AN INVESTIGATION OF THE TRANSVERSE STRENGTH OF ANCHOR BOLTS IN CONCRETE

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Introduction

The determination of the magnitude of the vertical load which can safely be placed on a horizontal anchor bolt imbedded in a concrete wall is of considerable interest to designers of reinforced concrete structures. Some building codes include tables of values for various sizes of bolts which may not be exceeded, but other codes leave the question to the engineer.

So far as is known by the authors, no purely analytical solution of the problem has been made. Timoshenko in "Strength of Materials" vol. II, p. 12, develops an expression for deflection of a semi-infinite beam on an elastic foundation, bent by a transverse force P and a moment Mo applied at the end, which condition would give the equivalent of a load applied at a distance from the beginning of the elastic support. However, the expression as developed is based upon the value of a constant k, which is constant only for a particular set of conditions, and must be determined experimentally for each type of loading. This method therefore reduces to an experimental determination.

Experimental data itself appears to be lacking on this particular problem. The building codes mentioned appear to be the sole available source for safe load values. It was to provide some reliable experimental data, and to compare the values obtained experimentally with the Los Angeles building code requirements, that the study which is the subject of this report was undertaken.

Description of Test Specimens and Apparatus

On the basis of the commonly used sizes of anchor bolts, the embedments desired, and the test equipment available, the size of concrete test specimen was determined. Blocks 8" square and 12" in height were used. It was necessary that the size be kept down for ease in handling, and at the same time it was necessary to make the specimen as large as possible in order to represent more closely actual conditions. Results indicated that a larger block would have been desirable, as will be noted later in this report.

Forty-four specimens were poured, with twenty-two variations in embedment, size, etc. They included the following:

1. A series of 10 specimens for determining the effect of length of bolt embedment in the concrete, in which 5/8" bolts were used, the embedment varying from 1" to 6" by 1" increments.

2. A series of 12 specimens to obtain a relation between size of bolt and allowable load, using a constant embedment of 3", and bolt sizes from 3/8" to 1" in 1/8" increments.

3. A series of 10 specimens which followed code requirements as to embedment, bolts varying from 1/2" to 7/8" in diameter. The purpose of this series was to give a direct comparison with code recommendations.

4. Sixteen miscellaneous special conditions, including changes in concrete mix and special anchorages of anchor bolts.

The test apparatus used consisted of a framework made up of 1/2" plate and 12" channels, one side being left open for easy access. The fixture may be seen in the photograph on page 12. The framework served to hold the test block in a fixed position while the transverse (vertical) load was applied. Load application was through a heavy plate in which a hole had been drilled to accomodate the anchor bolt. With the framework enclosing the test specimen and securely clamping it in position, load was applied to the upward projecting strap by means of the upper plate of an Olsen universal testing machine. Deformations were obtained by inserting a deflectometer under the machine head and resting on the concrete block itself.

Testing Procedure

In order to approximate actual conditions as closely as was practical, a concrete mix was designed which was representative of the concrete usually found on a construction job. The combined aggregate grading curve is attached. Material was mixed in a transit-mixer while being hauled to the pouring site, where all of the blocks were poured at the same time.

After 24 hours, the concrete blocks were placed in a water bath where they were kept for a minimum of 28 days before testing. Results from tests of three compression specimens show at 28 days a unit compression strength of 3190 lbs.

The procedure in testing was to place one of the 8" x 8" x 12" specimens in a framework made up of two channels connected by a 1/2" plate on one side, and 12" long bolts on the other side. The set-up is shown in the photographs on page 12. The concrete block was secured in place by wedging small wood blocks against the face of the channel and taking up on the 12" bolts. Load was then applied through a column made up of a 1/2" x 3" plate fastened to the anchor bolt by a nut and washer, and projecting upward far enough to allow load to be applied by the descending head of the testing machine. The machine used was an Olsen 150,000 lb. universal machine.

To obtain deflections, a deflectometer which multiplies the reading by 10 times, was placed as directly as possible under the point of loading, to avoid effects of eccentricity. Load readings were obtained by continuously balancing the weighing beam as the load was applied. For most of the tests the 30,000# rider was used to obtain maximum accuracy. Load was applied gradually, at the lowest speed of the machine for the first part of each test. Readings were taken usually at 100 lb. increments of load to 1000 lbs., then in 200 lb. increments to 5000#, and for the last portion of the tests readings were taken according to deflection, until a deflection of 1/2" was reached, at which time the deflectometer was removed and the test carried to failure.

Analysis of Results

The load-deflection curves for each of the 44 test specimens will be found in the Appendix, Charts 1 to 24. An inspection of these curves shows a fairly good agreement between the pairs of tests for each setup, considering the non-homogeneous nature of the concrete. From these curves, the following general observations may be made.

a. Effect of Length of Embedment of Bolt

In this series of tests, a 5/8" bolt was used, with an embedment varying in one inch steps from 1 inch to 6 inches. The curves for these tests are shown on charts 1 to 5 inclusive. A curve showing the variation of maximum load and also load necessary to produce a deflection of the bolt at the face of the concrete of 1/8" has been prepared on chart 23. As indicated by the curve, the strength of the bolt increases with embedment up to about 3-4 inches and then drops off. It would therefore appear that the optimum embedment for a 5/8" bolt would be about 3-4 inches or about 6 diameters. It should be pointed out, however, that the decrease in strength for the longer embedments was due in all probability to the relatively small size of the test blocks. For the longer embedments and larger bolt sizes, the ultimate failure was by a horizontal tension crack through the entire block.

b. Effect of Bolt Diameter with Constant Embedment

In this series of tests, six different sizes of bolts were tested using the same embedment of 3 inches. The results of these tests are shown on charts 3 and 6 to 10 inclusive.

These curves indicate a general increase in strength as the bolt diameter is increased. On the curves, chart 24, are shown the variation in the load producing a deflection of 1/8" and the ultimate load as a function of the bolt size. The ultimate load curve clearly brings out the insufficient size of the concrete test block. In all bolt sizes above 5/8", the ultimate load remains constant at about 12000#, indicating clearly that for bolts above this size for this particular embedment of 3", the ultimate failure is due to a concrete <u>tension</u> failure and not a bolt failure. See photographs, pages 12 and 16.

c. Effect of Different Types of Anchorage of Bolts

In this series of tests an attempt was made to obtain a qualitative comparison of the effects of different types of anchorages. In all of the standard specimens, a bolt with a square head and a standard plate washer were used for anchorage. In this special series, the following types of anchorage are compared:

(a) Bolt with standard washer

(b) Bolt without washer

(c) Bolt with 2" x 2" plate washer

(d) Bolt with 2" bend

The results of these tests are shown on charts 2, 11, 12 and 13. In each case a 5/8" bolt with a 2" embedment was used. The curves seem to indicate that the standard anchorage is most favorable as regards both deflection and ultimate strength. The omission of the washer shows a flattening of the load-deflection curve, indicating a slipping of the bolt. The use of the 2" x 2" plate washer instead of the small round washer shows a sudden failure as the concrete in front of the washer is broken out. This failure is shown in the photograph on page 15. The bent bolt seems to be about as effective as the standard anchorage, except for a slightly lower ultimate strength.

A test was also made on a headless 5/8" bolt with a 4 inch embedment. The curve for this test, chart 14, indicates definitely a slippage of the bolt through the concrete.

d. <u>Effect of Special Conditions</u>

Two special tests were made to determine the effect of a bearing plate and a nut on the face of the concrete. A 5/8" bolt with a $4\frac{1}{2}$" embedment was used in each case. In one case, a 3" x 3" x 3/8" plate was used. The resulting load-deflection curve shown on chart 15, shows a definite increase in ultimate strength and also in the slope of the curve. In the other case, a nut was placed on the inside of the form. The curve for this condition, chart 16, is probably the most favorable from the standpoint of deflection and ultimate strength of any of the tests made. The use of an extra nut on an anchor bolt would thus seem to be a very useful and easy method not only for increasing the transverse strength of the bolt, but also as an aid in holding the bolt in place in the forms. Photographs showing the results of these two tests may be found on pages 14 and 16.

e. Effect of Concrete Mix

Two extra series of tests were made in order to determine the effect of a variable concrete mix. A 5/8" bolt with a 4" embedment was used. The grading curve for the aggregate is shown on page 11. A comparison of the resulting curves, charts 17 and 18, with the standard specimen, chart 4, shows an increase in strength about in proportion to the theoretical concrete strength as determined by the water-cement ratio.

f. Comparison with Code Values

The following table is taken from the 1943 Los Angeles Building Code and gives the minimum embedment and allowable shear load on anchor bolts in concrete:

Bolt Dia.	1/2"	5/8"	3/4"	7/8"	1"	1 1/8"
Embedment	4"	4"	5"	6"	7"	8"
Shear	750 lb	1000 lb	1500 lb	2000 lb	2500 lb	3000 lb

A series of tests was made using the same embedments as above. The curves for these tests are shown in charts 4, and 19 to 22.

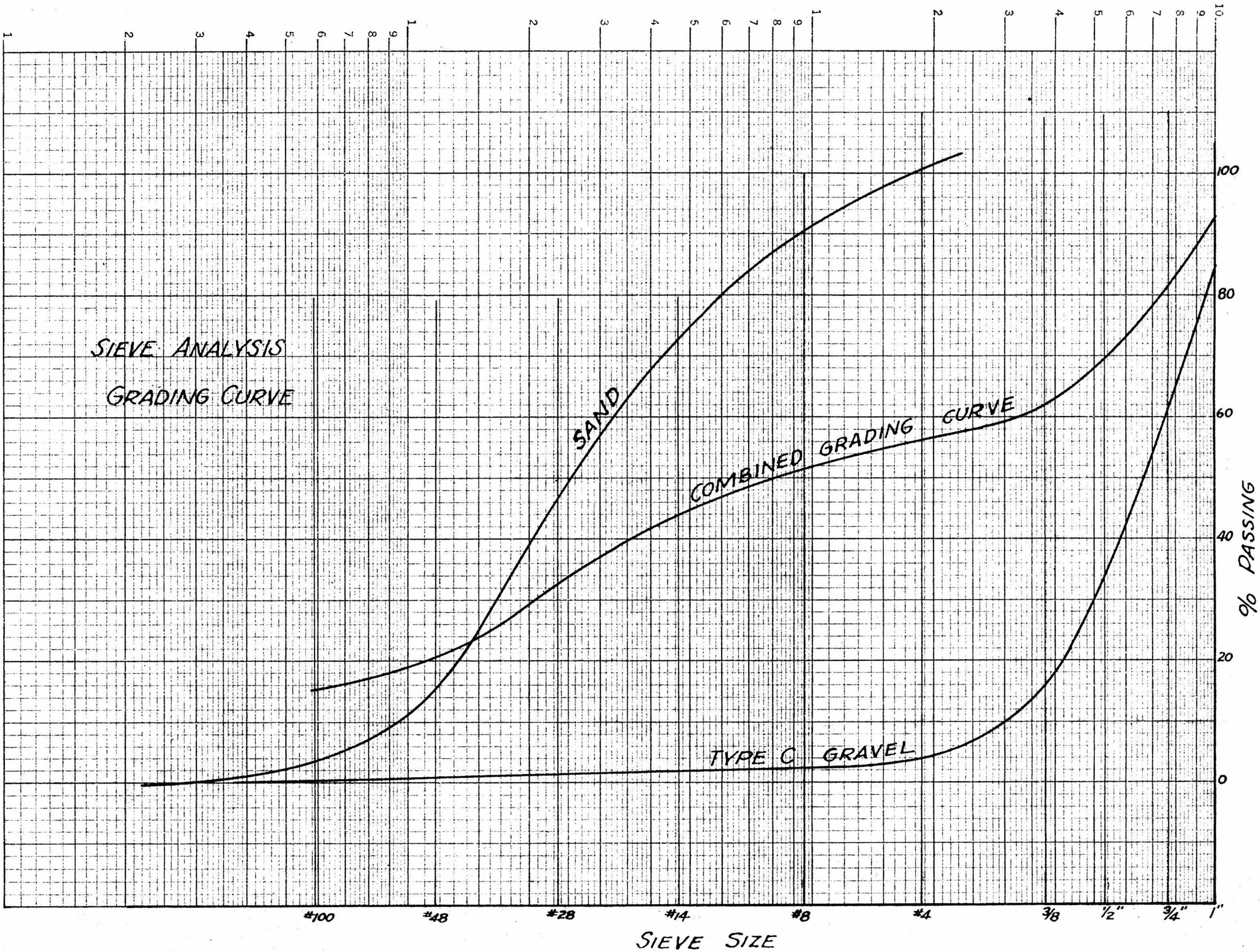
The following table is based upon the results of these tests:

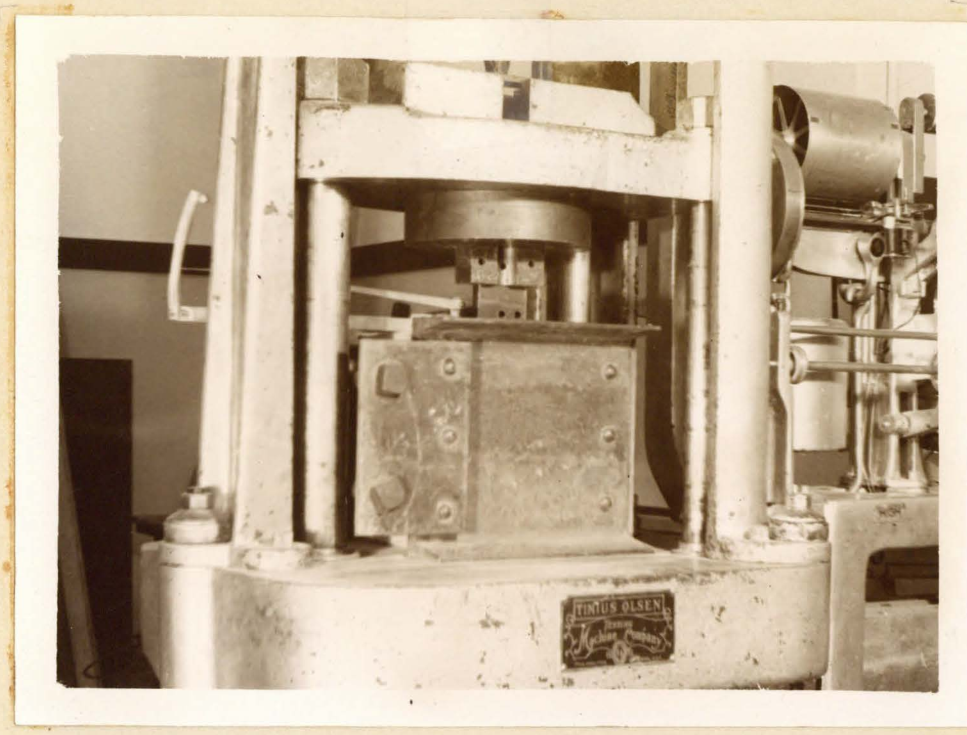
Bolt Dia.	1/2"	5/8"	3/4"	7/8"	1"
Load producing 1/8" deflection	4000#	6500#	6500#	6000#	6000#
Ultimate load	7000#	12000#	12000#	10,000#	14000#

As before noted, the limited size of the concrete test blocks invalidates the results of the tests for bolts above 5/8" to 3/4" in diameter. However, a comparison of the two tables above would seem to justify the Los Angeles Code values as being quite conservative. On the basis of the deflection curves obtained, the loadings allowed by the Code would correspond roughly to a deflection of about 1/32 of an inch. Based on the ultimate strength values, the present Code values would represent a factor of safety of about 8.

