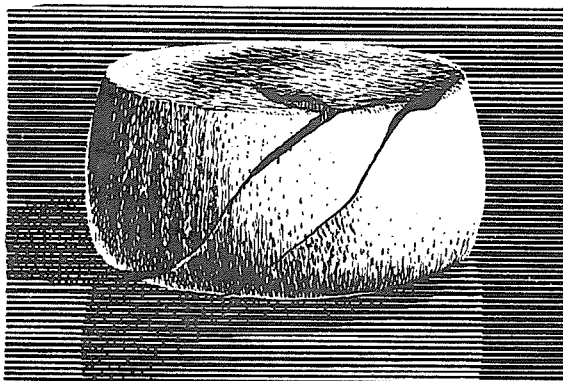
Picture No. 5 - Not acceptable.



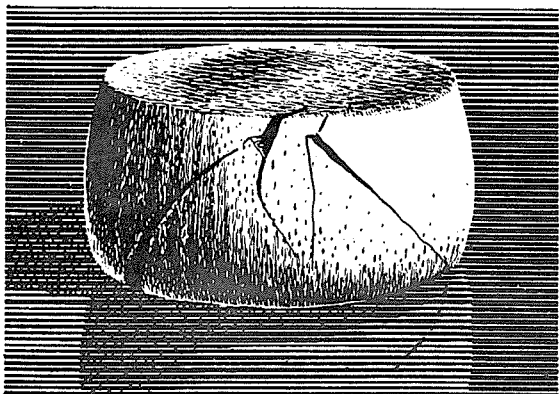
Picture No. 6 - Not acceptable.



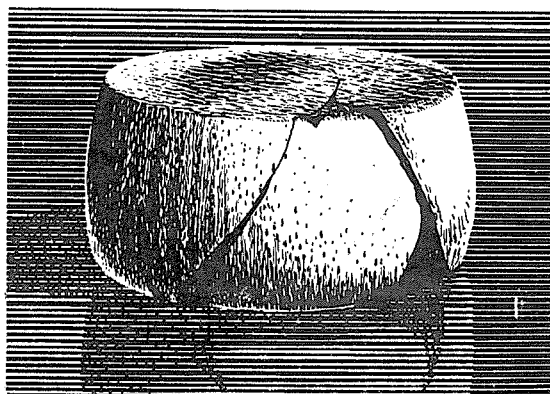
Picture No. 7 - Not acceptable.



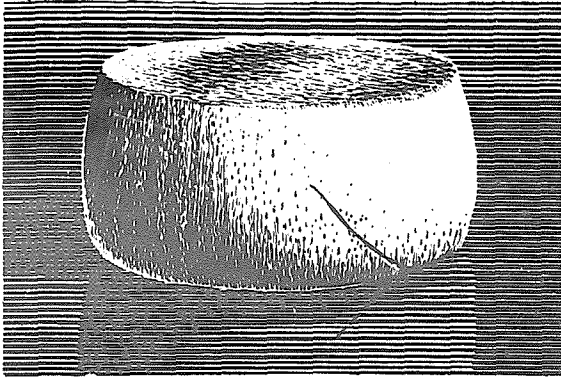
Picture No. 8 - Not acceptable.



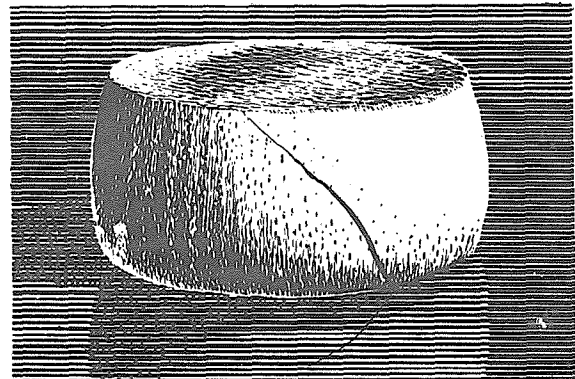
Picture No. 9 - Not acceptable.



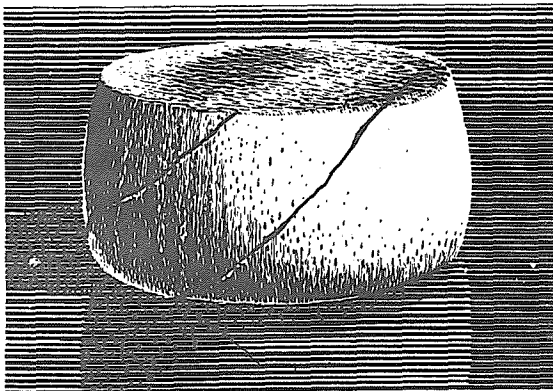
Picture No. 10 - Not acceptable.



Picture No. 1 - Acceptable provided cracks do not extend within a circle concentric with and having a diameter approximately 1.1 times the shank diameter.

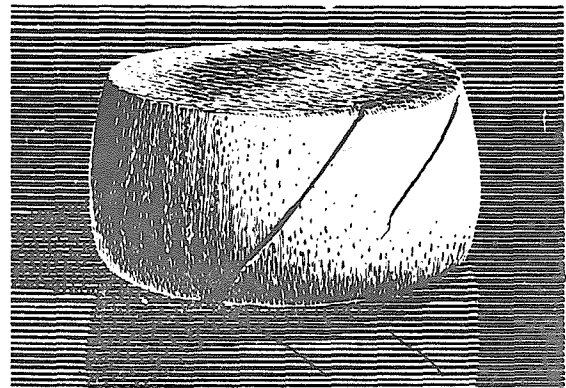


Picture No. 2 - Acceptable provided cracks do not extend within a circle concentric with and having a diameter approximately 1.1 times the shank diameter.

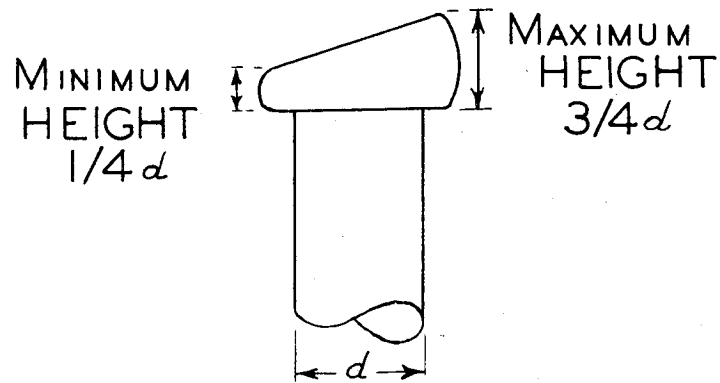


Picture No. 3 - Acceptable provided cracks do not extend within a circle concentric with and having a diameter approximately 1.1 times the shank diameter and provided the cracks do not tend to intersect so as to be a potential cause of a section of the head chipping out.

Picture No. 4 - Acceptable provided cracks do not extend within a circle concentric with and having a diameter approximately 1.1 times the shank diameter and provided the cracks do not tend to intersect so as to be a potential cause of a section of the head chipping out.

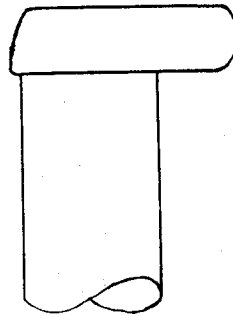


3. Cocked or beveled heads are acceptable provided the low side of the head is not less than one-quarter ($1/4$) the diameter of the rivet shank. The high side shall not be greater than three-quarters ($3/4$) the diameter of the rivet shank. This indicates that the intermediate or average height shall be at all times greater than the one-third " d " or the minimum dimension required for upset heads. In addition, the minimum head diameters given in paragraph 1 shall apply.

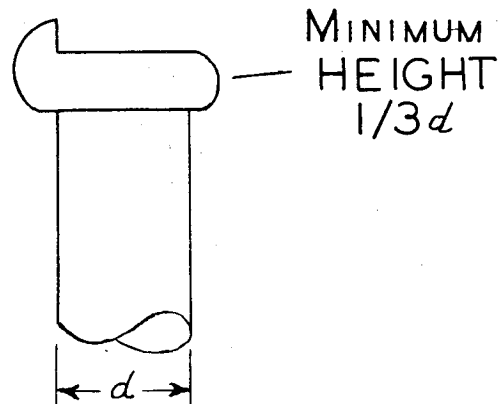


Rivet Size d	Low Side (Minimum)		High Side (Maximum)	
	Decimal	Fraction	Decimal	Fraction
$3/32$	0.023	$1/32$	0.070	$1/16$
$1/8$	0.031	$1/32$	0.094	$3/32$
$5/32$	0.039	$3/64$	0.117	$1/8$
$3/16$	0.047	$3/64$	0.141	$9/64$
$1/4$	0.063	$1/16$	0.188	$3/16$
$5/16$	0.078	$5/64$	0.235	$15/64$
$3/8$	0.094	$3/32$	0.281	$9/32$

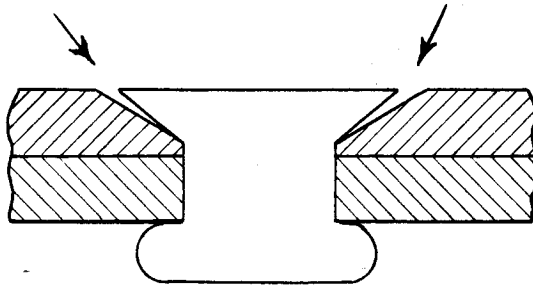
4. The head may be off-center to the shank of the rivet, provided no part of the hole shows, and the head conforms to the requirements of paragraphs 1 and 2.



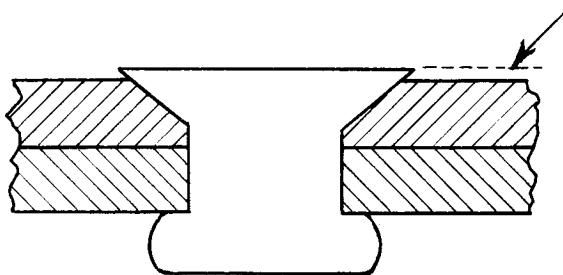
5. Stopped heads are acceptable if the formed part of the head meets the requirements as given by paragraphs 1 and 2. When necessary to remove the high section, it shall be done by filing only.



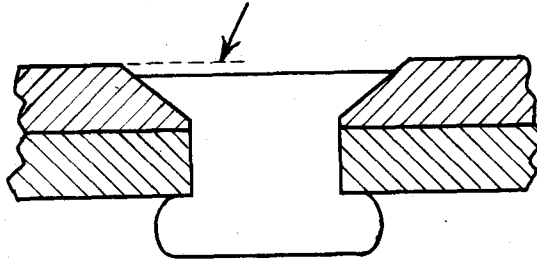
6. Open or partially open countersunk rivets are unacceptable. If the gage thickness of the sheet metal permits, remove and re-countersink for the next larger size rivet. If approved equipment is available for shaving, the shop head may be formed in the countersink and any projection shaved flush, provided aerodynamic or interference considerations make the operation advisable, and authorized engineering deviation is secured.



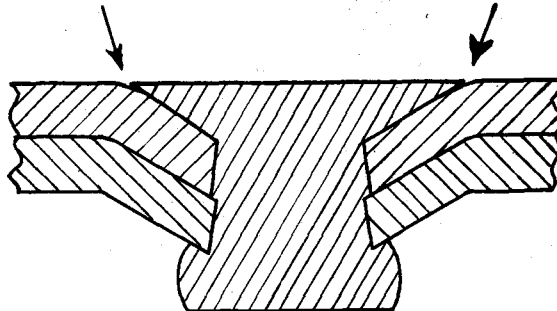
7. Projecting head countersunk rivets are acceptable provided the maximum tolerance on leading edges and upper wing surface in front of the ailerons is not greater than .002", or on other sections .004". If the tolerance is specified by engineering drawings such tolerance shall apply.



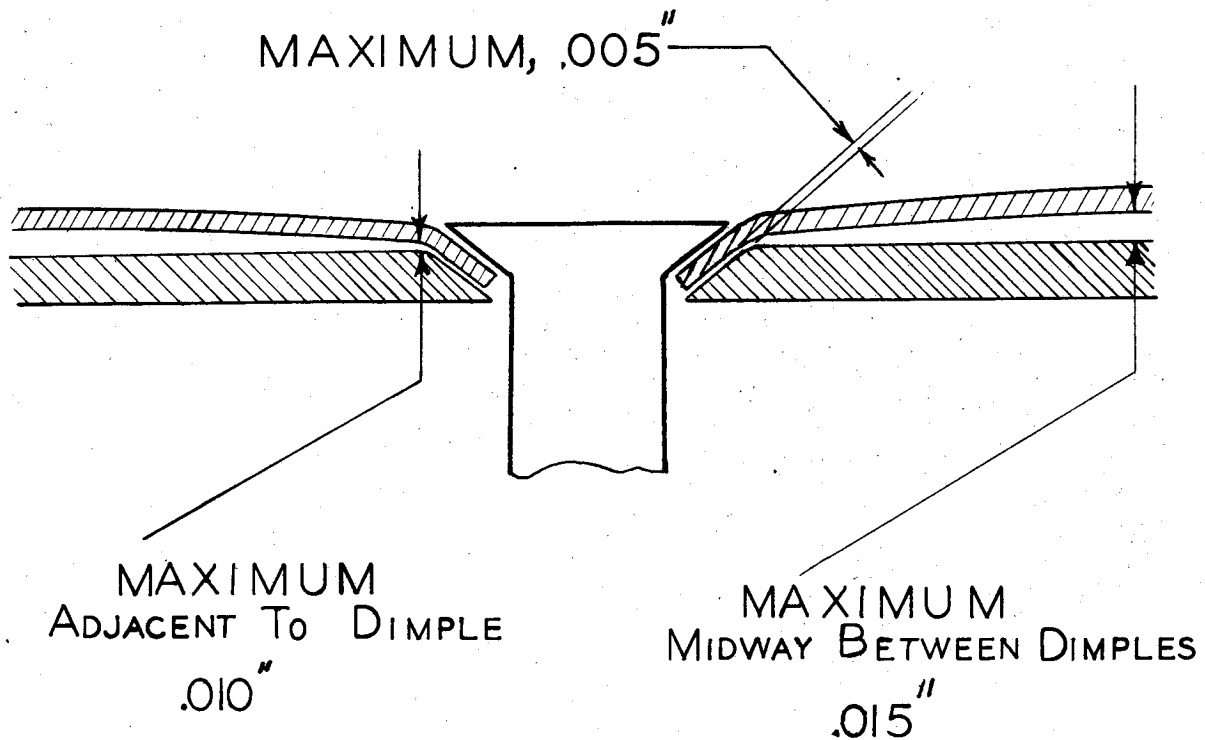
8. Depressed head countersunk head rivets are acceptable provided the head is not more than .004" below the sheet surface. If the machine countersink and skin thickness permit, replace with the next larger rivet size. As an alternate, the shop formed head may be formed in the countersink when authorized by Engineering.

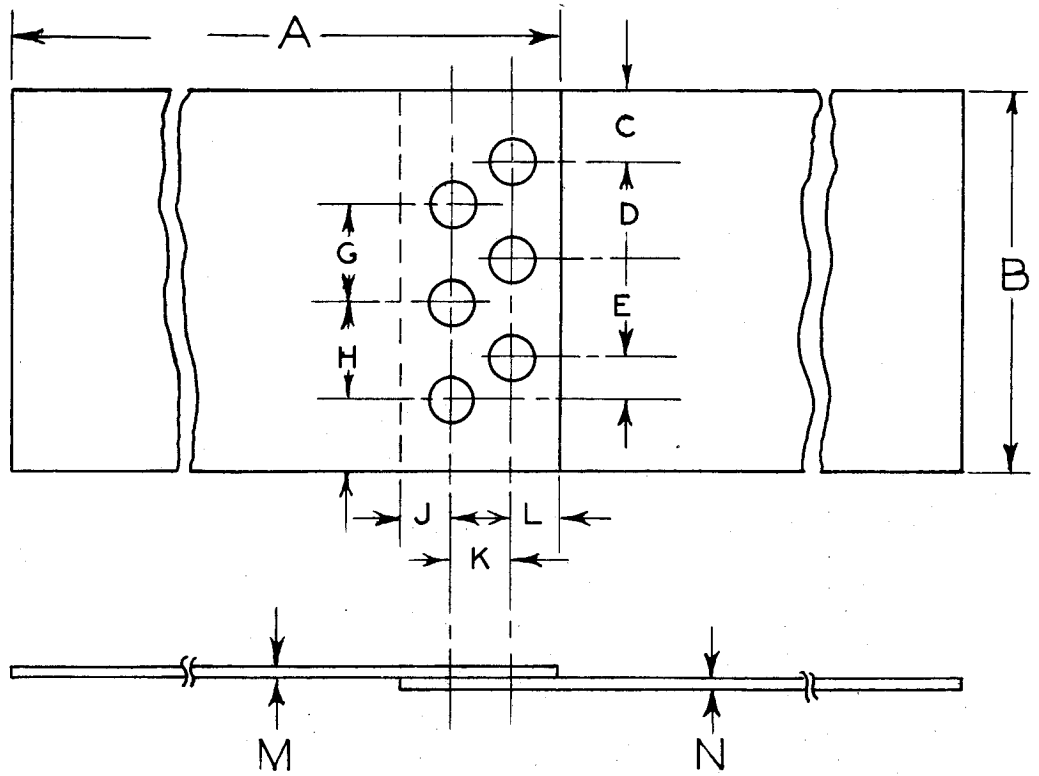


9. Since the countersink is pressed into the metal during the operation, a slight curvature will exist around the edge of the dimple or depression. This shall not constitute cause for rejection provided the rivet meets the requirements of paragraphs 1, 2, 3, 4, and 5. The small gap is superficial in nature and is characteristic of the operation, but is limited by allowing a .003" feeler gage to be inserted under the head for a distance of not more than $1/8$ the rivet shank diameter.



10. Countersink angles shall be 110° for mating with standard cold dimple and 100° for mating with a surface sheet which has been hot dimpled. The diameter shall be of proper size to insure nesting of underside of the dimple. The gap between sheets shall not exceed dimension shown. When a sub-countersink is used with a large radius surface dimple (aged alloy), the edge of the cone shall be radiused or chamfered to provide clearance for proper nesting.





