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Critical Joints in Large Composite Primary Aircraft Structures

Volume III — Ancillary Test Results

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PREFACE

This test report was prepared by Douglas Aircraft Company, McDonnell Douglas Corporation, under contract NAS1-16857, "Critical Joints in Large Composite Aircraft Structure." This program was conducted as part of the NASA Aircraft Energy Efficiency (ACEE) program.

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1.0 INTRODUCTION

The design and analysis of bolted joints in fibrous composite structures continues to be an area of concern with respect to the safe and efficient use of composite materials in aircraft structures. Douglas Aircraft Company, under NASA contract NAS1-16857, has developed technology for critical composite joints in large primary aircraft structures. The program contained a comprehensive test program including basic coupon tests, subcomponent multirow joint tests, and large technology demonstration specimens. This report contains an account of the test specimens, procedures, and results for the Ancillary Test Program, consisting of single hole joint tests and laminate property tests. The report also contains the results of NASA Standard Tests performed as part of this program on several new material systems.

A series of single row bolted joint specimens were tested in a variety of configurations to establish strength and stiffness properties for bolted joints in composite structures. Stress concentration factors for composite bolted joints were obtained by measuring the section strengths of single row loaded and unloaded hole coupon specimens. Bearing strengths were also measured by testing loaded hole coupons of sufficient width to force a bearing failure mode. The data obtained from these tests provide the necessary information to construct bearing-bypass interaction curves which serve as failure envelopes for multirow bolted joint analyses.

Loaded hole specimens also provided the load-deflection properties for single-bolt composite joints in both the linear and non-linear range of behavior. Bolted joint elastic spring rates were measured for all loaded hole tests. This data is essential to performing accurate load-sharing analyses of multirow bolted joints.

This report contains test results from Phase I and Phase II ancillary testing. The Phase I tests were conducted on loaded hole and unloaded hole specimens in single and double shear, with tension and compression loading. Unnotched tests were conducted for strength and stiffness properties of the two selected fiber patterns. Phase II ancillary tests were conducted for data recovery purposes from unsuccessful Phase I tests) or to examine specific configurations which were not investigated in Phase I.

2.0 SPECIMEN DESCRIPTION

2.1 Phase I Test Specimens

A total of 180 specimens was fabricated and tested at the Douglas Aircraft Company in Long Beach, California. These included a variety of configurations and geometries selected to generate a sufficient data base to support analysis methods.

Tension and compression tests were performed on three types of specimens: Double Shear Tension and Compression (DST and DSC), Single Shear Tension and Compression (SST and SSC), and Unloaded Hole Tension and Compression (UHT and UHC). Figures 1 through 15 present dimensioned drawings of each specimen type. The hole or bolt diameters were limited to 0.25 in. (6.35 mm), 0.50 in. (12.70 mm), and 0.75 in. (19.05 mm). Laminate widths and thicknesses were varied among specimen groups and will be discussed in subsequent sections.

Load was introduced to the tension specimens and single shear compression specimens through pin-loaded holes at each end which were reinforced with graphite/epoxy doublers. These doublers were constructed using the same layup pattern as the base laminate. Potted ends were used on double shear and unloaded hole compression specimens for the introduction of load. The ends were machined flat and parallel to stabilize and align the specimens.

Critical dimensions of each specimen were measured and recorded before testing. Specimens were visually inspected for any flaws or damage which could affect test results. Three identical specimens were tested for each configuration. Table 1 lists the coding or numbering system for all of the ancillary test specimens for Phase I.

The material system used in this program is the Ciba-Geigy Fiberdux 914/Toray T-300 graphite epoxy. The 914 resin is a so-called "toughened resin". The basic epoxy is modified with a polysulfone thermoplastic to create a more flexible, impact resistant matrix relative to established composite material systems. The Toray T-300 (hereafter T-300) was provided as a "thick ply" tape (approximately

0.01 in/ply). This consisted of two plies of 5 mil dry tape which were combined during the vendor preimpregnation process.

There were two fiber patterns used to build the laminates from which test specimens were made. Pattern A was (25% 0°, 50% ±45°, 25% 90°) and Pattern B was (37.5% 0°, 50% ±45°, 12.5% 90°). Laminates were inspected by C-scan for voids and delaminations prior to fabrication of test specimens.

Test laminate balanced layup sequences provided zero degree fibers at the surfaces of all parts. Only ±45 degree angle changes were allowed between adjacent interior plies. There were no stacked plies except two (2) 45-degree plies at the laminate mid-plane of symmetry and no 0°/90° interfaces except at the mid-plane of the 24-ply, 37.5 percent zero degree pattern (with 8-ply unit sequencing).

2.1.1 Unloaded Hole Specimens

Table 2 lists the nominal dimensions and characteristics of the unloaded hole tension and compression specimens. The narrow specimens maintained a w/d (width/hole diameter) ratio of 2.0, while for the wide specimens the w/d ratio was 8.0 with one exception. For the unloaded hole tension tests, the -533 specimens (UHT 16, 17, 18) were cut down from w = 6.0 in. (152.4 mm) to w = 4.5 in. (114.3 mm) giving a w/d ratio of 6.0 (to prevent recurrent doubler failure).

Figures 1 through 6 present dimensioned drawings for the unloaded hole specimens. The central holes were filled with 1/16 in. (1.59 mm) undersized bolts and tightened to moderate torque values. This provided some clamp-up effect at the hole without allowing load transfer through the bolt itself. All the unloaded hole specimens were fabricated from 24-ply laminates. Sixteen-ply tapered doublers were bonded to all UHT specimens for reinforcement at the load introduction holes, with one exception. As noted in Figure 2, the -531 specimens were inadvertently fabricated with 24-ply instead of 16-ply doublers.

2.1.2 Double Shear Specimens

Tables 3 and 4 depict the double shear tension and compression specimen configurations. The narrow and wide specimens maintained w/d ratios of 3.0 and 8.0 respectively, but again with one exception. The -529 compression specimens (DSC 10, 11, 12) had (inadvertently drilled) 0.50 in. (12.7 mm) central holes with a w/d ratio of 4.0. Torque levels for the three bolt sizes were:

Diameter	Torque
0.25 in. (6.35 mm)	25-30 in.-lb. (2.82-3.39 N-m)
0.50 in. (12.7 mm)	50-60 in.-lb. (5.65-6.78 N-m)
0.75 in. (19.05 mm)	75-90 in.-lb. (8.47-10.17 N-m)

Figures 7 through 12 contain dimensioned drawings of all double shear test specimens. In some cases there were slight clearances between the blade and the clevis plates and shims were used to eliminate the gap.

2.1.3 Single Shear Specimens

A general description of the single shear specimens is presented in Tables 5 and 6, including nominal dimensions. These specimens utilize a special aluminum fitting for one side of the joint (Figure 16) to reduce possible joint rotation due to eccentric loading and to assure the shear load application at the interface.

All of the single shear specimens had a w/d ratio of 8.0 and were generally free of flaws and defects. Bolts were torqued to the same values presented for the double shear specimens. Figures 13 through 15 contain dimensioned drawings of these specimens.

The bolts are installed in cup-shaped retainers in the loading fixture, rather than in a simple through-the-thickness hole, so that any fastener rotation would be more representative of a composite-to-composite single-shear joint.

2.2 Phase II Test Specimens

Ancillary tests in Phase II were conducted for data recovery purposes from inconclusive Phase I tests or to investigate joint configurations which were previously untested.

Tests were performed on three different configurations: Double Shear Tension and Compression, Unloaded Hole Tension and Unnotched Tension. Hole diameters of 0.375 in., 0.50 in., and 0.75 in. were used with specimens of varying width and thickness. The width to diameter ratios were chosen to ensure the desired mode of failure and were more representative of actual structure than prior tests. In addition, NASA standard resin toughness tests (NASA RP-1092) were run on two different material systems.

All tests were performed on a 100,000 pound capacity MTS test machine equipped with hydraulic grips to apply test loads. Reusable aluminum loading fixtures were used for the double shear tests. Figures 17 and 18 show typical double shear specimens.

The material system used was the 914/T-300 system with 5 mil or 10 mil tape. Patterns A (25%, 50%, 25%) and B (37.5%, 50%, 12.5%) were both tested. All laminates were inspected by C-scan for voids and delaminations prior to testing.

2.2.1 Unloaded Hole Specimens

Table 7 lists the specimen identifications and dimensions for Phase II unloaded hole tests. Figure 19 shows the specimen geometry.

These tests differ from Phase I tests in several respects. This is the first set of sepcimens fabricated with 5-mil tape as well as 10-mil. The w/d ratios of 3 and 5 used are more representative of bolted joint designs. In addition, these specimens were tested with filled holes (net fit) at roughly one-half the standard torque-up values, as opposed to open holes.

2.2.2 Double Shear Specimens

Table 8 lists the double shear specimen identifications and dimensions for Phase II testing. Figure 20 shows the specimen geometry.

The double shear tests include 12 tension and compression tests to be repeated from Phase I. The remainder of double shear tests concentrated on determining bolt flexibility effects in Pattern B laminates with carbon/epoxy and titanium splice members, and bearings strengths for central blade members in a double shear joint.

2.2.3 NASA Standard Tests

Table 9 lists the NASA Standard Toughness Tests (NASA RP-1092) that were used to evaluate material systems in Phase II. The new toughened resin/high strain fiber system chosen was the Ciba-Geigy 2566 resin with Celion high strain (CHS) fiber. Standard tests ST-1 through ST-5 were run for this material. In addition, ST-2 and ST-5 tests were run on 914/T300 laminates made with 5-mil tape for comparison to data from Phase I testing on 10-mil tape laminates.

3.0 TEST SETUP AND PROCEDURE

All ancillary test specimens were tested in a 100,000 pound capacity servo-hydraulic MTS test machine. For the double shear and unloaded hole specimens tested in Phase I, load was applied to theDST and UHT tension specimens through the combination of pin loading and clamping forces on the end fittings. Phase II tension tests were loaded through hydraulic grips. Compression specimens for the DSC and UHC tests were loaded directly through the potted ends. A spherical support was used for alignment of the compression specimens to minimize eccentric loads. Stabilizing plates were mounted to those compression specimens susceptible to premature buckling failure. Figure 21 shows a double shear tension specimen mounted in the MTS machine.

The single shear specimens (tension and compression) were loaded through bookend loading clevises. One clevis attached directly to the end of the specimen. The other clevis was attached to the steel test fixture which was then bolted to the test specimen. Figure 22 displays a single shear specimen and test fixture mounted in the MTS machine.

All specimens were loaded to failure using the stroke control (machine head travel) mode of loading. For the narrow specimens (w/d = 2,3) the stroke loading rate was varied between different configurations to induce a strain rate of 0.003 in./min. The wider, bearing critical specimens (w/d = 5,8) were loaded at one-half the rate of the narrow specimens. Loading rates for the ancillary tests are presented in Table 10.
ZCA10193 (Reference 1).

For the single shear and double shear tests a load deflection (P-δ) plot was continuously recorded to failure for each specimen. The deflection measurement for the double shear specimens is a record of the relative displacement between the clevis and the blade at the side edge of the specimen at the centerline of the central hole (Figure 23). The single shear deflection measurement is essentially the same except that the relative movement is between the test specimen and the aluminum test fixture (Figure 23).

The deflection recorded for the unloaded hole tests is head travel of the MTS machine.

Deflection measurements were recorded using MTS clip gages which were attached to specially designed adapters mounted on the specimens. These adapters attached to the specimens at the mid-thickness of each plate at the bolt centerline and were designed to insure that the true relative deflection was measured (Figure 24). These devices were used for both the single shear and double shear tests. Load versus deflection or load versus head travel plots were continuously recorded using a Hewlett-Packard X-Y plotter.

For the single shear tests, bolt head rotation (versus load and/or deflection) was also recorded. A laser beam was reflected from the bolt head to a graduated scale, from which readings were taken throughout each test. This data was then converted to angle change or rotation of the bolt head. The test setup is shown in Figure 25 (and Figure 20).

4.0 TEST RESULTS

The ancillary test program was primarily intended to provide the data necessary for the anlaysis of multi-row bolted joints (fabricated with Ciba-Geigy 914/T300) using the A4EJ computer program (Reference 1). The development of a sufficient data base to facilitate strength predictions at individual bolt locations in a bolted joint was of primary importance. This required a variety of specimens designed to exhibit a variety of failure modes. The three modes of failure to be examined were unloaded hole net-section failure, loaded hole net-section failure, and loaded hole bearing failure. Tension and compression specimens were tested for all cases.

In addition to strength data, the load-deflection behavior of bolted joints in both single and double shear was also examined. The prediction or determination of bolt load distributions in multi-row bolted joints is dependent upon the joint flexibility at each bolt location within the joint both in the linear (elastic) and non-linear (plastic) range.

Although most of the tests proceeded to failure as expected, many specimens displayed failure modes contrary to what had been planned. This was primarily the result of tapered bonded doublers attached to the specimens at the load introduction holes which occasionally failed prior to failure at the center test section. This occurred on both the double shear and unloaded hole tests as noted in the data and was, of course, limited to tension specimens. However, the basic problem was relatively steep machined tapers on the doublers. In a few instances, use of inadequate bond surface preparation and/or use of EA934 rather than higher strain to failure EA9320 adhesive was at fault. Subsequent analytic investigation provided design guidelines for future bonded and tapered doubler design (Reference 2).

The load-deflection curves are contained in Appendices A through D. Relative deflection measurements for the loaded hole tests were generally successful. The regions of elastic and plastic deformation are clearly defined along with the transition point between the two behavior modes. The test data are summarized in Tables 11 through 34. Bearing, net-section, and gross-section stresses at failure are calculated for all loaded hole specimens regardless of the failure mode noted. The area used in bearing was the specimen thickness times the hole diameter. For the double-shear tests, virtually all of the failures occurred in the outer clevis members. Stress calculations were made using the thickness of the two outer members.

4.1 Unloaded Hole Tests - Phase I

4.1.1 Unloaded Hole Tension Tests

Most of the unloaded hole tension tests resulted in net-section tension failures. However, out of 36 total UHT specimens, 13 of them failed in the tapered doublers and progressively through the net-section at the load introduction hole. All of the narrow specimens (w/d = 2) failed in net-tension through the central hole (Figure 26). The ultimate loads attained by these specimens were somewhat lower than expected, possibly as a result of the side edge effects involved in such narrow coupons. It has been concluded that a w/d ratio of 3 would be a more appropriate minimum for any future tests. The tapered doubler failures occurred in the wider (w/d = 8) specimens which resulted in 13 out of 18 specimens failing in this mode (Figure 27). Those that did fail in net-tension through the center experienced excessive delaminations and fiber separations at failure (Figure 28). These specimens also reached comparatively high load levels at failure, indicating relatively high bypass strength for this material system. Three of the wide specimens (UHT 16, 17, 18) were cut down in width from 6.0 in. to 4.5 in. to prevent early doubler failure. With 0.75 in. diameter central holes, these specimens then had a w/d ratio of 6.0 and all three failed in net-tension at the central hole (Figure 29). On three other specimens (UHT 34, 35, 36) the end holes were relocated and "C" clamps were mounted at the ends of the tapered doublers to add resistance to the high peel forces. Despite this modification, all three specimens failed in the doublers and end holes (Figures 27 and 30).

The load-deflection curves for the unloaded hole tension tests are presented in Appendix A. The test data are summarized in Tables 11 and 12.

4.1.2 Unloaded Hole Compression Tests

The unloaded hold compression specimens all failed through the net-section at the central hole (Figure 31). All tests proceeded without difficulties except for the UHC 13, 14, 15 series of three specimens. A malfunction in the data acquisition system occurred during the testing of UHC-13, with the result that no data was recorded for that specimen. Stabilizing plates were mounted on all wide (w/d = 8) specimens to prevent premature buckling failure. These plates were inadvertently omitted during the testing of UHC-14 and UHC-15. Both specimens failed at a much lower ultimate load than expected due to compressive buckling failures at the central hole net-section.

Plots of load versus head travel for the UHC tests are contained in Appendix A. Tables 13 and 14 summarize the test data.

4.2 Double Shear Tests - Phase I

4.2.1 Double Shear Tension Tests

The double shear tension tests resulted in a variety of failure modes for both the narrow (w/d = 3) and wide (w/d = 8) specimens. Figures 32 through 37 show several of the failed specimens with different modes of failure.

The narrow specimens were intended to provide data regarding loaded hole net-section strength. Approximately 50 percent of these specimens resulted in net-tension failures (Figure 32). Nearly all of the w/d = 3 specimens with 0.75 in. diameter bolts failed the tapered doublers at the end fittings, followed by a net-tension failure at the load introduction hole (Figure 33). Some of the narrow specimens also failed in bearing, and those that did fail in tension were working to a relatively high bearing stress.

The wider specimens were designed to fail in bearing and did so with reasonable consistency (Figure 34). The specimens with 0.25 in. diameter bolts actually failed in bolt bending with minor bearing deformation due to the bending of the bolts (Figure 35). The load-deflection curves for these specimens display a smooth transition from elastic to plastic behavior, clearly representative of the bolt bending failure. One wide specimen (DST 14) resulted in an adhesive failure of the bonded doubler between the two clevises, but not before the ultimate bearing strength had essentially been reached.

For virtually all the specimens that failed in net-tension or in bearing, the ultimate failure occurred in the two outer members (Figure 36). For this reason, the thicknesses of the two outer plates were used for stress calculations. In all cases the outer laminates were one-half the number of plies of the central member. The buckling and delamination of outer plies (in the strap members) associated with bearing failures was restricted in the central member due to clamp-up effects. This phenomenon contributed to the bearing deformation occurring predominantly in the outer members. In addition, any eccentricities causing unequal loading between the outer plates would result in failure of those members prior to the central blade.

One area of concern was the apparently high level of scatter between the slopes of the load deflection curves for identical specimens. In response to this, a number of steps were taken to ensure that the data acquisition system was not the cause of this scatter. More frequent checks were made to ensure that load and deflection scales on the plotter correctly represented the actual measurements. A total of 12 runs were made with DST specimen 14, all within the elastic range of behavior (see Appendix B). Sets of 3 runs were made with the extensometer adapter mounted on the plate centerline, 1/8 in. over the centerline, 1/8 in. under the centerline, and with the bolt torque increased from 50 to 90 in.-lb. The load-deflection curves yielded very consistent results throughout the repeated loadings despite these varied conditions. Suggesting the cause of this scatter would still be speculation at this time.

Appendix B contains the load-deflection curves for the double shear tension tests. A summary of the test data is presented in Tables 15 and 16.

4.2.2 Double Shear Compression Tests

The double shear compression tests were completed without any deviations from the anticipated behavior. Approximately 50 percent of the narrow (w/d = 3) specimens failed in compression, the remainder consisting of bearing failures (Figure 38). Compression failures for these specimens usually consisted of a shear/buckling failure occurring immediately at the boundary of the washer at the central hole. All of the specimens that failed in compression were working to a very high bearing stress. The remainder of the narrow specimens did, in fact, fail in bearing.

Most of the wide specimens (w/d = 8) resulted in bearing failures. The only exceptions were the three wide specimens with 0.25 in. diameter bolts (DSC-28, 29, 30) which failed in bolt bending with some minor bearing damage (Figure 39). Three specimens (DSC 10, 11, 12) which had 0.50 in. rather than the planned 0.25 in. holes also failed in bearing at a w/d ratio of 4.0. As was the case for the DST tests, failures occurred consistently in the outer clevis plates of the DSC specimens.

The slopes of the load deflection curves for the DSC tests were notably more consistent among identical specimens than they were for the DST tests. The load-deflection curves are presented in Appendix B. The test data are summarized in Tables 17 and 18.

4.3 Single Shear Tension & Compression Tests - Phase I

The single shear test results were consistent for both tension and compression tests. All the single shear specimens had a w/d ratio of 8.0 and all failed in bearing. Examination of the load deflection curves clearly indicates the yield point at which plastic bearing deformation begins. This change in stiffness was generally less severe than that observed for the double shear tests. Bearing strengths were fairly consistent between SST and SSC tests of the same geometry.

The plastic range of bearing deformation was also clearly audible from the initial ply failures through to ultimate load.

Measurements of bolt head rotation were taken for all single shear tests. Although readings of the laser beam deflection were taken incrementally, the variation of bolt head rotation with load appeared essentially bilinear and analogous to the path of each load-deflection curve. These data were gathered in anticipation of their potential significance to the load-deflection characteristics of single-shear joints. A measurable amount of permanent bearing deformation was sustained by the aluminum bushings as well as the graphite plates. The aluminum bushing bearing areas were the same as the graphite for each hole. Bearing yield deformation of both members must be considered when making use of the load-deflection data.

The load-deflection curves for the single-shear tests are presented in Appendix C. The test data are summarized in Tables 19 through 22.

4.4 Composite Stress Concentration Factors - Phase I

The composite stress concentration factors for all Phase I double shear tests that experienced net-section tension failures and for unloaded hole tests appear in Tables 23 through 25. Elastic stress concentration factors are calculated for each w/d ratio by the methods given in Reference 3. The composite stress concentration factors are calculated from the test data using the formula:

$$K_{tc} = \frac{(F_{tu})(w-d)(t)}{P_{ult}}$$

where F_{tu} is the unnotched tension allowable, P_{ult} is the specimen failure load, and w, d and t are the specimen width, diameter and thickness, respectively. Thus, the composite stress concentration factor is the ratio of the peak stress at the side of the hole (where failure occurs) to the average net-section stress.

4.5 Unloaded Hole Tests - Phase II

Tests were performed successfully on all 48 unloaded hole tension coupons. The results of these tests appear in Tables 26 through 28.

4.5.1 Unloaded Hole Tension

The unloaded hole tension testing consisted of two sets of 18 specimens. Specimen geometries used in each set were identical, the only difference being the 5 mil versus 10 mil tape prepreg used for laminate fabrication. Test results among geometrically identical specimens were generally consistent, with no significant difference between laminates of differing ply thickness. The 5 mil specimens did generally exhibit a more uniform net-section failure as compared to the 10 mil specimens which were more severly damaged and delaminated around the hole. The stress concentration factors derived from these tests provided an adequate data base to support analytical strength predictions for multirow bolted joints (Reference 3).

4.6 Double Shear Tests - Phase II

All but two of the 36 double shear specimens planned were successfully fabricated and tested, generating the requisite data. Table 29 contains the test results for the double shear tests. Load deflection curves for Phase II tests are contained in Appendix D.

4.6.1 Double Shear Tension

Test results for net-section tension strength and associated stress concentration factors are consistent with Phase I results. The stress concentration relief factors (C-factors) are equivalent to earlier test-generated values. They are approximately 0.25 for fiber pattern A and 0.41 for pattern B.

Two sets of specimens were bearing critical. Those with composite splice plates had simultaneous bearing failures in the splice and central skin, and reached ultimate bearing stress levels of 126 to 128 ksi. Those with titanium splices failed in the central composite skin at bearing stresses of 154 to 162 ksi. The results are attributed to clamp-up provided by the splices and somewhat higher fastener torque which may have prevented delamination in the surface plies of external composite splices.

4.6.2 Double Shear Compression

The compression tests were designed to provide bearing strength data not obtained by Phase I tests due to bolt bending. This series used 0.375 in. diameter bolts with w/d ratios of five.

The compression specimens with composite splices one half the thickness of the central skin experienced simultaneous bearing failures with bearing stress levels of 104 to 115 ksi. Specimens with thicker splices failed in the central skin at bearing stresses of 131 to 132 ksi, while experiencing some bolt bending with 0.375 in. diameter bolts. The early bearing failures can be attributed to a lack of clamp-up as the external splices begin to fail in bearing.

4.6.3 Composite Stress Concentration Factors - Phase II

Composite stress concentration factors were calculated for all Phase II double shear tests that experienced net-section tension failures and for unloaded hole tests. The Phase II values appear in those tables referenced in Sections 4.4 and 4.5. These values are used to predict the bearing-bypass strength in composite multi-row bolted joints.

4.7 Elastic Spring Rates

The measured elastic spring rate values from all of the Phase I and II loaded hole tension and compression tests appear in Table 30, 31 and 32. These values, found by taking the slope of the linear portion in the load-deflection plots for double shear tests (Appendix B and D), provide the data necessary for accurate solutions of bolt load distributions in multi-row bolted joints.

4.8 NASA Standard Tests

The NASA ST-1 through ST-5 tests were performed on several new material systems. The tests, as documented in NASA Reference Publication 1092, are Compression After Impact, Edge Delamination, Open Hole Tension, Open Hole Compression and Hinged Double Cantilever Beam Tests. In Phase I, the NASA Standard Tests were performed using the 914/T300 system with 10-mil tape (used through the joints development program). The results for these tests appear in Tables 33 through 37. As part of the Phase II effort a new toughened system using the Ciba Geigy 2566 resin with Celion High Strain Fibers was evaluated. Results from these tests appear in Tables 38 through 42. In addition, the ST-2 and ST-5 tests were performed on 914/T300 laminates fabricated with 5 mil tape for comparison to tests with 10 mil tape laminates from Phase I. Results of these tests appear in Tables 43 and 44.

The 5 mil specimens resulted in similar G_{IC} values to 10 mil tape laminates, but much higher Gc values obtained from the Edge Delamination Test, apparently due to the resulting lower interlaminar stresses. The 2566/CHS laminates demonstrated good properties for all toughness measurements. Figure 40 shows an open hole ST-3 specimen. Figure 41 shows thres ST-1 compression after impact specimens.

5.0 BASIC MECHANICAL PROPERTY TESTS

5.1 Phase I Tests

The ancillary test program included a series of tests to determine basic laminate strength allowables and modulus values. A total of six (6) tension and six (6) compression tests was fabricated as in Figure 42 Among each set of specimens, three (3) consisted of layup Pattern A, and three (3) of layup Pattern B.

The tension tests were run using self-tightening friction grips at the ends with an extensometer attached to the specimen along the constant section to measure Young's Modulus. One specimen of each group (Pattern A, B) had strain gauges at the minimum section. The extensometer was removed from each specimen at approximately 2/3 the anticipated failure load, and the test was then continued to failure.

The compression tests provided ultimate compression strength data only. The specimens were made with potted ends similar to all previous compression specimens (Figure 43).

Table 45 summarizes the results for the tension and compression tests. Ultimate tension stresses are calculated based on the minimum width section. In addition, these stress values are multiplied by the appropriate stress concentration factor associated with this type of specimen.

Several tension specimens failed at some distance away from the minimum cross-section (Figure 44). This result suggests that the stresses presented in Table 45 may be considered minimum allowable stresses in tension.

5.2 Phase II Tests

An additional series of tests to find basic laminate properties were run in Phase II. Three tension specimens made with 5 mil tape and three with 10 mil tape were tested in order to compare strength and stiffness properties. The results of these tests are presented in Table 46 .

6.0 SUMMARY AND CONCLUSIONS

Basic unloaded hole and single bolt loaded hole test data are presented which support the analysis of multirow bolted joints in thick, highly loaded composite structures. The results characterize the strengths and failure modes of composite joint specimens loaded in tension and compression. Unnotched laminate tests were also run to provide a basis from which the notched specimen strengths can be evaluated.

The measured section strengths for unloaded and loaded hole specimens provide the data necessary to calculate the stress concentration factors at failure for notched composite laminates. This data also reaffirms that composite cross-ply laminates do exhibit substantial relief from strength reductions associated with linear elastic stress concentration factors. The notched strength data also indicates that the B pattern laminate (37.5, 50, 12.5) is more notch sensitive (or, shows less stress concentration relief) than the quasi-isotropic pattern A, when compared to their respective unnotched strengths. Despite the greater sensitivity to discontinuities, the B pattern notched strengths are substantially higher than the quasi-isotropic A pattern.

The series of tests comparing the unloaded hole tensile performance of laminates fabricated with 5-mil and with 10-mil tape did not show any difference in strength levels between the two laminates. However, the appearance of the two specimen types after failure are quite different. The 5-mil tape laminates sustain a relatively "clean" net-section failure through the hole while the 10-mil tape specimens suffer extensive delamination and interlaminar fracture. This may be attributed to the higher interlaminar stresses that arise from the use of thick ply material.

The bearing strengths of composite joints were measured for single and double shear configurations. Phase I double shear specimens were all tested with splice plates that were one-half the thickness of the central blade. Thus, all failures occurred in the external splices which were not afforded any additional clamp-up beyond the washer surface area, providing less resistance to the buckling or delamination of outer plies; a failure mode which is typically associated with bearing failures in composite laminates. Phase II tests designed to fail the central blade of a double shear joint in bearing demonstrated bearing strength increases of 30 to 60 percent above that of an external splice.

Joint load-deflection properties were measured for a variety of laminate thicknesses, bolt diameters, and fiber patterns. The magnitude of these values vary considerably between configurations, and in many cases, an apparently large degree of scatter between elastic spring rates for identical specimens was shown. These measurements also indicated that composite joints may undergo substantial nonlinear deformations prior to failure, particularly in the case of bearing failures. In some cases, bolt bending failures were observed prior to the occurrence of any significant damage to the composite material.

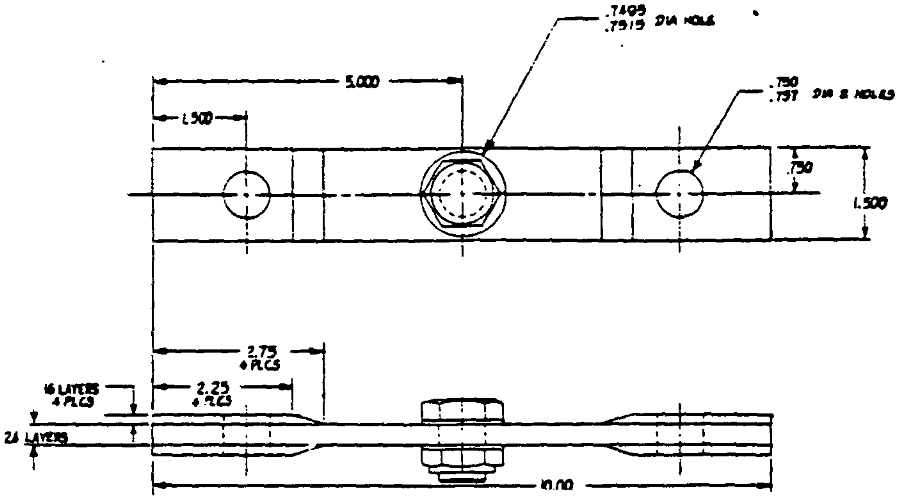
NASA Standard Test results provide a basis for comparison between different material systems. The edge delamination test results for the 914/T300 material for 5-mil and 10-mil tape laminates show that significant differences in performance exist between laminates with a relatively small change in the basic ply thickness. The results of standard tests on the CHS/2566 material indicate that there are substantial benefits available from the improved material properties of new systems which will have a significant impact on the design of composite aircraft structure. In the case of joints technology, the new high strength/high strain fibers used with toughened resin systems are yielding higher notched (and unnotched) strengths, which translate directly into improved joint performance.

7.0 REFERENCES

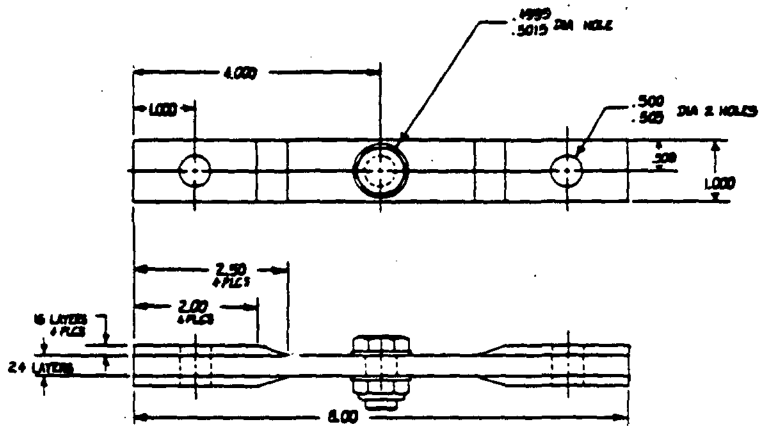
1. Hart-Smith, L.J., "Design Methodology for Bonded-Bolted Composite Joints - Analysis Derivations and Illustrative Solutions", Air Force *Wright Aeronautical Laboratories Report Number AFWAL-TR-81-3154*, February 1982.

2. Hart-Smith, L.J. and Bunin, B.L., "Selection of Taper Angles For Doublers, Splices, and Thickness Transitions in Fibrous Composite Structures", Douglas Paper 7299, presented to Sixth Conference on Fibrous Composites in Structural Design.

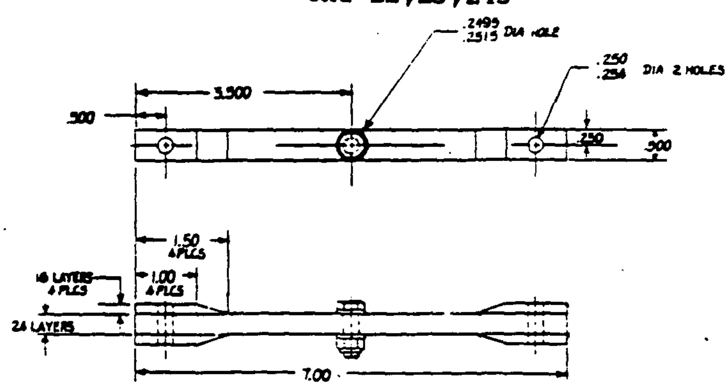
3. Bunin, B.L., "Critical Composite Joint Subcomponents - Analysis and Test Results", NASA CR 3711, September 1983.



