63483

FINAL REPORT

TESTS OF ANCHORAGES TO DETERMINE EFFECTS OF PRYING

by

Edwin G. Burdette

August 1982

Tests Performed for

United Engineers and Constructors

30 South 17th Street

Post Office Box 8223

Philadelphia, Pennsylvania 19101

Testing Facilities:

Department of Civil Engineering

The University of Tennessee

Knoxville, Tennessee 37996

Edwin G. Burdette

Edwin G. Burdette
Consultant

RESEARCH REPORT

TESTS OF ANCHORAGES TO DETERMINE EFFECTS OF PRYING

by

Edwin G. Burdette

1. INTRODUCTION

In nuclear power plants a commonly used type of pipe support consists of a structural shape--tube, wide flange, angle, or channel--welded to a base plate. The base plate is attached to concrete with anchor bolts. When the plate is attached to existing concrete, the anchor bolts used are frequently wedge bolts; on the Seabrook Project, these wedge bolts are Hilti Kwik Bolts. The pipe supports may be designed to resist bending about both axes as well as pure tension, and the anchor bolts are designed to resist these applied loads through tension developed in the bolts.

As loads are applied to an attached structural member and tensile forces are developed in the anchor bolts to resist these loads, bending moments are induced in the baseplate. These moments produce bending deformations in the plate. If the plate is relatively flexible, interface forces between the plate and the concrete may be developed at or near the corners of the plate, forces which act in a direction to increase the anchor forces. These interface forces, acting in a way that increases the bolt loads, are called "prying forces." The magnitudes of these forces are difficult to evaluate, as they depend on a number of variables which are difficult to define and which include (1) plate flexibility, (2) distance from the bolts to the corners of the plate, (3) axial stiffness of the bolt, (4) the degree and orientation of warping of the base plate, and (5) the surface condition of the concrete.

The potential presence of these difficult to quantify prying forces has led to some concern throughout the nuclear industry regarding the design of base plates for pipe supports. The approach taken by United Engineers and Constructors (UE&C) to the question of prying has been to multiply calculated anchor bolt forces by a "prying factor" of 1.2 and to use the increased bolt loads as design loads for the bolts. Then a safety factor of 4 is applied in the design of wedge bolts.

While one suspects, intuitively, that the preceding approach to the design of wedge bolts is conservative, essentially no experimental justification exists for the prying factor of 1.2. It was the perceived need for such experimental justification that led to the research reported here.

On March 24, 1981, a purchase order was executed authorizing tests to be performed on various structural attachments identified in Reference 1. These tests were to include bending about both axes and direct tension, and measurements were to be made to determine bolt forces during the tests and to evaluate the effect of prying. The purpose of the test program was to verify that the procedures used by UE&C to design the anchor bolts for attachments used as pipe supports is conservative, particularly with regard to the prying factor of 1.2.

1.1 Objective

The objective of this report is two-fold: (1) to describe the tests performed and present the pertinent data obtained from the tests, and (2) based on the test data, to address the subject of prying in base plates and to assess the adequacy of the UE&C approach to design of base plates.

1.2 Scope

Eight different attachments were tested, each one representing a standard base plate detail used by UE&C. Tests on each attachment consisted of bending about two axes (except for the angle attachment) and direct tension. Typically, each test was performed for three different levels of preload in the bolts. A large quantity of data was obtained in the tests; much of this information was of marginal use in addressing the test objectives and is not treated in detail herein. Those data that relate directly to the stated purpose of the research are the basis for this report.

1.3 Earlier Reports

Essentially all of the data have been transmitted to UE&C through appropriate correspondence. Along with the data, a number of graphs were also transmitted. The graphs are repeated in this report as summaries of the pertinent data; the actual data as obtained from the tests are not repeated here.

An earlier report titled "Effect of Anchor Preload on Flexible Baseplates" was transmitted to UE&C in June 1982 (Reference 2). This report describes the testing apparatus and testing procedure in considerable detail, along with some interpretation of test results. While some of this information is repeated herein for the sake of completeness, the reader is referred to the earlier report (Reference 2) for more detail.

1.4 Acknowledgments

A number of Civil Engineering students deserve special thanks for their contributions to the research described here. Most notable among these are Dick Copley, graduate student in charge of the testing program throughout the project; Pascal Hayes, graduate student who played a large role in the Phase I testing and who is principal author of Reference 2; and Bruce Clark, undergraduate student who made an especially significant contribution to the reduction of the computer data and the plotting of the graphs for Phase II.

2. DETAILS OF TESTS

2.1 Test Specimens

Each structural attachment was welded to a base plate which was bolted to a concrete block 36-in. x 40-in. x 27-in. These blocks were ones remaining from an earlier series of tests on liner anchors (Reference 3). The blocks were cast at the Seabrook Plant site in August 1980. At the time the tests reported here were performed, the age of the concrete varied from 228 days to greater than 600 days, and the compressive strength was on the order of 7,000 psi. Use of old, high strength concrete is consistent with typical conditions at a nuclear plant site and results in relatively high axial stiffness of the wedge bolts, a condition that would be expected to increase the degree of prying.

The attachments tested are described in References 1 and 4, and key information describing them is given in Tables 1 through 8 herein. The test apparatus for the moment and tension tests are shown in Figures 1 and 2. All of the base plates were attached to the concrete blocks with Hilti Kwik Bolts. In order to measure strain in the bolts while load was being applied, a special device for transmitting the bolt forces to the plates was devised. The resulting arrangement is illustrated in Figure 3.

Two electrical resistance strain gages were attached to opposite sides of each bolt and wired in series to eliminate the effects of bending in the bolts. Gages were also attached to the base plates. The most important of these plate gages were those located between the bolt holes and the corners of the plates, oriented along diagonal lines. The purpose of these gages was to detect any compression resulting from prying forces applied to the corners of the plates. The gaging arrangement is illustrated in more detail in Reference 2.

2.2 Test Facilities and Equipment

The test facilities of the structural testing laboratory at The University of Tennessee, Knoxville, were used. A Gilmore closed loop hydraulic testing system was used to apply load, and the load was monitored with a recently calibrated load cell. A linear variable differential transformer (LVDT) was used to monitor beam deflections on the moment tests to failure. Dial gages were used to obtain deflections in the other moment tests.

Strain gages attached to the bolts and to the plates were monitored with a manually operated strain indicator in all tests except for the tests performed on the last three attachments. In these tests a TRS-80 micro-computer was used to monitor loads, strains, and deflections.

2.3 Test Procedure

Each attachment was subjected to three types of tests: bending about the strong axis, bending about the weak axis, and pure tension. For the tests of the equal leg angle attachments, the strong and weak axes were the same.

For each test without a computer, the load was increased in increments up to a value approximately twenty percent larger than the design value; and all strains and deflections were read at each increment. One of the bolts of particular interest in each test--for example, a top bolt in the moment tests--was wired through a digital strain indicator to an XY plotter so that a continuous plot of force in the bolt versus applied load on the beam could be obtained. For the last tests utilizing a micro-computer, the load was applied continuously up to its maximum value, and readings were taken by the computer at very small time intervals.

For all tests except the moment tests to failure, the test was "controlled on load"; that is, a small voltage corresponding to a load was dialed into the Gilmore, and the testing system responded to produce that load in the load cell. In each moment test to failure, the test was controlled on deflection to permit the definition of the descending portion of the load-deflection curve. In the tension tests, including the tests to failure, the tests were controlled on load.

3. THE TESTING PROGRAM

It was not practical to test all of the base plate designs used by UE&C for pipe supports. Thus, a study was made to identify the designs which would be most likely to experience high prying forces when subjected to flexure or to tension. The attachments identified are described in Appendix A, and descriptions of the tests and the attachments are given in Tables 1 through 4 herein. Tests on these attachments were completed in September 1981. These tests are referred to herein as Phase I of the testing program. All data and graphs for the Phase I testing were transmitted to UE&C, the last transmittal on October 5, 1981.

After review of the test data by UE&C, concern was expressed that perhaps the worst cases for prying had not yet been tested, that the frequent necessity to relocate anchor bolts in the field to miss rebars sometimes resulted in more flexible plates which were more subject to prying. This concern led to Phase II of the testing program in which plates with much larger areas were tested. The base plate details for Phase II are given in Appendix A, and descriptions of the Phase II tests and the attachments are given in Tables 5 through 8.

4. TEST RESULTS

As noted earlier, test data and graphs have been sent to UE&C. The graphs are repeated herein as Figures 4 through 54. The figures are arranged such that the results of all tests on a particular attachment are presented consecutively. For example, the results of the Phase I tests on Part 807-2 are depicted in Figures 4 through 11, and the results of the Phase II tests on Part 807-2 with one combination of plate and bolt sizes are shown in Figures 24 through 30. This arrangement of results is consistent with the description of the tests presented in Tables 1 through 8.

Not all of the data obtained during the tests have been reduced and plotted; to do so would have required an extremely large expenditure of effort to obtain information, much of which does not directly address the objectives of the testing program. Instead, attention was focused on those data that dealt with (1) the specific topic of prying and how prying affects the behavior of an anchorage system and (2) the general topic of adequacy of the UE&C approach to design of anchor bolts for attachments used as pipe supports.

The moment arms of the internal couples were calculated for the moment tests of the 4-bolt connections by dividing the change in applied moment by the change in the sum of the forces in the top two bolts. This calculation was made for a particular test based on the straight line portion of the curve of bolt load versus moment. The moment arms as calculated from the curves are shown on the appropriate graphs along with the UE&C design value for moment arm. A discussion of the Phase I results is presented in Reference 2.

5. DISCUSSION OF TEST RESULTS

5.1 Phase I Tests

The results of the Phase I tests have been discussed in detail in earlier correspondence with UE&C and in Reference 2. A summary of that discussion is included in the following paragraphs.

Perhaps the most exhaustive and most meaningful data obtained in the entire program of testing were those obtained from the tests on Part 807-2 which are described in Table 1. The test results are illustrated by the graphs in Figures 4-11. The tests were performed on an anchorage that could best be described as "typical." The design of the anchorage was essentially "balanced"; in the strong axis bending test to failure, the load was limited by the anchors, but as the load began to drop off somewhat, the plate rotated significantly, and the weld between beam and plate failed. The measured moment arm of the internal couple in both strong and weak axis bending tests was slightly larger than that predicted by UE&C design procedures (UE&C Bulletin No. 7--included in Reference 1), indicating a small degree of conservatism in the design. The factor of safety for the anchorage, obtained by dividing the applied moment required to cause failure by the design moment, was 6.24. The corner gages, located for the purpose of detecting prying, did not measure any compression. Thus, prying, as this writer understands the term, was insignificant in these tests. However, the lower curves in Figure 6 for the direct tension tests did indicate bolt load increases at low values of applied load that might possibly be attributed to prying. On the other hand, the top two curves in Figure 6 for the tests with high preloads do not indicate any prying. In any event it is clear that prying was of no practical significance in the behavior of this anchorage.

Similar results were obtained from the tests on the angle (Part 805-2) and the channel (Part 808-1) as illustrated in Figures 12-18. The moment arms obtained from the test data were consistently larger than the UE&C design values, and prying did not appear to influence the behavior of the anchorages.

The data obtained from the tests on the six bolt connection, Part 808-1, are illustrated by the graphs in Figures 19-23. Some of the data are difficult to interpret, particularly the data from the strong axis bending tests, because of the presence of six bolts. The moment arms in the weak axis bending tests were slightly larger than the UE&C design value, and the safety factor in strong axis bending was greater than 5, as illustrated in Figure 23. The graphs in Figure 21 indicate some increase in the sum of the bolt loads before the applied tension had reached the magnitude of the applied preload, a situation that could be interpreted as prying. However, most of the increase in bolt load came from the center bolts and, in this writer's opinion, reflected a redistribution of interface stresses between plate and concrete. The corner gages did not indicate any prying, and one is led again to the conclusion that prying was of no significance in the behavior of this anchorage.

In summary, the Phase I tests gave no evidence that prying was of any importance in the standard anchorages considered. The moment arms obtained from data were consistently larger than the design values used by UE&C. Thus, the conclusion is reached that the UE&C design approach utilizing a prying factor of 1.2 is conservative.

5.2 Phase II Tests

As noted earlier the Phase II tests came about because of concern that the anchorages tested in Phase I were not the most critical from the viewpoint of prying. Thus, other anchorages with base plates significantly more flexible than those used in Phase I were fabricated and tested.

The difference in prying potential of the base plates in the two test phases is illustrated by a comparison of Part 807-2 tested in Phase I and the two versions of Part 807-2 tested in Phase II. All of these anchorages had four bolts and a W5 x 16 attachment. The plate in the Phase I tests was 12 x 12 x 3/4-in. with 3/4-in. diameter bolts. The plate in the first set of tests of Part 807-2 in Phase II was 22 1/2 x 22 1/2 x 3/4-in. with 1-in. diameter bolts. The distance from the holes in the plate to the edge of the plate was 1 1/2-in. for the Phase I case and 2 1/4-in. for the Phase II case. The larger area of plate with the same thickness, coupled with stiffer bolts and larger edge distances, made the attachment in the Phase II test much more likely to experience prying forces.

The results of the moment tests on the first version of Part 807-2 are plotted in Figures 24-30. There was no evidence of prying in the moment tests in which the maximum moment was slightly greater than the design moment for the anchorage. The rather erratic, low strains recorded by the corner gages illustrate this fact. However, in the moment test to failure, the corner gages went into compression which indicated the presence of prying forces; this prying continued throughout the test until failure of the attachment weld occurred. Prying also took place in the tension tests as evidenced by the strains in the corner gages plotted in Figure 30. Also, the plots in Figure 25 show increased bolt loads due to prying.

It is important to note that the presence of prying forces in the moment tests did not appear to affect adversely the behavior of the anchorages. The moment arm of the internal couple obtained from test data was slightly larger in each test than the value used by UE&C in design. In the moment test to failure, the loads in the top bolts were at less than two-thirds capacity when the weld failed. Thus, prying had no effect on the load-carrying capacity of the anchorage.

The tests of the second version of Part 807-2--22 1/2 x 22 1/2 x 1-in. plate and 1 1/4-in. diameter bolts--indicated essentially no prying at all. Apparently, the thicker plate was sufficient to eliminate any significant prying forces. The test results for this anchorage are shown in Figures 31-38.

The weak axis bending tests gave reasonably predictable results. The moment arm obtained from data was significantly larger than the UE&C design value. In the strong axis bending tests, however, the data for bolt loads are erratic as illustrated in Figure 33. As the strains in the corner gages plotted in Figure 34 show no evidence of prying, it was not deemed necessary to repeat the strong axis test to obtain more meaningful data on bolt loads.

Only in the tension test to failure was there any evidence of prying, as illustrated in Figure 38. In this plot of average strain in the corner gages, there seemed to be a very slight amount of prying up to a tensile load of almost 50,000 pounds, after which the gages went into tension. Then, at very high loads, the average strain went toward compression again. This apparent anomaly can be explained by noting that the W5 x 16 attachment had been inadvertantly welded to the plate 1-in. off center. Thus, at very high tensile loads, one edge of the plate was being pushed against the concrete, causing high average compressive strains in the corner gages. In fact, prying in the usual sense was of no significance for this anchorage. It should be noted that the weld joining the W-section to the plate was deliberatly "beefed up" to give a weld stronger than the design value in order to be able to study the behavior of the anchorage at higher loads. Interestingly, the weld was still the limiting component.

The test results for the angle attachment, Part 805-2, are shown in Figures 39-46. For the most part these results are consistent and predictable. The moment arms, with one exception, are larger than the design value. The one exception is the moment test to failure where the data points are scattered somewhat erratically, and the slope of the curve is difficult to define. The other moment tests produced much more consistent data. Failure in the moment test occurred through lateral-torsional buckling of the angle attachment.

In the moment test with the load applied downward and the bolts fully torqued, the strain plot in Figure 40 indicates a relatively small amount of prying. Other than this one instance, there appeared to be no prying in the moment tests of Part 805-2. In the tension tests there was a measurable degree of prying for the case with the bolts at full torque and one-half full torque, as evidenced by the plots of bolt load versus applied load in Figure 43. Also, the strain plots in Figure 44 verify the presence of prying forces for these two cases. For the case with the bolts hand tight, there was no apparent prying. The strains plotted in Figure 44 indicate that, if the tensile load had been increased to approach failure, the prying forces would have rapidly diminished to zero.

The tests on the channel attachment, Part 806-4, gave results similar to but more consistent than the results of the tests on the angle. There was essentially no prying in the moment tests, and the moment arms obtained from test data were consistently larger than the UE&C design value.

In the tension tests with full torque and one-half full torque on the bolts, there was measurable prying, as evidenced by the graphs in Figures 51 and 52. The tension test was not extended far enough to observe any reduction in strain in the corner gages which would signal a reduction in prying force. Again, in the strong axis bending test, failure occurred by lateral-torsional buckling of the channel attachment.

5.3 Comments

Based on the results of the Phase I and Phase II tests, the following comments with regard to prying are in order:

(1) If prying is going to occur at all, it will more likely occur when the bolt preloads are large.

(2) Prying is much more apt to occur in direct tension than in bending.

(3) There is no indication that prying in any way reduced the capacity of any of the anchorages tested.

6. DISCUSSION AND CONCLUSIONS

6.1 Discussion

In evaluating the effect of prying on the behavior of an anchorage system, it is appropriate to begin by considering the possible modes of failure of the system. These modes may be categorized in terms of two cases: (1) failure of the anchor bolts, and (2) failure of the base plate or attachment. The latter may include failure in bending (or shear) of the attachment, excessive deformation of the base plate, or failure of the weld between base plate and attachment. If the anchor bolts are wedge bolts, as in all the tests reported herein, failure in the first case typically occurs by the bolts' slipping out of the holes in the concrete, a failure accompanied by significant movement of the bolts in the direction of applied load.

Case 1: Capacity Limited by Anchors

For the capacity of a structural attachment to concrete to be limited by the anchors, there are a number of provisions which must be met. The structural member itself cannot fail in bending or shear, for a member subjected to flexure, or in tension for a member axially loaded. The plate cannot deform excessively. The welds between plate and attachment cannot fail.

For a connection to satisfy the provisions just described, the base plate must be relatively strong and stiff compared to the anchor bolts. Connections in this category were tested in the Phase I testing reported here. In these tests there was little evidence of prying. The corner strain gages showed essentially no compressive strain, and the plots of bolt load versus applied load (tension tests) or applied moment (flexure tests) indicated that prying was not of significant importance.

Let it be emphasized here that the last statement did not say that there was no prying in the Phase I tests. In fact the non-ideal behavior of the bolts in the transition zone where the bolt loads were increased to values greater than the original preloads indicates some redistribution of interface stress that may be thought of as "prying." However, this phenomenon was of no discernible importance relative to the behavior of the attachment.

Finally--and most importantly--the presence of any prying forces had no effect at all on the strength of an attachment subjected to either bending or tension. In all instances the corners of the steel plate had pulled away from the concrete well before peak load was reached. This is a typical situation--an inevitable situation--for attachments like those in the Phase I tests where the capacity is limited by the pull-out capacity of the wedge bolts.

Case 2: Capacity Not Limited by Anchors

Anchorages in Case 2 frequently occur when a base plate is modified, typically to avoid rebar interference, in such a way that a large base plate relative to the size of the anchor bolts results. This type of anchorage was tested in the Phase II tests. In this case the relatively stiff anchor bolts, coupled with a relatively flexible plate, tend to create prying forces at the corners of the plate.

If prying forces are generated, they cause an increase in bolt loads. They do not, however, cause any additional deflection of the attachment or deformation of the base plate. In fact they act in a way that tends to "fix" the ends of the plate and reduce rotation. A plate subjected to prying forces does tend to deform more than one without prying, but this additional deformation is the result of the plate's additional flexibility--not in any way due to the prying action itself.

Prying in base plates in Case 2 does not affect the capacity of the anchorage system, as capacity is limited by some component other than the anchor bolts. The fact that prying forces may very well exist throughout the spectrum of load application from zero to failure in no way alters the load capacity of the system.

Case 3: Combination of Cases 1 and 2

Some base plates exist which represent a combination of Cases 1 and 2; that is, some of the anchor bolts are located close to the attachment while others, due to relocation to avoid rebar interference, are located near the edges of the plate. In such a situation the anchors near the attachment attract most of the load, and the anchors far away from the attachment are more lightly loaded. The loads in the lightly loaded anchors are increased somewhat by the presence of prying forces at the corners of the plate, but the more heavily loaded anchors are unaffected by prying. Thus, as before, the load capacity of the system is in no way affected by the presence of prying.

6.2 Conclusions

Based on the test results discussed in Section 5 and on the discussion of prying just presented, the following conclusions are drawn:

(1) It is not possible to predict with a reasonable degree of accuracy the magnitudes of the loads in the wedge bolts for a particular anchorage system subjected to design bending moment. These magnitudes depend upon a number of variables which are difficult to evaluate, including the "fit" of plate to concrete surface and the axial stiffness of each wedge bolt. But the most important variable is the magnitude of the anchor preload, a variable which defies precise definition in a field installation.

(2) For a 4-bolt connection, if sufficient moment is applied to produce bolt loads significantly larger than the bolt preloads, the approximate calculation of a change in bolt load for a particular increment of moment is more reasonable. The key variable in this calculation is the moment arm of the internal couple; the method given in UE&C Bulletin No. 7 (Reference 1) gives a reasonable, somewhat conservative, value for this moment arm.

(3) If an anchorage is subjected to a tensile load greater than the sum of the preloads in the bolts, the sum of the actual bolt loads is equal to the applied load plus the magnitude of the prying force. For the anchorages in Case 1, as discussed earlier, the prying force may be taken as zero. For the anchorages in Case 2, the prying force is extremely difficult to quantify, but the magnitudes of the bolt loads are of little practical importance.

(4) The phenomenon of prying has little practical significance in anchorage systems utilizing wedge bolts. This conclusion follows from the earlier discussion in which it was pointed out that prying action does not have a detrimental effect on either behavior at service loads or on load carrying capacity.

(5) The UE&C method of designing anchor bolts for attachments used as pipe supports is conservative. The method of calculation of the moment arm of the internal couple acting on a base plate, as noted earlier, is reasonable and somewhat conservative; and one can make a strong argument that there is no real justification for using a prying factor greater than 1.0. Thus, the use by UE&C of a prying factor of 1.2 is clearly conservative.

REFERENCES

1. United Engineers & Constructors, Inc., P.O. No. SNH-683, 9763.006-210-9, with attachments, March 24, 1981.

2. Hayes, Pascal and Edwin G. Burdette, "Effect of Anchor Preload on Flexible Baseplates," Report Submitted to United Engineers & Constructors, Inc., May 1982.

3. Burdette, Edwin G., Final Report: <u>Containment Liner Anchor Load Tests,</u> Report submitted to United Engineers & Constructors, Inc., February 5, 1981.

4. United Engineers & Constructors, Inc., change Order No. 1 to P.O. No. SNH-683, 9763.006-210-9, with attachments, January 25, 1982.

TABLE 1

PHASE I TESTS ON PART 807-2 WITH 12-in. x 12-in. PLATE

-W5 x 16 Attachment
-4 Bolts, 3/4-in. Dia., 10-in. O.C., 6-in. Embedment
-Plate 12-in. x 12-in. x 3/4-in.

UT Test Number	Test Type	Average Preload in Bolts (lbs.)
81-8-1	Strong Axis Bending	6,090
81-8-2	Strong Axis Bending	570
81-8-3	Strong Axis Bending	1,000
81-8-4	Strong Axis Bending	3,850
81-8-5	Strong Axis Bending	2,000
81-8-6	Weak Axis Bending	640
81-8-7a	Weak Axis Bending	8,100
81-8-7b	Weak Axis Bending	1,580
81-8-7c	Weak Axis Bending	530
81-8-8a	Tension	7,160
81-8-8b	Tension	780
81-8-8c	Tension	1,520
81-8-9a	Tension	7,220
81-8-9b	Tension	510
81-8-9c	Tension	1,570
81-8-10a	Weak Axis Bending	6,600
81-8-10b	Weak Axis Bending	470
81-8-10c	Weak Axis Bending	1,500
81-8-11	Strong Axis Bending	5,960
81-8-12a	Strong Axis Bending	6,200
81-8-12b	Strong Axis Bending	510
81-8-13	Strong Axis Bending to Failure	1,340

TABLE 2

PHASE I TESTS ON PART 805-2 WITH 8-in. x 8-in. PLATE

-3 x 3 x 3/8 Angle Attachment
-4 Bolts, 1/2-in. Dia., 6-in. O.C., 2 3/4-in., Embedment
-Plate 8-in. x 8-in. x 5/8-in.
-Vertical Leg of Angle Down (Bending Tests)

UT Test Number	Test Type	Load Direction	Average Preload in Bolts (lbs.)
81-8-14a	Bending	Down	2,920
81-8-14b	Bending	Down	200
81-8-14c	Bending	Down	660
81-8-15a	Bending	Up	2,420
81-8-15b	Bending	Up	220
81-8-15c	Bending	Up	670
81-8-16a	Tension	--	2,500
81-8-16b	Tension	--	200
81-8-16c	Tension	--	540

TABLE 3

PHASE I TESTS ON PART 806-4 WITH 8-in. x 12-in. PLATE

-C 8 x 11.5 Channel Attachment
-4 Bolts, 3/4-in. Dia., 5-in. x 9-in. Pattern, 6-in. Embedment
-Plate 8-in. x 12-in. x 3/4-in.
-Outstanding Legs of Channel Down (Weak Axis Bending)

UT Test Number	Test Type	Load Direction	Average Preload in Bolts (lbs.)
81-8-17a	Strong Axis Bending	--	5,850
81-8-17b	Strong Axis Bending	--	550
81-8-17c	Strong Axis Bending	--	1,420
81-8-18a	Weak Axis Bending	Down	7,070
81-8-18b	Weak Axis Bending	Down	440
81-8-18c	Weak Axis Bending	Down	1,450
81-8-19a	Weak Axis Bending	Up	5,130
81-8-19b	Weak Axis Bending	Up	720
81-8-20a	Tension	--	6,330
81-8-20b	Tension	--	1,670
81-8-20c	Tension	--	560

TABLE 4

PHASE I TESTS ON PART 808-1 WITH 12-in. x 20-in. PLATE

-W 8 x 21 Attachment
-6 Bolts, 1 1/4-in. Dia., Spacing 7 1/2-in. x 7 3/4-in. x 7 3/4-in., 7 1/2-in. Embedment
-Plate 12-in. x 20-in. x 1-in.

UT Test Number	Test Type	Average Preload in Bolts (lbs.)
81-8-21a	Strong Axis Bending	8,224
81-8-21b	Strong Axis Bending	4,920
81-8-21c	Strong Axis Bending	1,590
81-8-22a	Weak Axis Bending	5,740
81-8-22b	Weak Axis Bending	1,350
81-8-22c	Weak Axis Bending	4,490
81-8-23a	Tension	5,880
81-8-23b	Tension	1,470
81-8-23c	Tension	4,150
81-8-24a	Strong Axis Bending	1,540
81-8-24b	Strong Axis Bending	4,250
81-8-24c	Strong Axis Bending to Failure	7,860

TABLE 5

PHASE II TESTS ON PART 807-2 WITH 22 1/2-in. x 22 1/2-in. PLATE

-W 5 x 16 Attachment
-4 Bolts, 1-in. Dia., 18-in. O.C., 6-in. Embedment
-Plate 22 1/2-in. x 22 1/2-in. x 3/4-in.

UT Test Number	Test Type	Average Preload in Bolts (lbs.)
82-1-1a	Weak Axis Bending	11,360
82-1-1b	Weak Axis Bending	6,040
82-1-1c	Weak Axis Bending	160
82-1-2a	Tension	11,110
82-1-2b	Tension	1,540
82-1-2c	Tension	90
82-1-3a	Strong Axis Bending	8,670
82-1-3b	Strong Axis Bending	50
82-1-3c	Strong Axis Bending to Failure	5,940

TABLE 6

PHASE II TESTS ON PART 807-2 WITH 22 1/2-in. x 22 1/2-in. PLATE

-W 5 x 16 Attachment
-4 Bolts, 1 1/4-in. Dia., 18-in. O.C., 7 1/2-in. Embedment
-Plate 22 1/2-in. x 22 1/2-in. x 1-in.