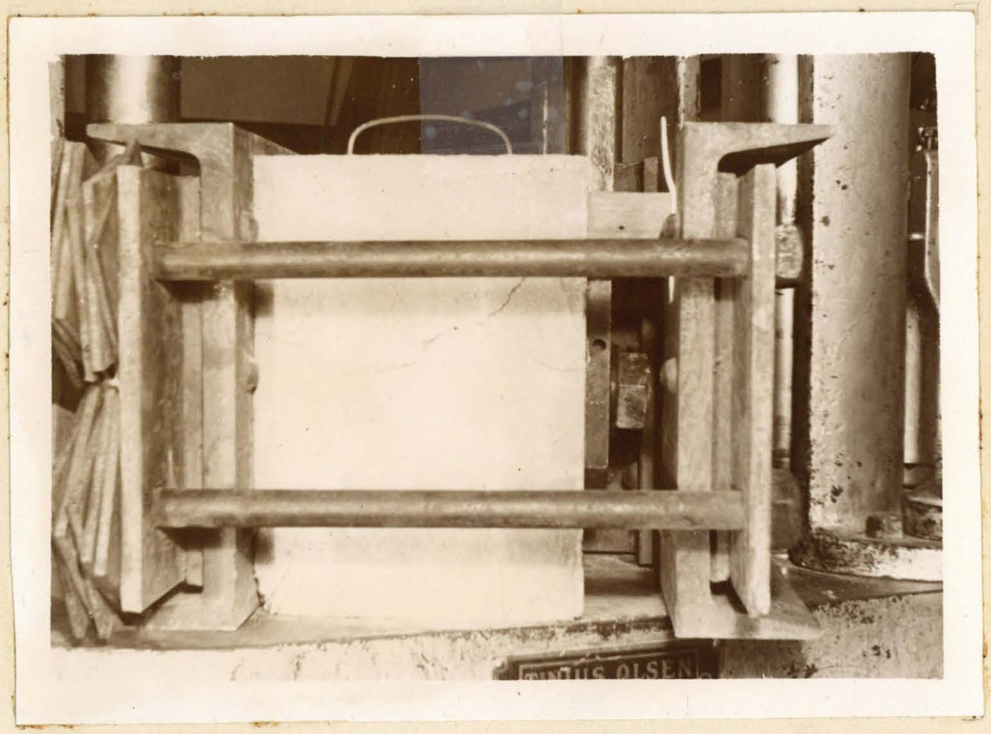
Conclusions

The results obtained from this series of tests indicate that in an actual concrete wall the shear strength of the bolt itself could be attained without difficulty, and with a comparatively short embedment. Present code values appear to be overly conservative both in required embedment and allowable load.


SIEVE ANALYSIS
GRADING CURVE
SAND
COMBINED GRADING CURVE
TYPE C GRAVEL
100
80
60
40
20
0
% PASSING
#100
#48
#28
#14
#8
#4
3/8
1/2"
3/4"
1"
SIEVE SIZE



TEST SET-UP (FRONT VIEW)

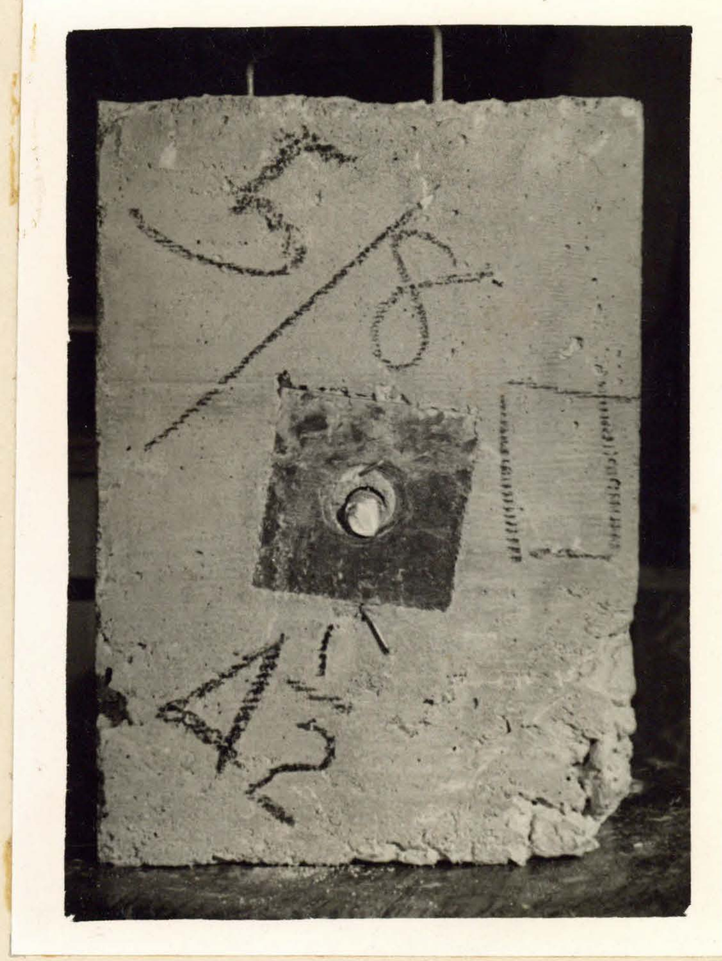


TEST SET-UP SIDE VIEW

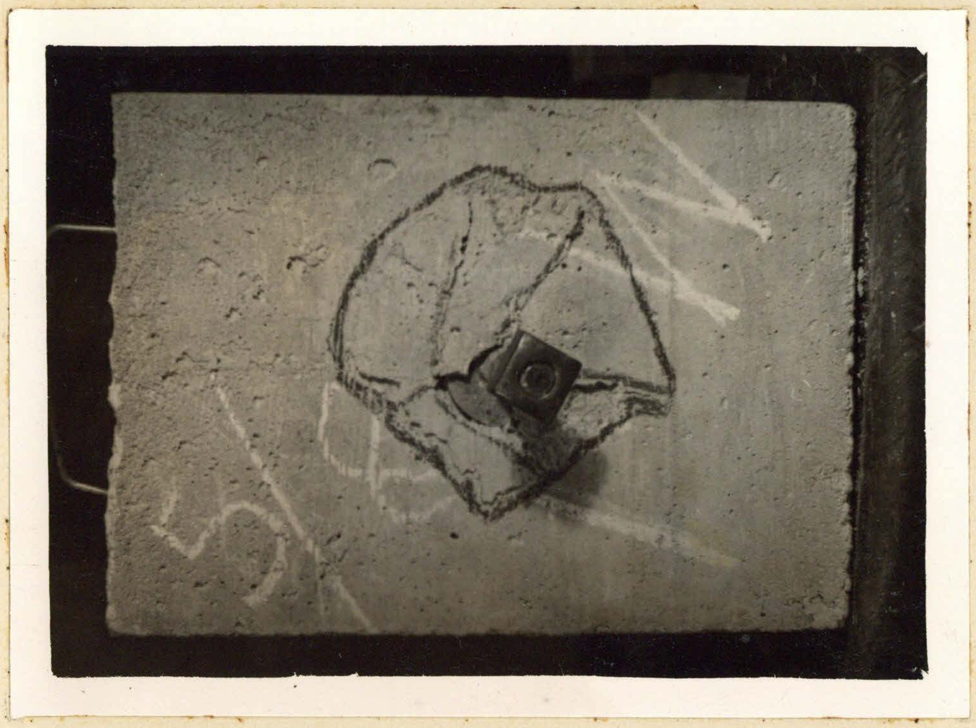
LOADING PLATE IN PLACE

COMPRESSION SPECIMEN

TYPICAL FAILURE PATTERN



BOLT WITH FACE PLATE

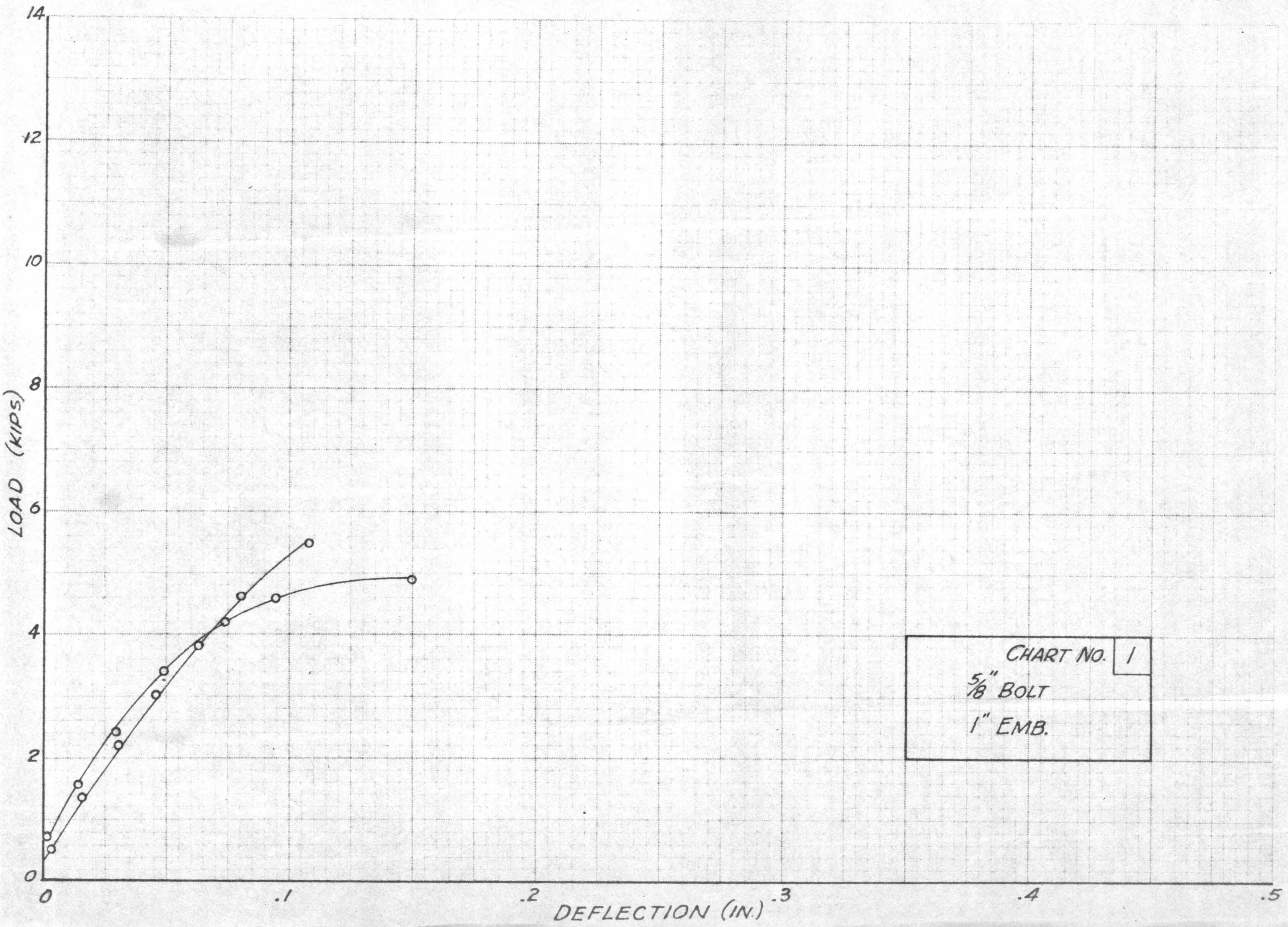


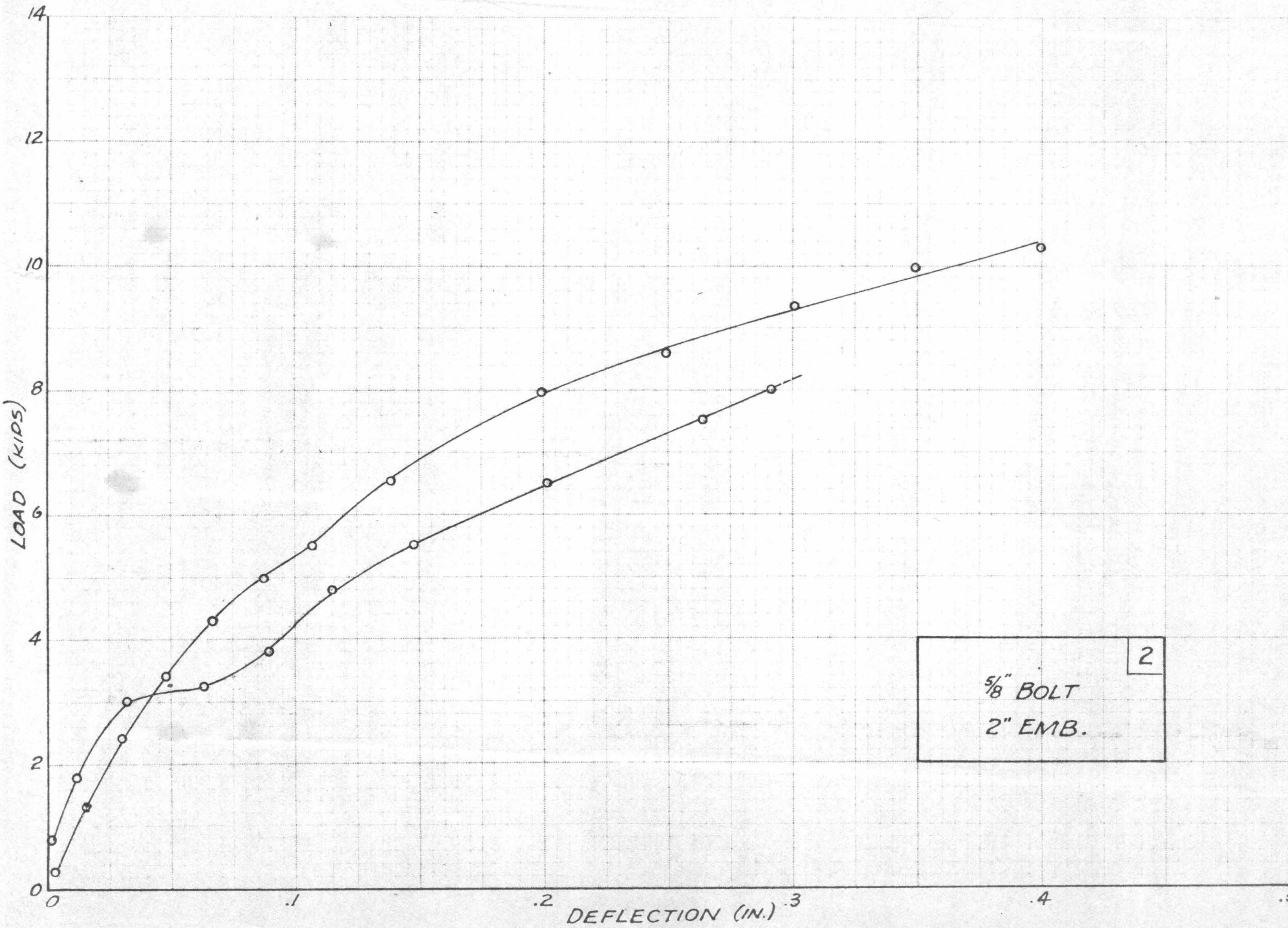
FAILURE WITH 1" EMBEDMENT

TYPICAL SMALL BOLT FAILURE

EFFECT OF NUT ON FACE

APPENDIX


14
12
10
8
6
4
2
0
LOAD (KIPS)
0
.1
.2
.3
.4
.5
DEFLECTION (IN.)
CHART NO. 1
5/8" BOLT
1" EMB.