UHT 7,8,9
UHT 25,26,27

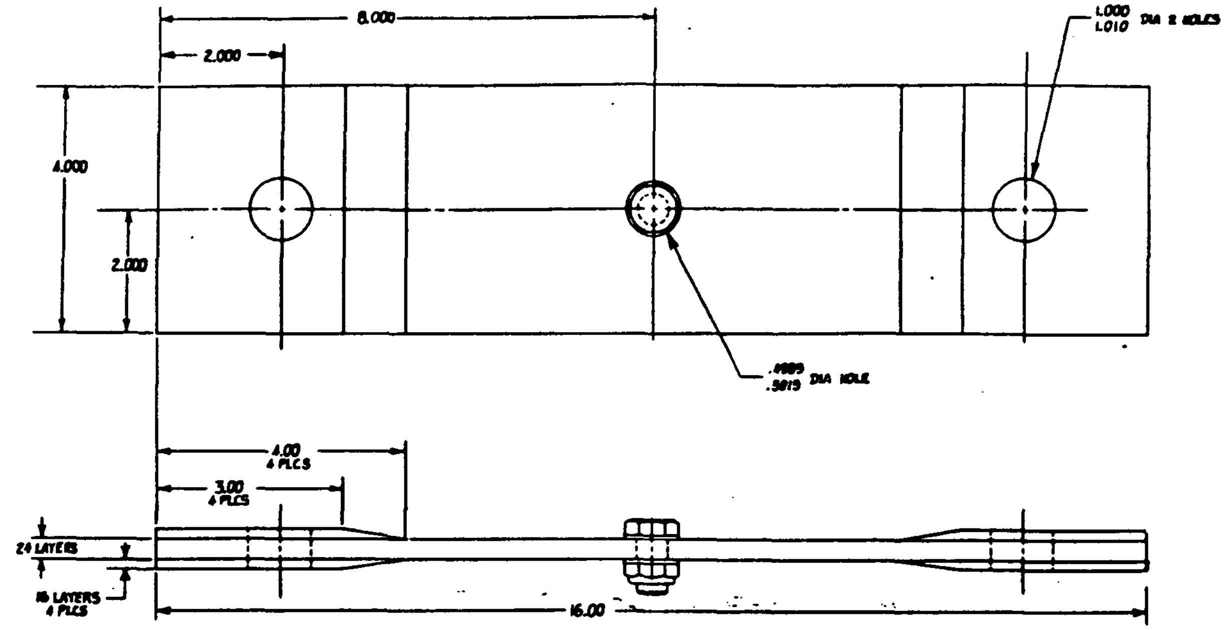


UHT 4,5,6
UHT 22,23,243

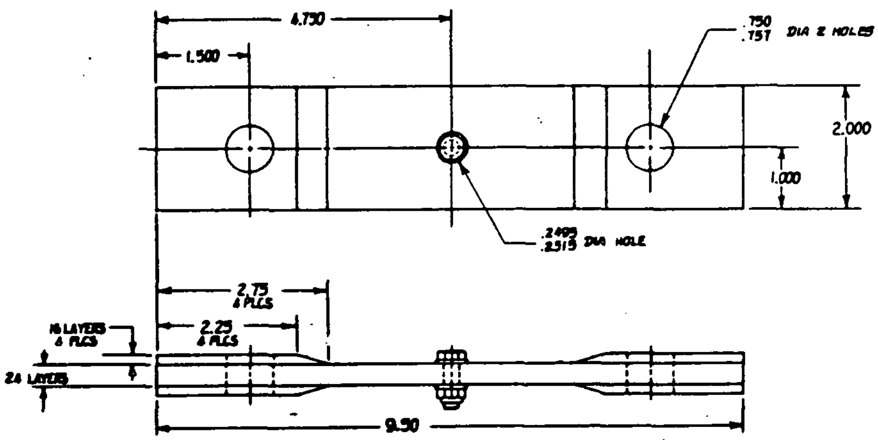


UHT 1,2,3
UHT 19,20,21

FIGURE 1 - UNLOADED HOLE TENSION SPECIMENS

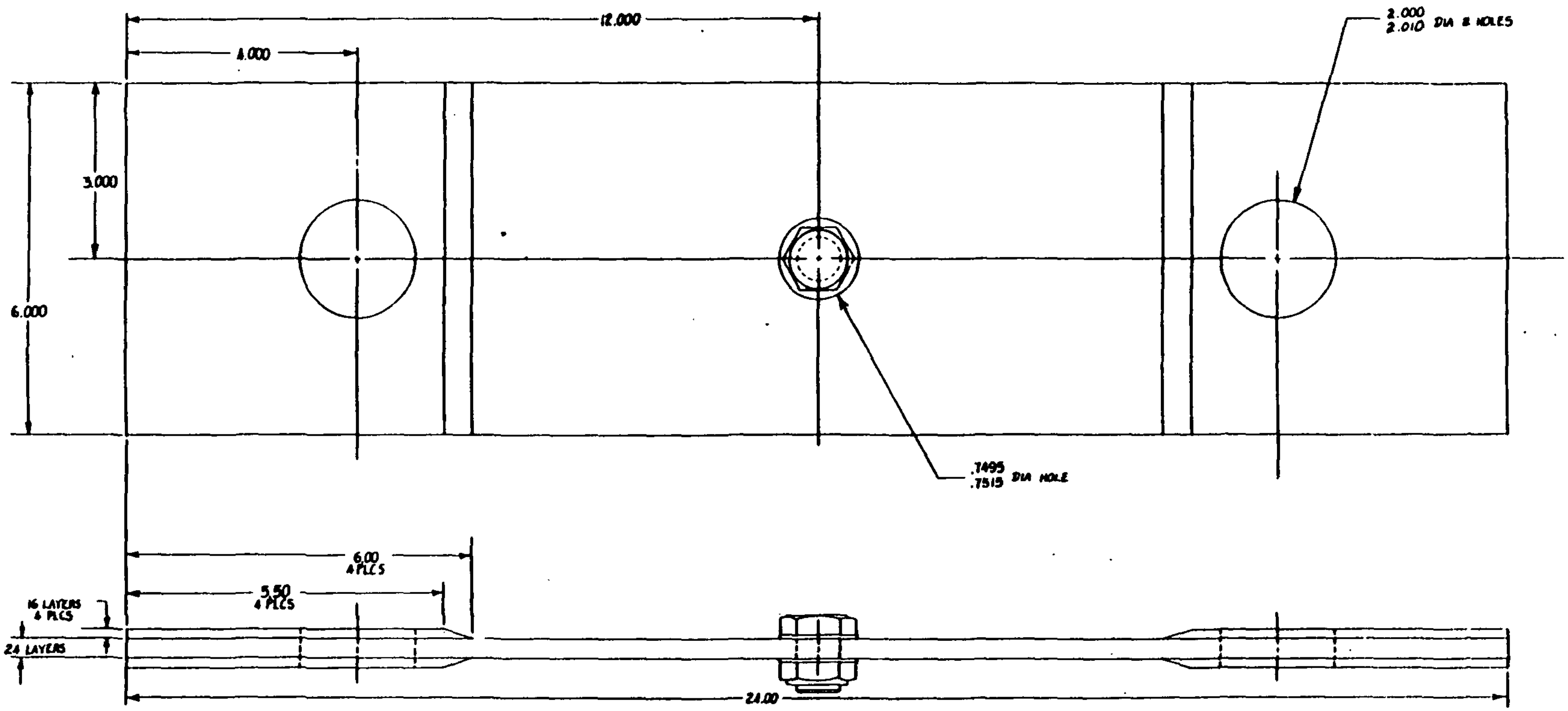


UHT 13,14,15
UHT 31,32,33



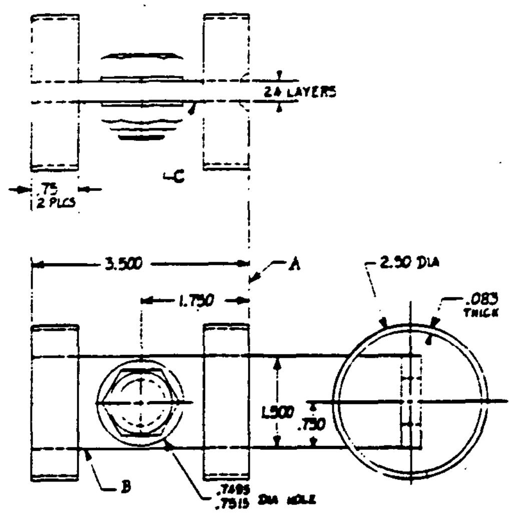
UHT 10,11,12
UHT 28,29,30

FIGURE 2 - UNLOADED HOLE TENSION SPECIMENS

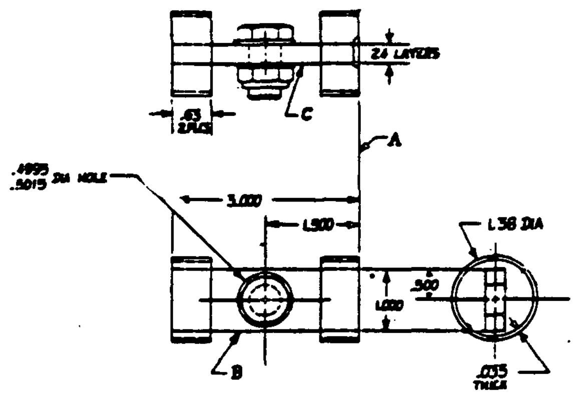


UHT 16,17,18
UHT 34,35,36

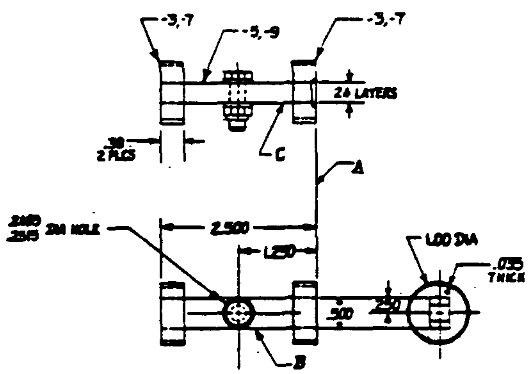
FIGURE 3 - UNLOADED HOLE TENSION SPECIMEN



UHC 7,8,9
UHC 25,26,27

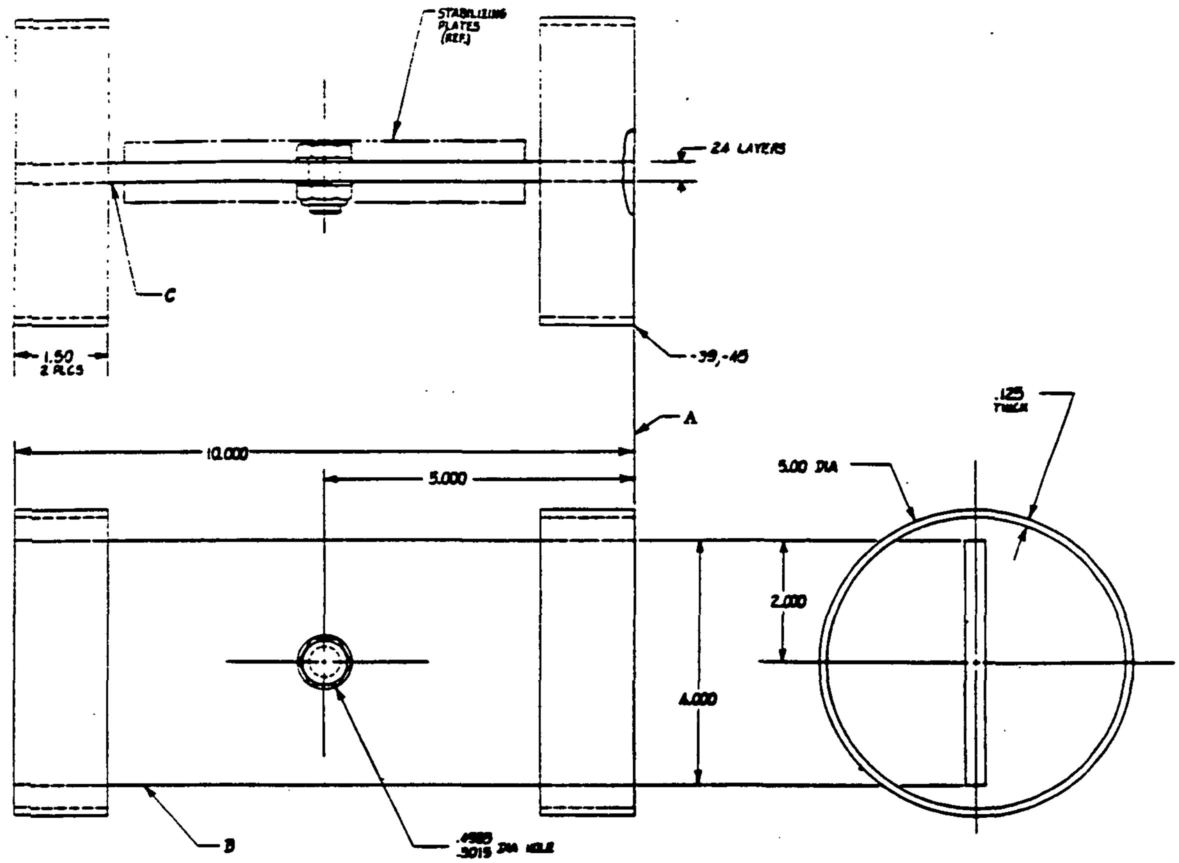


UHC 4,5,6
UHC 22,23,24

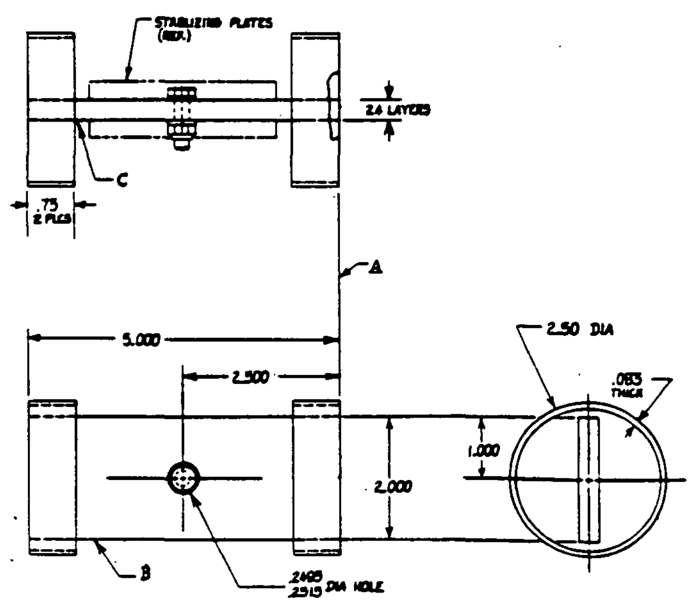


UHC 1,2,3
UHC 19,20,21

FIGURE 4 - UNLOADED HOLE COMPRESSION SPECIMENS

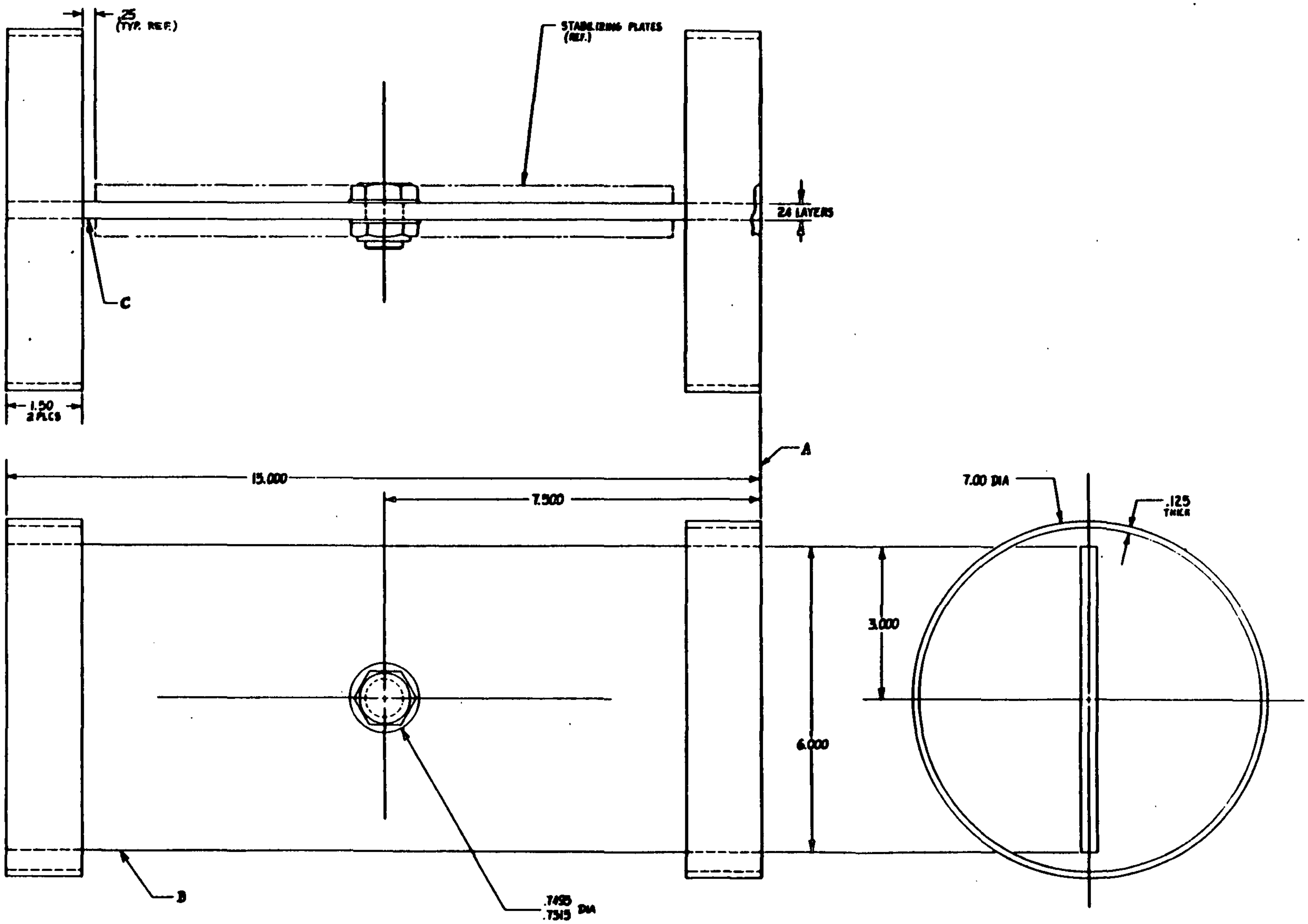


UHC 13,14,15
UHC 31,32,33



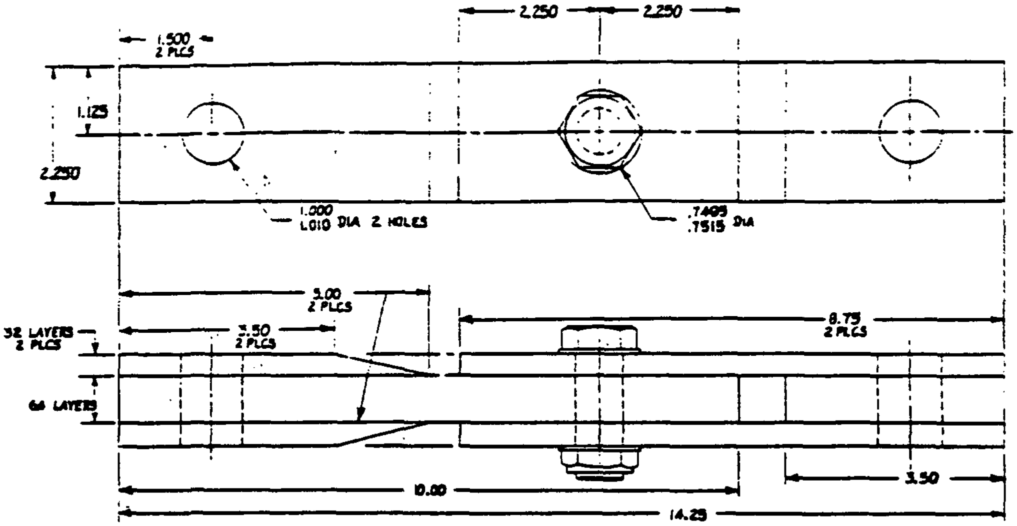
UHC 10,11,12
UHC 28,29,30

FIGURE 5 - UNLOADED HOLE COMPRESSION SPECIMENS

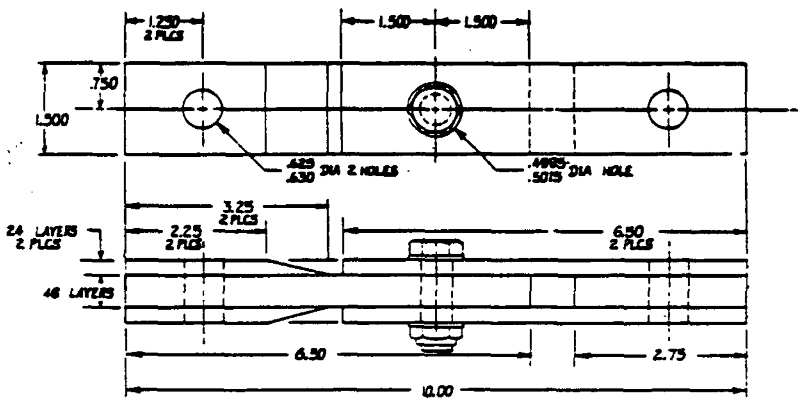


UHC 16,17,18
UHC 34,35,36

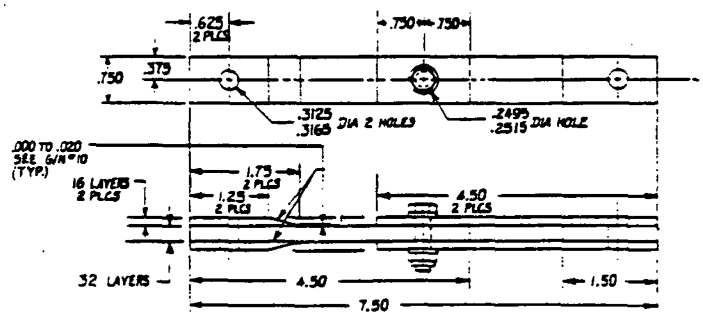
FIGURE 6 - UNLOADED HOLE COMPRESSION SPECIMEN



DST 7,8,9
DST 25,26,27

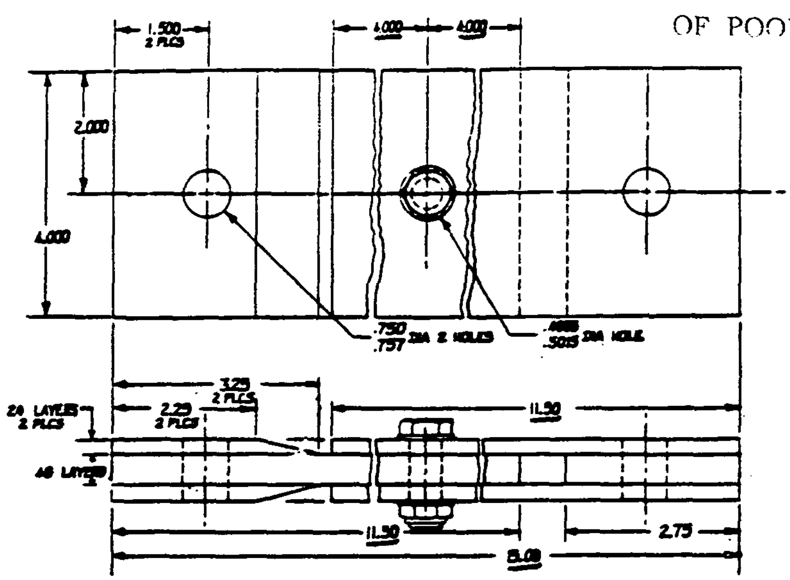


DST 4,5,6
DST 22,23,24

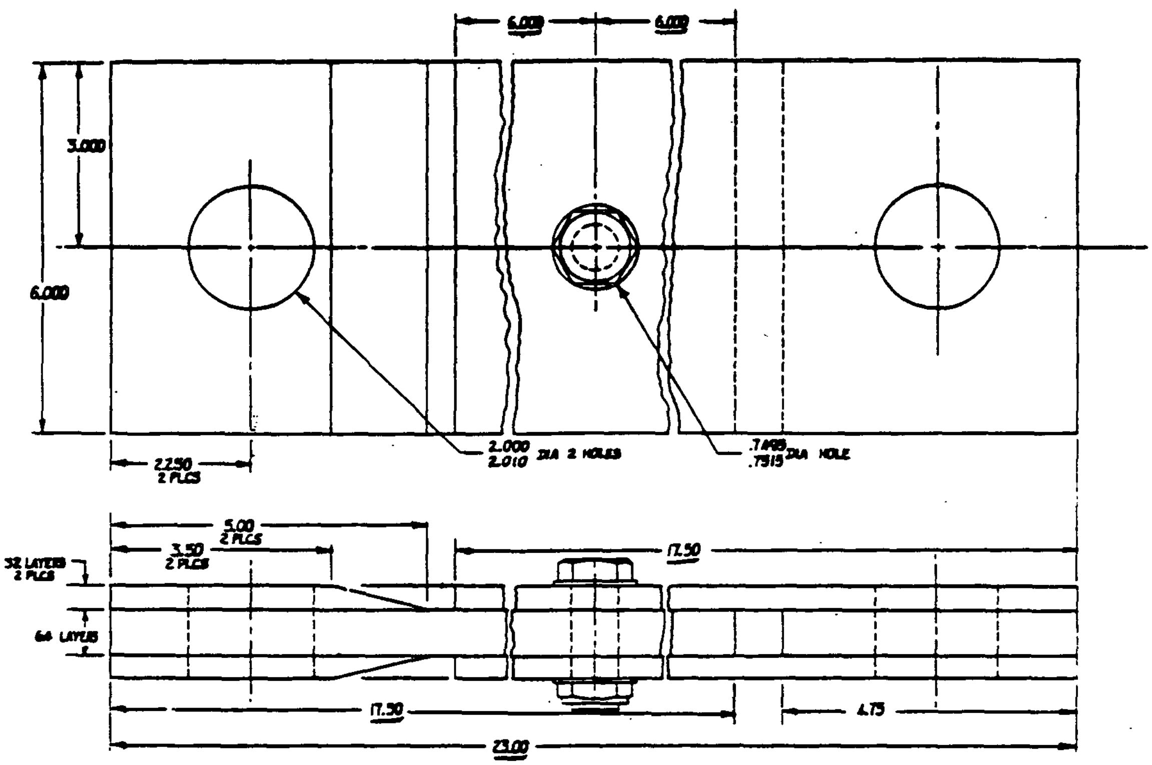


DST 1,2,3
DST 19,20,21

FIGURE 7 - DOUBLE SHEAR TENSION SPECIMENS

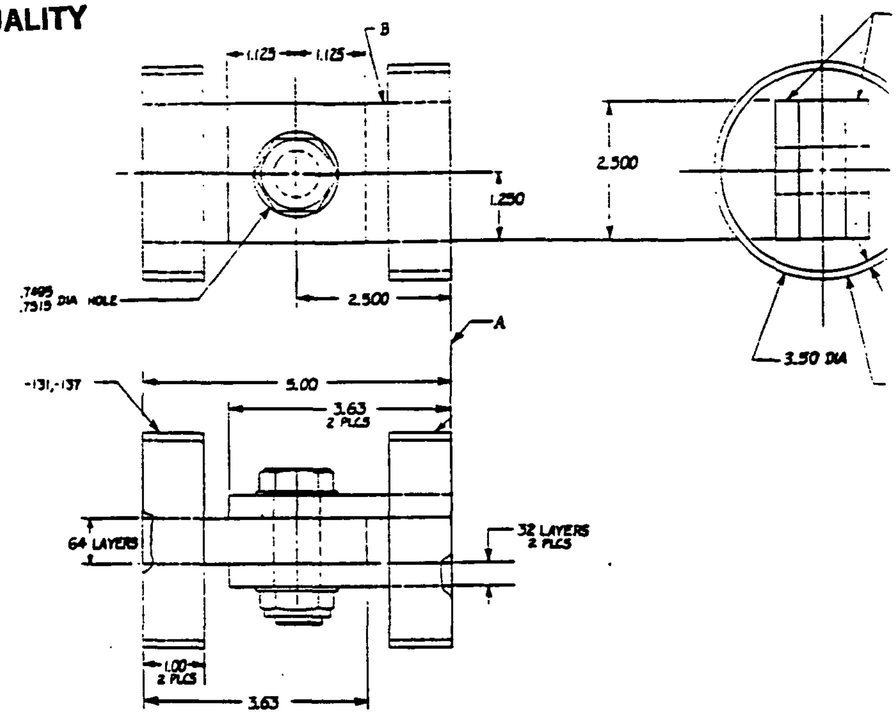


DST 13,14,15
DST 31,32,33

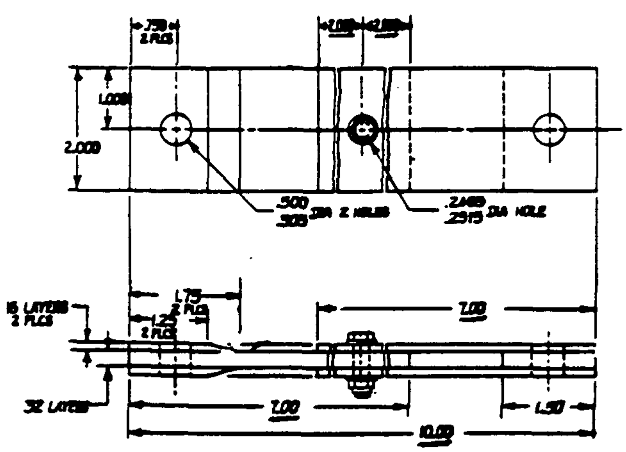


DST 16,17,18
DST 34,35,36

FIGURE 8 - DOUBLE SHEAR TENSION SPECIMENS



DSC 7,8,9
DSC 25,26,27



DST 10,11,12
DST 28,29,30

FIGURE 9 - DOUBLE SHEAR COMPRESSION AND TENSION SPECIMENS

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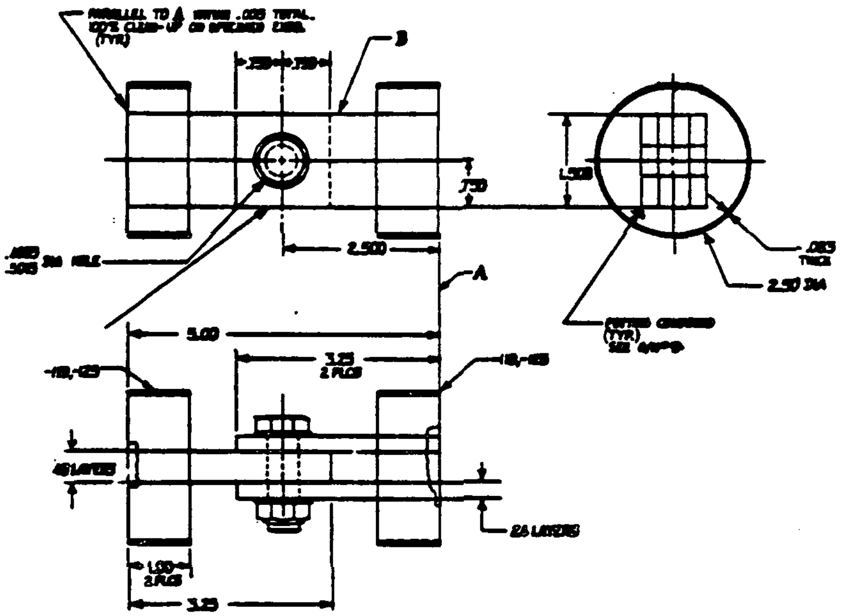
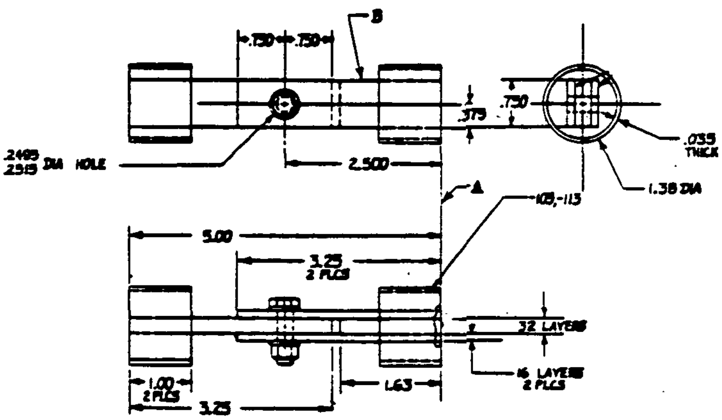
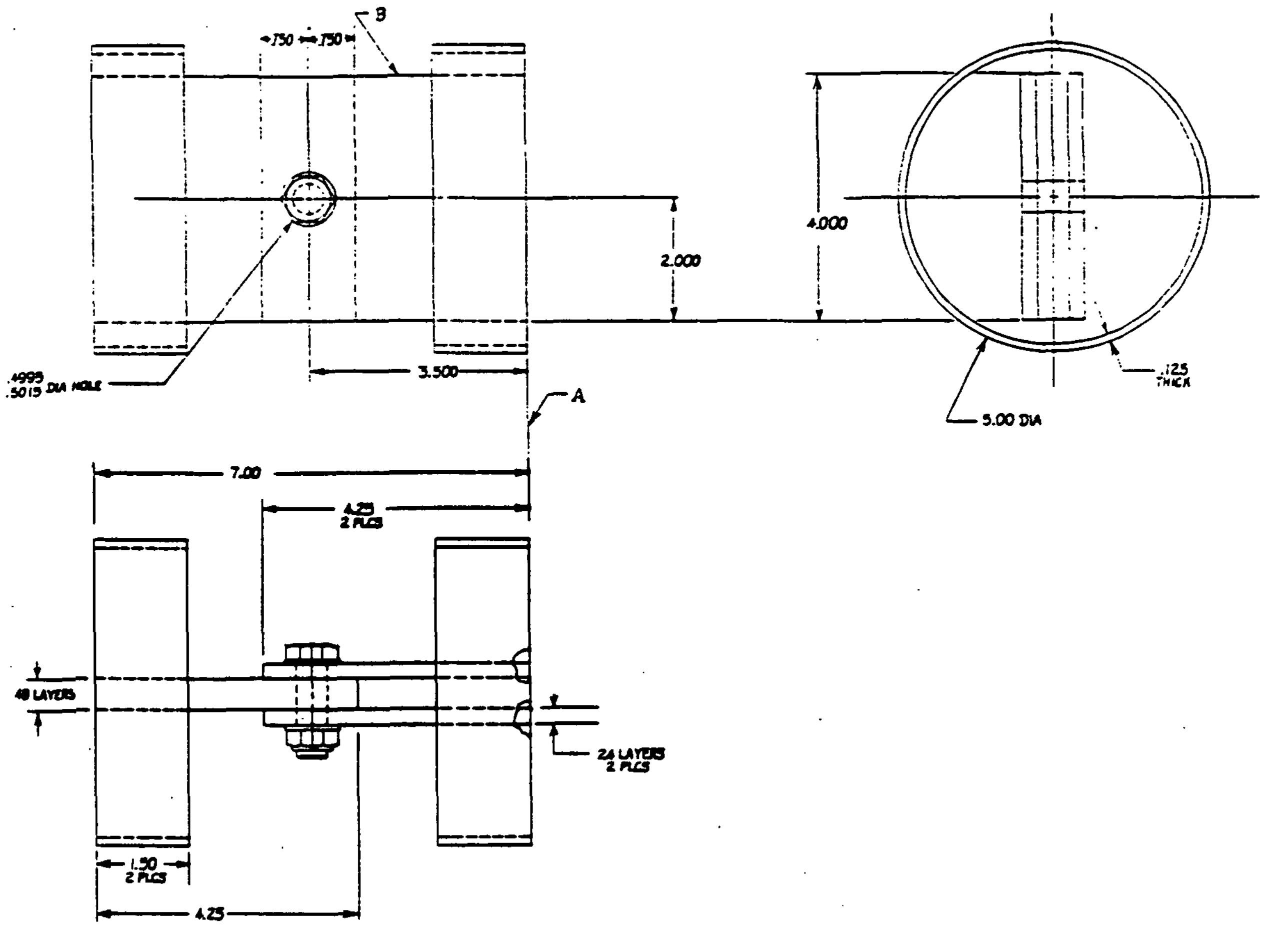


DSC 4,5,6
DSC 22,23,24

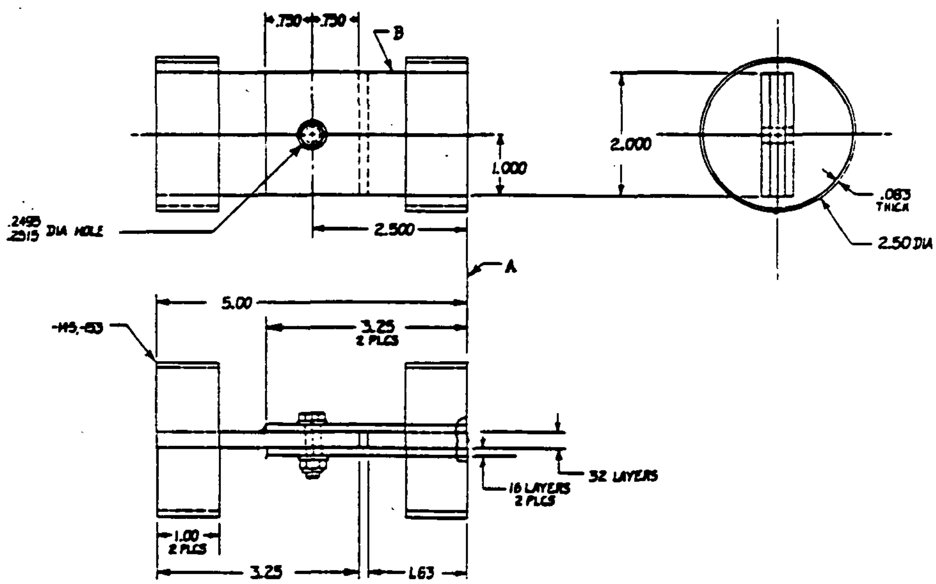


DSC 1,2,3
DSC 19,20,21

FIGURE 10 - DOUBLE SHEAR COMPRESSION SPECIMENS



DSC 13,14,15
DSC 31,32,33



DSC 10,11,12
DSC 28,29,30

FIGURE 11 - DOUBLE SHEAR COMPRESSION SPECIMENS

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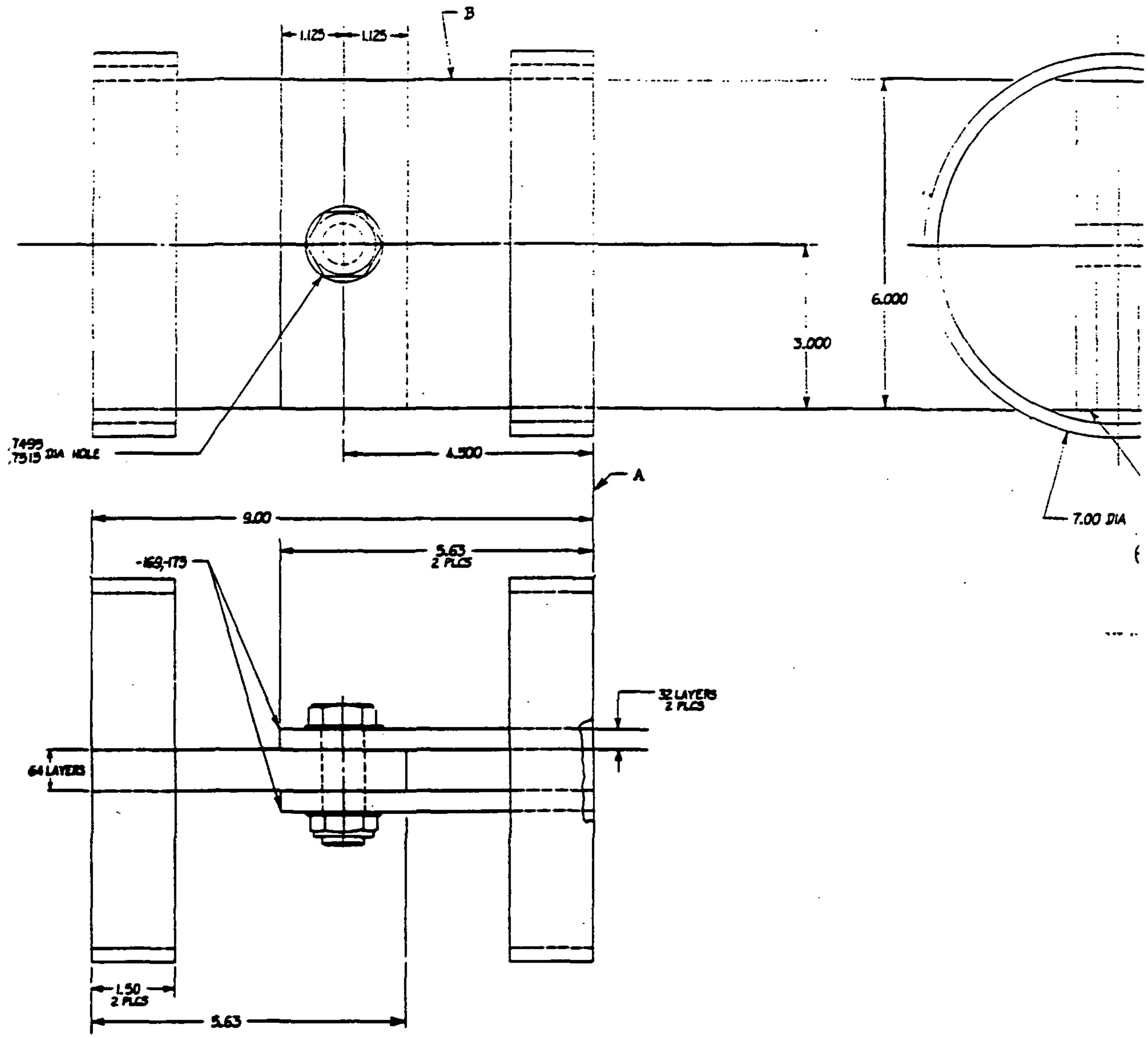
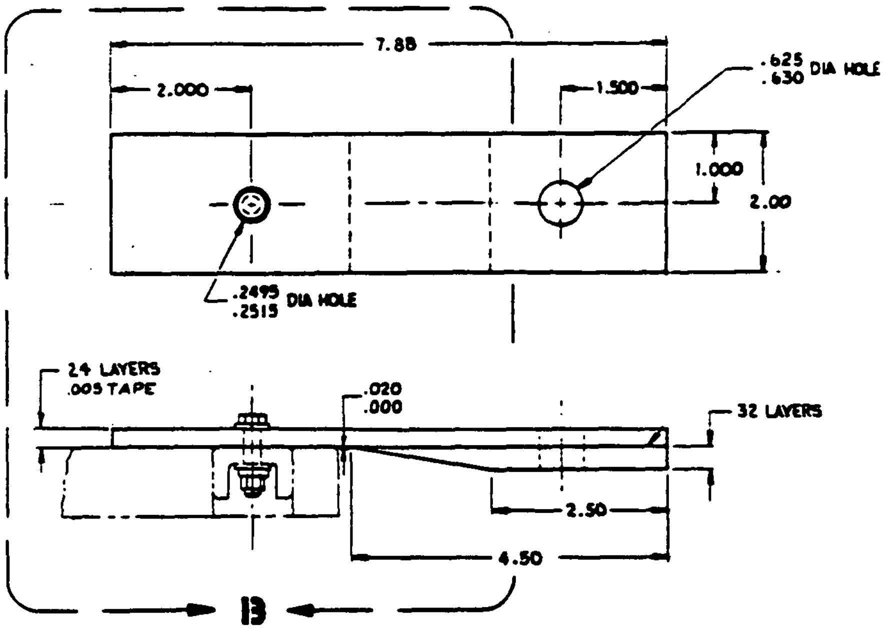
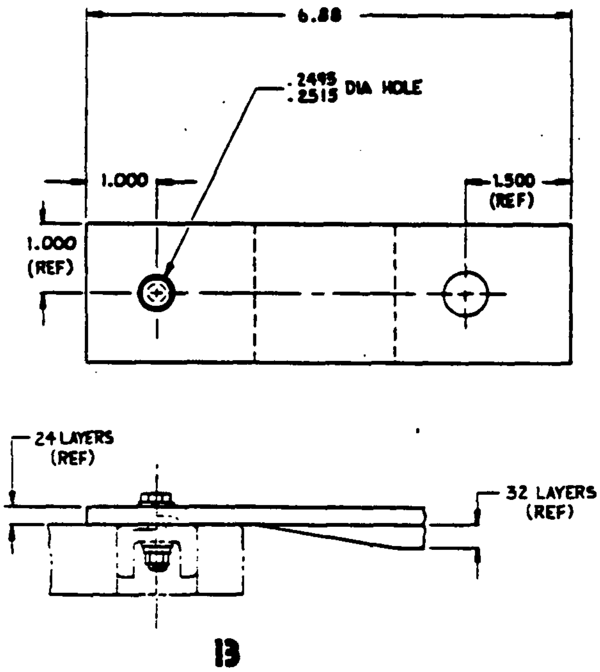