RIVET DIA.	A	B	C	D	E	F	G	H	I	J	K	L	M	N
$\frac{1}{8}$	8	2	$\frac{3}{8}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{4}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{3}{8}$	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{1}{4}$		
$\frac{5}{32}$	8	$2\frac{1}{2}$	$\frac{15}{32}$	$\frac{5}{8}$	$\frac{5}{8}$	$\frac{5}{16}$	$\frac{5}{8}$	$\frac{5}{8}$	$\frac{15}{32}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{5}{16}$	NOTED	NOTED
$\frac{3}{16}$	8	3	$\frac{9}{16}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{3}{8}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{9}{16}$	$\frac{3}{8}$	$\frac{1}{2}$	$\frac{3}{8}$	NOTED	NOTED
$\frac{1}{4}$	8	4	$\frac{3}{4}$	1	1	$\frac{1}{2}$	1	1	$\frac{3}{4}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{5}{8}$		

TYPE "A"

FIG. 1 JOINT DIMENSIONS

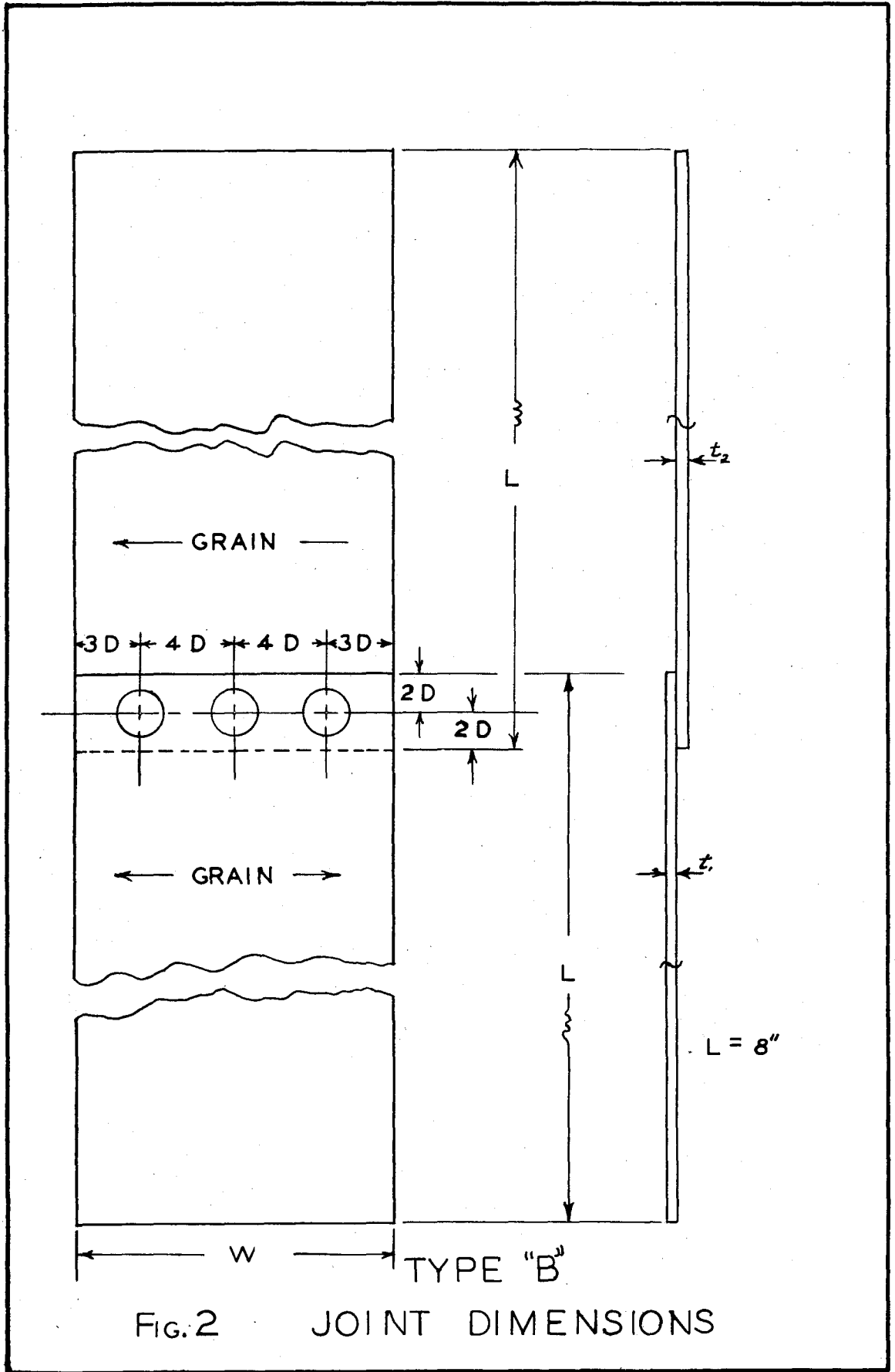


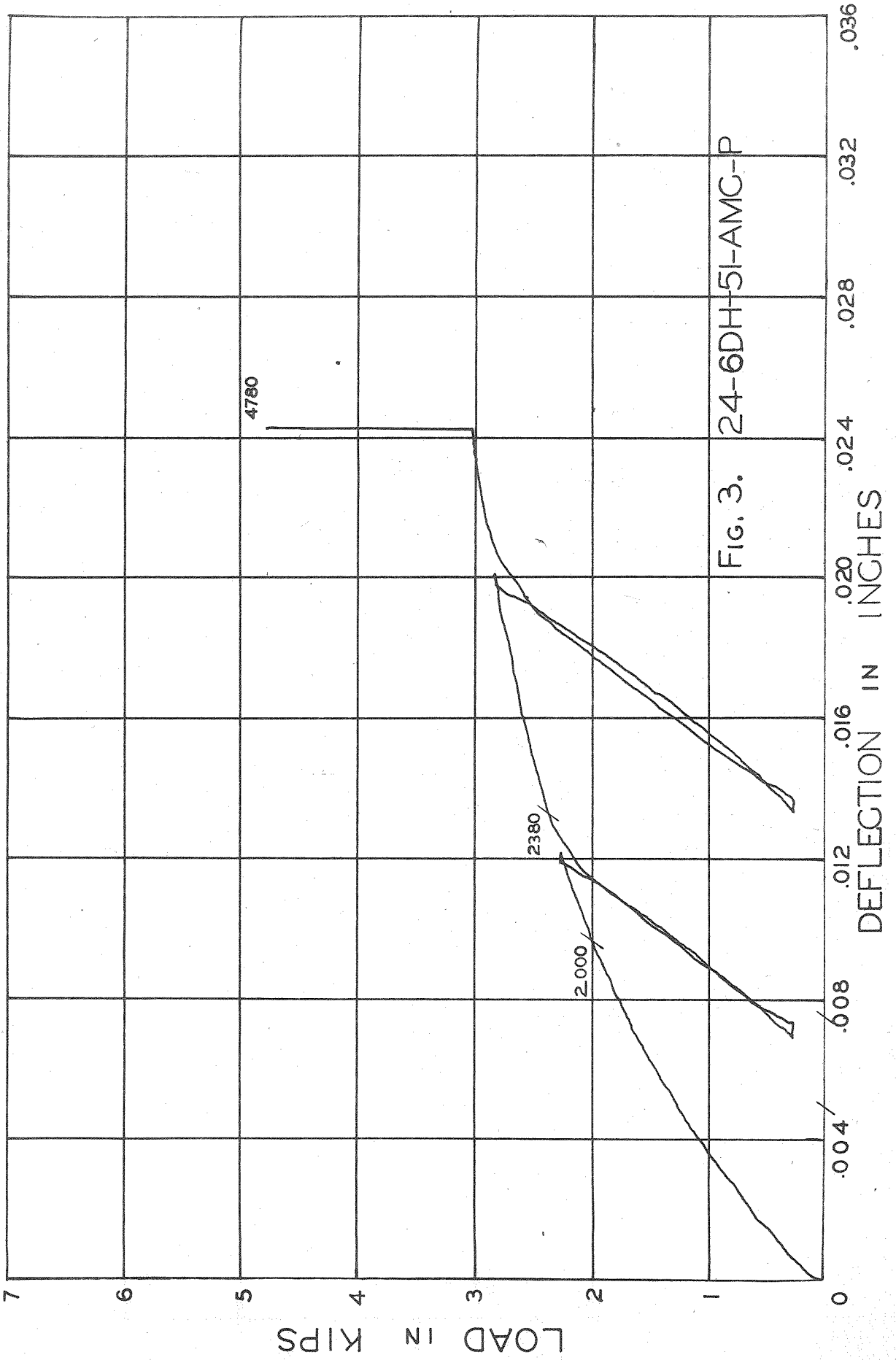
FIG. 2 JOINT DIMENSIONS

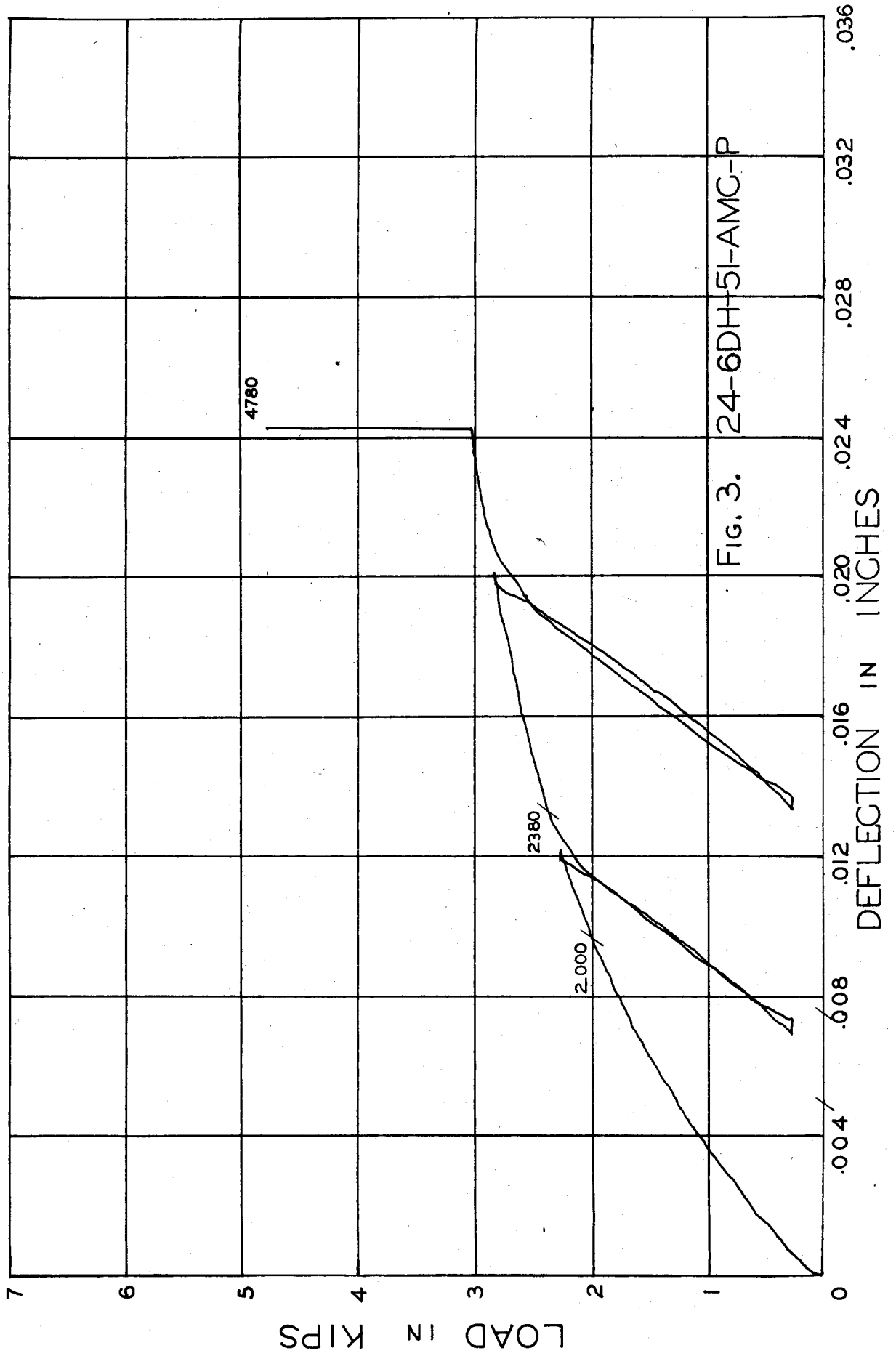
LOAD DEFLECTION CURVES

(Fig. 3.....Fig. 20) Machine Countersunk

(Fig. 21.....Fig. 32) Double Dimple

(Fig. 33.....Fig. 36) Sub-Countersunk





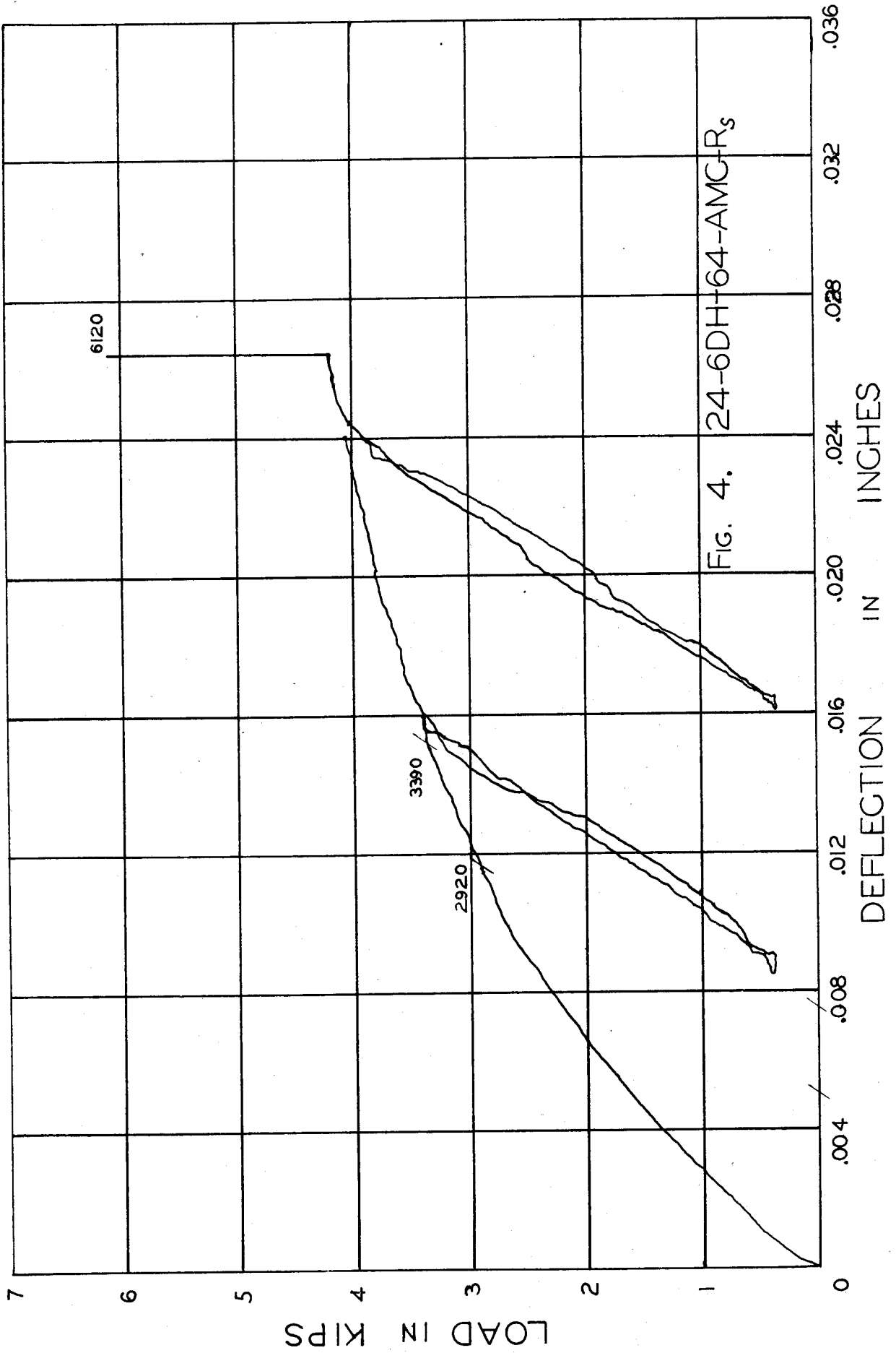


FIG. 4. 24-6DH-64-AMG-R_s

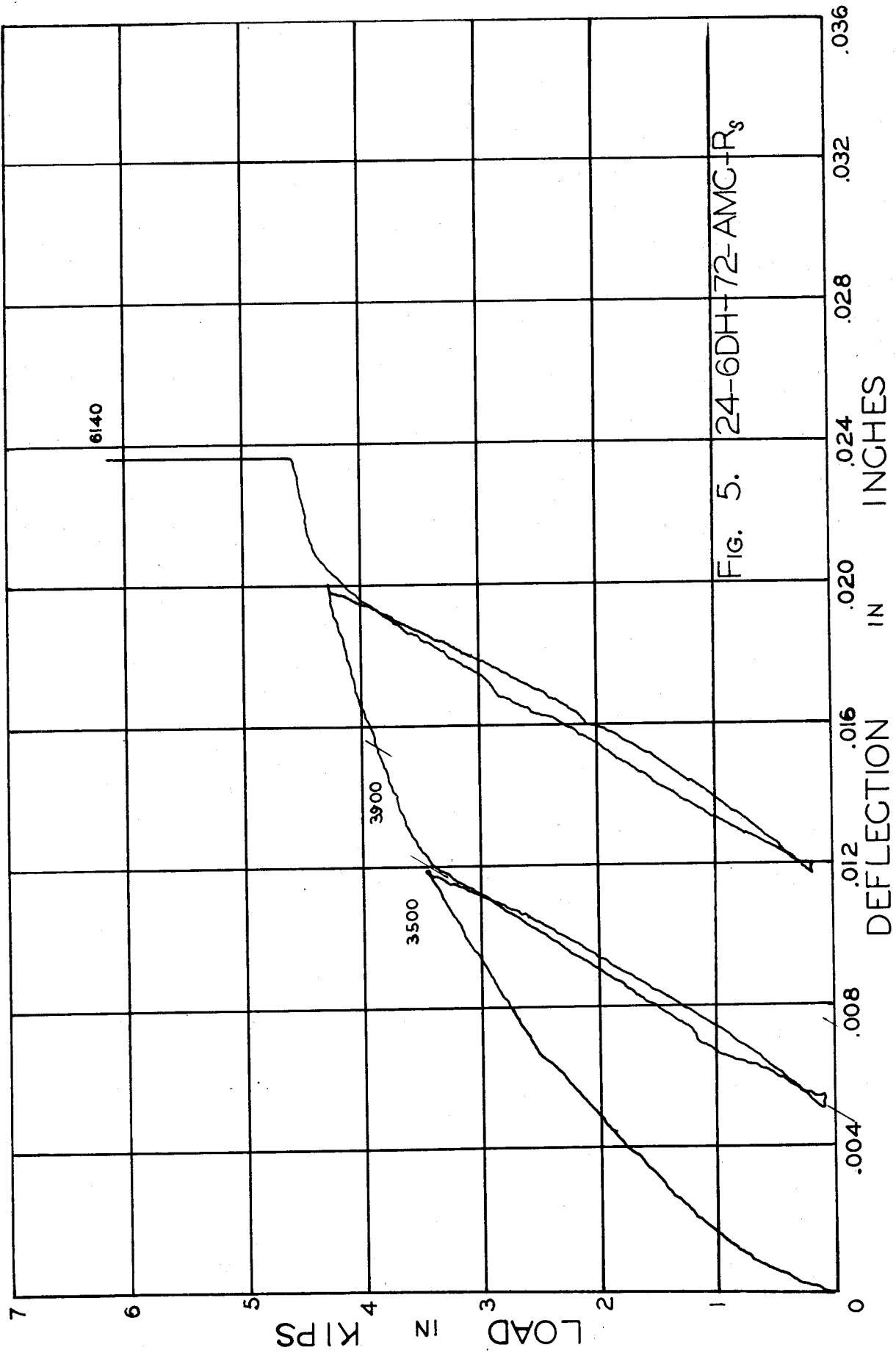
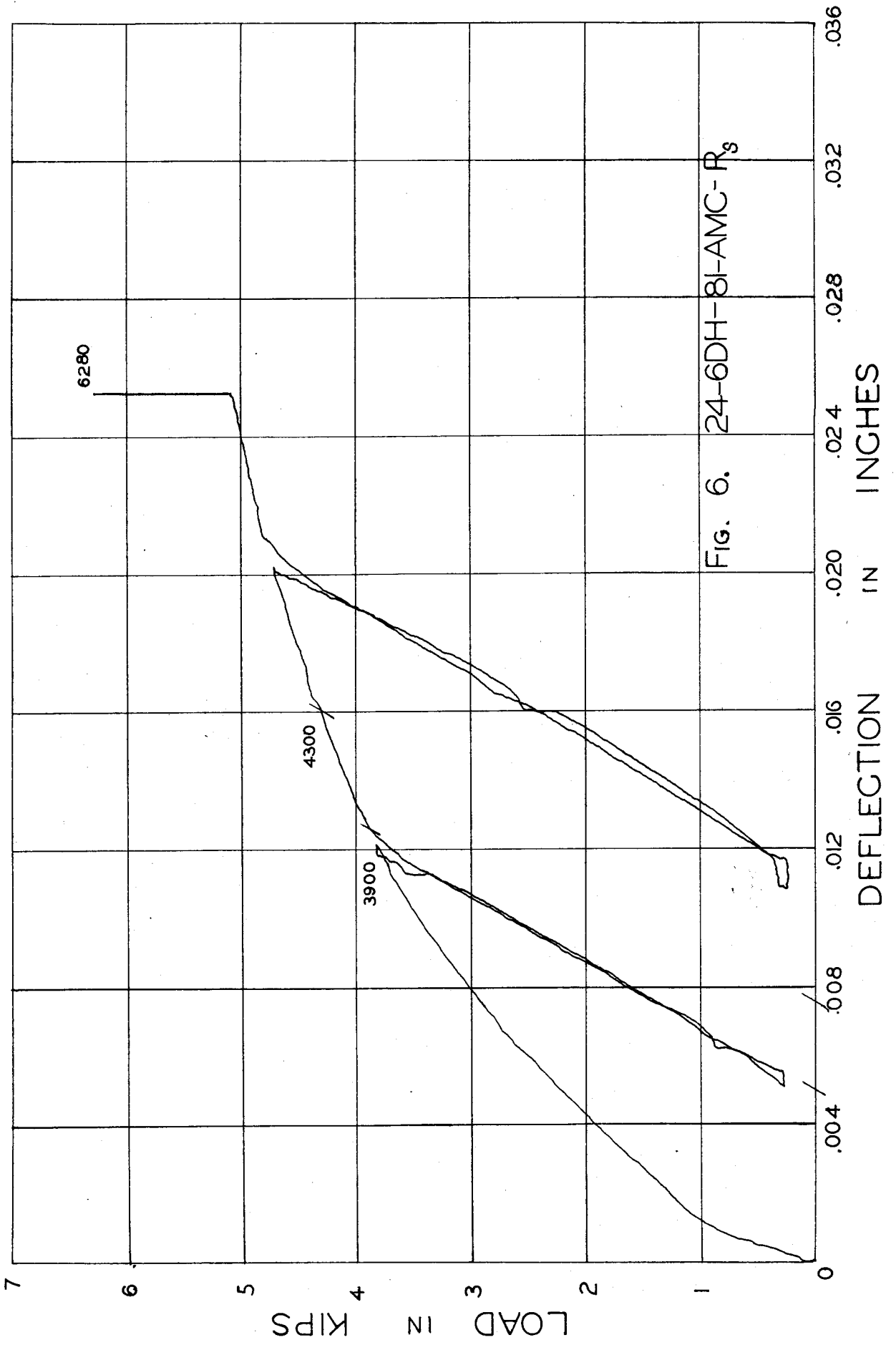