14
12
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4
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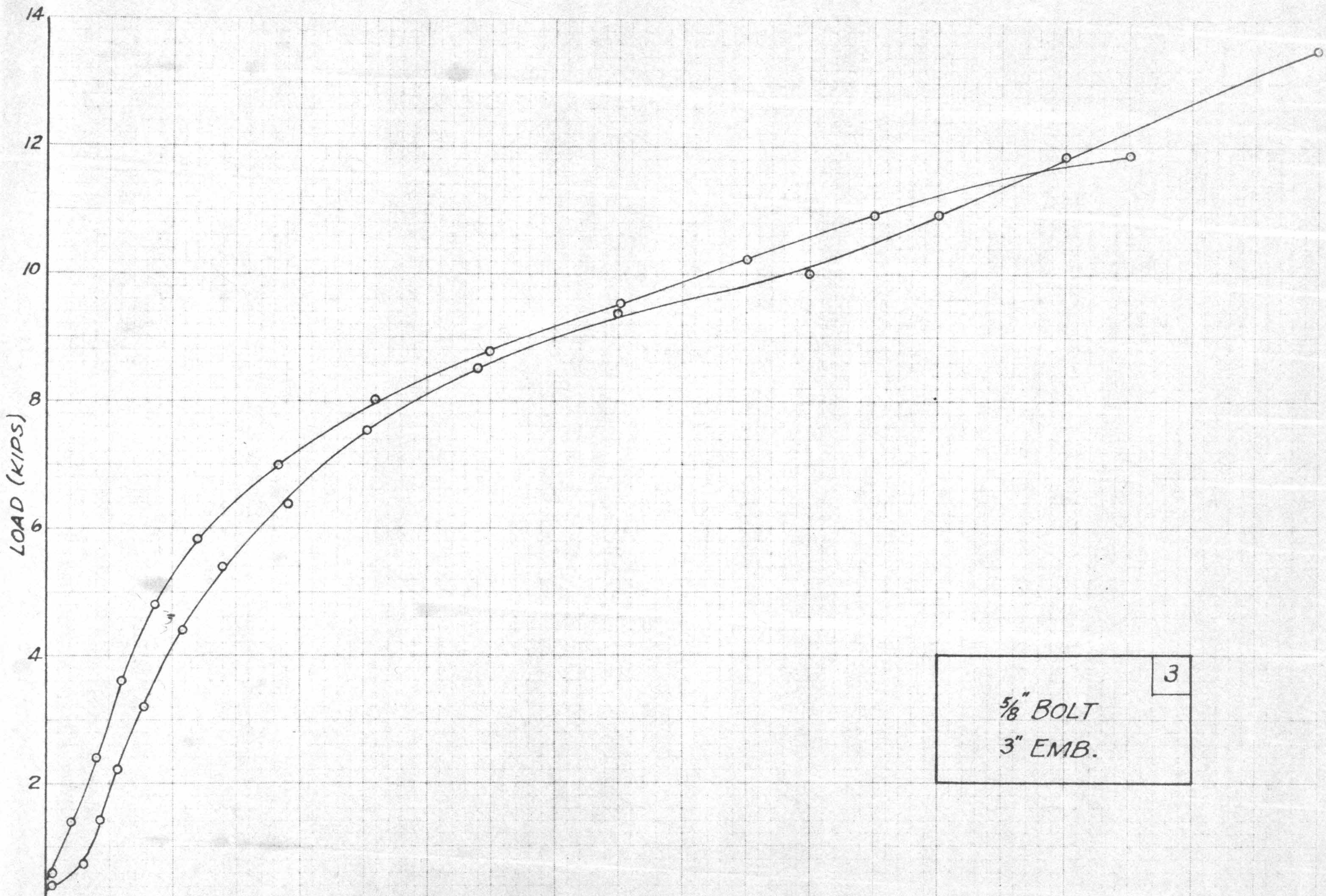
.4
.5
DEFLECTION (IN.)
2
5/8" BOLT
2" EMB.