DSC 16,17,18
DSC 34,35,36

FIGURE 12 - DOUBLE SHEAR COMPRESSION SPECIMEN

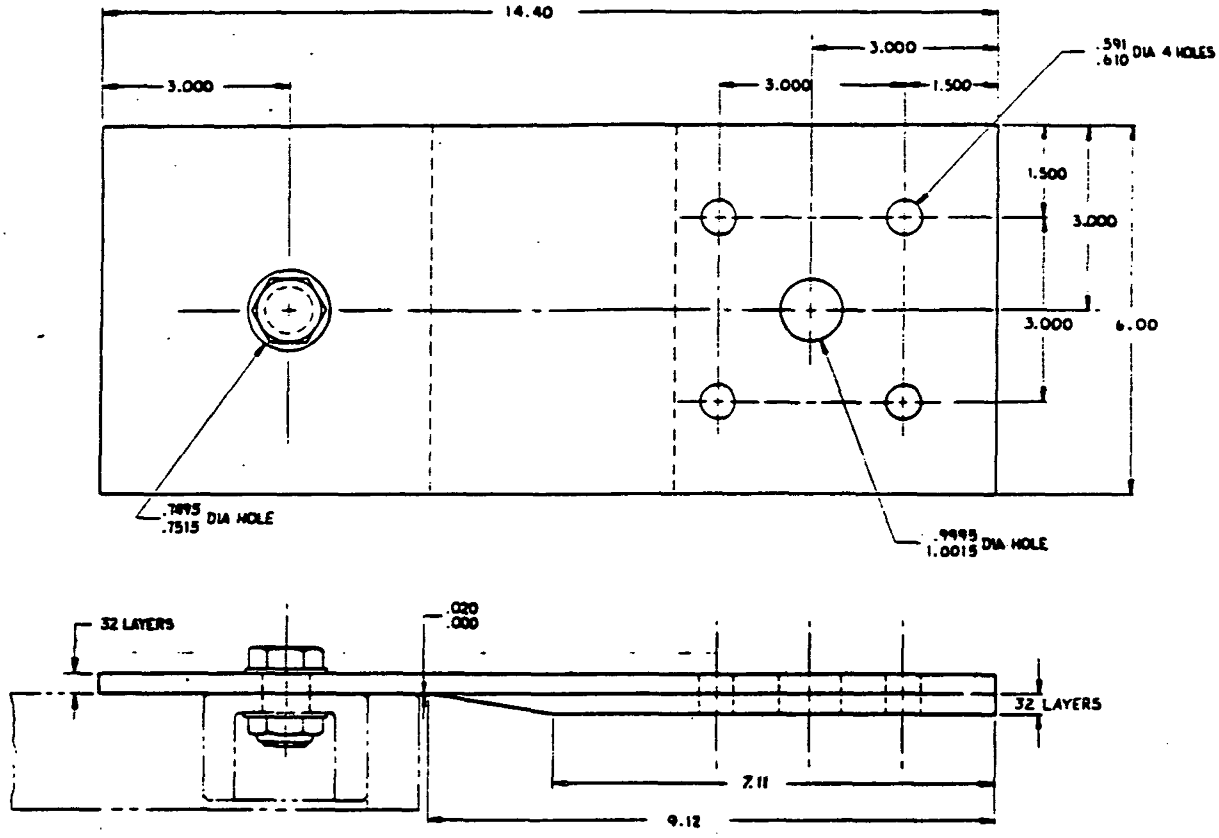


SST 1,2,3
SST 10,11,12

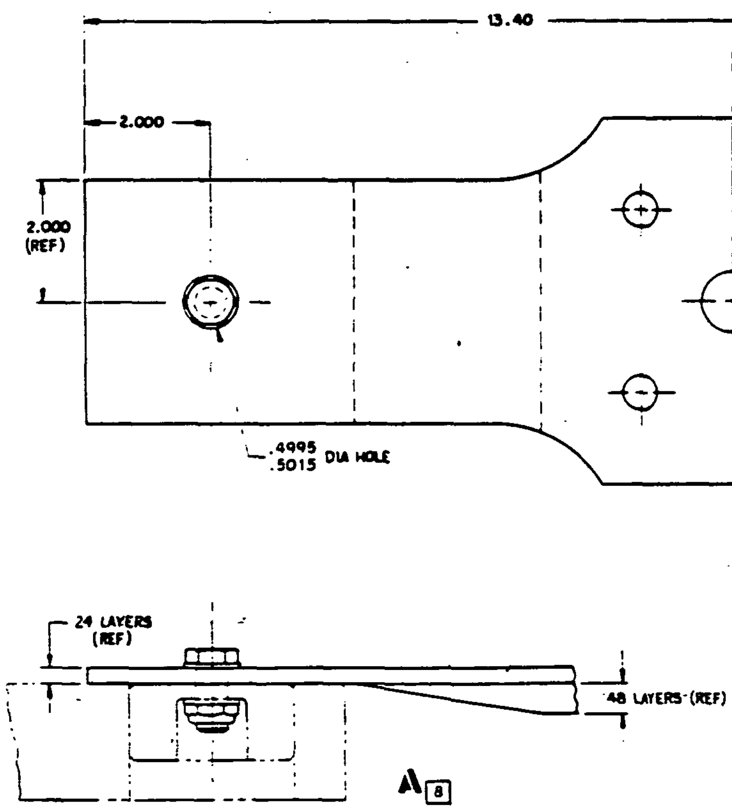


SSC 1,2,3
SSC 10,11,12

FIGURE 13 - SINGLE SHEAR SPECIMENS



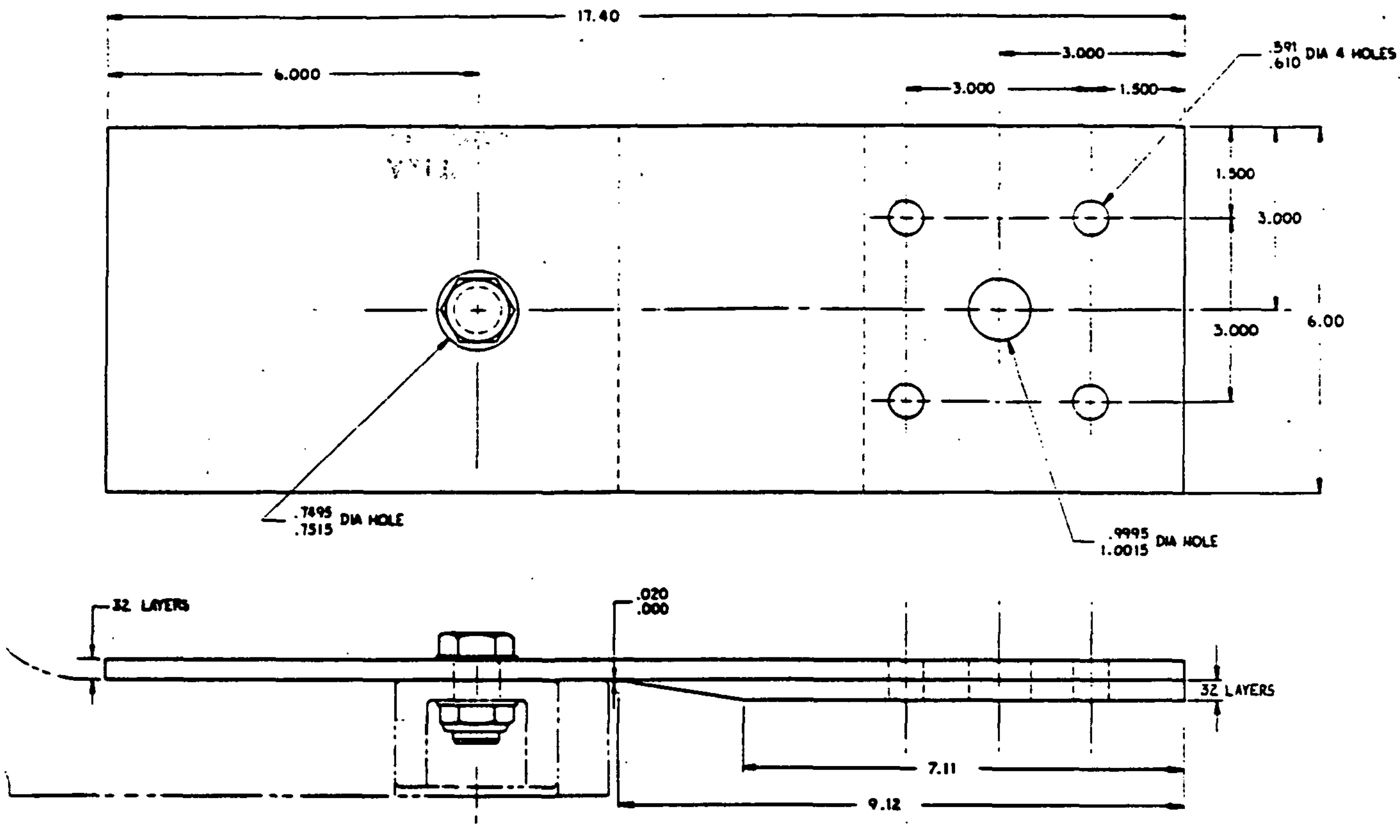
SSC 7,8,9
SSC 16,17,18



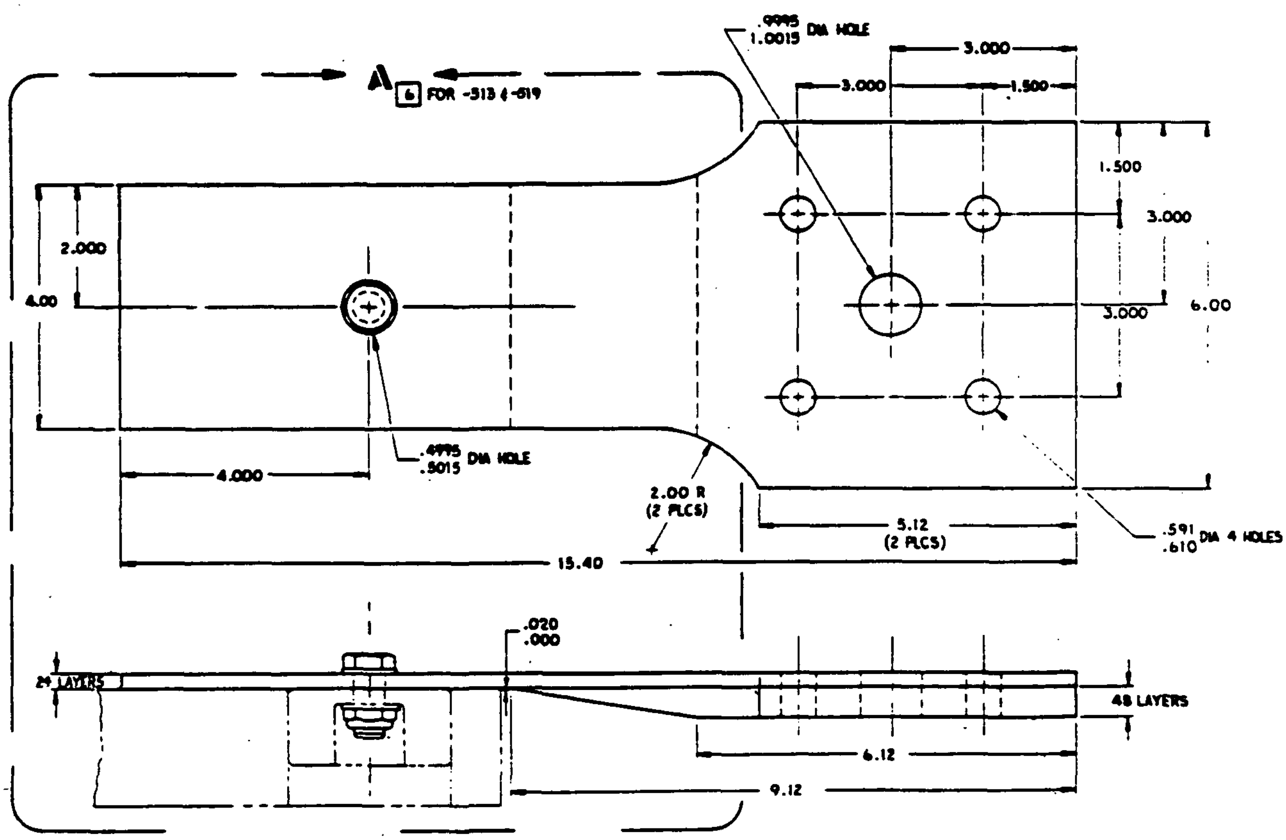
A 8

SSC 4,5,6
SSC 13,14,15

FIGURE 14 - SINGLE SHEAR SPECIMENS



SST 7,8,9
SST 16,17,18



SST 4,5,6
SST 13,14,15

FIGURE 15 - SINGLE SHEAR SPECIMENS

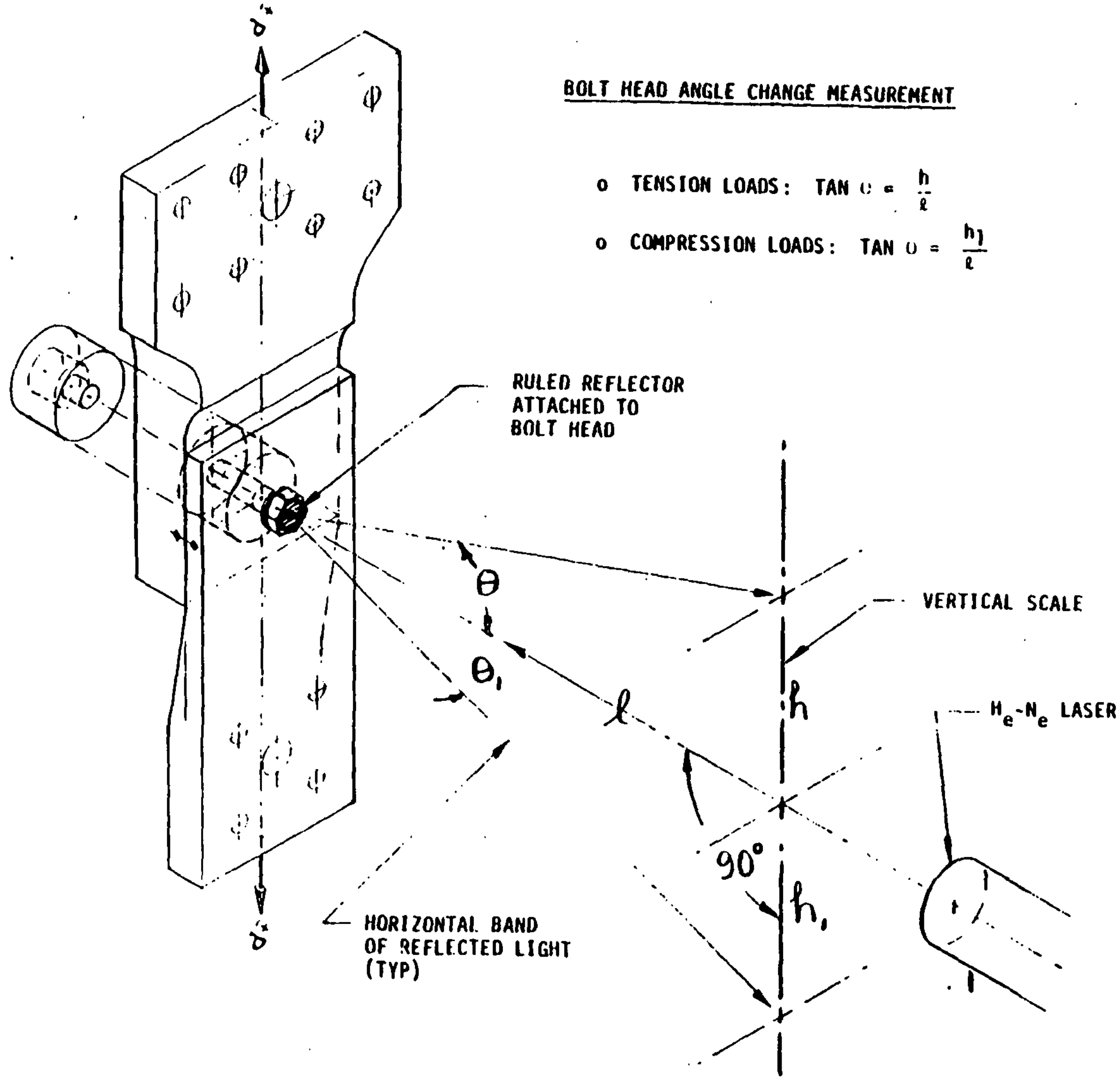


FIGURE 16 - BOLT HEAD ANGLE CHANGE MEASUREMENT

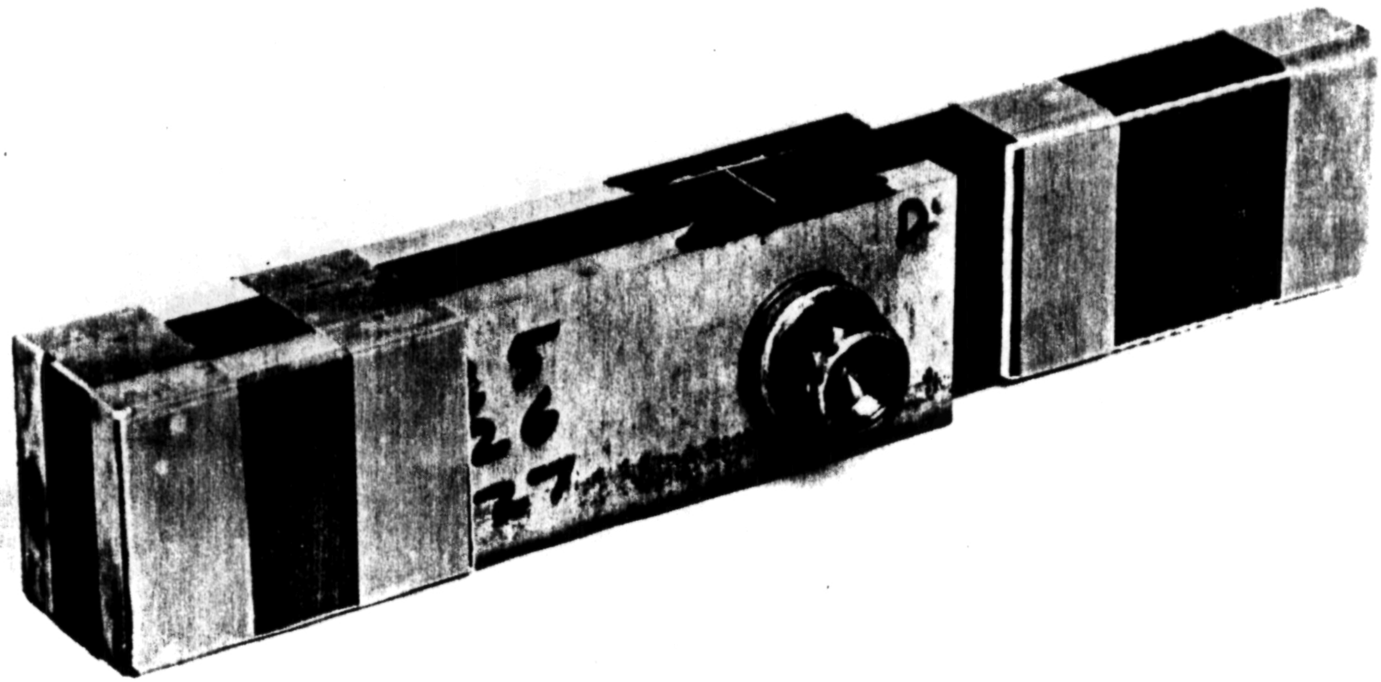


FIGURE 17 DOUBLE SHEAR TENSION SPECIMEN - PHASE II

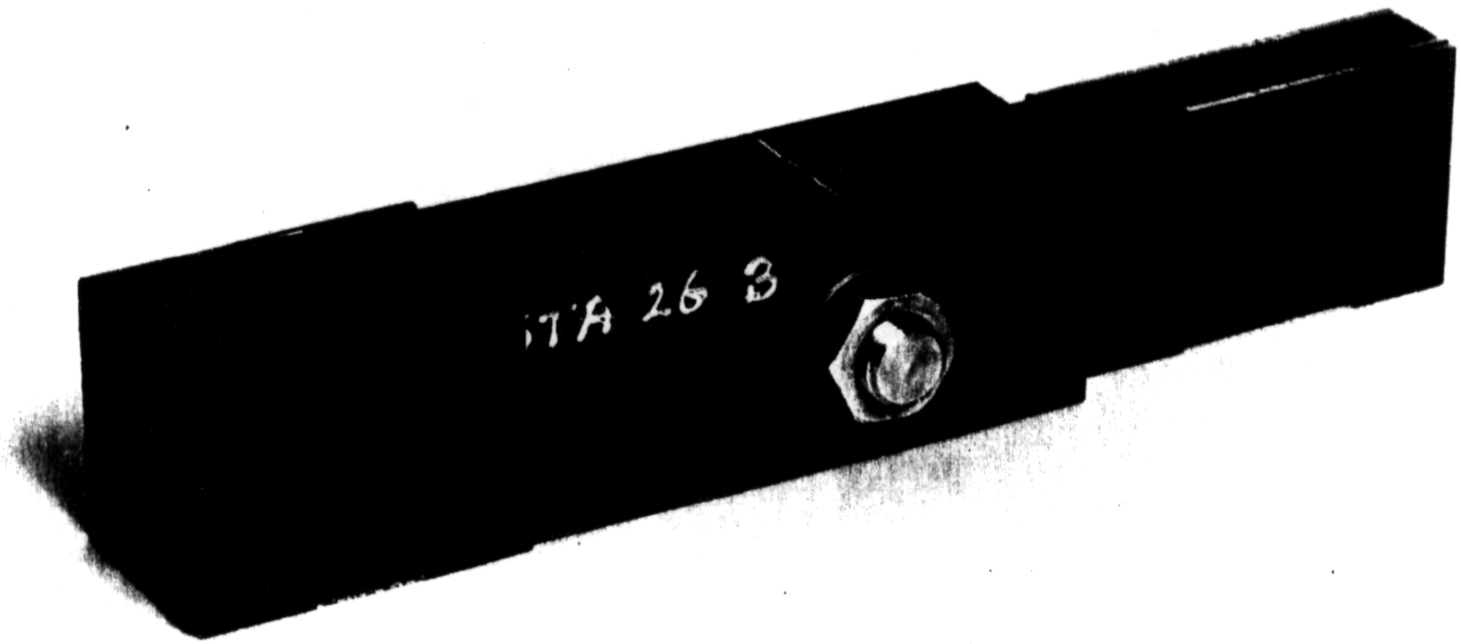


FIGURE 18 DOUBLE SHEAR TENSION SPECIMEN - PHASE II

FIGURE 19

UNLOADED HOLE TENSION TEST SPECIMEN CONFIGURATION

PHASE II

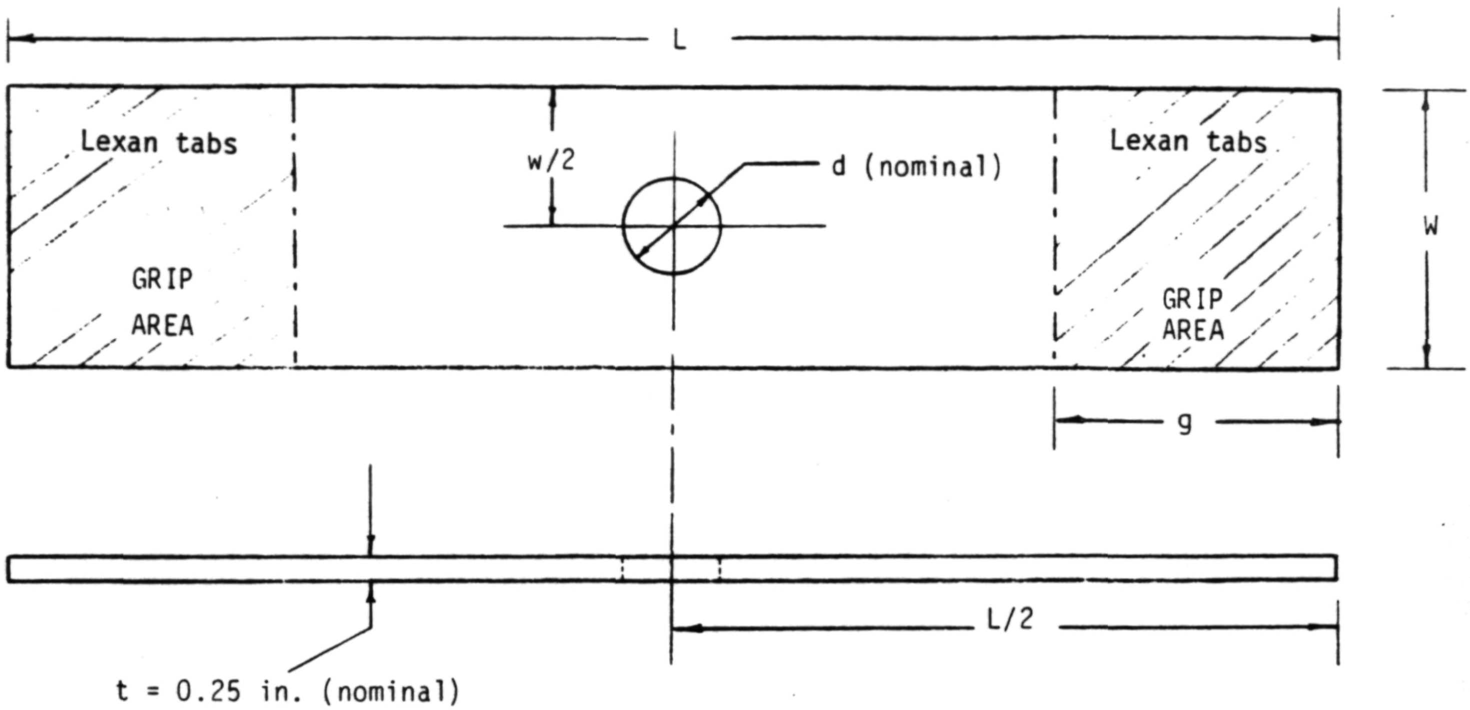
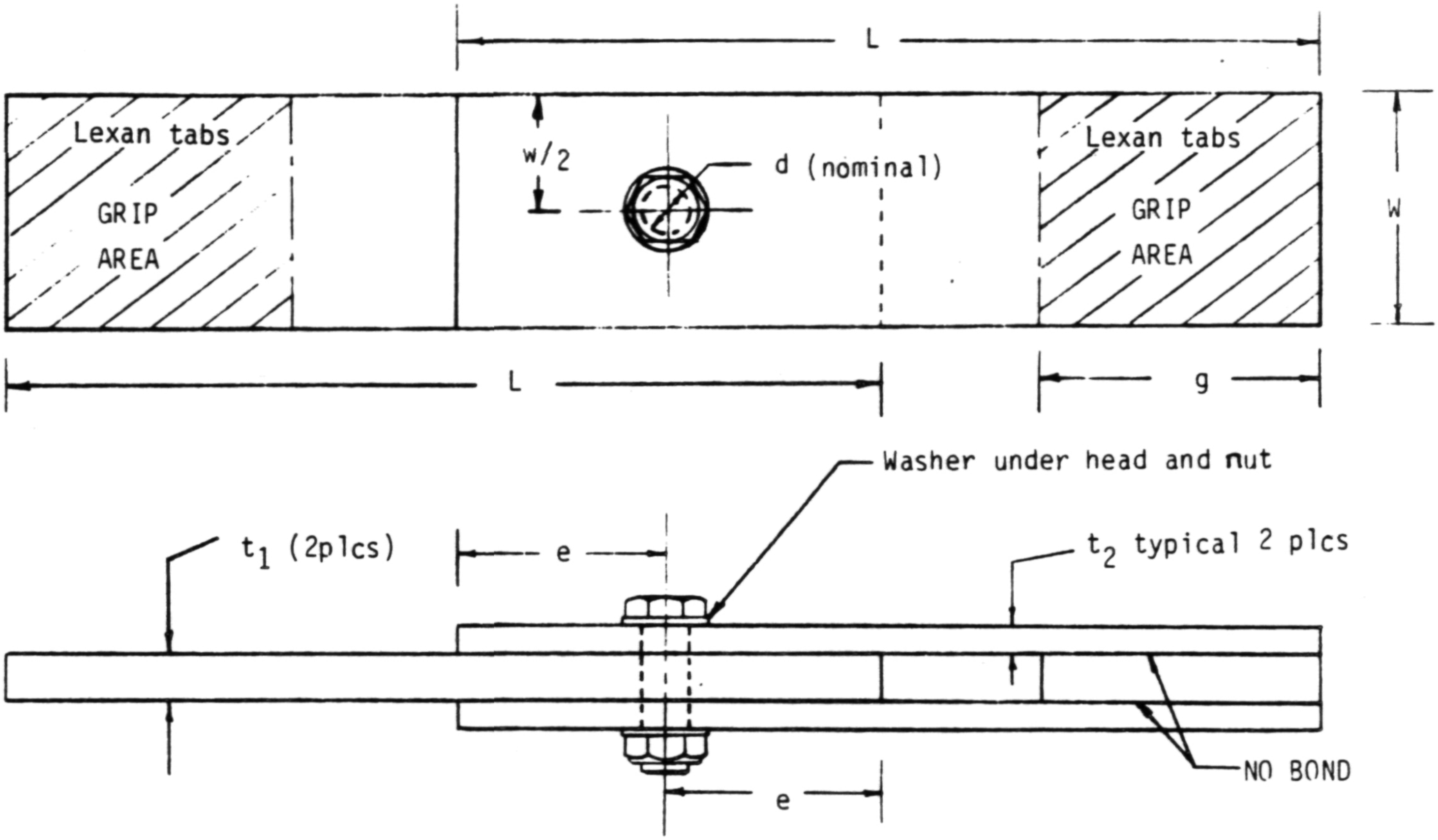


FIGURE 20

BOLTED DOUBLE SHEAR SPECIMEN CONFIGURATION



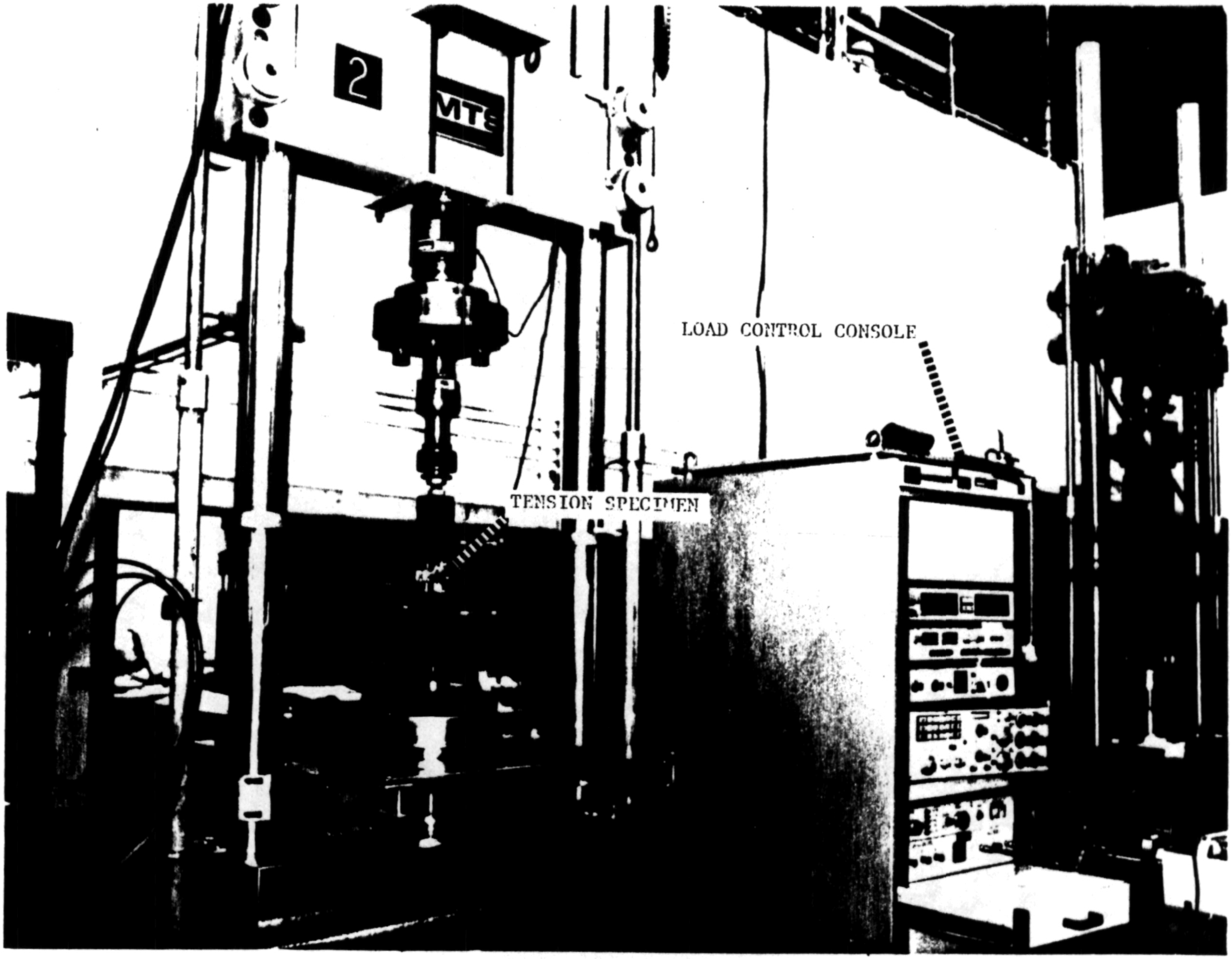


FIGURE 21 TEST SET-UP - DOUBLE SHEAR TENSION TEST

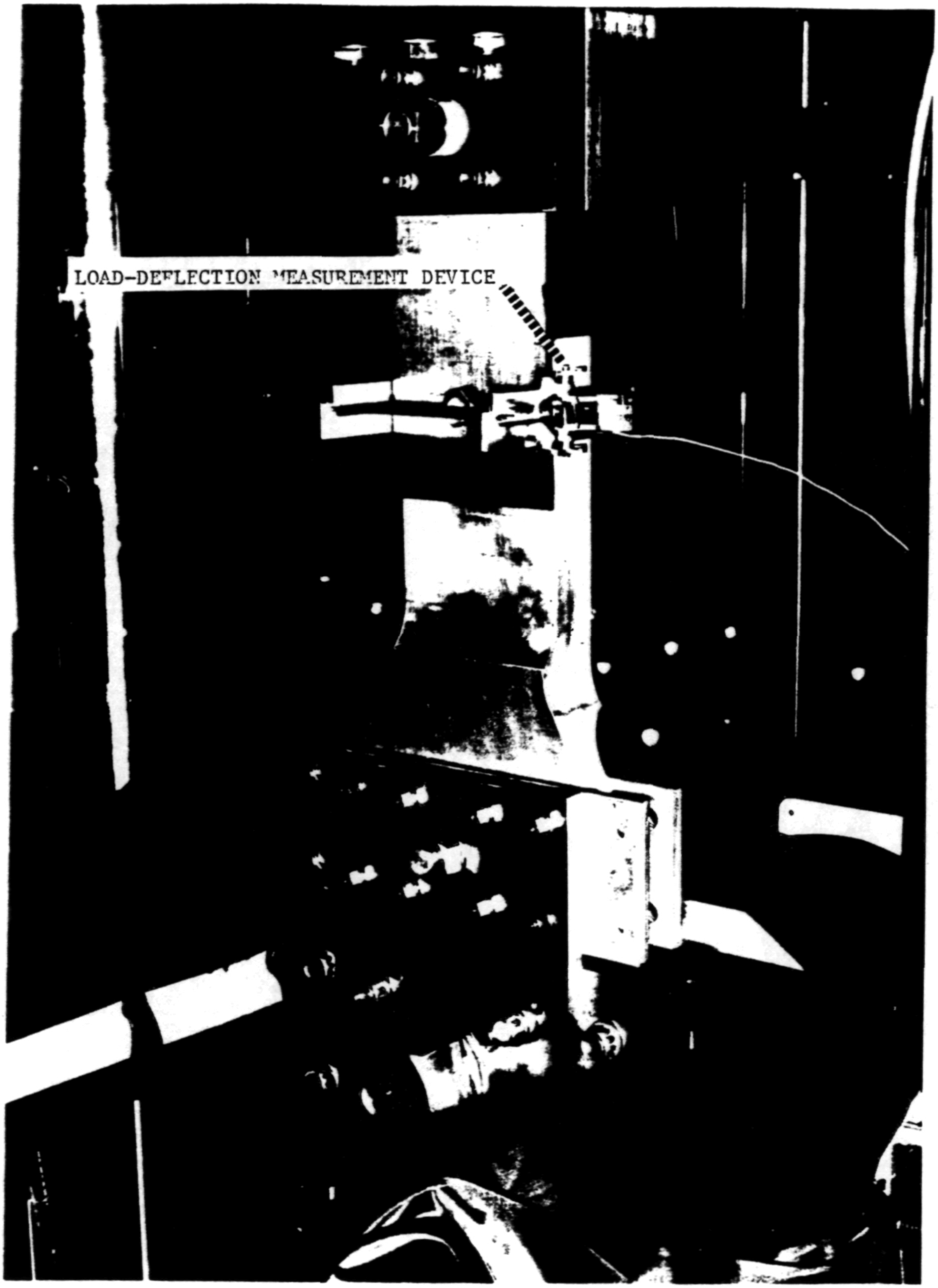


FIGURE 22. SINGLE SHEAR TEST SET-UP

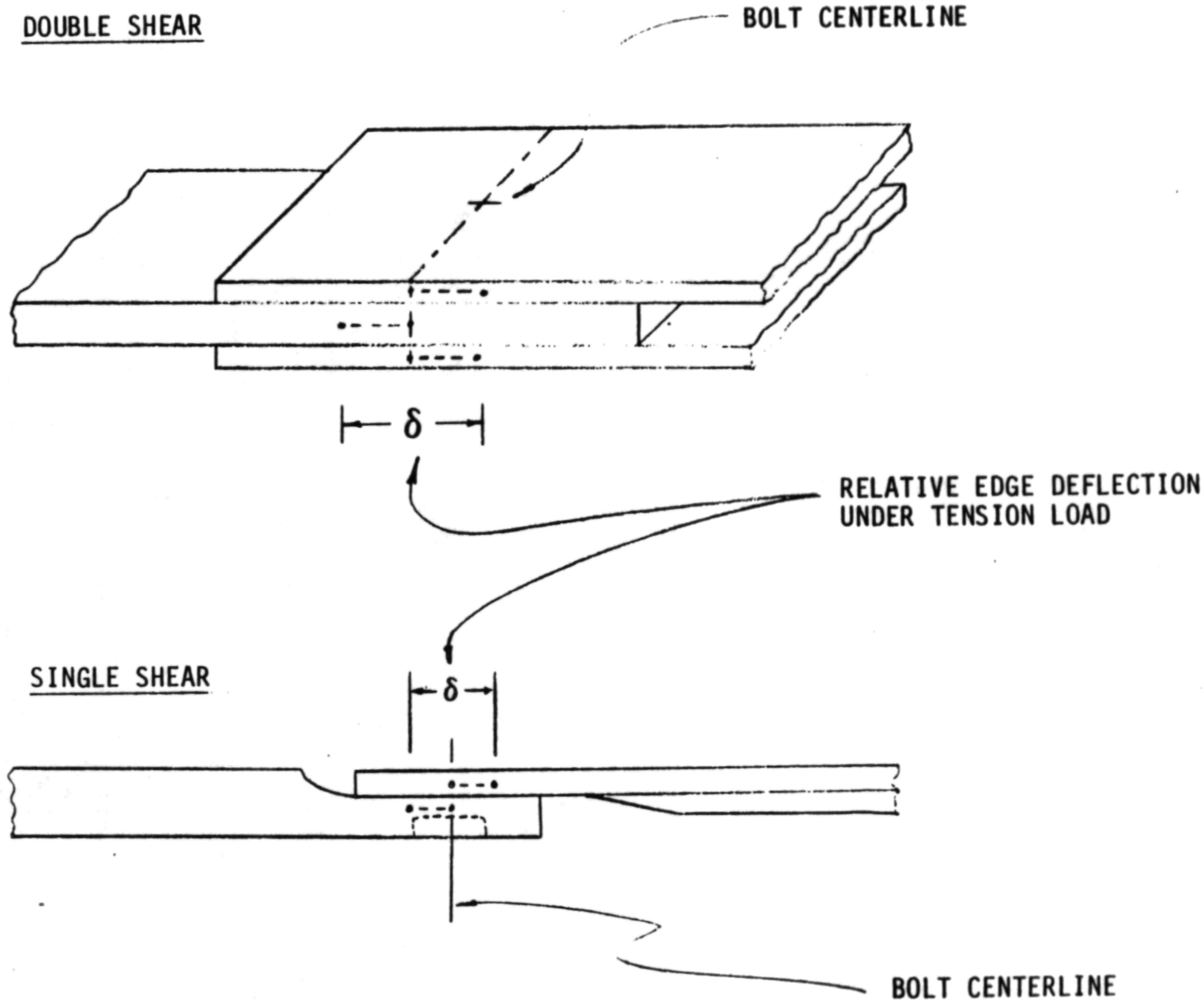


FIGURE 23
DEFINITION OF RELATIVE DEFLECTION MEASUREMENT

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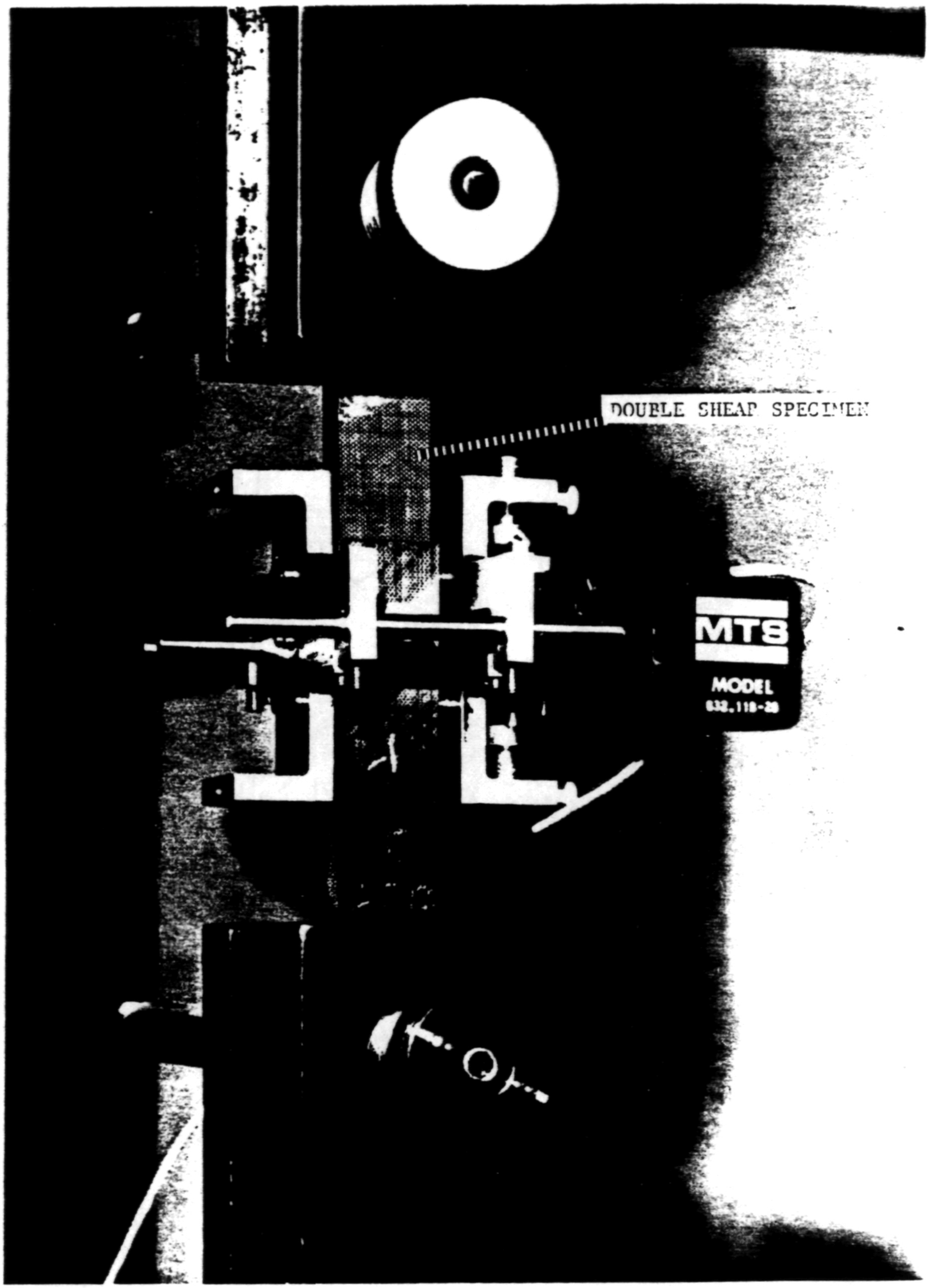