FIG. 5. 24-GDH-72-AMC-R_s



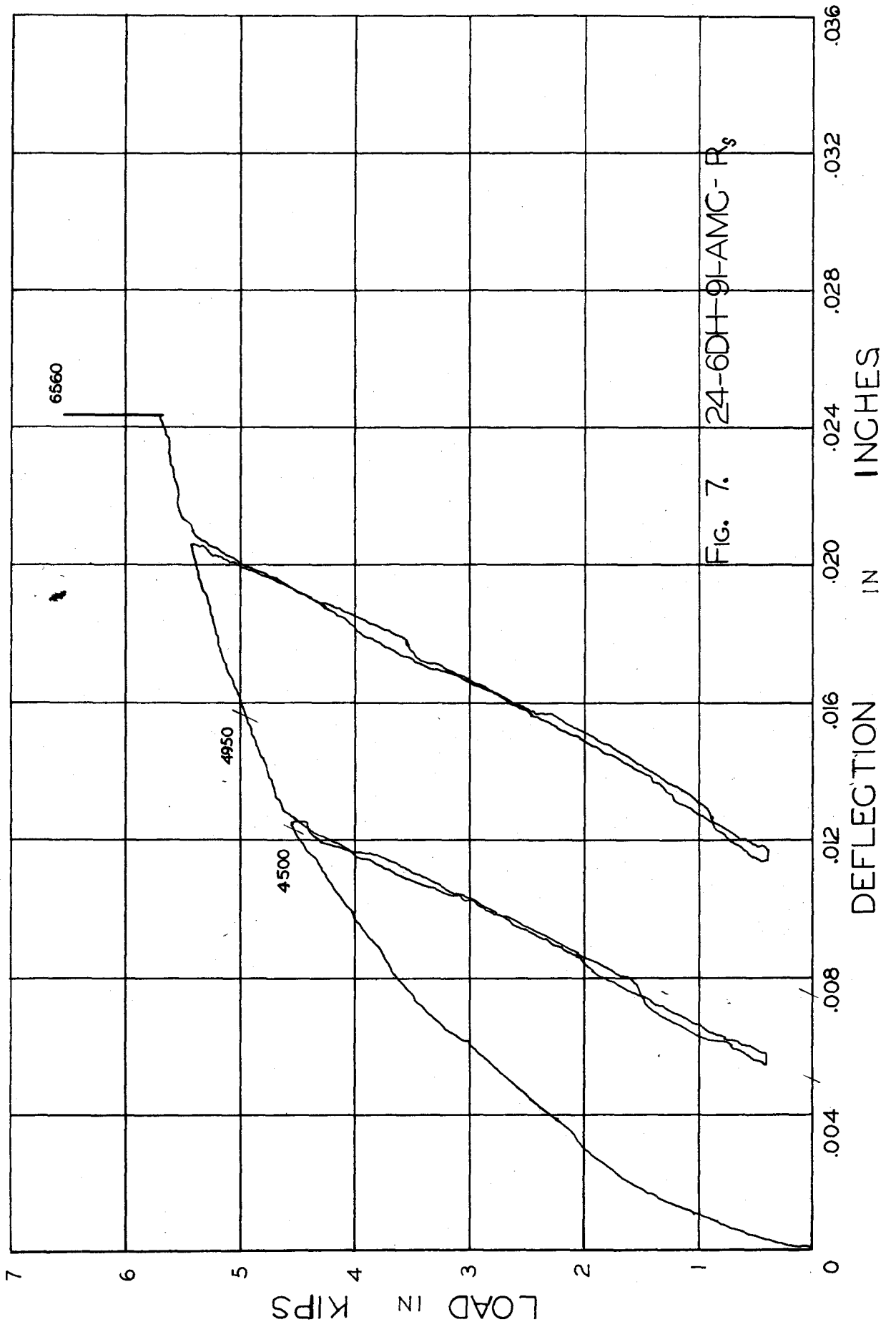
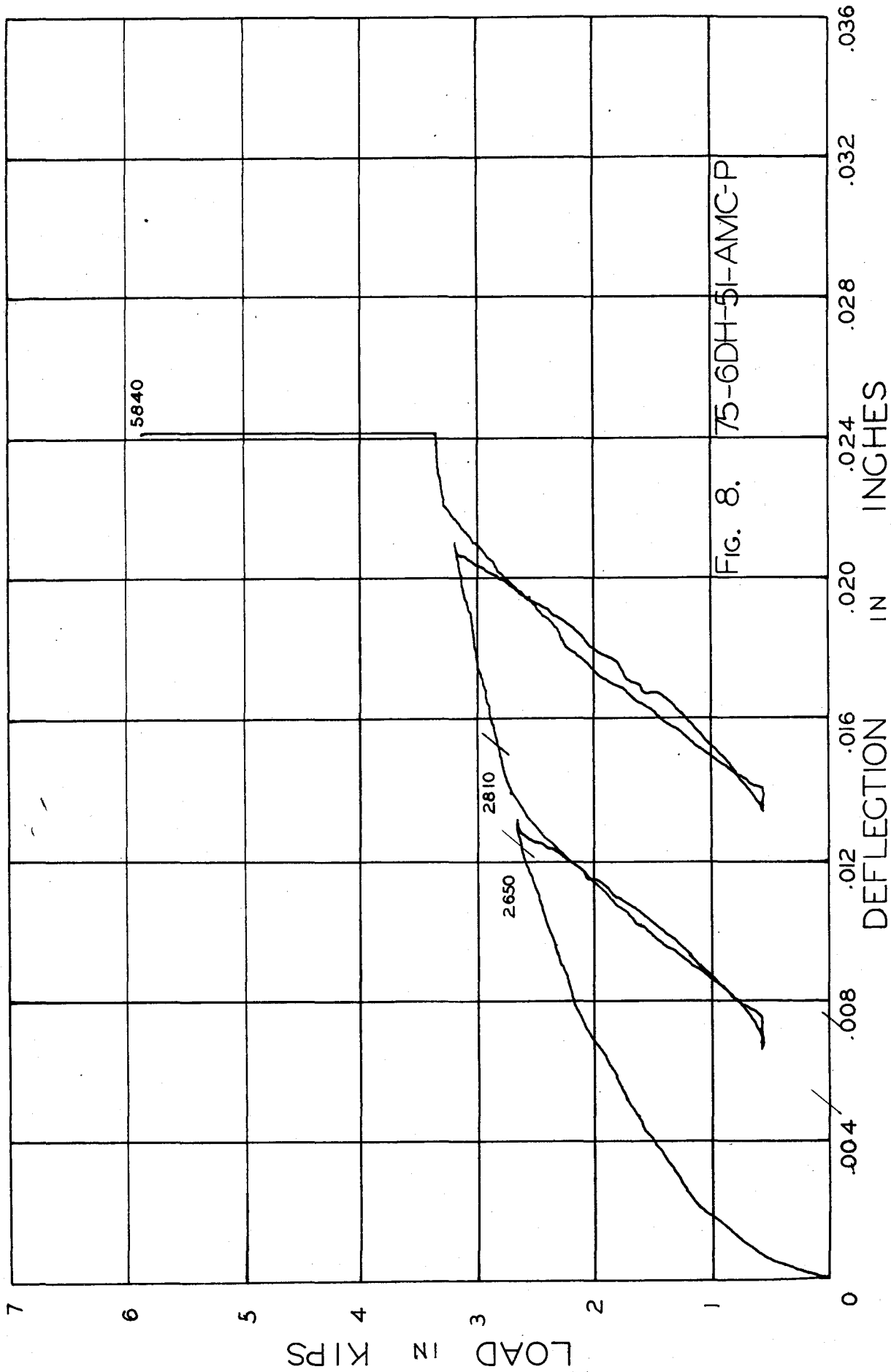


FIG. 7. 24-6DH-9F-AMC-R_s



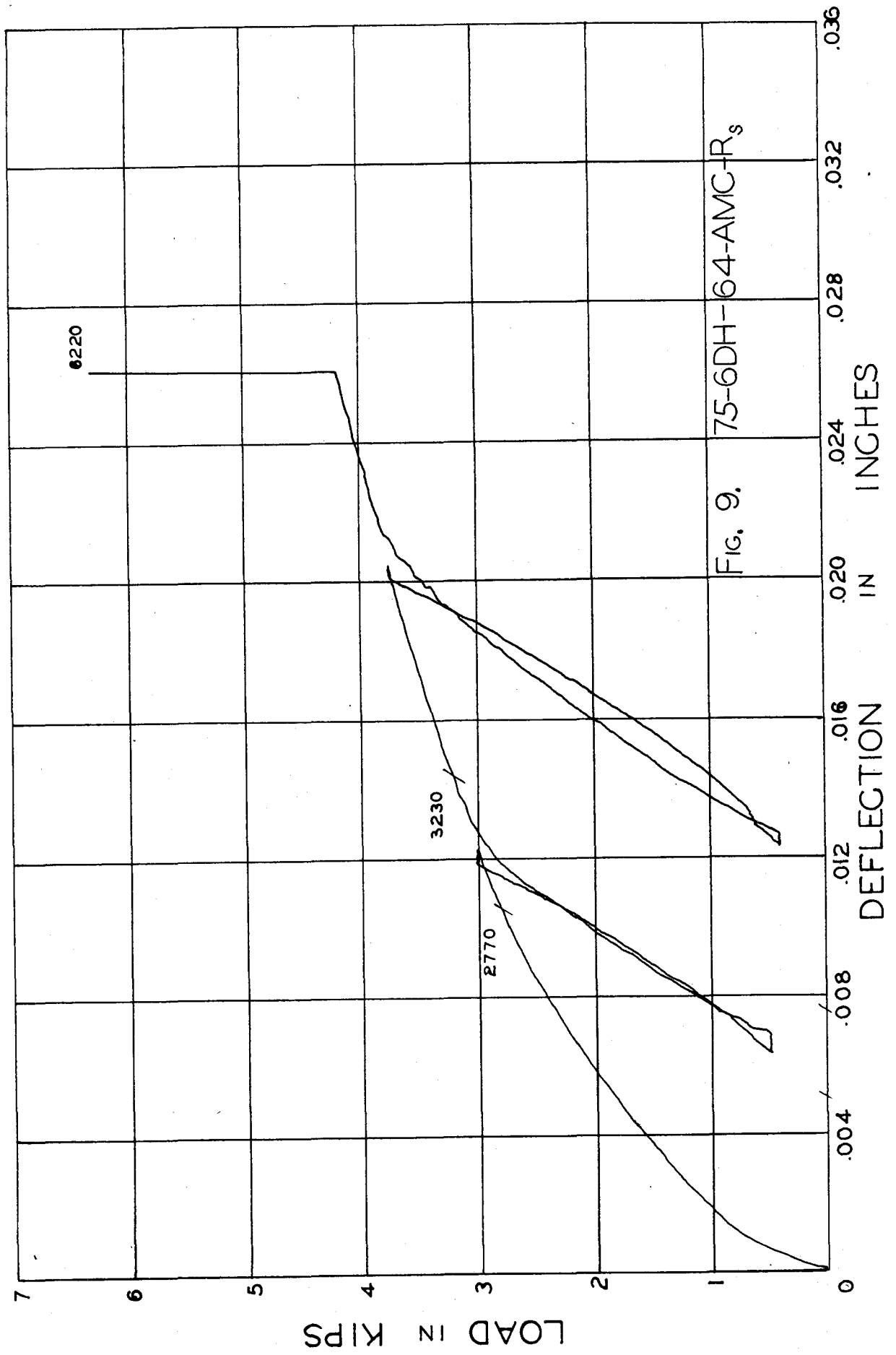
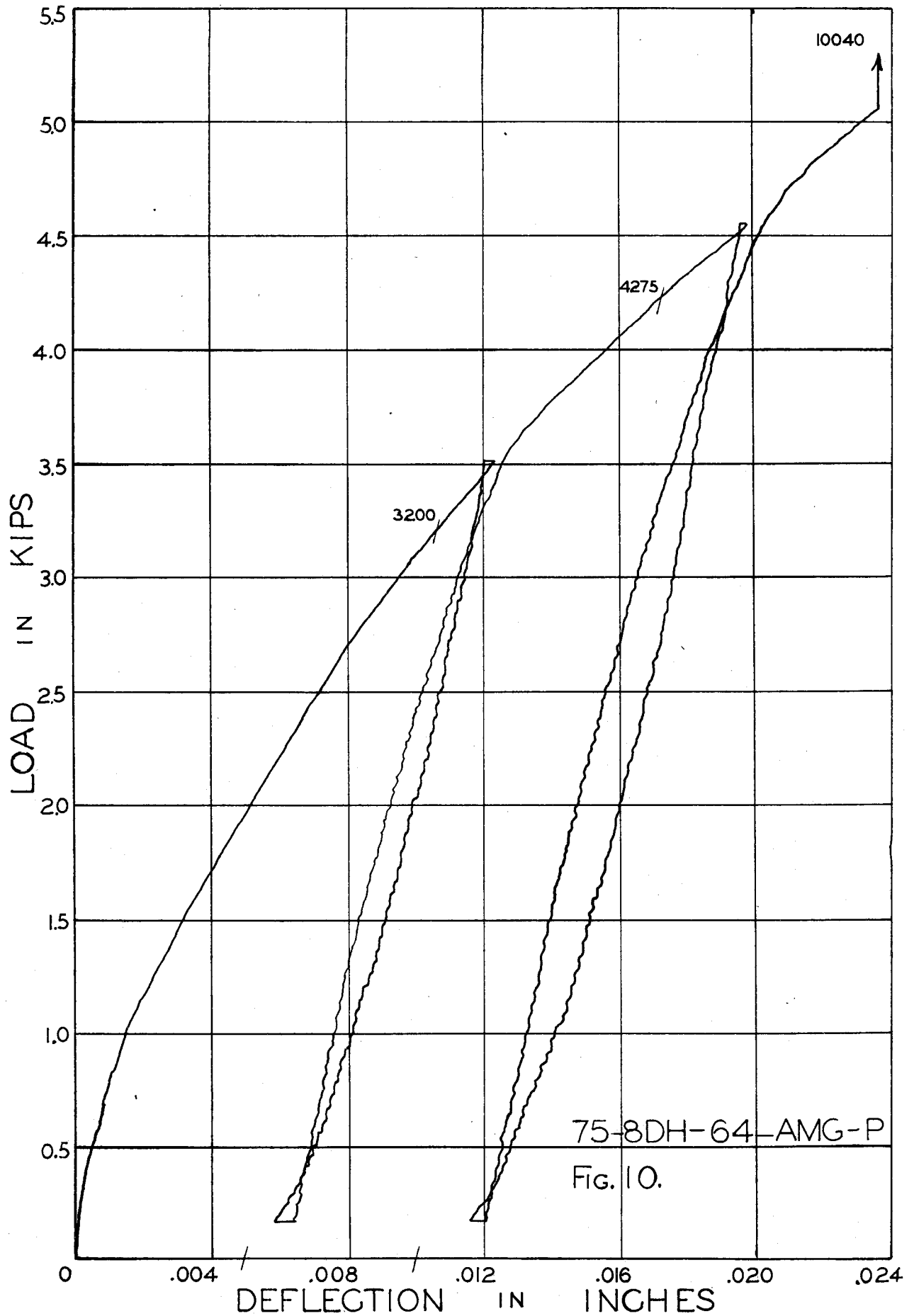
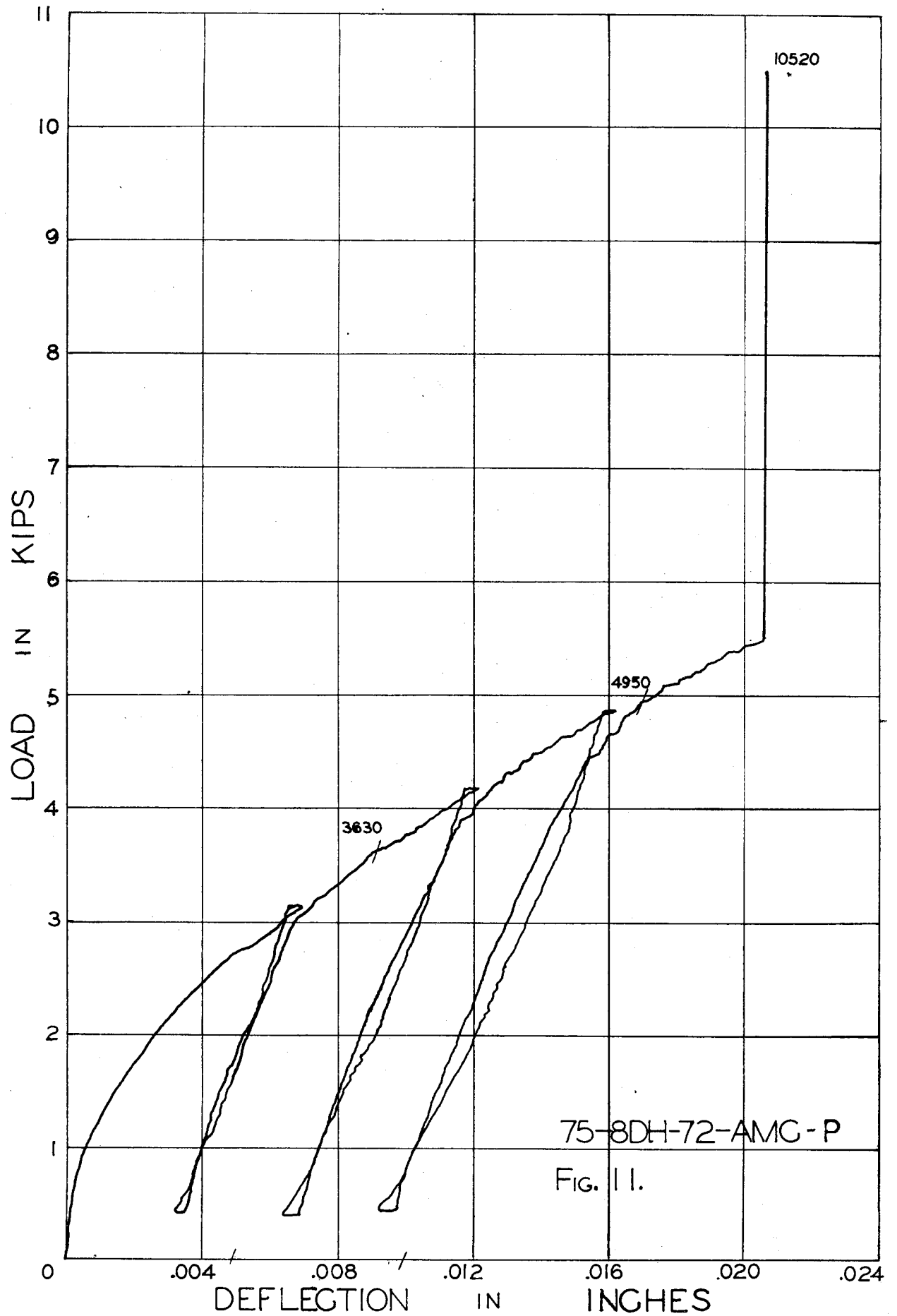