UT TEST Number	Test Type	Average Preload in Bolts (lbs.)
82-1-4a	Weak Axis Bending	6,500
82-1-4b	Weak Axis Bending	4,100
82-1-4c	Weak Axis Bending	100
82-1-5a	Strong Axis Bending	7,700
82-1-5b	Strong Axis Bending	2,600
82-1-5c	Strong Axis Bending	900
82-1-6a	Tension Test	9,700
82-1-6b	Tension Test	3,250
82-1-6c	Tension Test	125
82-1-7	Tension Test to Failure	4,000

TABLE 7

PHASE II TESTS ON PART 805-2 WITH 19-in. x 19-in. PLATE

-3 x 3 x 3/8 Angle Attachment
-4 Bolts, 5/8-in. Dia., 16-in. O.C., 4 1/2-in. Embedment
-Plate 19-in. x 19-in. x 3/4-in.
-Vertical Leg of Angle Down (Bending Tests)

UT Test Number	Test Type	Load Direction	Average Preload in Bolts (lbs.)
82-1-8a	Bending	Down	3,800
82-1-8b	Bending	Down	100
82-1-8c	Bending	Down	1,600
82-1-8d	Bending	Up	2,900
82-1-8e	Bending	Up	25
82-1-8f	Bending	Up	1,650
82-1-9a	Tension	--	2,200
82-1-9b	Tension	--	0
82-1-9c	Tension	--	1,600
82-1-14a	Bending Test to Failure	Down	2,100

TABLE 8

PHASE II TESTS ON PART 806-4 WITH 19 1/2-in. x 23 1/2-in. PLATE

-C 8 x 11.5 Channel Attachment
-4 Bolts, 1-in. Dia., 15-in. x 19-in. Pattern, 6-in Embedment
-Plate 19 1/2-in.x 23 1/2-in. x 1-in.
-Outstanding Legs of Channel Up (Weak Axis Bending)

UT Test Number	Test Type	Load Direction	Average Preload in Bolts (lbs.)
82-1-10a	Strong Axis Bending	--	10,500
82-1-10b	Strong Axis Bending	--	5,100
82-1-10c	Strong Axis Bending	--	100
82-1-11a	Weak Axis Bending	Down	11,000
82-1-11b	Weak Axis Bending	Down	5,300
82-1-11c	Weak Axis Bending	Down	500
82-1-12a	Tension	--	10,500
82-1-12b	Tension	--	4,900
82-1-12c	Tension	--	100
82-1-13a/a	Strong Axis Bending Test to Failure	--	2,300
82-1-13a/b	Strong Axis Bending Test to Failure	--	1,500

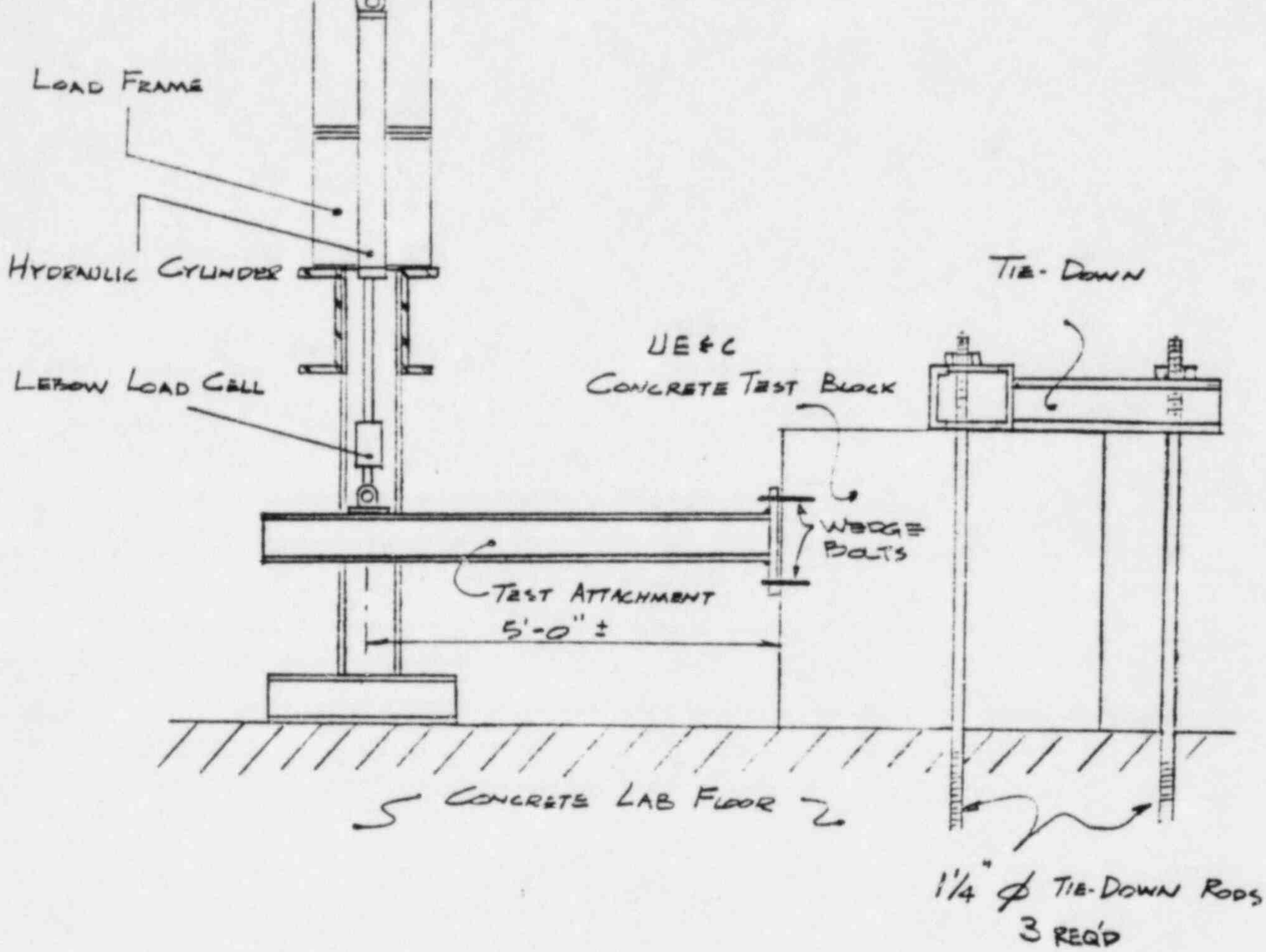


FIGURE 1. TEST APPARATUS FOR MOMENT TESTS

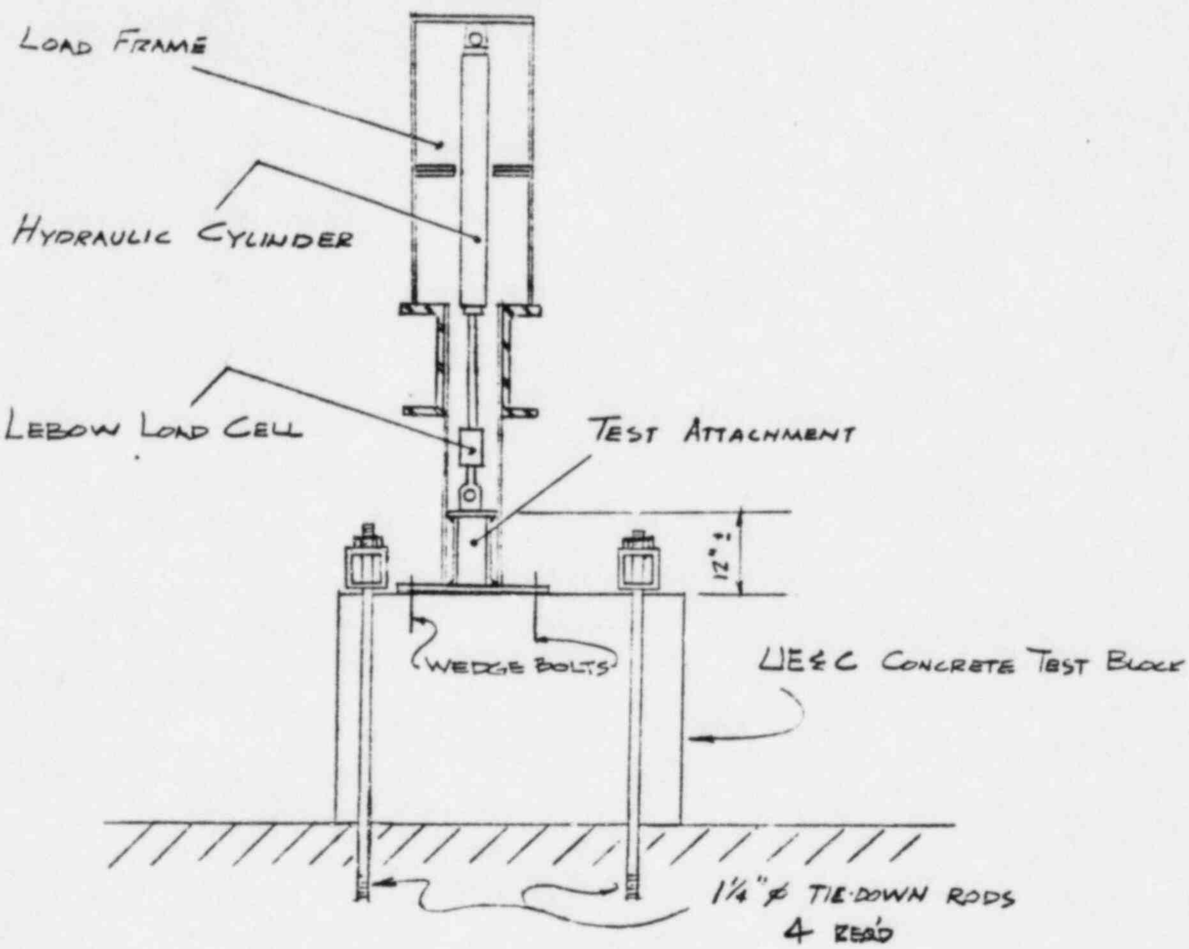
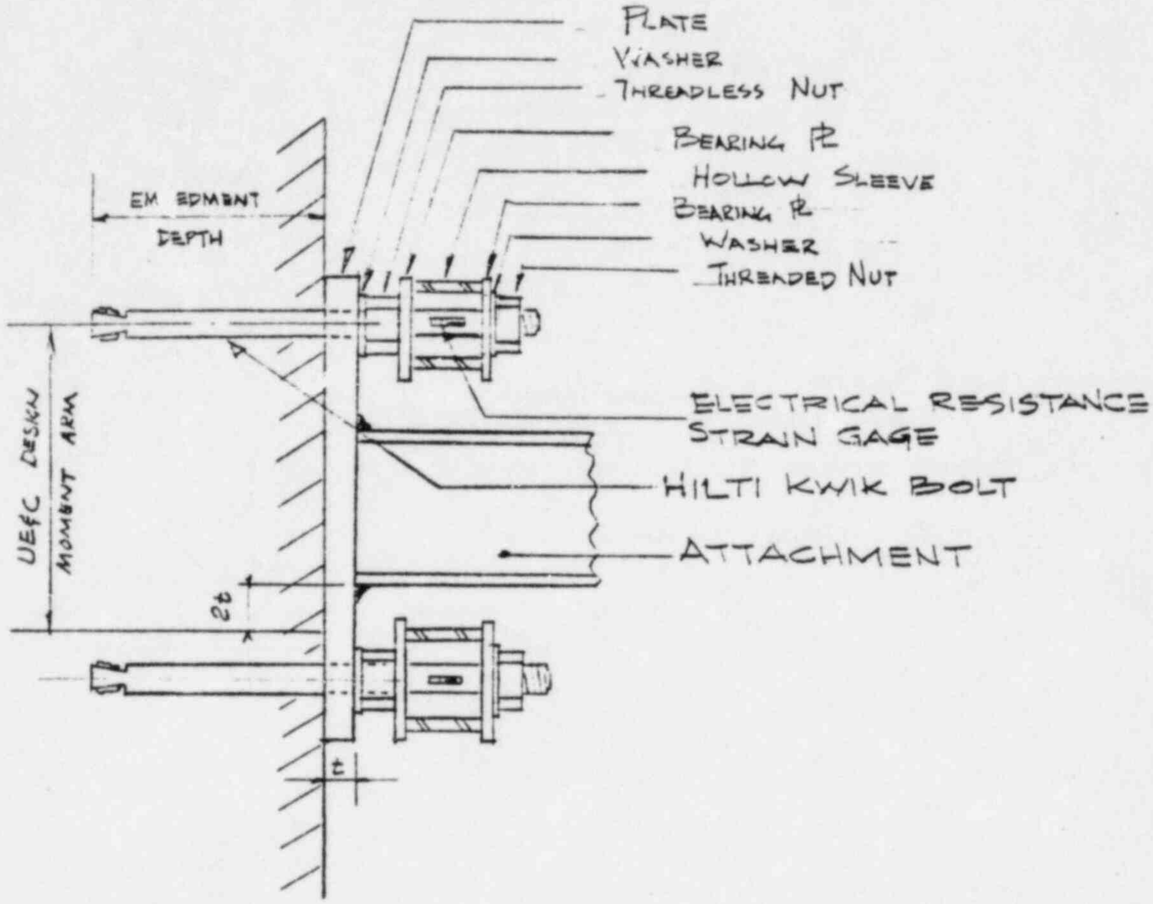
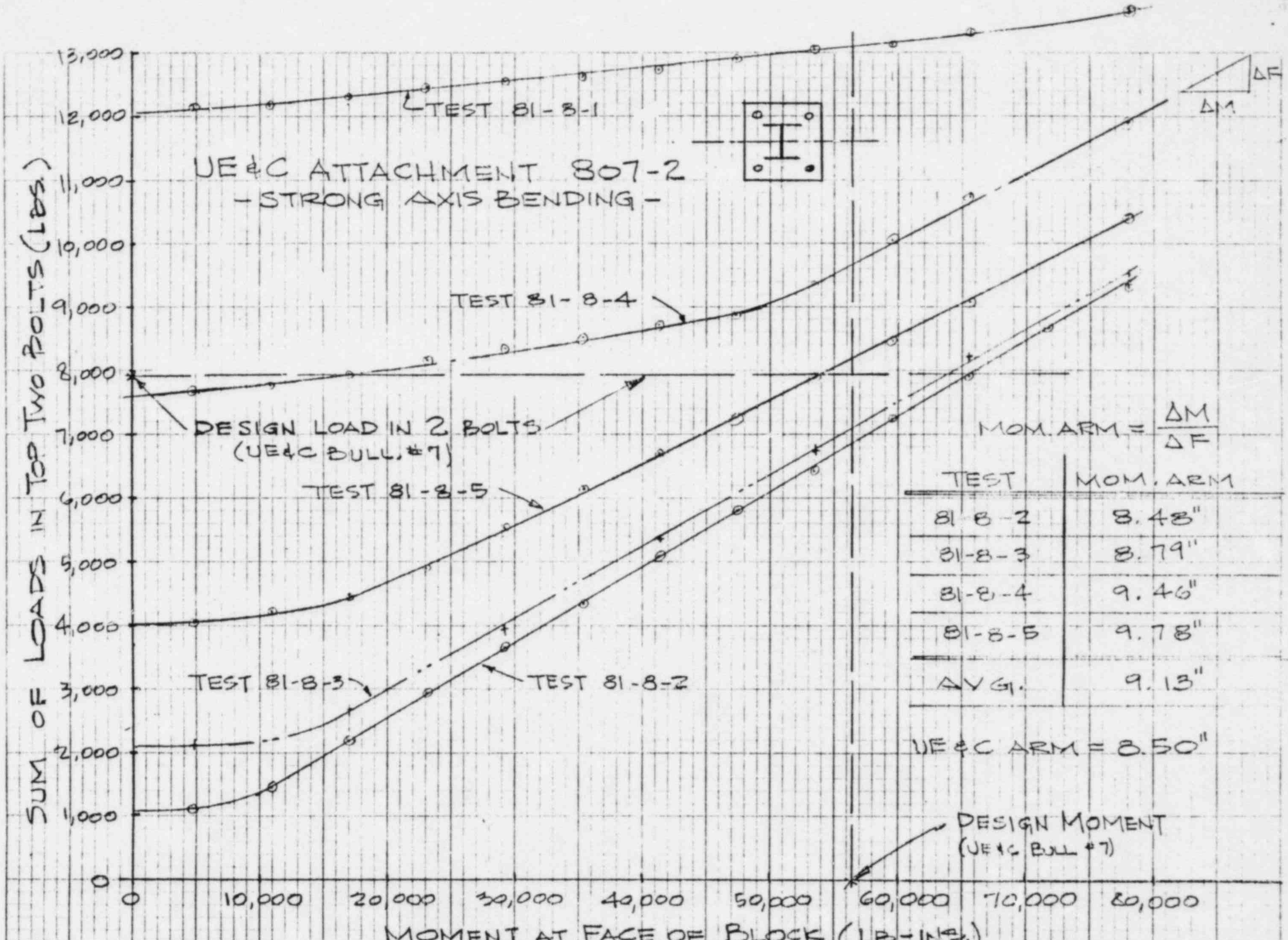


FIGURE 2. APPARATUS FOR TENSION TEST



BOLT Ø	LENGTH OF BOLT	EMBEDMENT DEPTH	INSTALLATION TORQUE
INCHES	INCHES	INCHES	FT-LBS
1/2	7	2 3/4	60
3/4	10	6	192
1	12	6	360
1 1/4	14	7 1/2	480

FIGURE 3. DETAILS OF WEDGE BOLT BEARING AGAINST PLATE



TEST	MOM. ARM
81-8-2	8.48"
81-8-3	8.79"
81-8-4	9.46"
81-8-5	9.78"
AVG.	9.13"

UE&C ARM = 8.50"

FIGURE 4. BOLT LOAD VS. MOMENT FOR PART N° 807-2 (STRONG AXIS) [#1]

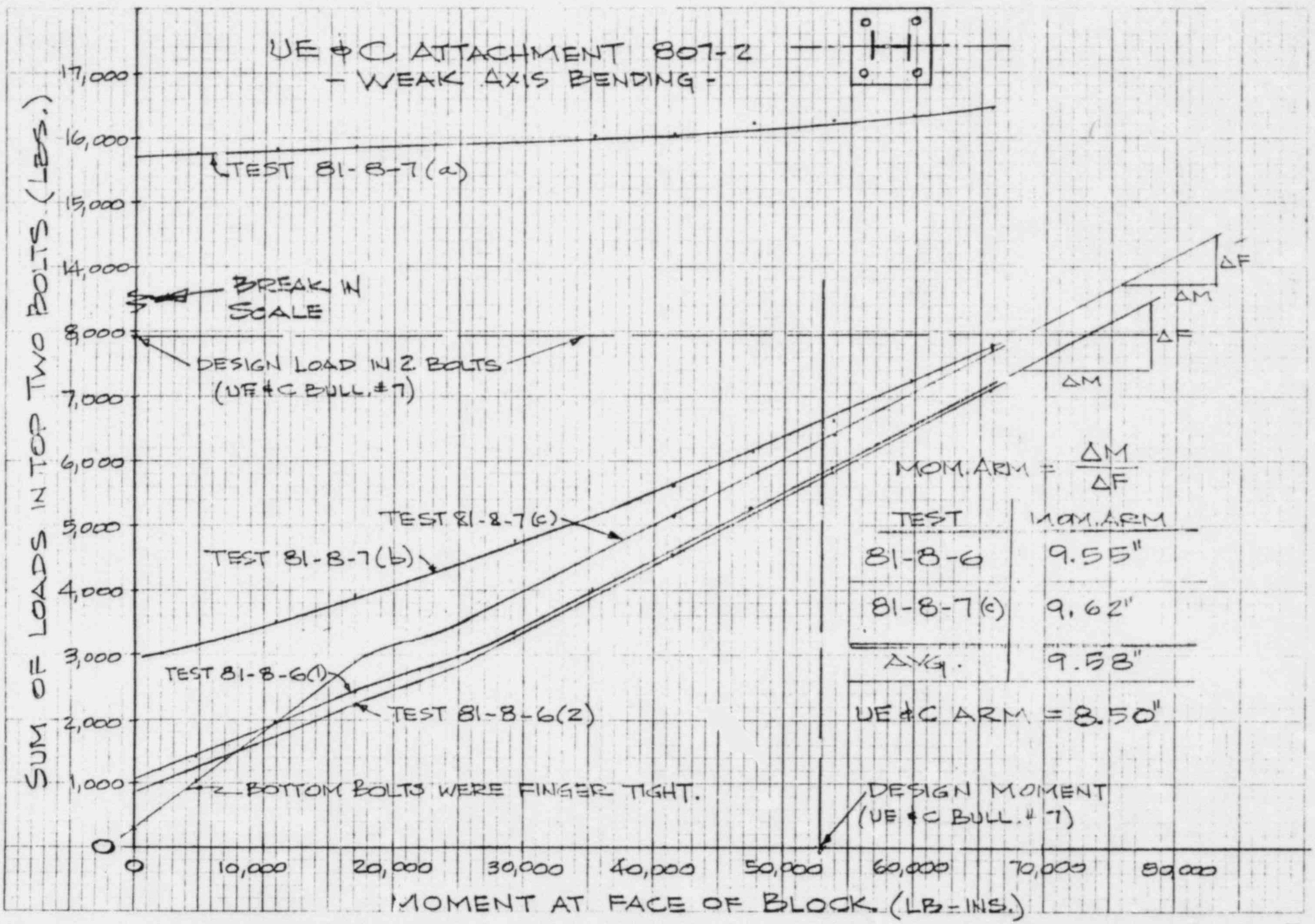


FIGURE 5. Bolt Load vs. Moment for Part № 807-2 (weak axis) [#1]

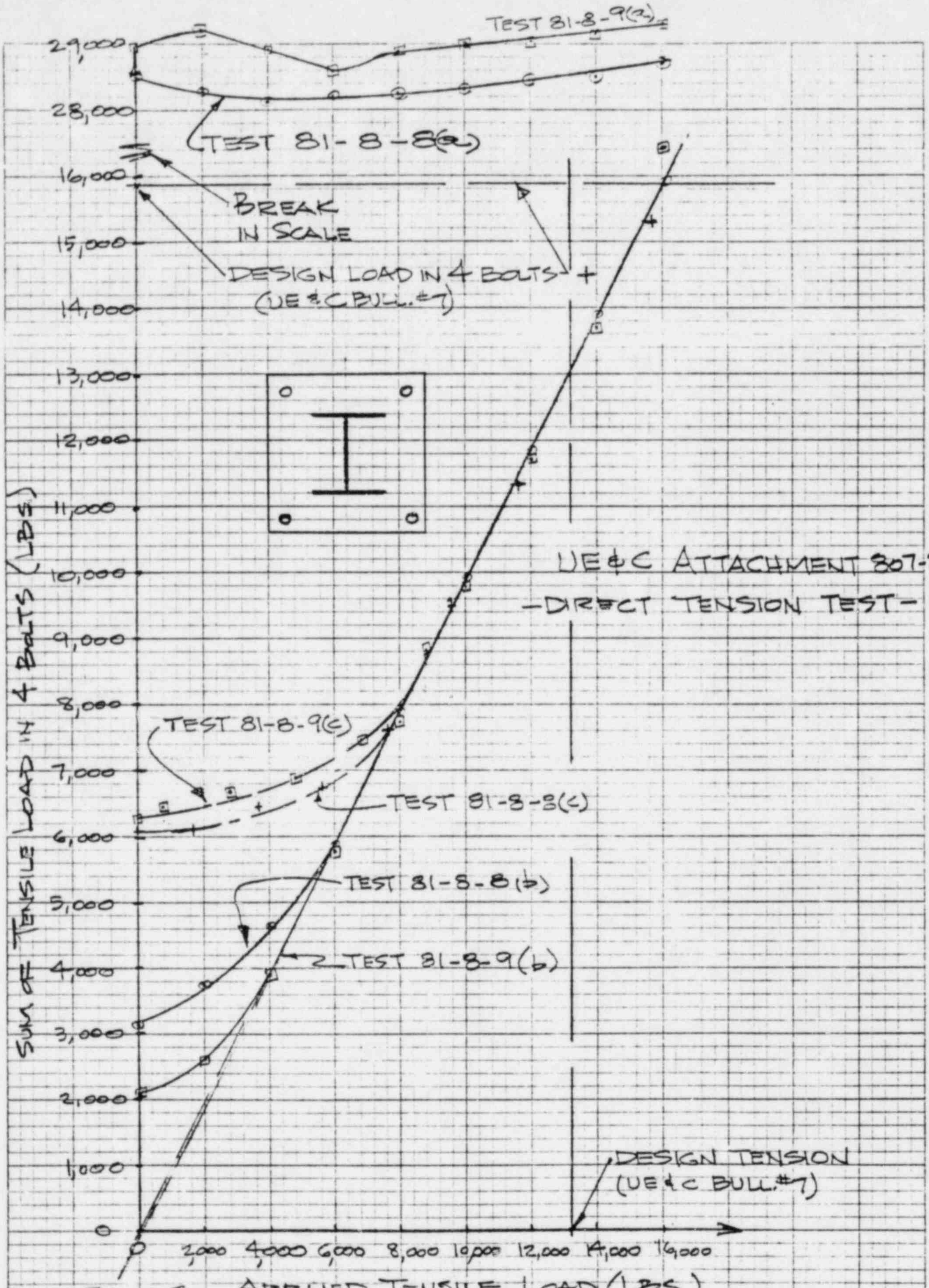


FIG. 6.

BOLT LOAD (SUM OF 4 BOLTS) VS. APPLIED TENSION

10 Squares to the Inch

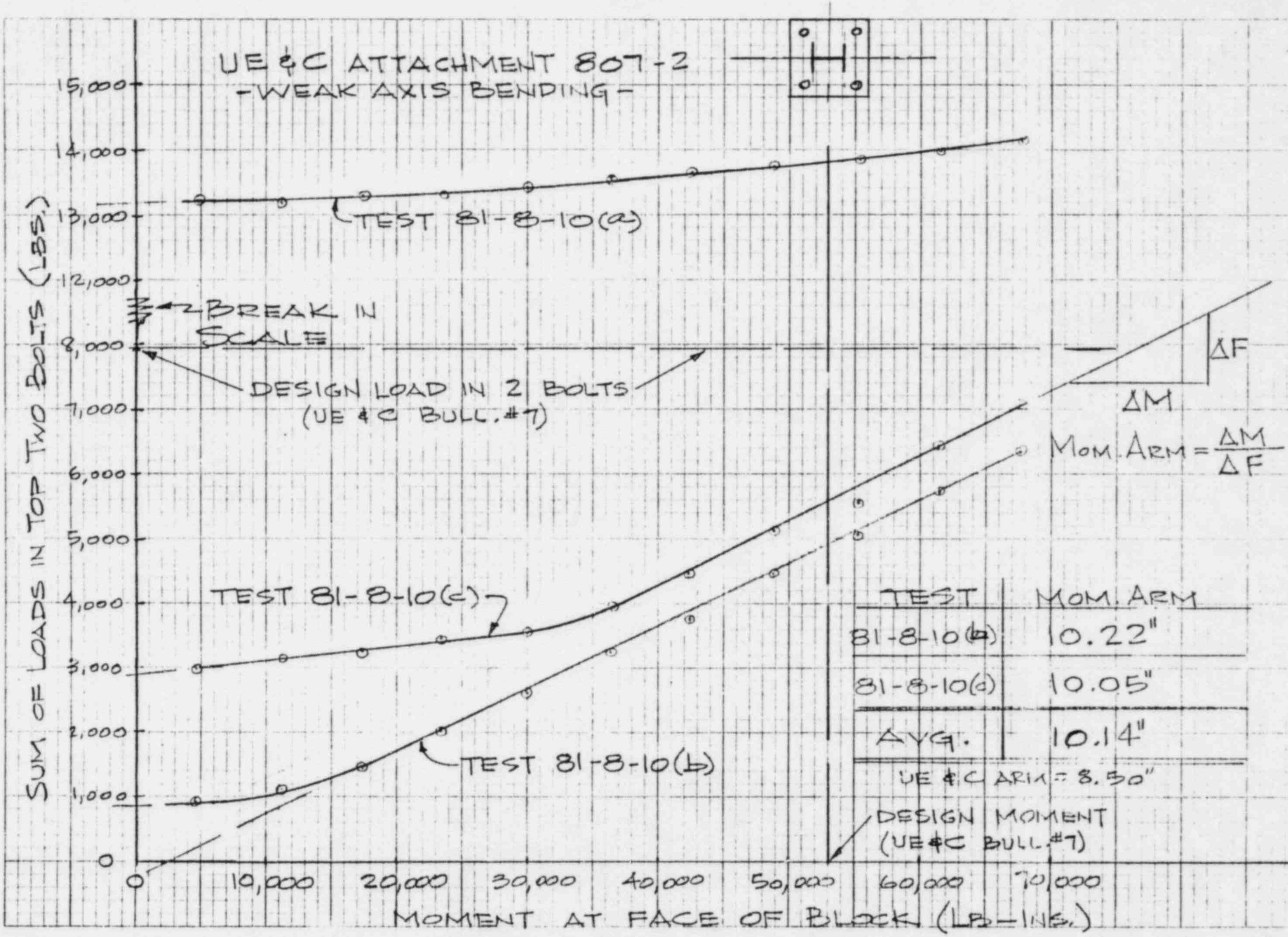


FIGURE 7. Bolt Load vs. Moment for Part № 807-2 (Weak Axis) [#2]

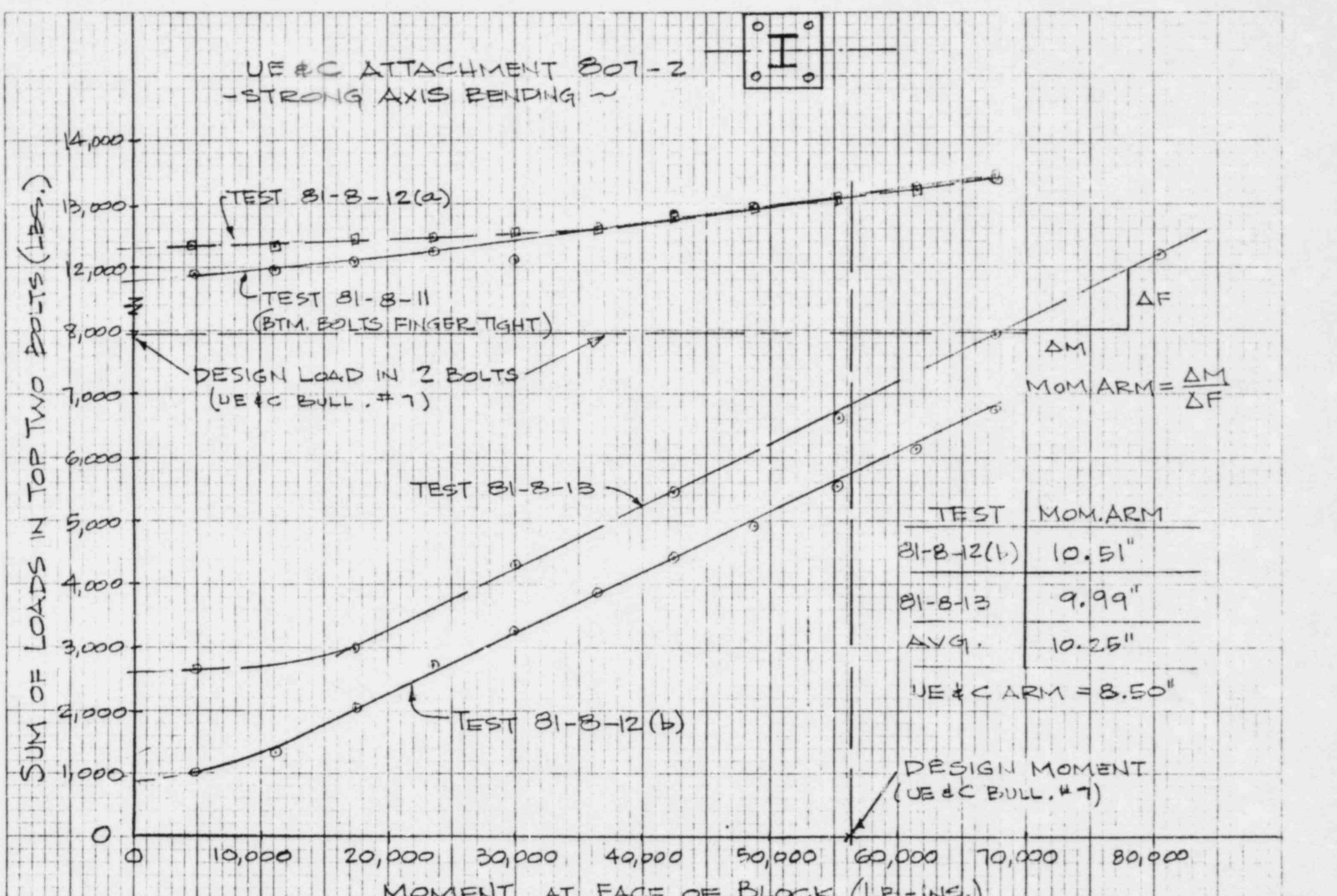


FIGURE 8. BOLT LOAD VS. MOMENT FOR PART NO. 807-2 (STRONG AXIS) [#2]