FIGURE 24 DEFLECTION MEASUREMENT DEVICE

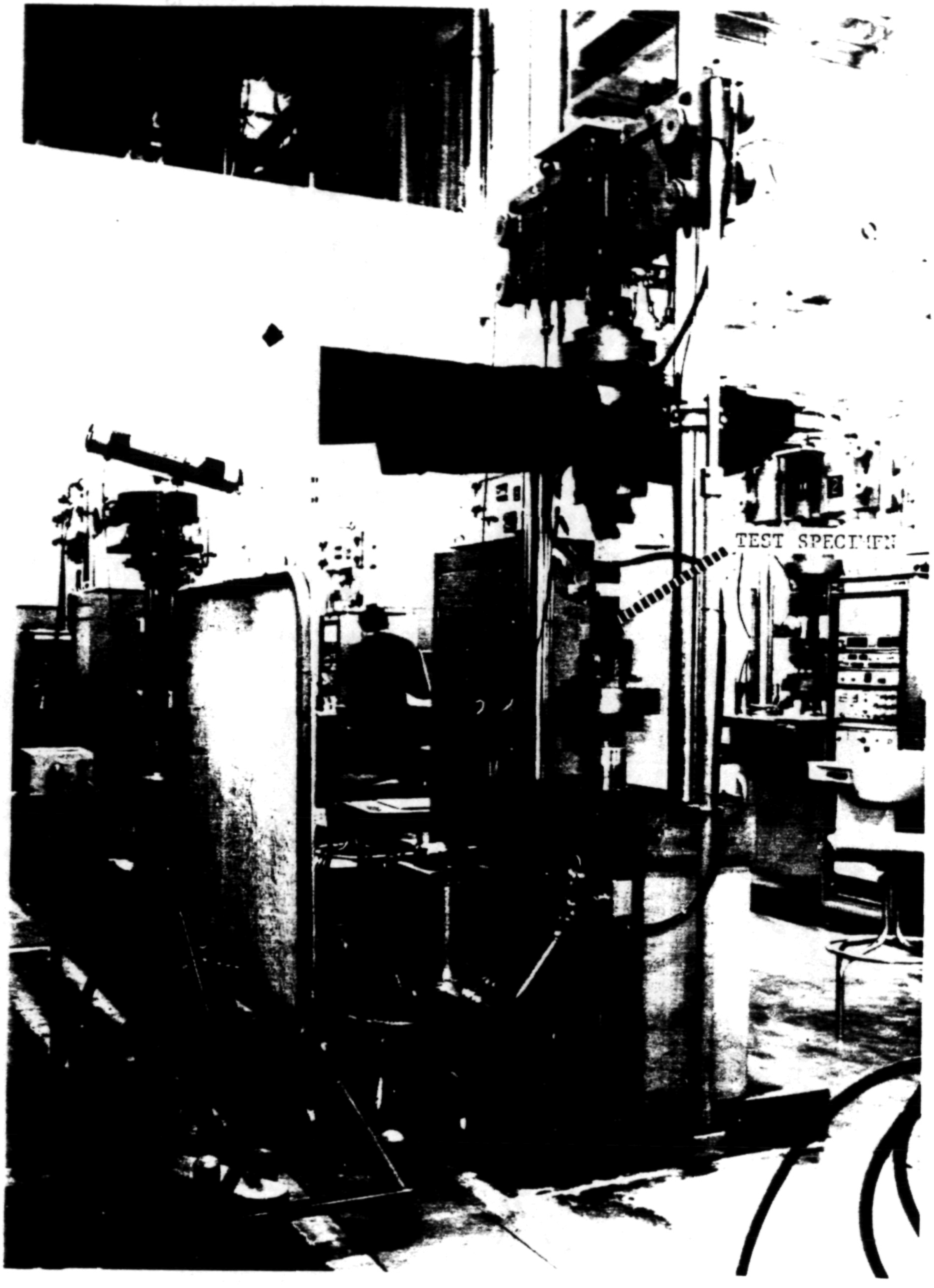

FIGURE 25 SINGLE SHEAR TEST -
MEASUREMENT SYSTEM FOR BOLT HEAD ROTATION

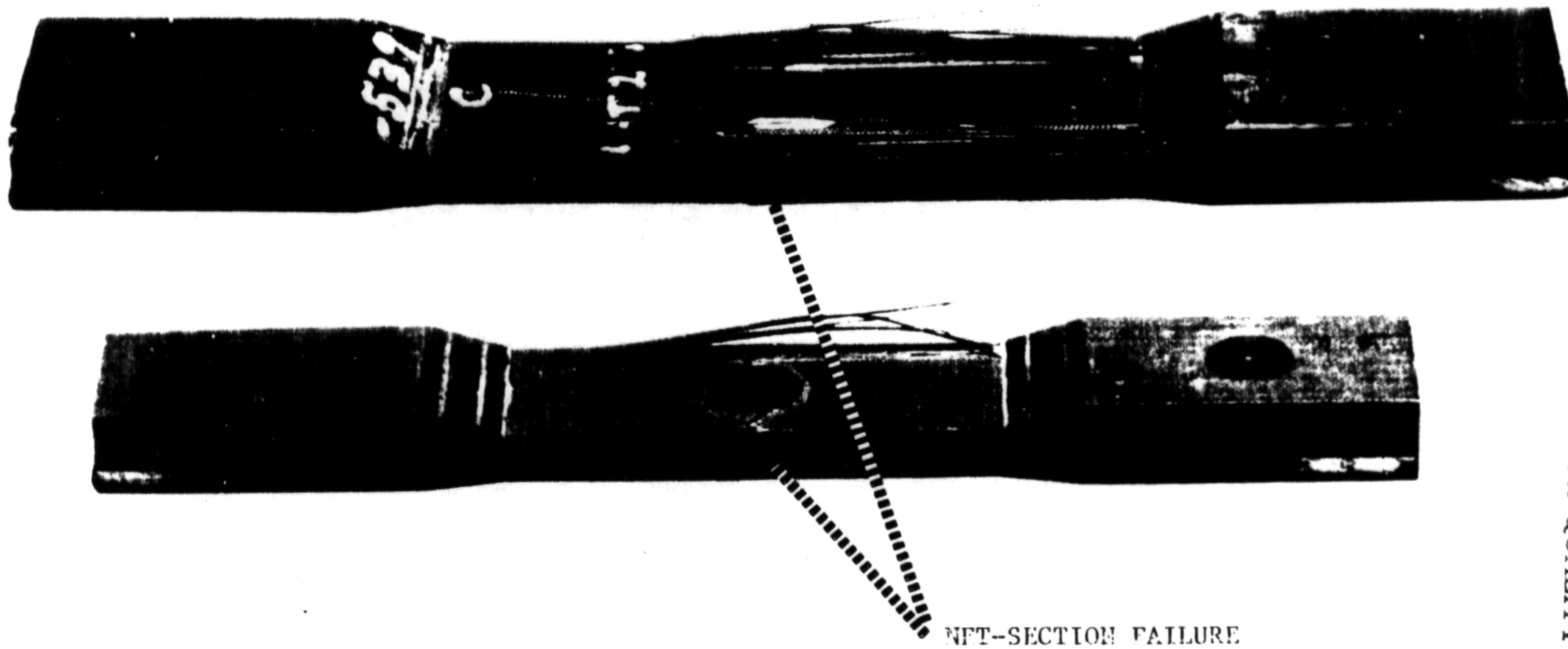

FIGURE 26 UNLOADED HOLE TENSION TEST - NET-SECTION FAILURES

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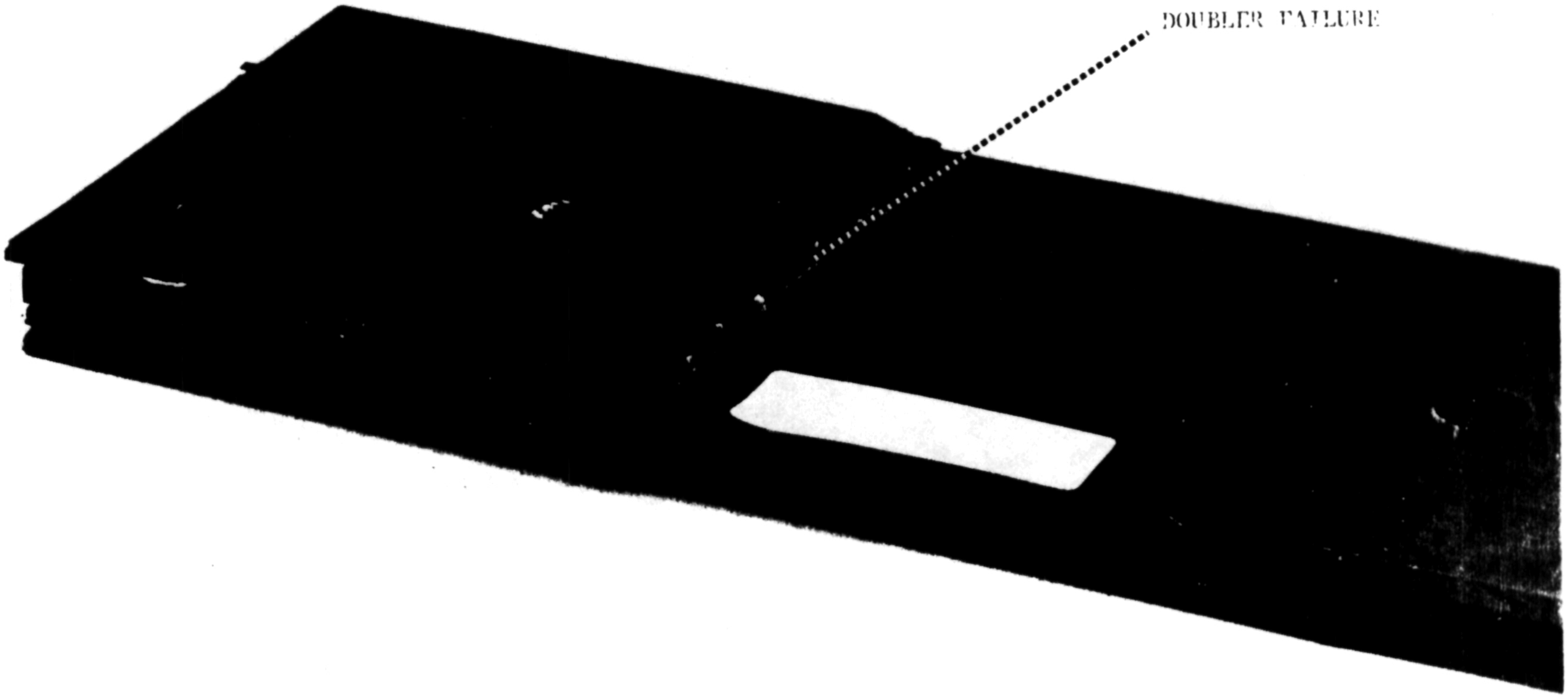


FIGURE 27 UNLOADED HOLE TENSION TEST - BONDED DOUBLER FAILURE

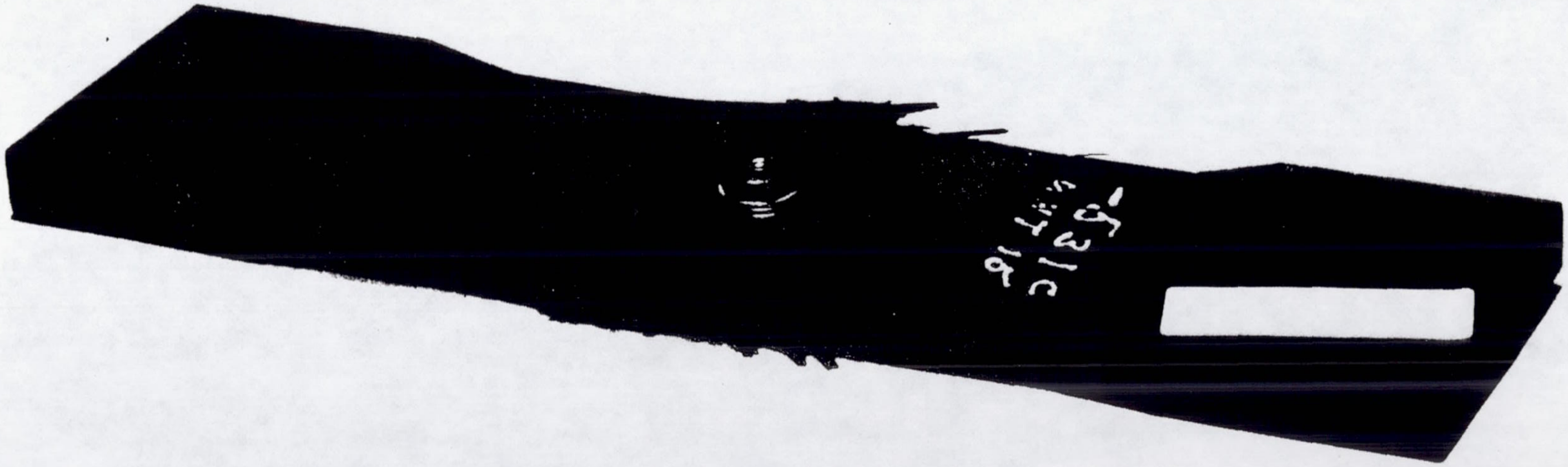


FIGURE 28 UNLOADED HOLE TENSION TEST - NET-SECTION FAILURE

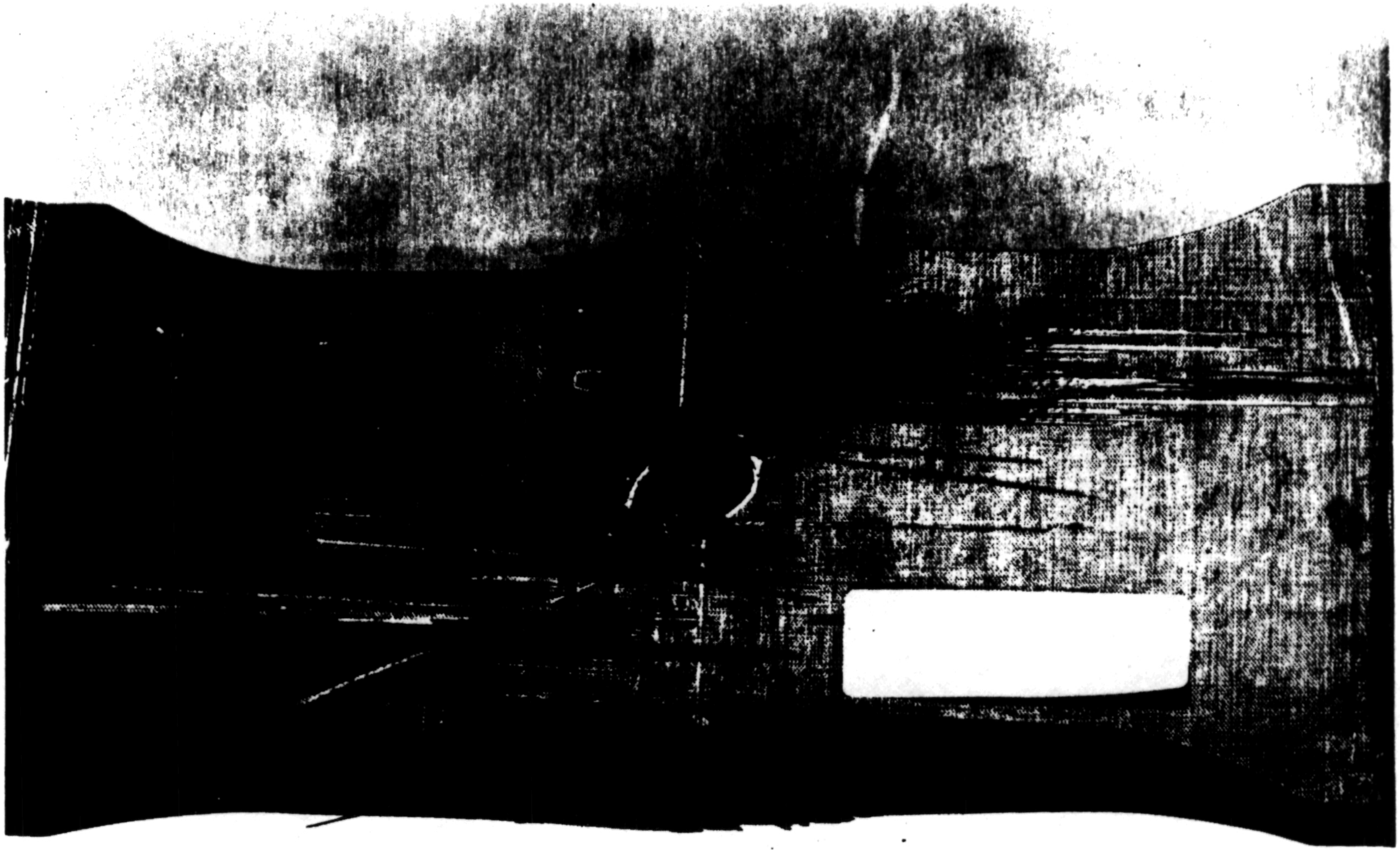


FIGURE 29 UNLOADED HOLE TENSION TEST - (w/d = 6) - NET-SECTION FAILURE

FIGURE 30 UNLOADED HOLE TENSION TEST - BONDED DOUBLER AND END HOLE FAILURE

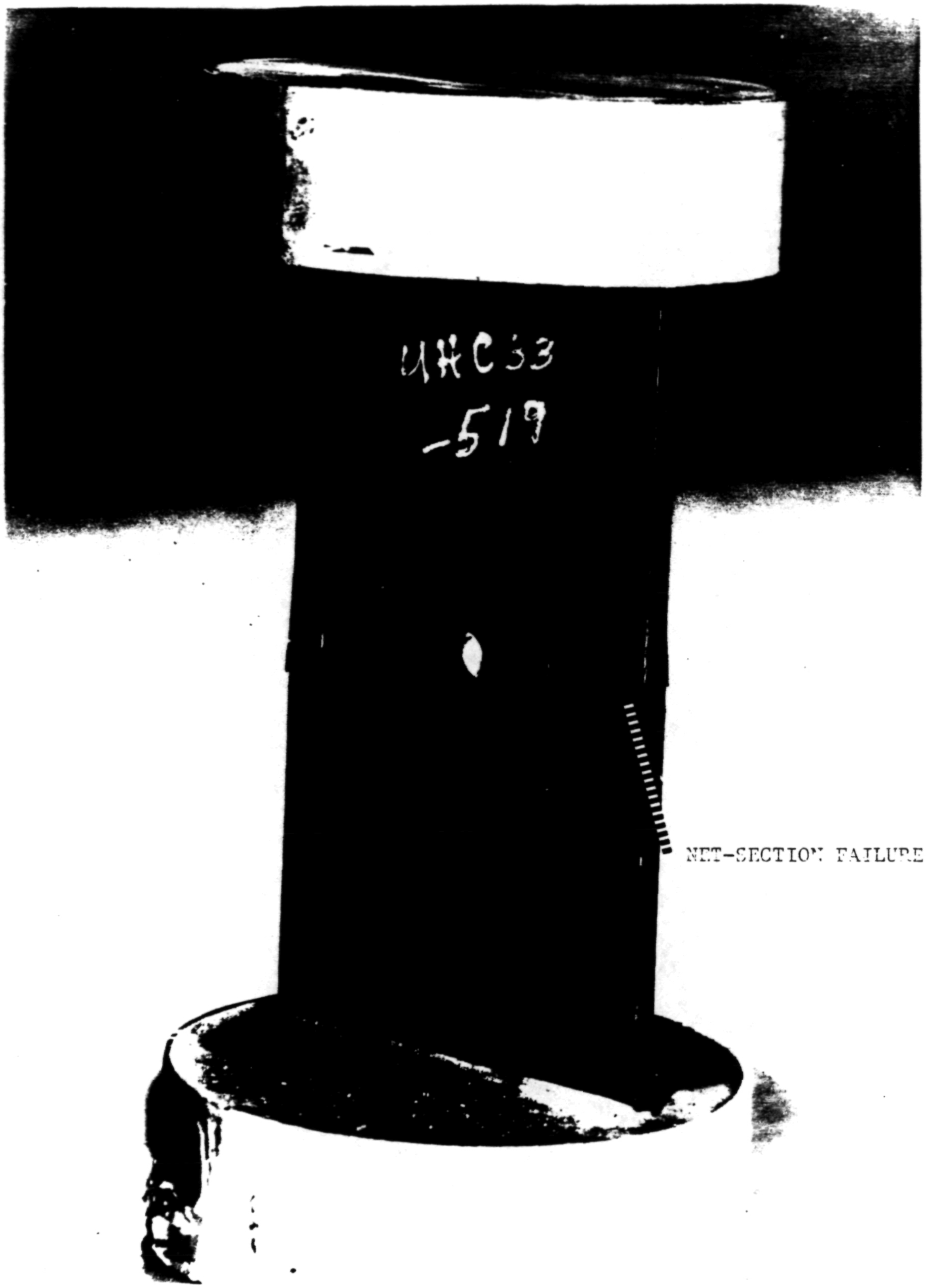


FIGURE 31 UNLOADED HOLE COMPRESSION TEST - NET-SECTION FAILURE

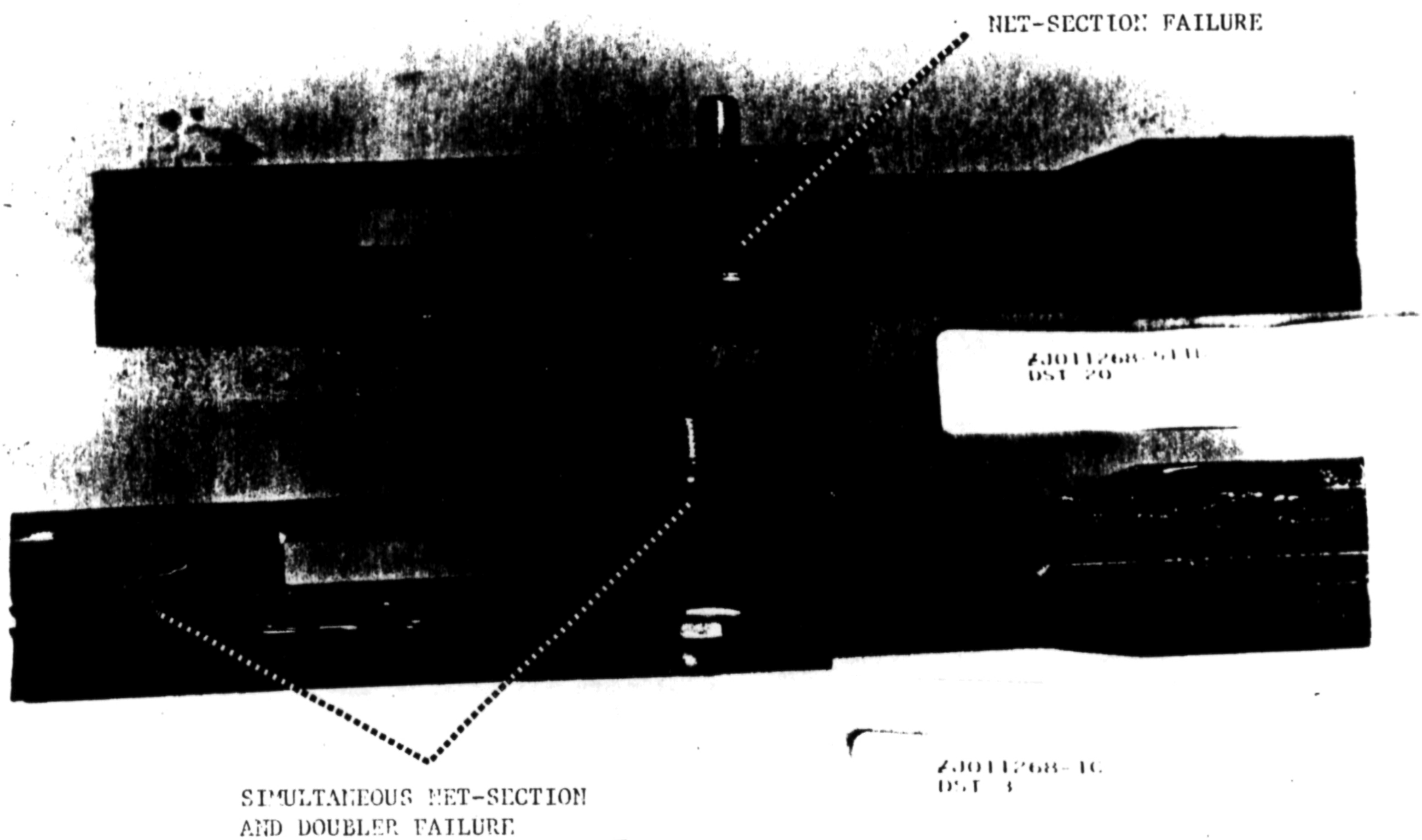


FIGURE 32 DOUBLE SHEAR TENSION TESTS - NET-SECTION FAILURES

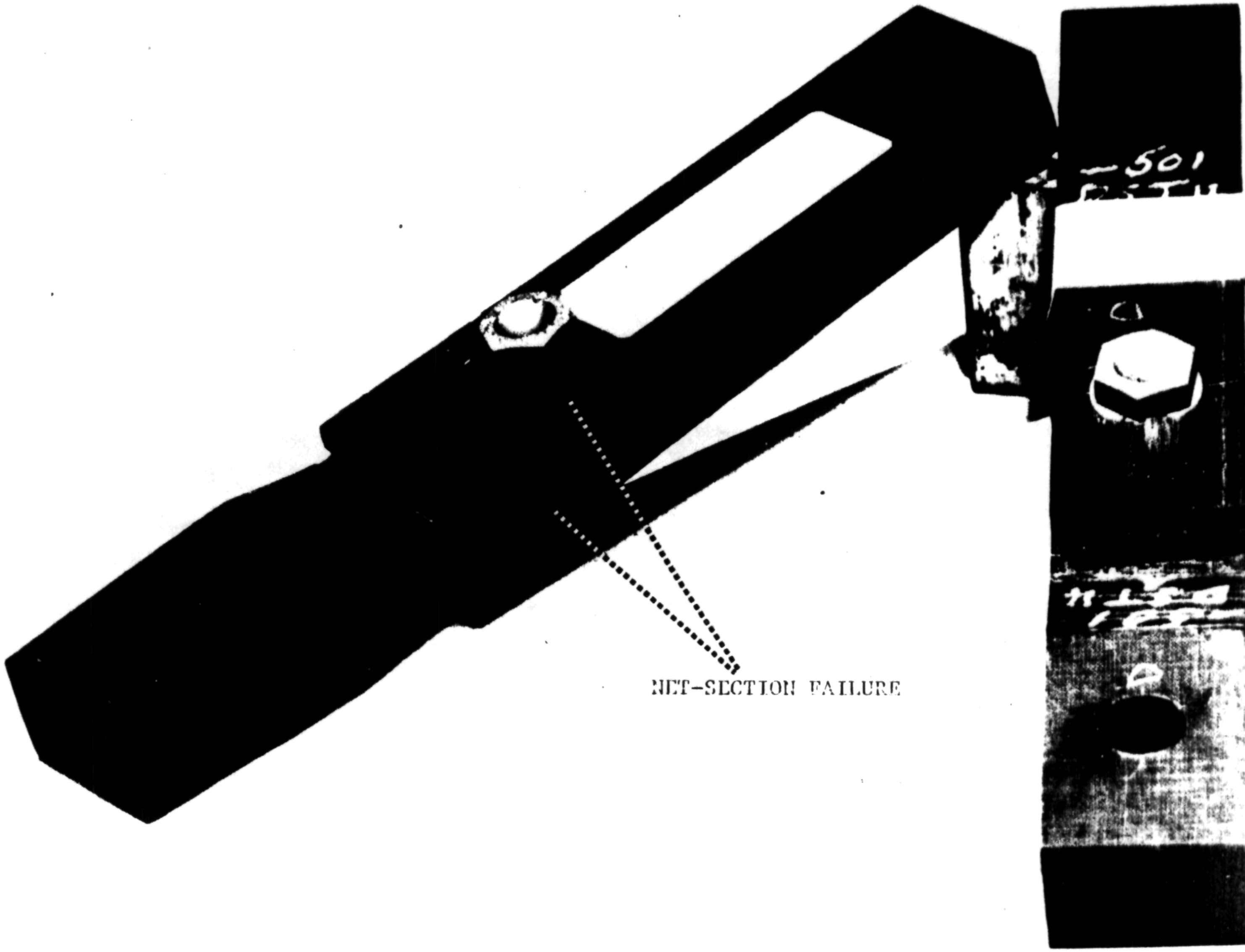


FIGURE 33 DOUBLE SHEAR TENSION TESTS - NET-SECTION FAILURES

FIGURE 34 DOUBLE SHEAR TENSION TESTS - BOLT BENDING FAILURE

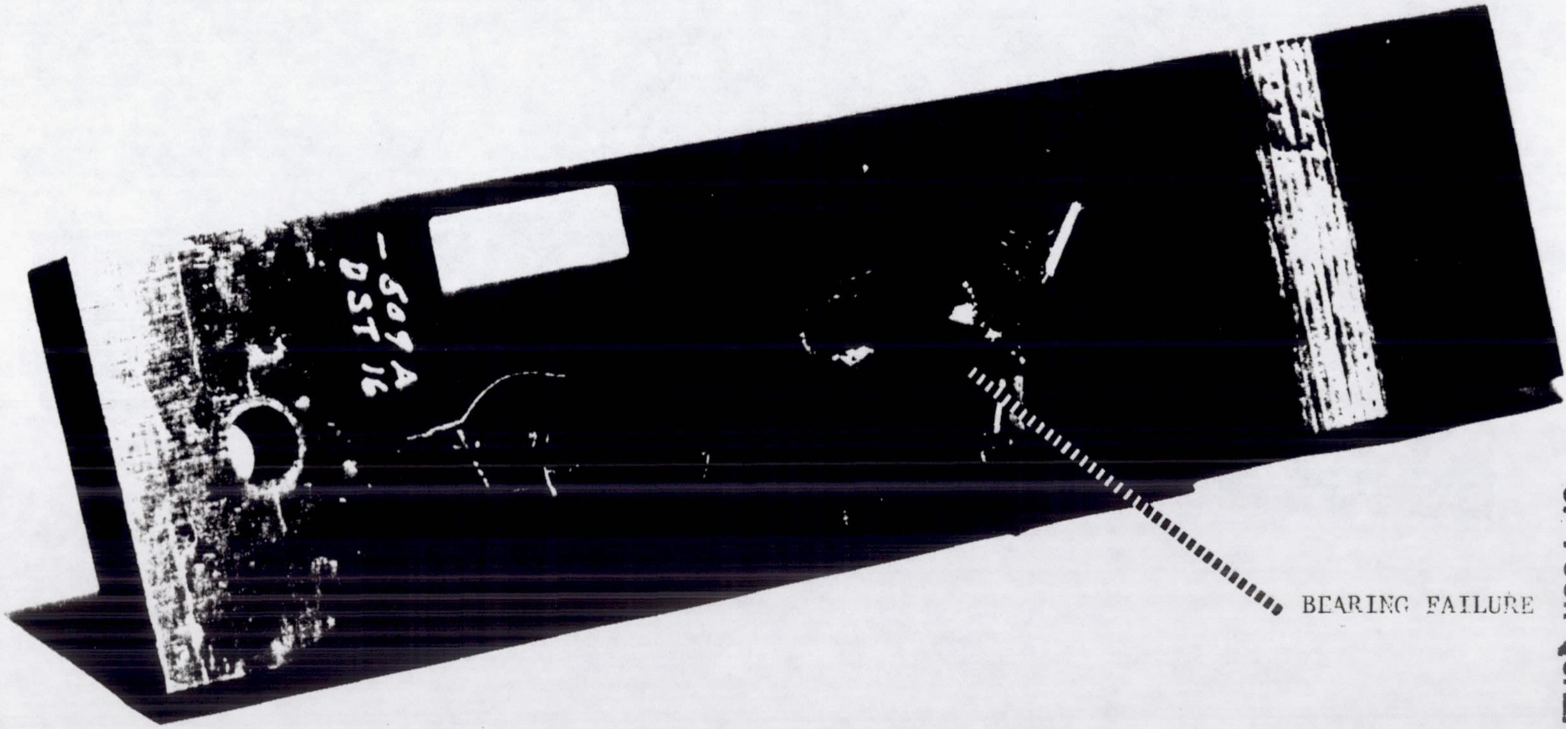
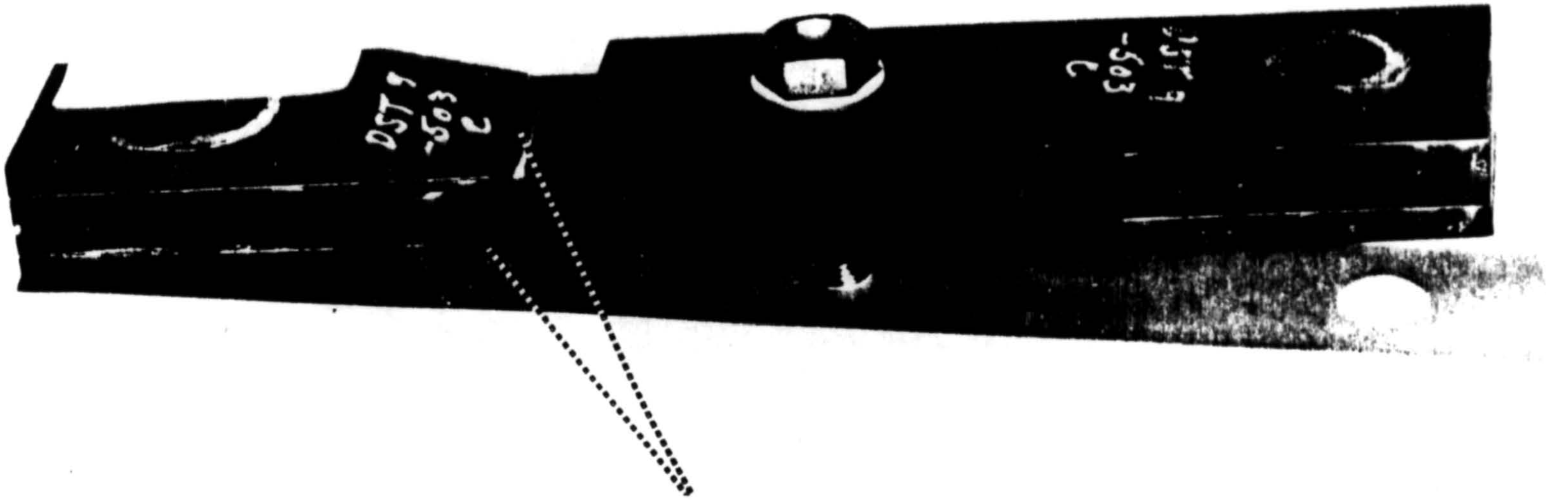