Fig. 9. 75-6DH-64-AMC-R_s

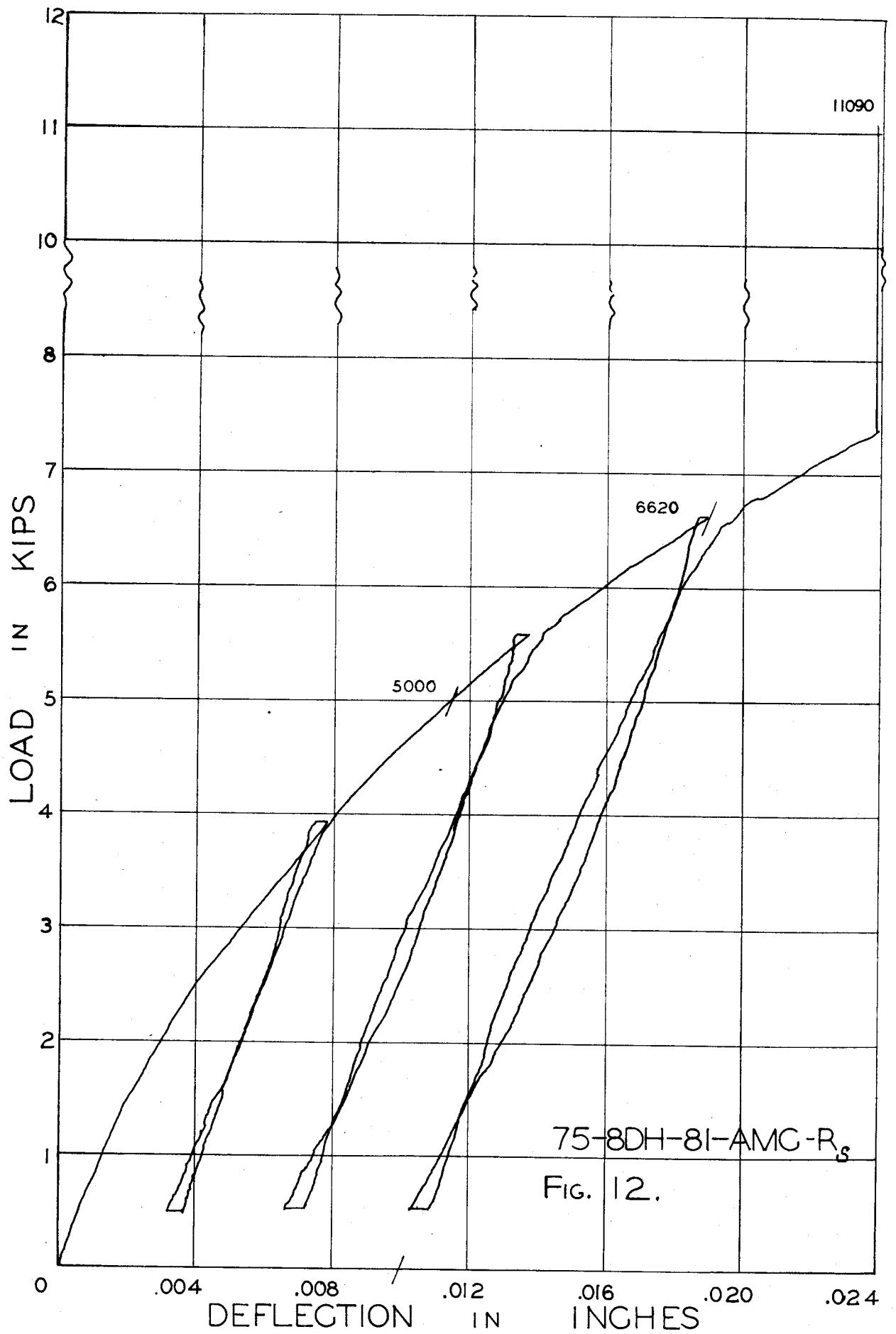


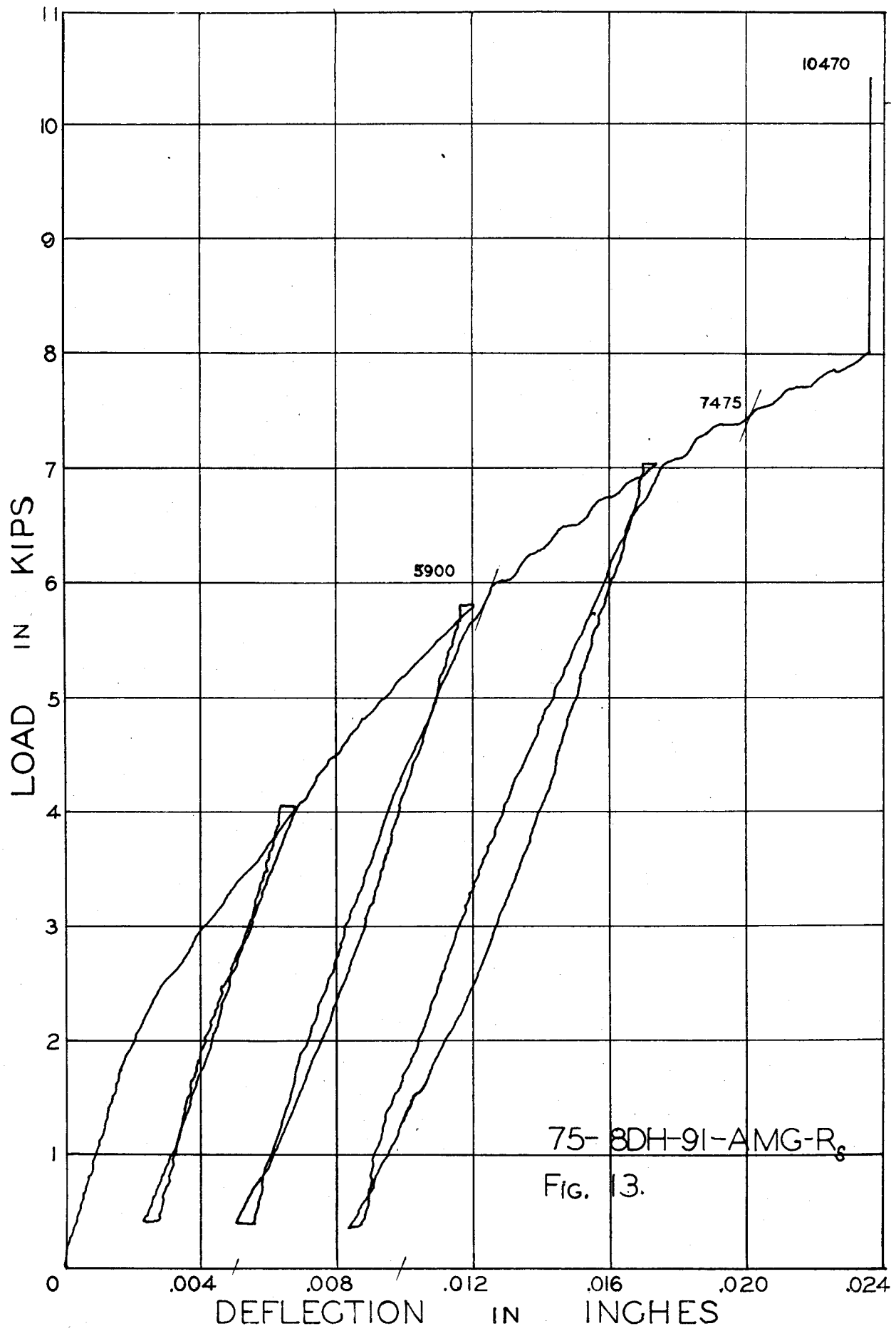
75-8DH-64-AMG-P
FIG. 10.

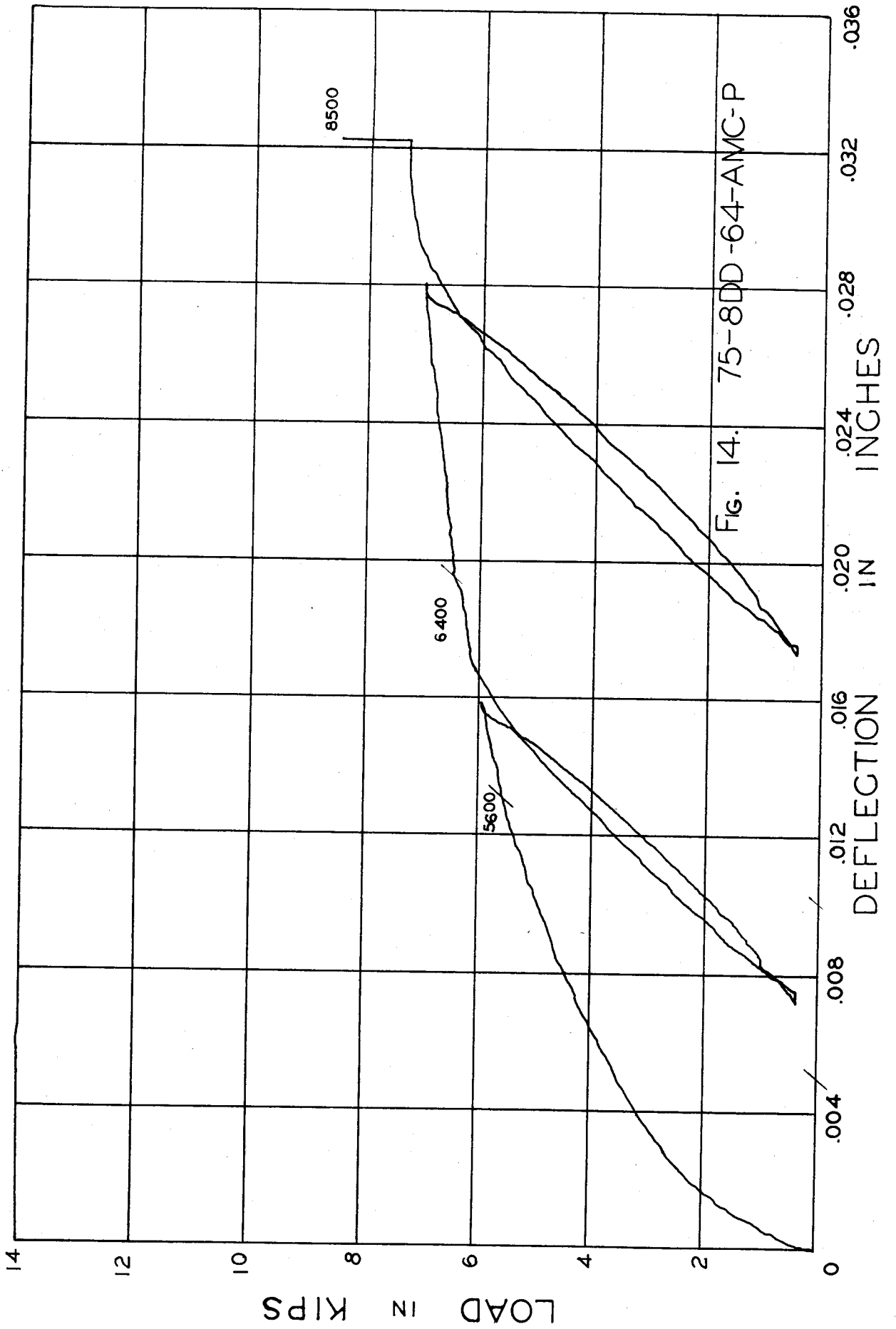


75-8DH-72-AMC-P

FIG. 11.