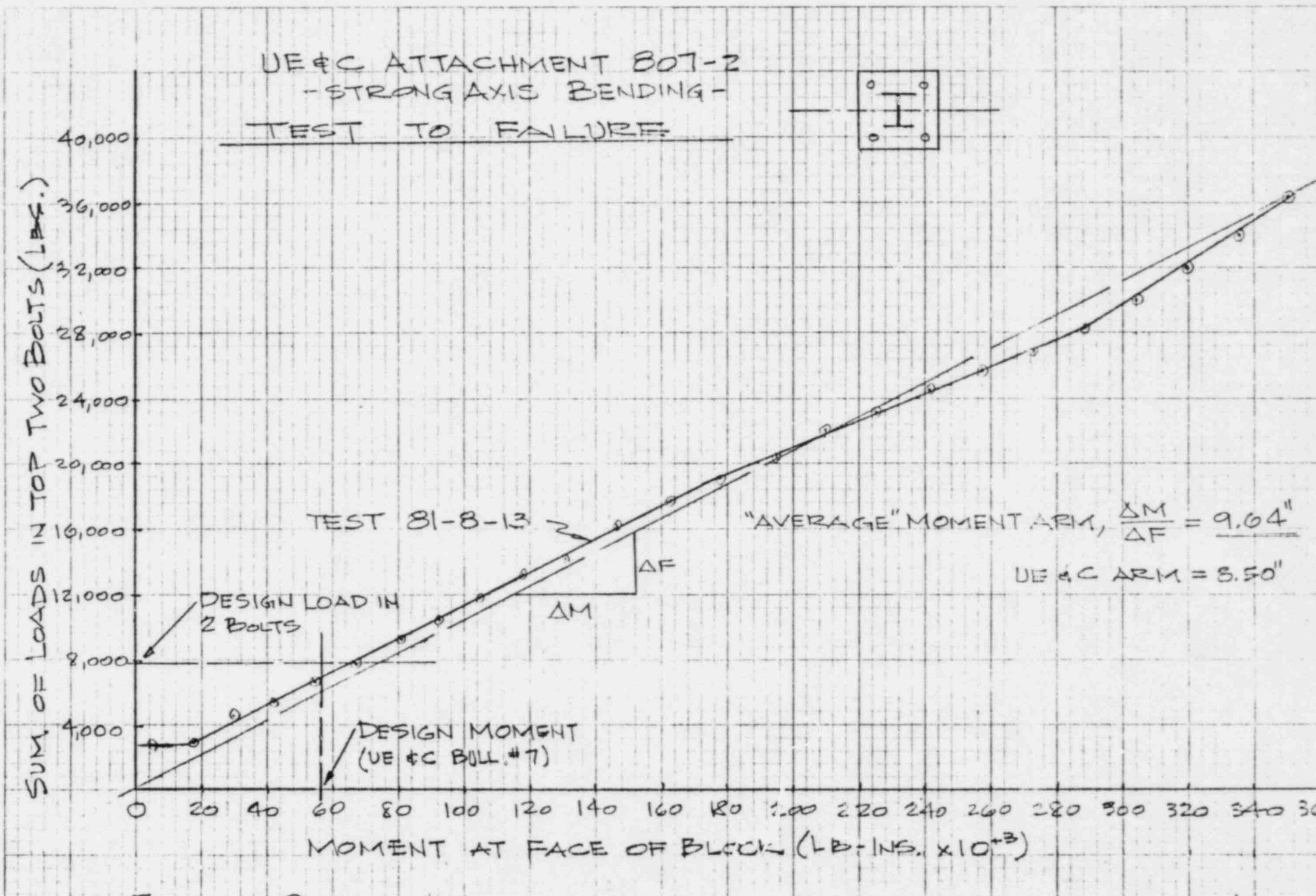


FIGURE 9. BOLT LOAD VS. MOMENT FOR PART NO. 807-2 (STRONG AXIS)
~ TEST TO FAILURE ~

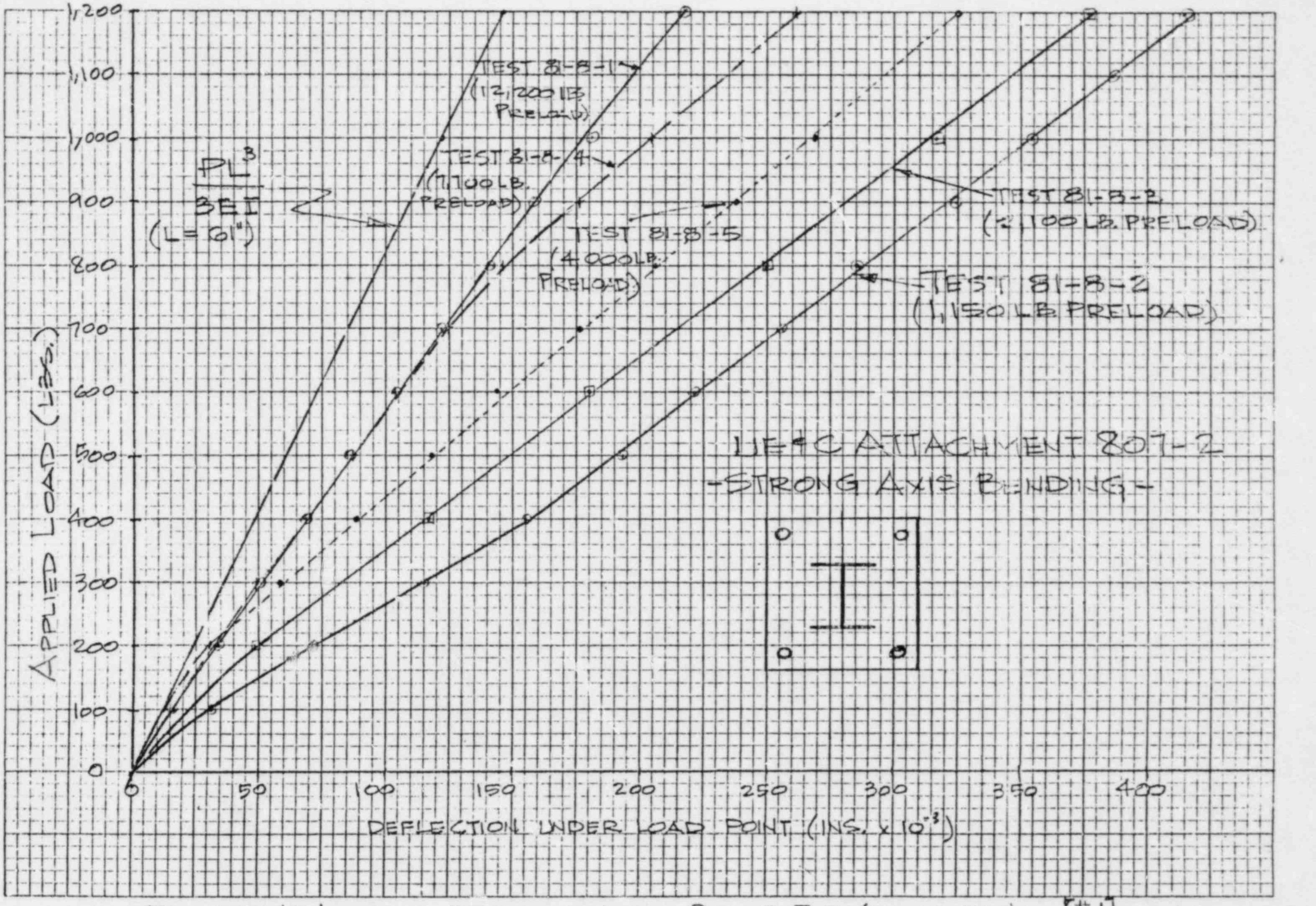


FIGURE 10. LOAD VS. DEFLECTION FOR PART 807-2 (STRONG AXIS) [#1]

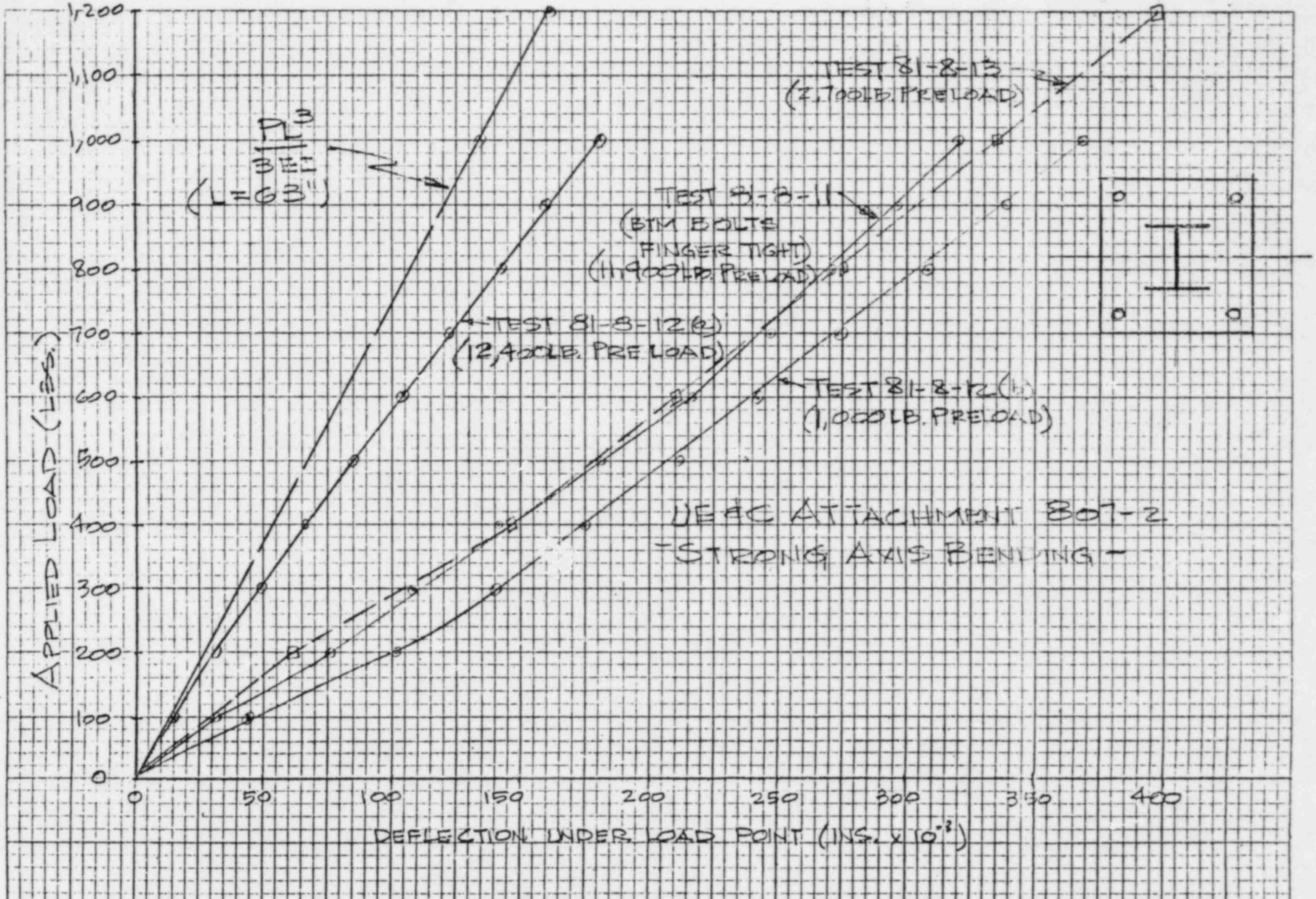
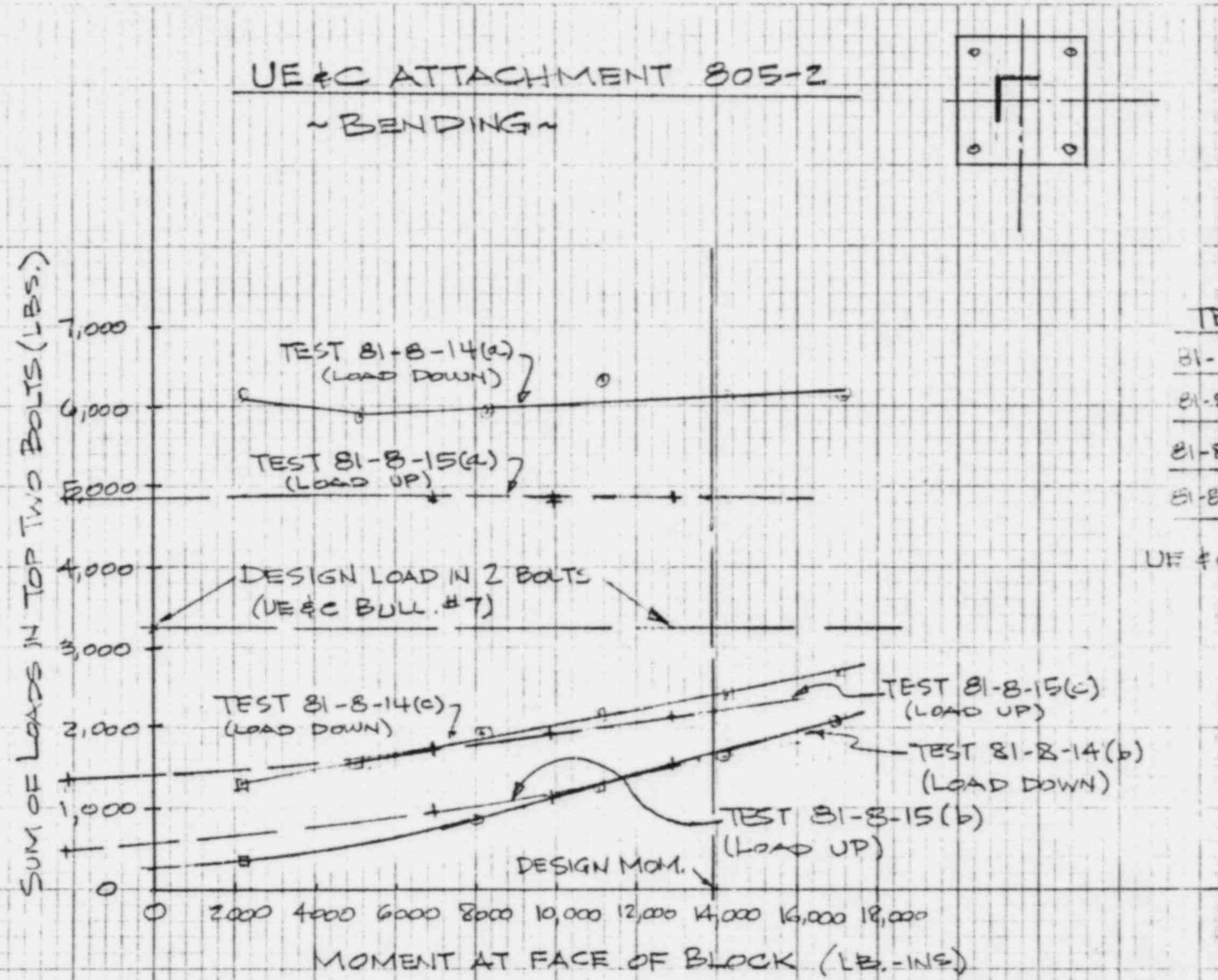


FIGURE 11. Load vs. Deflection for Part 807-2 (Strong Axis) [#2]



TEST	MOM. ARM
81-8-14(b)	7.43"
81-8-14(c)	10.19"
81-8-15(b)	7.50" ±
81-8-15(c)	13.16"

UE&C ARM = 5.75"

FIGURE 12. BOLT LOAD VS. MOMENT FOR PART No. 805-2

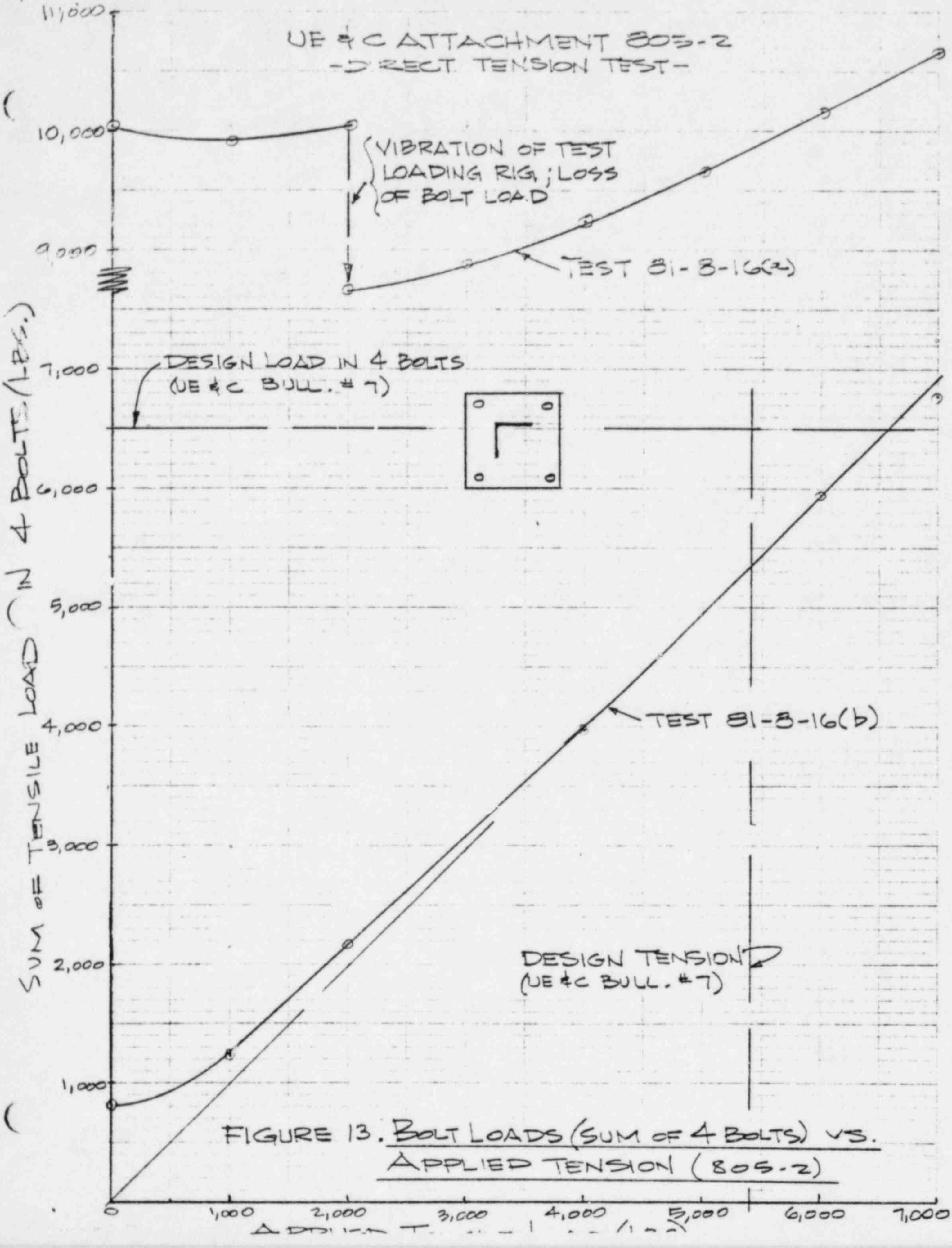


FIGURE 13. BOLT LOADS (SUM OF 4 BOLTS) VS. APPLIED TENSION (805-2)

UE&C ATTACHMENT 805-2

- DIRECT TENSION TEST TO FAILURE -

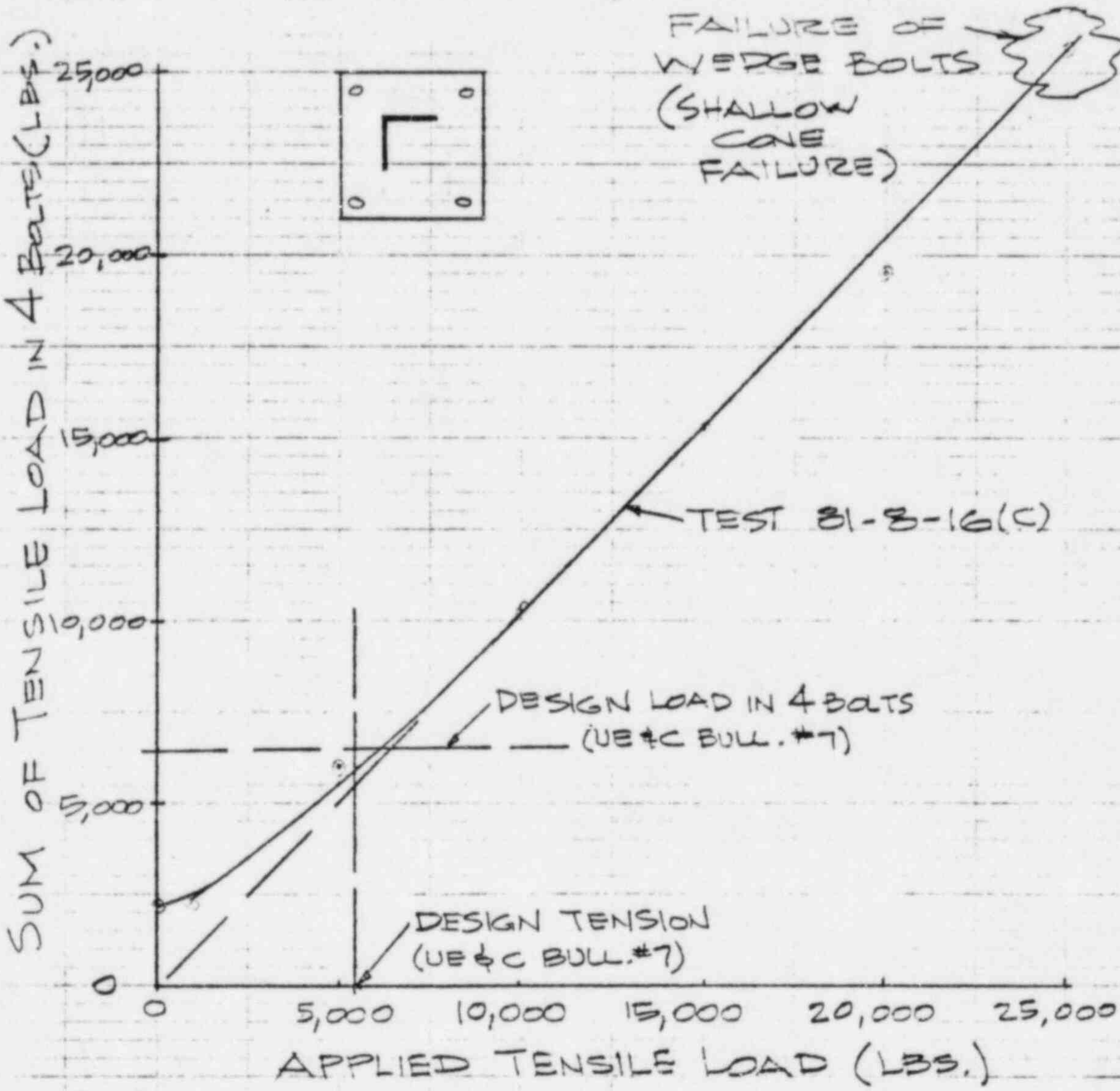


FIGURE 14. BOLT LOAD (SUM OF 4 BOLTS) VS. APPLIED TENSION

(805-2)

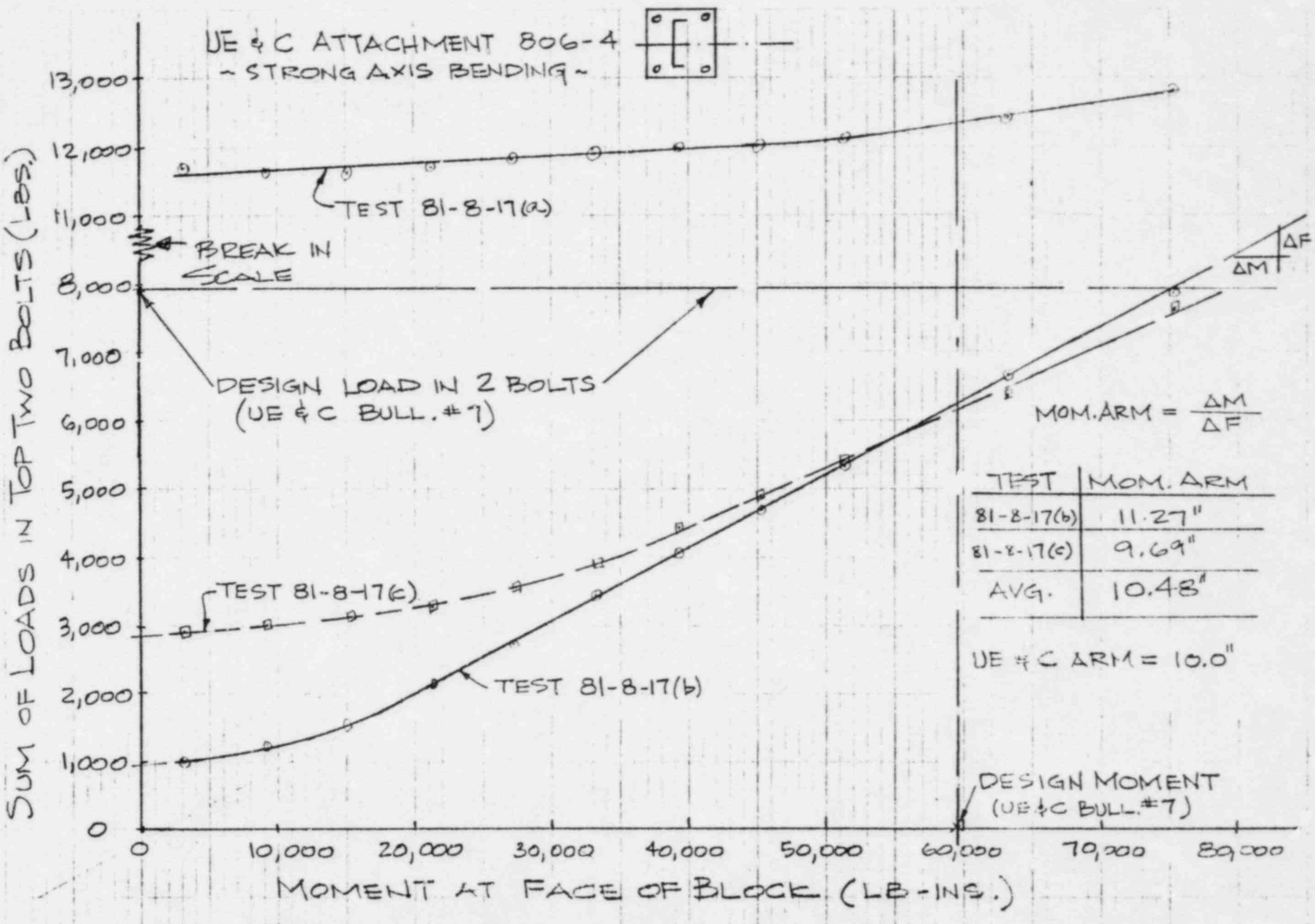


FIGURE 15. BOLT LOAD VS. MOMENT FOR PART No. 806-4 (STRONG AXIS)