FIGURE 35 DOUBLE SHEAR TENSION TESTS - BEARING FAILURE



BONDED DOUBLER FAILURE

FIGURE 36 DOUBLE SHEAR TENSION TESTS - BONDED DOUBLER FAILURE

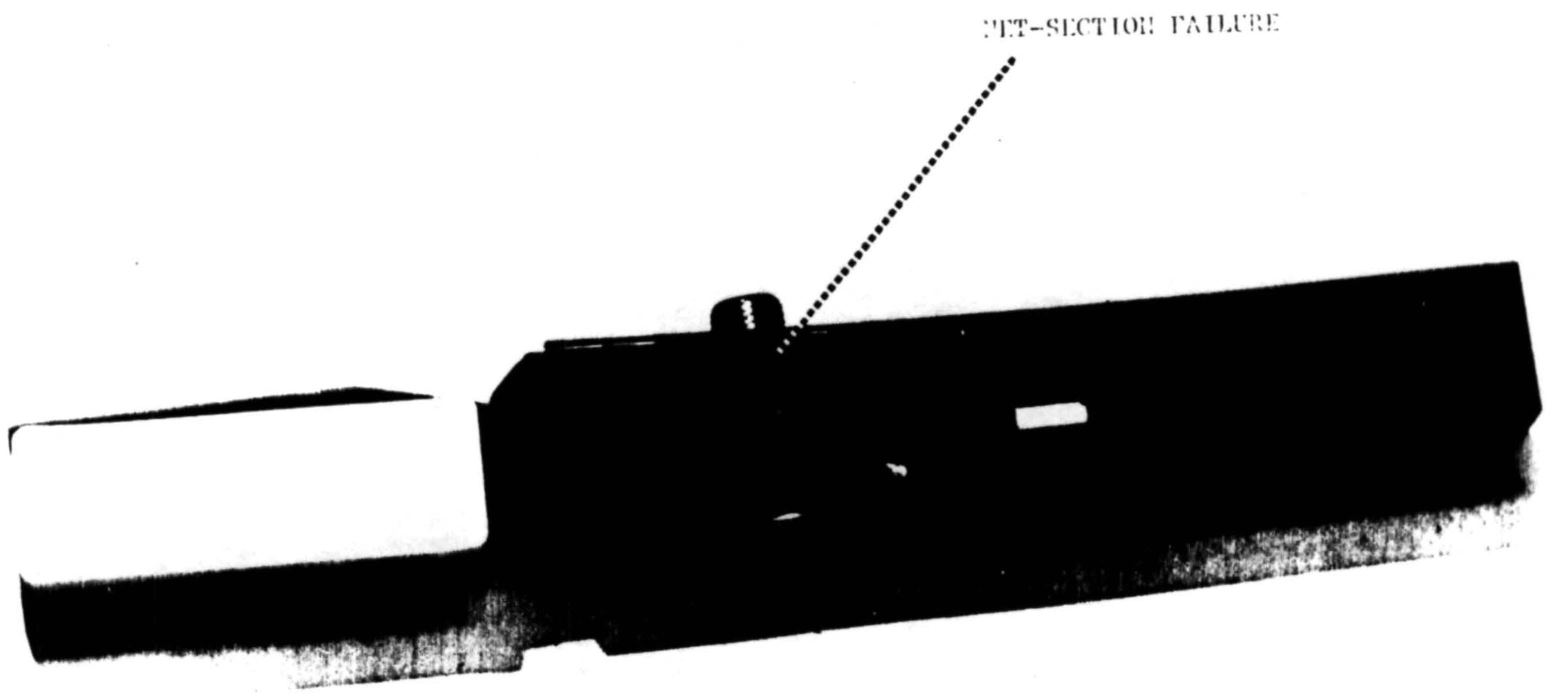


FIGURE 37 DOUBLE SHEAR TENSION TESTS - NET-SECTION FAILURE

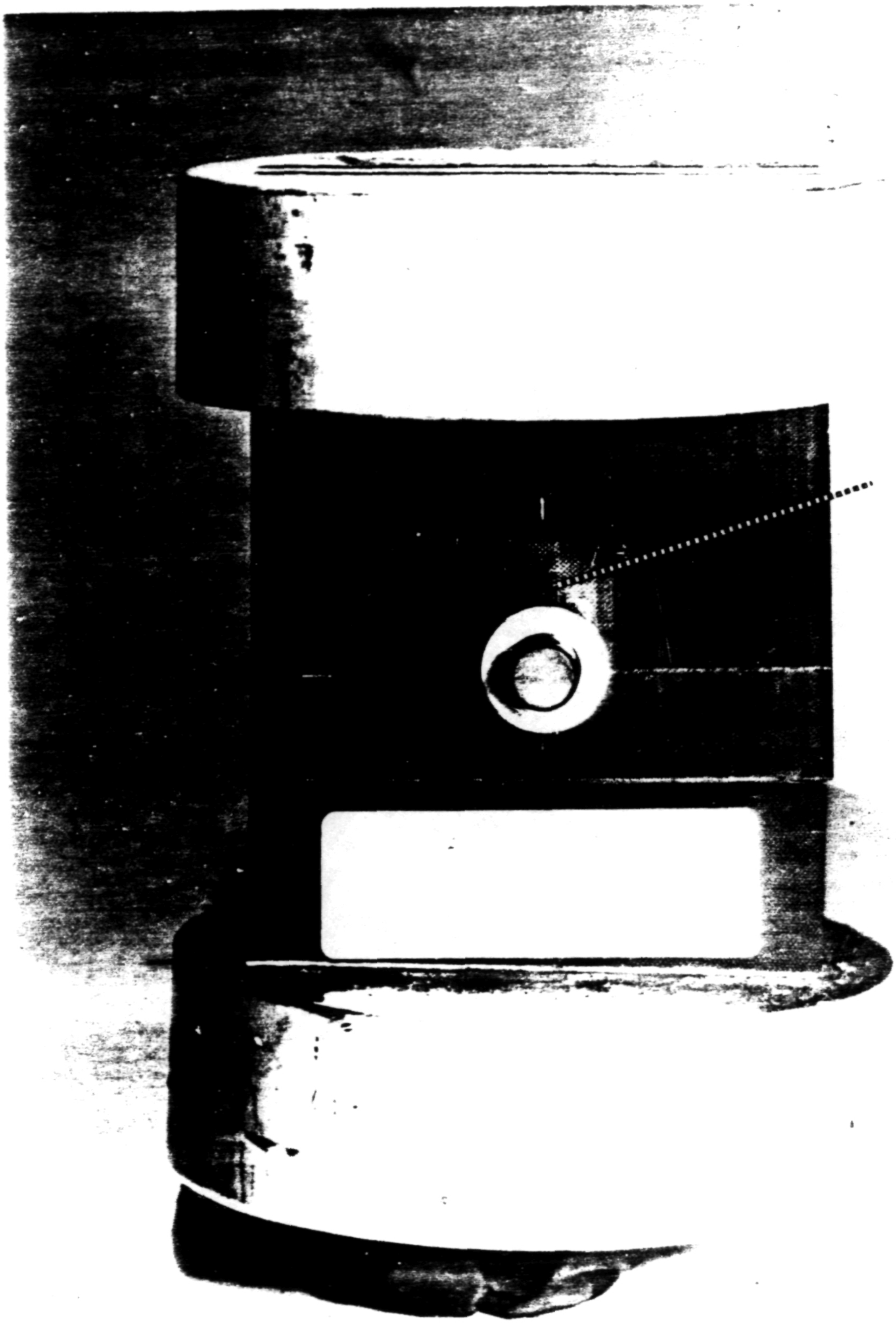


FIGURE 38 DOUBLE SHEAR COMPRESSION TEST - BEARING FAILURE

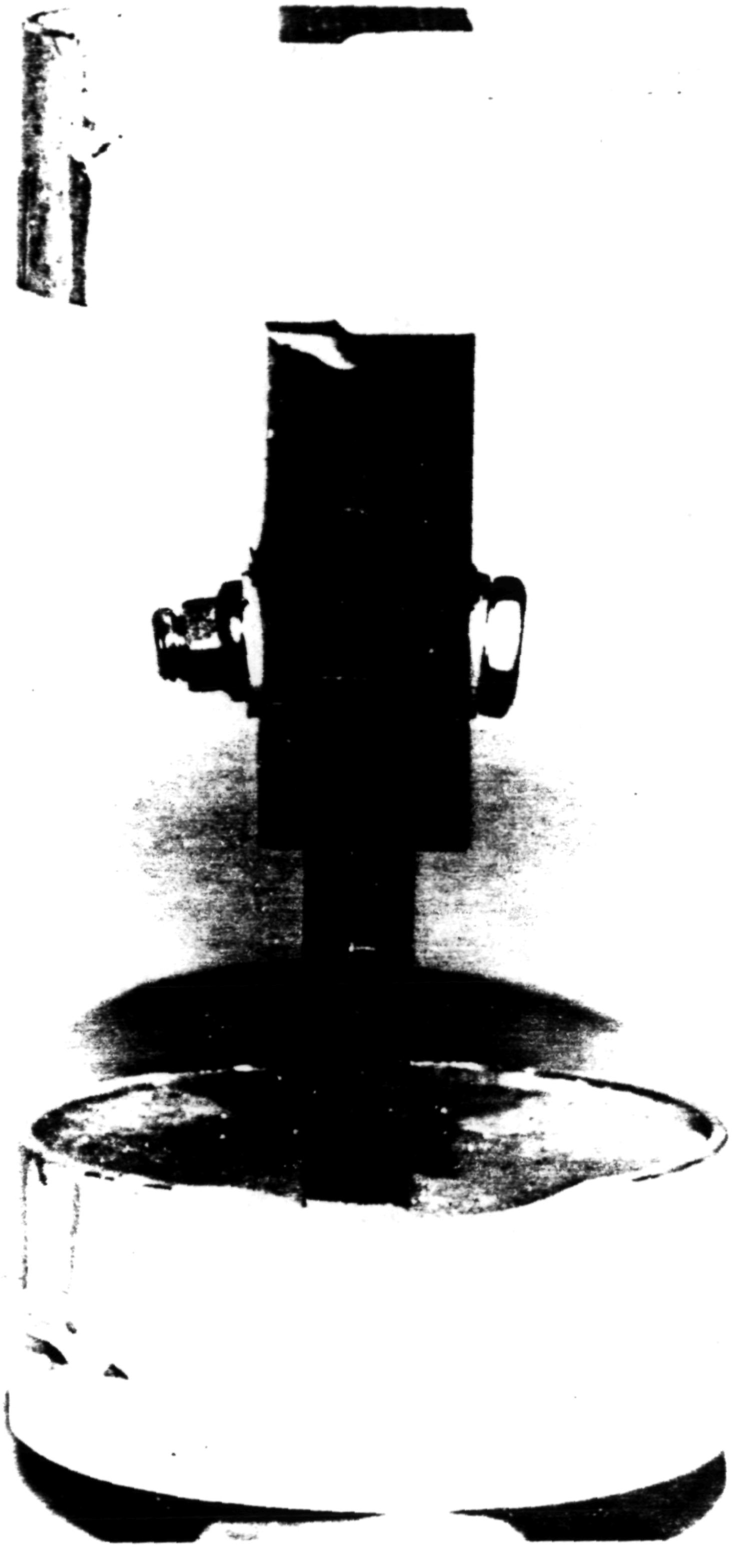
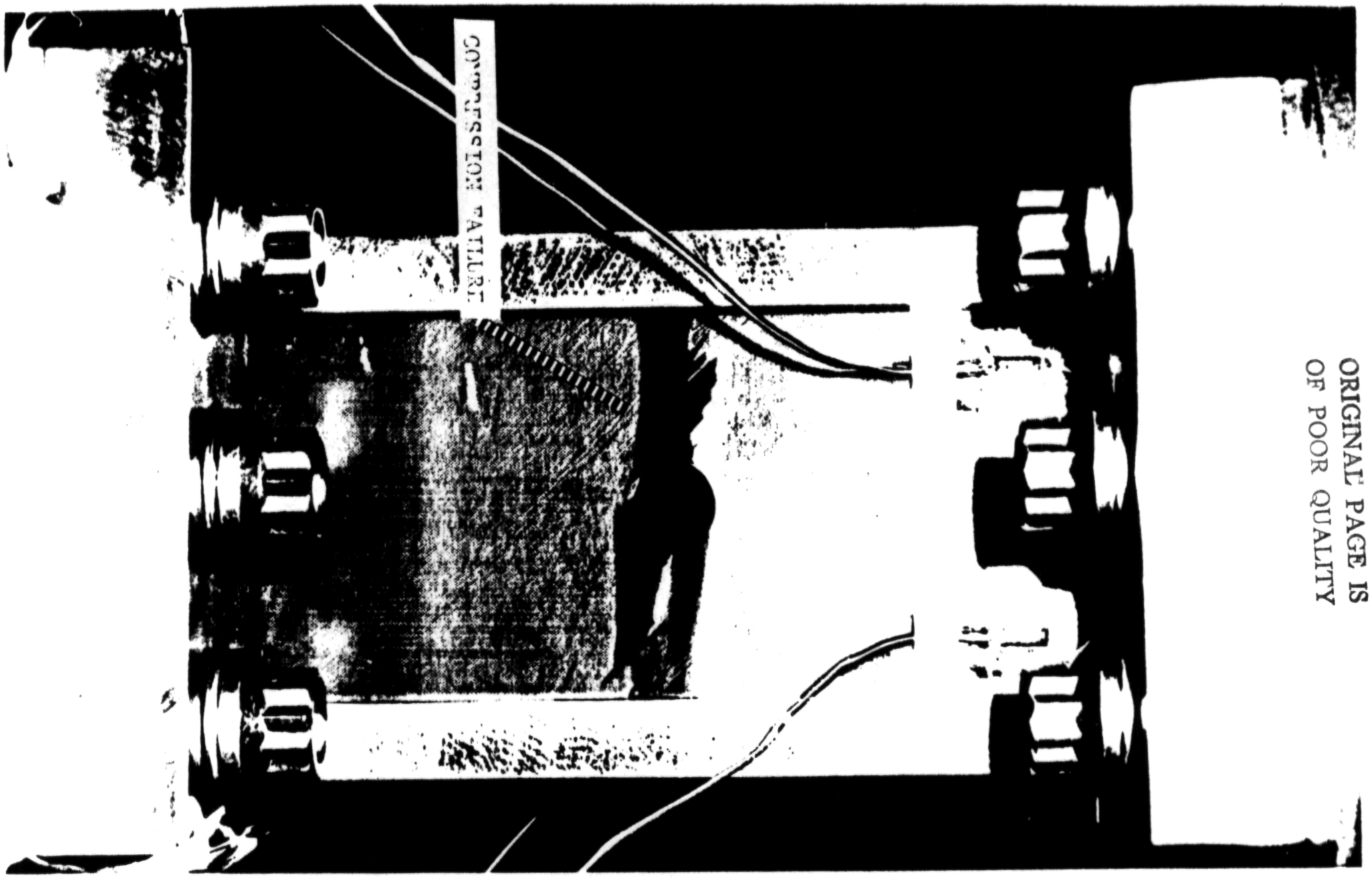
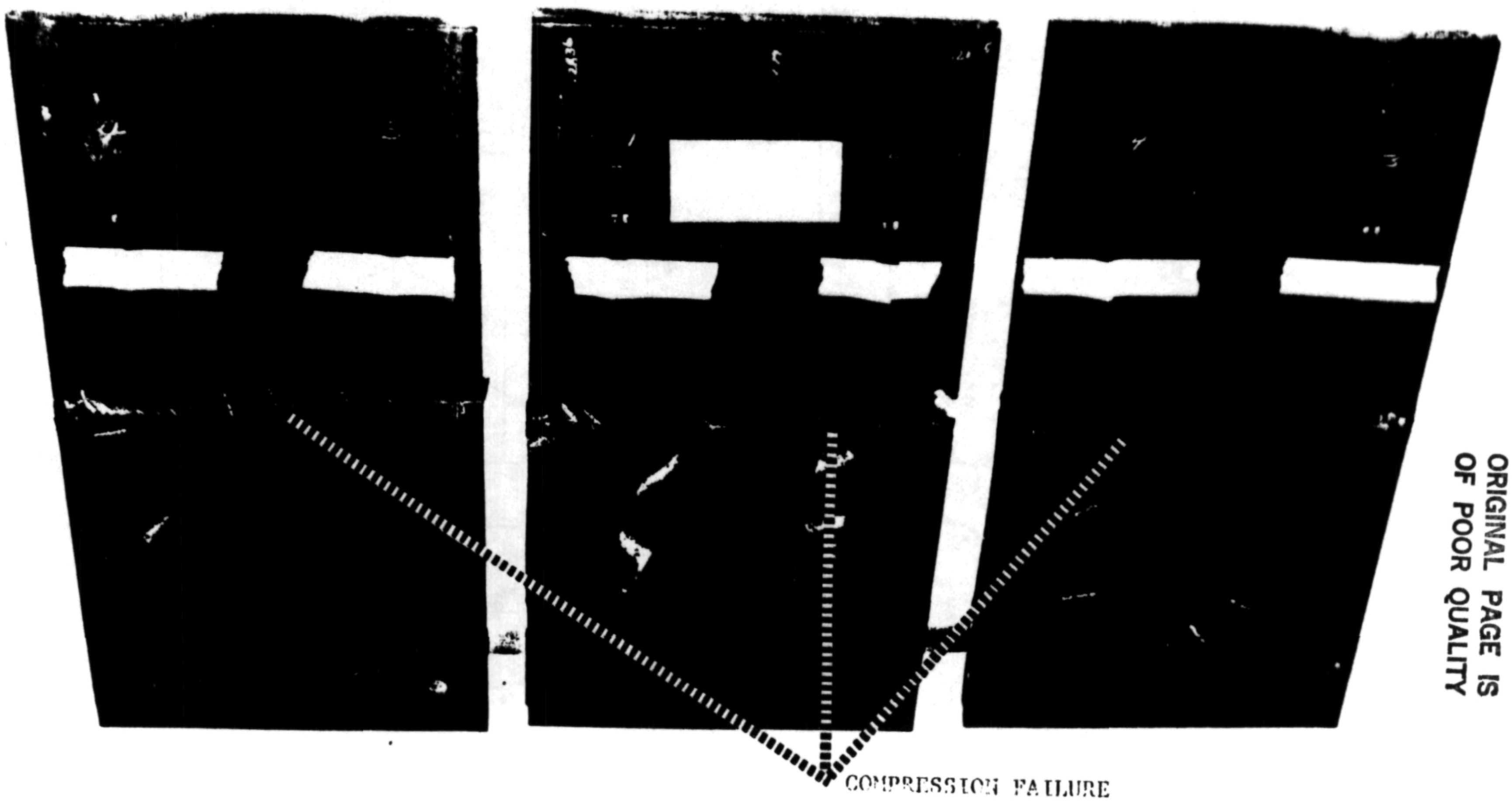


FIGURE 39 DOUBLE SHEAR COMPRESSION TEST - BOLT BENDING FAILURE



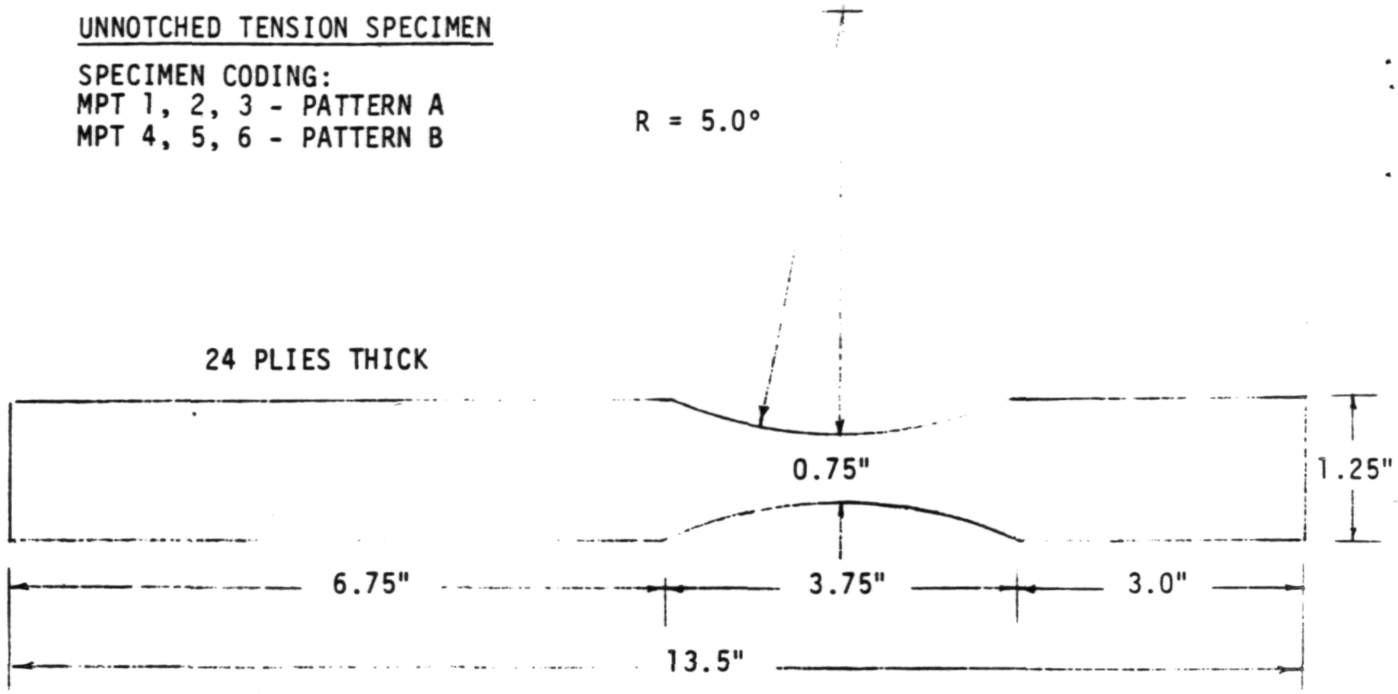
F[illegible] OPEN-HOLE COMPRESSION TEST ST-4

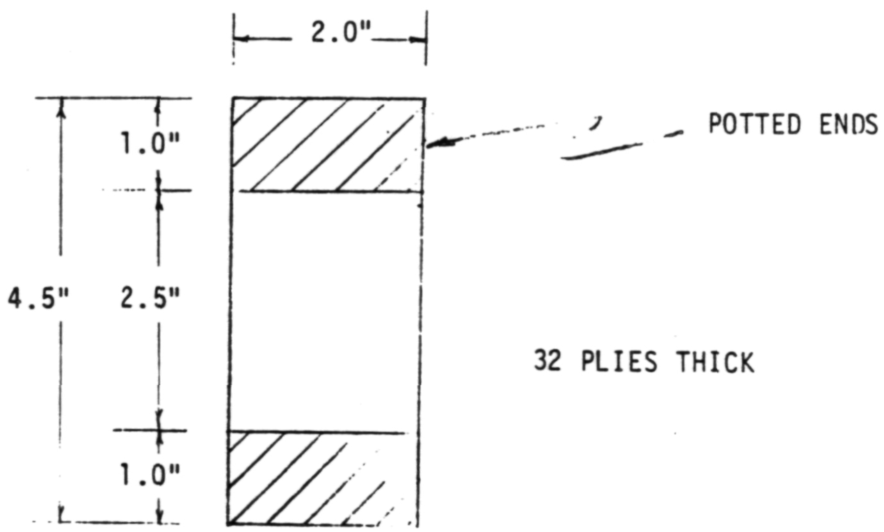


FI 41 COMPRESSION AFTER IMPACT SPECIMENS - ST-1

UNNOTCHED TENSION SPECIMEN

SPECIMEN CODING:
MPT 1, 2, 3 - PATTERN A
MPT 4, 5, 6 - PATTERN B





UNNOTCHED COMPRESSION SPECIMEN

SPECIMEN CODING: MPC 1, 2, 3, - PATTERN A
MPT 4, 5, 6, - PATTERN B

FIGURE 42
SPECIMEN CONFIGURATIONS - MECHANICAL PROPERTY TESTS

FIGURE 43 UNNOTCHED COMPRESSION SPECIMEN

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FIGURE 44 UNNOTCHED TENSION SPECIMENS

Specimen Coding	Layup Patt.
DST 1,2,3 4,5,6 7,8,9 10,11,12 13,14,15 16,17,18	A
19,20,21 22,23,24 25,26,27 28,29,30 31,32,33 34,35,36	B
DSC 1,2,3 4,5,6 7,8,9 10,11,12 13,14,15 16,17,18	A
19,20,21 22,23,24 25,26,27 28,29,30 31,32,33 34,35,36	B

DST - Double Shear Tension
DSC - Double Shear Compression

Specimen Coding	Layup Patt.
SST 1,2,3 4,5,6 7,8,9	A
10,11,12 13,14,15 16,17,18	B
SSC 1,2,3 4,5,6 7,8,9	A
10,11,12 13,14,15 16,17,18	B

SST - Single Shear Tension
SSC - Single Shear Compression

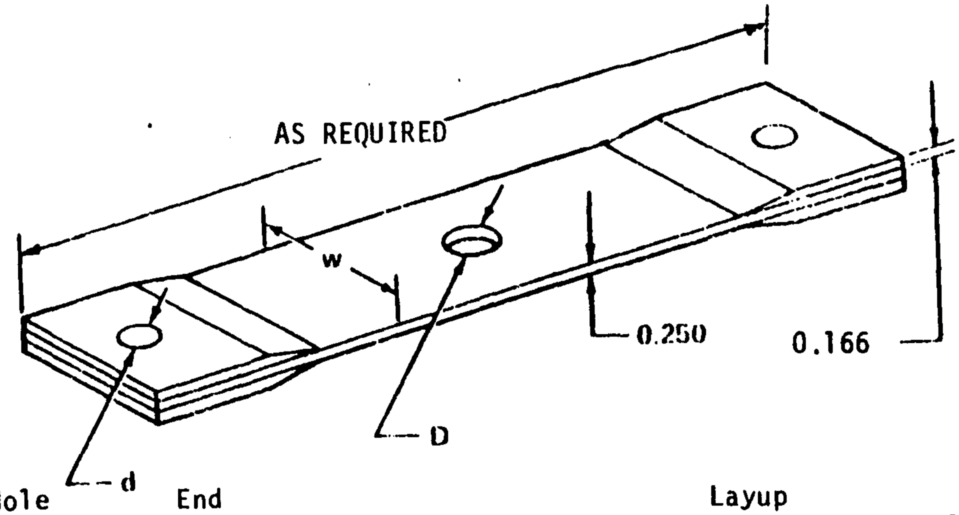
Layup Pattern A
0°, ±45°, 90°
25%, 50%, 25%

Layup Pattern B
0°, ±45°, 90°
37.5%, 50%, 12.5%

Specimen Coding	Layup Patt.
UHC 1,2,3 4,5,6 7,8,9 10,11,12 13,14,15 16,17,18	A
19,20,21 22,23,24 25,26,27 28,29,30 31,32,33 34,35,36	B
UHT 1,2,3 4,5,6 7,8,9 10,11,12 13,14,15 16,17,18	A
19,20,21 22,23,24 25,26,27 28,29,30 31,32,33 34,35,36	B

UHT - Unloaded Hole Tension
UHC - Unloaded Hole Compression

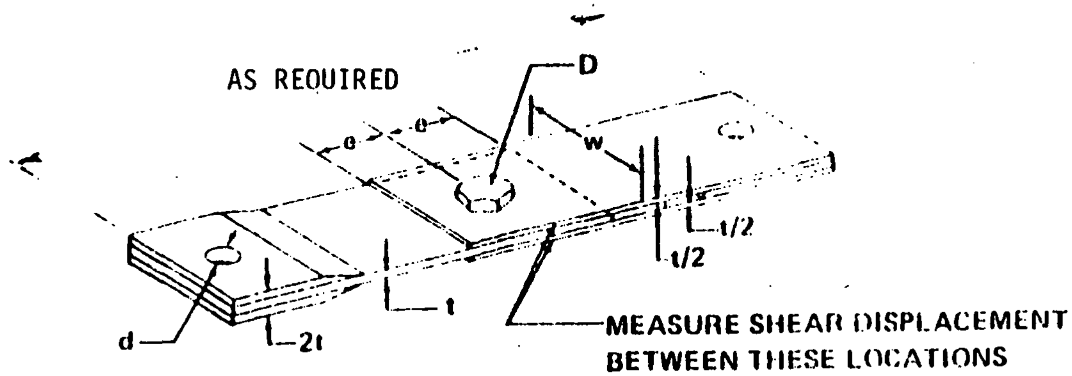
Table 1. Ancillary Test Specimen Coding - Phase I



SPECIMEN I.D. #	Hole Diameter (D)	End Attachment (d)	Thickness (t)	Width (w)	Layup Pattern	Load Direction
UHT 1,2,3	0.250	0.250	0.250	0.500	0°, 45°, 90°	
4,5,6	0.500	0.500		1.000	25%, 50%, 25%	
7,8,9	0.750	0.750		1.500		
10,11,12	0.250	0.750		2.00		
13,14,15	0.500	1.000		4.00		
16,17,18	0.750	2.000		6.00	0°, 45°, 90°	
					25%, 50%, 25%	Tension
						and
19,20,21	0.250	0.250		0.500	0°, 45°, 90°	Compression
22,23,24	0.500	0.500		1.000	37.5%, 50%, 12.5%	
25,26,27	0.750	0.750		1.500		
28,29,30	0.250	0.750		2.000		
31,32,33	0.500	1.000		4.000		
UHT 34,35,36	0.750	2.000	0.250	6.000	0°, 45°, 90°	
					37.5%, 50%, 12.5%	
72	TOTAL					

Table 2

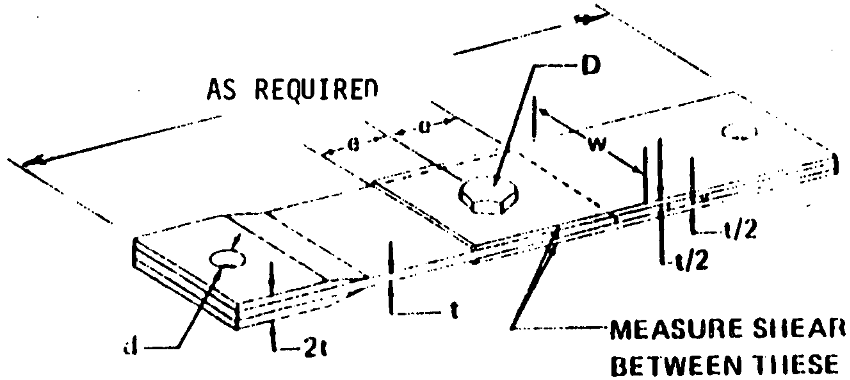
Unloaded Hole Ancillary Test Specimen
Dimensions in Customary Units (Inches)
Tension Specimen Shown



SPECIMEN I.D. #	Edge Distance (e)	Center Attachment Diameter (D)	End Attachment Diameter (d)	Thickness (t)	Width (w)	Layup Pattern	Load Direction
DST 1,2,3	0.75	0.250	0.312	0.333	0.75	0°, 45°, 90°	
4,5,6	1.50	0.500	0.625	0.500	1.50	25%, 50%, 25%	
7,8,9	2.25	0.750	1.000	0.666	2.25		
10,11,12	2.00	0.250	0.500	0.333	2.00		
13,14,15	4.00	0.500	0.750	0.500	4.00		
16,17,18	6.00	0.750	2.000	0.666	6.00	0°, 45°, 90°	
						25%, 50%, 25%	Tension
19,20,21	0.75	0.250	0.312	0.333	0.75	0°, 45°, 90°	
22,23,24	1.50	0.500	0.625	0.500	1.50	37.5%, 50%, 12.5%	
25,26,27	2.25	0.750	1.000	0.666	2.25		
28,29,30	2.00	0.250	0.500	0.333	2.00		
31,32,33	4.00	0.500	0.750	0.500	4.00		
DST 34,35,36	6.00	0.750	2.000	0.666	6.00	0°, 45°, 90°	
						37.5%, 50%, 12.5%	
36	Total						

Table 3.

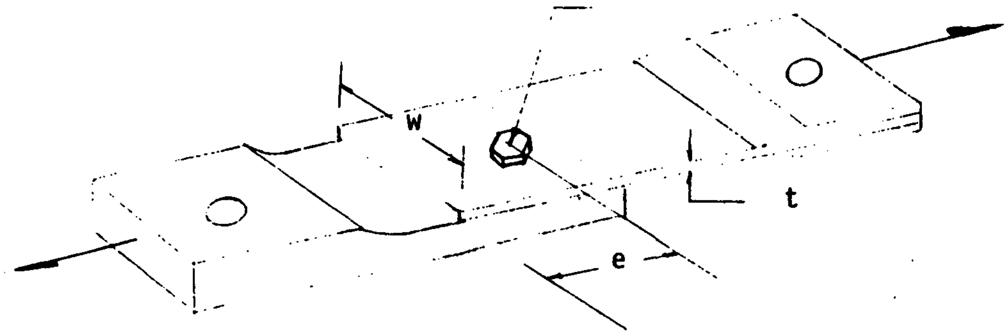
Double Shear Ancillary Tension Specimen
Dimensions Shown in Customary Units (Inches)
(Tension Specimen Shown)



SPECIMEN I.D. #	Edge Distance (e)	Center Attachment Diameter (D)	Thickness (t)	Width (w)	Layup Pattern	Load Direction
DSC 1,2,3	0.750	0.250	0.333	0.75	0°, 45°, 90°	
4,5,6	0.750	0.500	0.500	1.50	25%, 50%, 25%	
7,8,9	1.125	0.750	0.666	2.25		
10,11,12	0.750	0.250	0.333	2.00		
13,14,15	0.750	0.500	0.500	4.00		
16,17,18	1.125	0.750	0.666	6.00	0°, 45°, 90°	
					25%, 50%, 25%	Compression
19,20,21	0.750	0.250	0.333	0.75	0°, 45°, 90°	
22,23,24	0.750	0.500	0.500	1.50	37.5%, 50%, 12.5%	
25,26,27	1.125	0.750	0.666	2.25		
28,29,30	0.750	0.250	0.333	2.00		
31,32,33	0.750	0.500	0.500	4.00		
DSC 34,35,36	1.125	0.750	0.666	6.00	0°, 45°, 90°	
					37.5%, 50%, 12.5%	
36	TOTAL					

Table 4.