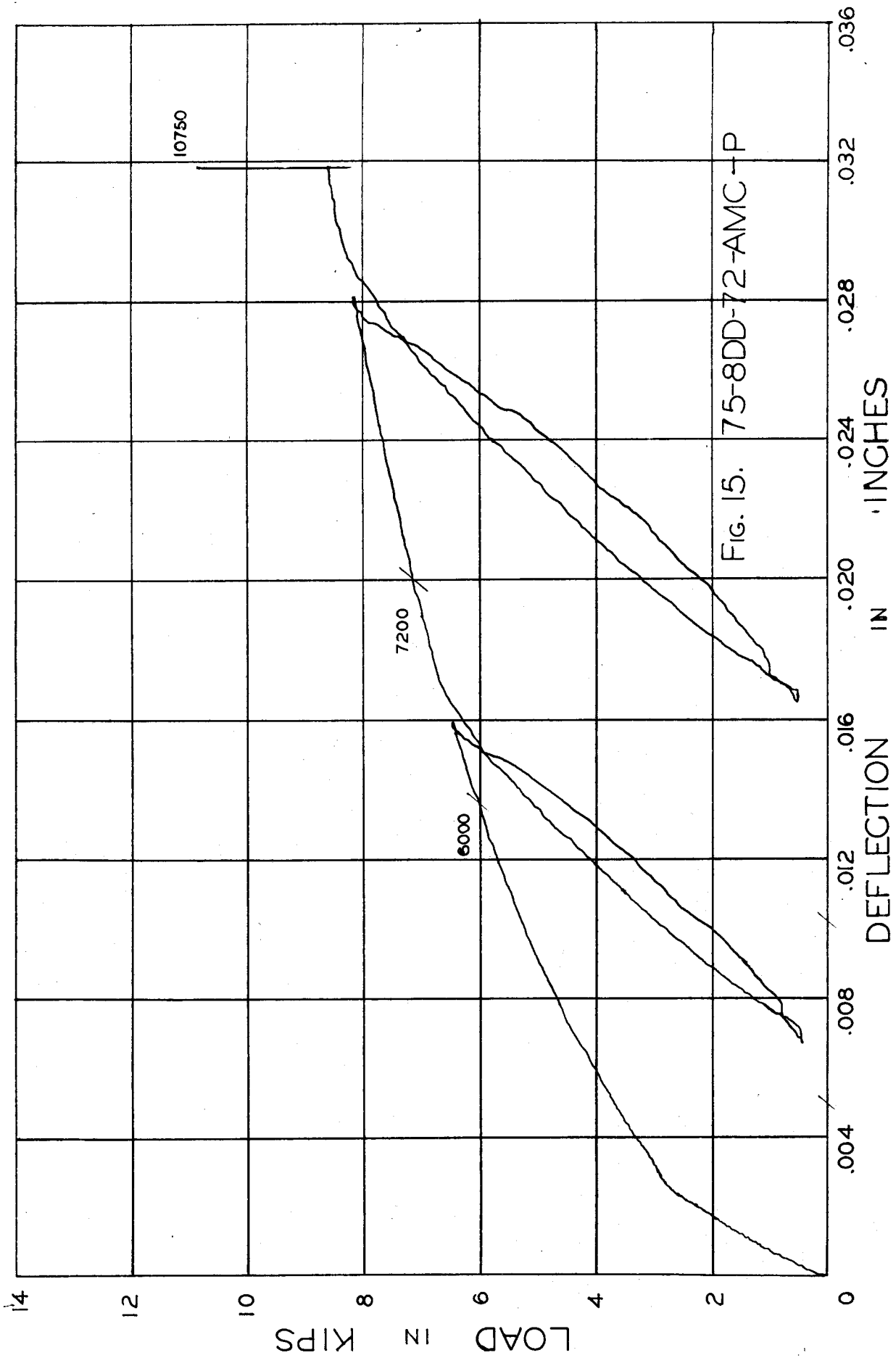


Fig. 15. 75-8DD-72-AMC-P

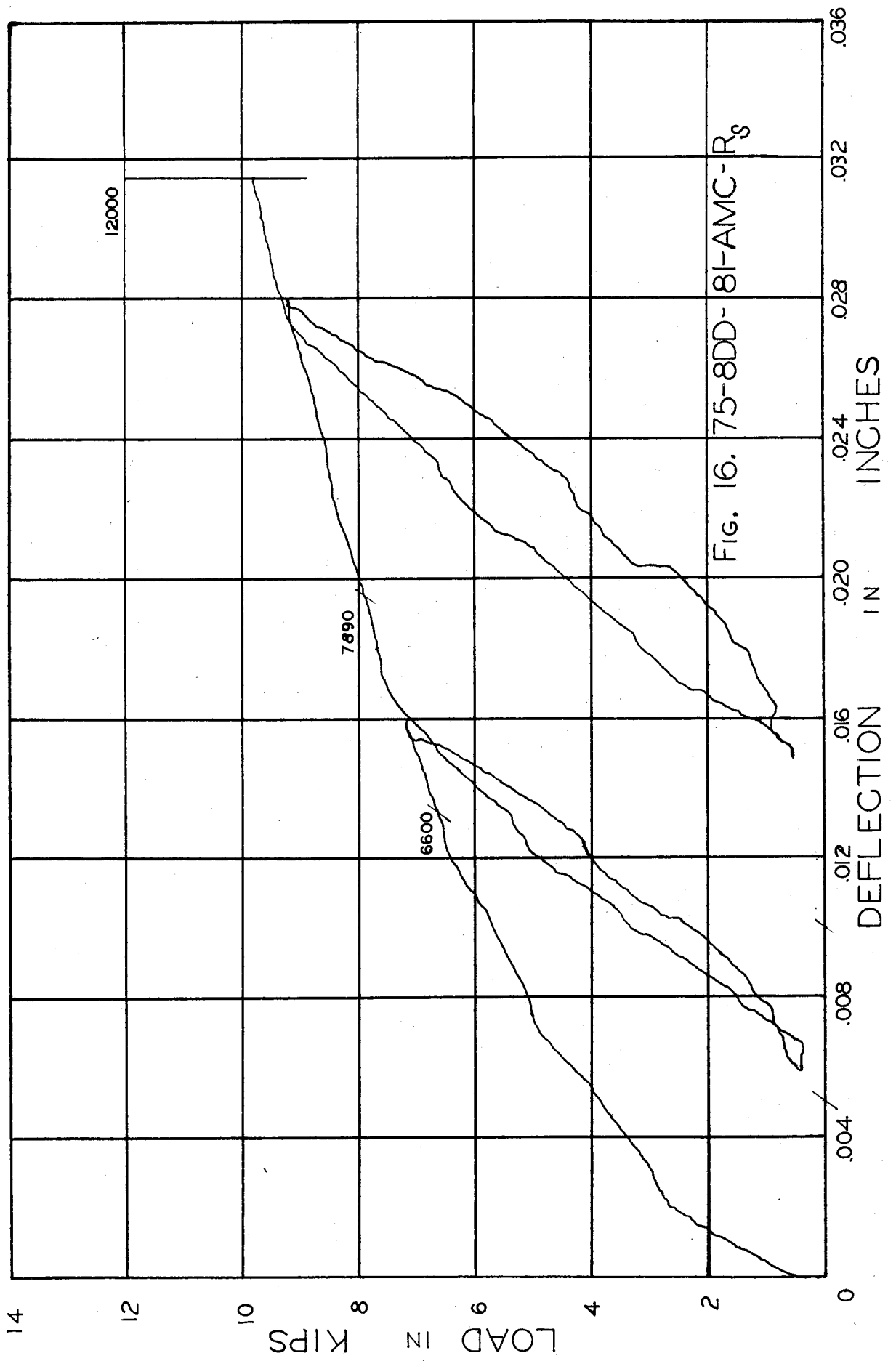


Fig. 16. 75-8DD-8I-AMC-R_s

7890

6600

12000

14

12

10

8

6

4

2

0

LOAD IN KIPS

DEFLECTION IN

INCHES

.036

.032

.028

.024

.020

.016

.012

.008

.004

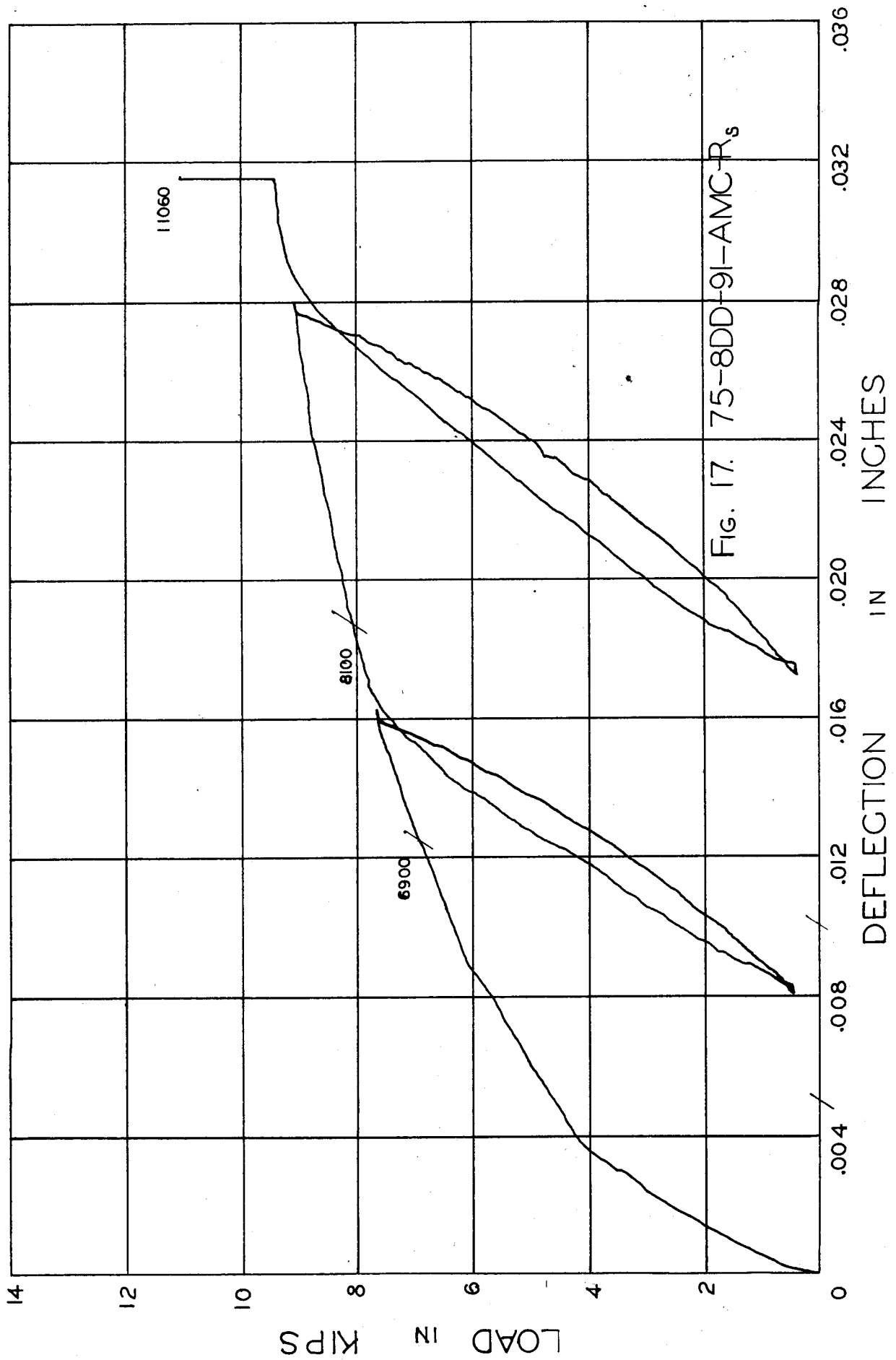
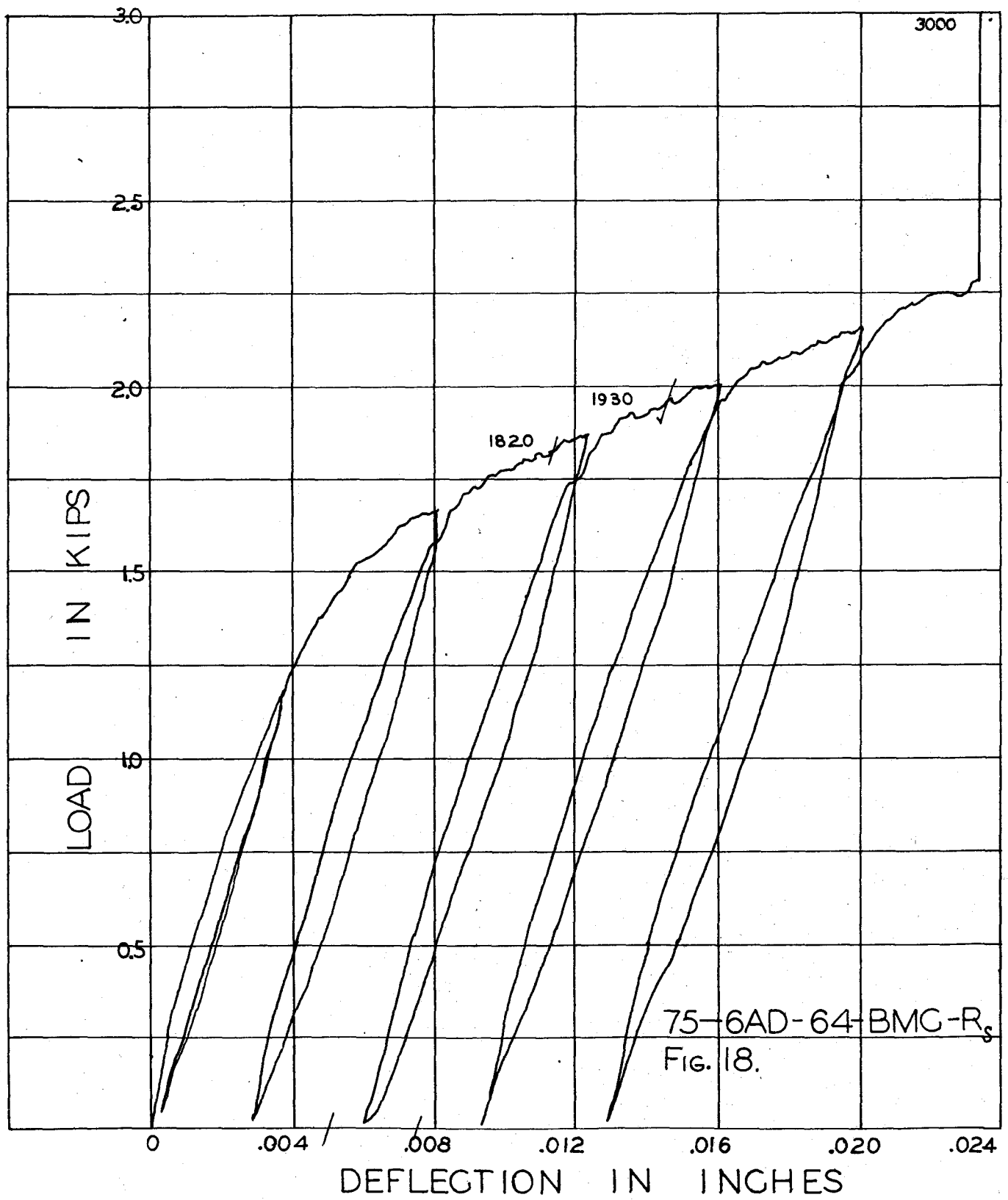
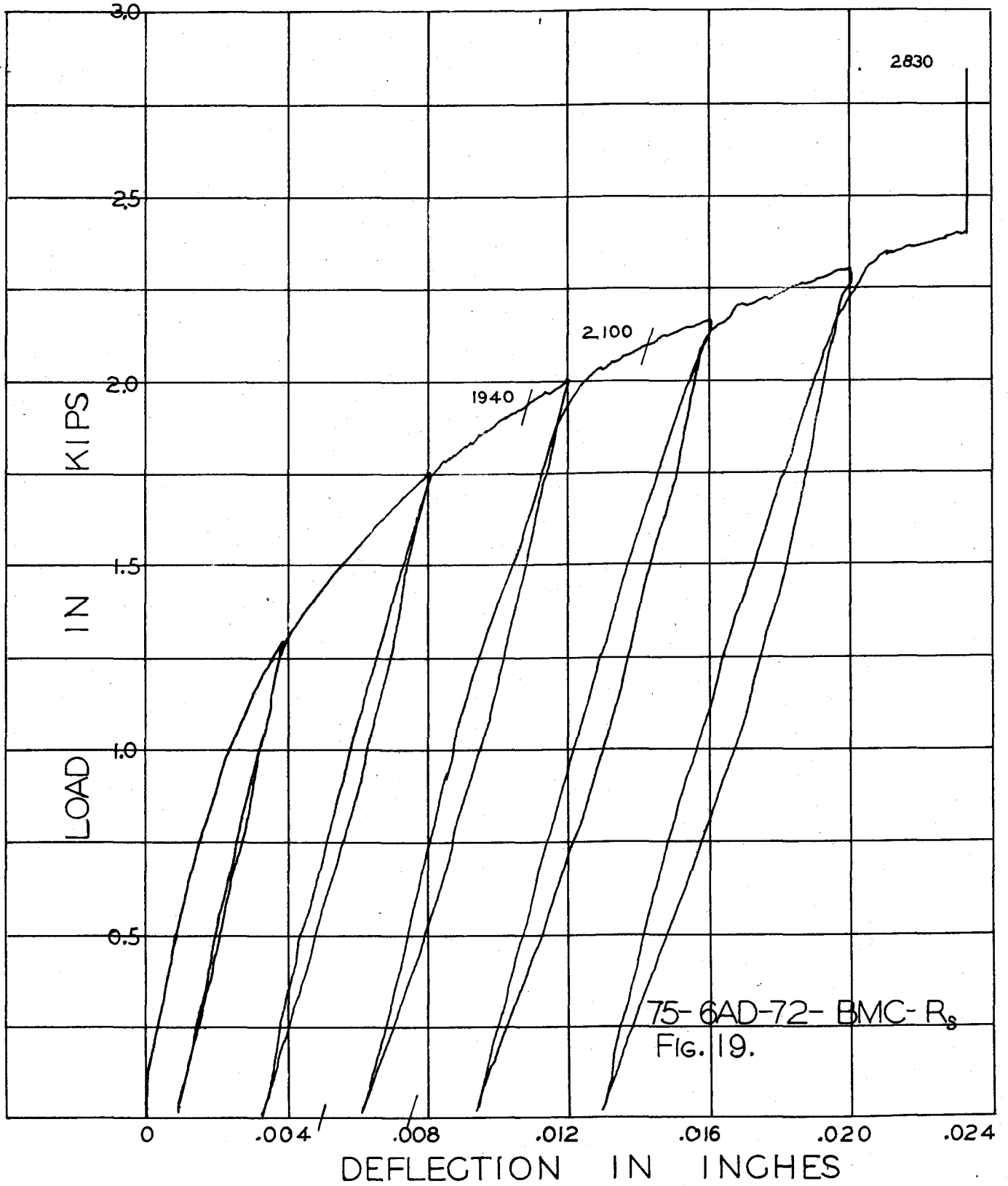
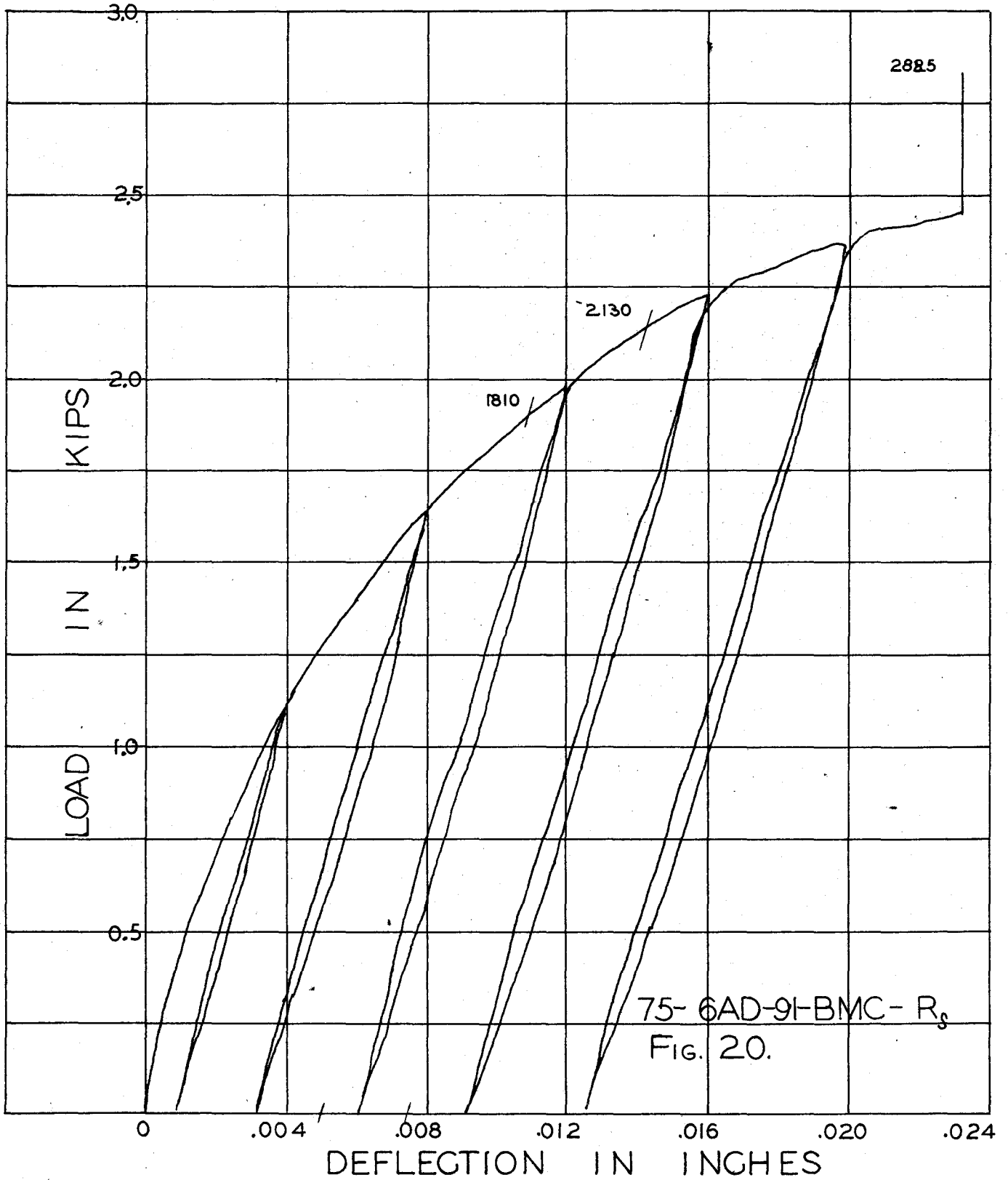
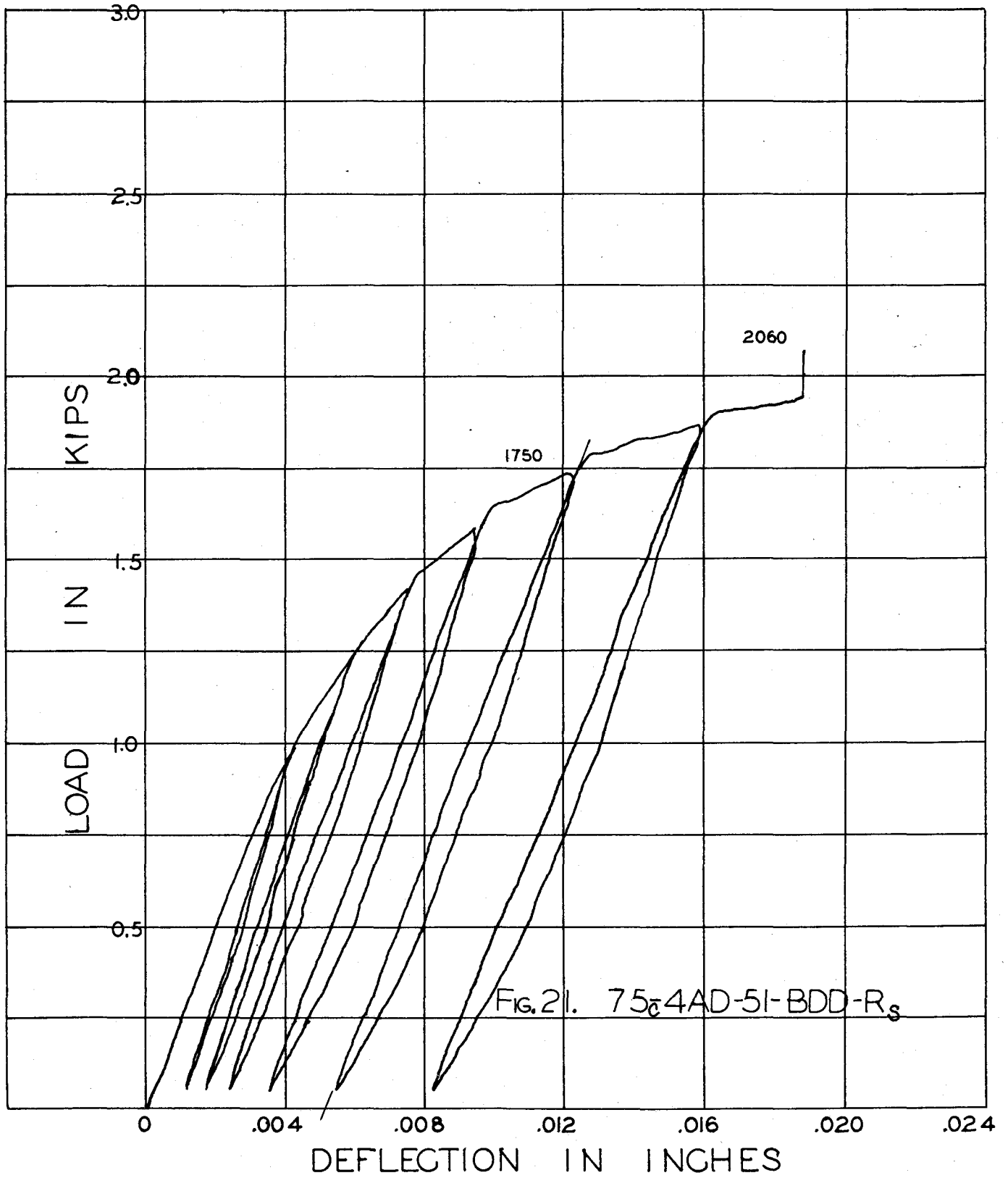