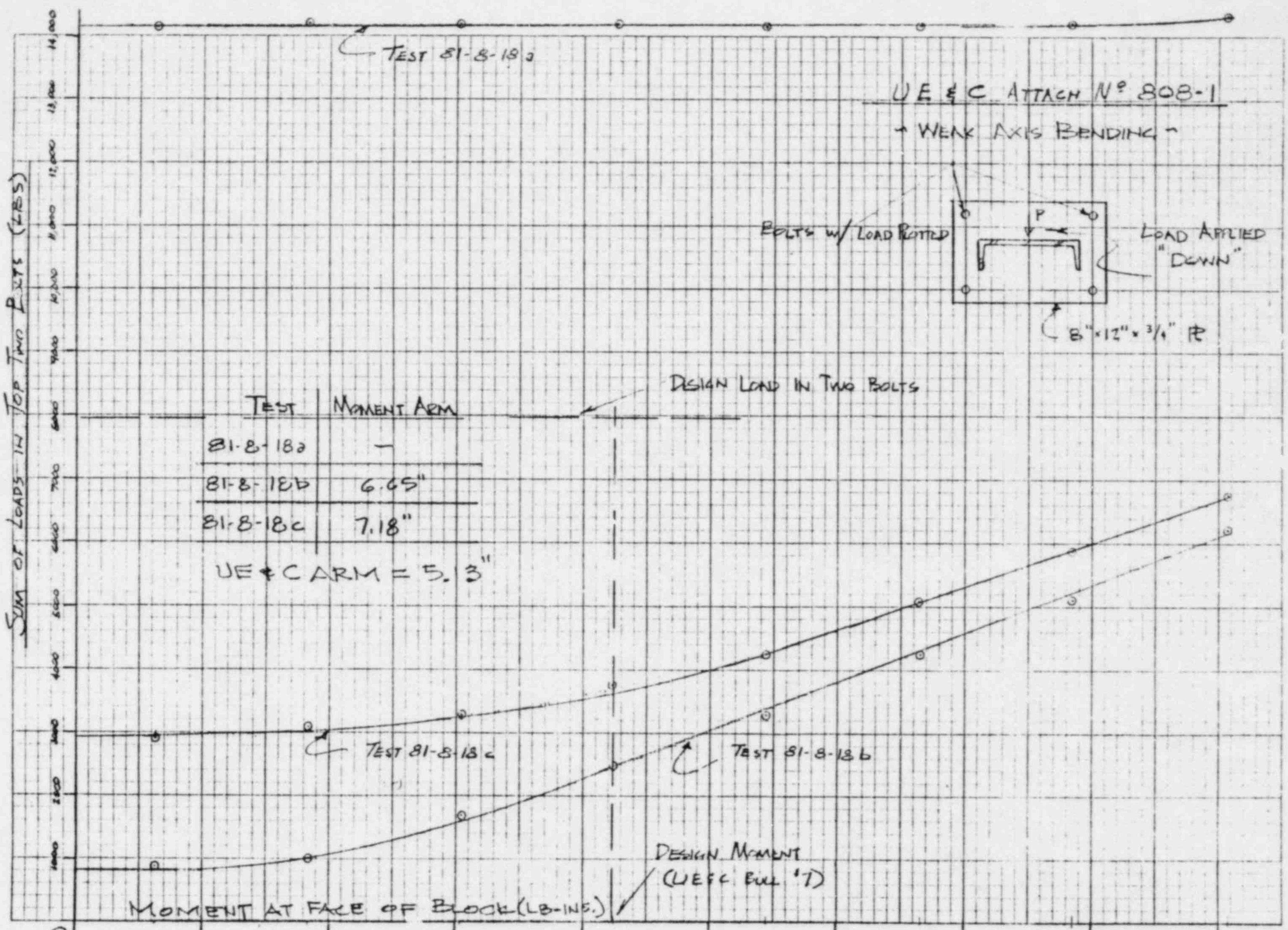


FIGURE 16 BOLT LOAD VS. MOMENT FOR PART Nº 808-1

10 Squares to the Inch

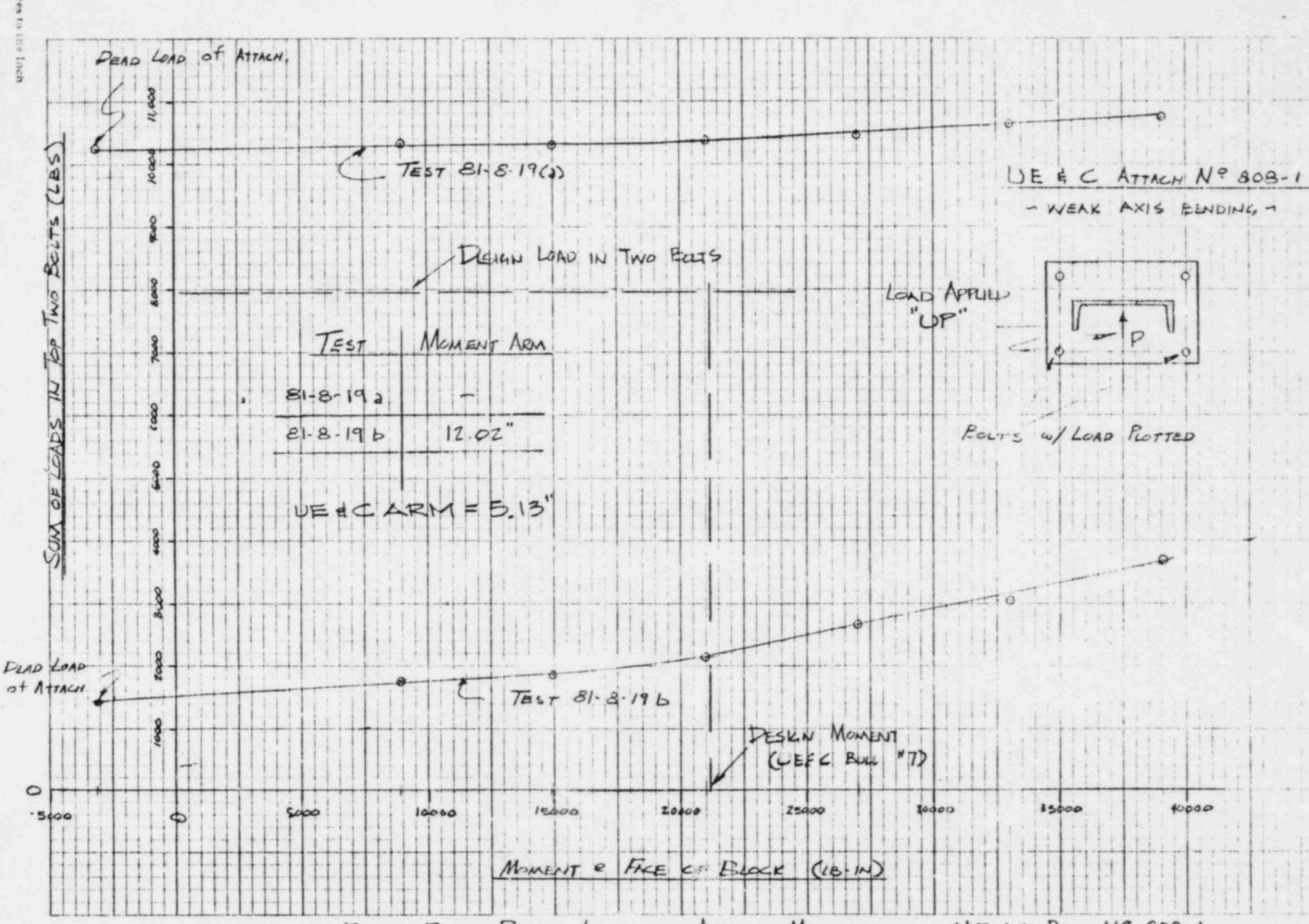


FIGURE 17 BOLT LOAD vs APPLIED MOMENT - UE & C PART Nº 808-1

10 Squares to the Inch

UE & C ATTACHMENT 806-4
~DIRECT TENSION TEST~

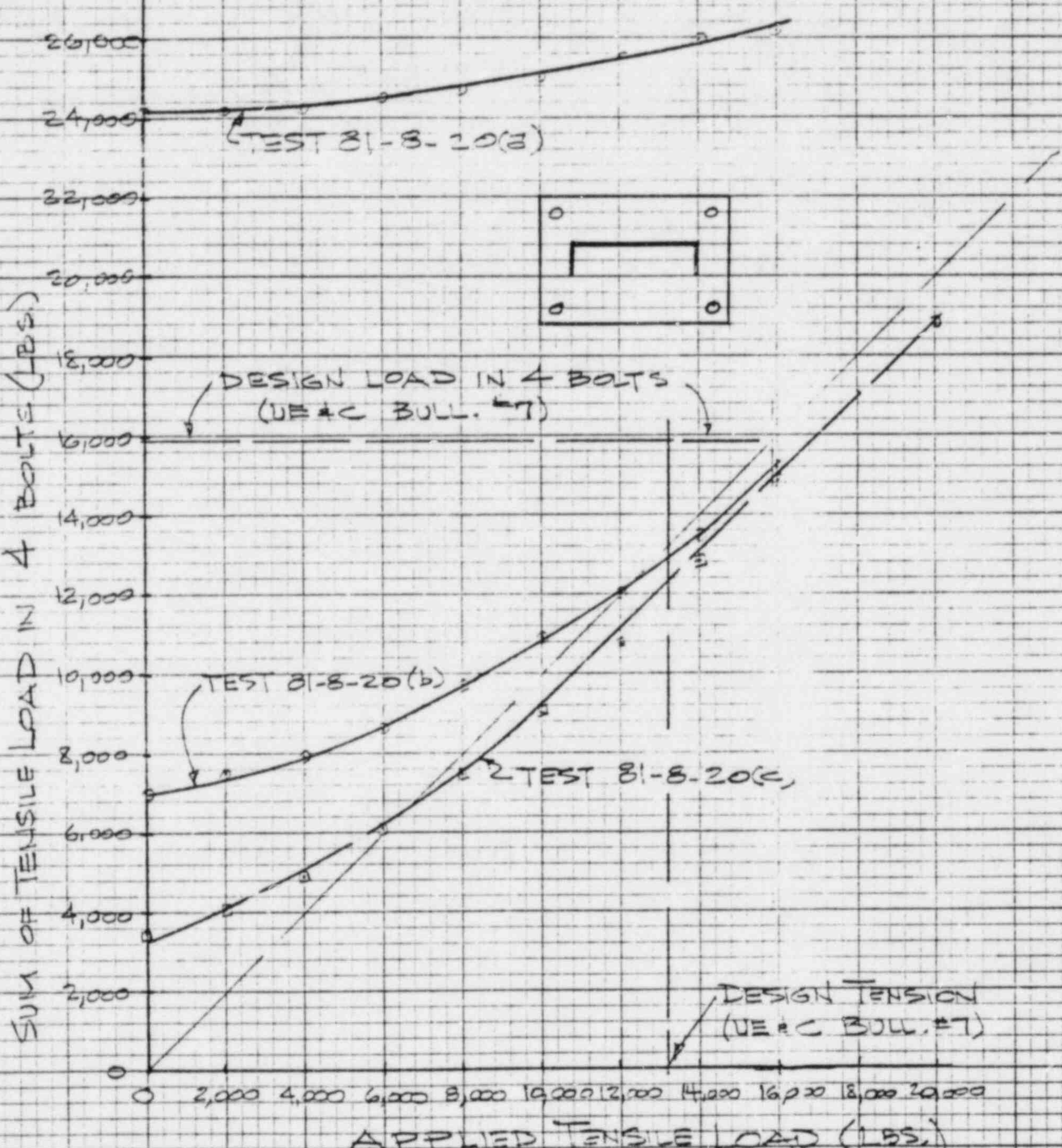


FIGURE 18

BOLT LOAD VS. APPLIED TENSION - PART № 806-4

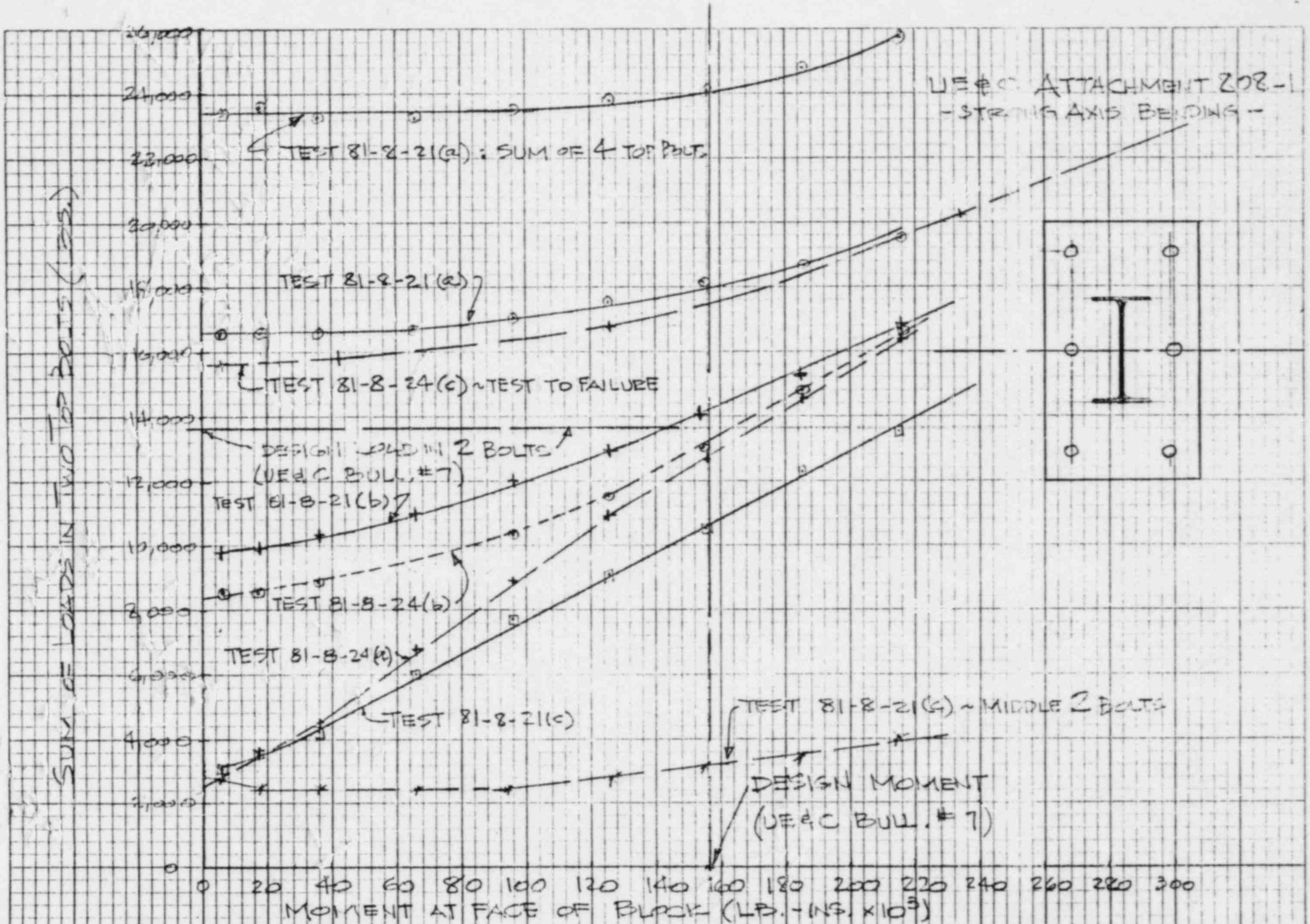


FIGURE 19. BOLT LOAD VS. MOMENT FOR PART No 808-1 (STRONG AXIS)

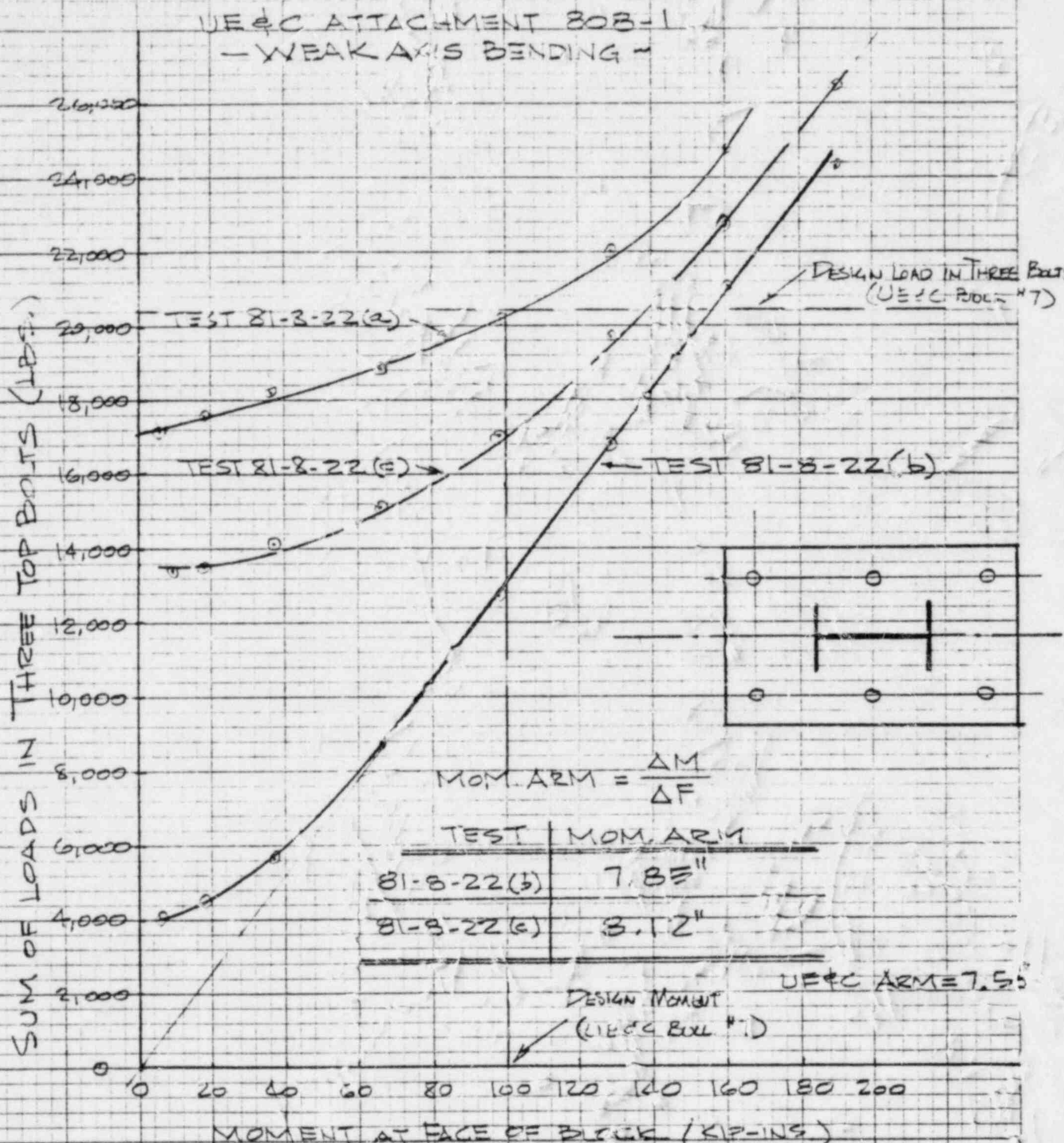
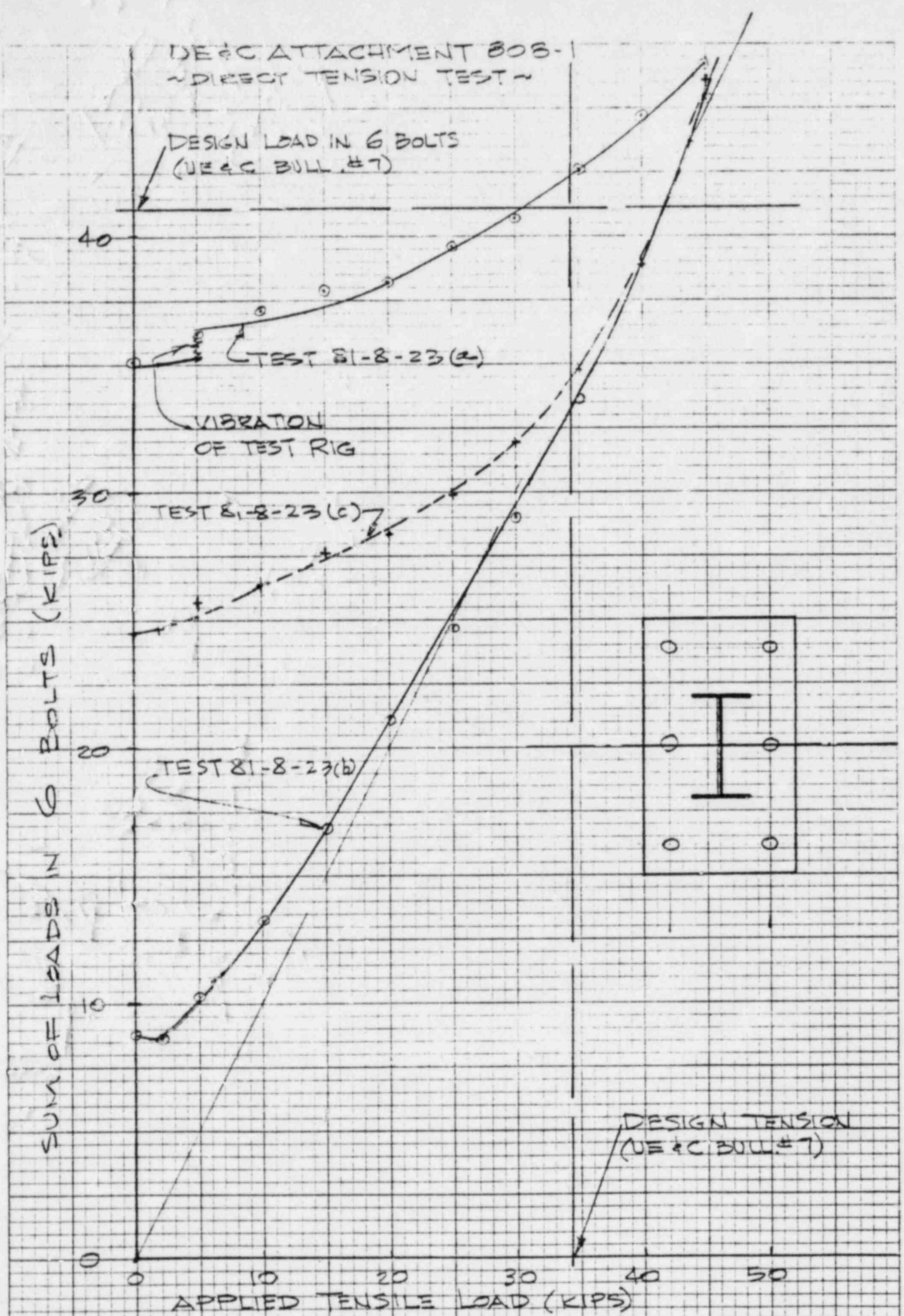


FIGURE 20 BOLT LOAD VS. MOMENT FOR PART No 808-1 (WEAK AXIS)



10 Squares to the Inch

FIGURE 21 Bolt Load vs. Applied Tension - Part No 808-1

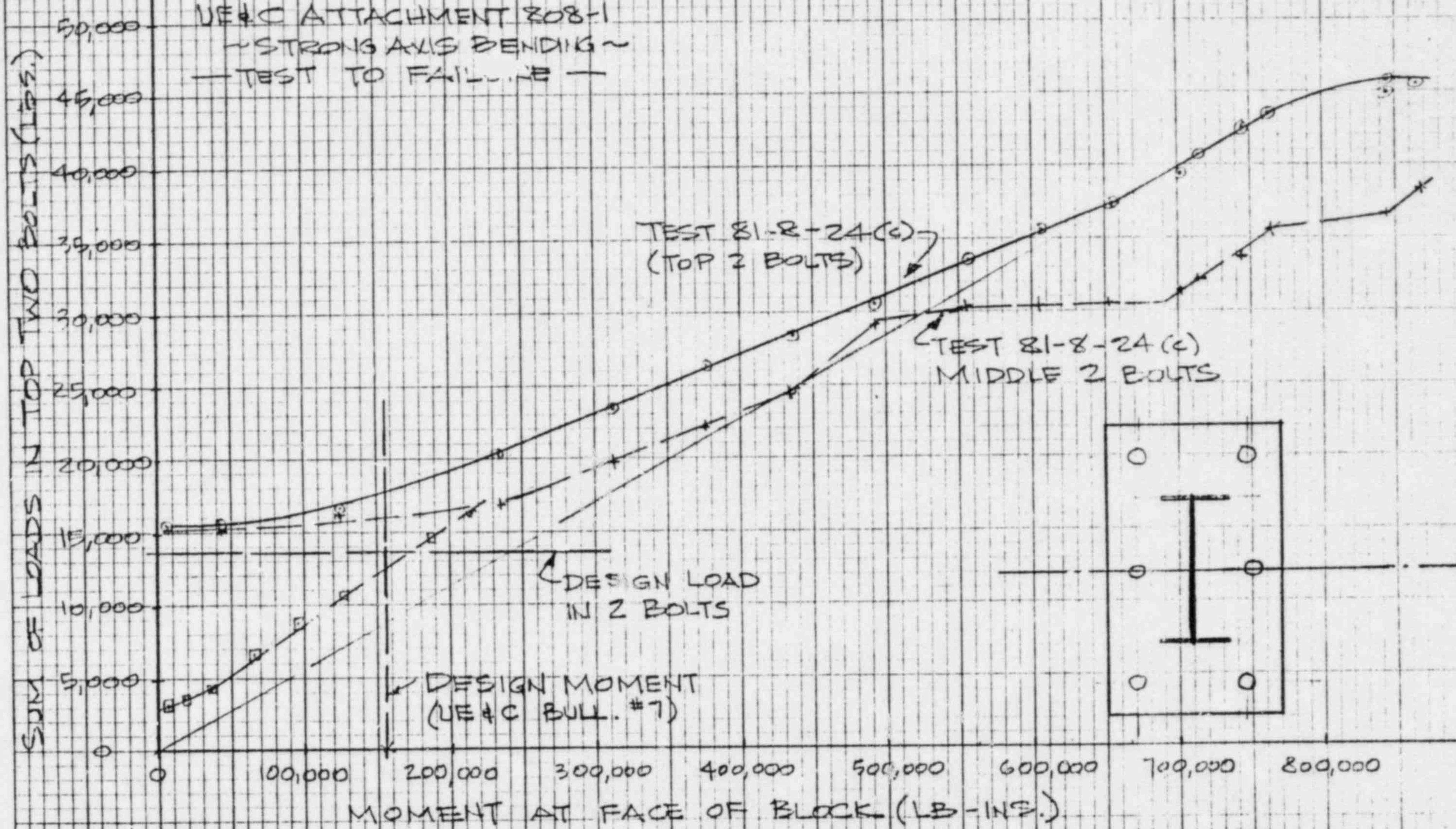


FIGURE 22 BOLT LOAD VS. MOMENT FOR PART № 808-1 (STRONG AXIS)

~ TEST TO FAILURE ~

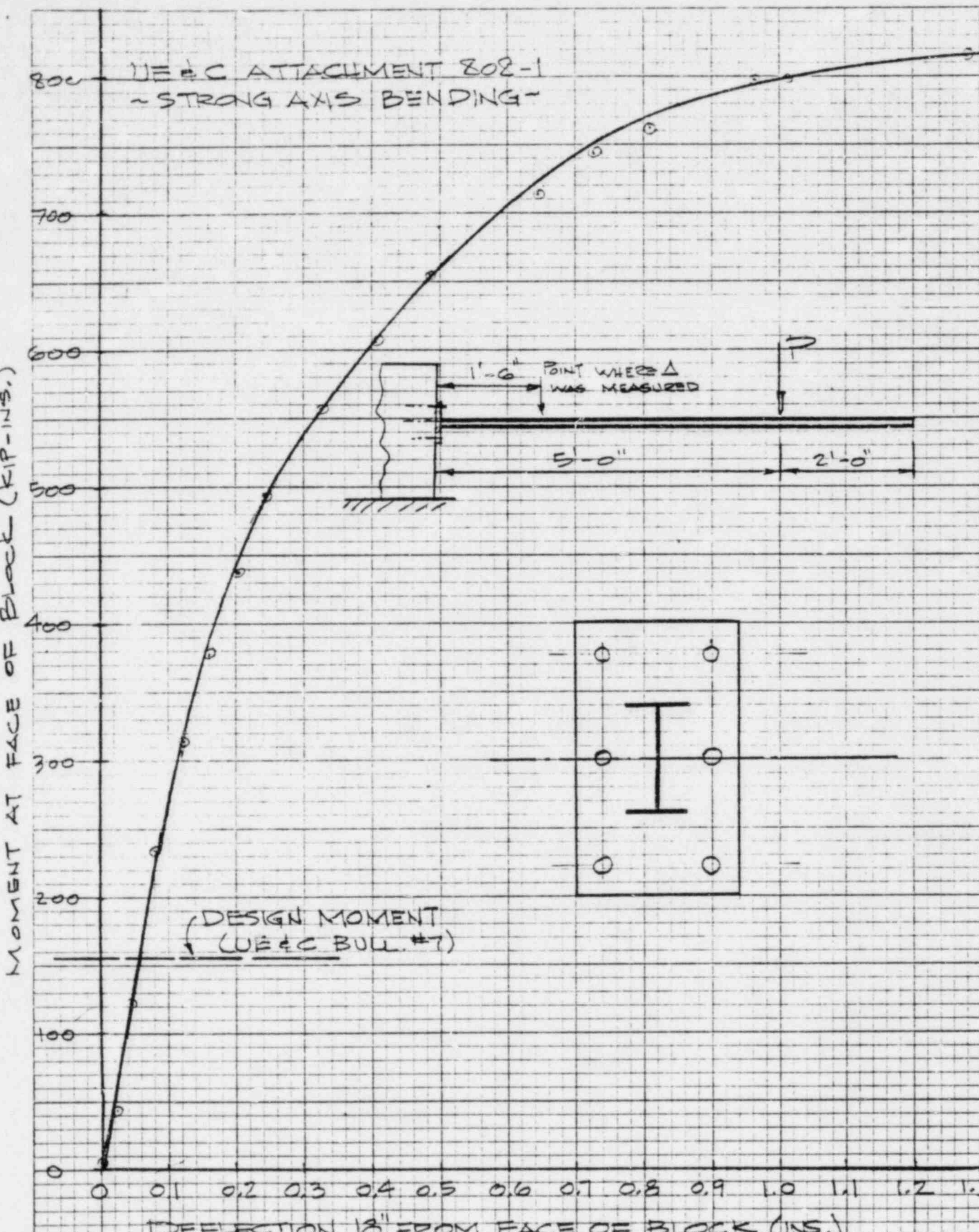


FIGURE 23 MOMENT VS. DEFLECTION (STRONG AXIS)