14
12
10
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6
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2
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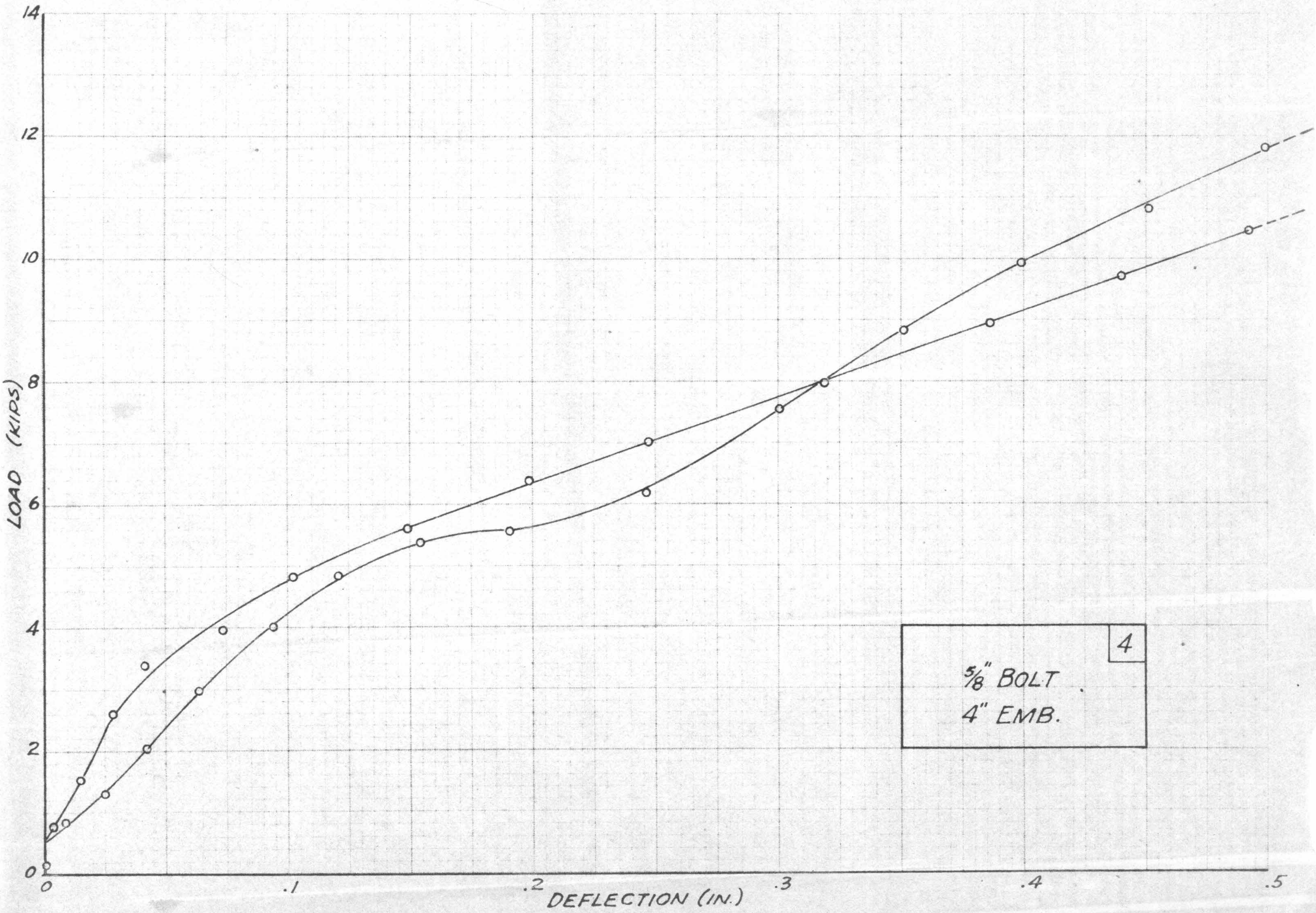
.5
DEFLECTION (IN.)
3
5/8" BOLT
3" EMB.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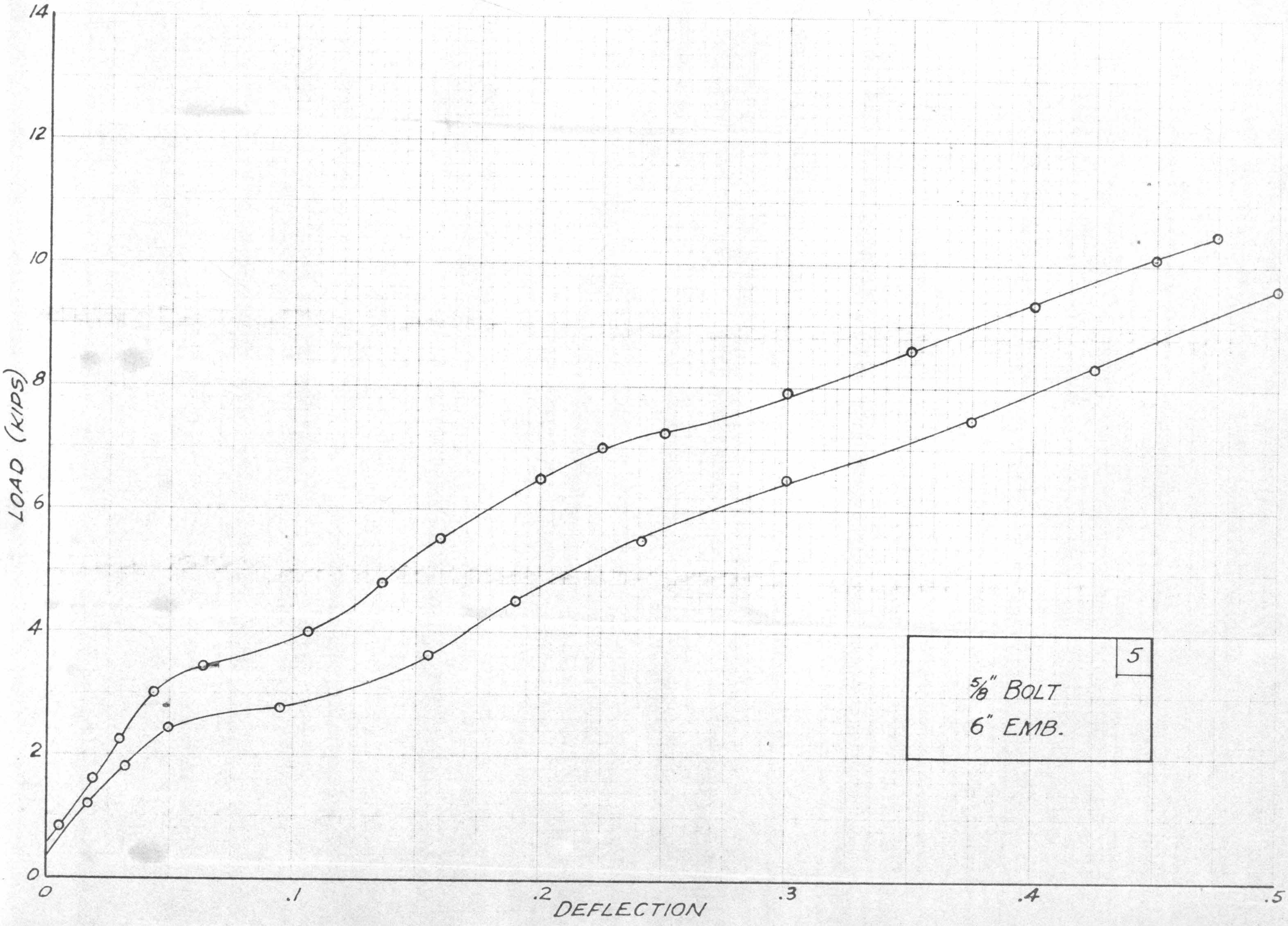
4
5/8" BOLT
4" EMB.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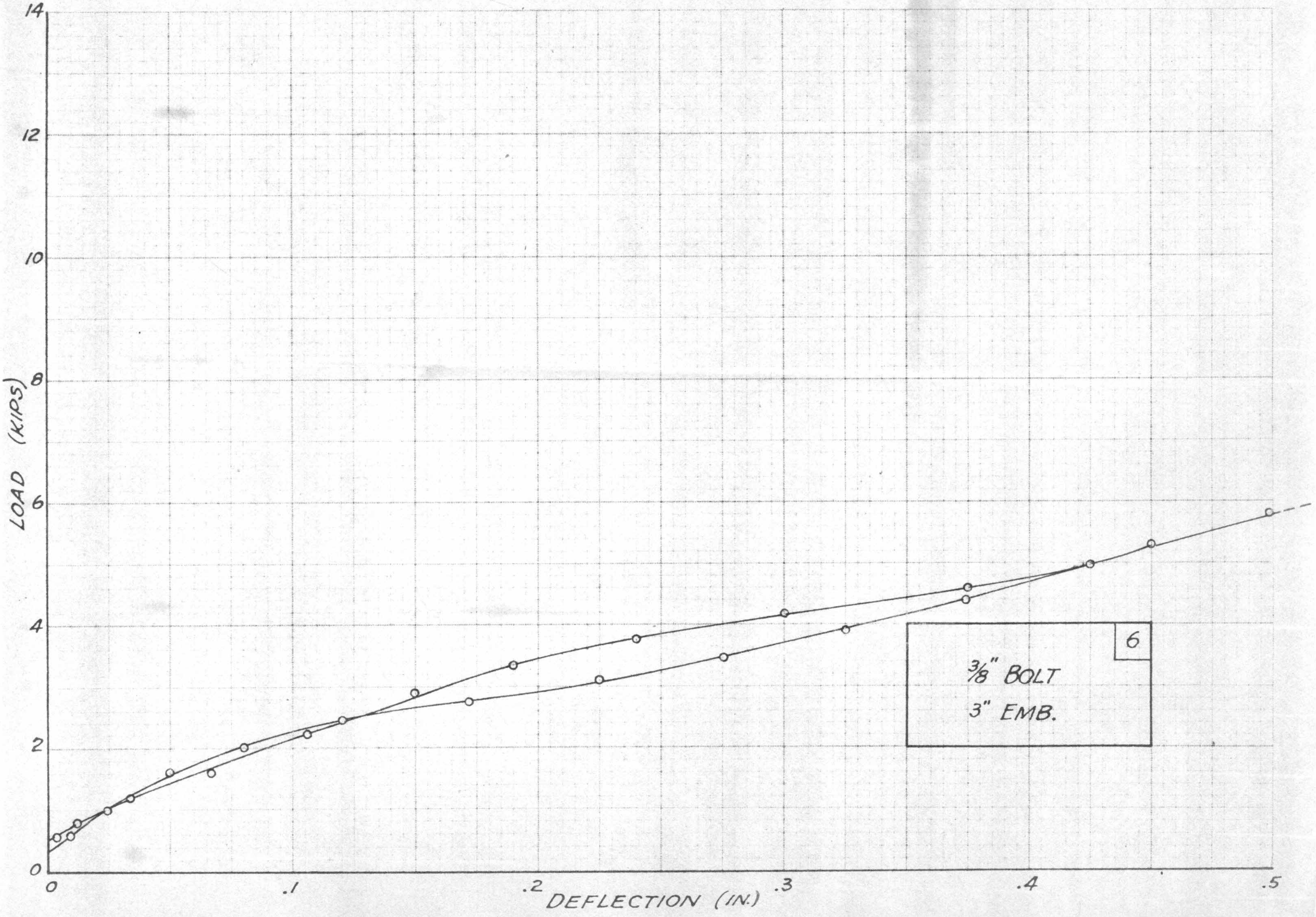
.5
DEFLECTION
5
5/8" BOLT
6" EMB.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6
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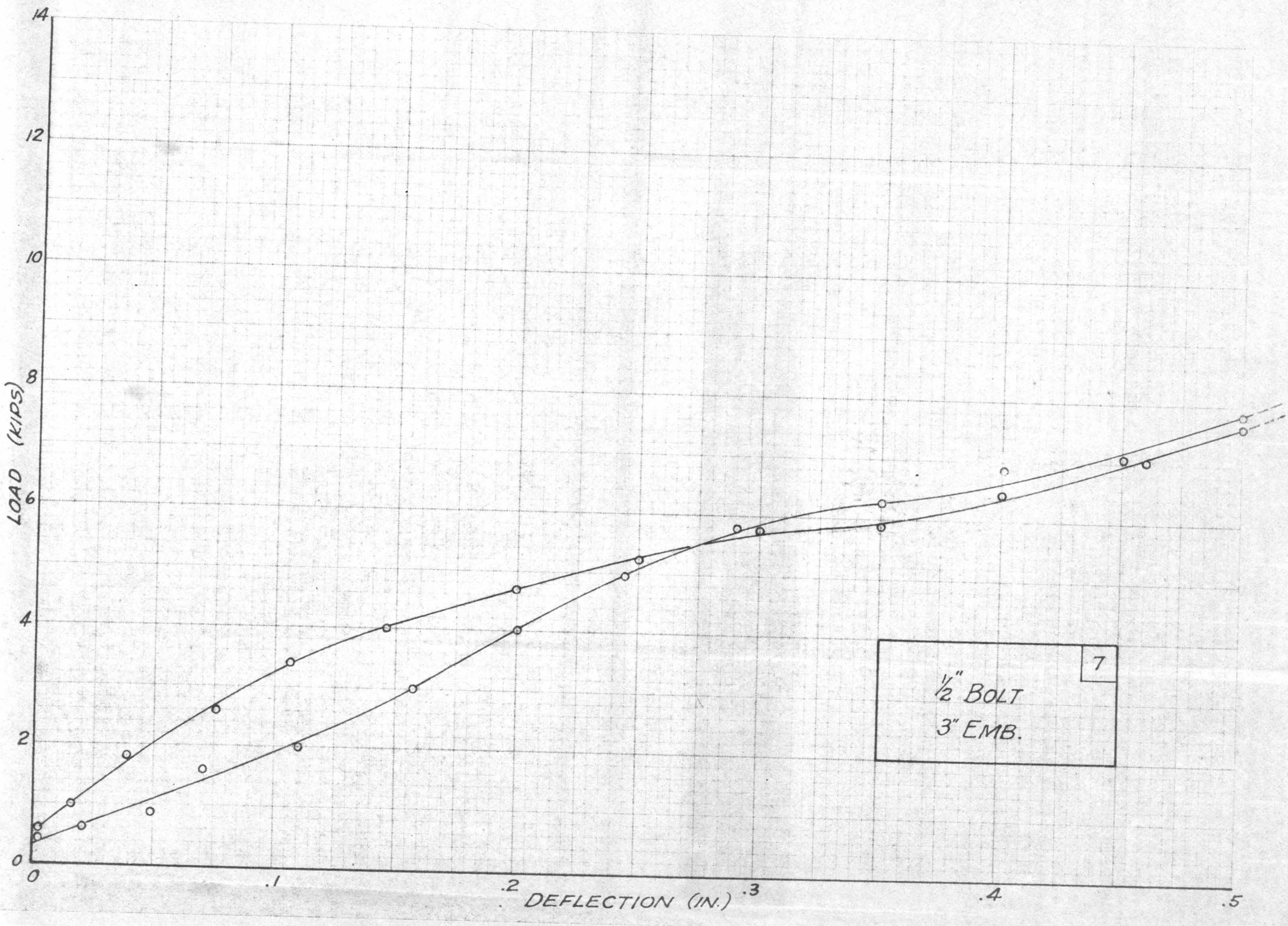
.5
DEFLECTION (IN.)
6
3/8" BOLT
3" EMB.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6
4
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LOAD (KIPS)
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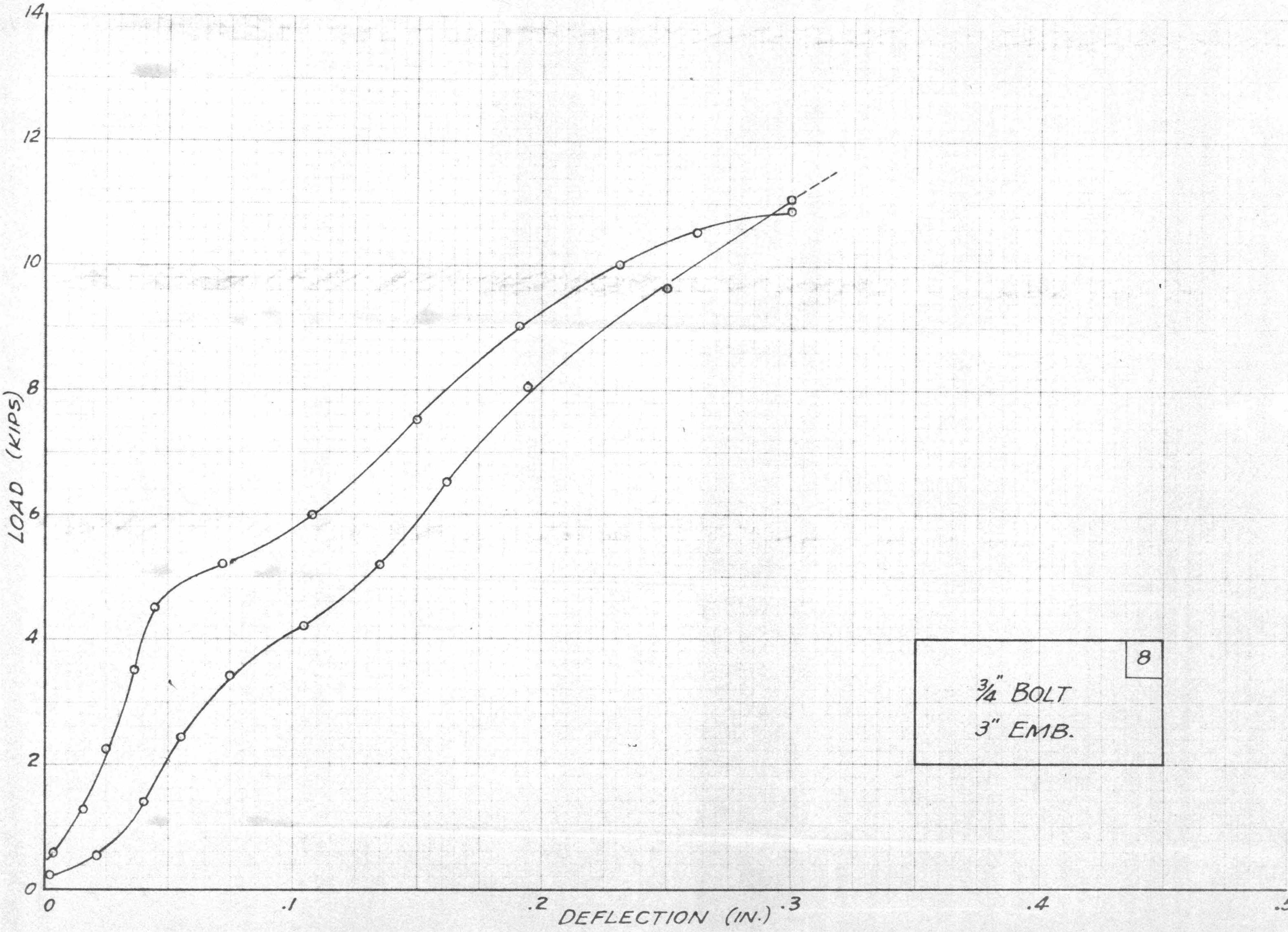
.3
.4
.5
DEFLECTION (IN.)
7
1/2" BOLT
3" EMB.