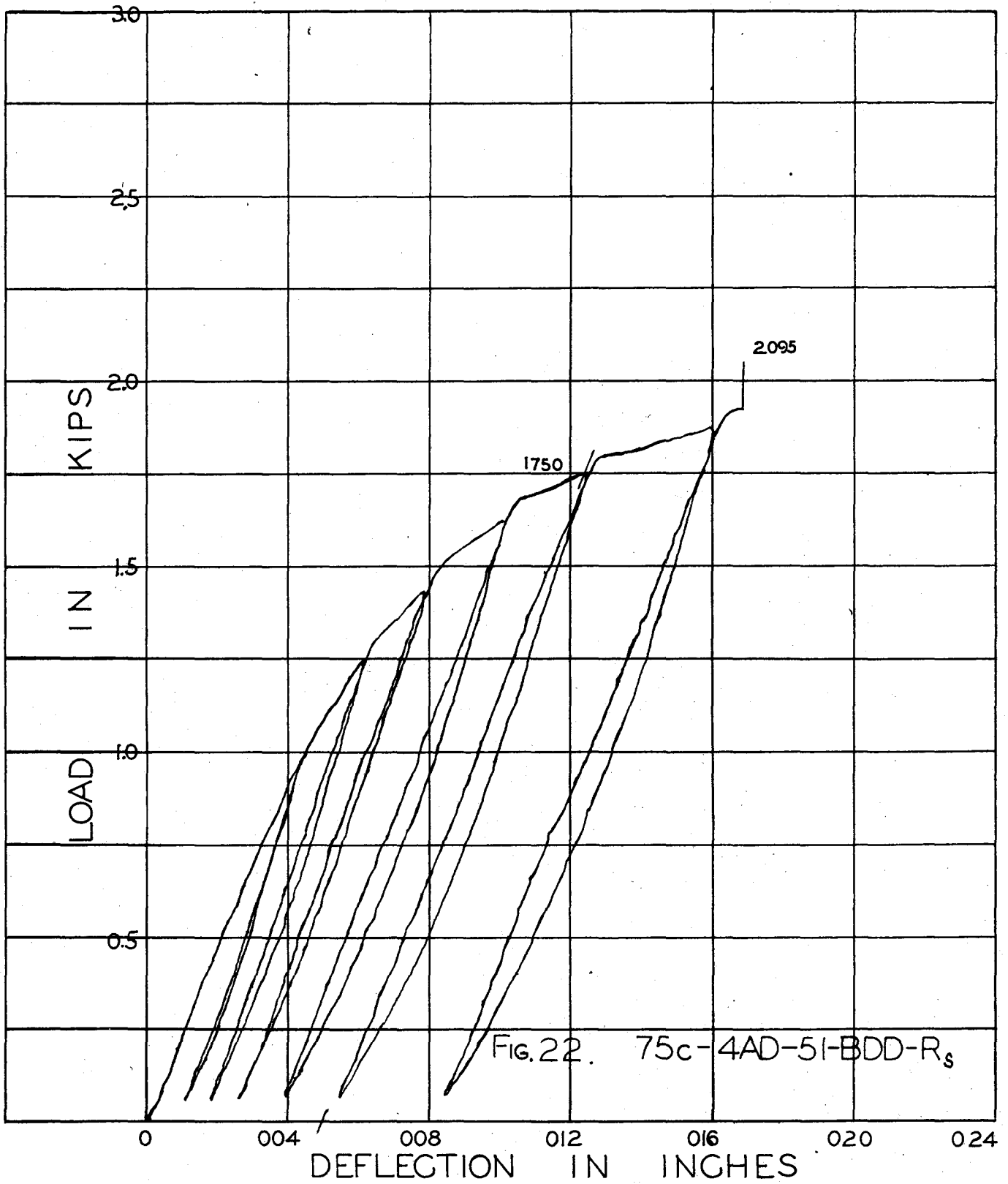
Fig. 17. 75-8DD-9I-AMC-R_s

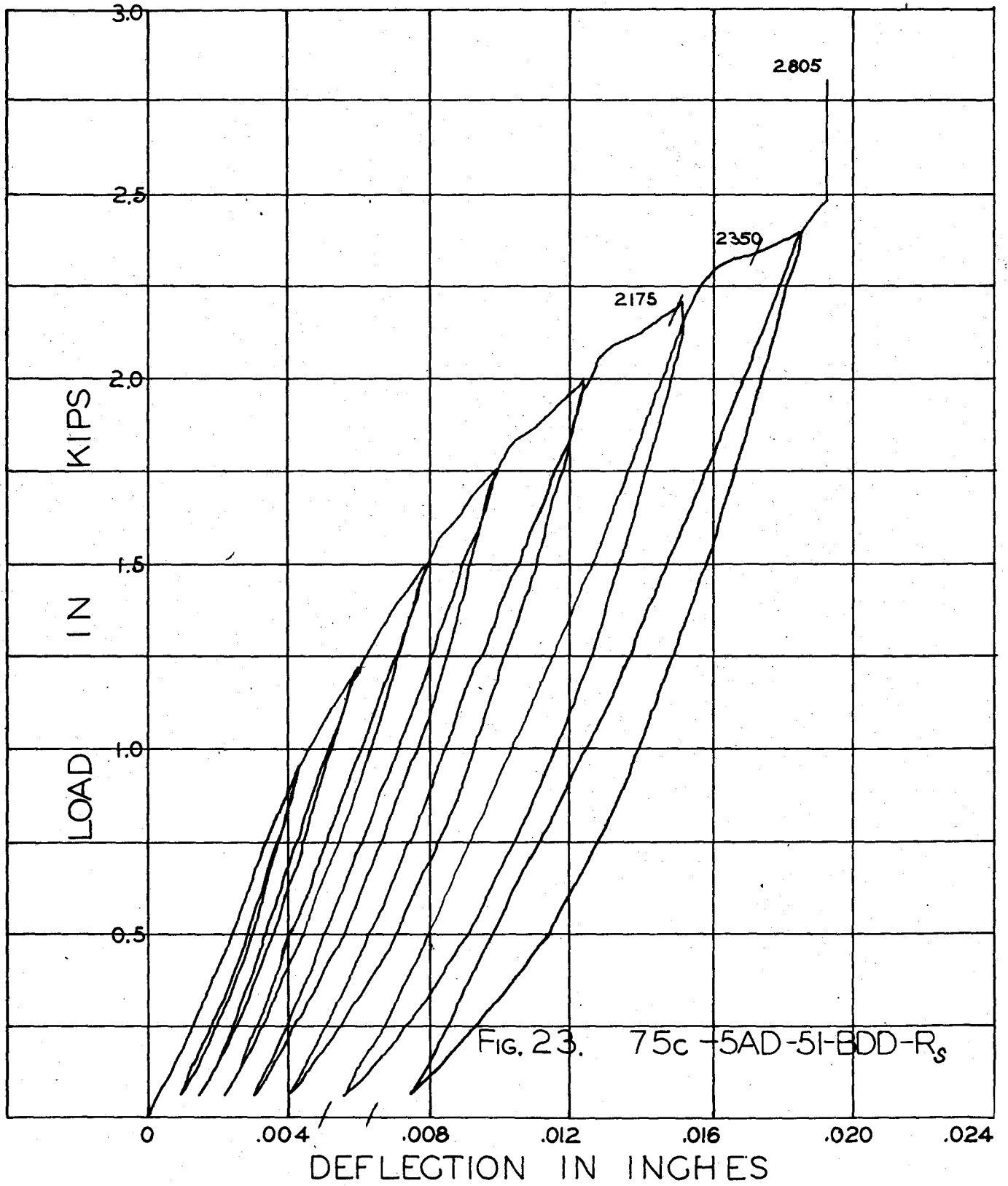


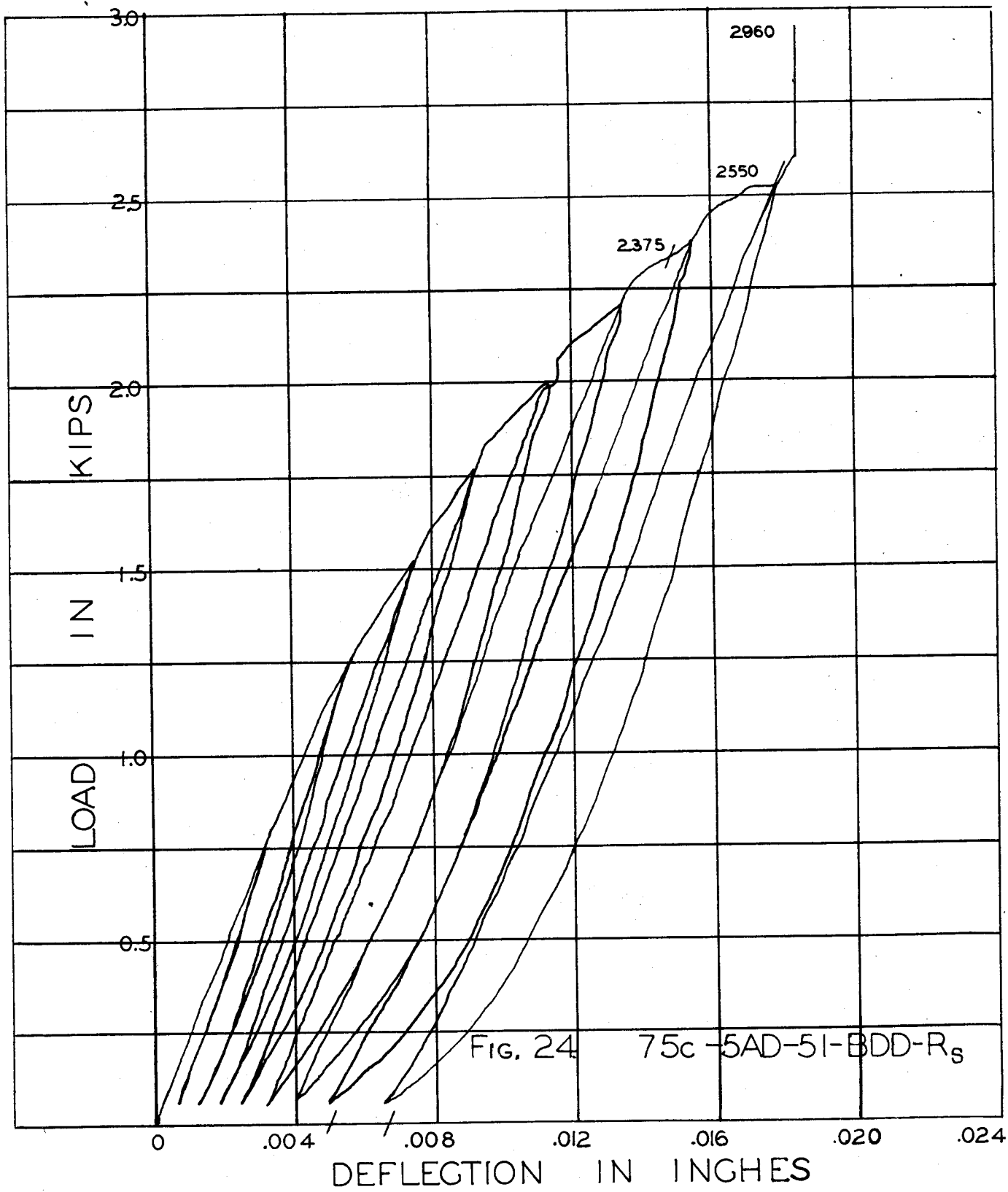


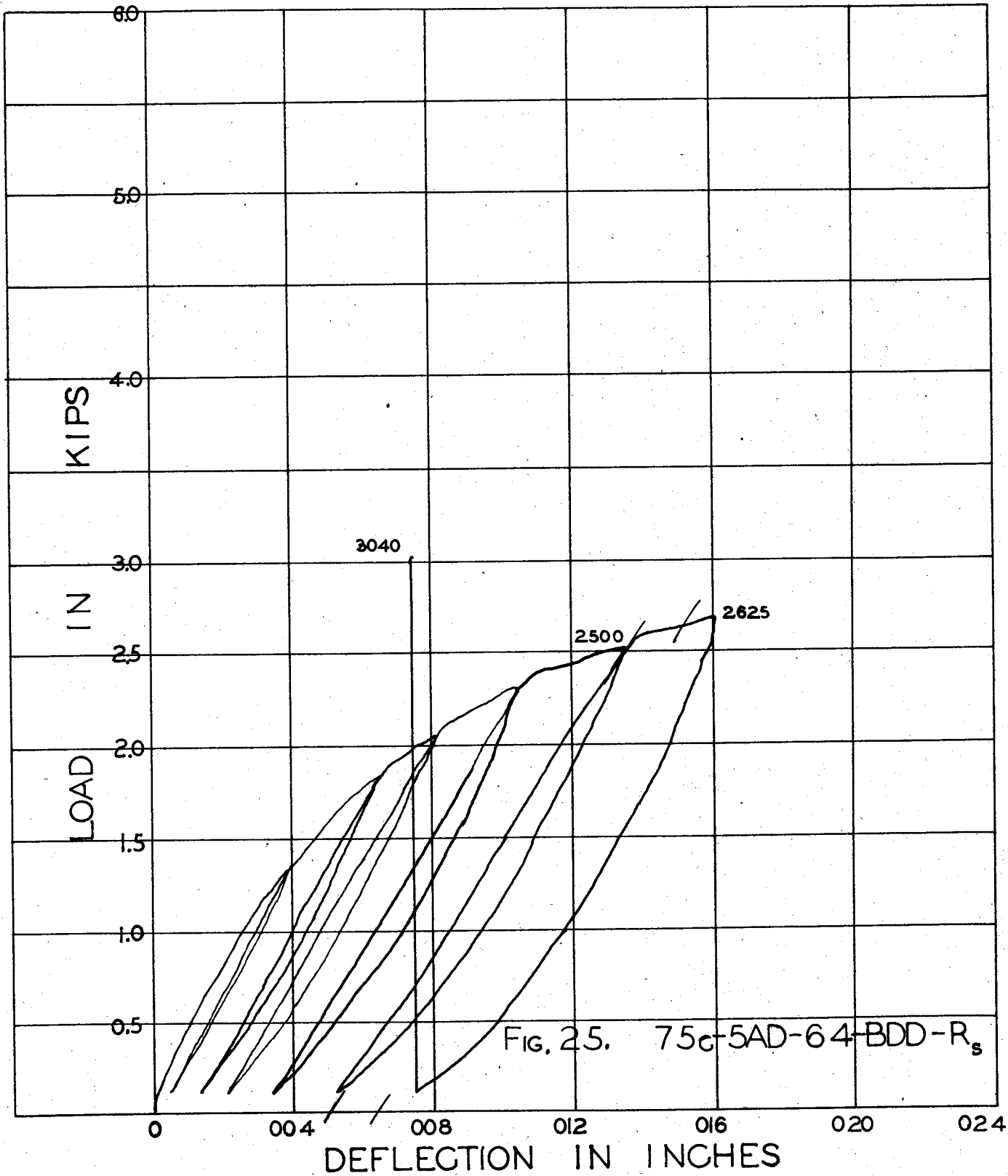


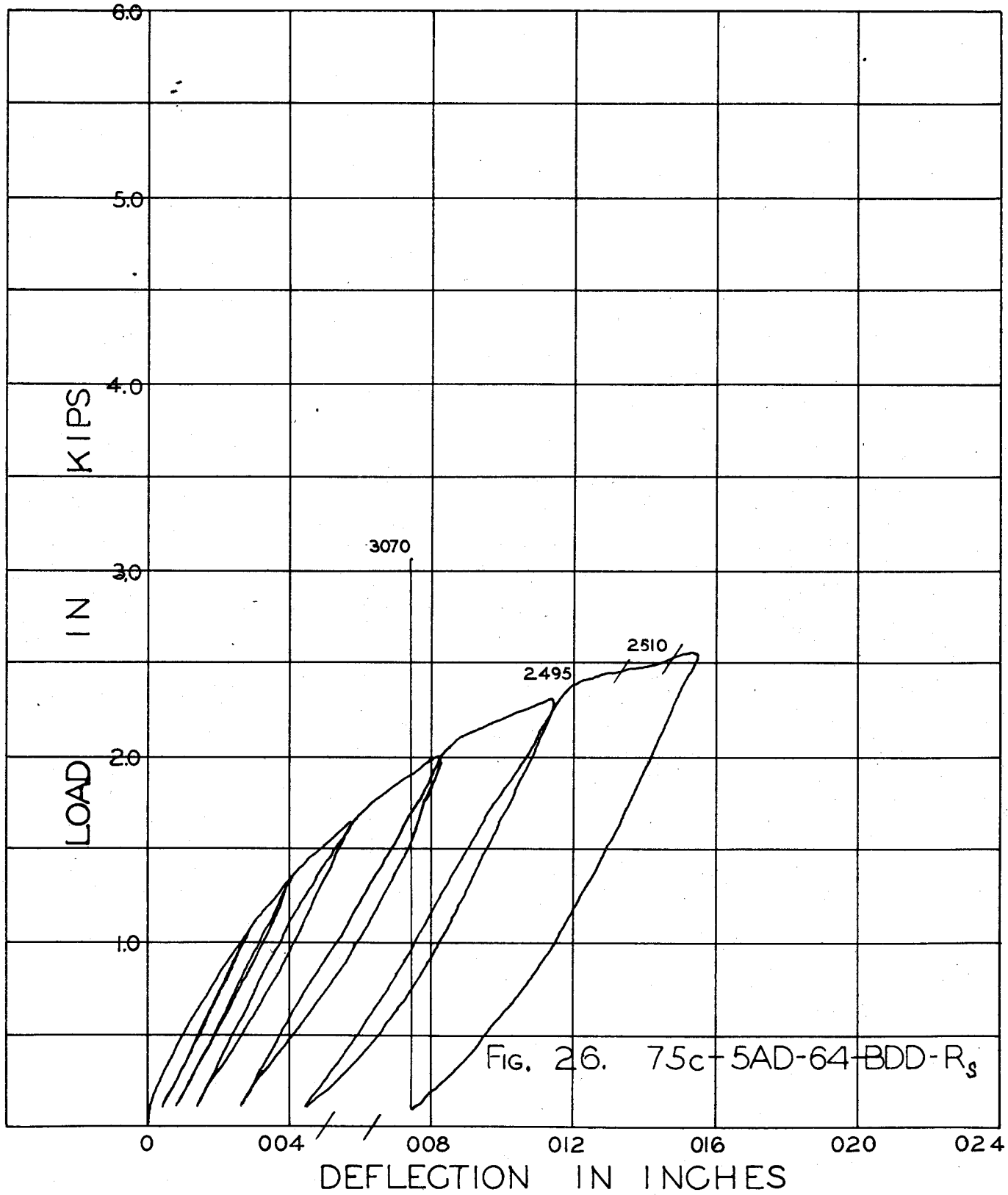


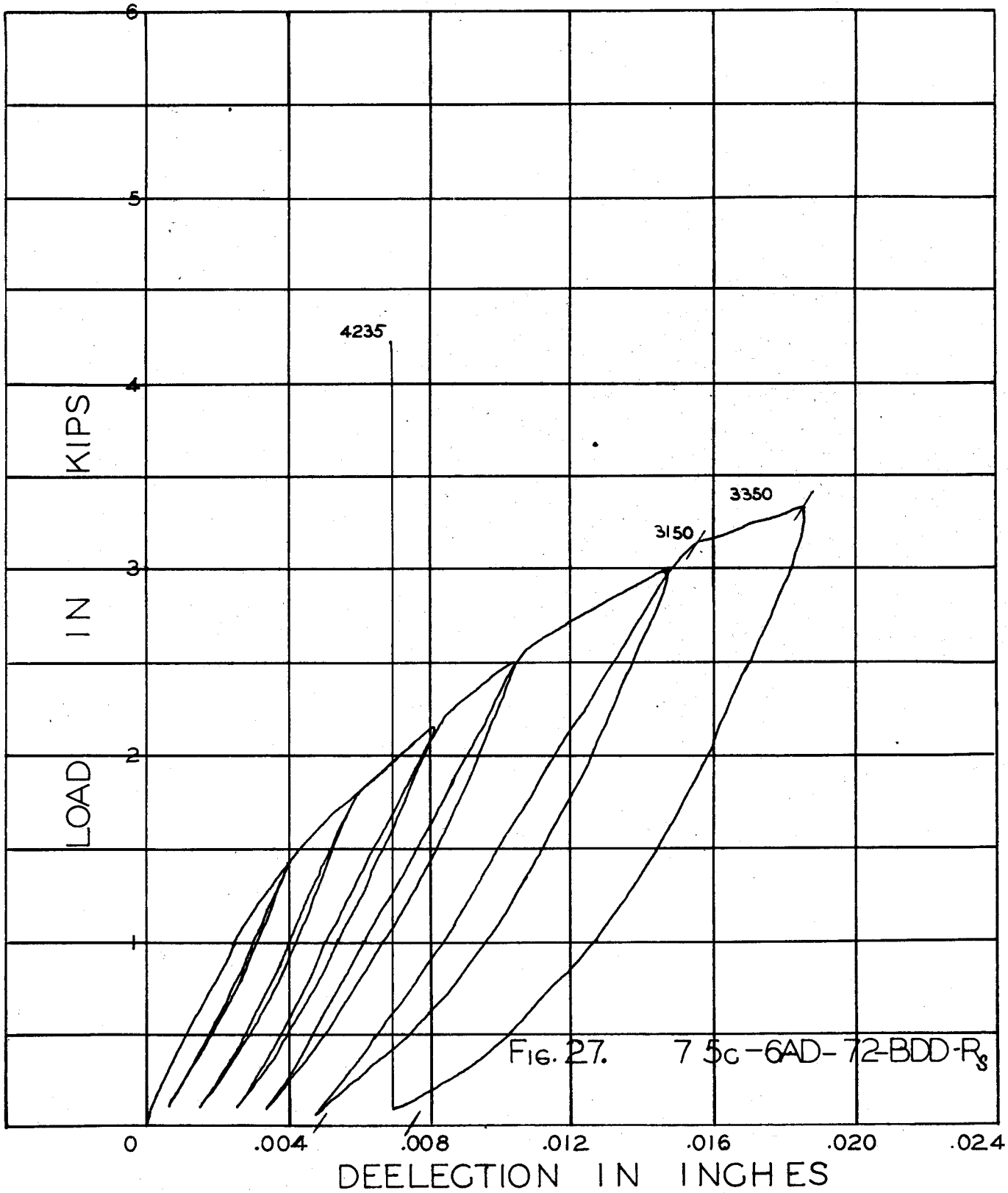


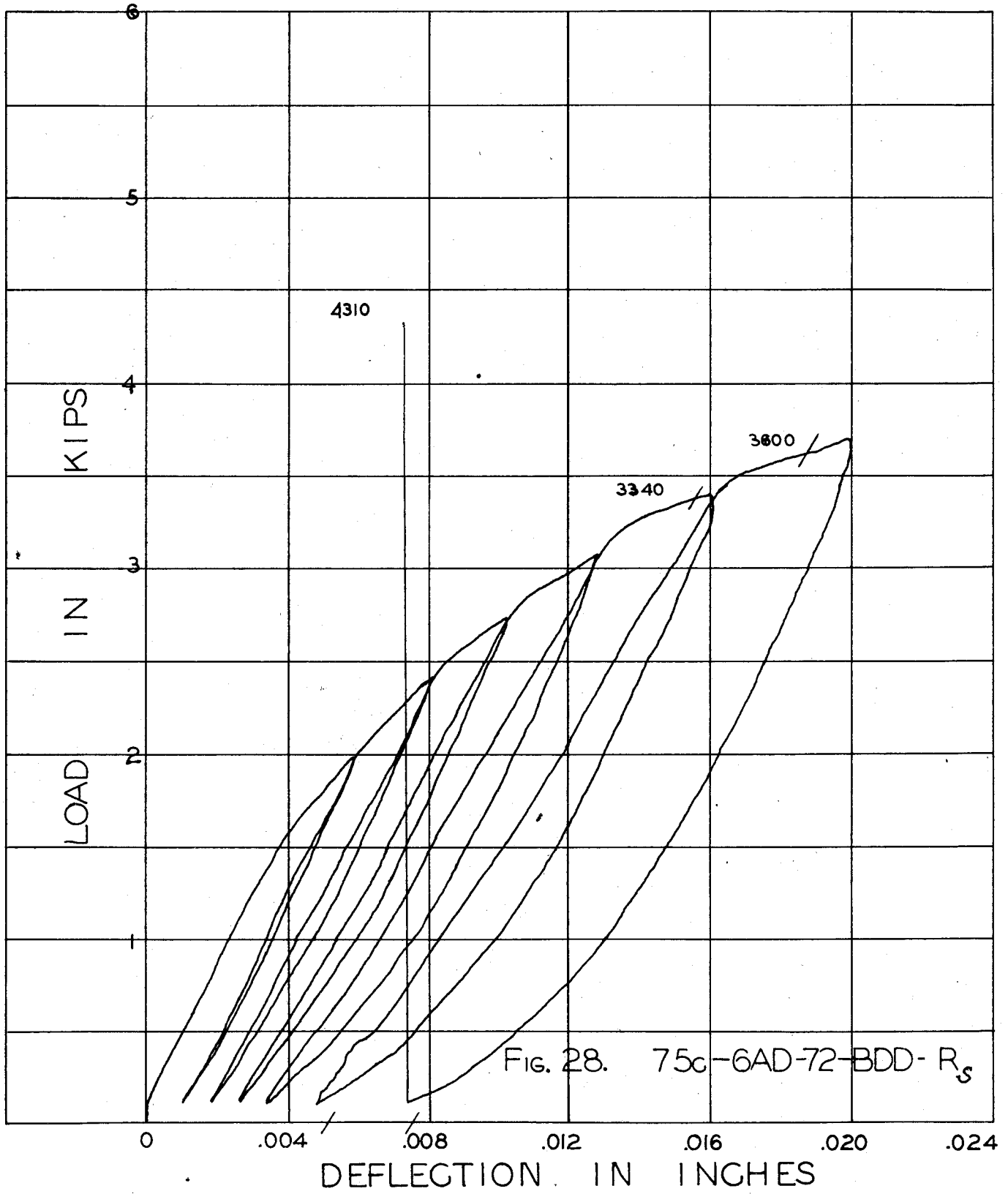