10 Squares to the Inch

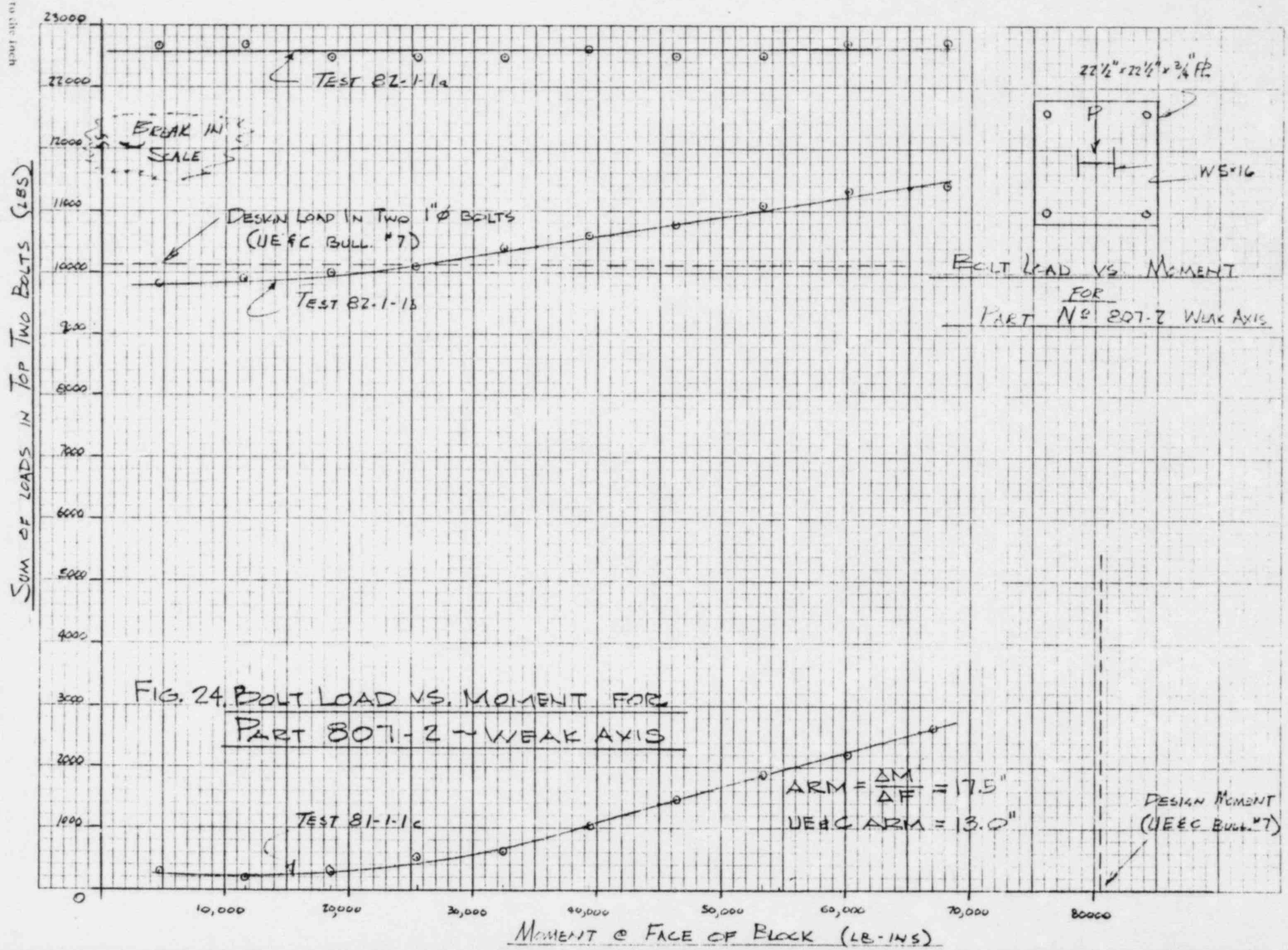


FIG. 24. BOLT LOAD VS. MOMENT FOR PART 807-2 ~ WEAK AXIS

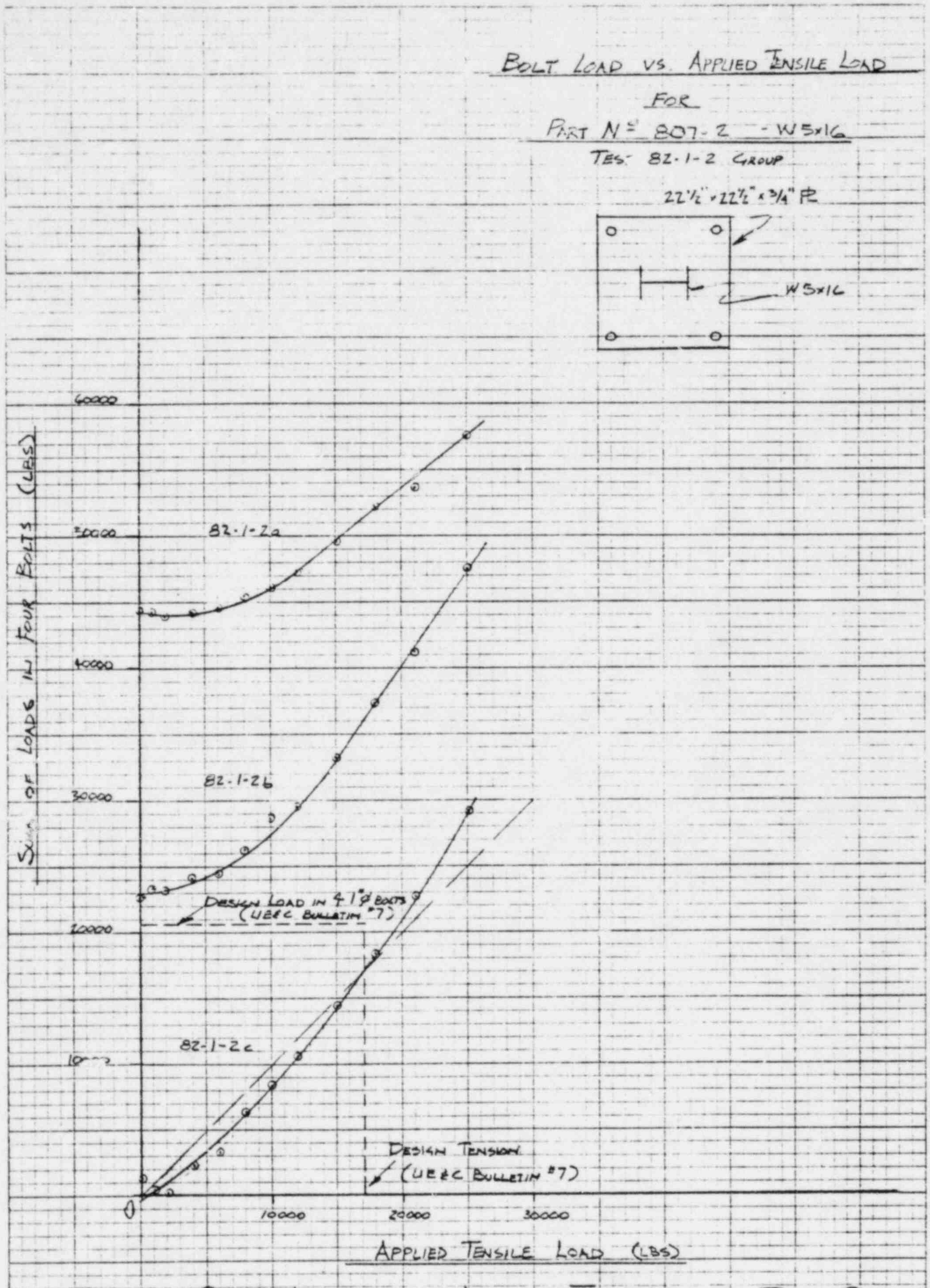


FIG 25. BOLT LOAD VS. APPLIED TENSION FOR PART 807-2

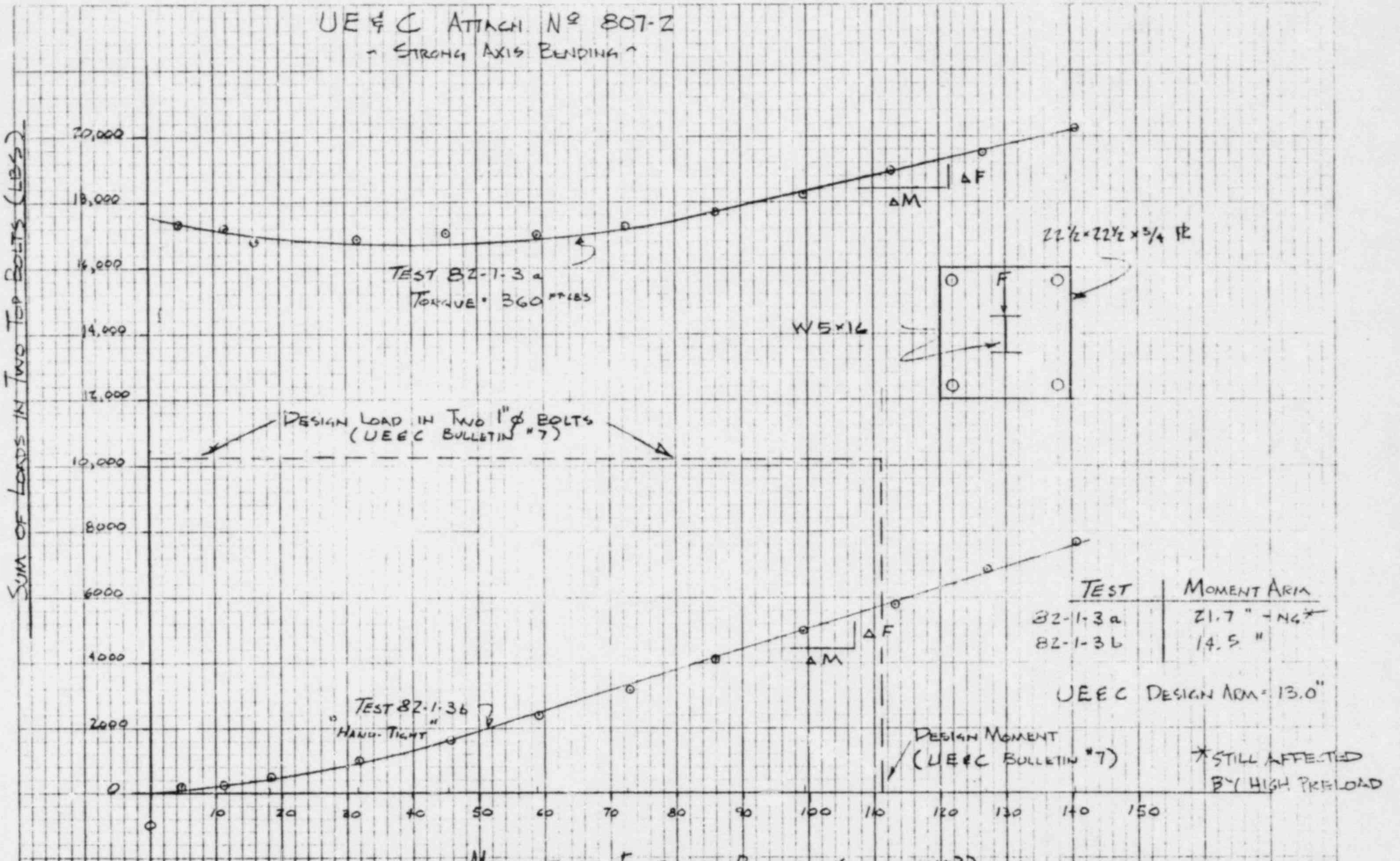


FIG 26. BOLT LOAD VS. MOMENT FOR PART 807-Z ~ STRONG AXIS

10 Squares to the Inch

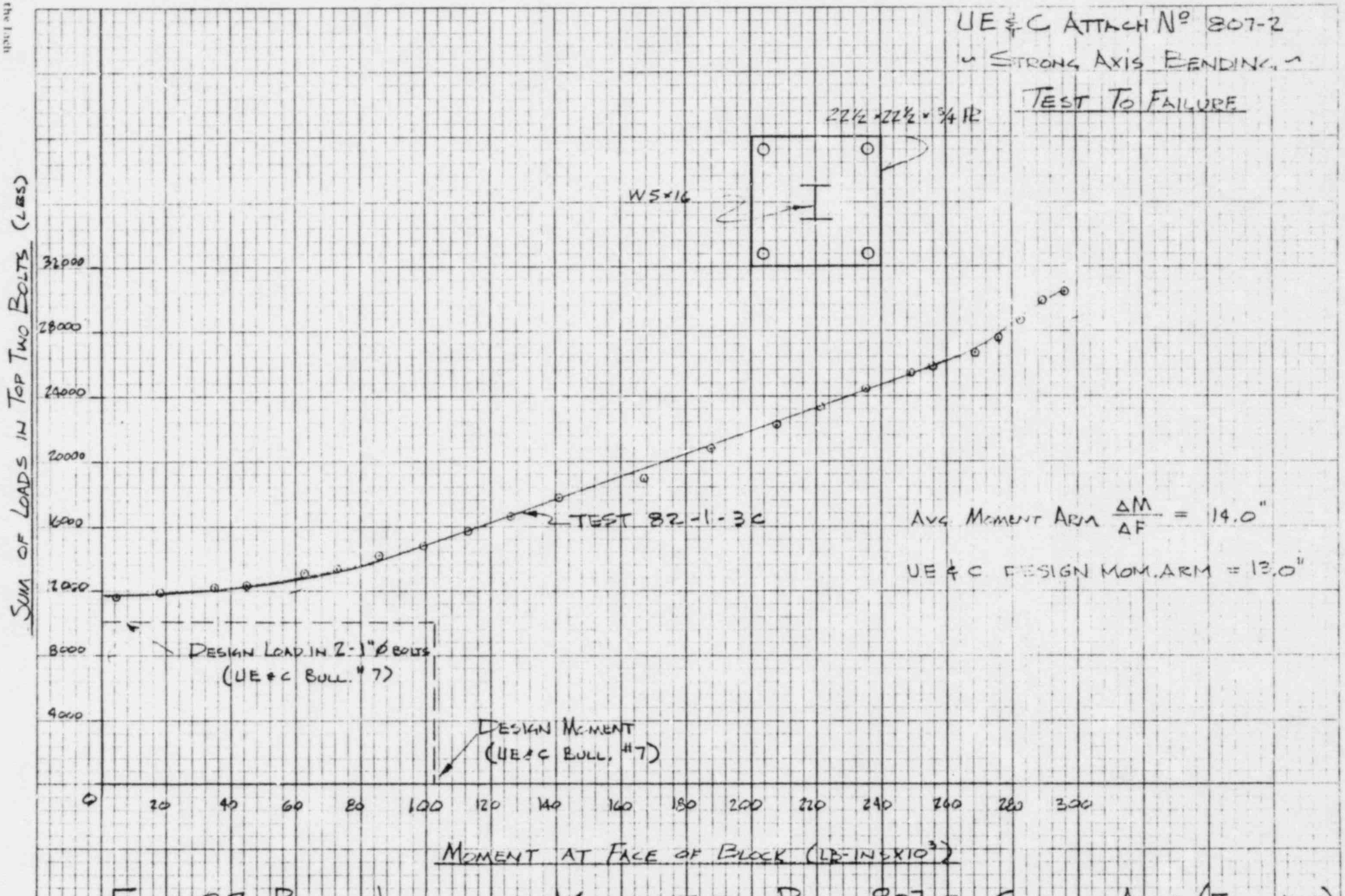


FIG. 27. BOLT LOAD VS. MOMENT FOR PART 807-2 - STRONG AXIS (FAILURE)

10 Squares to the Inch

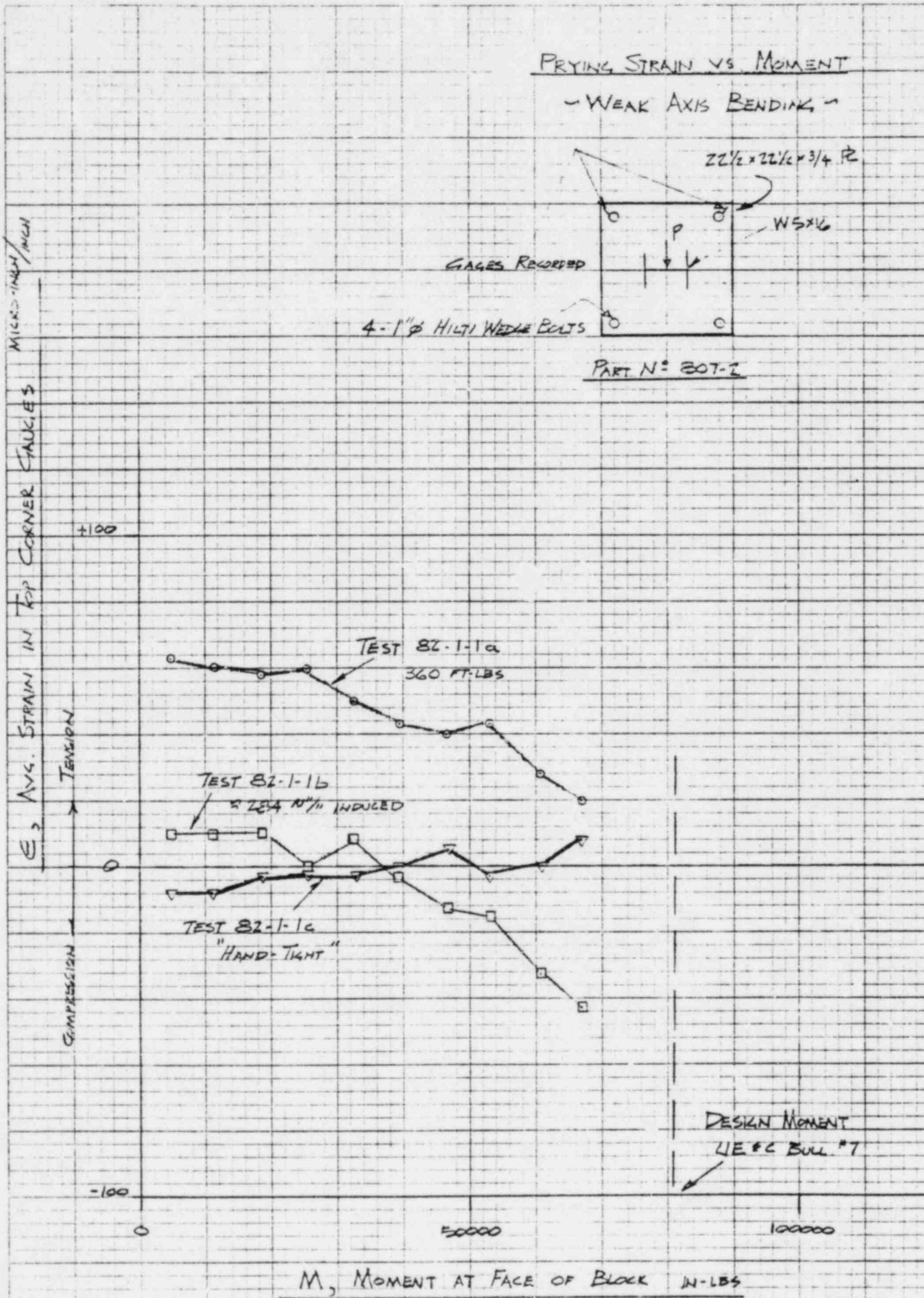
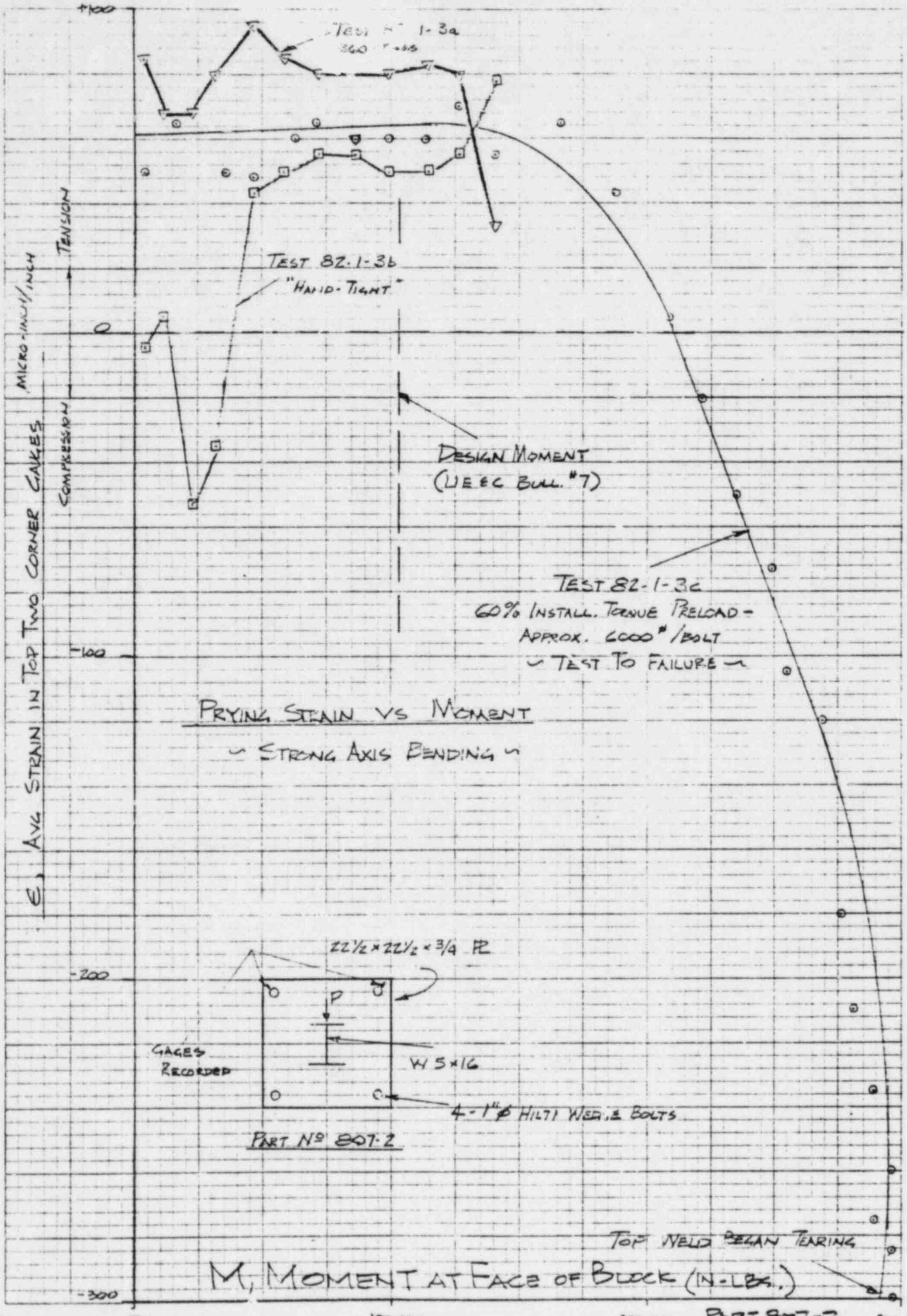


FIG 28 AVERAGE STRAIN IN CORNER GAGES VS. MOMENT

PART 807-2



20 Squares to the Inch

FIG. 29. AVERAGE STRAIN IN CORNER GAGES VS. MOMENT

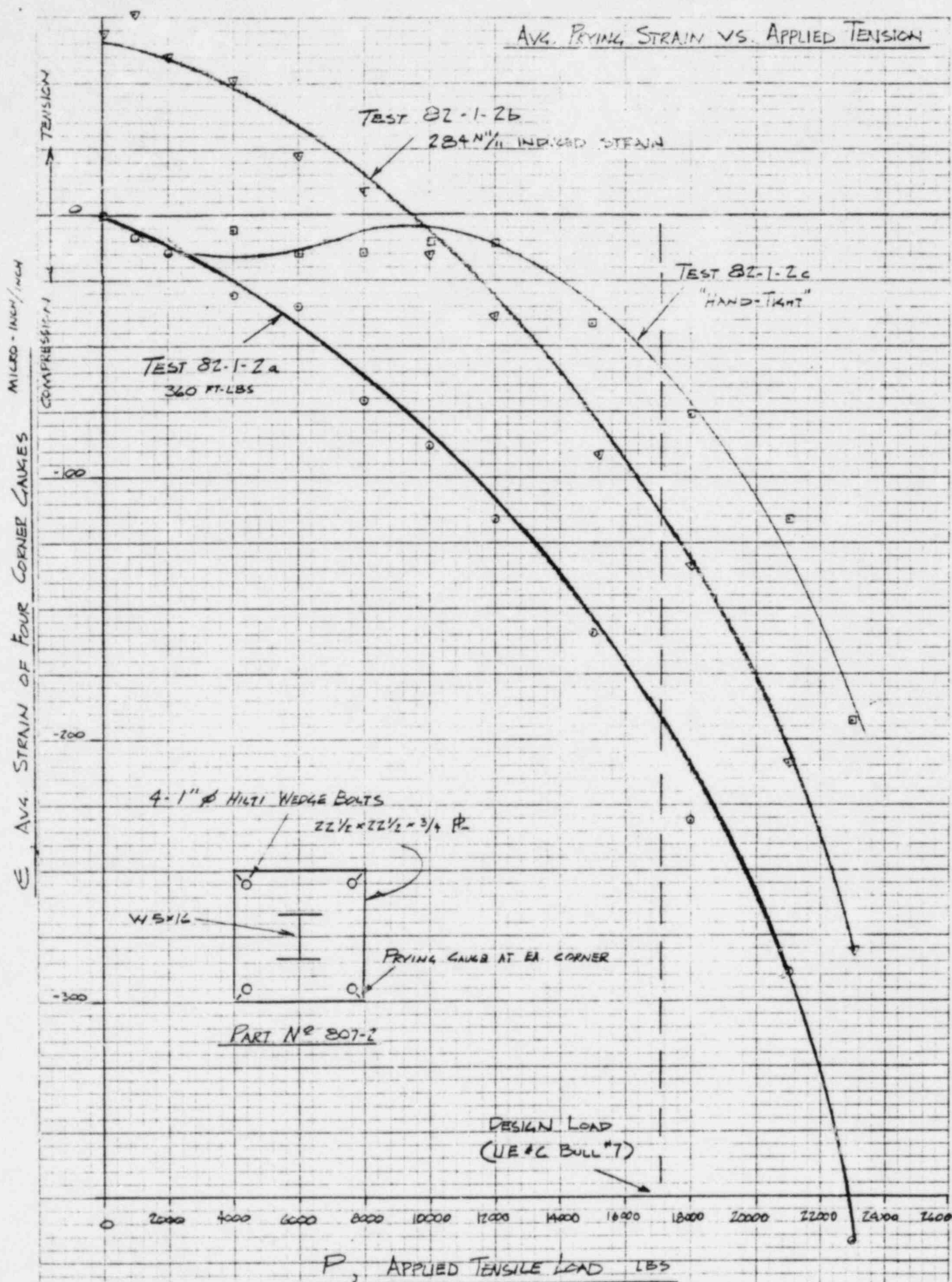


FIG 30. AVERAGE STRAIN IN CORNER GAGES VS. TENSILE LOAD

PART 807-2

squares to the inch

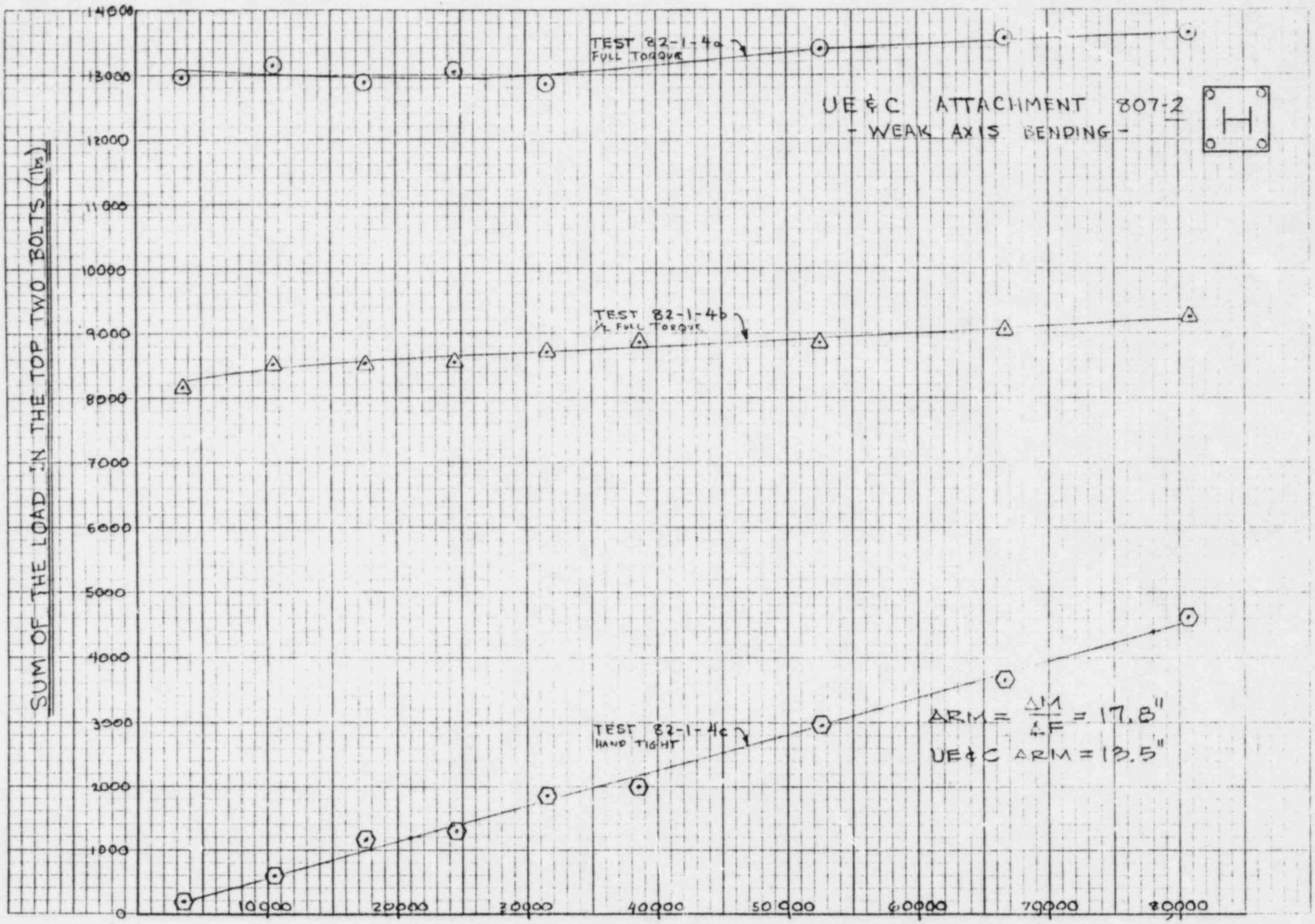
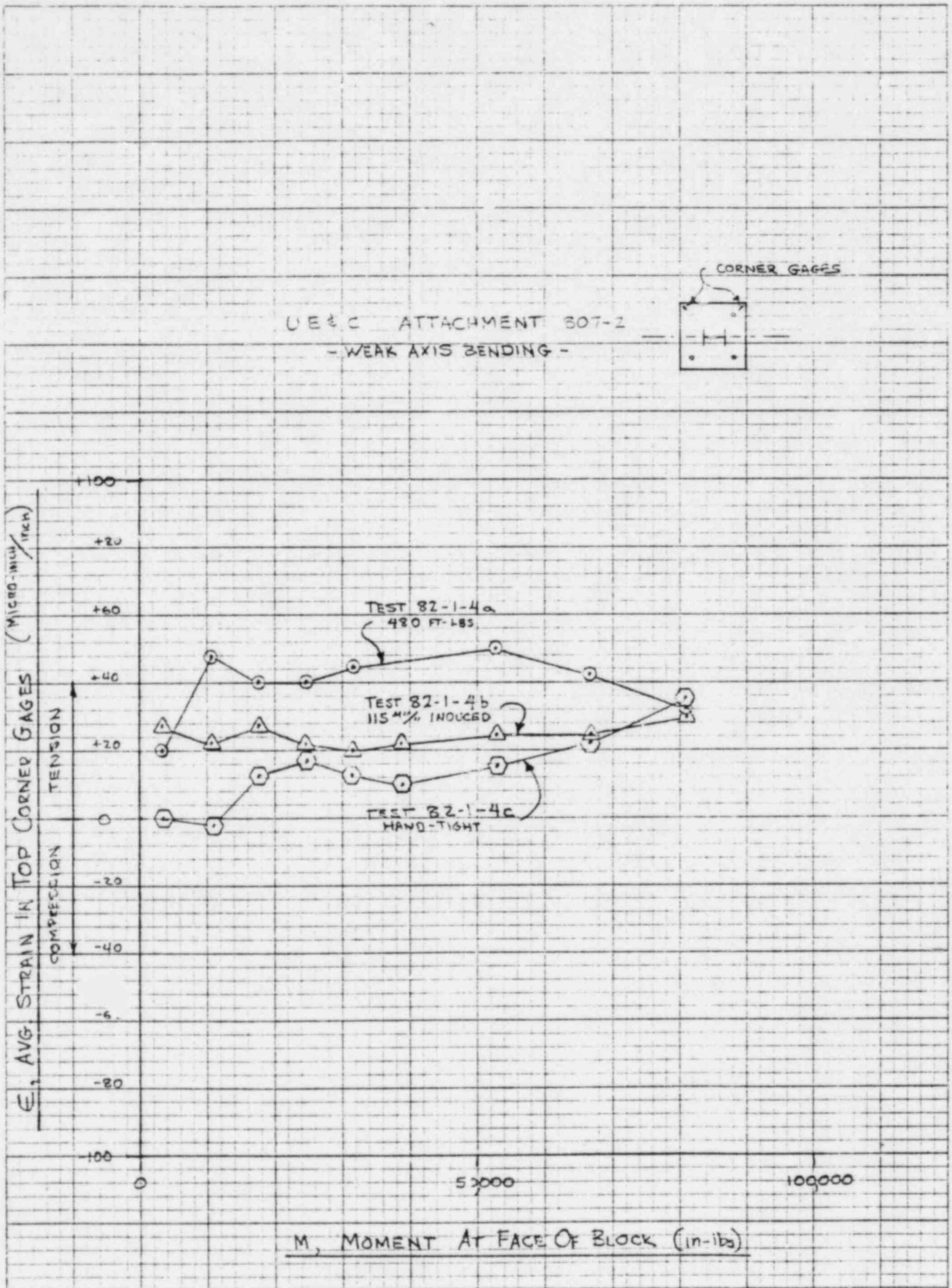