LOAD (KIPS)
0
2
4
6
8
10
12
14
DEFLECTION (IN.)
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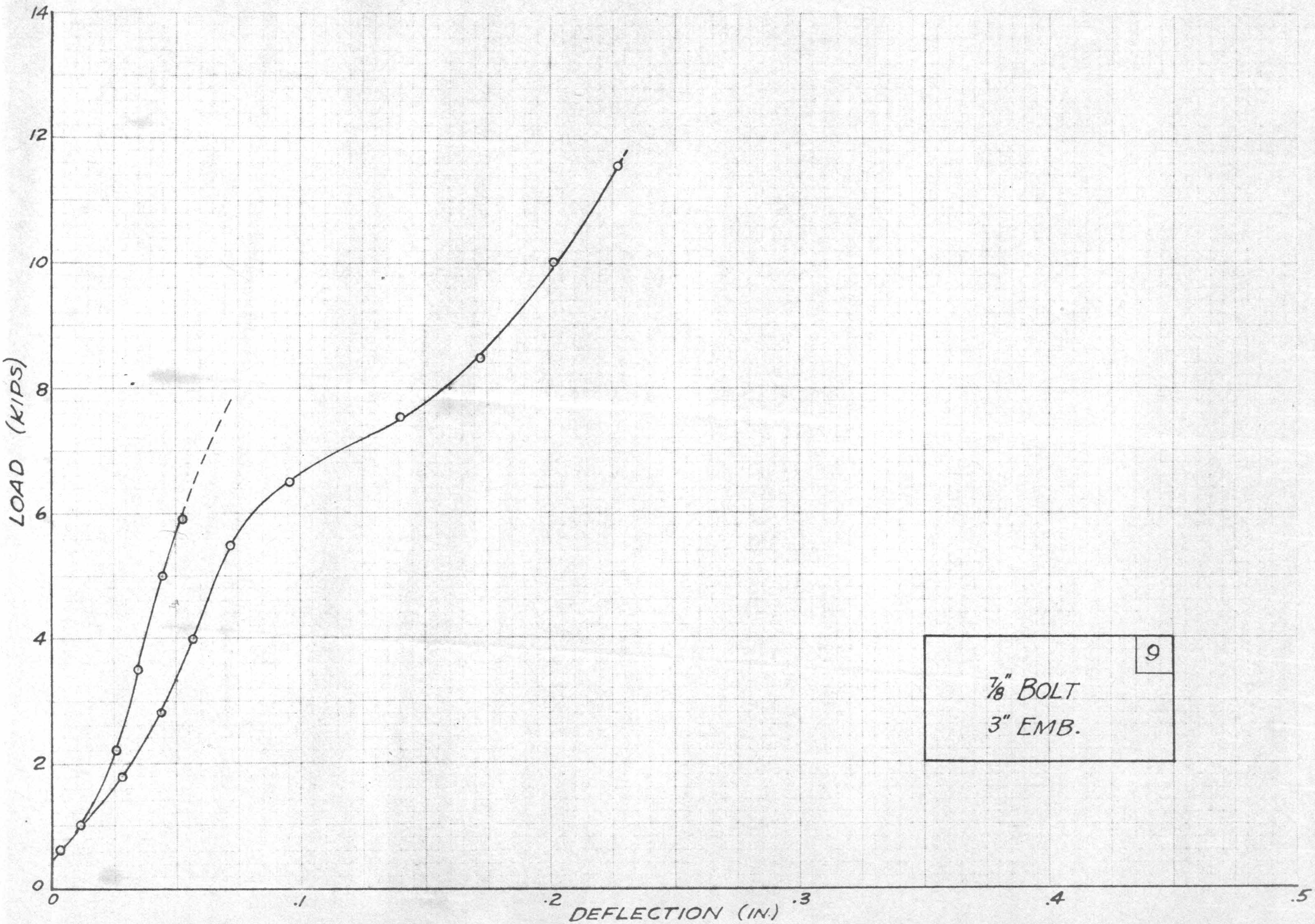
.1
.2
.3
.4
.5
8
3/4" BOLT
3" EMB.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DEFLECTION (IN.)
0
2
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12
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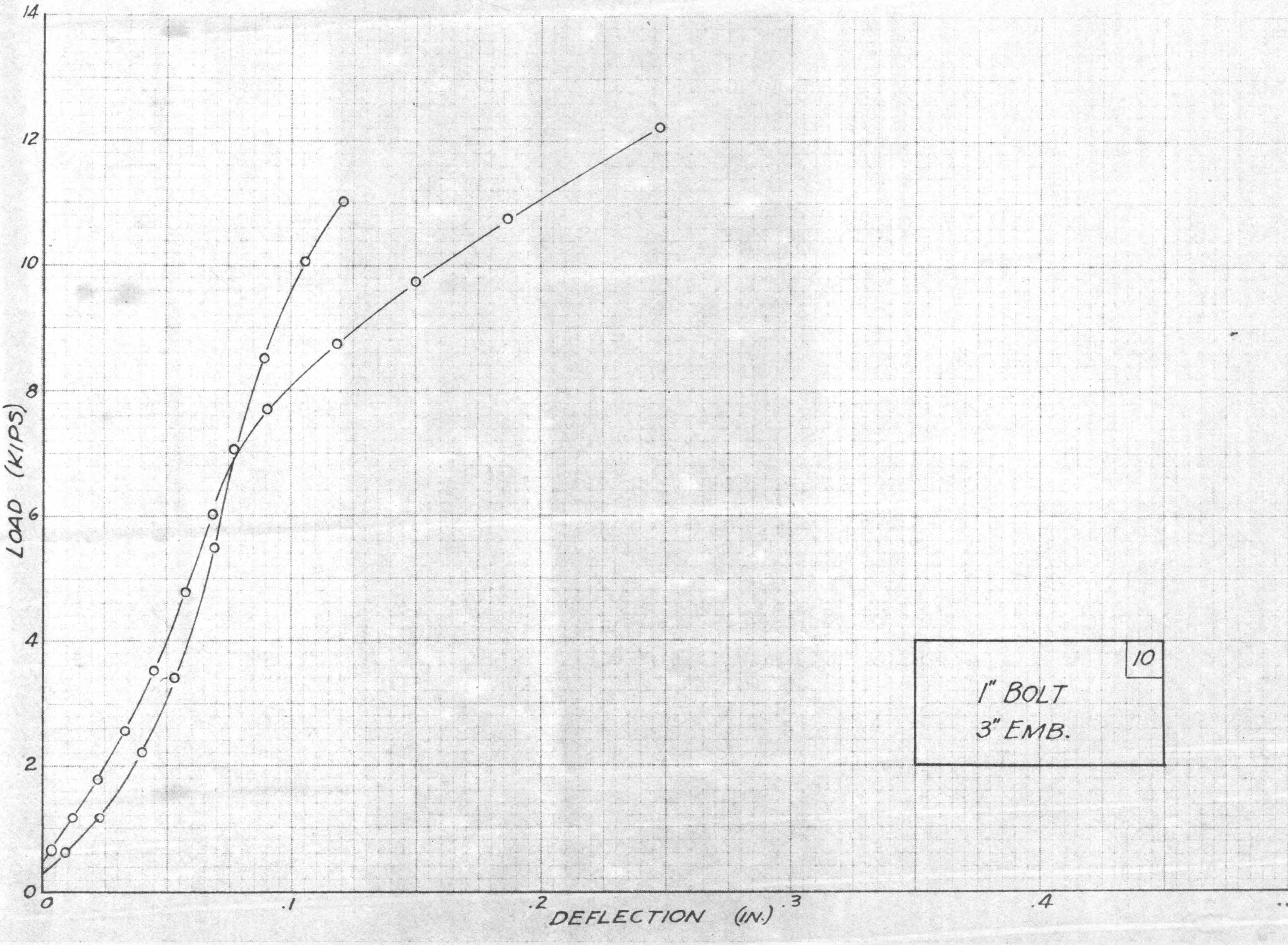
9
7/8" BOLT
3" EMB.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2
4
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DEFLECTION (IN.)
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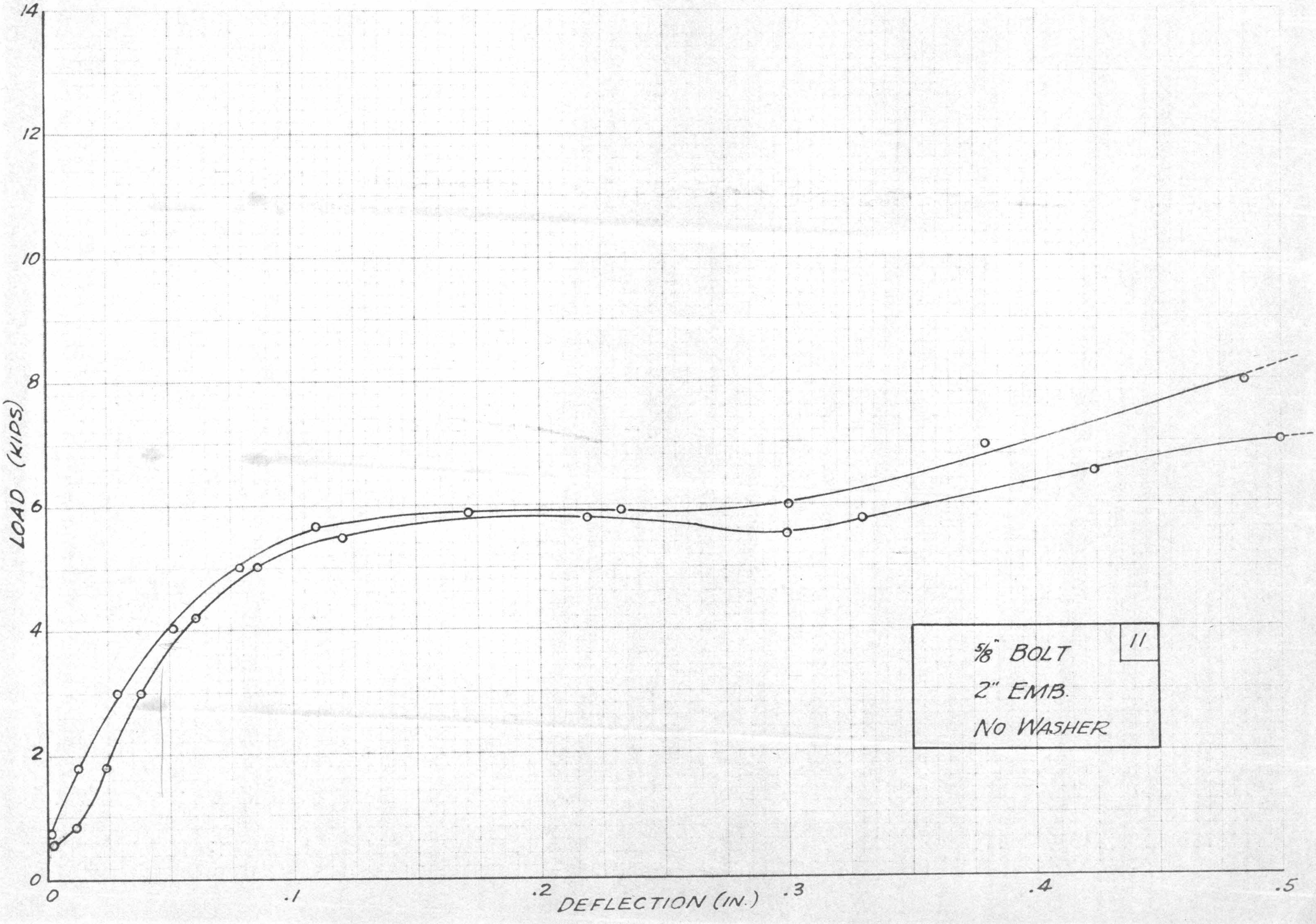
.4
.5
10
1" BOLT
3" EMB.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2
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.3
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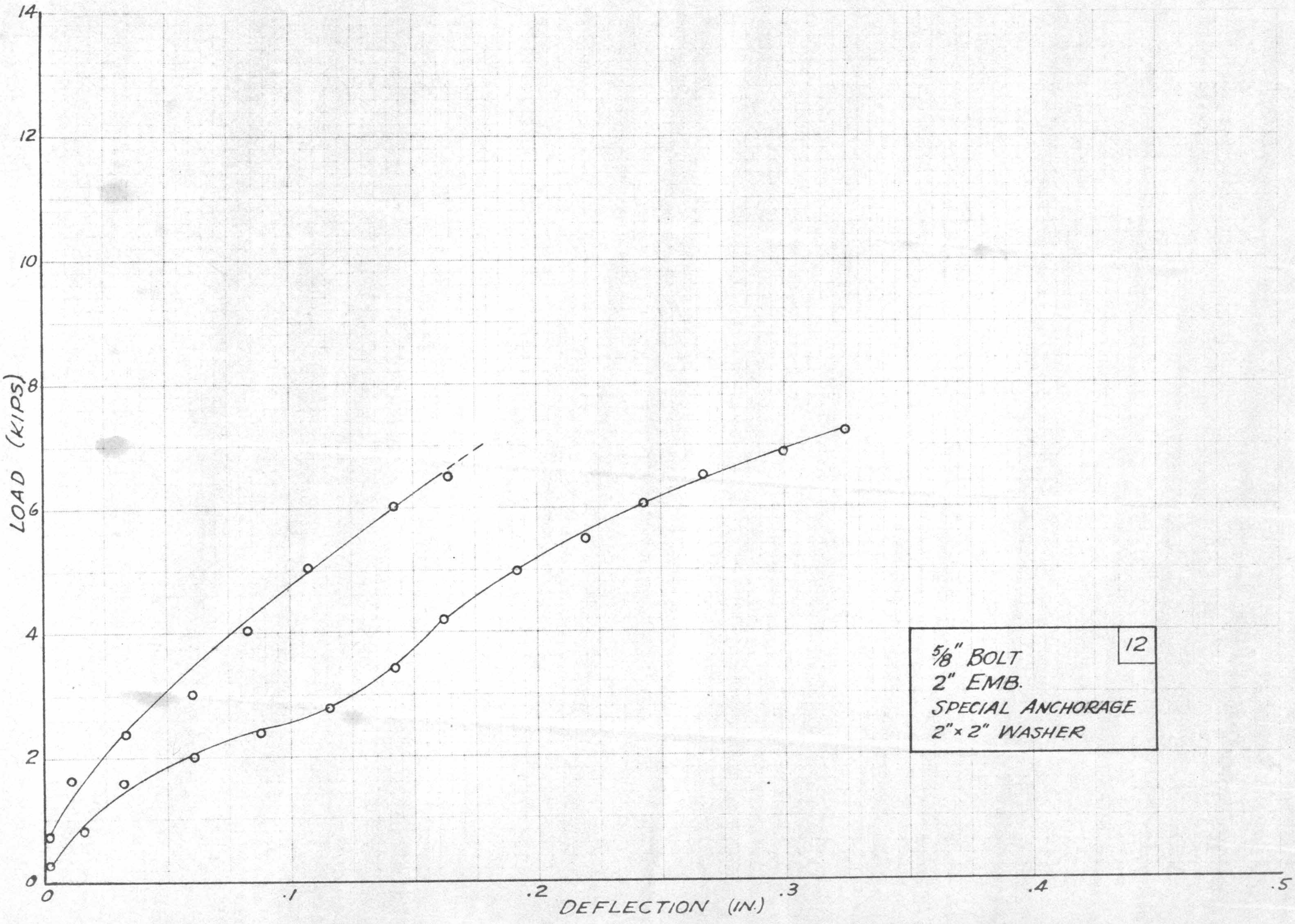
.5
DEFLECTION (IN.)
5/8" BOLT
2" EMB.
NO WASHER
11