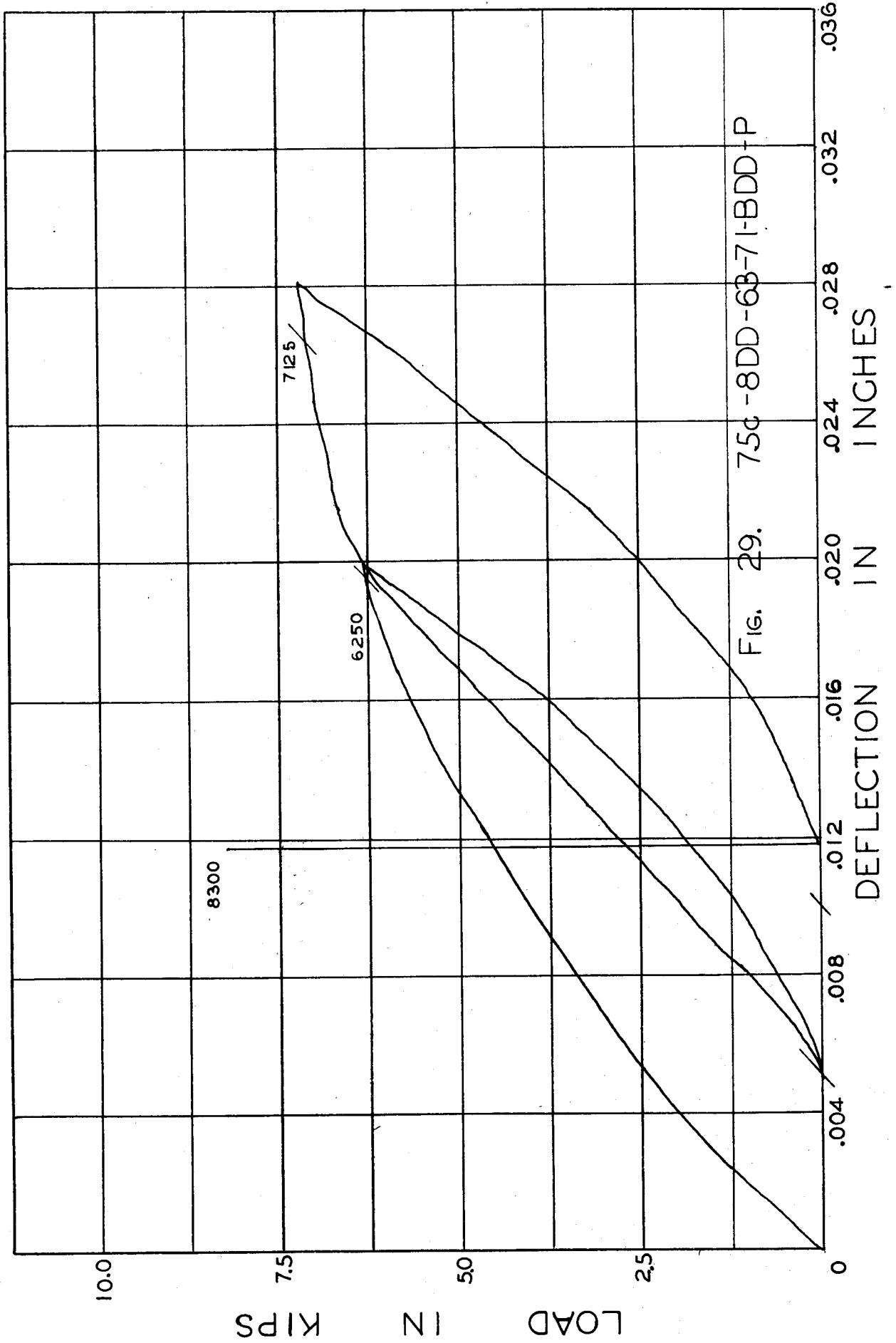


FIG. 29. 75c-8DD-63-71-BDD+P

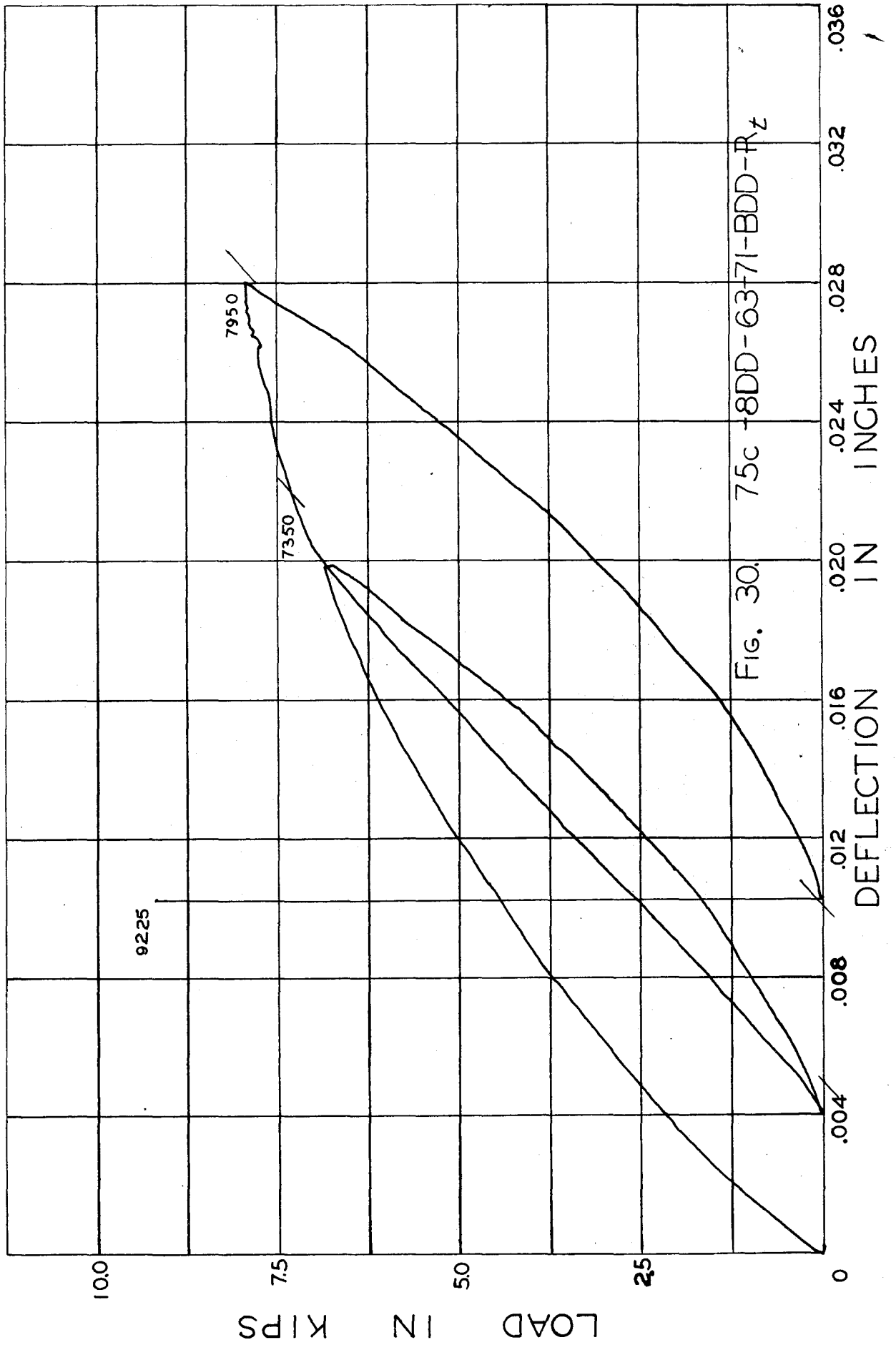


Fig. 30. 75c +8DD-63-71-BDD-R_z

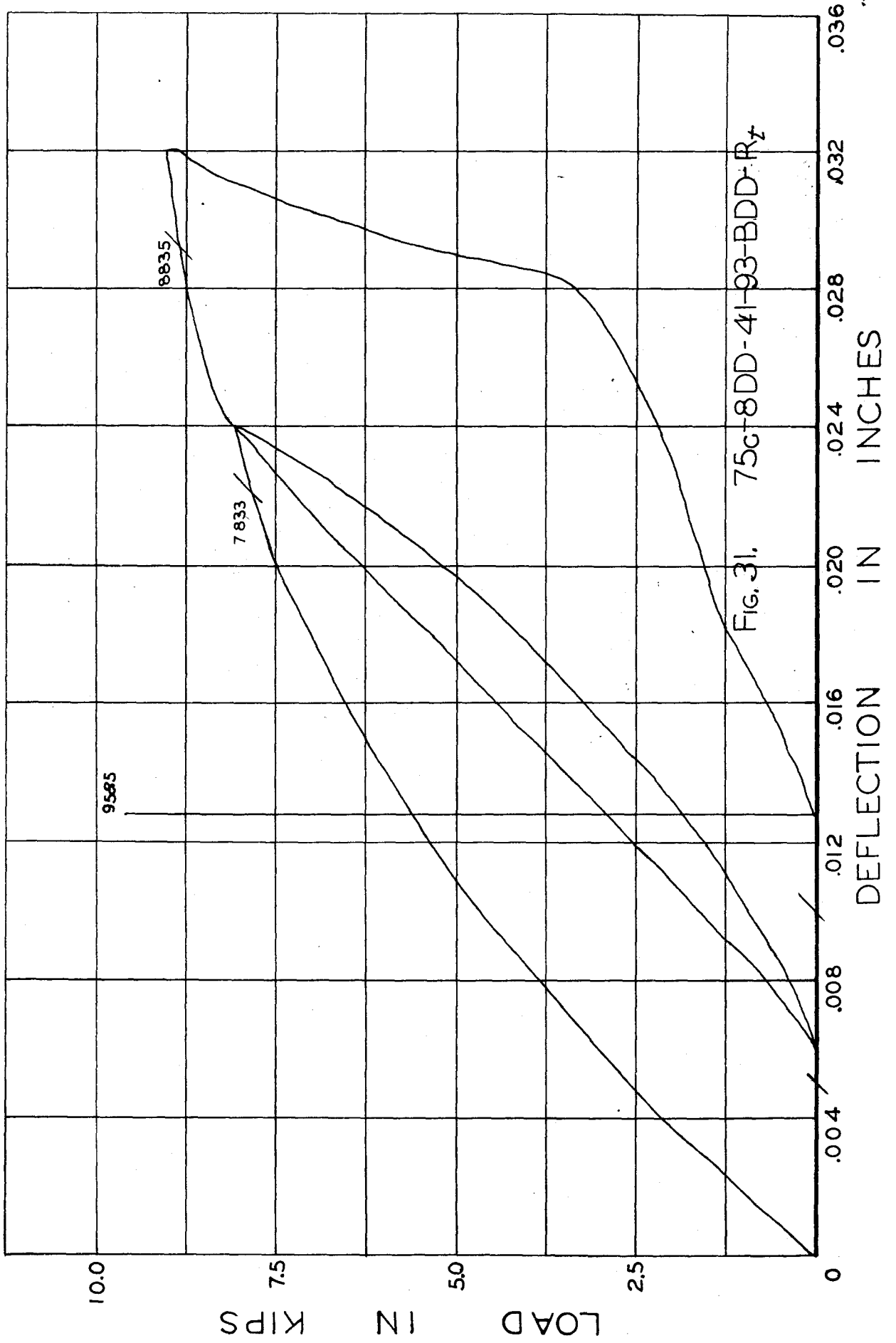


Fig. 31. 75c-8DD-41-93-BDD-R_z

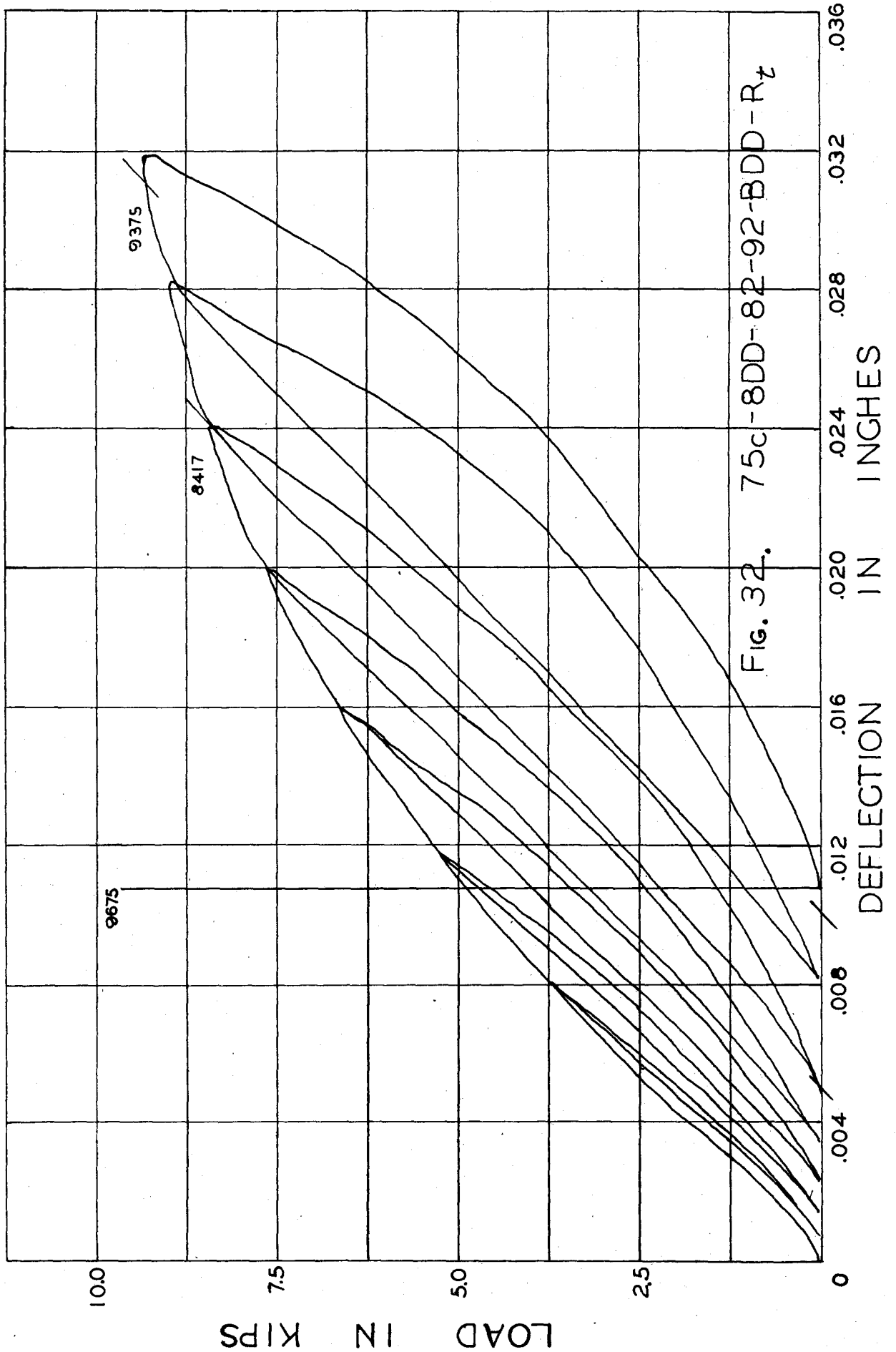
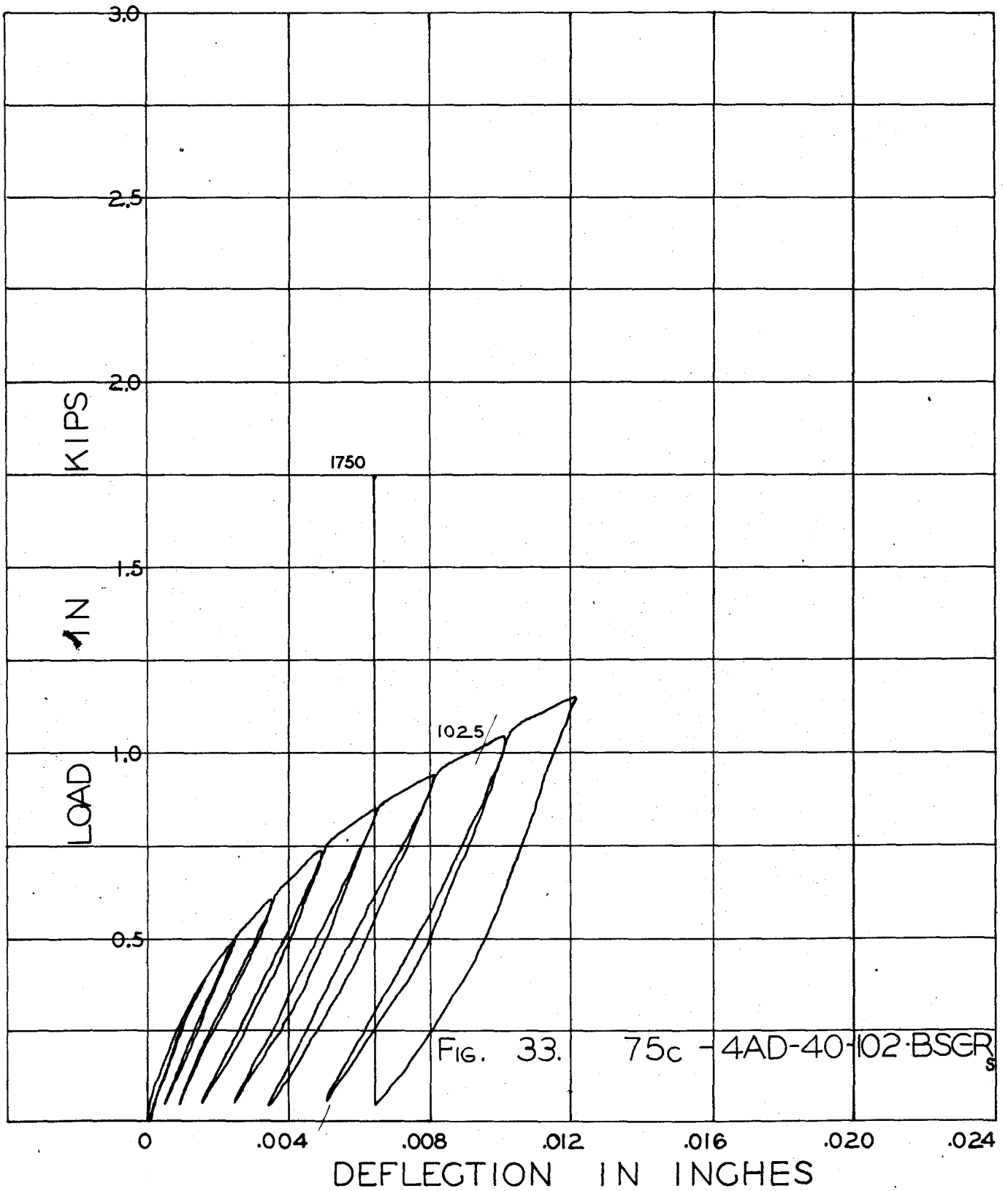