FIG. 31. BOLT LOAD - vs - APPLIED MOMENT UE&C PART No. 807-2

10 Squares to the Inch



10 Squares to the Inch

FIG. 32. AVERAGE STRAIN IN TOP CORNER GAGES -VS- MOMENT

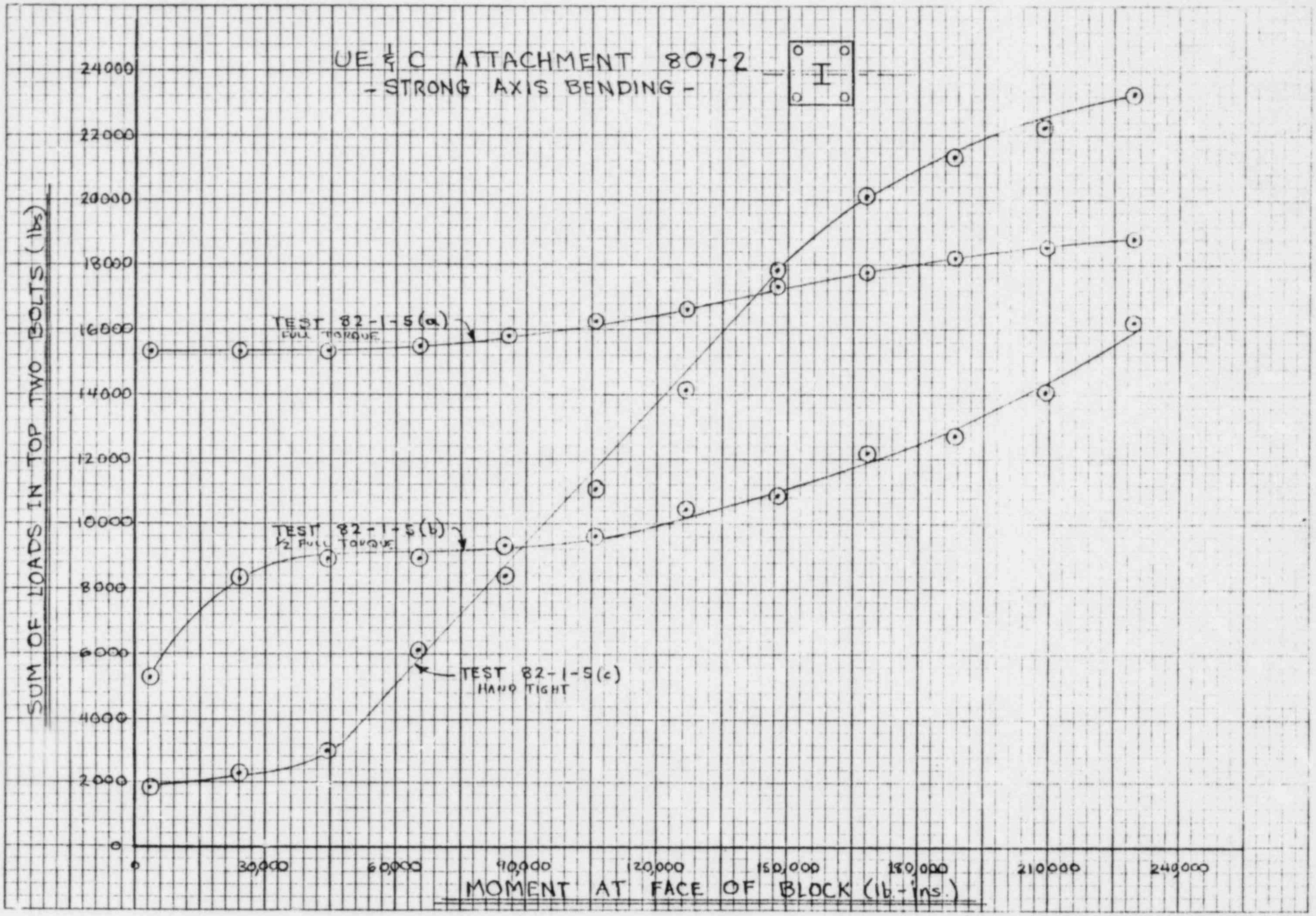
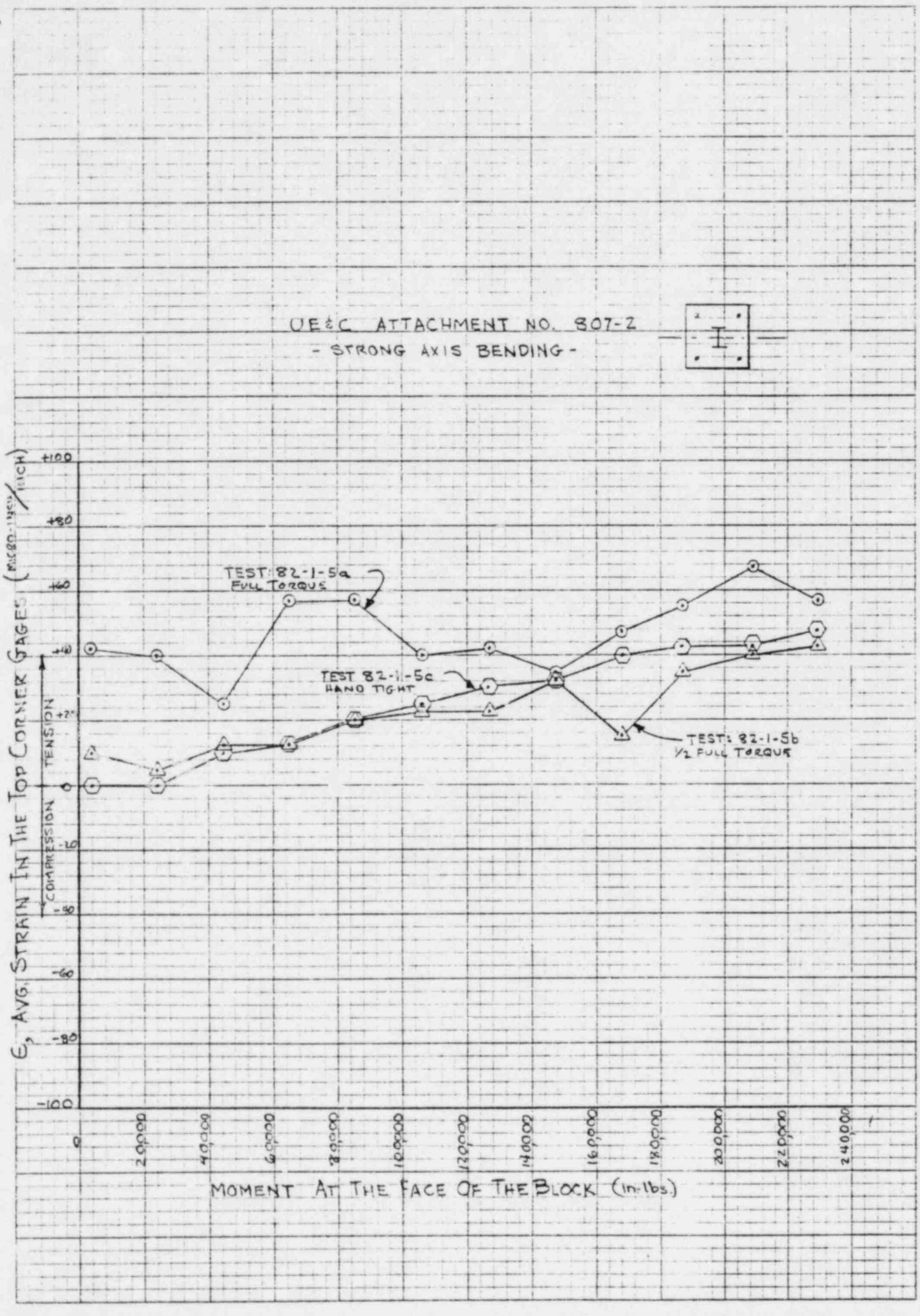


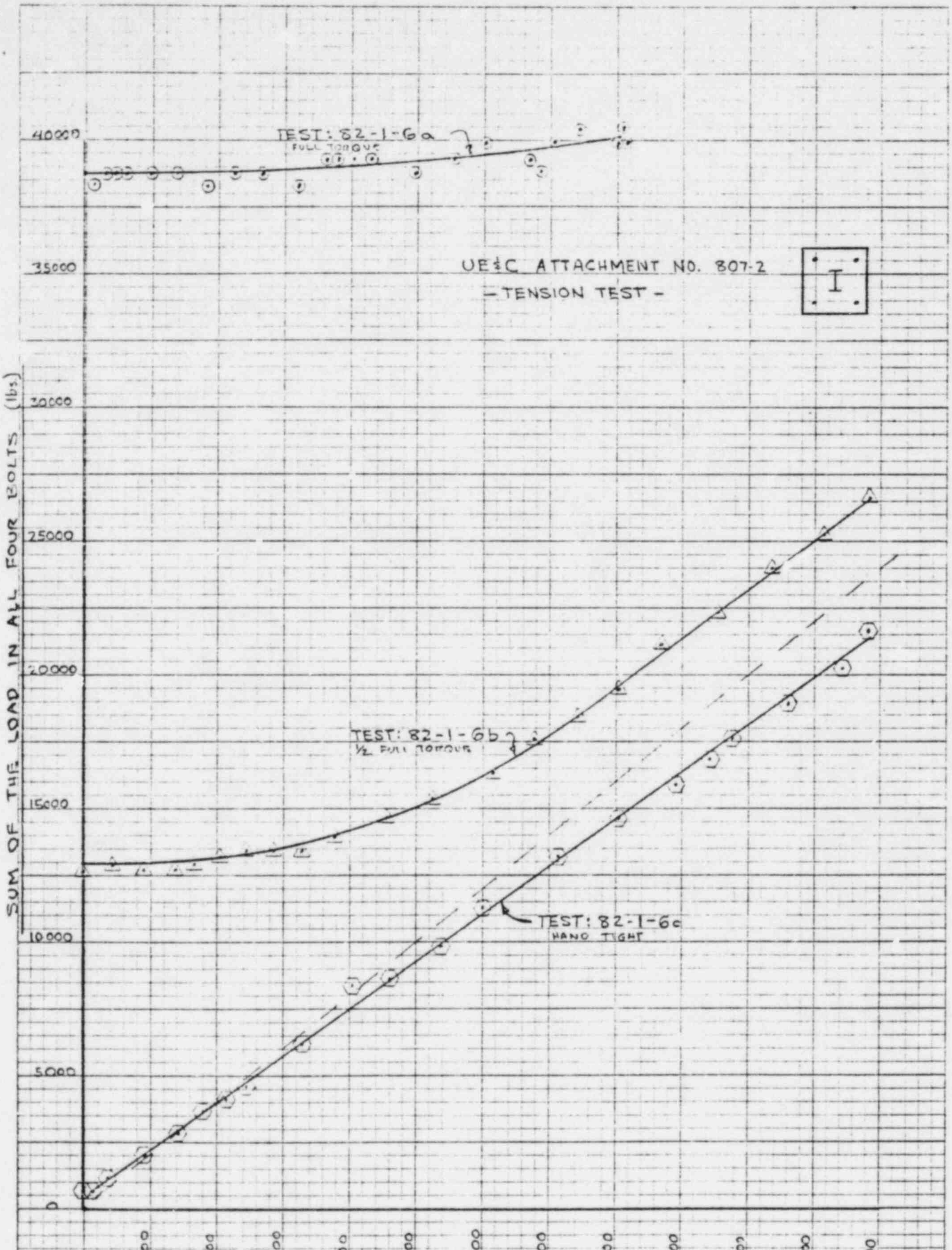
FIG. 33. BOLT LOAD -vs- MOMENT UE&C PART No. 807-2

10 Squares to the Inch



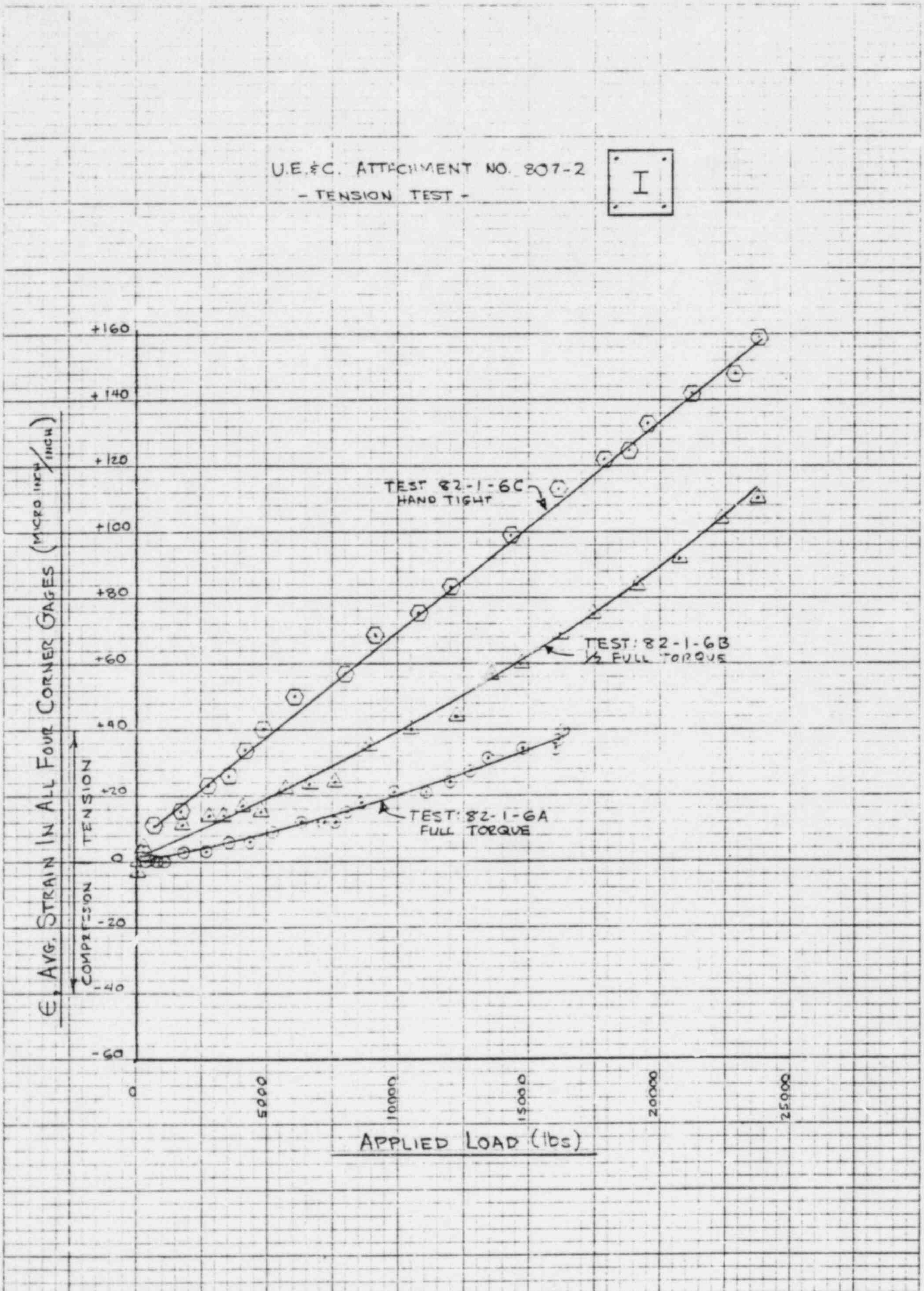
10 Squares to the Inch

FIG. 34. AVG. STRAIN IN TOP CORNER GAGES -VS- MOMENT



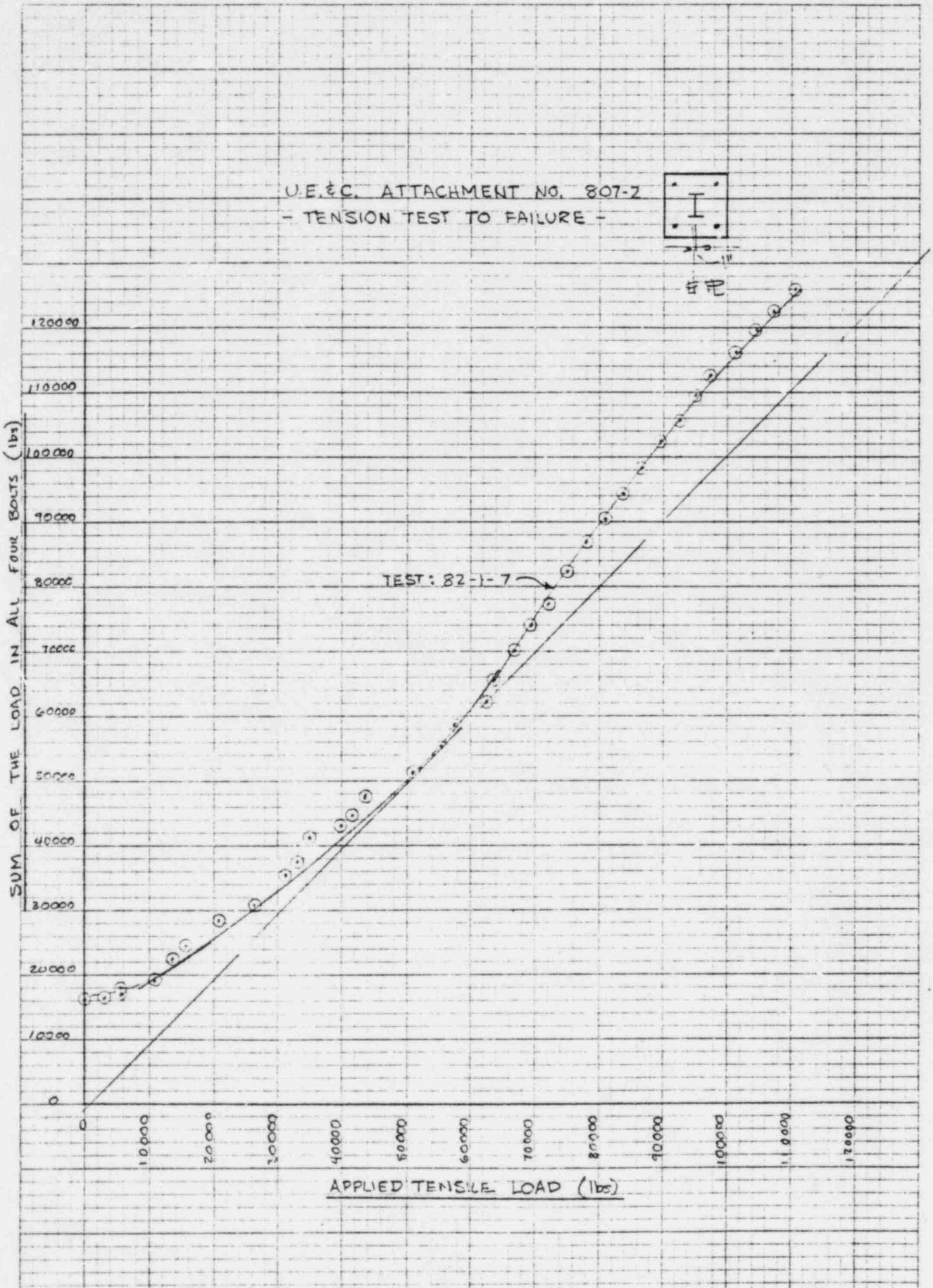
10 Squares to the Inch

FIG. 35. BOLT LOAD -VS- APPLIED TENSILE LOAD



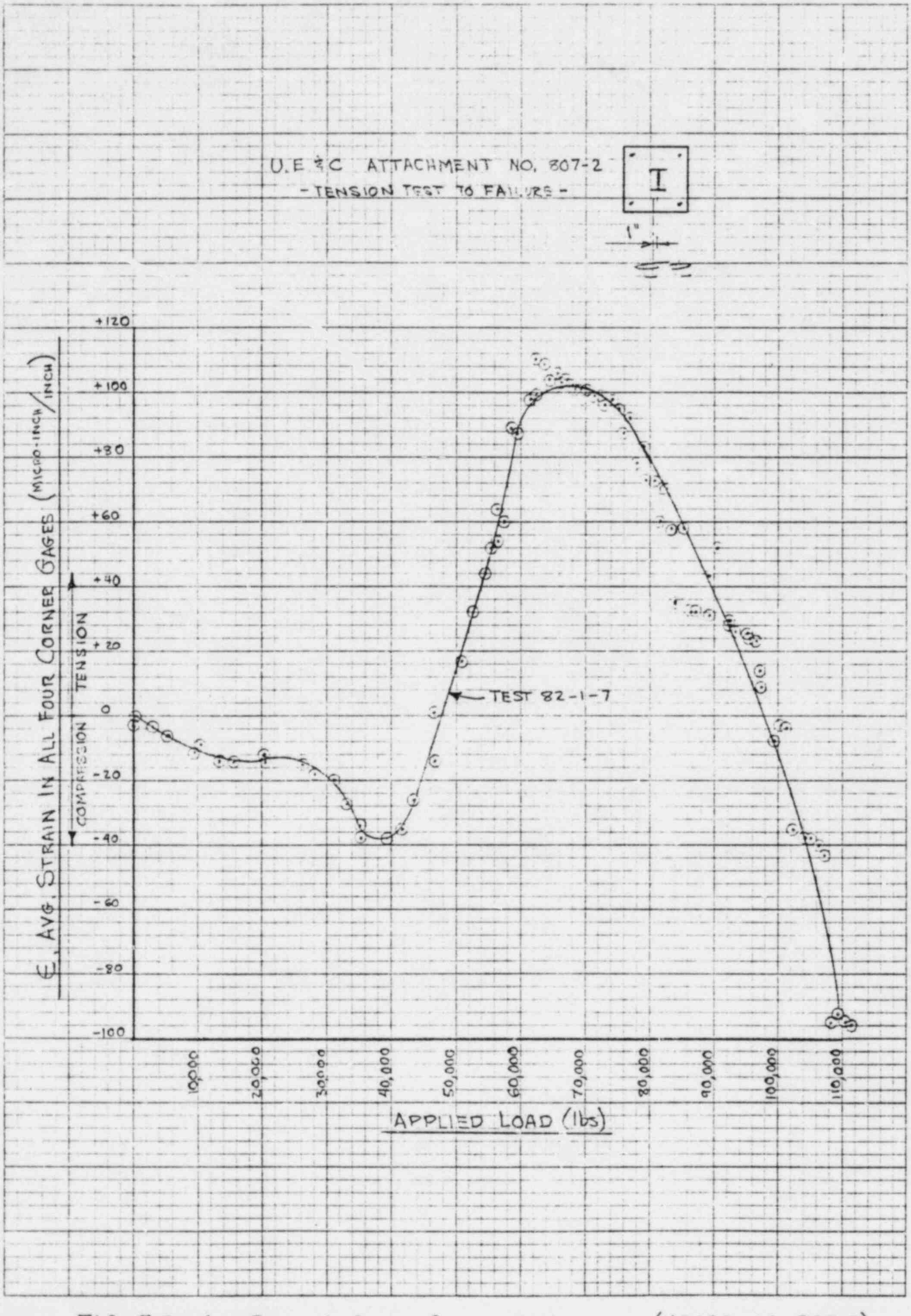
10 Squares to the Inch

FIG. 36. AVG. STRAIN IN CORNER GAGES -VS- LOAD (U.E.&C. PART NO. 807-2)



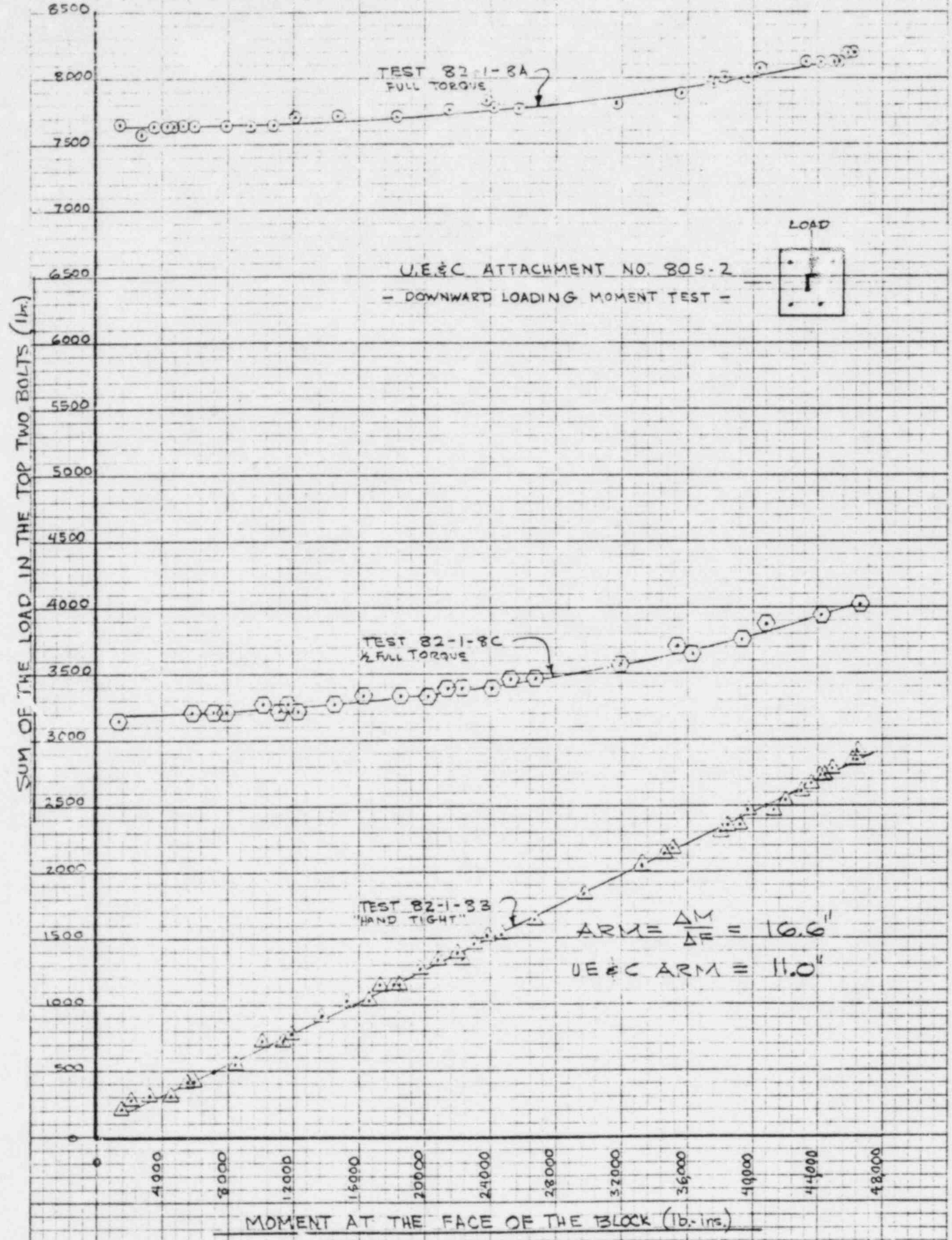
10 Squares to the Inch

FIG. 37. BOLT LOAD -VS- APPLIED TENSILE LOAD



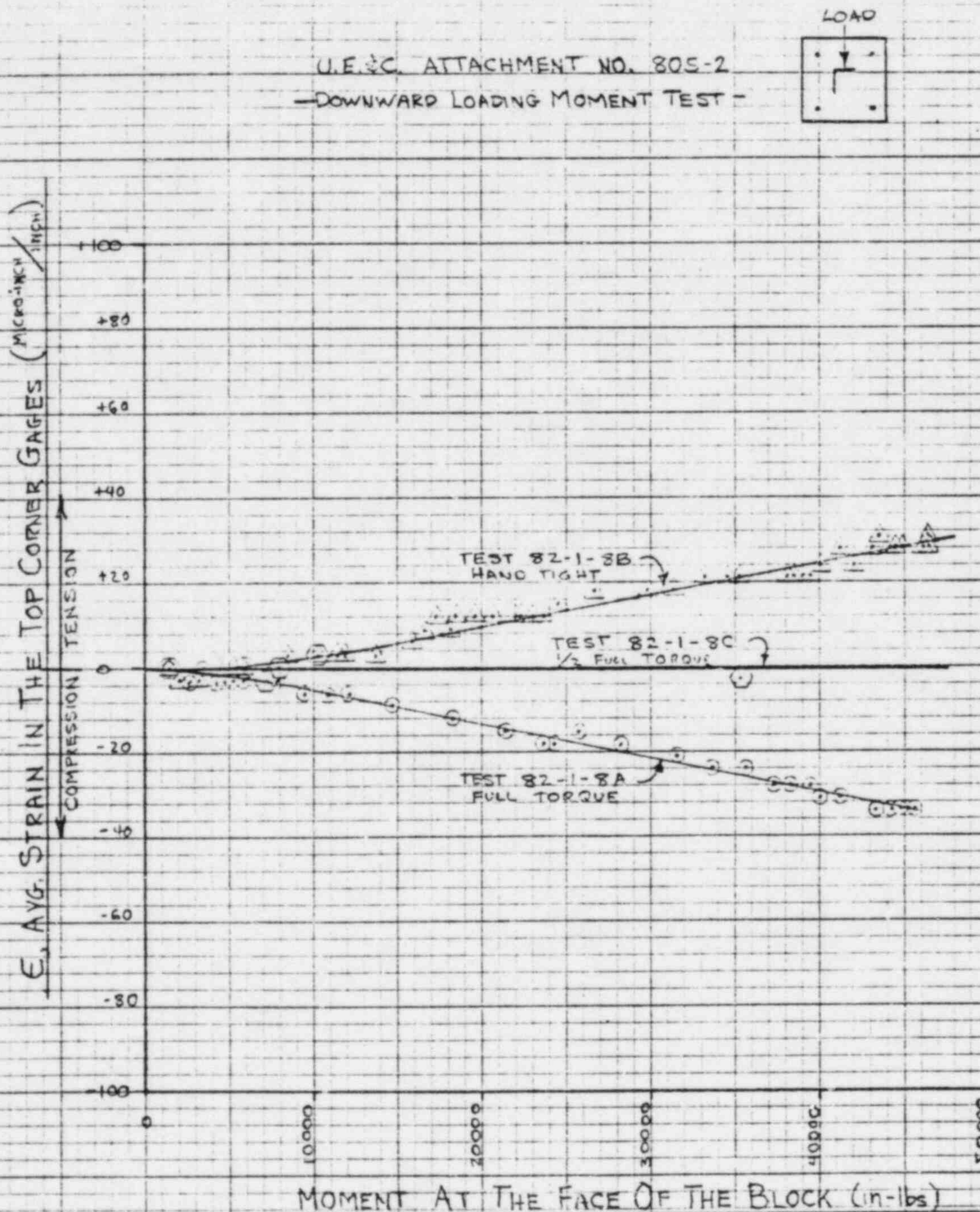
10 Squares to the inch

FIG. 38. AVG. STRAIN IN CORNER GAGES -VS- LOAD (U.E &C. PART NO 807-2)



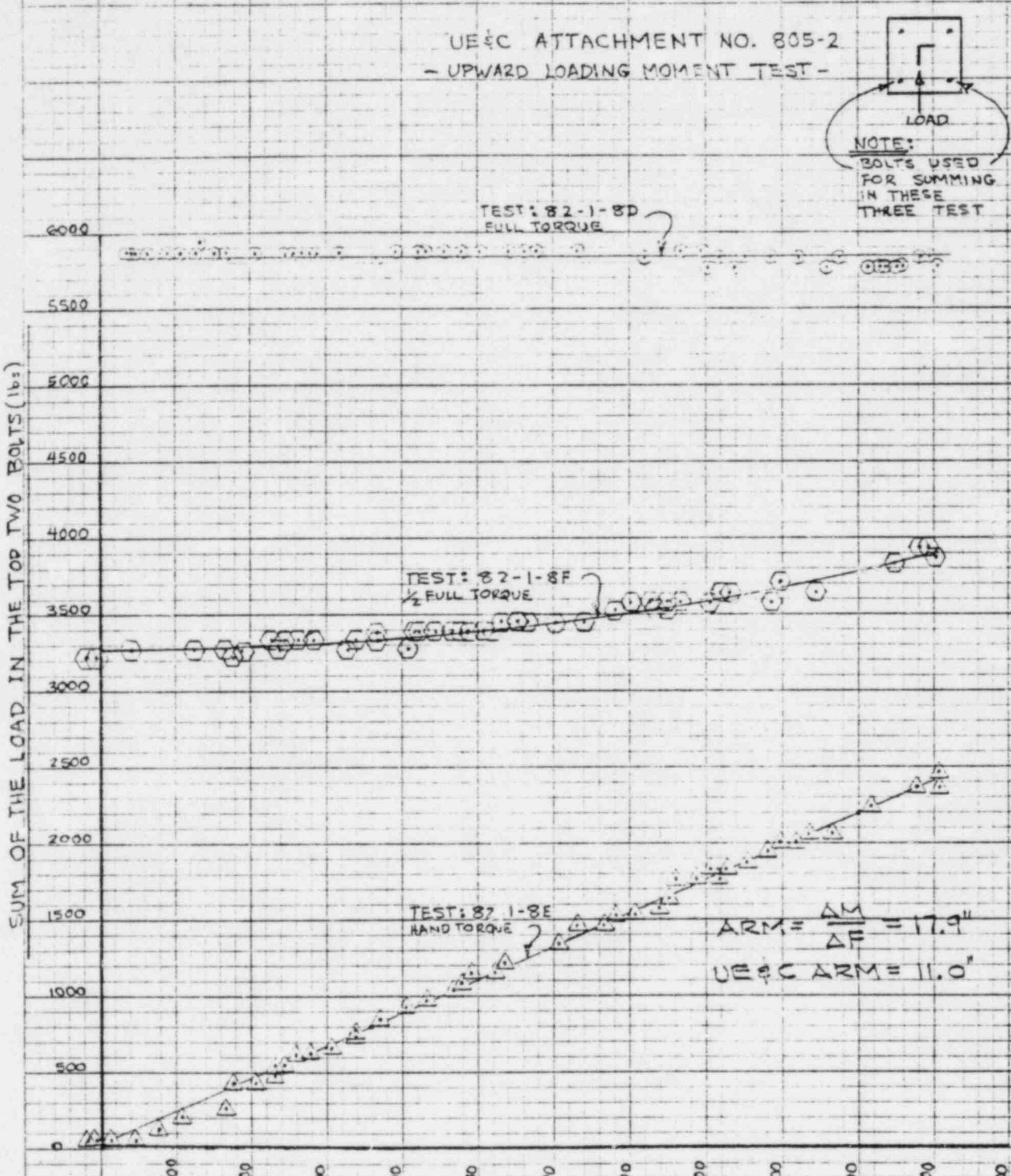
10 Squares to the Inch

FIG. 39. BOLT LOAD -VS- MOMENT (UE&C PART No. 805-2)