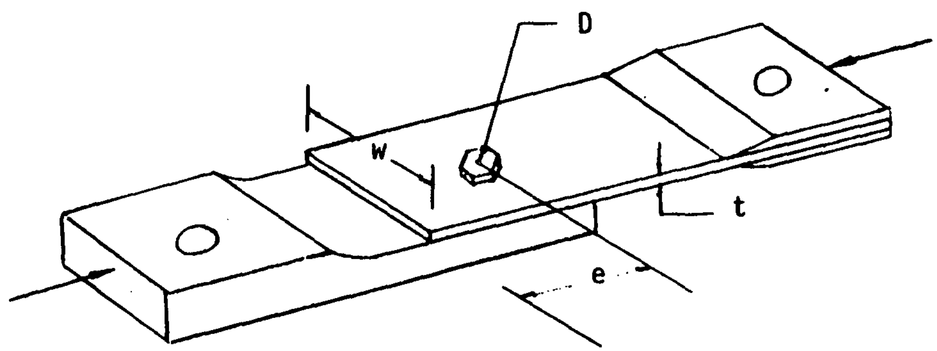
Double Shear Ancillary Compression Specimen
Dimensions Shown in Customary Units (Inches)
(Tension Specimen Shown)



SPECIMEN I.D. #	Edge Distance (e)	Attachment Diameter (D)	Thickness (t)	Width (w)	Layup Pattern	Load Direction
SST 1,2,3	2.00	0.250	0.333	2.00	0°, 45°, 90° 25%, 50%, 25%	
4,5,6	4.00	0.500	0.500	4.00		
7,8,9	6.00	0.750	0.666	6.00	0°, 45°, 90° 25%, 50%, 25%	
10,11,12	2.00	0.250	0.333	2.00	0°, 45°, 90° 37.5%, 50%, 12.5%	Tension
13,14,15	4.00	0.500	0.500	4.00		
SST 16,17,18	6.00	0.750	0.666	6.00	0°, 45°, 90° 37.5%, 50%, 12.5%	
18	Total					

Table 5

Single Shear Ancillary Tension Specimen
Dimensions Shown in Customary Units (Inches)



SPECIMEN I.D. #	Edge Distance (e)	Attachment Diameter (D)	Thickness (t)	Width (w)	Layup Pattern	Load Direction
SSC 1,2,3	1.00	0.250	0.333	2.00	0°, 45°, 90° 25%, 50%, 25%	Compression
4,5,6	2.00	0.500	0.500	4.00		
7,8,9	3.00	0.750	0.666	6.00	0°, 45°, 90° 25%, 50%, 25%	
10,11,12	1.00	0.250	0.333	2.00	0°, 45°, 90° 37.5%, 50%, 12.5%	
13,14,15	2.00	0.500	0.500	4.00		
SSC 16,17,18	3.00	0.750	0.666	6.00	0°, 45°, 90° 37.5%, 50%, 12.5%	
18	TOTAL					

Table 6

Single Shear Ancillary Compression Specimen
Dimensions Shown in Customary Units (Inches)

TABLE 7

UNLOADED HOLE TENSION SPECIMEN DESCRIPTION - PHASE II

Dimensions in inches: L,W tolerances $\pm$ .015

SPECIMEN CODING	NUMBER OF SPECIMENS	LAYUP PATT.	LENGTH L	WIDTH W	NOM. HOLE DIA. d	HYDR. GRIP LENGTH g	PLY THICKNESS	NUMBER OF PLIES
UHT5-19,20,21	3	B5	14.000	1.125	.375	3.000	.0055	48
22,23,24	3	↓	↓	1.500	.500	↓	↓	↓
25,26,27	3	↓	↓	2.250	.750	↓	↓	↓
31,32,33	3	↓	↓	2.500	.500	↓	↓	↓
34,35,36	3	↓	↓	3.750	.750	↓	↓	↓
UHT5-37,38,39	3	↓	↓	3.000	1.000	↓	↓	↓
UHT10-19,20,21	3	B10	14.000	1.125	.375	3.000	.0104	24
22,23,24	3	↓	↓	1.500	.500	↓	↓	↓
25,26,27	3	↓	↓	2.250	.750	↓	↓	↓
31,32,33	3	↓	↓	2.500	.500	↓	↓	↓
34,35,36	3	↓	↓	3.750	.750	↓	↓	↓
UHT10-37,38,39	3	↓	↓	3.000	1.000	↓	↓	↓
UHT10-4,5,6	3	A	14.000	1.500	.500	3.000	.0104	24
7,8,9	3	↓	↓	2.250	.750	↓	↓	↓
13,14,15	3	↓	↓	2.500	.500	↓	↓	↓
UHT10-16,17,18	3	↓	↓	3.750	.750	↓	↓	↓

Total =48

MATERIAL: CIBA - GEIGY 914/T300

THICKNESS: 0.250 in. Nominal (All tests)

LAYUP PATTERNS: A - $(45/0/-45/90)_{3S}$, 24 Ply , 10 mil tape

B5 - $(45/0/-45/0/45/0/-45/90)_{3S}$, 48 Ply, 5 mil tape

B10 - $[(45/0/-45/0/45/0/-45/90) + (45/0/-45/0/90/-45/0/45) + (90/-45/0/45/0/-45/0/45)]_T$, 24 Ply. 10 mil tape

TABLE 8

BOLTED DOUBLE SHEAR SPECIMEN DESCRIPTION - PHASE II

Dimensions in inches: L, W, e tolerances ± .015

SPECIMEN CODING	NUMBER OF SPECIMENS	LAYUP PATT.	LENGTH L	WIDTH W	EDGE DIST. e	NOM. HOLE DIA. d	HYDR. GRIP LENGTH g	BLADE THICKNESS t_1	SPLICE THICKNESS t_2
DSC 10,11,12		A	9.25	1.875	3.0	.375	3	.333	.167
DSC 28,29,30		B				.375			.167
DSCA 28,29,30		B				.375			.250
DST 7,8,9		A	9.25	2.25	3.0	.750	3	.666	.333
DST 25,26,27		B				.750			
DSTA 7,8,9		A	9.25	2.25	3.0	.750	3	.666	.499
DSTA 25,26,27	3 each	B				.750			
DSTB 25,26,27		B	9.25	2.25	3.0	.750	3	.666	.375*
DSTB 22,23,24		B		1.50		.500		.499	.250*
DSTB 31,32,33		B		2.50		.500		.499	.250*
DSTA 22,23,24		B	9.25	1.50	3.0	.500	3	.499	.333
DSTA 31,32,33		B		2.50		.500		.499	.333

Total = 36

* For DSTB25 through DSTB33, splice plates are to be made of 6al-4V titanimum

** Stacking sequences for each thickness are given in Table III

See fabrication criteria section 3.0

TABLE 9

NASA STANDARD TESTS - SPECIMEN IDENTIFICATION

ST x B = STANDARD TEST NUMBER X, B MATERIAL (EPOXY)
ST x C = STANDARD TEST NUMBER X, C MATERIAL (BISMALEAMIDE)

TEST NAME	TEST NUMBER (per RD1092)		SPECIMEN CODES	NUMBER OF TESTS AT DAC	COMMENTS
Compression After Impact	ST-1		ST1B -1,-2,-3 ST1C -1,-2,-3	3 3	NASA makes theirs from 22 x 22 panel
Edge Delamination	ST-2, 8ply		ST2B -1 thru -5 ST2C -1 thru -5	5 5	NASA tests 5 each also, make 10 each
	ST-2, 11ply		ST2B -6 thru -10 ST2C -6 thru -10	5 5	NASA tests 5 each also, make 10 each
Supporting Data	Directional Properties	0	ST25B -0 ST25C -0	3 3	Same Material batch as ST-2 specimens
		90	ST25B -90 ST25C -90	3 3	
		±45	ST25B -45 ST25C -45	3 3	
Open Hole Tension	ST-3		ST3B -1,-2,-3 ST3C -1,-2,-3	3 3	- -
Open Hole Compression	ST-4		ST4B -1,-2,-3 ST4C -1,-2,-3	3 3	NASA makes theirs from 22 x 22 panel
Hinged Double Cantilever Beam	ST-5		ST5B -1,-2,-3 ST5C -1,-2,-3	3 3	- -

Table 10 Ancillary Test Specimen Loading Rates

Double Shear

SPECIMEN I.D. #	δ (in/min)	P (lb/min)
DST 1,2,3	.02	6,000
4,5,6	.022	18,000
7,8,9	.034	36,000
10,11,12	.018	12,000
13,14,15	.027	35,000
16,17,18	.044	70,000
19,20,21	.02	7,500
22,23,24	.022	22,500
25,26,27	.034	45,000
28,29,30	.015	12,000
31,32,33	.022	35,000
DST 34,35,36	.035	70,000
DSC 1,2,3	.015	6,000
4,5,6	.015	18,000
7,8,9	.015	36,000
10,11,12	.011	12,000
13,14,15	.015	35,000
16,17,18	.015	70,000
19,20,21	.015	7,500
22,23,24	.015	22,500
25,26,27	.015	45,000
28,29,30	.009	12,000
31,32,33	.013	35,000
DSC 32,35,36	.016	70,000

Single Shear

SPECIMEN I.D. #	δ (in/min)	P (lb/min)
SST 1,2,3	.010	4,360
4,5,6	.021	17,500
7,8,9	.024	35,000
10,11,12	.010	4,368
13,14,15	.021	17,500
SST 16,17,18	.024	35,000
SSC 19,20,21	.010	4,368
22,23,24	.021	17,500
25,26,27	.024	35,000
28,29,30	.010	4,368
31,32,33	.021	17,500
SSC 34,35,36	.024	35,000

Unloaded Hole

SPECIMEN I.D. #	δ (in/min)	P (lb/min)
UHC 1,2,3	.007	3,000
4,5,6	.009	6,000
7,8,9	.010	9,000
10,11,12	.015	12,000
13,14,15	.03	24,000
16,17,18	.056	36,000
19,20,21	.007	3,750
22,23,24	.009	7,500
25,26,27	.010	11,250
28,29,30	.015	15,000
31,32,33	.03	30,000
UHC 34,35,36	.045	45,000
UHT 1,2,3	.018	3,000
4,5,6	.018	6,000
7,8,9	.021	9,000
10,11,12	.019	12,000
13,14,15	.036	24,000
16,17,18	.048	36,999
19,20,21	.018	3,750
22,23,24	.018	7,500
25,26,27	.021	11,250
28,29,30	.019	15,000
31,32,33	.036	30,000
UHT 34,35,36	.048	45,000

δ : is the stroke loading rate - inches per minute

P : is the <u>estimated</u> rate of applied load in pounds per minute for the specified δ

TABLE 11

UNLOADED HOLE TENSION SPECIMENS

FIBER PATTERN A - (25% 0°,50% ±45°,25% 90°)

U.S. CUSTOMARY UNITS

SPECIMEN NUMBER	HOLE DIAM. IN.	PANEL WIDTH IN.	W/D RATIO	PANEL THICK. IN.	FAILURE LOAD LB	FAILURE MODE	NET-SECT. STRESS KSI	GROSS-SECT. STRESS KSI
UHT- 1	0.250	0.503	2.0	0.254	3040.0	TENS	47.31	23.79
UHT- 2	0.250	0.503	2.0	0.254	3220.0	TENS	50.11	25.20
UHT- 3	0.250	0.503	2.0	0.254	3160.0	TENS	49.17	24.73
UHT- 4	0.500	0.995	2.0	0.245	5680.0	TENS	46.34	23.30
UHT- 5	0.500	0.995	2.0	0.240	6000.0	TENS	50.51	25.13
UHT- 6	0.500	0.998	2.0	0.245	6075.0	TENS	49.79	24.85
UHT- 7	0.750	1.493	2.0	0.247	8965.0	TENS	48.85	24.31
UHT- 8	0.750	1.493	2.0	0.247	9510.0	TENS	51.82	25.79
UHT- 9	0.750	1.493	2.0	0.244	8700.0	TENS	47.99	23.88
UHT-10	0.250	2.001	8.0	0.245	27200.0	TENS	63.40	55.43
UHT-11	0.250	2.005	8.0	0.250	23000.0	DBLR	52.42	45.89
UHT-12	0.250	2.000	8.0	0.250	25625.0	DBLR	58.57	51.25
UHT-13	0.500	4.002	8.0	0.244	32100.0	DBLR	37.57	32.87
UHT-14	0.500	4.000	8.0	0.244	38500.0	DBLR	45.08	39.45
UHT-15	0.500	4.000	8.0	0.243	50000.0	TENS	58.79	51.44
UHT-16	0.750	4.500	6.0	0.245	49300.0	TENS	53.66	44.72
UHT-17	0.750	4.500	6.0	0.244	51100.0	TENS	55.85	46.54
UHT-18	0.750	4.500	6.0	0.245	50600.0	TENS	55.07	45.90

TENS = TENSION
COMP = COMPRESSION
BRNG = BEARING
B/B = BOLT BENDING
DBLR = DOUBLER

TABLE 12

UNLOADED HOLE TENSION SPECIMENS

FIBER PATTERN B - (37.5% 0°, 50% ±45°, 12.5% 90°)

U.S. CUSTOMARY UNITS

SPECIMEN NUMBER	HOLE DIAM. IN.	PANEL WIDTH IN.	W/D RATIO	PANEL THICK. IN.	FAILURE LOAD LB	FAILURE MODE	NET-SECT. STRESS KSI	GROSS-SECT. STRESS KSI
UHT-19	0.250	0.485	2.0	0.251	4190.0	TENS	71.04	34.42
UHT-20	0.250	0.490	2.0	0.251	4500.0	TENS	74.70	36.59
UHT-21	0.250	0.495	2.0	0.251	4500.0	TENS	73.18	36.22
UHT-22	0.500	0.999	2.0	0.242	8470.0	TENS	70.14	35.04
UHT-23	0.500	1.000	2.0	0.242	8600.0	TENS	71.07	35.54
UHT-24	0.500	0.995	2.0	0.240	8520.0	TENS	71.72	35.68
UHT-25	0.750	1.446	2.0	0.246	12500.0	TENS	73.01	35.14
UHT-26	0.750	1.445	2.0	0.243	12900.0	TENS	76.38	36.74
UHT-27	0.750	1.444	2.0	0.246	12820.0	TENS	75.09	36.09
UHT-28	0.250	1.995	8.0	0.246	20750.0	DBLR	48.34	42.28
UHT-29	0.250	1.998	8.0	0.242	25400.0	DBLR	60.05	52.53
UHT-30	0.250	2.000	8.0	0.244	28650.0	DBLR	67.10	58.71
UHT-31	0.500	4.000	8.0	0.240	49350.0	DBLR	53.75	51.41
UHT-32	0.500	3.999	8.0	0.241	47300.0	DBLR	56.09	49.08
UHT-33	0.500	4.002	8.0	0.239	53000.0	DBLR	63.32	55.41
UHT-34	0.750	5.993	8.0	0.240	66800.0	DBLR	53.09	46.44
UHT-35	0.750	5.992	8.0	0.243	49300.0	DBLR	38.70	33.86
UHT-36	0.750	5.996	8.0	0.244	70500.0	DBLR	55.08	48.19

TENS = TENSION
COMP = COMPRESSION
BRNG = BEARING
B/B = BOLT BENDING
DBLR = DOUBLER

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TABLE 13

UNLOADED HOLE COMPRESSION SPECIMENS

FIBER PATTERN A - (25% 0°,50% ±45°,25% 90°)

U.S. CUSTOMARY UNITS

SPECIMEN NUMBER	HOLE DIAM. IN.	PANEL WIDTH IN.	W/D RATIO	PANEL THICK. IN.	FAILURE LOAD LB	FAILURE MODE	NET-SECT. STRESS KSI	GROSS-SECT. STRESS KSI
UHC- 1	0.250	0.510	2.0	0.246	4490.0	COMP	70.20	35.79
UHC- 2	0.250	0.507	2.0	0.253	4320.0	COMP	66.44	33.69
UHC- 3	0.250	0.505	2.0	0.253	3490.0	COMP	54.10	27.32
UHC- 4	0.500	1.003	2.0	0.255	7350.0	COMP	57.30	28.74
UHC- 5	0.500	1.001	2.0	0.255	8100.0	COMP	63.40	31.73
UHC- 6	0.500	1.002	2.0	0.254	7900.0	COMP	61.96	31.04
UHC- 7	0.750	1.490	2.0	0.253	9700.0	COMP	51.81	25.73
UHC- 8	0.750	1.491	2.0	0.255	10340.0	COMP	54.72	27.20
UHC- 9	0.750	1.489	2.0	0.254	9600.0	COMP	51.14	25.39
UHC-10	0.250	1.998	8.0	0.253	26250.0	COMP	59.36	51.93
UHC-11	0.250	1.996	8.0	0.254	25250.0	COMP	56.94	49.80
UHC-12	0.250	2.002	8.0	0.253	25400.0	COMP	57.30	50.15
UHC-13	0.500	3.995	8.0	0.252	0.0	COMP	0.00	0.00 *
UHC-14	0.500	3.995	8.0	0.251	26550.0	COMP	30.27	26.48 **
UHC-15	0.500	3.997	8.0	0.253	26000.0	COMP	29.39	25.71 **
UHC-16	0.750	5.993	8.0	0.252	65000.0	COMP	49.20	43.04
UHC-17	0.750	5.999	8.0	0.253	67300.0	COMP	50.68	44.34
UHC-18	0.750	5.995	8.0	0.252	58700.0	COMP	44.41	38.86

TENS = TENSION
COMP = COMPRESSION
BRNG = BEARING
B/B = BOLT BENDING
DBLR = DOUBLER

* Malfunction of data acquisition system
** Anti-buckling plates omitted during test

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TABLE 14

UNLOADED HOLE COMPRESSION SPECIMENS

FIBER PATTERN B - (37.5% 0°, 50% ±45°, 12.5% 90°)

U.S. CUSTOMARY UNITS

SPECIMEN NUMBER	HOLE DIAM. IN.	PANEL WIDTH IN.	W/D RATIO	PANEL THICK. IN.	FAILURE LOAD LB	FAILURE MODE	NET-SECT. STRESS KSI	GROSS-SECT. STRESS KSI
UHC-19	0.250	0.509	2.0	0.252	4520.0	COMP	69.25	35.24
UHC-20	0.250	0.506	2.0	0.251	4670.0	COMP	72.68	36.77
UHC-21	0.250	0.508	2.0	0.250	5070.0	COMP	75.60	39.92
UHC-22	0.500	1.030	2.0	0.254	8770.0	COMP	65.15	33.52
UHC-23	0.500	1.020	2.0	0.250	9020.0	COMP	69.38	35.37
UHC-24	0.500	1.020	2.0	0.254	8700.0	COMP	65.37	33.58
UHC-25	0.750	1.500	2.0	0.251	12880.0	COMP	68.42	34.21
UHC-26	0.750	1.504	2.0	0.251	12930.0	COMP	68.32	34.25
UHC-27	0.750	1.504	2.0	0.254	12980.0	COMP	67.78	33.98
UHC-28	0.250	2.120	8.0	0.254	33450.0	COMP	70.42	62.12
UHC-29	0.250	2.130	8.0	0.251	30950.0	COMP	65.59	57.89
UHC-30	0.250	2.150	8.0	0.254	28500.0	COMP	59.06	52.19
UHC-31	0.500	4.090	8.0	0.258	53400.0	COMP	57.65	50.61
UHC-32	0.500	4.090	8.0	0.256	43900.0	COMP	53.21	46.70
UHC-33	0.500	4.090	8.0	0.256	47500.0	COMP	51.68	45.37
UHC-34	0.750	6.050	8.0	0.257	72200.0	COMP	53.01	46.44
UHC-35	0.750	6.000	8.0	0.252	72100.0	COMP	54.50	47.69
UHC-36	0.750	6.030	8.0	0.249	67200.0	COMP	51.11	44.76

TENS = TENSION
COMP = COMPRESSION
BRNG = BEARING
B/B = BOLT BENDING
DBLR = DOUBLER

TABLE 15

DOUBLE-SHEAR TENSION SPECIMENS

FIBER PATTERN A - (25% 0°,50% ±45°,25% 90°)

U.S. CUSTOMARY UNITS

SPECIMEN NUMBER	HOLE DIAM. IN.	PANEL WIDTH IN.	W/D RATIO	CENTER THICK. IN.	SPLICE THICKx2 IN.	FAILURE LOAD LB	FAILURE MODE	BEARING STRESS KSI	NET-SECT. STRESS KSI	GROSS-SECT. STRESS KSI
DST- 1	0.250	0.755	3.0	0.350	0.336	7410.0	TENS	88.21	43.67	29.21
DST- 2	0.250	0.743	3.0	0.354	0.326	6880.0	TENS	84.42	42.81	28.40
DST- 3	0.250	0.752	3.0	0.352	0.326	7080.0	TENS	86.87	43.26	28.88
DST- 4	0.500	1.500	3.0	0.512	0.506	23175.0	TENS	91.60	45.80	30.53
DST- 5	0.500	1.500	3.0	0.515	0.506	23050.0	BRNG	91.11	45.55	30.37
DST- 6	0.500	1.500	3.0	0.513	0.497	23600.0	TENS	94.97	47.48	31.66
DST- 7	0.750	2.250	3.0	0.630	0.699	36900.0	DBLR	70.39	35.19	23.46
DST- 8	0.750	2.249	3.0	0.635	0.696	30800.0	DBLR	59.00	29.52	19.68
DST- 9	0.750	2.249	3.0	0.635	0.699	43800.0	DBLR	83.55	41.83	27.87
DST-10	0.250	2.005	8.0	0.349	0.337	9875.0	B/B	117.21	16.70	14.61
DST-11	0.250	2.005	8.0	0.343	0.339	8600.0	B/B	101.47	14.46	12.65
DST-12	0.250	2.005	8.0	0.346	0.339	8400.0	B/B	99.12	14.11	12.35
DST-13	0.500	4.001	8.0	0.508	0.504	27200.0	BRNG	107.94	15.42	13.49
DST-14	0.500	4.001	8.0	0.512	0.505	27500.0	DBLR	108.91	15.55	13.61
DST-15	0.500	4.000	8.0	0.508	0.509	26150.0	BRNG	102.75	14.68	12.84
DST-16	0.750	6.000	8.0	0.682	0.694	48000.0	BRNG	92.22	13.17	11.53
DST-17	0.750	6.004	8.0	0.687	0.694	51150.0	BRNG	98.27	14.03	12.28
DST-18	0.750	6.000	8.0	0.687	0.695	49500.0	BRNG	94.96	13.57	11.87

TENS = TENSION
COMP = COMPRESSION
BRNG = BEARING
B/B = BOLT BENDING
DBLR = DOUBLER

TABLE 16

DOUBLE-SHEAR TENSION SPECIMENS

FIBER PATTERN B - (37.5% 0°,50% ±45°,12.5% 90°)

U.S. CUSTOMARY UNITS

SPECIMEN NUMBER	HOLE DIAM. IN.	PANEL WIDTH IN.	W/D RATIO	CENTER THICK. IN.	SPLICE THICKx2 IN.	FAILURE LOAD LB	FAILURE MODE	BEARING STRESS KSI	NET-SECT. STRESS KSI	GROSS-SECT. STRESS KSI
DST-19	0.250	0.750	3.0	0.343	0.333	8090.0	TENS	97.18	48.59	32.39
DST-20	0.250	0.753	3.0	0.346	0.343	8420.0	TENS	98.19	48.80	32.60
DST-21	0.250	0.754	3.0	0.345	0.339	7700.0	TENS	90.96	44.62	29.93
DST-22	0.500	1.497	3.0	0.513	0.519	23400.0	BRNG	90.17	45.22	30.12
DST-23	0.500	1.496	3.0	0.513	0.509	20725.0	DBLR	81.59	40.96	27.27
DST-24	0.500	1.496	3.0	0.516	0.511	24850.0	TENS	97.26	48.33	32.51
DST-25	0.750	2.250	3.0	0.678	0.685	45000.0	BRNG	87.59	43.50	29.20
DST-26	0.750	2.249	3.0	0.681	0.681	26000.0	DBLR	50.91	25.49	16.98
DST-27	0.750	2.243	3.0	0.678	0.679	26500.0	DBLR	52.04	26.05	17.36
DST-28	0.250	2.003	8.0	0.344	0.342	8775.0	B/B	102.63	14.64	12.81
DST-29	0.250	2.002	8.0	0.342	0.344	8650.0	B/B	100.58	14.35	12.56
DST-30	0.250	2.003	8.0	0.342	0.343	9075.0	B/B	105.83	15.09	13.21
DST-31	0.500	3.937	8.0	0.512	0.503	25700.0	BRNG	101.18	14.51	12.69
DST-32	0.500	3.937	8.0	0.512	0.511	26250.0	BRNG	102.74	14.73	12.83
DST-33	0.500	3.937	8.0	0.511	0.508	26250.0	BRNG	103.35	14.82	12.96
DST-34	0.750	6.001	8.0	0.678	0.690	49600.0	BRNG	95.85	13.69	11.98
DST-35	0.750	6.000	8.0	0.674	0.686	50100.0	BRNG	97.39	13.97	12.14
DST-36	0.750	6.000	8.0	0.671	0.684	52700.0	BRNG	102.73	14.68	12.84

TENS = TENSION
COMP = COMPRESSON
BRNG = BEARING
B/B = BOLT BENDING
DBLR = DOUBLER

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TABLE 17

DOUBLE-SHEAR COMPRESSION SPECIMENS

FIBER PATTERN A - (25% 0°, 50% ±45°, 25% 90°)

U.S. CUSTOMARY UNITS

SPECIMEN NUMBER	HOLE DIAM. IN.	PANEL WIDTH IN.	W/D RATIO	CENTER THICK. IN.	SPLICE THICKx2 IN.	FAILURE LOAD LB	FAILURE MODE	BEARING STRESS KSI	NET-SECT. STRESS KSI	GROSS-SECT. STRESS KSI
DSC- 1	0.250	0.752	3.0	0.335	0.329	8200.0	COMP	99.70	49.65	33.14
DSC- 2	0.250	0.754	3.0	0.339	0.333	8230.0	COMP	98.86	49.04	32.79
DSC- 3	0.250	0.757	3.0	0.334	0.333	8530.0	BRNG	102.46	50.52	33.84
DSC- 4	0.500	1.499	3.0	0.515	0.503	25950.0	COMP	103.18	51.64	34.42
DSC- 5	0.500	1.500	3.0	0.512	0.506	26450.0	BRNG	104.55	52.27	34.85
DSC- 6	0.500	1.500	3.0	0.513	0.507	25050.0	COMP	98.82	49.41	32.94
DSC- 7	0.750	2.490	3.0	0.654	0.676	48900.0	BRNG	96.45	41.57	29.05
DSC- 8	0.750	2.492	3.0	0.658	0.675	51700.0	BRNG	102.12	43.97	30.74
DSC- 9	0.750	2.492	3.0	0.655	0.673	51900.0	BRNG	102.82	44.27	30.95
DSC-10	0.500	2.003	4.0	0.339	0.336	16400.0	BRNG	97.62	32.47	24.37
DSC-11	0.500	2.005	4.0	0.333	0.339	16300.0	BRNG	96.17	31.95	23.98
DSC-12	0.500	2.005	4.0	0.335	0.340	18400.0	BRNG	108.24	35.96	26.99
DSC-13	0.500	4.002	8.0	0.508	0.510	26500.0	BRNG	103.92	14.84	12.99
DSC-14	0.500	4.003	8.0	0.513	0.509	27800.0	BRNG	109.23	15.59	13.64
DSC-15	0.500	4.000	8.0	0.512	0.507	28900.0	BRNG	114.00	16.29	14.25
DSC-16	0.750	5.997	8.0	0.651	0.675	54800.0	BRNG	108.25	15.47	13.54
DSC-17	0.750	5.997	8.0	0.645	0.677	53000.0	BRNG	104.38	14.92	13.05
DSC-18	0.750	5.995	8.0	0.645	0.675	52000.0	BRNG	102.72	14.69	12.85

TENS = TENSION
COMP = COMPRESSION
BRNG = BEARING
B/B = BOLT BENDING
DBLR = DOUBLER

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TABLE 18

DOUBLE-SHEAR COMPRESSION SPECIMENS

FIBER PATTERN B - (37.5% 0°, 50% ±45°, 12.5% 90°)

U.S. CUSTOMARY UNITS

SPECIMEN NUMBER	HOLE DIAM. IN.	PANEL WIDTH IN.	W/D RATIO	CENTER THICK. IN.	SPLICE THICKx2 IN.	FAILURE LOAD LB	FAILURE MODE	BEARING STRESS KSI	NET-SECT. STRESS KSI	GROSS-SECT. STRESS KSI
DSC-19	0.250	0.761	3.0	0.335	0.337	7970.0	COMP	94.60	46.28	31.08
DSC-20	0.250	0.760	3.0	0.337	0.339	7310.0	COMP	86.25	42.28	28.37
DSC-21	0.250	0.755	3.0	0.335	0.320	7900.0	COMP	98.75	48.39	32.70
DSC-22	0.500	1.505	3.0	0.517	0.494	25200.0	COMP	102.02	50.76	33.90
DSC-23	0.500	1.503	3.0	0.518	0.500	24550.0	COMP	98.20	48.95	32.67
DSC-24	0.500	1.504	3.0	0.515	0.493	23500.0	BRNG	94.38	47.00	31.35
DSC-25	0.750	2.494	3.0	0.676	0.679	46350.0	BRNG	91.02	39.14	27.37
DSC-26	0.750	2.490	3.0	0.675	0.678	46950.0	BRNG	92.33	39.80	27.81
DSC-27	0.750	2.493	3.0	0.682	0.679	45500.0	BRNG	89.35	38.45	26.83
DSC-28	0.250	2.006	8.0	0.337	0.343	9575.0	B/B	111.66	15.90	13.92
DSC-29	0.250	2.005	8.0	0.335	0.343	9400.0	B/B	109.62	15.62	13.67
DSC-30	0.250	2.006	8.0	0.335	0.341	9440.0	B/B	110.73	15.76	13.80
DSC-31	0.500	4.005	8.0	0.510	0.477	25950.0	BRNG	108.81	15.52	13.58
DSC-32	0.500	4.000	8.0	0.513	0.492	26450.0	BRNG	107.52	15.36	13.44
DSC-33	0.500	4.003	8.0	0.510	0.500	27550.0	BRNG	110.20	15.73	13.76
DSC-34	0.750	5.996	8.0	0.650	0.676	50800.0	BRNG	100.20	14.32	12.53
DSC-35	0.750	5.996	8.0	0.652	0.678	52300.0	BRNG	102.85	14.70	12.87
DSC-36	0.750	5.997	8.0	0.655	0.678	52000.0	BRNG	102.26	14.62	12.79

TENS = TENSION
COMP = COMPRESSION
BRNG = BEARING
B/B = BOLT BENDING
DBLR = DOUBLER

TABLE 19

SINGLE-SHEAR TENSION SPECIMENS

FIBER PATTERN A - (25% 0°,50% ±45°,25% 90°)

U.S. CUSTOMARY UNITS

SPECIMEN NUMBER	HOLE DIAM. IN.	PANEL WIDTH IN.	W/D RATIO	PANEL THICK IN.	FAILURE LOAD LB	FAILURE MODE	BEARING STRESS KSI	NET-SECT. STRESS KSI	GROSS-SECT. STRESS KSI
SST- 1	0.250	2.000	8.0	0.133	3100.0	BRNG	93.23	13.32	11.65
SST- 2	0.250	1.996	8.0	0.133	3600.0	BRNG	108.27	15.50	13.56
SST- 3	0.250	1.996	8.0	0.132	3710.0	BRNG	112.42	16.10	14.08
SST- 4	0.500	3.995	8.0	0.246	13725.0	BRNG	111.59	15.96	13.97
SST- 5	0.500	3.999	8.0	0.247	13400.0	BRNG	108.50	15.50	13.57
SST- 6	0.500	3.999	8.0	0.246	13025.0	BRNG	105.89	15.13	13.24
SST- 7	0.750	5.998	8.0	0.322	25700.0	BRNG	106.42	15.21	13.31
SST- 8	0.750	5.998	8.0	0.326	24320.0	BRNG	99.47	14.22	12.44
SST- 9	0.750	6.000	8.0	0.325	25350.0	BRNG	104.00	14.86	13.00

TENS = TENSION
COMP = COMPRESSION
BRNG = BEARING
B/B = BOLT BENDING
DBLR = DOUBLER

TABLE 20

SINGLE-SHEAR TENSION SPECIMENS

FIBER PATTERN B - (37.5% 0°, 50% ±45°, 12.5% 90°)

U.S. CUSTOMARY UNITS

SPECIMEN NUMBER	HOLE DIAM. IN.	PANEL WIDTH IN.	W/D RATIO	PANEL THICK IN.	FAILURE LOAD LB	FAILURE MODE	BEARING STRESS KSI	NET-SECT. STRESS KSI	GROSS-SECT. STRESS KSI
SST-10	0.250	1.993	8.0	0.133	3770.0	BRNG	113.39	16.22	14.19
SST-11	0.250	1.990	8.0	0.133	3160.0	BRNG	95.04	13.65	11.94
SST-12	0.250	1.999	8.0	0.134	4130.0	BRNG	124.79	17.84	15.60
SST-13	0.500	4.001	8.0	0.248	12350.0	BRNG	103.67	14.80	12.95
SST-14	0.500	4.000	8.0	0.245	14200.0	BRNG	115.92	16.56	14.49
SST-15	0.500	3.997	8.0	0.246	13620.0	BRNG	110.73	15.93	13.35
SST-16	0.750	5.997	8.0	0.327	26500.0	BRNG	103.05	15.44	13.51
SST-17	0.750	6.003	8.0	0.327	24300.0	BRNG	99.09	14.15	12.38
SST-18	0.750	6.005	8.0	0.326	24250.0	BRNG	99.19	14.16	12.39

TENS = TENSION
COMP = COMPRESSION
BRNG = BEARING
B/B = BOLT BENDING
DBLR = DOUBLER

TABLE 21

SINGLE-SHEAR COMPRESSION SPECIMENS

FIBER PATTERN A - (25% 0°,50% ±45°,25% 90°)

U.S. CUSTOMARY UNITS

SPECIMEN NUMBER	HOLE DIAM. IN.	PANEL WIDTH IN.	W/D RATIO	PANEL THICK IN.	FAILURE LOAD LB	FAILURE MODE	BEARING STRESS KSI	NET-SECT. STRESS KSI	GROSS-SECT. STRESS KSI
SSC- 1	0.250	1.999	8.0	0.133	3740.0	BRNG	112.48	16.08	14.07
SSC- 2	0.250	2.002	8.0	0.134	2500.0	BRNG	74.63	10.65	9.32
SSC- 3	0.250	2.000	8.0	0.134	3800.0	BRNG	113.47	16.20	14.15
SSC- 4	0.500	4.001	8.0	0.238	12580.0	BRNG	105.71	15.10	13.21
SSC- 5	0.500	4.004	8.0	0.248	11820.0	BRNG	95.32	13.60	11.90
SSC- 6	0.500	4.003	8.0	0.247	12880.0	BRNG	104.29	14.89	13.03
SSC- 7	0.750	6.001	8.0	0.325	26750.0	BRNG	109.74	15.67	13.72
SSC- 8	0.750	6.000	8.0	0.327	26200.0	BRNG	106.83	15.26	13.35
SSC- 9	0.750	6.000	8.0	0.323	26600.0	BRNG	109.17	15.45	13.52

TENS = TENSION
COMP = COMPRESSION
BRNG = BEARING
B/B - BOLT BENDING
DBLR = DOUBLER

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TABLE 22

SINGLE-SHEAR COMPRESSION SPECIMENS

FIBER PATTERN B - (37.5% 0°, 50% ±45°, 12.5% 90°)

U.S. CUSTOMARY UNITS

SPECIMEN NUMBER	HOLE DIAM. IN.	PANEL WIDTH IN.	W/D RATIO	PANEL THICK IN.	FAILURE LOAD LB	FAILURE MODE	BEARING STRESS KSI	NET-SECT. STRESS KSI	GROSS-SECT. STRESS KSI
SSC-10	0.250	2.002	8.0	0.133	3860.0	BRNG	116.09	16.57	14.50
SSC-11	0.250	1.997	8.0	0.135	4200.0	BRNG	124.44	17.31	15.58
SSC-12	0.250	2.003	8.0	0.133	4070.0	BRNG	122.41	17.46	15.28
SSC-13	0.500	3.996	8.0	0.249	12940.0	BRNG	103.94	14.86	13.00
SSC-14	0.500	4.001	8.0	0.246	12320.0	BRNG	100.16	14.30	12.52
SSC-15	0.500	4.003	8.0	0.255	12200.0	BRNG	95.69	13.66	11.95
SSC-16	0.750	6.002	8.0	0.326	25400.0	BRNG	103.88	14.84	12.98
SSC-17	0.750	6.001	8.0	0.326	23950.0	BRNG	97.96	13.99	12.24
SSC-18	0.750	6.000	8.0	0.326	23650.0	BRNG	96.73	13.82	12.09

TENS = TENSION
COMP = COMPRESSION
BRNG = BEARING
B/B = BOLT BENDING
DBLR = DOUBLER

TABLE 23

COMPOSITE STRESS CONCENTRATION FACTORS

UNLOADED HOLE TENSION TESTS - PATTERN A

(PHASE I)

Test Number	Diameter (in)	Width (in)	Thickness (in)	Layup Pattern	Failure Mode	K_{te} Net Area	K_{tc} Net Area
UHT 1				25% 0°	Net-Sect	2.125	1.44
UHT 2	0.25	0.50	0.25	50% ±45°	Net-Sect	2.125	1.34
UHT 3				25% 90°	Net-Sect	2.125	1.38
UHT 4					Net-Sect	2.125	1.45
UHT 5	0.50	1.0	0.25	"	Net-Sect	2.125	1.35
UHT 6					Net-Sect	2.125	1.37
UHT 7					Net-Sect	2.125	1.39
UHT 8	0.75	1.50	0.25	"	Net-Sect	2.125	1.31
UHT 9					Net-Sect	2.125	1.42
UHT 10					Net-Sect	2.125	1.07
UHT 11	0.25	2.0	0.25	"	Doubler	-	
UHT 12					Doubler	-	
UHT 13					Doubler	-	
UHT 14	0.50	4.0	0.25	"	Doubler	-	
UHT 15					Net-Sect	2.125	1.16
UHT 16					Net-Sect	2.58	1.27
UHT 17	0.75	4.5*	0.25	"	Net-Sect	2.58	1.22
UHT 18					Net-Sect	2.58	1.23

*Cut down from 6" width - new w/d = 6

Ftu_A = 68 ksi

Ftu_B = 95 ksi

TABLE 24

COMPOSITE STRESS CONCENTRATION FACTORS

UNLOADED HOLE TENSION TESTS - PATTERN B

Test Number	Diameter (in)	Width (in)	Thickness (in)	Layup Pattern	Failure Mode	K_{te} Net Area	K_{tc} Net Area
UHT 19	0.25	0.50	0.25	37.5% 0°	Net-Sect	2.125	1.34
UHT 20				50% ±45°	Net-Sect	2.125	1.27
UHT 21				12.5% 90°	Net-Sect	2.125	1.30
UHT 22	0.50	1.0	0.25	"	Net-Sect	2.125	1.35
UHT 23					Net-Sect	2.125	1.34
UHT 24					Net-Sect	2.125	1.32
UHT 25	0.75	1.50	0.25	"	Net-Sect	2.125	1.30
UHT 26					Net-Sect	2.125	1.24
UHT 27					Net-Sect	2.125	1.27
UHT 28	0.25	2.0	0.25	"	Doubler	-	-
UHT 29					Doubler		
UHT 30					Doubler		
UHT 31	0.50	4.0	0.25	"	Doubler	-	-
UHT 32					Doubler		
UHT 33					Doubler & Net-Sect		
UHT 34	0.75	6.0	0.25	"	Doubler	-	-
UHT 35					End Bearing		
UHT 36					Doubler		

F_{tu_A} = 68 ksi

F_{tu_B} = 95 ksi

C-2

TABLE 25

COMPOSITE STRESS CONCENTRATION FACTORS

DOUBLE-SHEAR TENSION TESTS

(PHASE I)

(w/d - 3)

Test Number	Diameter (in)	Width (in)	Thickness (in)	Layup Pattern	Failure Mode	K_{tc} (Net Area)	K_{tc} (Net Area)
DST 1				25% 0°	Tension	3.25	1.64
DST 2	0.25	0.75	0.33	50% ±45°	Tension	3.25	1.76
DST 3				25% 90°	Tension	3.25	1.71
DST 4				25% 0°	Tension	3.25	1.59
DST 5	0.50	1.50	0.50	50% ±45°	Bearing	-	-
DST 6				25% 90°	Tension	3.25	1.56
DST 7	(1.00)*			25% 0°	Doubler	2.93**	1.66**
DST 8	0.75	2.25	0.67	50% ±45°	Doubler	-	-
DST 9	(1.00)*			25% 90°	Doubler	2.93**	1.40**
DST 19				37.5% 0°	Tension	3.25	1.97
DST 20	0.25	0.75	0.33	50% ±45°	Tension	3.25	1.89
DST 21				12.5% 90°	Tension	3.25	2.07
DST 22	0.50			37.5% 0°	Bearing	-	-
DST 23	(0.625)*	1.50	0.50	50% ±45°	Tension	2.78**	2.04**
DST 24	0.50			12.5% 90°	Tension	3.25	1.94
DST 25				37.5% 0°	Bearing	-	-
DST 26	0.75	2.25	0.67	50% ±45°	Doubler	-	-
DST 27				12.5% 90°	Test Deferred		

*Based on End Load Pin Diameter

**Based on Net-Section Failure at Load Introduction Pin After Doubler Failure.

K_{tc} values are determined using tested unnotched laminate allowables:

F_{tu_A} = 68,000 psi

F_{tu_B} = 95,000 psi

TABLE 26

UNLOADED HOLE TENSION TEST RESULTS
(PHASE II)

Specimen Number	Width W (in.)	Diameter d (in.)	w/d	Failure Load P_{ult} (lb)	Gross Stress f_{tu} (psi)	K_{te}	K_{tc} *
UHT 19-5	1.125	.375	3	12,600	44,800	2.30	1.41
UHT 20	1.125	.375	3	12,860	45,725	2.30	1.39
UHT 21	1.125	.375	3	13,460	47,860	2.30	1.32
UHT 22	1.50	.500	3	17,460	46,560	2.30	1.36
UHT 23	1.50	.500	3	17,440	46,510	2.30	1.36
UHT 24	1.50	.500	3	18,640	49,710	2.30	1.27
UHT 25	2.25	.750	3	25,750	45,780	2.30	1.38
UHT 26	2.25	.750	3	27,100	48,180	2.30	1.31
UHT 27	2.25	.750	3	26,550	47,200	2.30	1.34
UHT 31	2.50	.500	5	30,400	48,640	2.51	1.56
UHT 32	2.50	.500	5	30,250	48,400	2.51	1.57
UHT 33	2.50	.500	5	32,050	51,280	2.51	1.48
UHT 34	3.75	.750	5	46,150	49,225	2.51	1.54
UHT 35	3.75	.750	5	49,500	52,800	2.51	1.44
UHT 36	3.75	.750	5	45,500	48,535	2.51	1.57
UHT 37	3.00	1.00	3	37,000	49,330	2.30	1.28
UHT 38	3.00	1.00	3	36,750	49,000	2.30	1.29
UHT 39-5	3.00	1.00	3	38,150	50,870	2.30	1.25

Fiber Pattern B - (37.5% 0^{0}, 50% $\pm 45^{0}$, 12.5% 90^{0})
Ply Thickness - 0.0055 in.
Laminate Thickness - 0.25 in. (Nominal)

*Based on F_{tu} = 95 ksi

TABLE 27

UNLOADED HOLE TENSION TEST RESULTS

(PHASE II)