14
12
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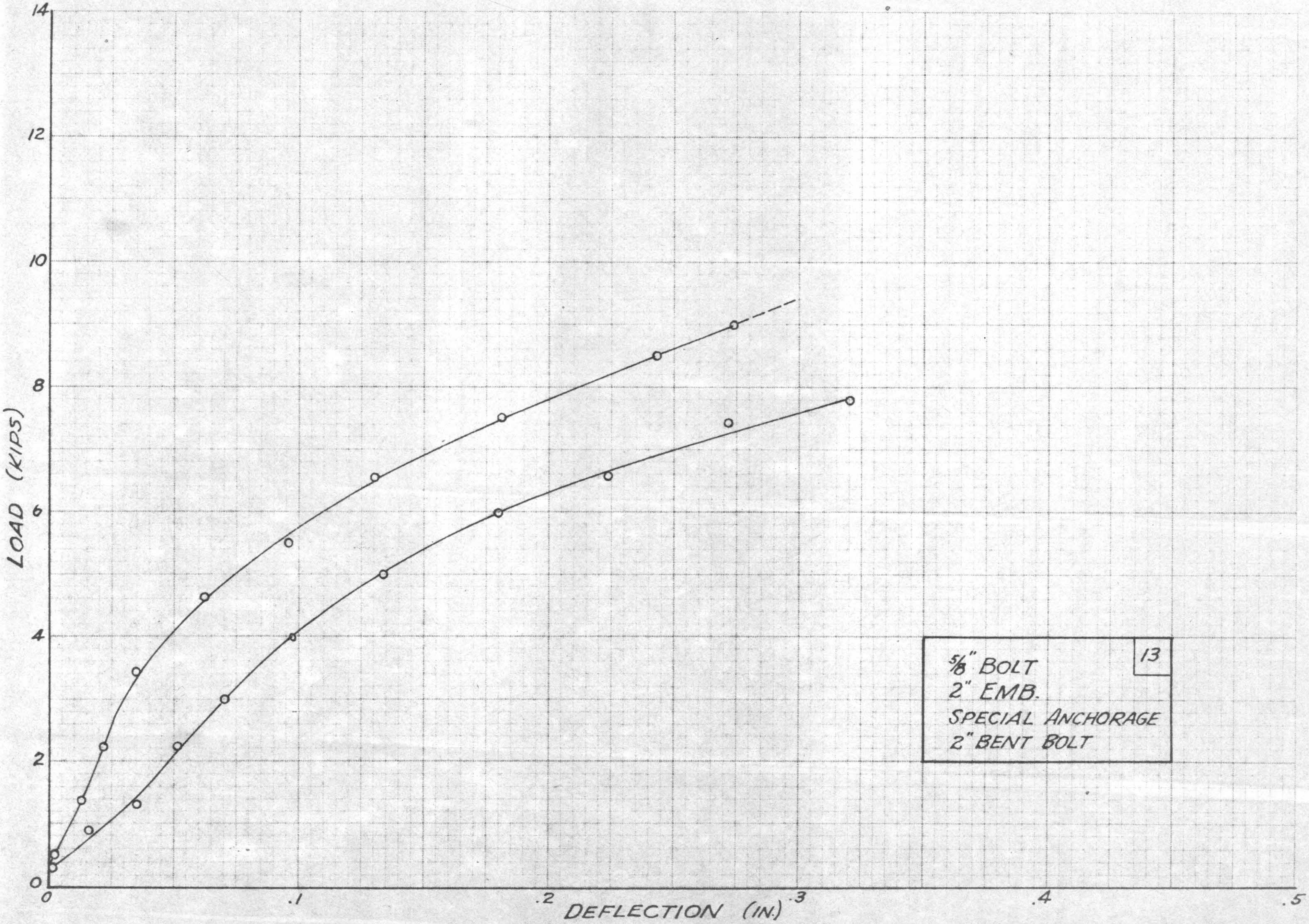
8
6
4
2
0
LOAD (KIPS)
0
.1
.2
.3
.4
.5
DEFLECTION (IN.)
12
5/8" BOLT
2" EMB.
SPECIAL ANCHORAGE
2" × 2" WASHER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LOAD (KIPS)
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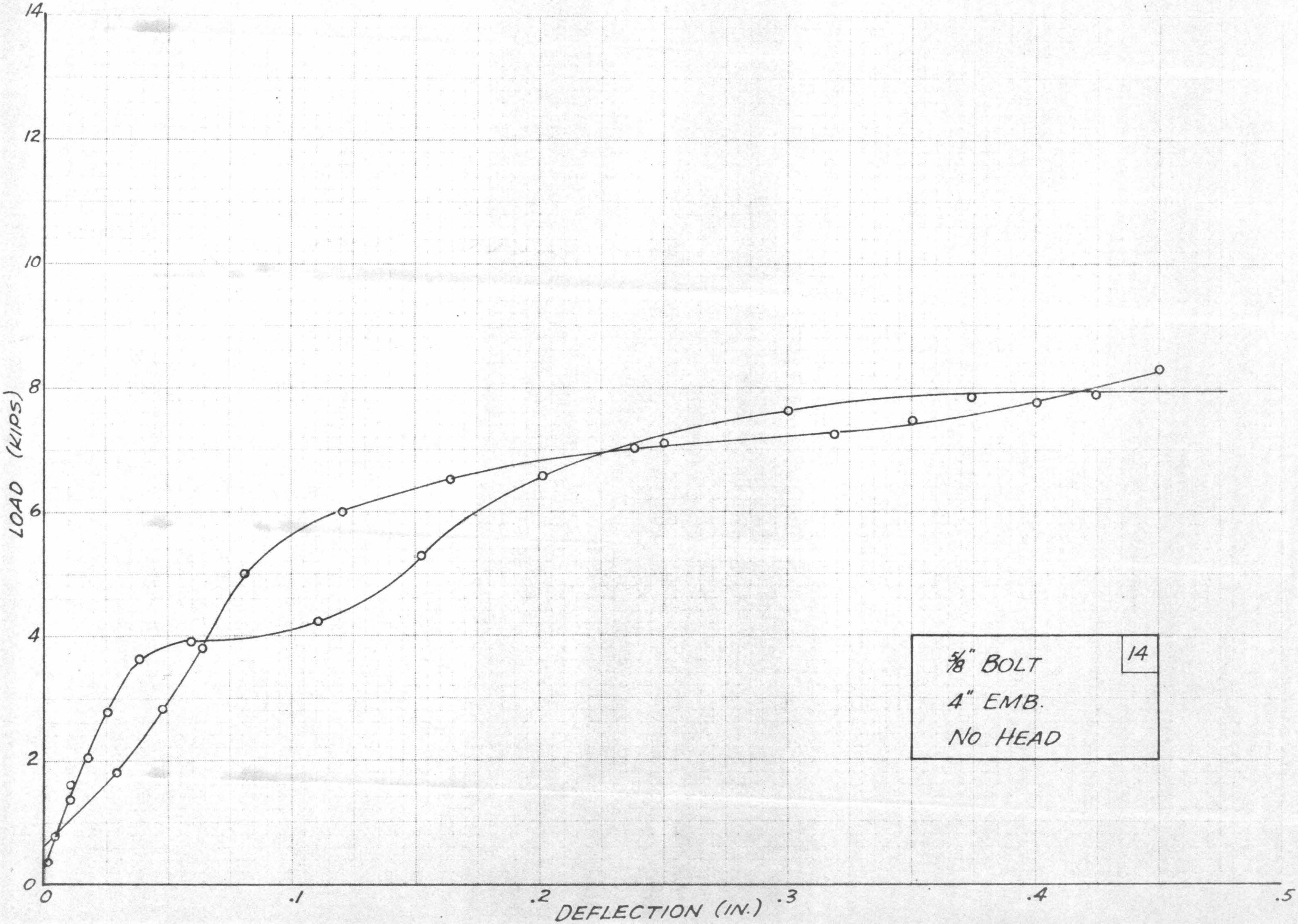
.5
DEFLECTION (IN.)
13
5/8" BOLT
2" EMB.
SPECIAL ANCHORAGE
2" BENT BOLT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6
4
2
0
LOAD (KIPS)
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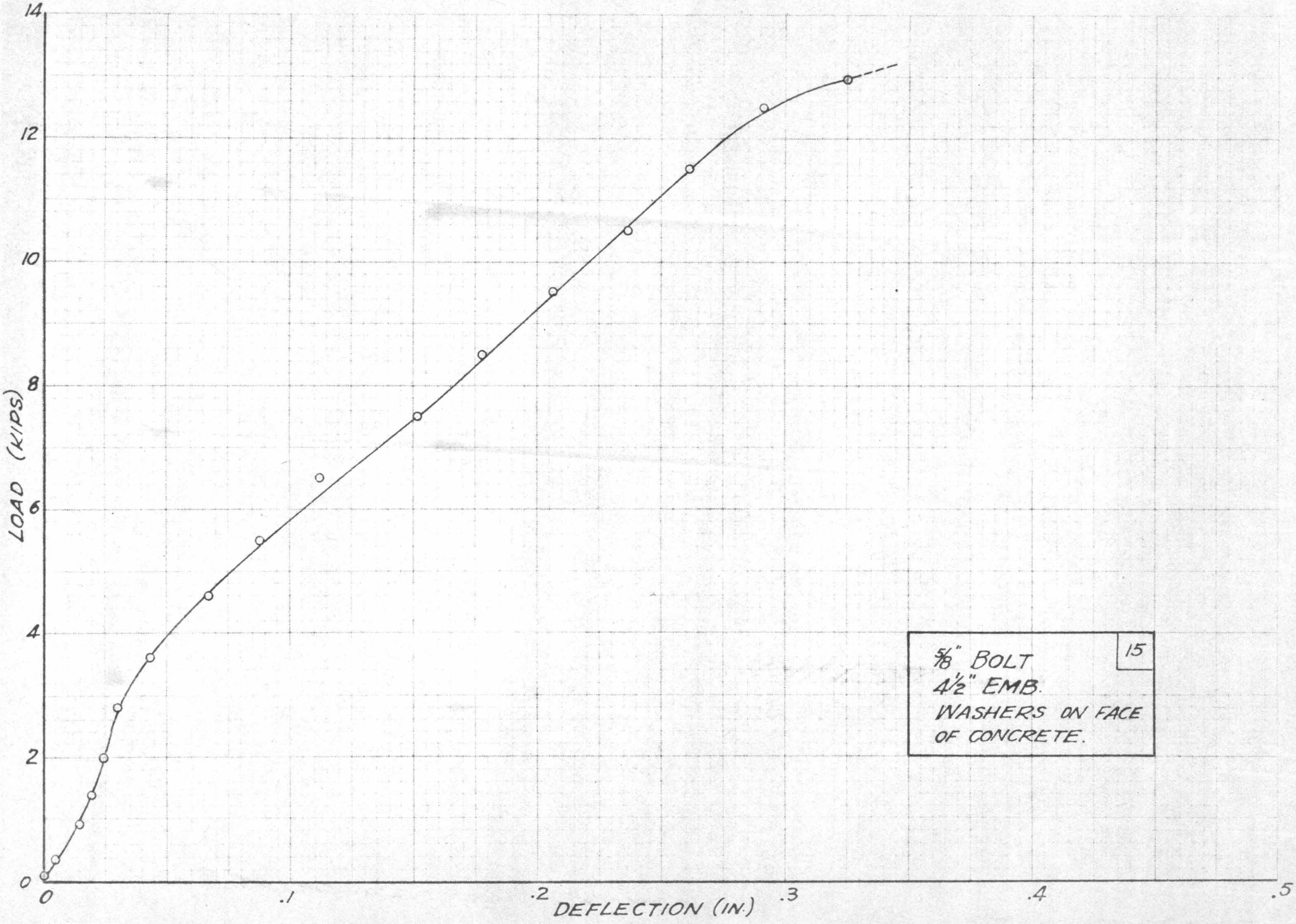
.5
DEFLECTION (IN.)
14
5/8" BOLT
4" EMB.
NO HEAD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12
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4
2
0
LOAD (KIPS)
0
.1
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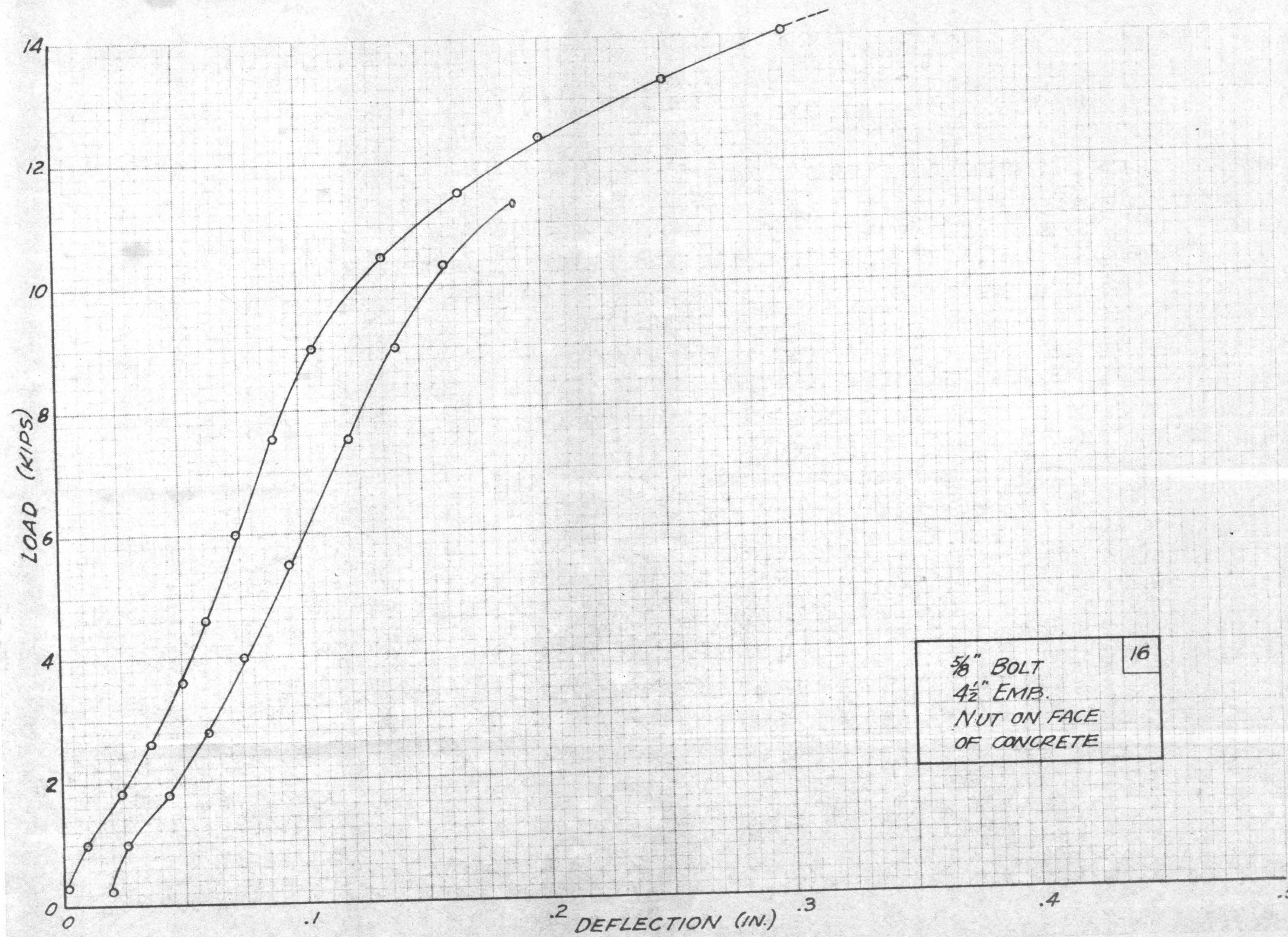
.3
.4
.5
DEFLECTION (IN.)
15
5/8" BOLT
4 1/2" EMB.
WASHERS ON FACE
OF CONCRETE.