FIG. 32. 75c-8DD-82-92-BDD-R_t



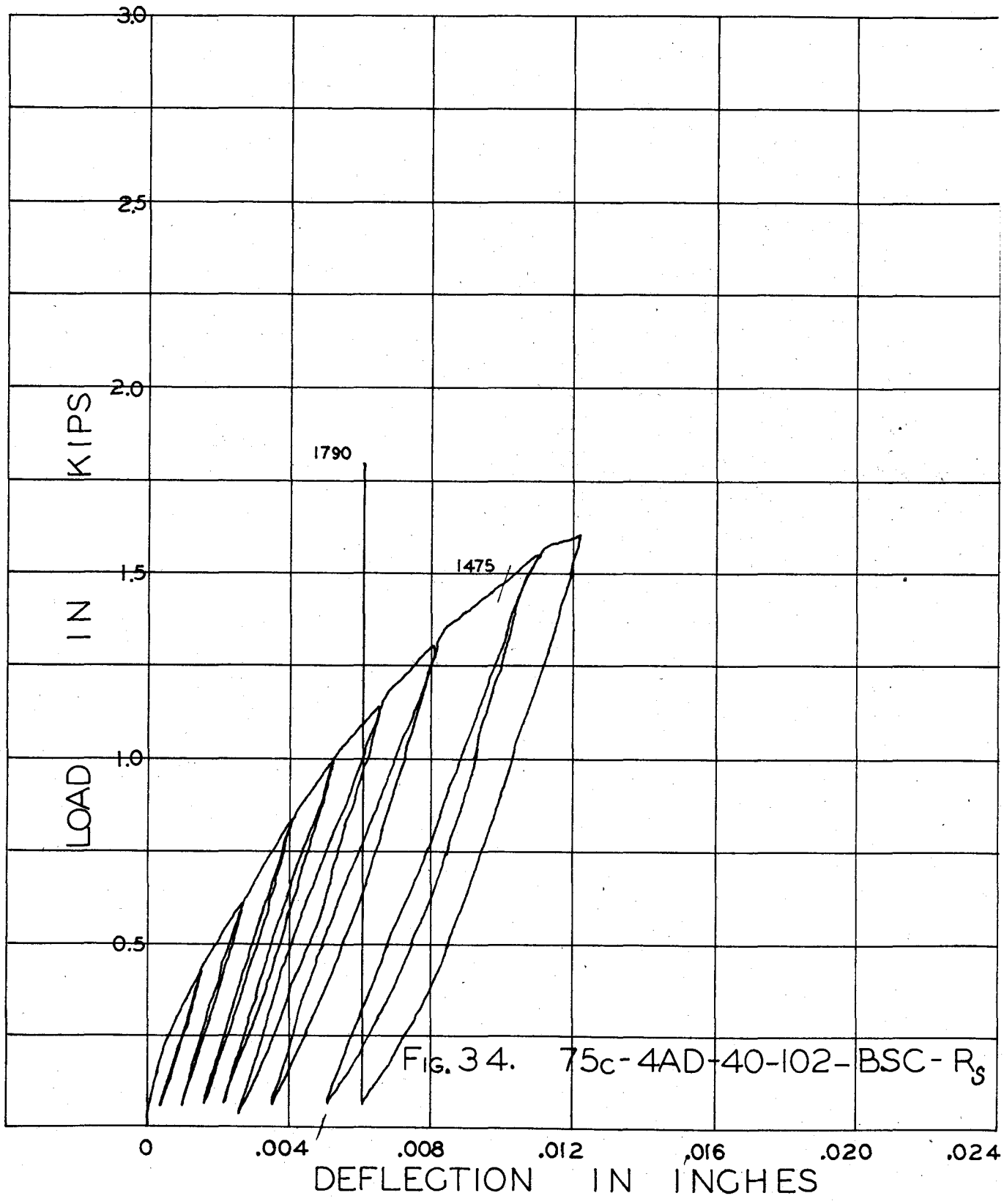
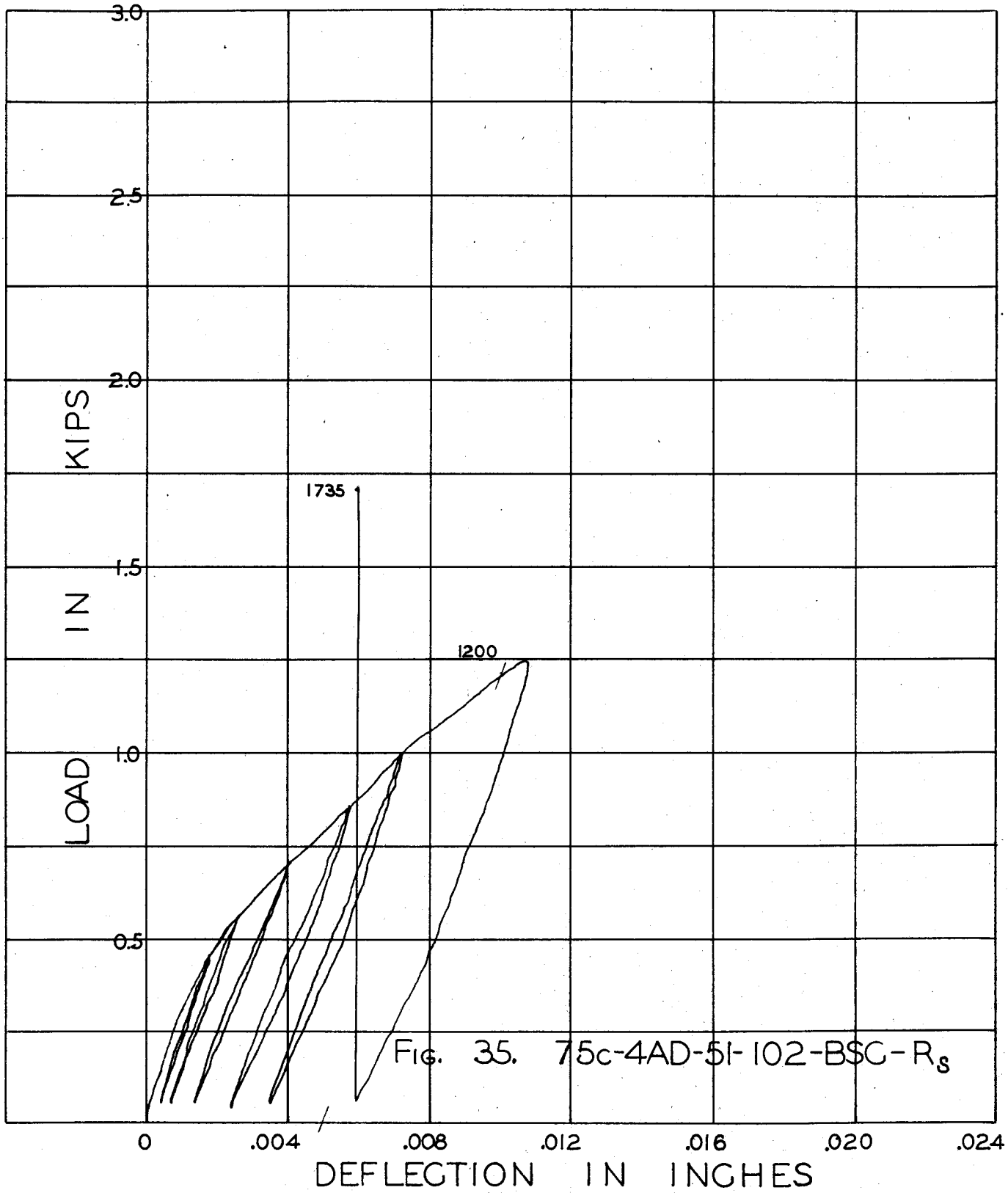
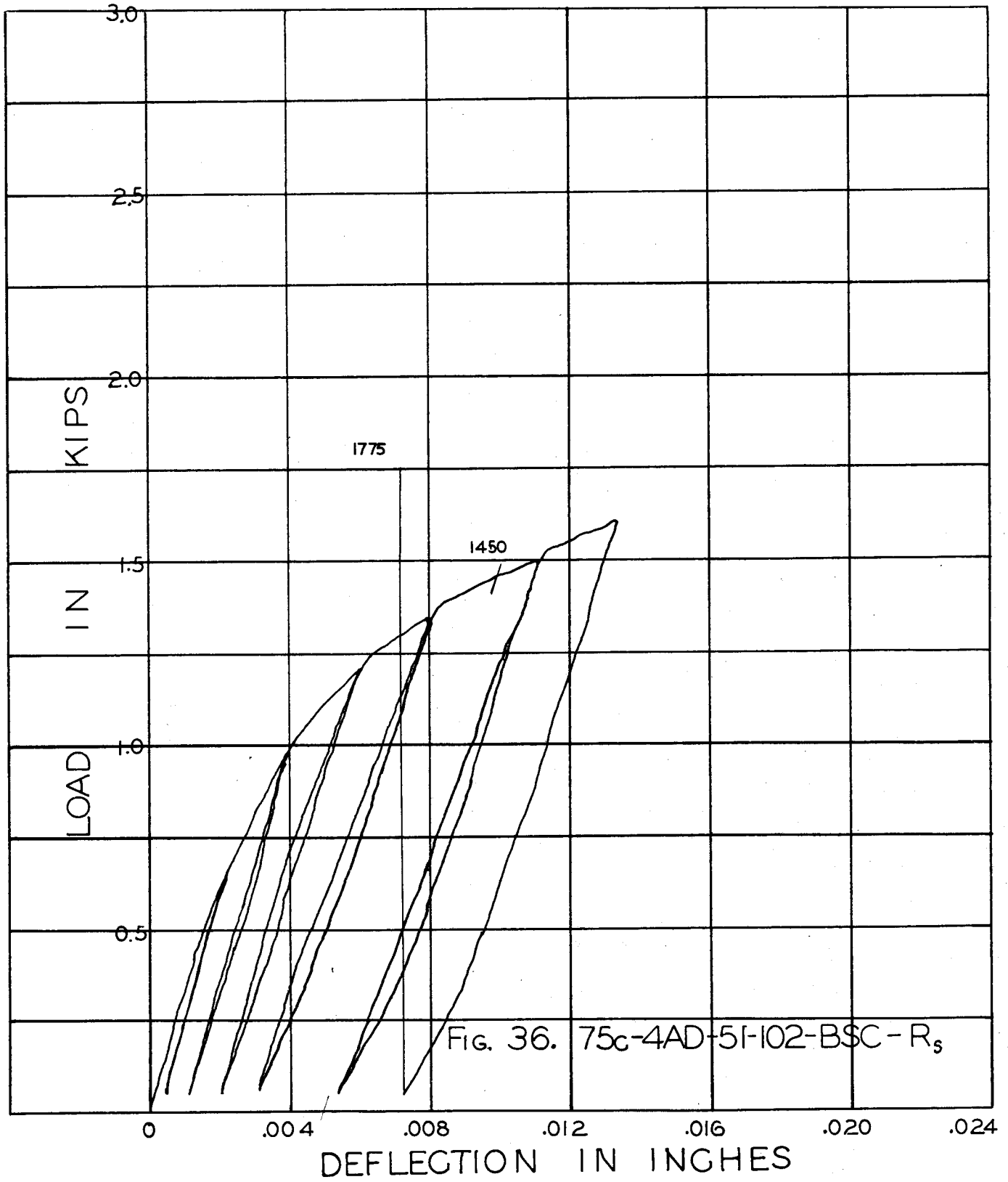


FIG. 34. 75c-4AD-40-102-BSC-R_s





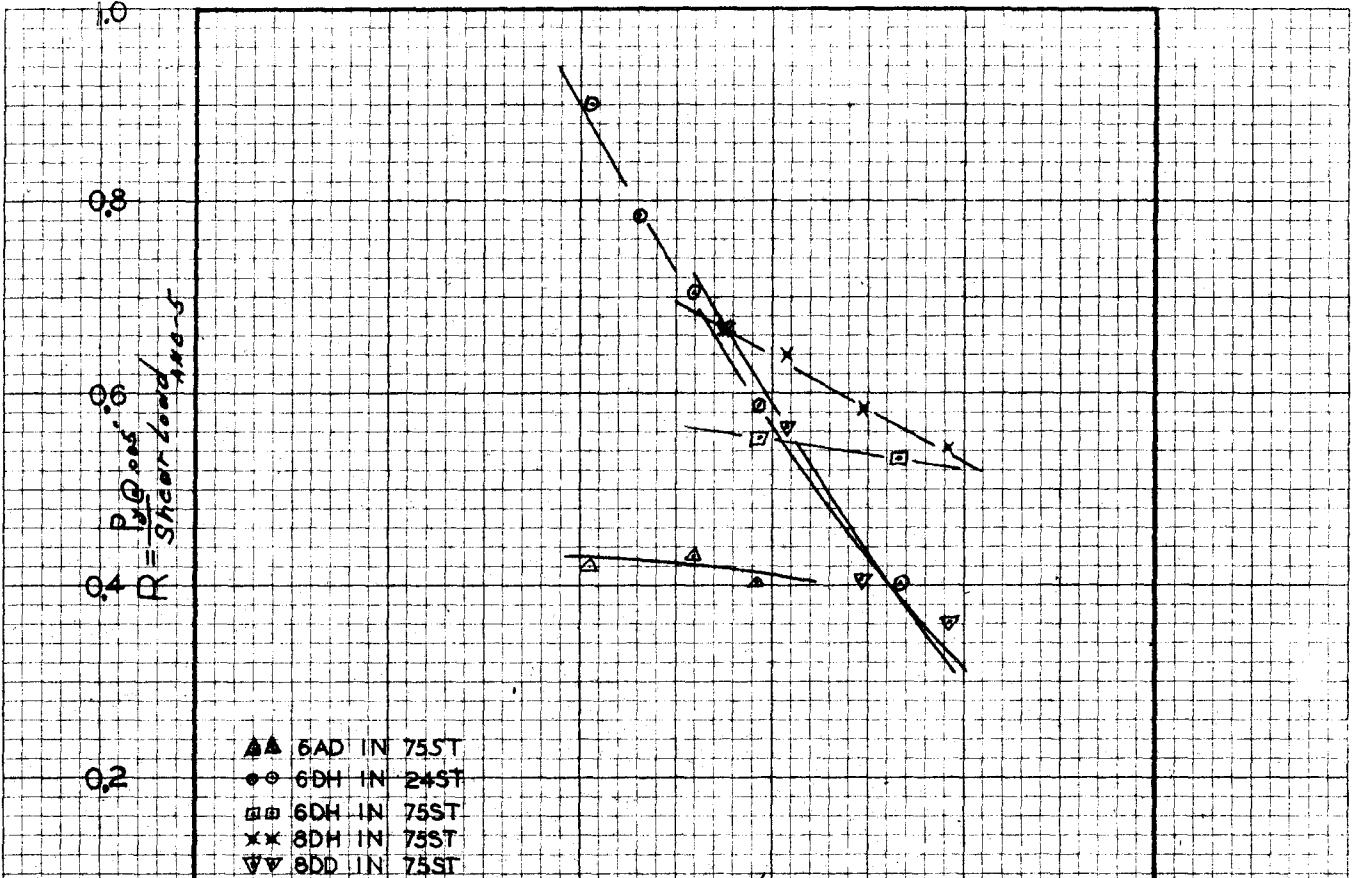


FIG-37. EFFECT OF $\frac{d}{2}$ ON $P_y @ 0.005$

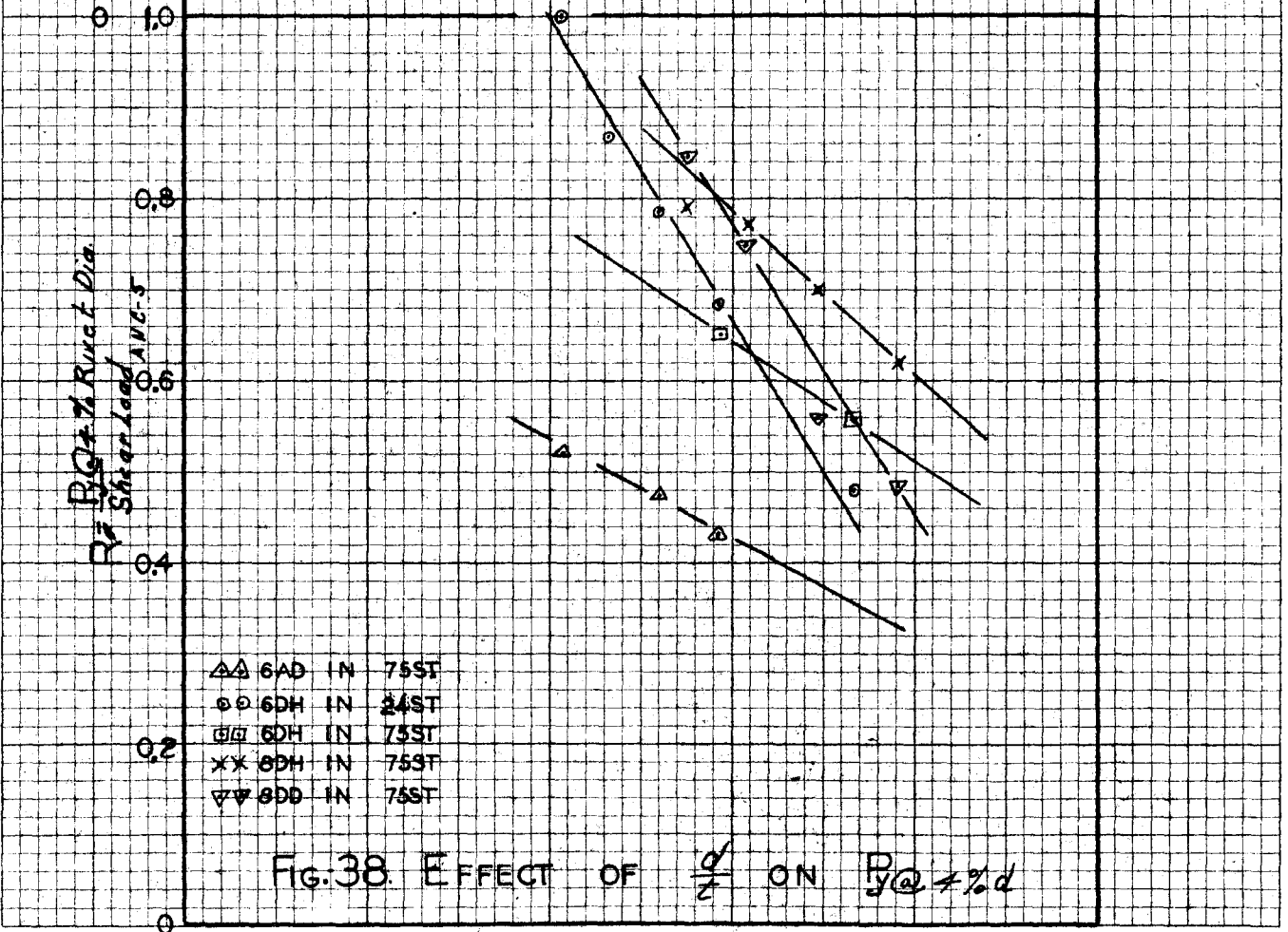


FIG-38. EFFECT OF $\frac{d}{2}$ ON $P_y @ 7\% d$