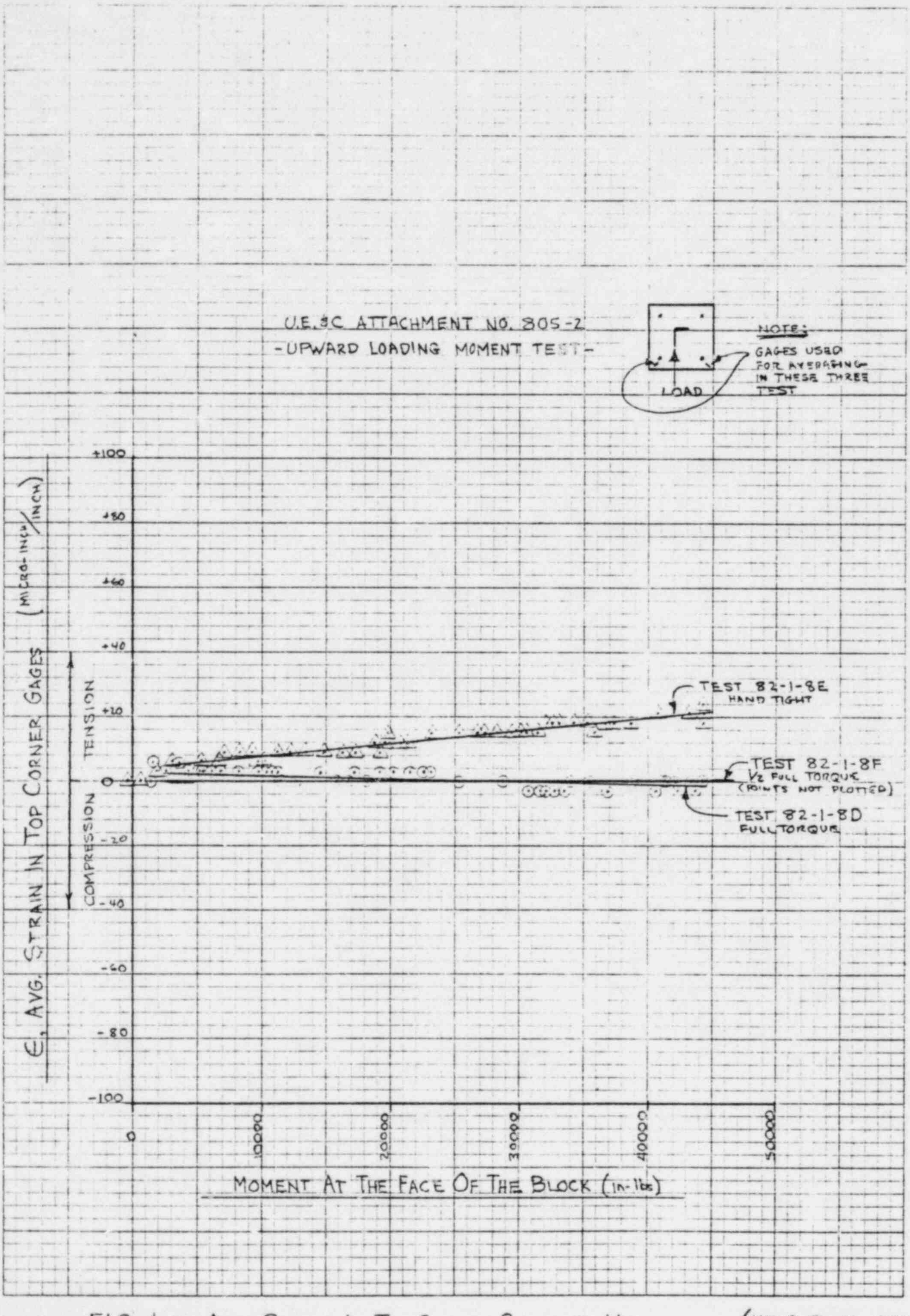
10 Squares to the Inch

FIG. 40. AVG. STRAIN IN TOP CORNER GAGES - VS - MOMENT (UE&C PART No. 805-2)



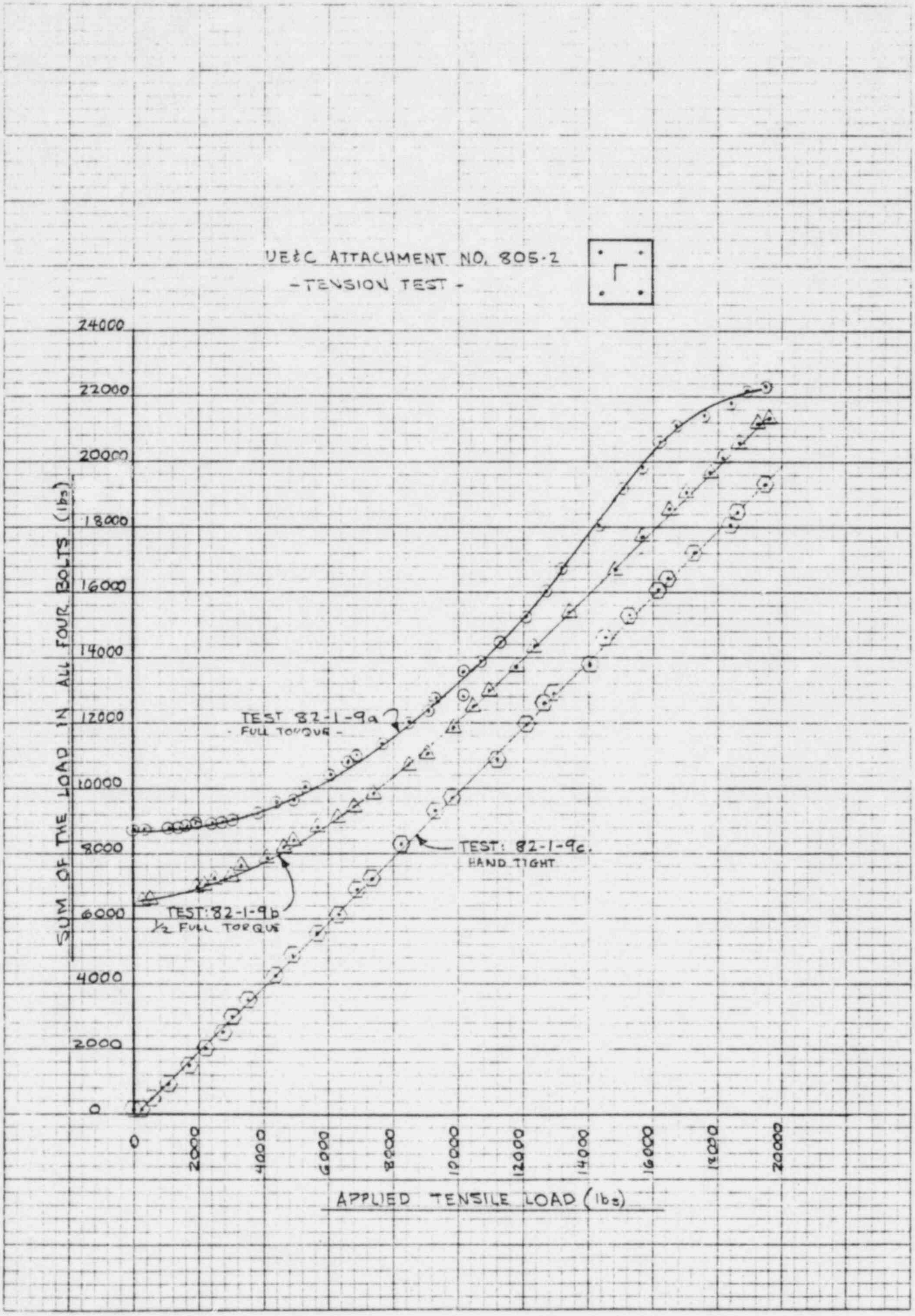
10 Squares to the Inch

FIG. 41. BOLT LOAD -vs- MOMENT (UE&C PART No. 805-2)



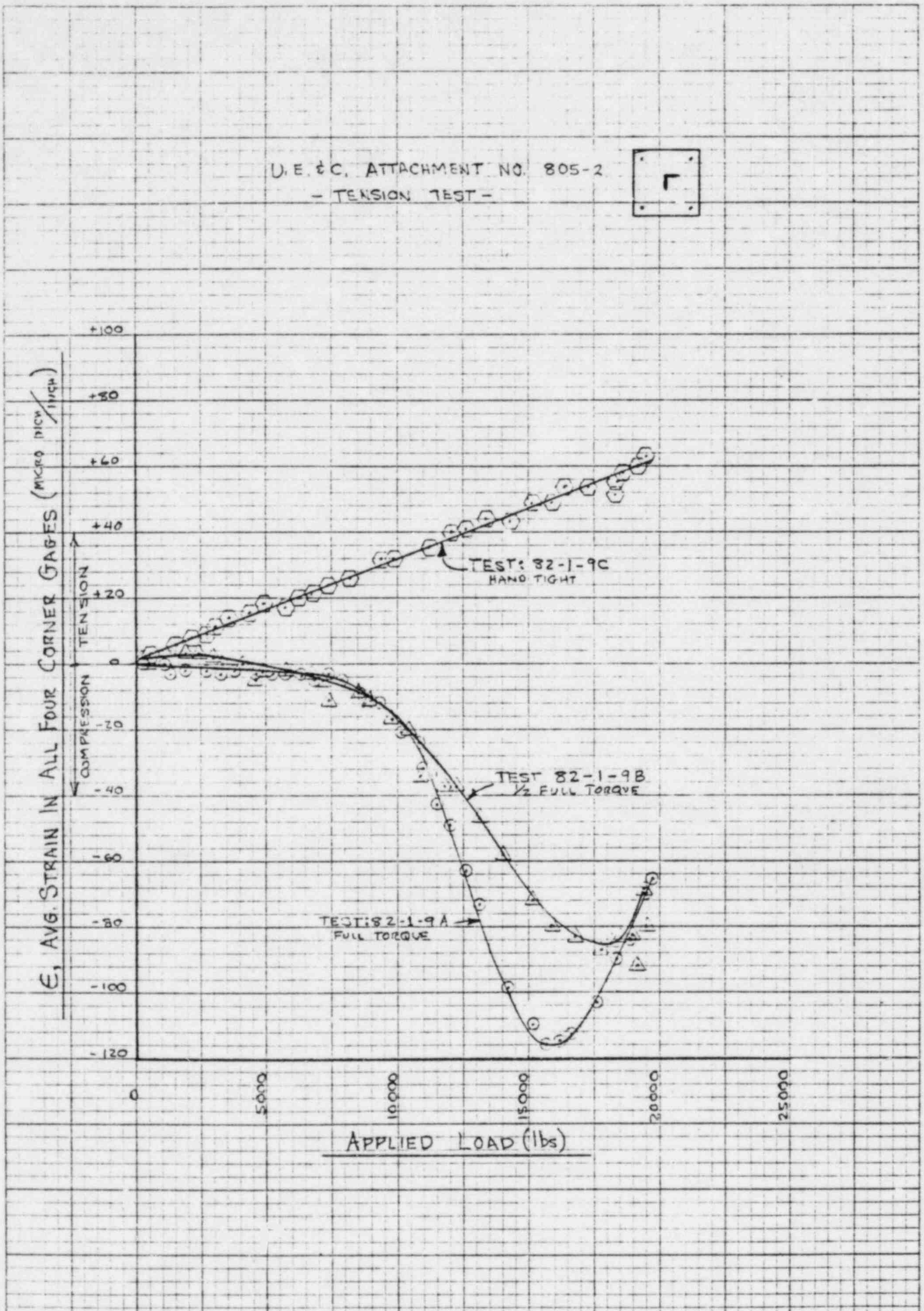
10 Squares to the Inch

FIG. 42. AVG. STRAIN IN TOP CORNER GAGES -VS- MOMENT (UE&C PART No. 805-2)



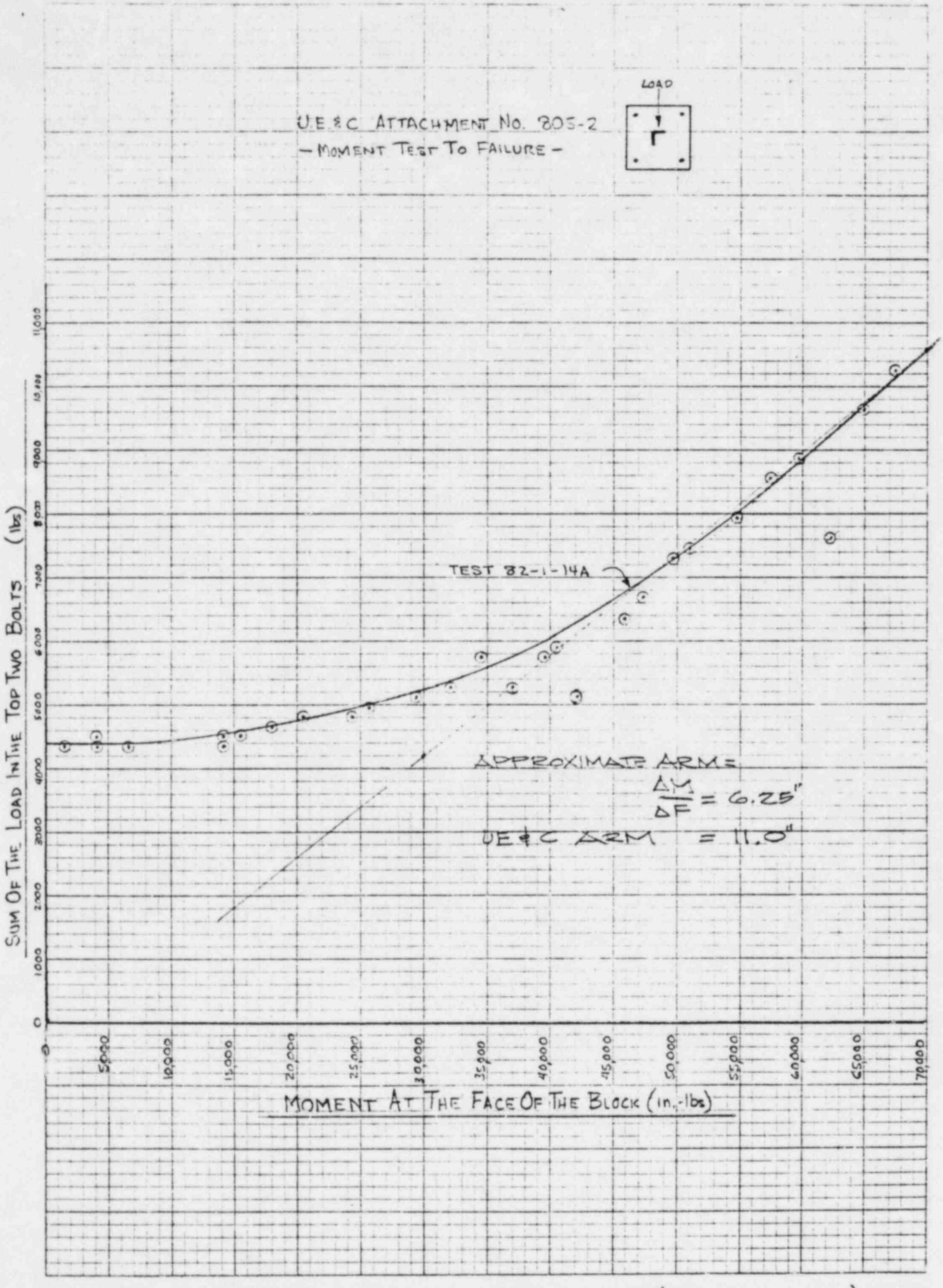
10 Squares to the Inch

FIG. 43. BOLT LOAD -vs- APPLIED TENSILE LOAD (UE&C PART No. 805-2)



10 Squares to the Inch

FIG. 44. AVG. STRAIN IN CORNER GAGES -VS- LOAD (U.E.&C. PART No. 805-2)



10 Squares to the Inch

FIG. 45. BOLT LOAD -VS- MOMENT (U.E.&C PART No. 805-2)

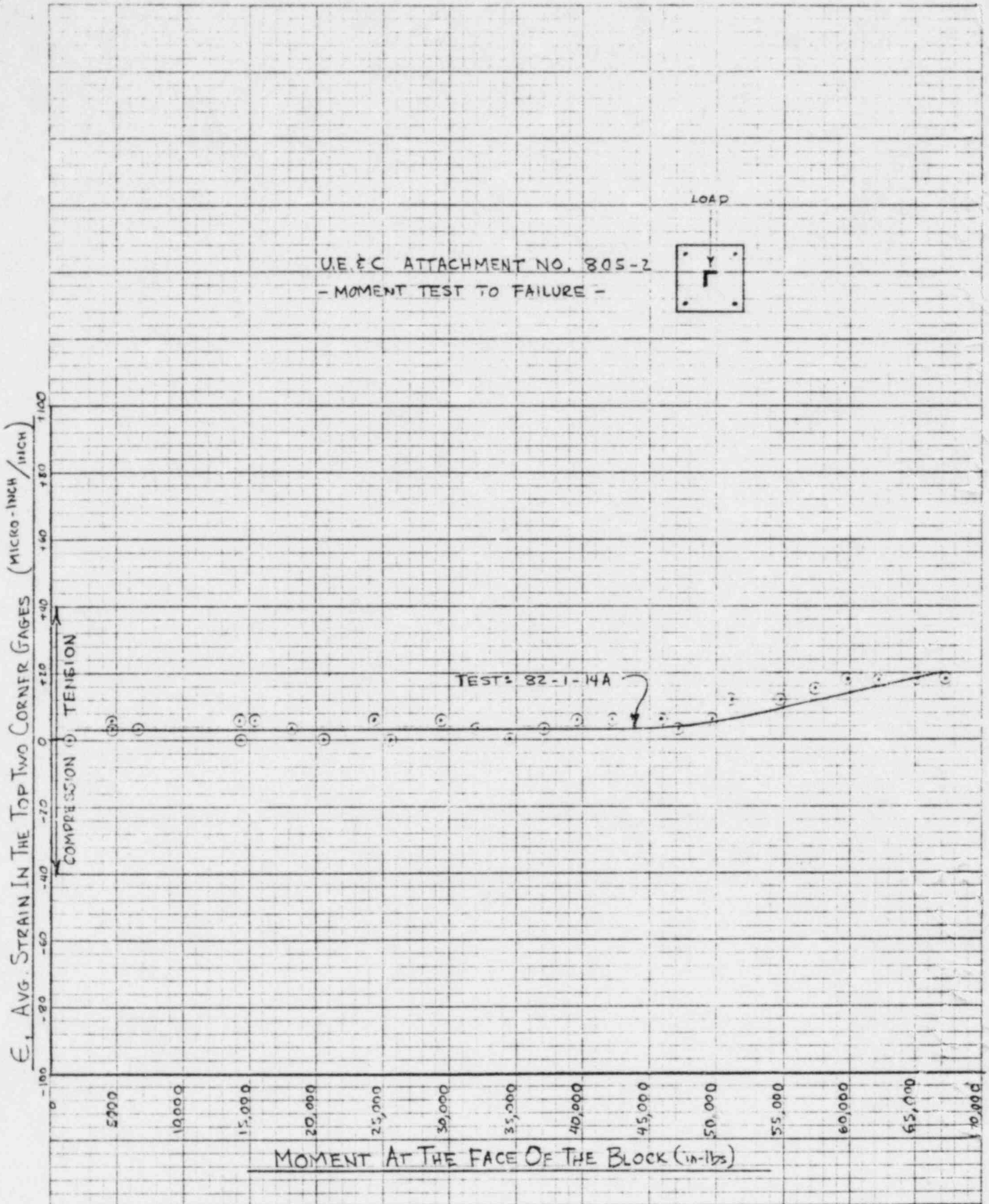
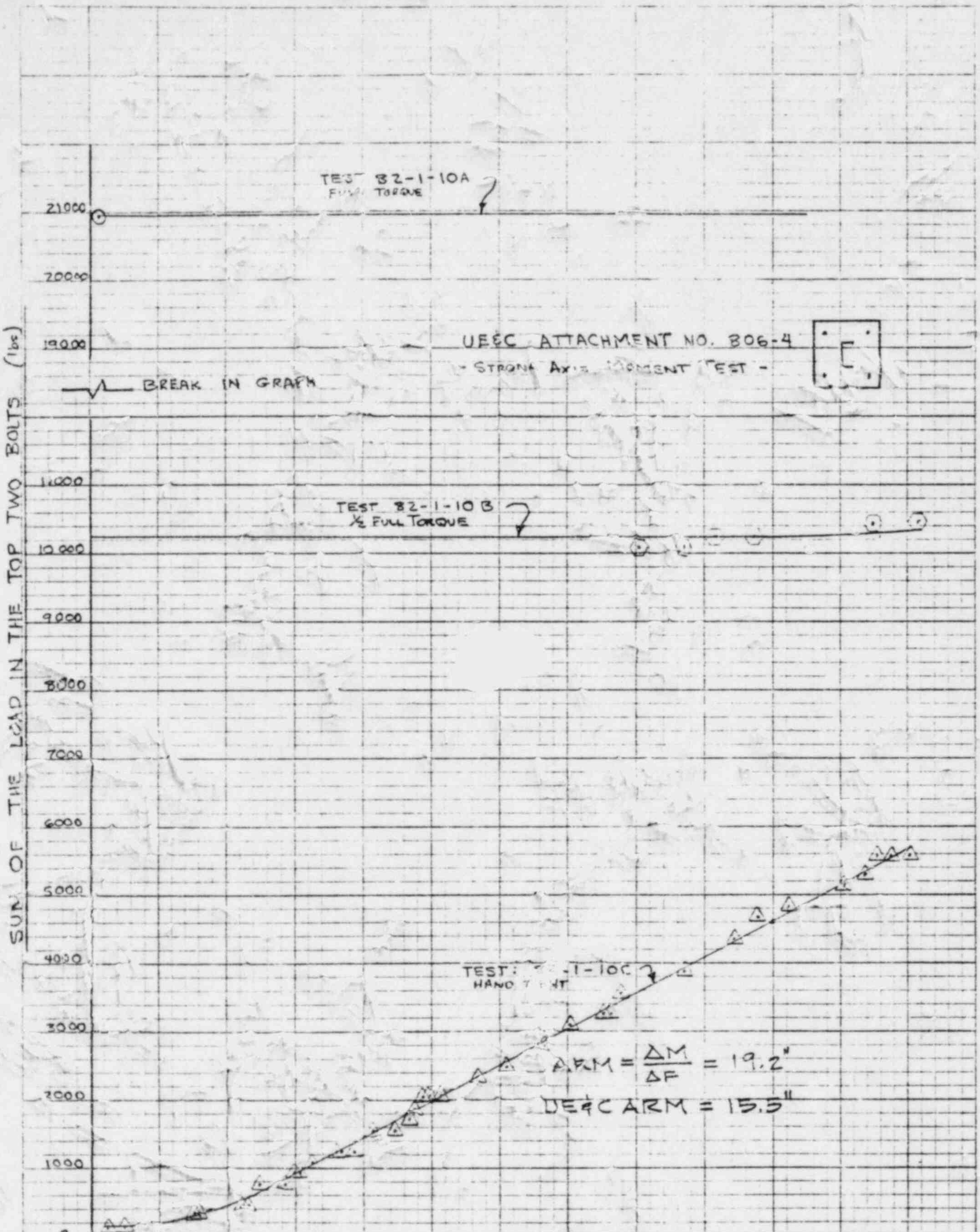
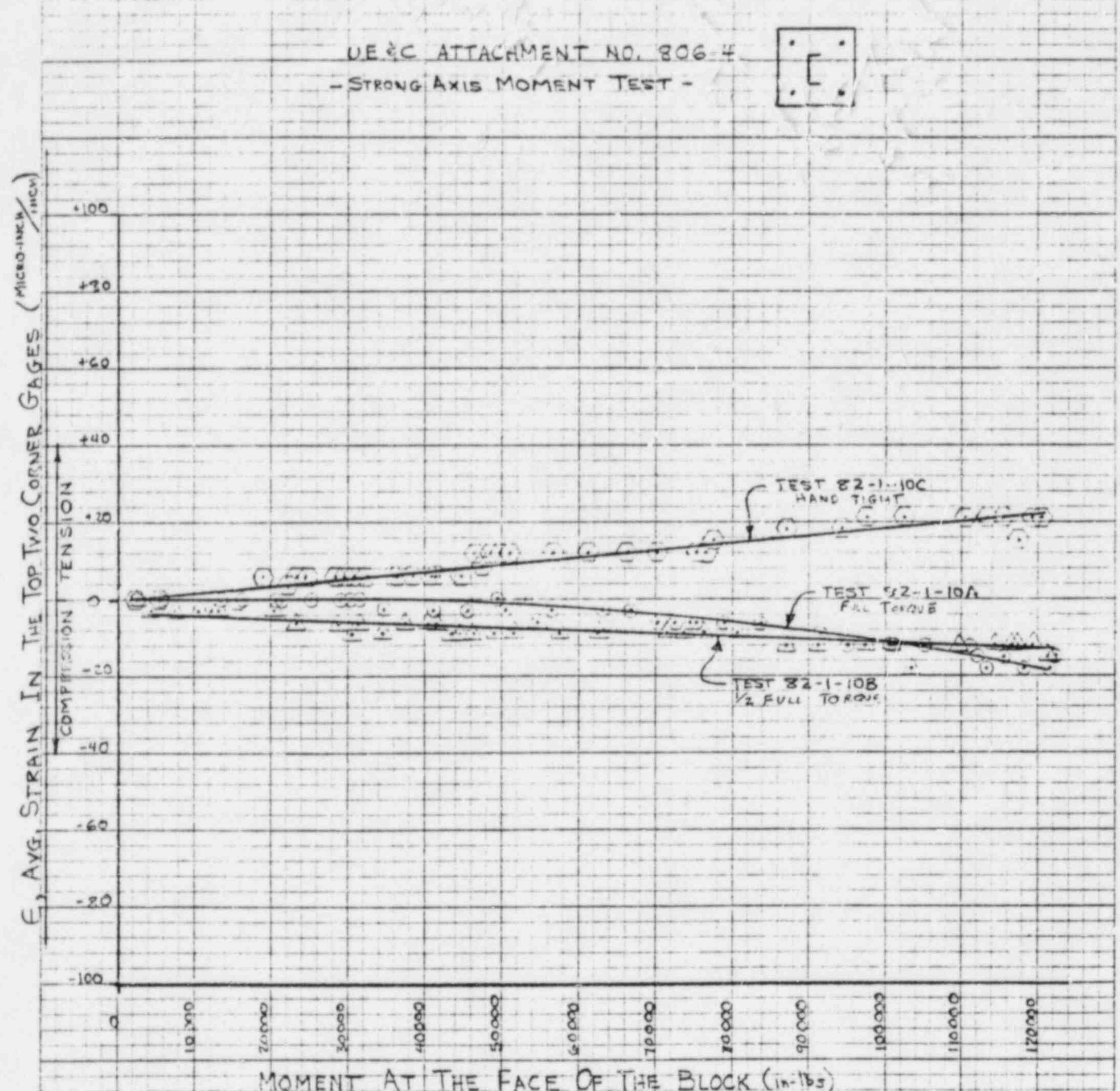


FIG. 46. AVG. STRAIN IN TOP CORNER GAGES -VS- MOMENT (U.E.&C PART NO. 805-2)



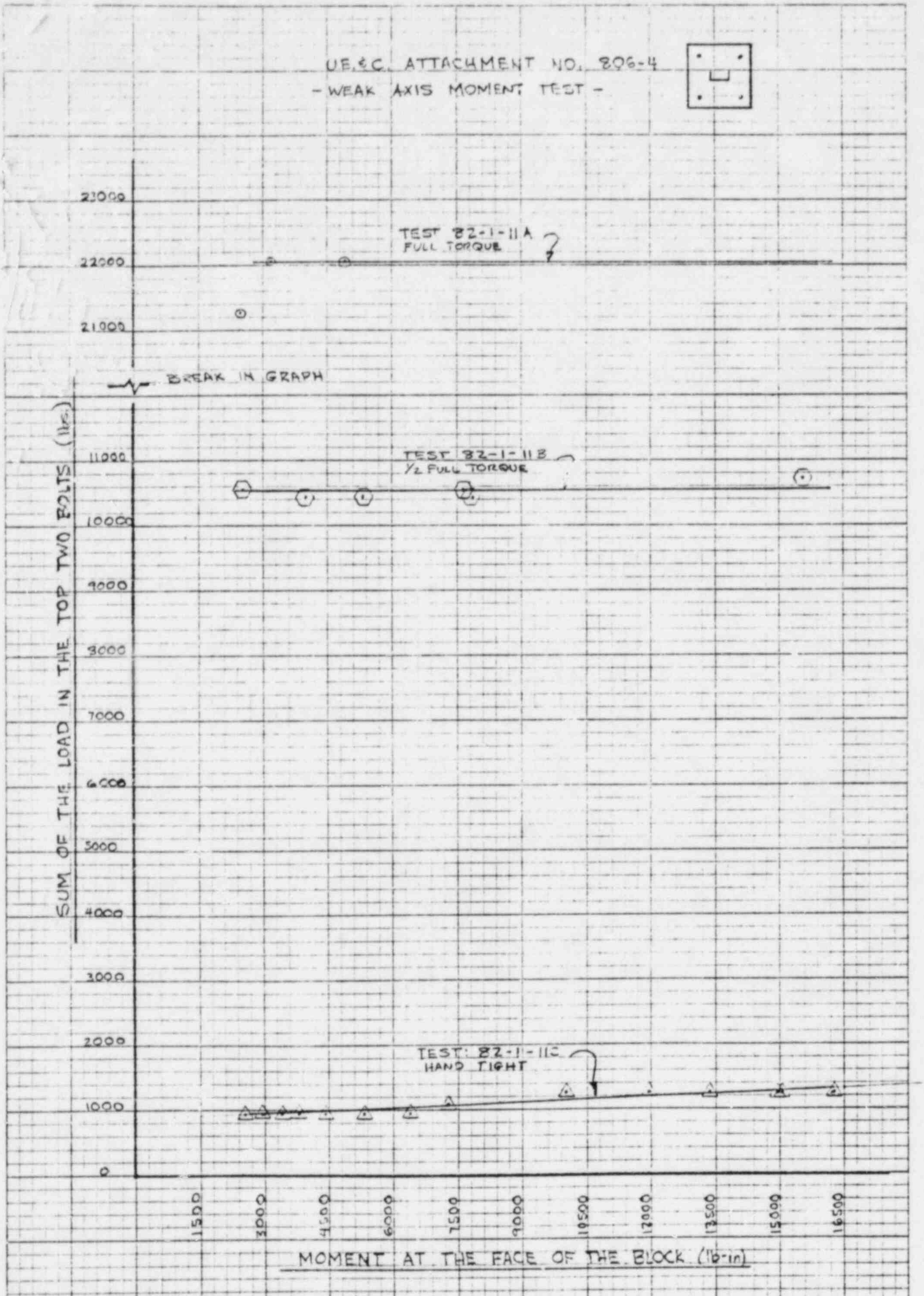
10 Squares to the Inch

FIG. 47. BOLT LOAD -VS- MOMENT (UE&C PART No. 806-4)