14
12
10
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6
4
2
0
LOAD (KIPS)
0
.1
.2
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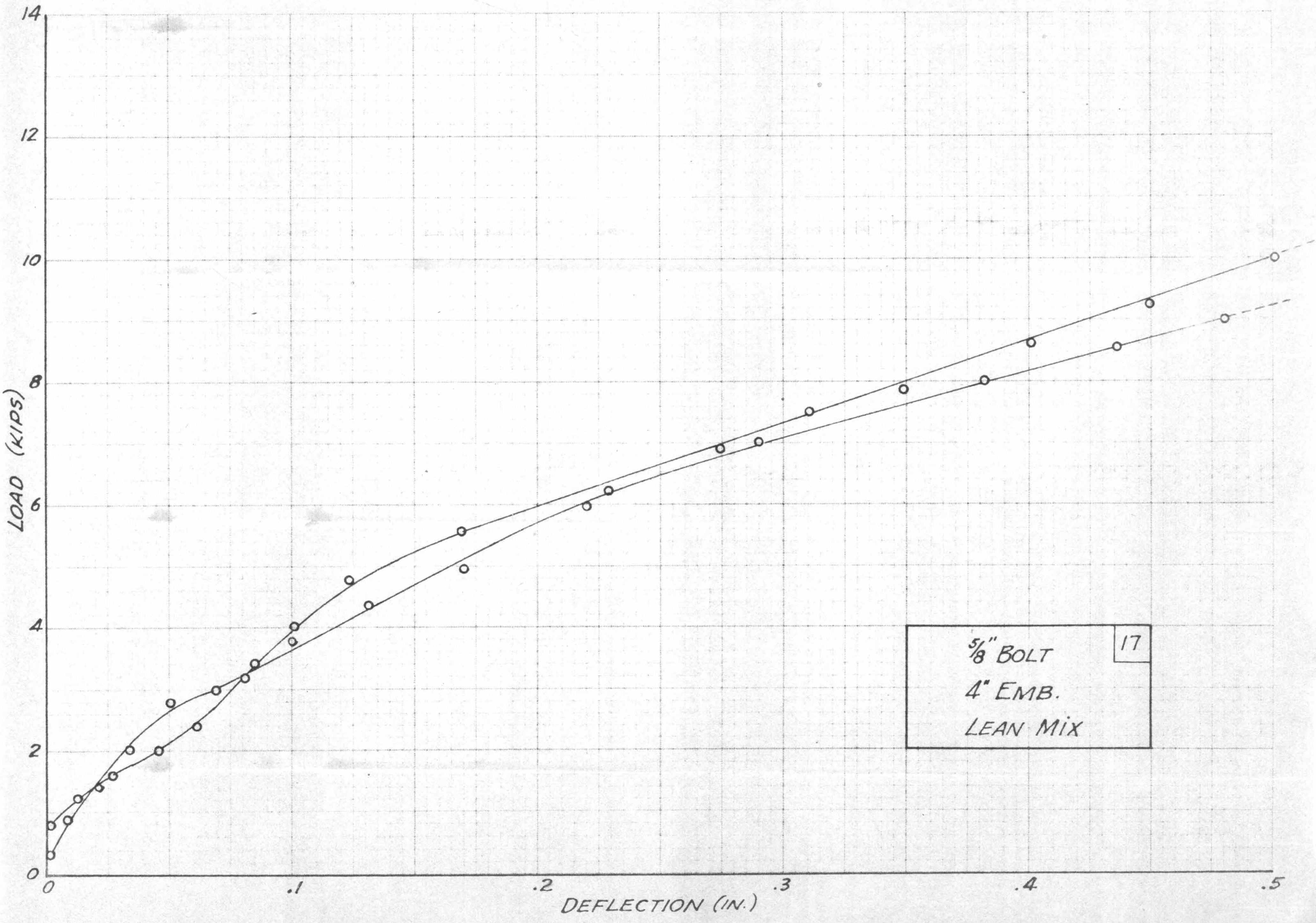
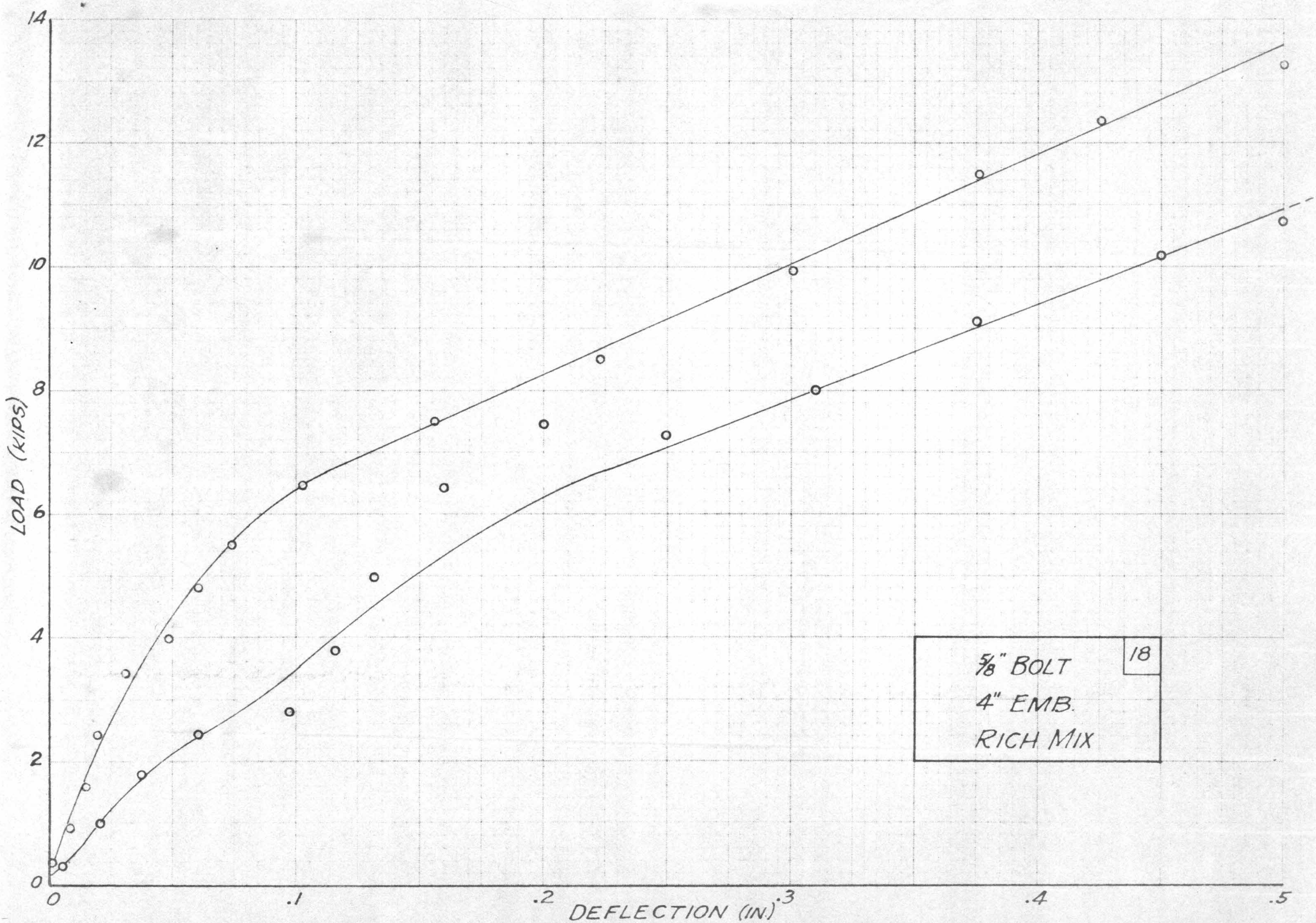
.5
DEFLECTION (IN.)
16
5/8" BOLT
4 1/2" EMB.
NUT ON FACE
OF CONCRETE


14
12
10
8
6
4
2
0
LOAD (KIPS)
0
.1
.2
.3
.4
.5
DEFLECTION (IN.)
17
5/8" BOLT
4" EMB.
LEAN MIX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4
2
0
LOAD (KIPS)
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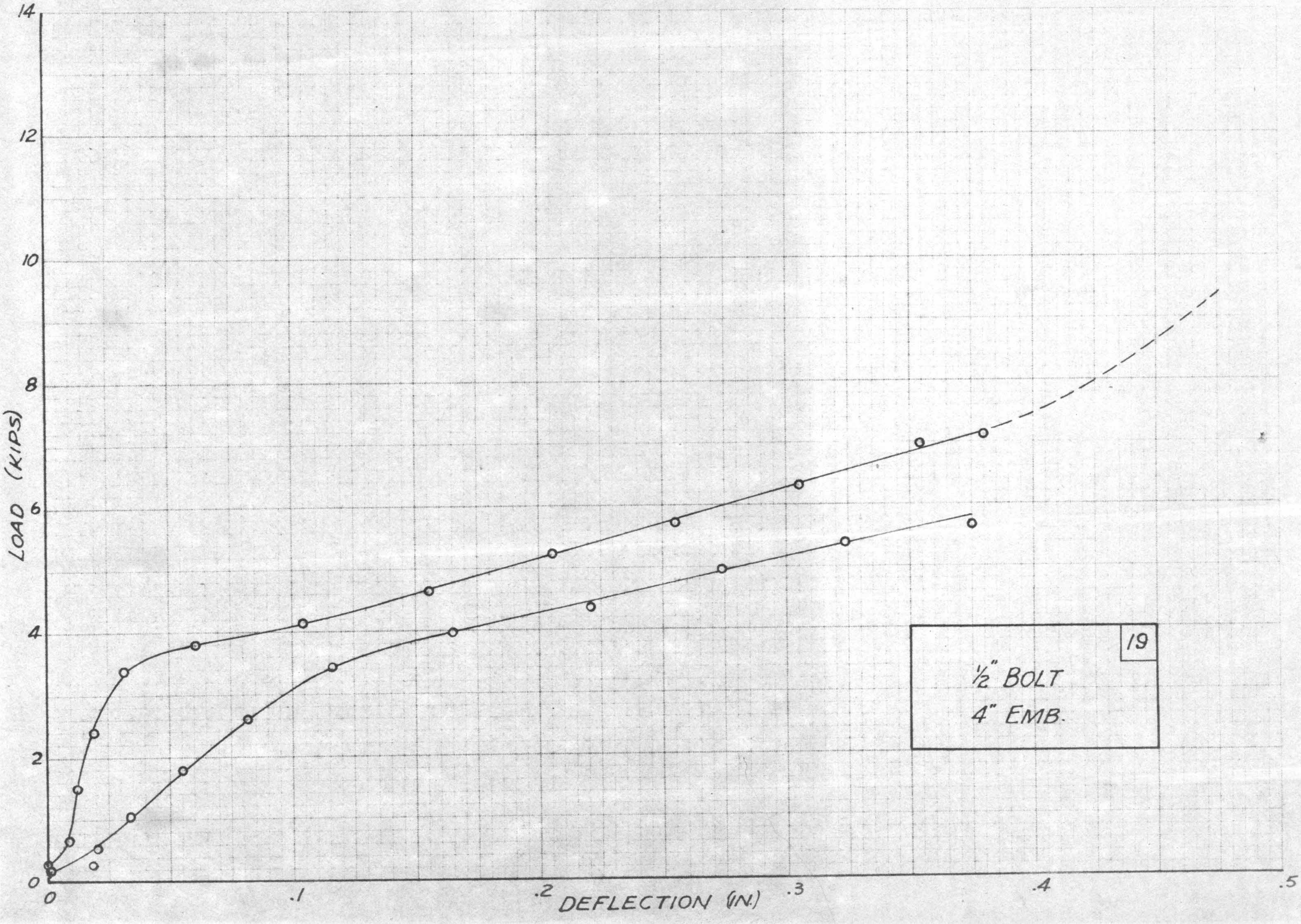
.1
.2
.3
.4
.5
DEFLECTION (IN.)
18
5/8" BOLT
4" EMB.
RICH MIX