Specimen Number	Width W (in.)	Diameter d (in.)	w/d	Failure Load P_{ult} (lb)	Gross Stress f_{tu} (psi)	K_{te}	K_{tc} *
UHT 19-10	1.125	.375	3	13,940	49,560		1.29
UHT 20	1.125	.375	3	14,420	51,270	2.30	1.24
UHT 21	1.125	.375	3	13,640	48,500		1.31
UHT 22	1.50	.500	3	17,700	47,200		1.34
UHT 23	1.50	.500	3	16,660	44,430	2.30	1.43
UHT 24	1.50	.500	3	15,580	41,550		1.52
UHT 25	2.25	.750	3	26,250	46,670		1.36
UHT 26	2.25	.750	3	26,500	47,110	2.30	1.34
UHT 27	2.25	.750	3	25,700	45,690		1.39
UHT 31	2.50	.500	5	30,800	49,280		1.54
UHT 32	2.50	.500	5	31,050	49,680	2.51	1.53
UHT 33	2.50	.500	5	31,400	50,240		1.51
UHT 34	3.75	.750	5	47,150	43,930		1.51
UHT 35	3.75	.750	5	46,650	49,760	2.51	1.53
UHT 36	3.75	.750	5	45,050	48,050		1.58
UHT 37	3.00	1.00	3	32,950	43,930		1.44
UHT 38	3.00	1.00	3	34,800	46,400	2.30	1.36
UHT 39-10	3.00	1.00	3	37,100	49,470		1.28

Fiber Pattern B - (37.5% 0^{0}, 50% $\pm 45^{0}$, 12.5% 90^{0})
Ply Thickness - 0.0104 in.
Laminate Thickness - 0.25 in. (Nominal)

*Based on F_{tu} = 95 ksi

TABLE 28

UNLOADED HOLE TENSION TEST RESULTS

(PHASE II)

Specimen Number	Width W (in.)	Diameter d (in.)	w/d	Failure Load P_{ult} (lb)	Gross Stress f_{tu} (psi)	K_{te}	K_{tc}
UHT 4-10				14,660	39,090		1.16
5	1.50	.50	3	14,820	39,520	2.30	1.15
6				14,540	38,770		1.17
7				23,150	41,160		1.10
8	2.25	.750	3	23,200	41,240	2.30	1.10
9				22,400	39,820		1.14
13				25,700	42,720		1.27
14	2.50	.50	5	27,350	43,760	2.51	1.24
15				27,150	43,440		1.25
16				35,950	38,350		1.42
17	3.75	.750	5	39,550	42,190	2.51	1.29
18-1C				38,600	41,170		1.32

Fiber Pattern A - (25% 0^{o}, 50% $\pm 45^{o}$, 25% 90^{o})
Ply Thickness - 0.0104 in.
Laminate Thickness - 0.25 in. (Nominal)

*Based on F_{tu} = 68 ksi

TABLE 29A

DOUBLE SHEAR TEST RESULTS

(PHASE II)

SPECIMEN NUMBER	FIBER PATTERN	HOLE DIA. (IN.)	WIDTH (IN.)	SKIN THICKNESS (IN.)	SPLICE THICKNESS (IN.)	FAILURE LOAD (LB)	FAILURE MODE	GROSS-SECT. STRESS (PSI)	BEARING STRESS+ (PSI)
DSC 10						13,000		21,010	104,100
11	A	.375	1.875	.333	.167	13,980	BEARING	22,595	112,000
12						14,420		23,305	115,500
DSC 28						13,650		22,060	109,300
29	B	.375	1.875	.333	.167	13,780	BEARING	22,270	110,400
30						12,940		22,530	103,600
DSCA 28						16,460		26,360	131,800
29	B	.375	1.875	.333	.250	16,320	BEARING	26,140	130,700
30*						-		-	-
DST 7						44,200		29,495	89,290
8	A	.750	2.25	.666	.333	46,200	NET TENSION	30,830	93,330
9						44,600		29,765	90,100
DST 25						48,400		32,300	97,780
26	B	.750	2.25	.666	.333	49,200	NET TENSION	32,835	99,390
27						49,000		32,700	98,990
DSTA 7						46,200		30,830	93,330
8	A	.750	2.25	.666	.499	43,300	NET TENSION	28,895	87,470
9						44,100		29,430	89,090
DSTA 25						48,400		32,300	97,780
26	B	.750	2.25	.666	.499	49,700	NET TENSION	33,170	100,400
27						50,200		33,500	101,410

* No Data Recovered or Defective Specimen

** Titanium

\+ Bearing Stress in Central Blade

TABLE 29B

DOUBLE SHEAR TEST RESULTS

(PHASE II)

SPECIMEN NUMBER	FIBER PATTERN	HOLE DIA. (IN.)	WIDTH (IN.)	SKIN THICKNESS (IN.)	SPLICE THICKNESS (IN.)	FAILURE LOAD (LB)	FAILURE MODE	GROSS SECT. STRESS (PSI)	BEARING STRESS+ (PSI)
DSTB 25						50,000		33,365	100,100
26	B	.750	2.25	.666	.375**	50,800	NET TENSION	33,900	101,700
27						49,100		32,765	98,300
DSTB 22						25,950		34,670	104,000
23	B	.500	1.50	.499	.250**	25,850	NET TENSION	34,535	103,600
24						25,500		34,070	102,200
DSTB 31						40,500		32,465	162,000
32	B	.500	2.50	.499	.250**	39,150	BEARING	31,385	156,600
33						38,450		30,820	153,800
DSTA 22						24,950		33,330	100,000
23	B	.500	1.50	.499	.333	26,150	NET TENSION	34,935	104,800
24						26,350		35,205	105,600
DSTA 31						31,950		25,610	127,800
32	B	.500	2.50	.499	.333	31,500	BEARING	25,250	126,000
33*						-		-	-

* No Data Recovered or Defective Specimen

** Titanium

\+ Bearing Stress in Central Blade

TABLE 30

LOAD DEFLECTION DATA - SPRING RATES (ELASTIC)

DOUBLE-SHEAR TENSION TESTS

(PHASE I)

Test Number	Spring Rate (lb/in)	Test Number	Spring Rate (lb/in)
DST 1	342,900, 377,800	DST 19	700,000
DST 2	550,000	DST 20	542,900*
DST 3	333,300	DST 21	287,900
DST 4	2.5×10^6	DST 22	1.5×10^6
DST 5	1.39×10^6	DST 23	933,000
DST 6	960,000	DST 24	1.25×10^6*
DST 7	1.37×10^6	DST 25	1.27×10^6
DST 8	1.50×10^6	DST 26	1.20×10^6
DST 9	1.70×10^6	DST 27	-
DST 10	385,700	DST 28	**
DST 11	787,500*	DST 29	371,400
DST 12	525,000*	DST 30	362,500
DST 13	1.11×10^6	DST 31	729,700*
DST 14	1.04×10^6*	DST 32	818,200
DST 15	866,700	DST 33	848,800
DST 16	1.35×10^6	DST 34	1.60×10^6
DST 17	1.73×10^6*	DST 35	1.04×10^6
DST 18	1.14×10^6	DST 36	1.17×10^6

*Average Value over Elastic Range

**Slope in Elastic Range not Discernible

TABLE 31

LOAD DEFLECTION DATA - SPRING RATES (ELASTIC)

DOUBLE SHEAR COMPRESSION TESTS

(PHASE I)

Test Number	Spring Rate (lb/in)	Test Number	Spring Rate (lb/in)
DSC 1	1.0×10^6	DSC 19	600,000
DSC 2	509,100	DSC 20	661,500
DSC 3	857,100	DSC 21	472,700
DSC 4	1.23×10^6	DSC 22	1.19×10^6
DSC 5	1.58×10^6	DSC 23	1.35×10^6
DSC 6	1.44×10^6	DSC 24	1.22×10^6
DSC 7	1.38×10^6	DSC 25	1.11×10^6
DSC 8	1.38×10^6	DSC 26	1.0×10^6
DSC 9	1.43×10^6	DSC 27	1.15×10^6
DSC 10	816,700*	DSC 28	485,700
DSC 11	755,600*	DSC 29	466,700
DSC 12	760,000*	DSC 30	438,100
DSC 13	812,500	DSC 31	1.0×10^6
DSC 14	1.0×10^6	DSC 32	973,700
DSC 15	944,400	DSC 33	968,800
DSC 16	1.23×10^6	DSC 34	1.07×10^6
DSC 17	1.18×10^6	DSC 35	1.27×10^6
DSC 18	1.28×10^6	DSC 36	1.27×10^6

*Specimens inadvertently drilled to 1/2" diameter.
Resulting Specimens - t = 0.33", d = 0.50", w/d = 4.0

TABLE 32

LOAD DEFLECTION DATA - SPRING RATES (ELASTIC)

DOUBLE SHEAR TESTS

(PHASE II)

TEST NUMBER	SPRING RATE (lb/in)	TEST NUMBER	SPRING RATE (lb/in)
DSC 10	763,300	DSTA 25	1.468×10^6
DSC 11	811,400	DSTA 26	1.596
DSC 12	858,200	DSTA 27	1.609
DSC 28	981,200	DSTB 25	1.904×10^6
DSC 29	921,100	DSTB 26	1.844
DSC 30	698,100	DSTB 27	1.984
DSCA 28	810,000	DSTB 22	1.431×10^6
DSCA 29	866,700	DSTB 23	1.599
		DSTB 24	1.335
DST 7	1.479×10^6	DSTB 31	1.491×10^6
DST 8	1.365	DSTB 32	1.308
DST 9	1.452	DSTB 33	1.230
DST 25	1.422×10^6	DSTA 22	1.045×10^6
DST 26	1.533	DSTA 23	1.200
DST 27	1.446	DSTA 24	1.117
DSTA 7	1.600×10^6	DSTA 31	1.035×10^6
DSTA 8	1.442	DSTA 32	1.072
DSTA 9	1.596		

TABLE 33

ST-1 - COMPRESSION AFTER IMPACT TEST RESULTS

CIBA -GEIGY 914/T300 - 10-mil Tape

Resin content: 29.5%									
Specimen identification	Thickness, in.	Width, in.	Impact energy, ft-lb	Impact width, in.	Impact area, in.^{2}	Failure load, kips	Failure stress, ksi	Failure strain, μin/in.	Modulus, msi
ST-1A	0.247	5.031	30		3.0	-23.00	-18.51	-2620	7.06
ST-1B	.243	5.031	30		3.0	-23.20	-18.97	-2610	7.27
Average					3.0		-18.74	-2615	7.17

TABLE 34

ST-2 - EDGE DELAMINATION TENSION TEST RESULTS

CIBA-GEIGY 914/T300 - 10-mil Tape

(g) T300/914 edge delamination test results, ply thickness = 0.010 in.

Laminate orientation $(\pm 35/0/90)_s$
Resin content: 29.5%

Specimen identification	Thickness, in.	Width, in.	Delamination onset strain, μin./in. (a)	Delamination onset strain, μin./in. (b)	Failure strain, μin./in.	Tensile modulus, msi	Interlaminar fracture toughness, G_c, $\frac{\text{in.-lb}}{\text{in.}^2}$
ST-2F	0.0700	1.5374	3060		8250	8.80	0.496
-2G	.0712	1.5331	3130		6000	9.03	.527
-2H	.0708	1.5337	3060		6750	9.37	.501
-2I	.0699	1.5365	3060		7000	8.87	.495
-2J	.0706	1.5340	3000		7000	8.62	.480
Average			3062				0.500

Laminate orientation $(\pm 30/\pm 30/90/\overline{90})_s$
Resin content: 29.5%

Specimen identification	Thickness, in.	Width, in.	Delamination onset strain, μin./in. (a)	Delamination onset strain, μin./in. (b)	Tensile modulus, msi	Secant modulus, msi	Interlaminar fracture toughness, G_c, $\frac{\text{in.-lb}}{\text{in.}^2}$
ST-2A	0.1082	1.5043	2630		7.45		0.949
-2B	.1133	1.5042	2500		7.25		.898
-2C	.1042	1.4917	3000		7.51		1.190
-2D	.1140	1.4956	2750		7.44		1.090
-2E	.1103	1.5012	2840		7.64		1.130
Average			2744				1.050

[a]Strain at first deviation from linear stress-strain curve.
[b]Strain at first visible delamination.

TABLE 35

ST-3 - UNLOADED HOLE TENSION TEST RESULTS

914/T300 - 10-mil Tape

Resin content: 29.5%							
Specimen identification	Thickness, in.	Width, in.	Hole diameter, in.	Failure load, kips	Failure stress, ksi	Failure strain, μin./in.	Modulus, msi
ST 3-1	0.238	2.000	0.250	19.75	41.492	5730	7.6
-2	.248	2.003	.250	24.00	48.290	6750	7.5
-3	.248	2.000	.250	21.50	43.347	5910	7.3
Average					44.376	6130	7.47

TABLE 36

ST-4 - UNLOADED HOLE COMPRESSION TEST RESULTS

914/T300 - 10-mil Tape

Resin content: 29.5%							
Specimen identification	Thickness, in.	Width, in.	Hole diameter, in.	Failure load, kips	Failure stress, ksi	Failure strain, μin./in.	Compression modulus, msi
ST-4A	0.2432	5.000	1.000	-42.50	-34.95	-5100	6.85
-4B	.2499	5.000	1.000	-46.70	-37.37	-5900	6.33
-4C	.2473	5.000	1.000	-43.50	-35.18	-5200	6.77
Average					-35.83	-5401	6.65

TABLE 37

ST-5 - HINGED DOUBLE CANTILEVER BEAM TEST RESULTS

914/T300 - 10-mil Tape

Laminate orientation: $[0]_n$
Resin content: ___% by weight
Test condition: 75°F dry

Coupon ID	Total thickness, 2t, in.	Width, in.	a_1, in.	δ_1, in.	P_1, lb	a_2, in.	δ_2, in.	P_2, lb	a_3, in.	δ_3, in.	P_3, lb	a_4, in.	δ_4, in.	P_4, lb	a_5, in.	δ_5, in.	P_5, lb	G_{Ic}, $\frac{\text{in-lb}}{\text{in}^2}$
1	0.138	1.500	2.31	0.23	14.1	3.37	0.43	10.0	0.66	8.2	5.15	0.91	6.4					1.140
2	0.128	1.500	2.41	0.22	11.7	3.30	0.43	9.1	0.67	6.8	5.11	0.95	5.6					1.070
3	0.139	1.500	2.34	0.21	12.8	3.34	0.40	9.7	0.62	7.1	5.11	0.84	6.1					1.010

TABLE 38

ST-1 - COMPRESSION AFTER IMPACT TEST RESULTS

CIBA-GIEGY 2566/CELION HIGH STRAIN FIBERS (CHS)

Resin content: 30.0%									
Specimen identification	Thickness, in.	Width, in.	Impact energy, ft-lb	Impact width, in.	Impact area, $in.^2$	Failure load, kips	Failure stress, ksi	Failure strain, μin/in.	Modulus, msi
ST1-B1	0.276	5.024	20	2.68	1.387	-49.00	-35.34	-5251	
-B2	.276	5.052	20	2.14	1.394	-47.90	-34.35		
-B3	.276	5.000	20	1.76	1.365	-47.80	-35.02	-5283	
Average					1.38		-34.90	-5267	

TABLE 39

ST-2 - EDGE DELAMINATION TENSION TEST RESULTS

914/T300 - 5-mil Tape

Laminate orientation $(\pm35/0/90)_s$ Resin content: 30%							
Specimen identification	Thickness, in.	Width, in.	Delamination onset strain, μin./in.		Failure strain, μin./in.	Tensile modulus, msi	Interlaminar fracture toughness, G_c, $\frac{in.\text{-}lb}{in.^2}$
			(a)	(b)			
ST25-6	0.0424	1.512	6500		9 125	9.14	1.35
-7	.0449	1.509	6200		7 500	8.86	1.30
-8	.0450	1.514	6825		11 250	8.92	1.58
-9	.0451	1.509	6300		9 750	8.82	1.35
-10	.0443	1.503	7000		9 750	8.88	1.64
Average			6565		9 475	8.92	1.44

Laminate orientation $(\pm30/\pm30/90/\overline{90})_s$ Resin content: 30%							
Specimen identification	Thickness, in.	Width, in.	Delamination onset strain, μin./in.		Tensile modulus, msi	Secant modulus, msi	Interlaminar fracture toughness, G_c, $\frac{in.\text{-}lb}{in.^2}$
			(a)	(b)			
ST25-1	0.0633	1.509	5875		6.98	6.42	2.77
-2	.0633	1.507	5000		6.71	6.76	2.01
-3	.0580	1.510	5375		7.25	7.27	2.12
-4	.0623	1.512	5000		7.17	7.00	1.97
-5	.0613	1.511	5125		7.37	7.24	2.04
Average			5275		7.10	6.94	2.18

[a]Strain at first deviation from linear stress-strain curve.
[b]Strain at first visible delamination.

TABLE 40

ST-3 - UNLOADED HOLE TENSION TEST RESULTS

CHS/2566 - 5-mil Tape

Resin content: 30.0%							
Specimen identification	**Thickness, in.**	**Width, in.**	**Hole diameter, in.**	**Failure load, kips**	**Failure stress, ksi**	**Failure strain, μin./in.**	**Modulus, msi**
ST 3-1	**0.132**	**1.900**	**0.250**	**15.05**	**60.01**		
-2	**.135**	**1.950**	**.250**	**16.20**	**61.53**		
-3	**.131**	**2.009**	**.250**	**15.26**	**57.76**		
Average					**59.77**		

TABLE 41

ST-4 - UNLOADED HOLE COMPRESSION TEST RESULTS

CHS/2566 - 5-mil Tape

Resin content: 30.0%							
Specimen identification	Thickness, in.	Width, in.	Hole diameter, in.	Failure load, kips	Failure stress, ksi	Failure strain, μin./in.	Compression modulus, msi
ST4-B1	0.281	5.031	1.000	-55.00	-38.91	-6100	
-B2	.278	5.039	1.000	-54.20	-38.69	-5837	
-B3	.281	5.042	1.000	-55.00	-38.91	-5852	
Average					-38.84	-5930	

TABLE 42

ST-5 - HINGED DOUBLE CANTILEVER BEAM TEST RESULTS

CHS/2566 - 5-mil Tape

Laminate orientation: $(0)_n$																				
Specimen identification	Thickness, in.	Width, in.	A_1, in.	δ_1, in.	P_1, lb	A_2, in.	δ_2, in.	P_2, lb	A_3, in.	δ_3, in.	P_3, lb	A_4, in.	δ_4, in.	P_4, lb	A_5, in.	δ_5, in.	P_5, lb	G_{Ic}, $\frac{\text{in-lb}}{\text{in}^2}$
ST5-B1	0.130	1.512	2.71	0.432	14.40	3.74	0.78	11.3	5.07	1.45	9.10	6.09	2.03	7.60				2.19
-B2	.131	1.508	2.70	.424	15.20	3.87	.808	10.80	5.18	1.40	8.30	6.38	2.08	6.95				2.10
-B3	.136	1.508	2.72	.400	15.70	3.80	.780	12.40	4.98	1.324	10.30	6.06	1.86	8.10				2.29
Average																		2.19

TABLE 43

ST-5 - EDGE DELAMINATION TENSION TEST RESULTS

914/T300 - 5-mil Tape

Laminate orientation: $[\pm 35/0/90]_s$ E_{lam} = 9.78 × 10^6 psi E^* = 5.75 × 10^6 psi
Laminate resin content: 30% by weight
Test condition: 75°F dry $E_{[\pm 35/0]_s}$ = 10.57 × 10^6 psi

Specimen ID	Thickness, in.	Width, in.	Delamination onset strain, μin/in. ①	Delamination onset strain, μin/in. ②	Failure strain, μin/in.	Tensile modulus, psi	Interlaminar fracture toughness, G_c, $\frac{\text{in-lb}}{\text{in}^2}$
ST-25-6	.0424	1.512	6500		9125	9.14	1.35
ST-25-7	.0449	1.509	6200		7500	8.86	1.30
ST-25-8	.0450	1.514	6825		11250	8.92	1.58
ST-25-9	.0451	1.509	6300		9750	8.82	1.35
ST-25-10	.0443	1.503	7000		9750	8.88	1.64
Average:	.0443	1.509	6565		9475	8.92	1.44

(G_{IC} = 1.30)

E_{11} = 20.27 × 10^6 psi E_{22} = 1.36 × 10^6 psi G_{12} = 0.80 × 10^6 psi ν_{12} = 0.21

Laminate orientation: $[\pm 30/\pm 30/90/\overline{90}]_s$ E_{lam} = 8.28 × 10^6 psi E^* = 8.27 × 10^6 psi
Laminate resin content: 30 % by weight
Test condition: 75°F dry $E[\pm 30]_s$ = 7.39 × 10^6 psi

Specimen ID	Thickness, in.	Width, in.	Delamination onset strain, μin/in. ①	Delamination onset strain, μin/in. ②	Tensile modulus, psi	Secant modulus, psi	Interlaminar fracture toughness, G_c, $\frac{\text{in-lb}}{\text{in}^2}$
ST-25-1	.0633	1.509	5875		6.98	6.42	2.77
ST-25-2	.0633	1.507	5000		6.71	6.76	2.01
ST-25-3	.0580	1.510	5375		7.25	7.27	2.12
ST-25-4	.0623	1.512	5000		7.17	7.00	1.97
ST-25-5	.0613	1.511	5125		7.37	7.24	2.04
Average:	.0616	1.510	5275		7.10	6.94	2.18

① Strain at first deviation from linear stress-strain curve.

② Strain at first visible delamination.

(G_{IC} = 1.24)

TABLE 44

ST-5 - HINGED DOUBLE CANTILEVER BEAM TEST RESULTS

914/T300 - 5-mil Tape

Laminate orientation: $[0]_n$
Resin content: ___ % by weight
Test condition: 75°F dry

Coupon ID	Total thickness, 2t, in.	Width, in.	a_1, in.	δ_1, in.	P_1, lb	a_2, in.	δ_2, in.	P_2, lb	a_3, in.	δ_3, in.	P_3, lb	a_4, in.	δ_4, in.	P_4, lb	a_5, in.	δ_5, in.	P_5, lb	G_{Ic}, $\frac{\text{in-lb}}{\text{in}^2}$
1D	0.243	1.480	2.63	0.15	24.05	4.06	0.28	17.20	5.21	0.43	13.85							0.963
1E	0.248	1.480	2.40	0.14	28.65	3.43	0.23	21.85	4.31	0.33	18.15	5.44	0.46	14.65				1.095
IF	0.244	1.490	2.86	0.16	25.65	4.32	0.31	18.40	5.13	0.47	16.95							1.173

TABLE 45

UNNOTCHED TENSION TEST RESULTS

SPECIMEN NUMBER	LAYUP PATTERN	WIDTH (IN.)	THICKNESS (IN.)	FAILURE LOAD (LB)	FAILURE STRESS (PSI)	$F_{tu} \times K_t$* (PSI)	YOUNG'S MODULUS (PSI)
MPT-1	A	0.737	0.253	12,200	65,525	68,146	7.625×10^6
MPT-2	A	0.756	0.254	12,600	65,738	68,368	7.224×10^6
MPT-3	A	0.756	0.250	12,450	65,890	68,526	7.322×10^6
MPT-4	B	0.764	0.253	16,850	87,254	90,744	9.31×10^6
MPT-5	B	0.762	0.250	17,450	91,626	95,291	9.33×10^6
MPT-6	B	0.759	0.254	18,250	94,677	98,464	9.34×10^6

*$K_t = 1.04$

UNNOTCHED COMPRESSION TEST RESULTS

SPECIMEN NUMBER	LAYUP PATTERN	WIDTH (IN.)	THICKNESS (IN)	FAILURE LOAD (LB)	FAILURE STRESS (PSI)
MPC-1	A	2.0	0.333	46,850	70,362
MPC-3	A	2.0	0.332	47,850	72,139
MPC-4	A	2.0	0.332	43,000	64,827
MPC-2	B	2.0	0.325	62,200	95,692
MPC-5	B	2.0	0.325	65,500	100,769
MPC-6	B	2.0	0.325	62,150	95,615

TABLE 46

UNNOTCHED 914/T300 TENSILE STRENGTH AND STIFFNESS

ID (1)	WIDTH (IN.)	THICK (IN.)	LOAD (KIP)		STRESS (KSI)	STRAIN AT FAIL (μ)	MODULUS (MSI)
MPT 5-1	2.492	.273	74.0		108.77	12,150	8.70
MPT 5-2	2.487	.274	72.4		106.25	11,510	9.23
MPT 5-3	2.492	.260	65.7		101.99	10,730	9.51
				AVG.	105.67	11,463	9.15
MPT 10-1	2.504	.274	63.8		92.99	10,900	8.43
MPT 10-2	2.509	.272	65.1		95.39	11,020	8.66
MPT 10-3	2.509	.261	57.3		87.67	10,390	8.43
				AVG.	92.02	10,770	8.53

NOTES: (1) MPT 5 is 0.0055 in/ply
MPT 10 is 0.0113 in/ply

(2) Pattern: 37.5% 0^{o}, 50% $\pm 45^{o}$ ("B")

APPENDIX A

PHASE I UNLOADED HOLE TESTS

SPECIMEN CODING:

UHT - UNLOADED HOLE TENSION
UHC - UNLOADED HOLE COMPRESSION

FAILURE MODES

UHT	
1	Net Section Failure
2	Net-Section Failure
3	Net-Section Failure
4	Net-Section Failure
5	Net-Section Failure
6	Net-Section Failure
7	Net-Section Failure
8	Net-Section Failure
9	Net-Section Failure
10	Net-Section Failure. Visible failure along 45° lines
11	Doubler failure and net-section failure at load pin
12	Tapered doubler failure and net-section failure at load pin
13	Tapered doubler failure and net-section failure at load pin
14	Tapered doubler failure and net-section failure at load pin
15	Net-Section Failure. Vibisle along 45° line.
16	Net-Section Failure. Severe delaminations, inter-fiber failures and lateral displacement at test hole (specimen cut down to width = 4.5", (W/D = 6).
17	Net-Section Failure. Severe delaminations, inter-fiber failures and lateral displacement at test hole (specimen cut down to width = 4.5", W/D = 6).
18	Net-Section Failure. Severe delaminations, inter-fiber failures and lateral displacement at test hole (specimen cut down to width = 4.5", W/D = 6).
19	Net-Section Failure
20	Net-Section Failure
21	Net-Section Failure
22	Net-Section Failure
23	Net-Section Failure
24	Net-Section Failure
25	Net-Section Failure
26	Net-Section Failure
27	Net-Section Failure

UHT (Continued)

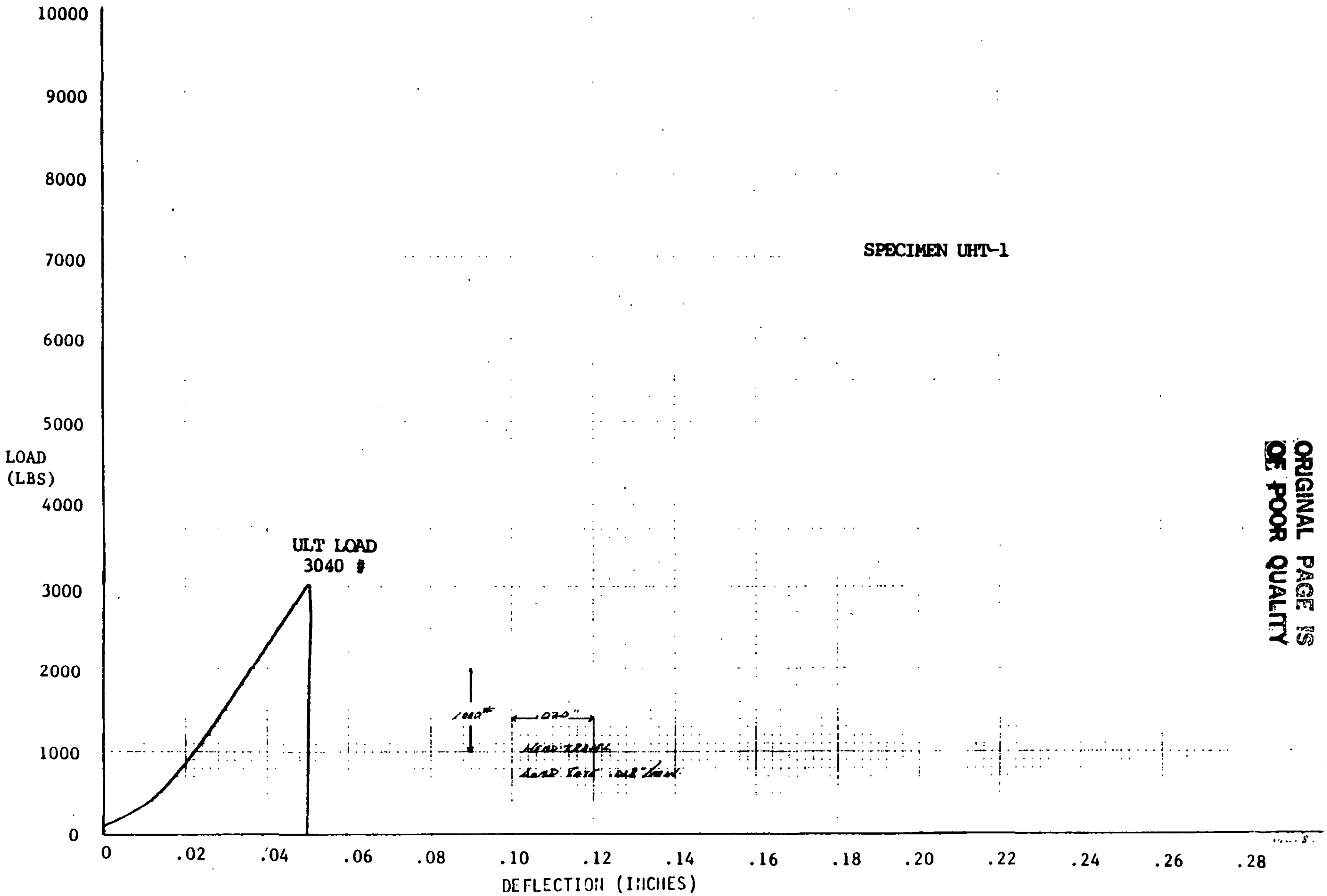
28	Tapered-Doubler Failure
29	Tapered-Doubler Failure
30	Tapered-Doubler Failure
31	Tapered Doubler Failure and net section failure at load pin primarily through 45° lines on side away from test hole
32	Tapered doubler failure and net-section failure at load pin
33	Tapered doubler failure and net section failure at load pin. Near complete failure at test hole area. Extensive delaminations along length of specimen and throughout thickness
34	Extra holes drilled at ends. Failed in bearing/shearout at outer holes for load introduction
35	Tapered doubler failure at load pin
36	Tapered doubler failure. Shearout at load pin hole. Some oneset of failure at net-section.

UHC

1	Compression failure at net-section
2	Compression failure at net-section
3	Compression failure at net-section
4	Compression failure at net-section
5	Compression failure at net-section
6	Compression failure at net-section
7	Compression failure at net-section
8	Compression failure at net-section
9	Compression failure at net-section
10	Compression failure at net-section
11	Compression failure at net-section
12	Compression failure at net-section
13	Compression failure at net-section with ply buckling and delaminations.
14	Compression failure at net-section with ply buckling and delaminations.
15	Compression failure at net-section with ply buckling and delaminations.
16	Compression failure at net-section
17	Compression failure at net-section
18	Compression failure at net-section

UHC (Continued)

19	Compression failure at net-section
20	Compression failure at net-section
21	Compression failure at net-section
22	Compression failure at net-section
23	Compression failure at net-section
24	Compression failure at net-section
25	Compression failure at net-section
26	Compression failure at net-section
27	Compression failure at net-section
28	Compression failure at net-section
29	Compression failure at net-section
30	Compression failure at net-section
31	Compression failure at net-section
32	Compression failure at net-section
33	Compression failure at net-section
34	Compression failure at net-section
35	Compression failure at net-section
36	Compression failure at net-section



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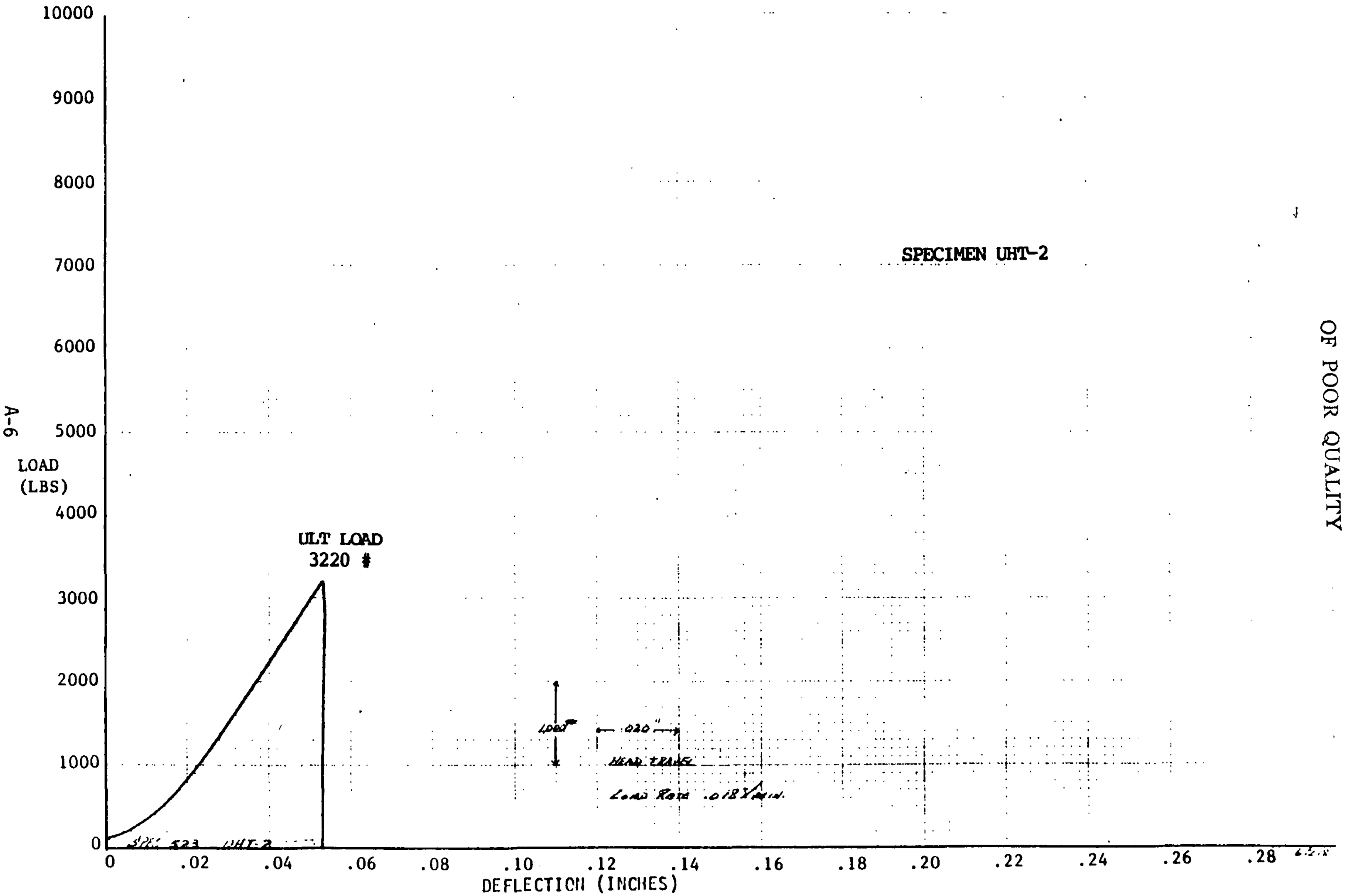
8000
7000
6000
5000
4000
3000
2000
1000
0
0
.02
.04
.06
.08
.10
.12
.14
.16
.18
.20
.22
.24
.26
.28
DEFLECTION (INCHES)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ULT LOAD
3220 #
LOAD (LBS)
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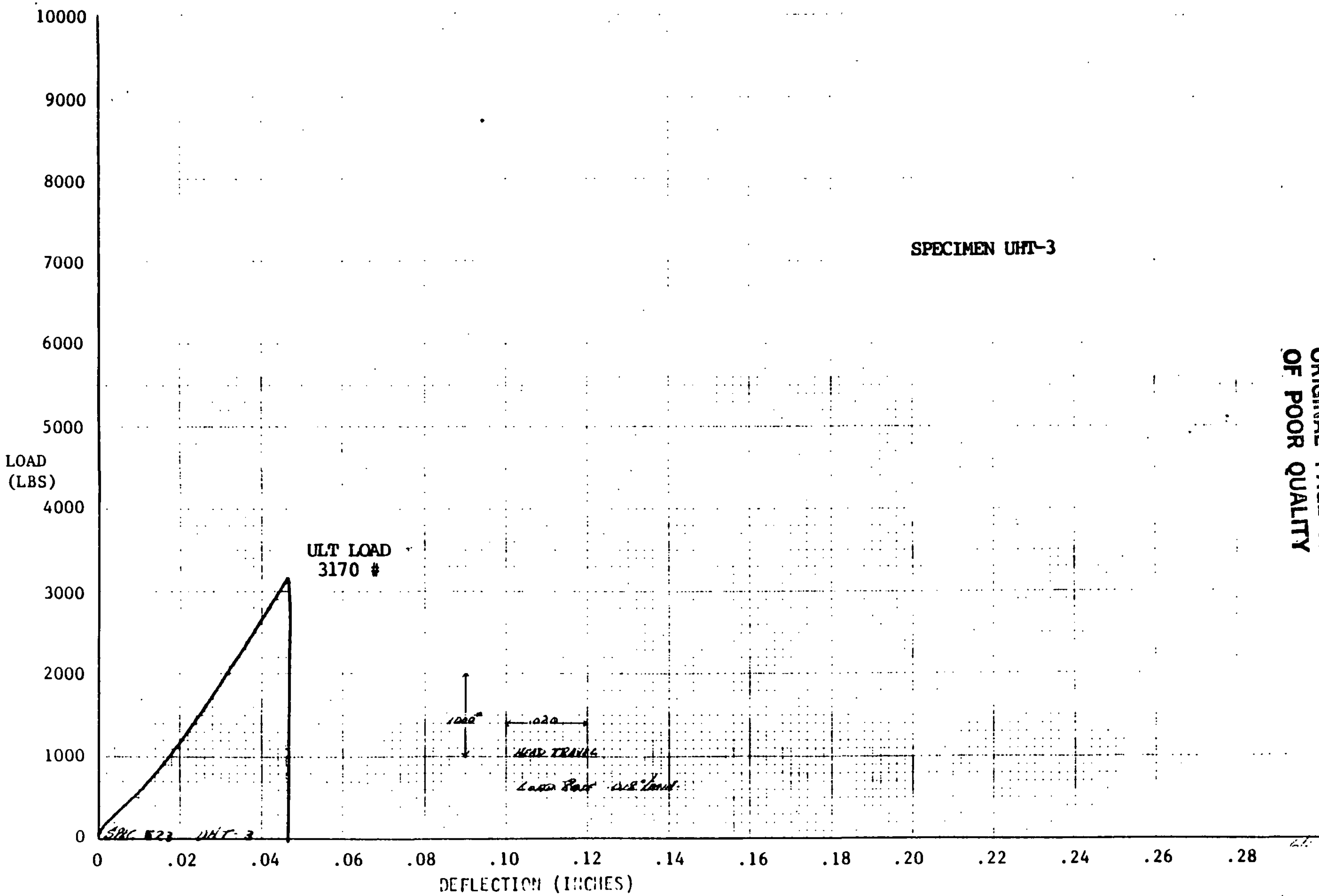
8000
7000
6000
5000
4000
3000
2000
1000
0
0
.02
.04
.06
.08
.10
.12
.14
.16
.18
.20
.22
.24
.26
.28
DEFLECTION (INCHES)