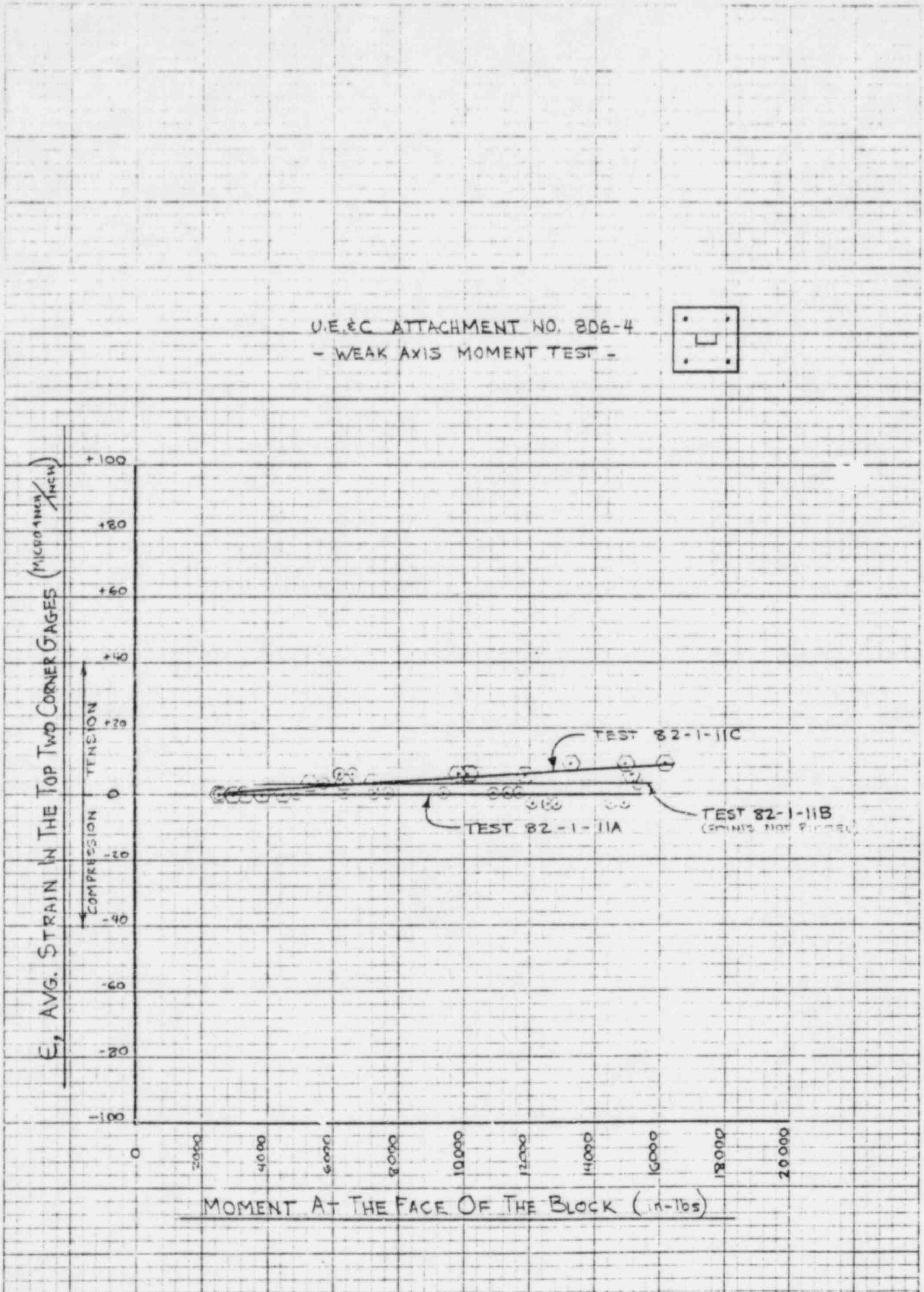
10 Squares to the inch

FIG. 48. AVG. STRAIN IN TOP CORNER GAGES -VS- MOMENT (U.E.&C PART NO. 806-4)



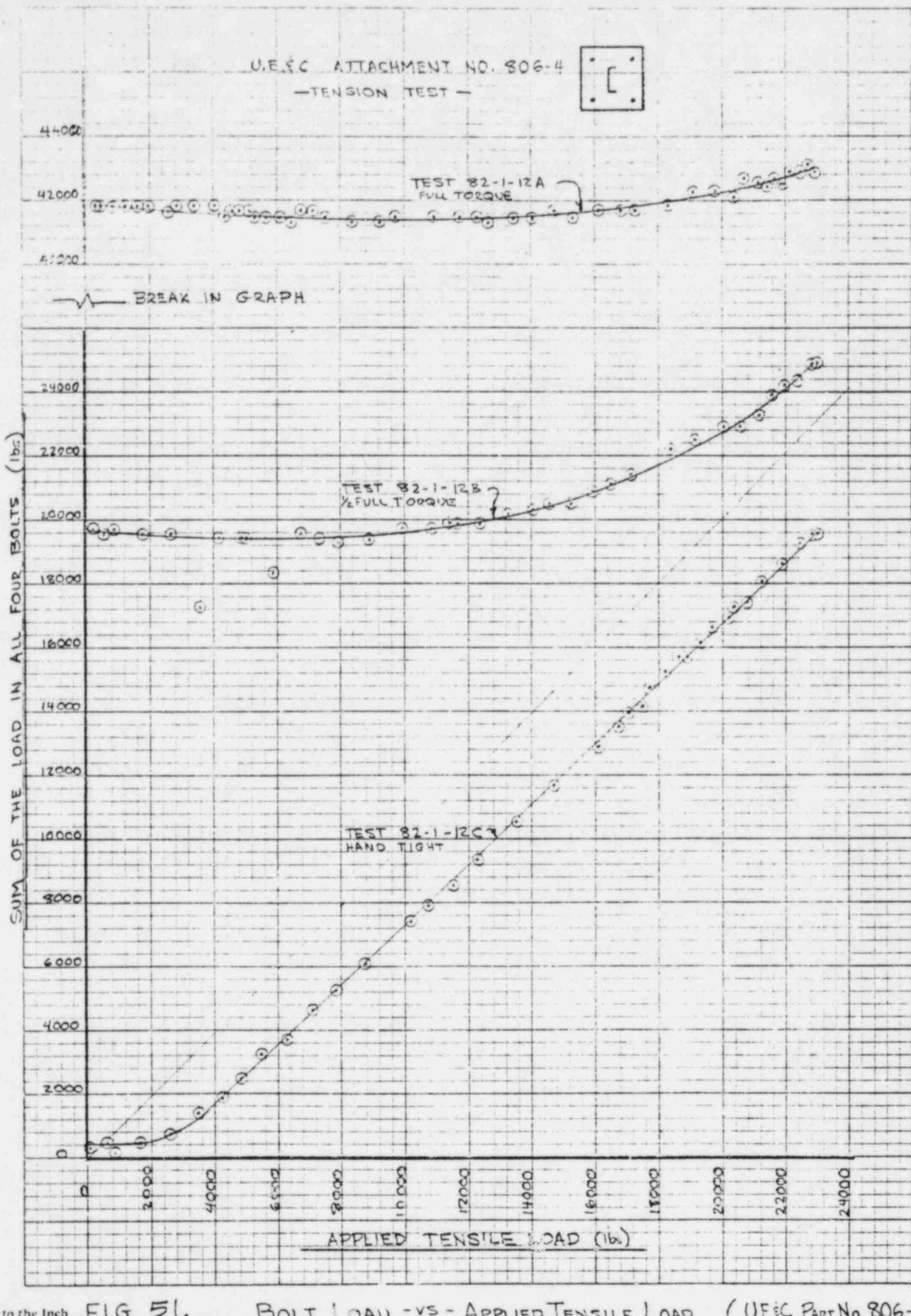
10 Squares to the Inch

FIG. 49. BOLT LOAD -vs- MOMENT (UE&C PART No. 806-4)

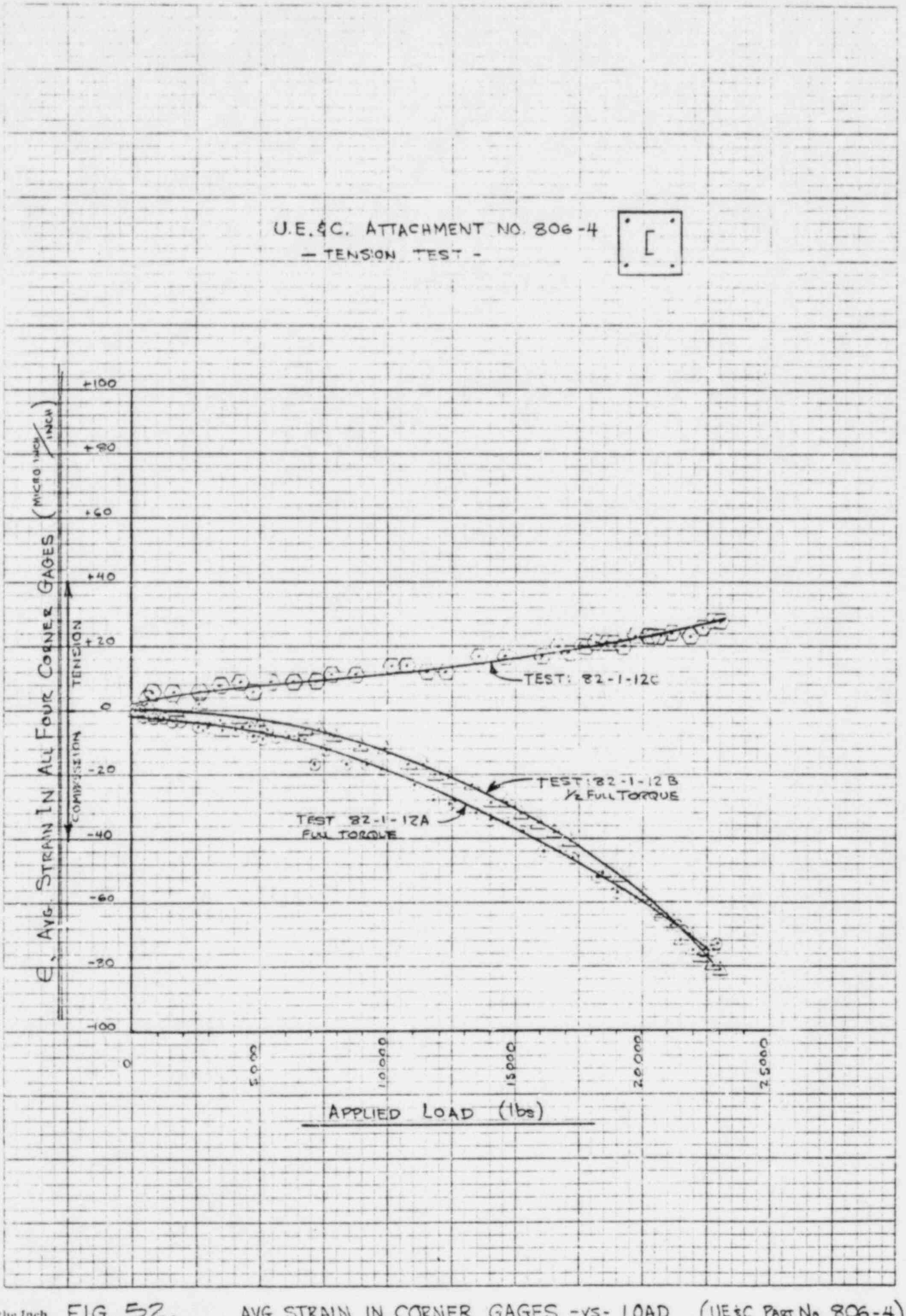


10 Squares to the Inch

FIG. 50. AVG. STRAIN IN TOP CORNER GAGES -VS- MOMENT (UE&C PART NO. 806-4)

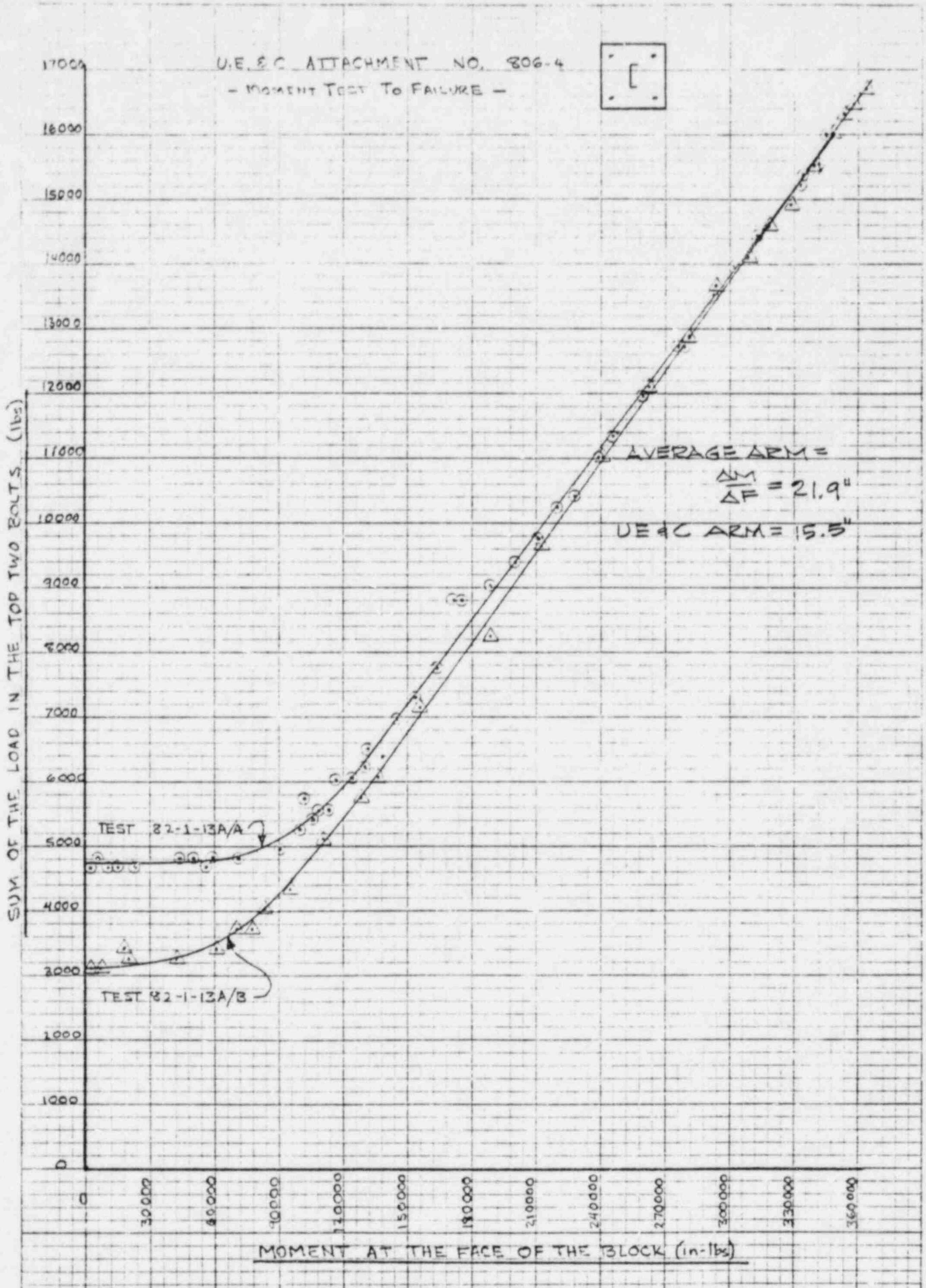


10 Squares to the Inch FIG. 51. BOLT LOAD - VS - APPLIED TENSILE LOAD (U.E.&C PART NO. 806-4)



10 Squares to the Inch

FIG. 52. AVG. STRAIN IN CORNER GAGES -VS- LOAD (UE&C PART No. 806-4)



10 Squares to the Inch

FIG. 53. BOLT LOAD -VS- MOMENT (UE&C PART No 806-4)

U.E. & C ATTACHMENT NO. 806-4

— MOMENT TEST TO FAILURE —

[

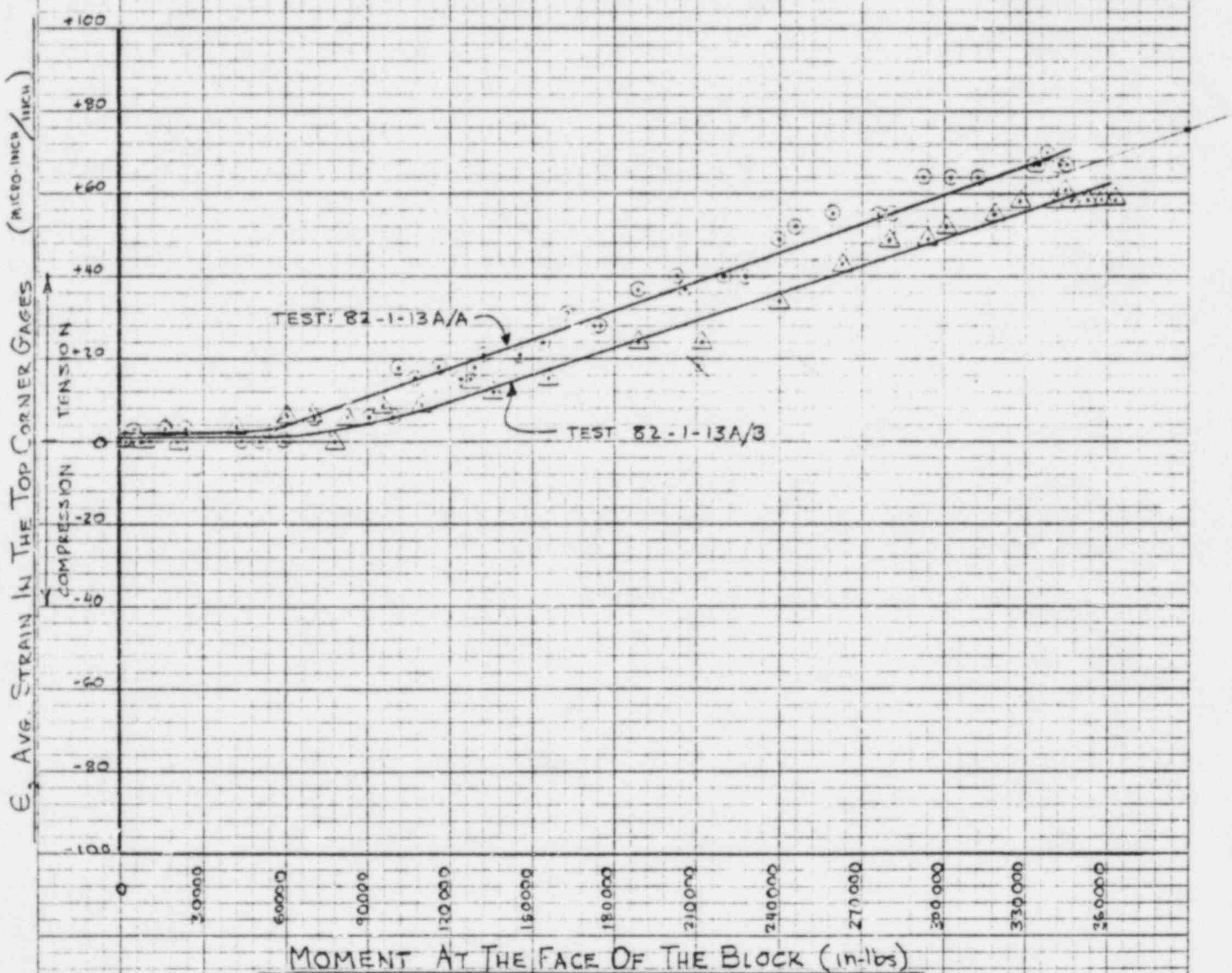
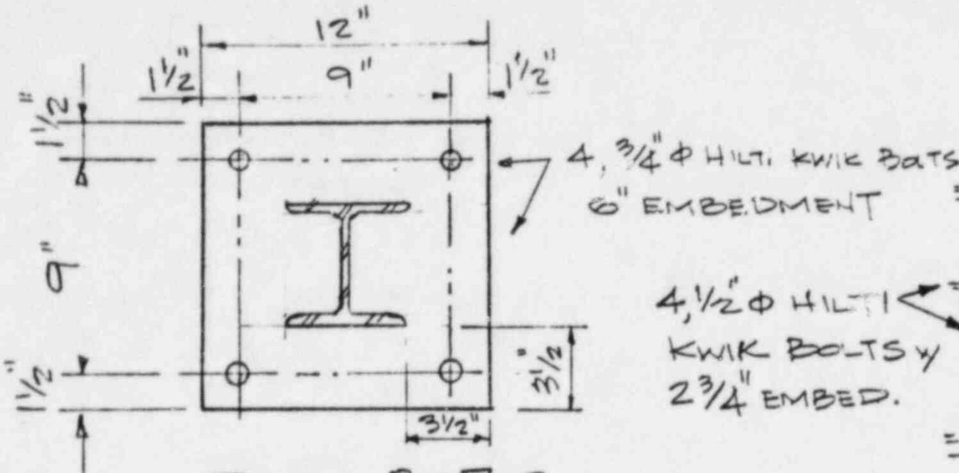


FIG. 54. AVG. STRAIN IN TOP CORNER GAGES -vs- MOMENT (U.E&C PART NO. 806-4)

APPENDIX A

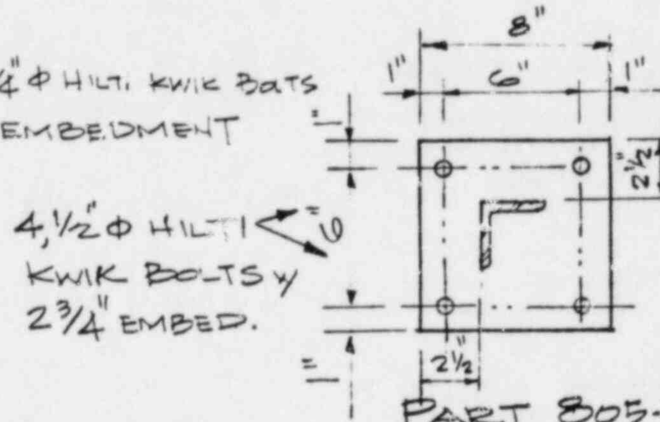
DETAILS OF BASE PLATES AND ATTACHMENTS

PHASES I & II



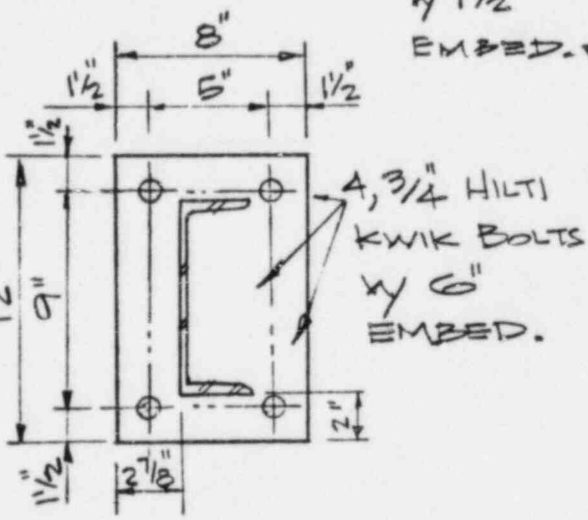
PART 807-2

12"x12"x¾" PL w/ W5x16



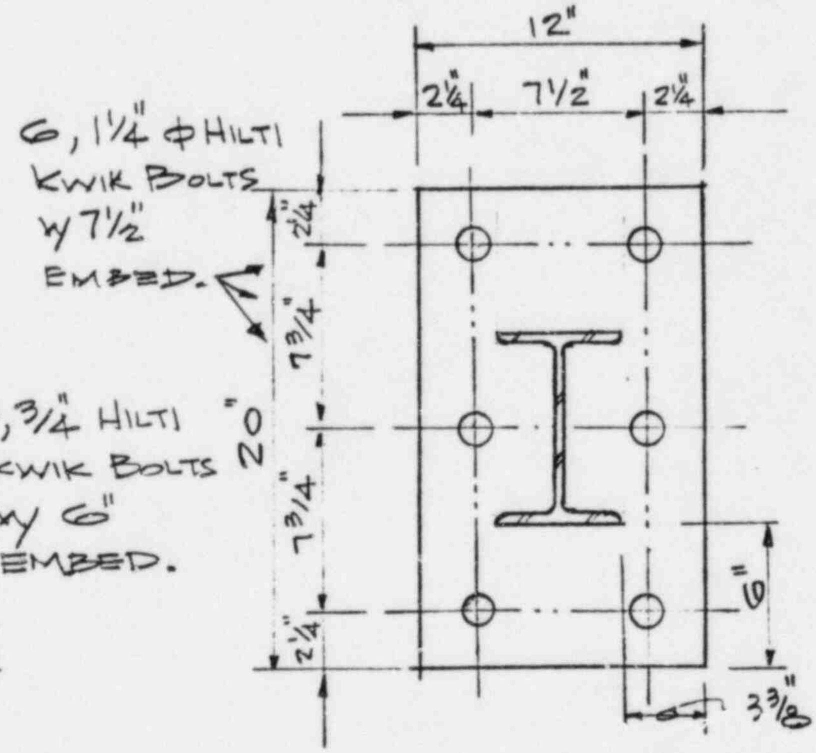
PART 805-2

8"x8"x⅝" PL w/ ∠3x3x⅜



PART 806-4

8"x12"x¾" PL w/ C8x11.5

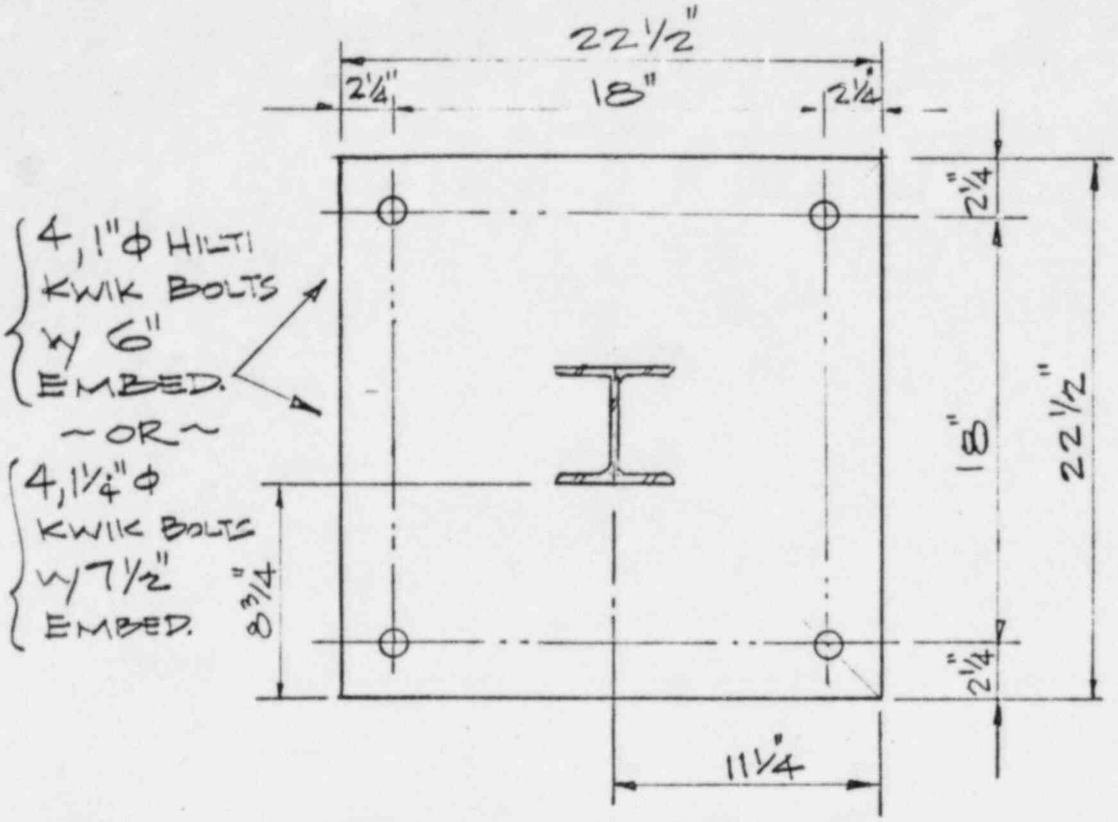


PART 808-1

12"x20"x1" PL w/ W8x21

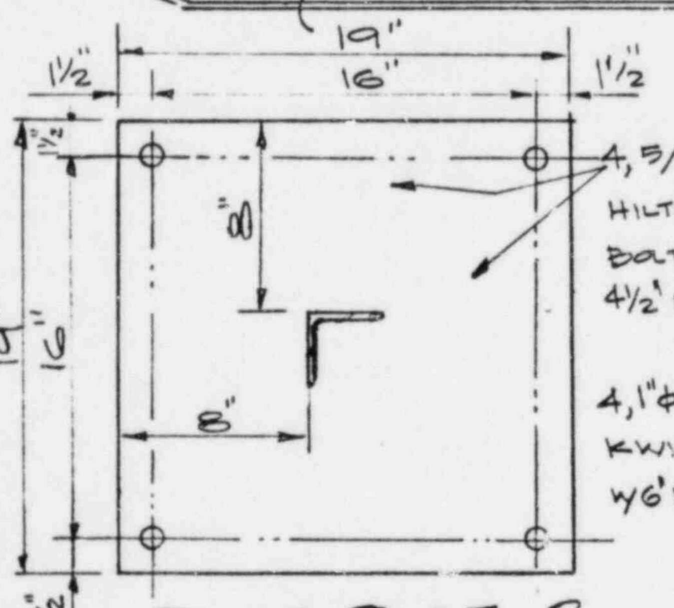
BASE PLATE DETAILS

~PHASE I TESTS~



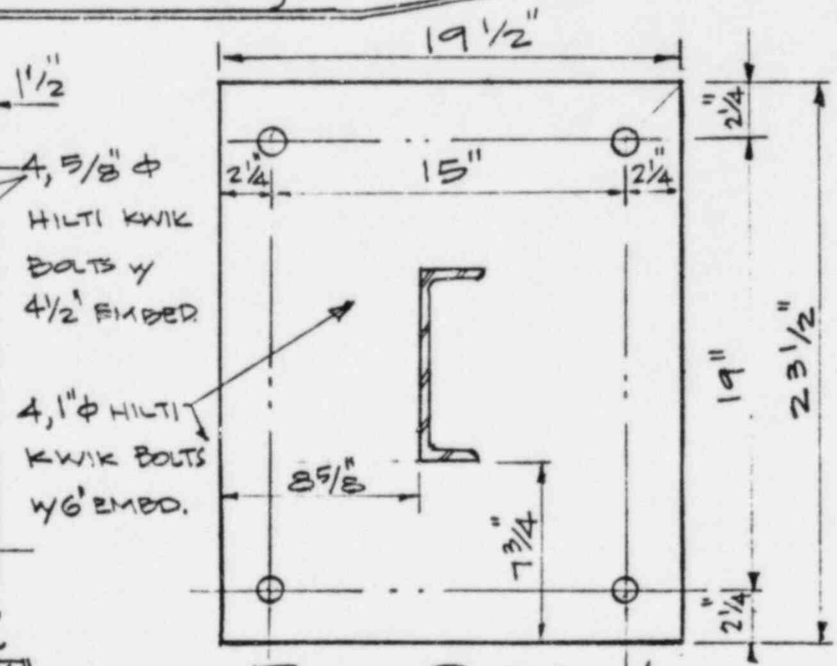
PART 807-2

{22 1/2" x 22 1/2" x 3/4" PL or 22 1/2" x 22 1/2" x 1" PL} w/ W5x16



PART 805-2

19" x 19" x 3/4" PL w/ ∠3 x 3 x 3/8



PART 806-4

19 1/2" x 23 1/2" x 1" PL w/ C8 x 11.5

BASE PLATE DETAILS

~ PHASE II TESTS ~