14
12
10
8
6
4
2
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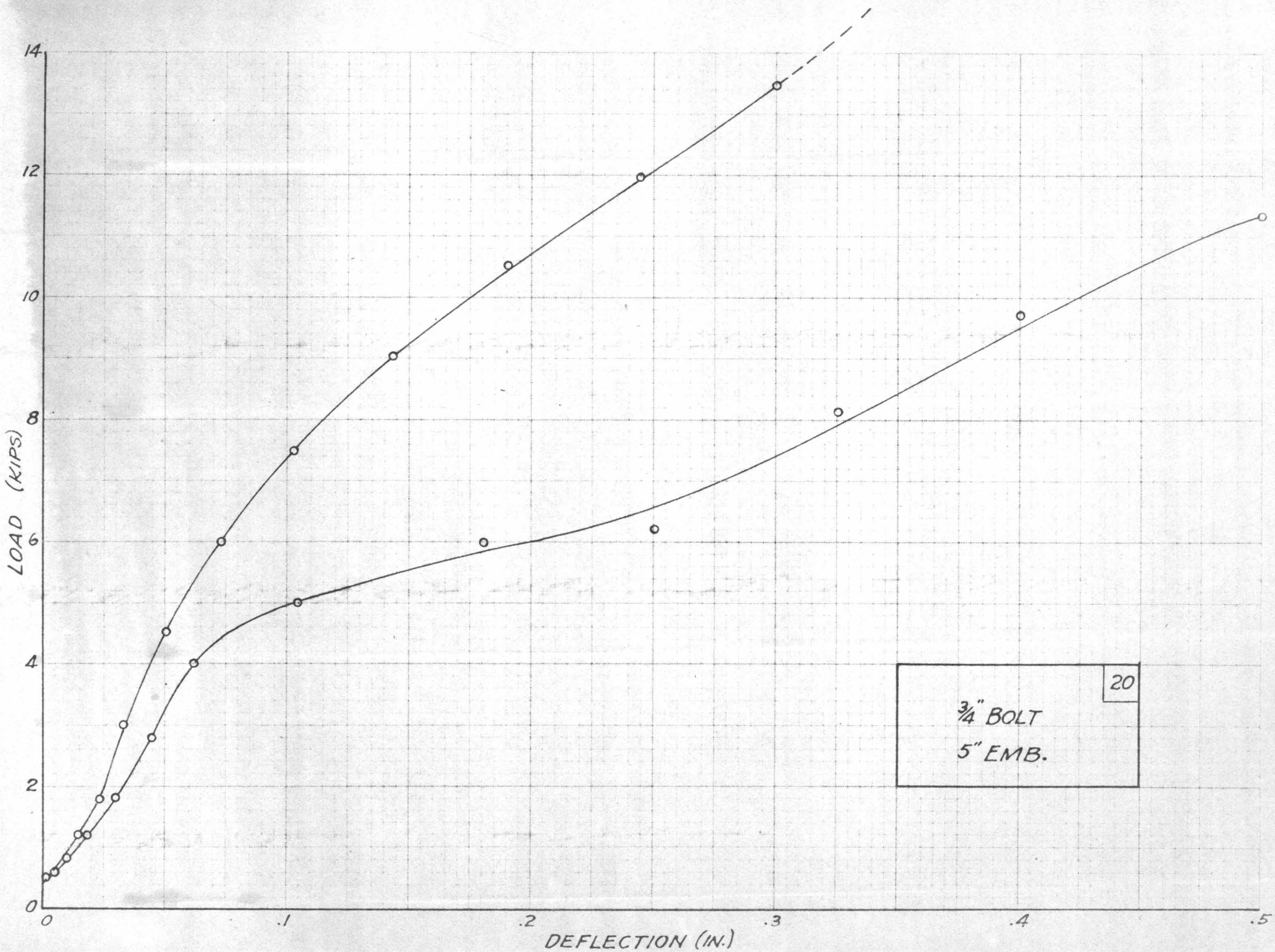
LOAD (KIPS)
0
.1
.2
.3
.4
.5
DEFLECTION (IN.)
19
½" BOLT
4" EMB.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10
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6
4
2
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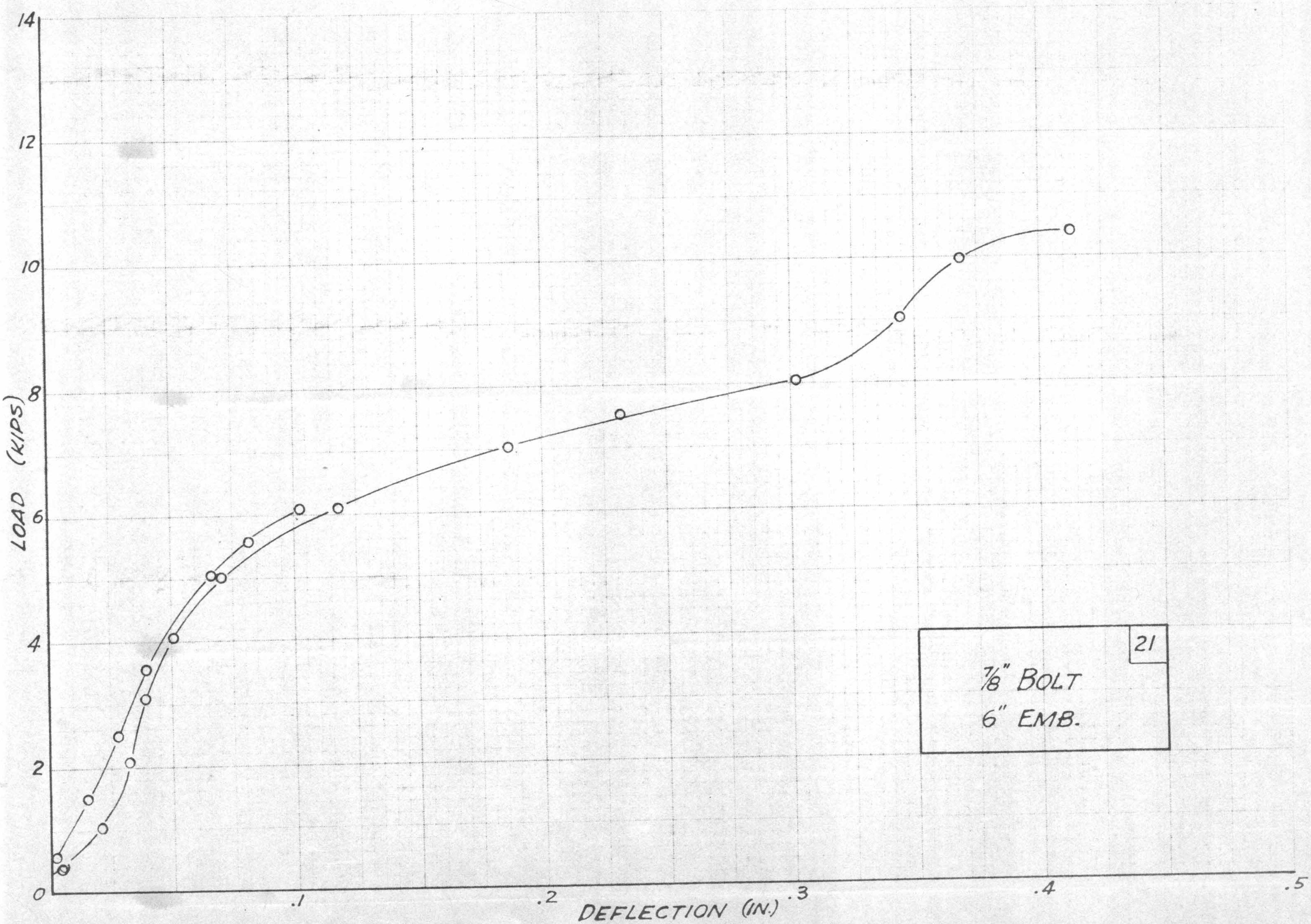
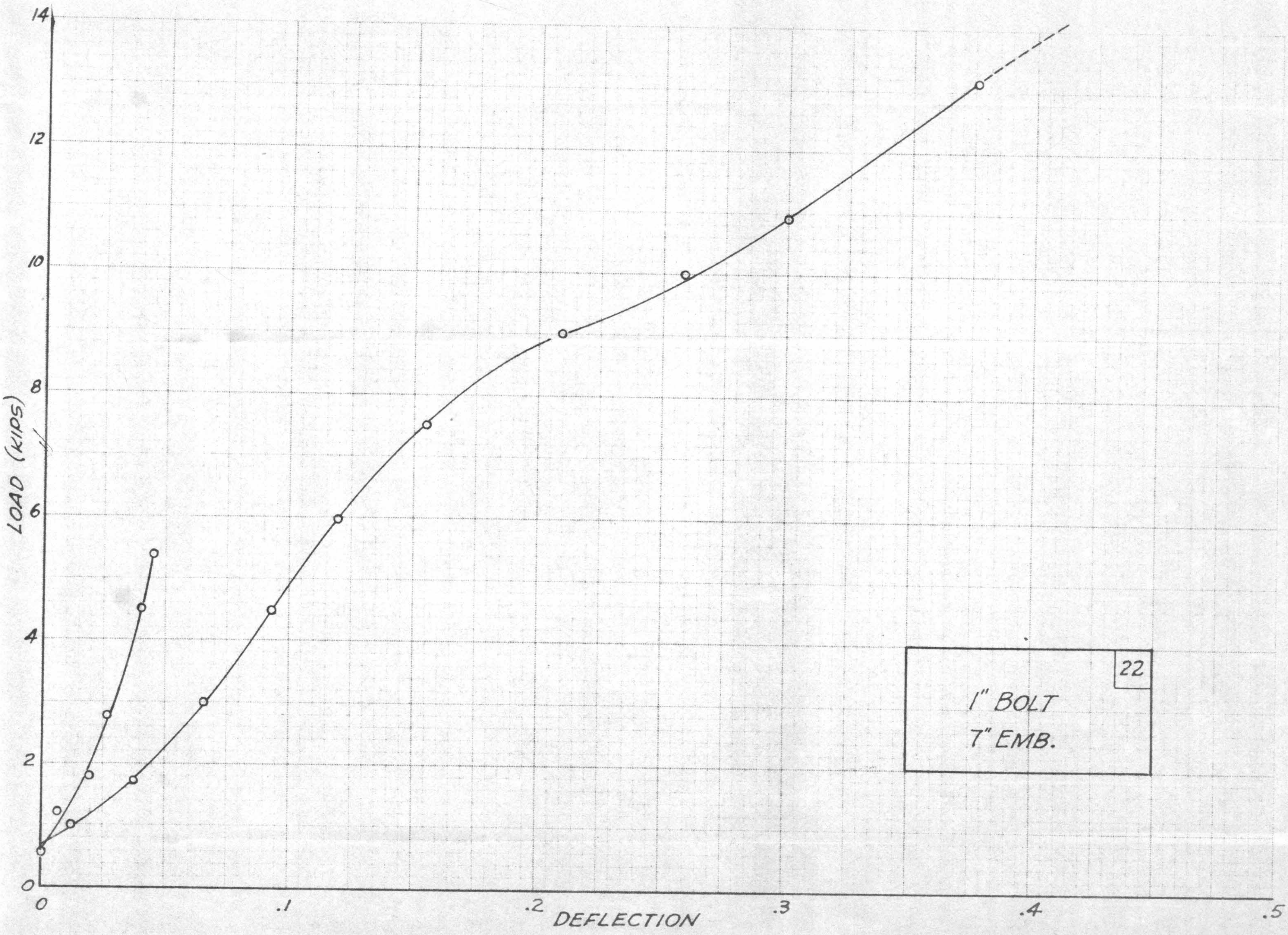
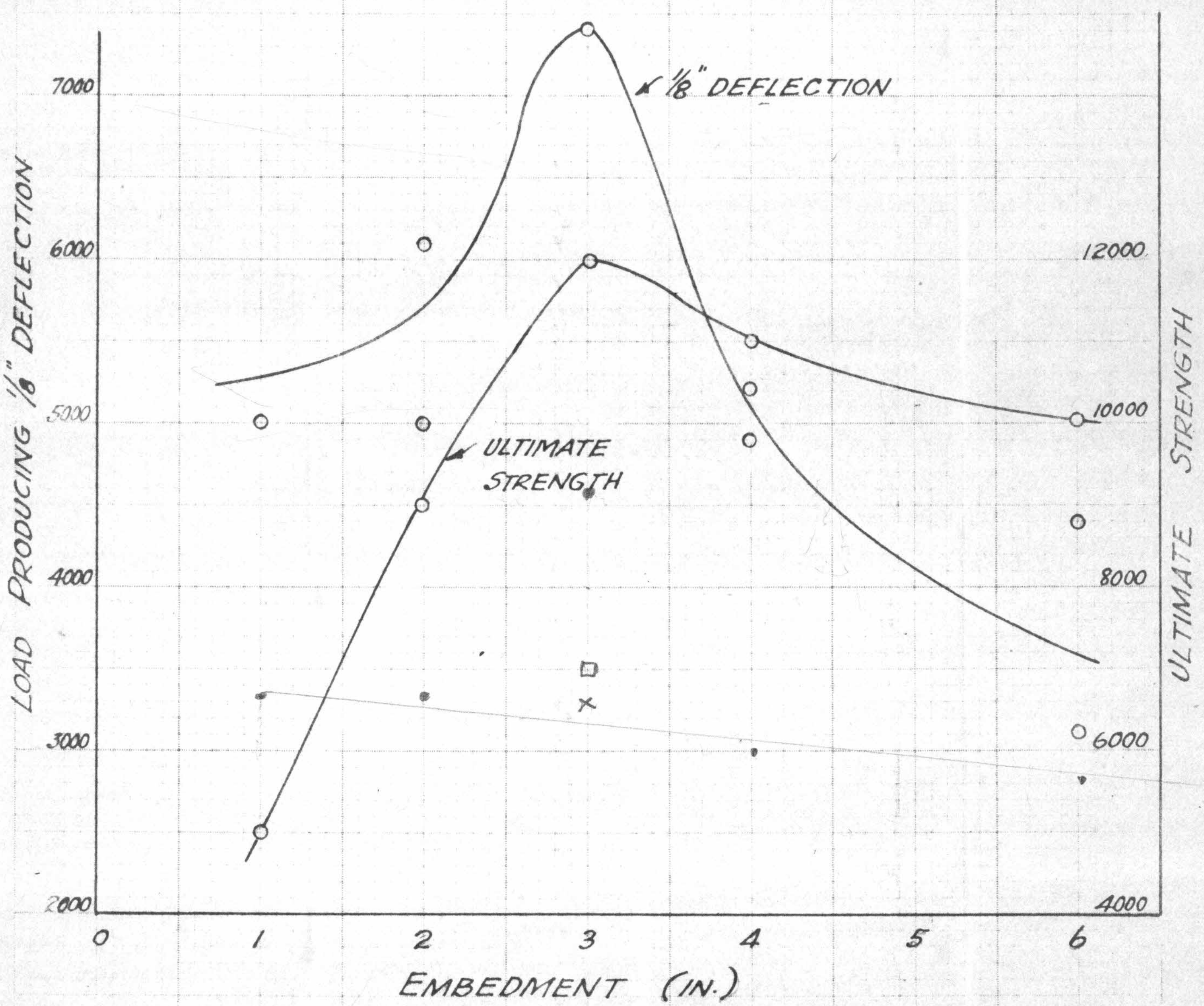
LOAD (KIPS)
0
.1
.2
.3
.4
.5
DEFLECTION (IN.)
20
3/4" BOLT
5" EMB.

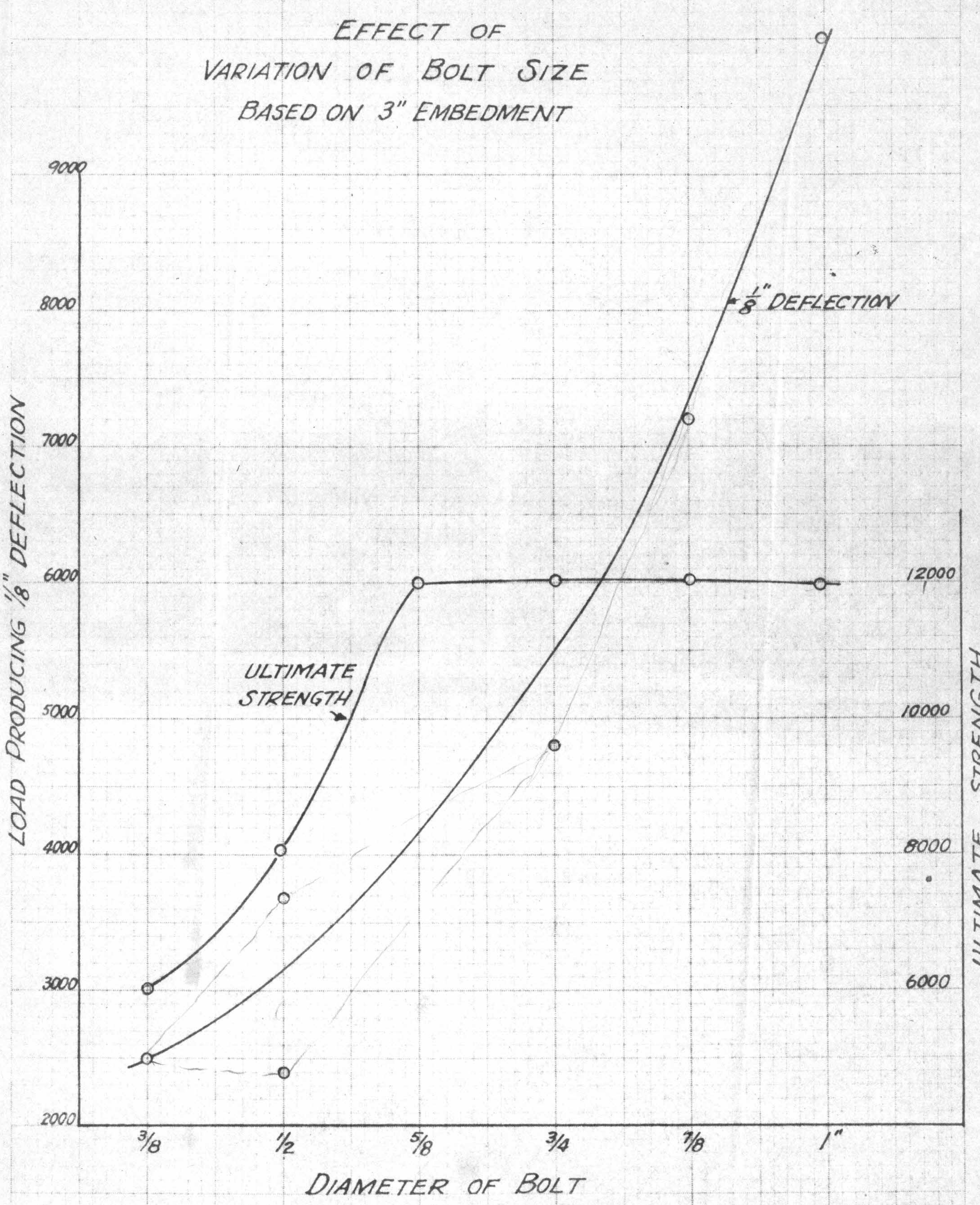

LOAD (KIPS)
14
12
10
8
6
4
2
0
.1
.2
.3
.4
.5
DEFLECTION (IN.)
21
7/8" BOLT
6" EMB.


22
1" BOLT
7" EMB.
LOAD (KIPS)
DEFLECTION
0
2
4
6
8
10
12
14
.1
.2
.3
.4
.5

EFFECT OF VARIATION OF EMBEDMENT

BASED ON 5/8" BOLT





EFFECT OF
VARIATION OF BOLT SIZE
BASED ON 3" EMBEDMENT
9000
8000
7000
6000
5000
4000
3000
2000
LOAD PRODUCING 1/8" DEFLECTION
12000
10000
8000
6000
ULTIMATE STRENGTH
1/8" DEFLECTION
ULTIMATE STRENGTH
3/8
1/2
5/8
3/4
7/8
1"
DIAMETER OF BOLT