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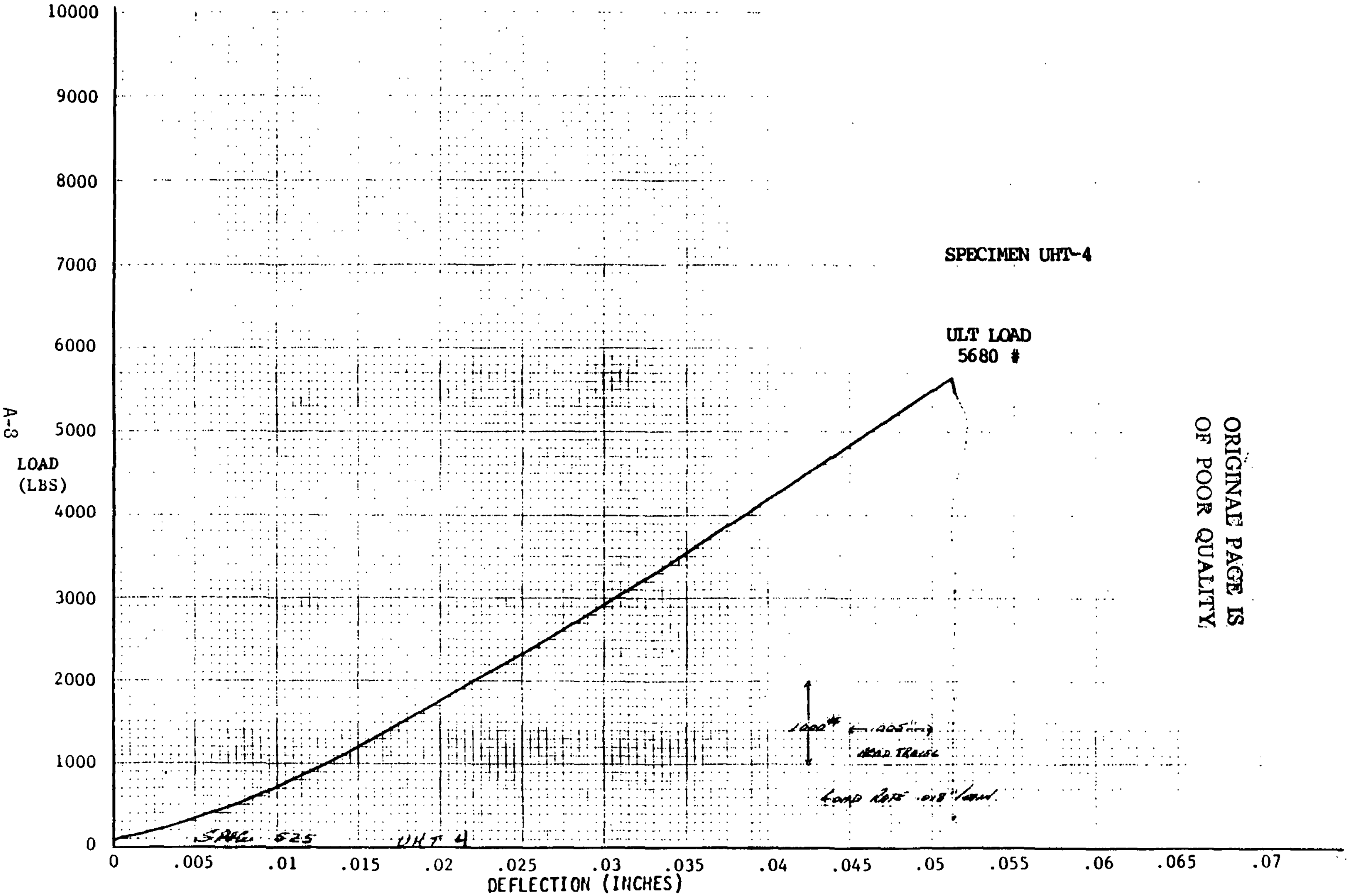
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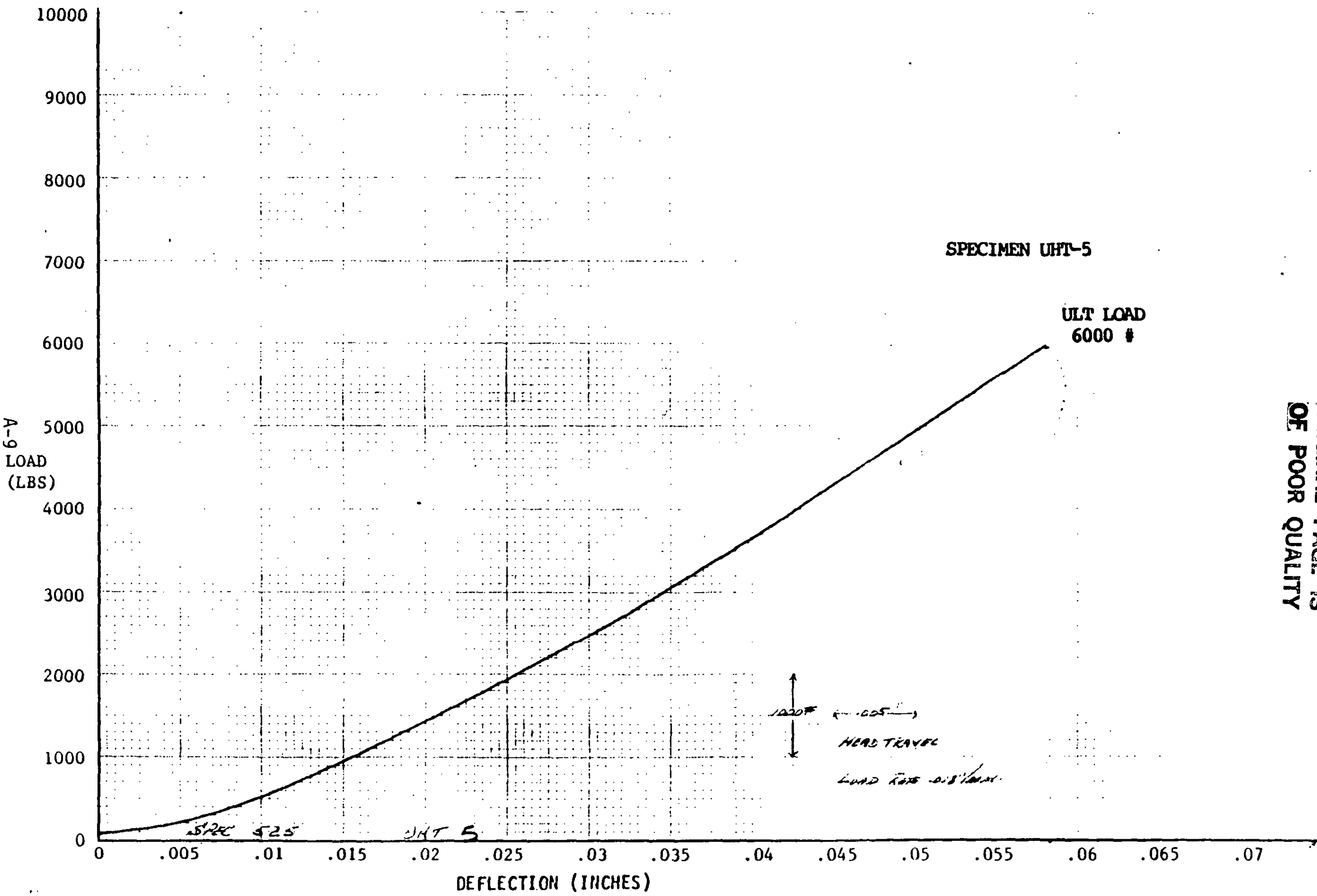
8000
7000
6000
5000
4000
3000
2000
1000
0
.005
.01
.015
.02
.025
.03
.035
.04
.045
.05
.055
.06
.065
.07
DEFLECTION (INCHES)
1000#
.005"
HEAD TRAVEL
UHT 4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LOAD
(LBS)
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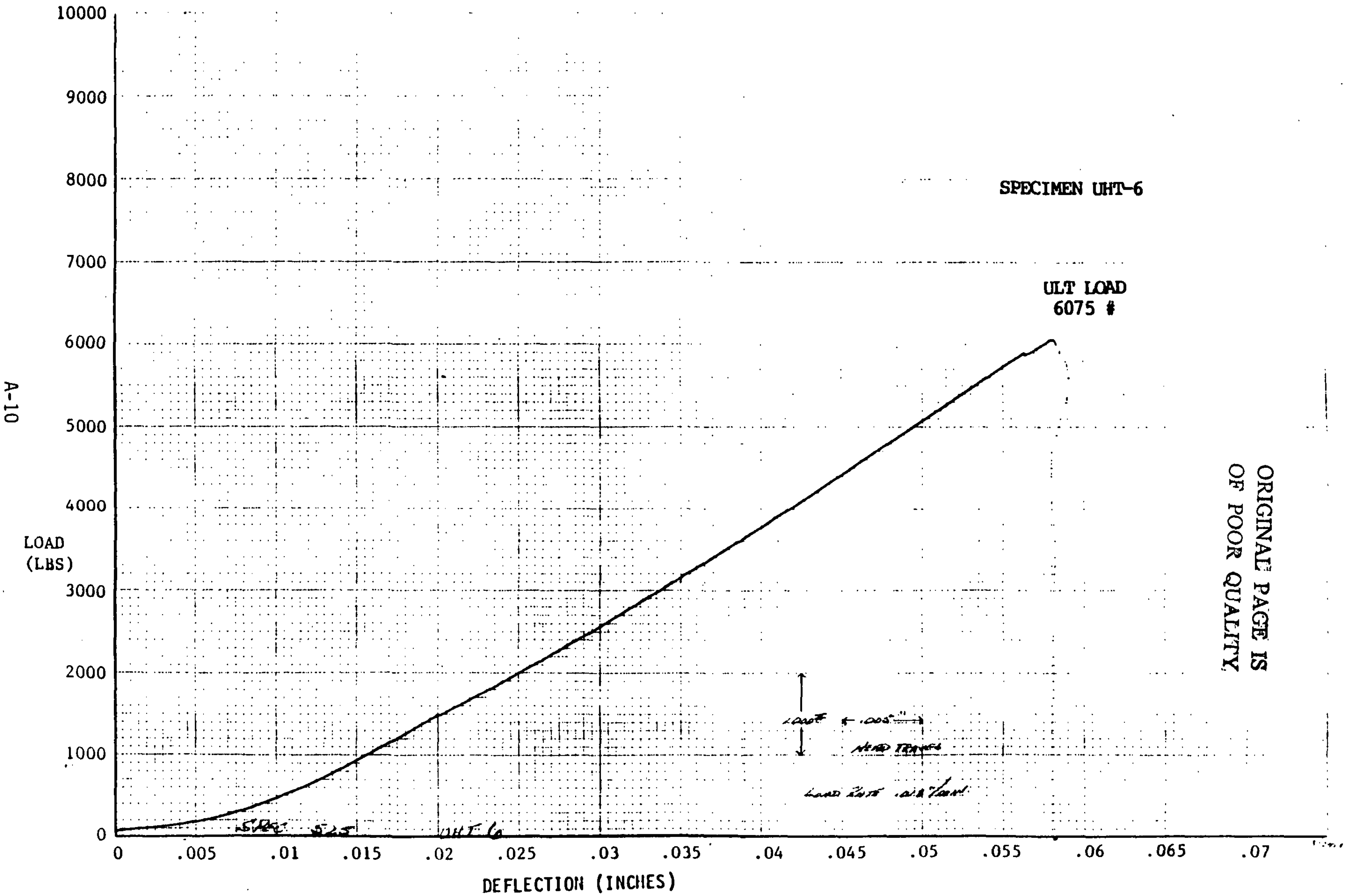
8000
7000
6000
5000
4000
3000
2000
1000
0
0
.005
.01
.015
.02
.025
.03
.035
.04
.045
.05
.055
.06
.065
.07
DEFLECTION (INCHES)
SPEC 525
UHT 5
HEAD TRAVEL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ULT LOAD
6075 #
LOAD
(LBS)
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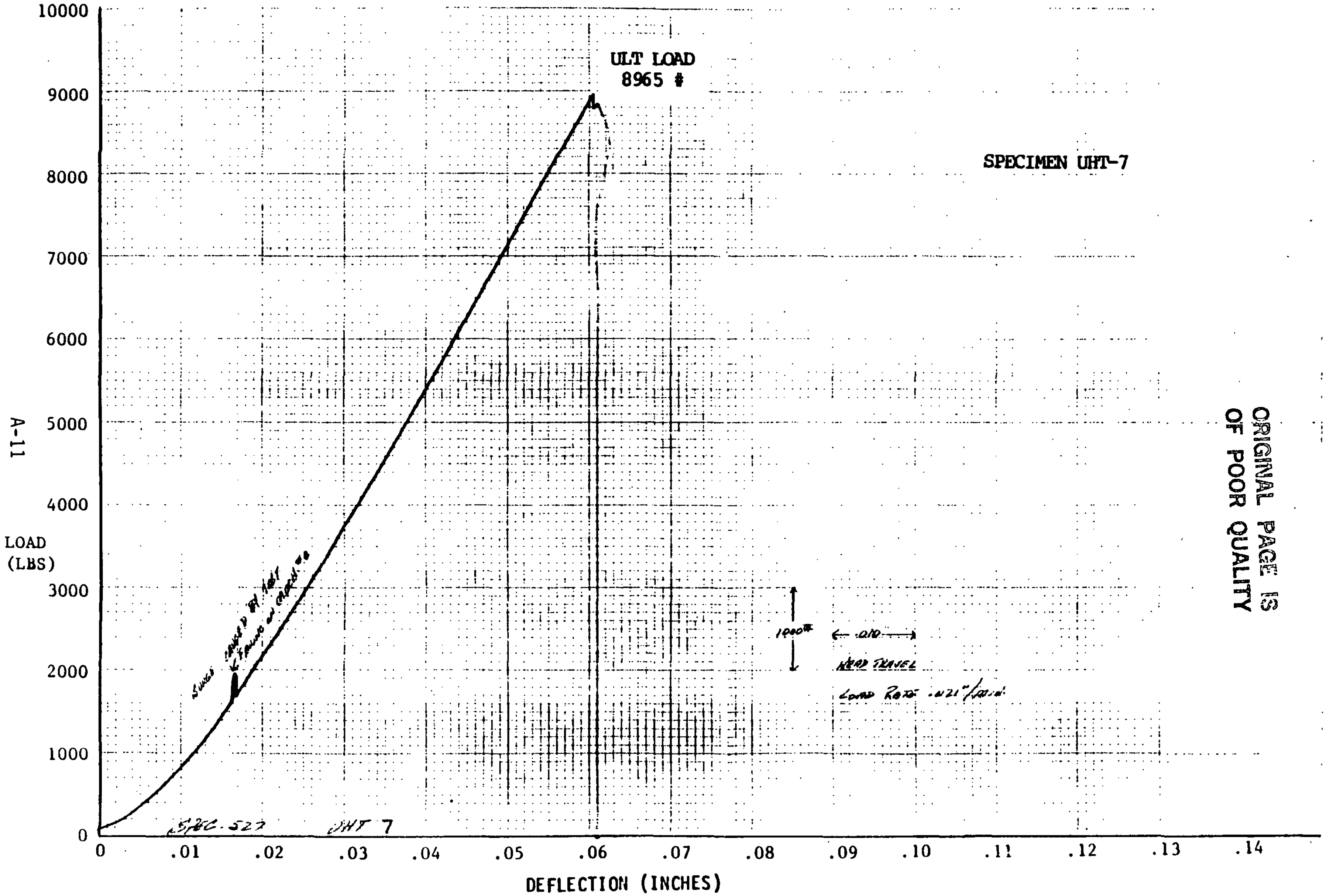
8000
7000
6000
5000
4000
3000
2000
1000
0
0
.005
.01
.015
.02
.025
.03
.035
.04
.045
.05
.055
.06
.065
.07
DEFLECTION (INCHES)



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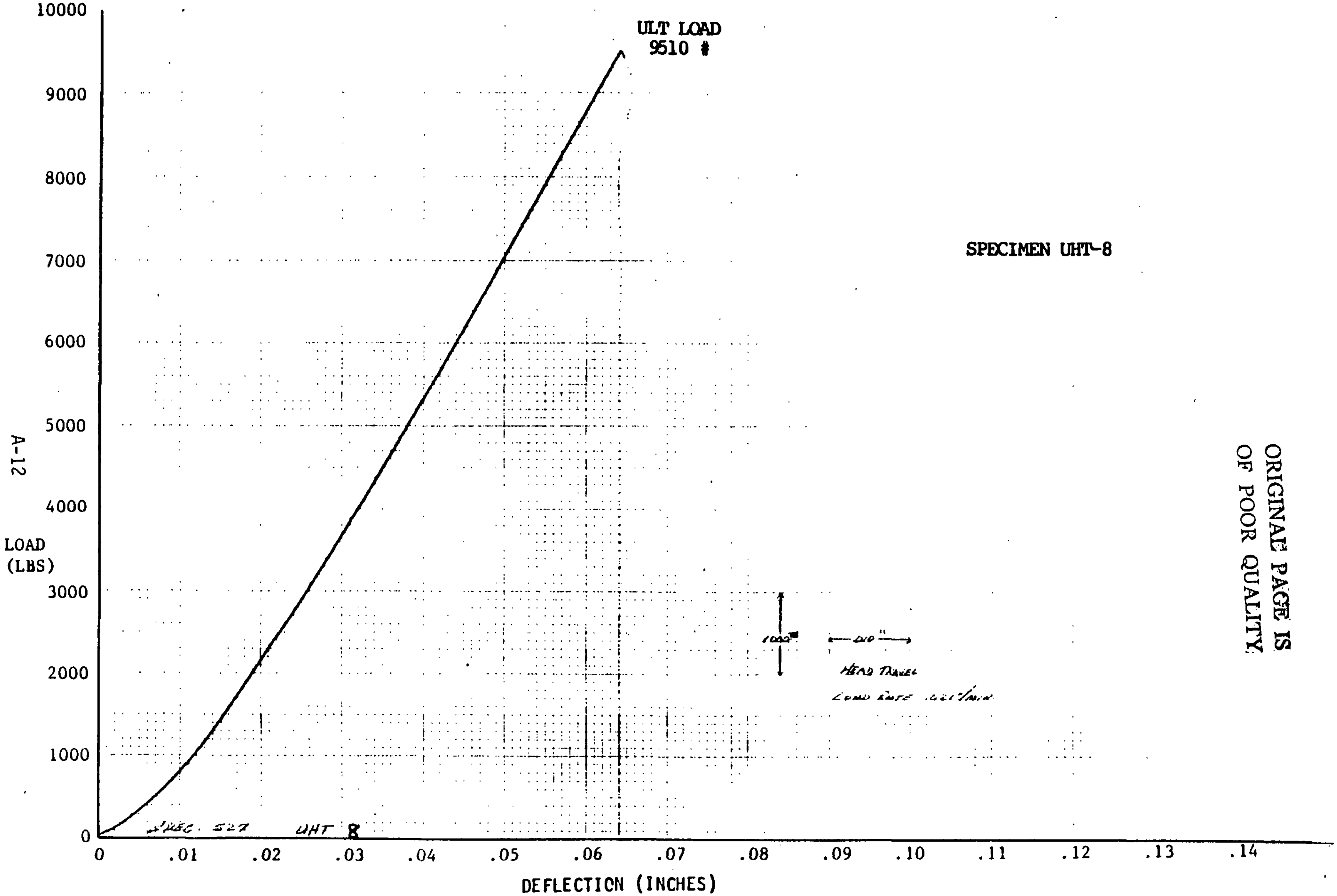
ULT LOAD
9510 #
SPECIMEN UHT-8
LOAD
(LBS)
DEFLECTION (INCHES)
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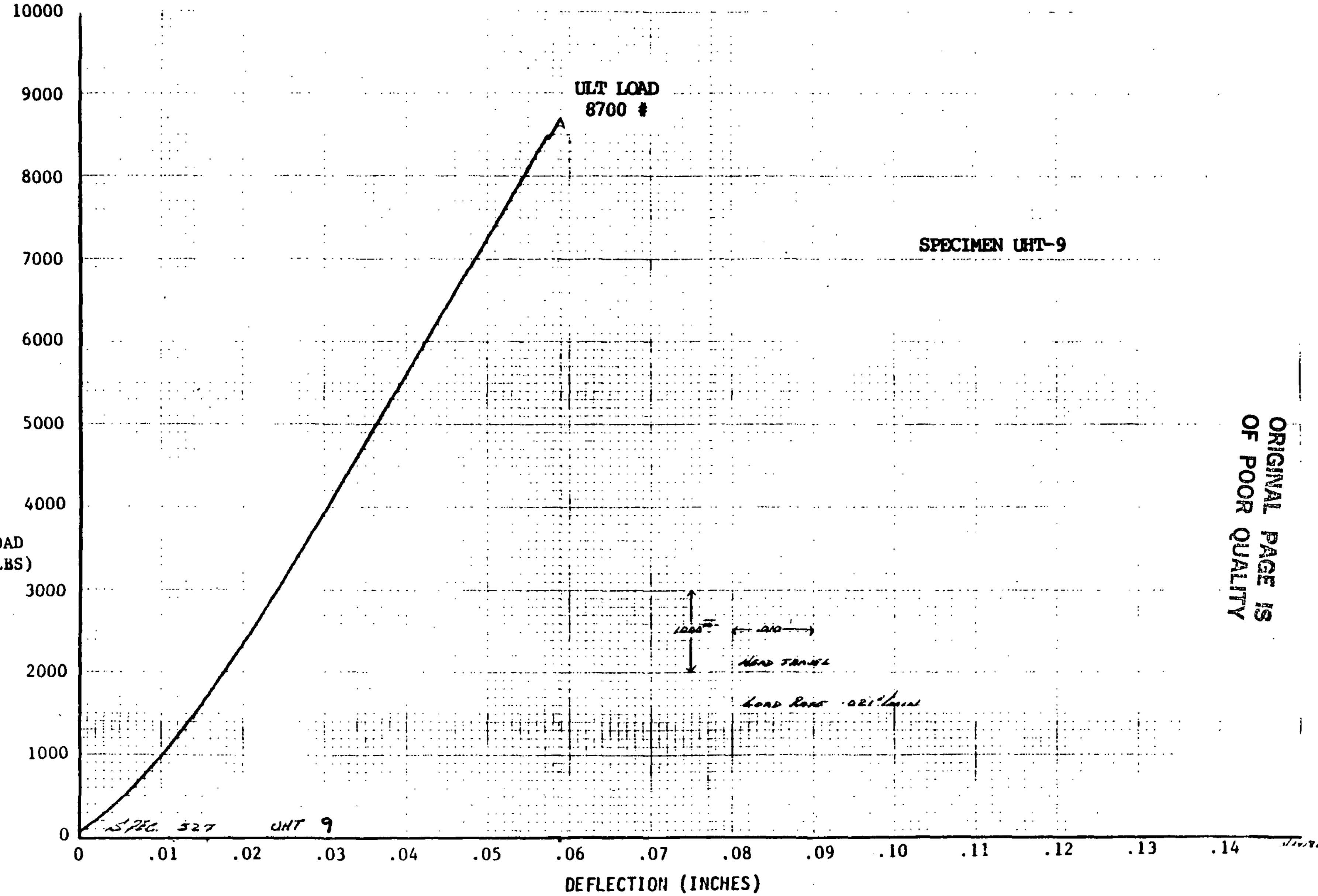
8000
7000
6000
5000
4000
3000
2000
1000
0
0
.01
.02
.03
.04
.05
.06
.07
.08
.09
.10
.11
.12
.13
.14


ULT LOAD
8700 #
SPECIMEN UHT-9
LOAD
(LBS)
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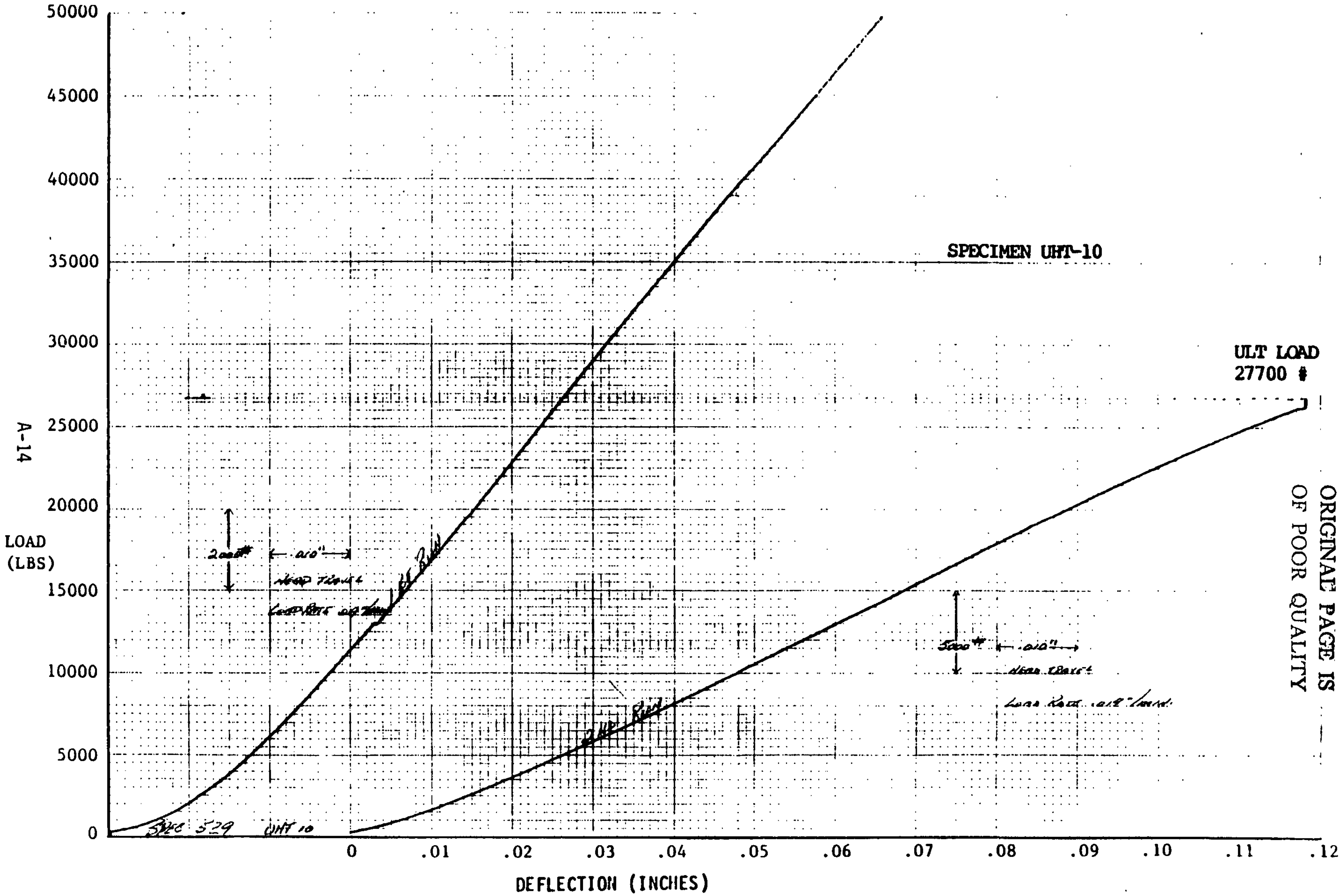
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
0
.01
.02
.03
.04
.05
.06
.07
.08
.09
.10
.11
.12
.13
.14
DEFLECTION (INCHES)
A
SPEC. 527
UHT 9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ULT LOAD
27700 #
LOAD
(LBS)
DEFLECTION (INCHES)
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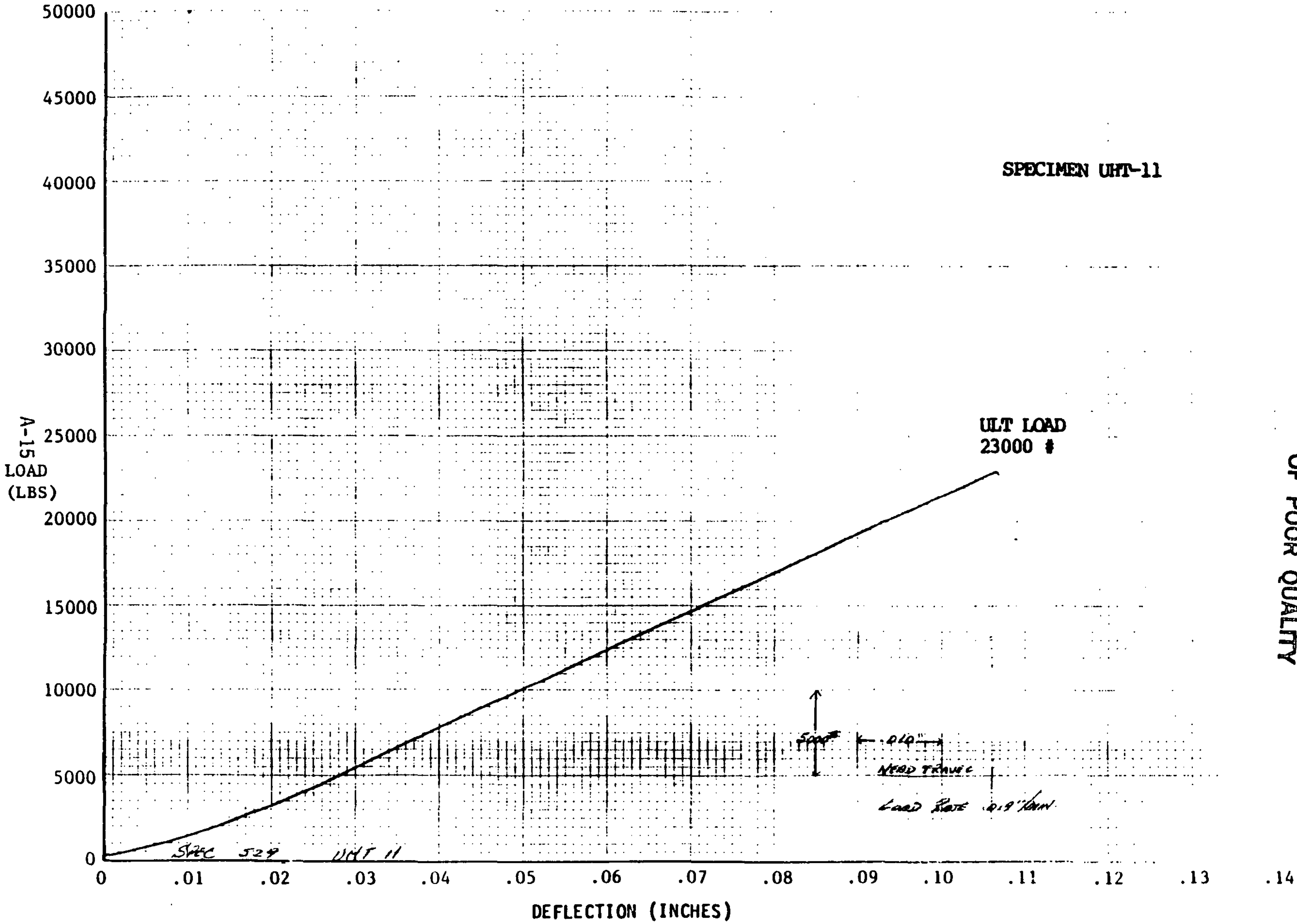
40000
35000
30000
25000
20000
15000
10000
5000
0
0
.01
.02
.03
.04
.05
.06
.07
.08
.09
.10
.11
.12

A-15



SPECIMEN UHT-11
ULT LOAD
23000 #
LOAD
(LBS)
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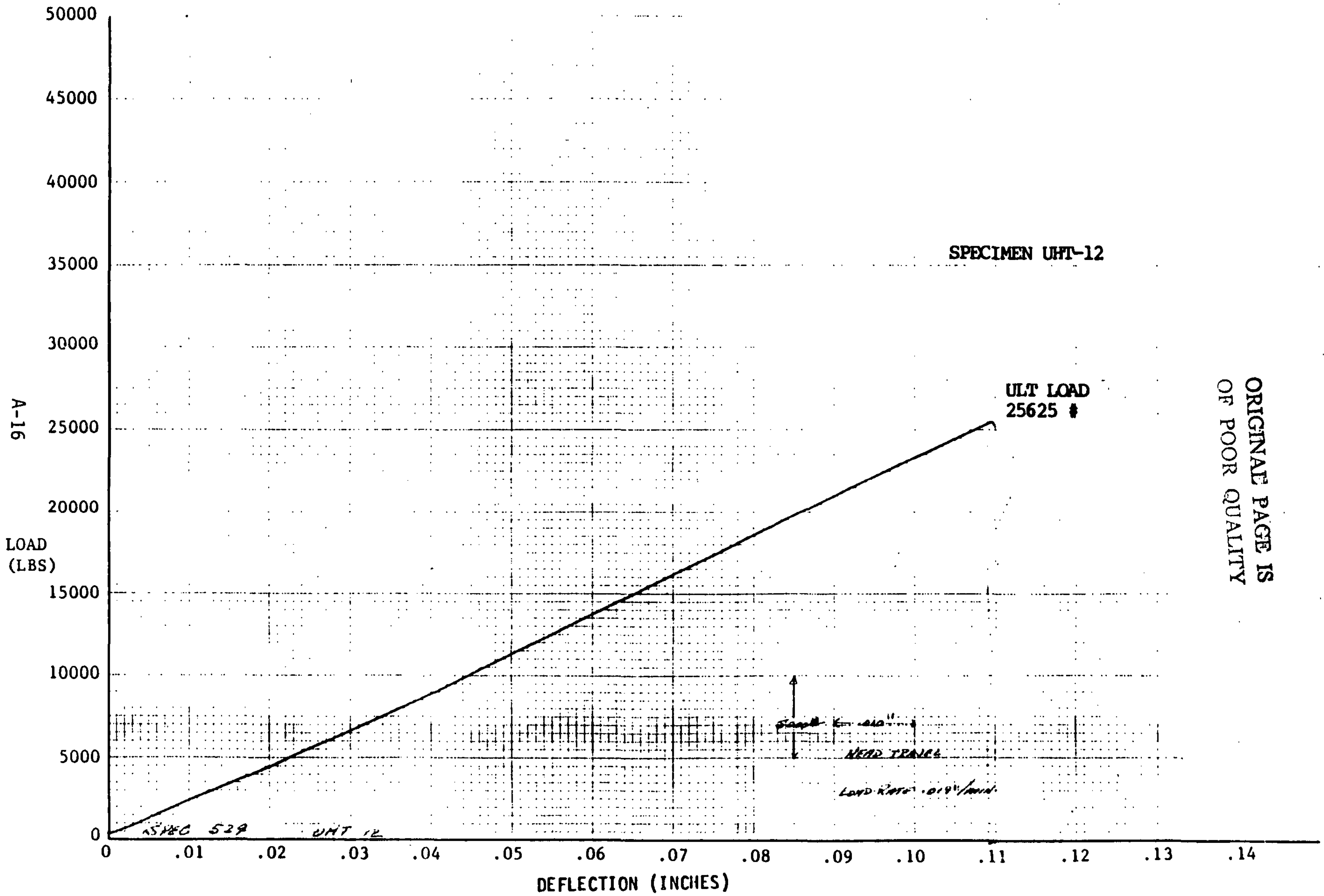
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
0
.01
.02
.03
.04
.05
.06
.07
.08
.09
.10
.11
.12
.13
.14
DEFLECTION (INCHES)
500#
.010"
HEAD TRAVEL
LOAD RATE .019"/MIN
SPEC 529
UHT 11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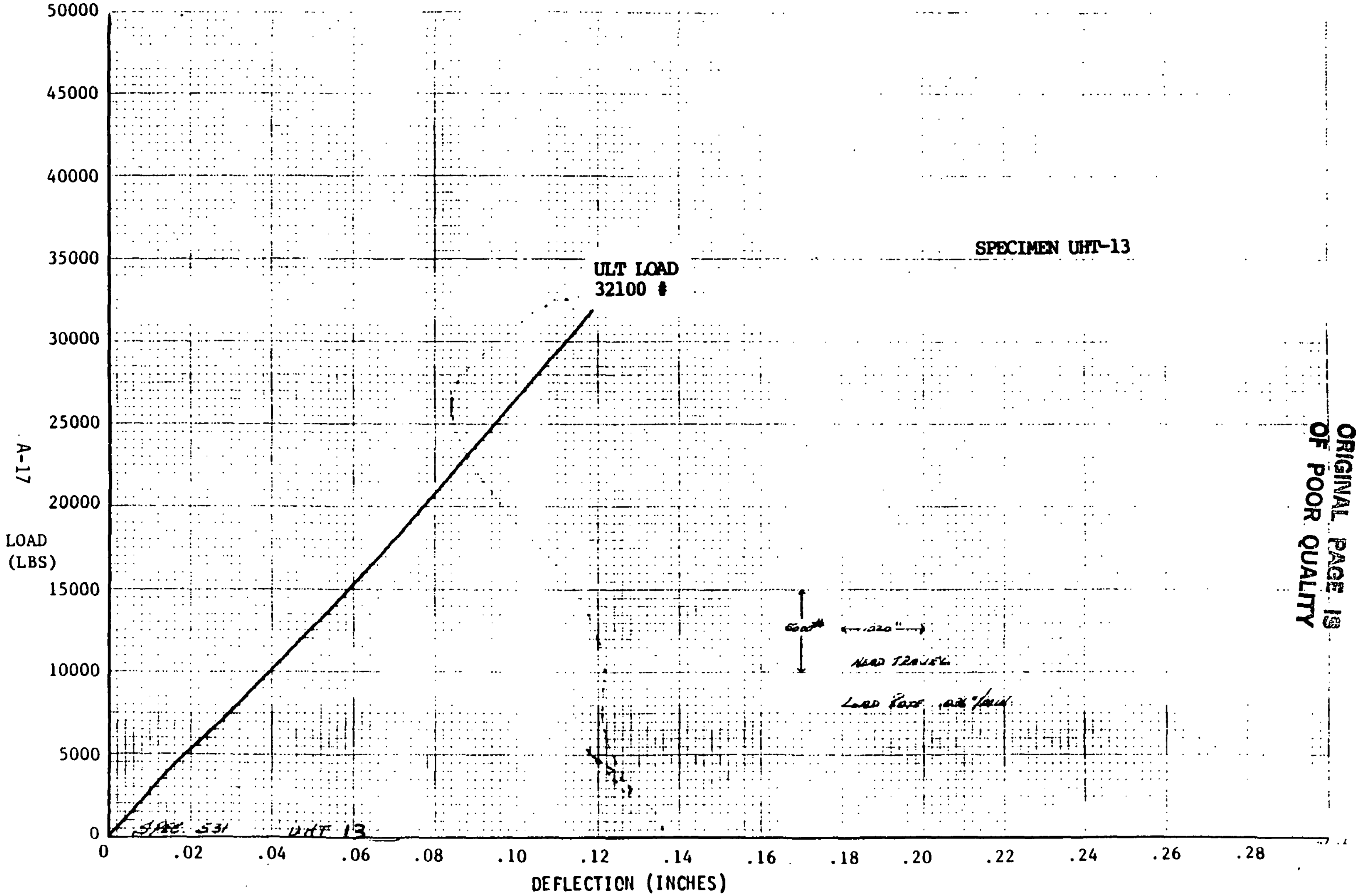
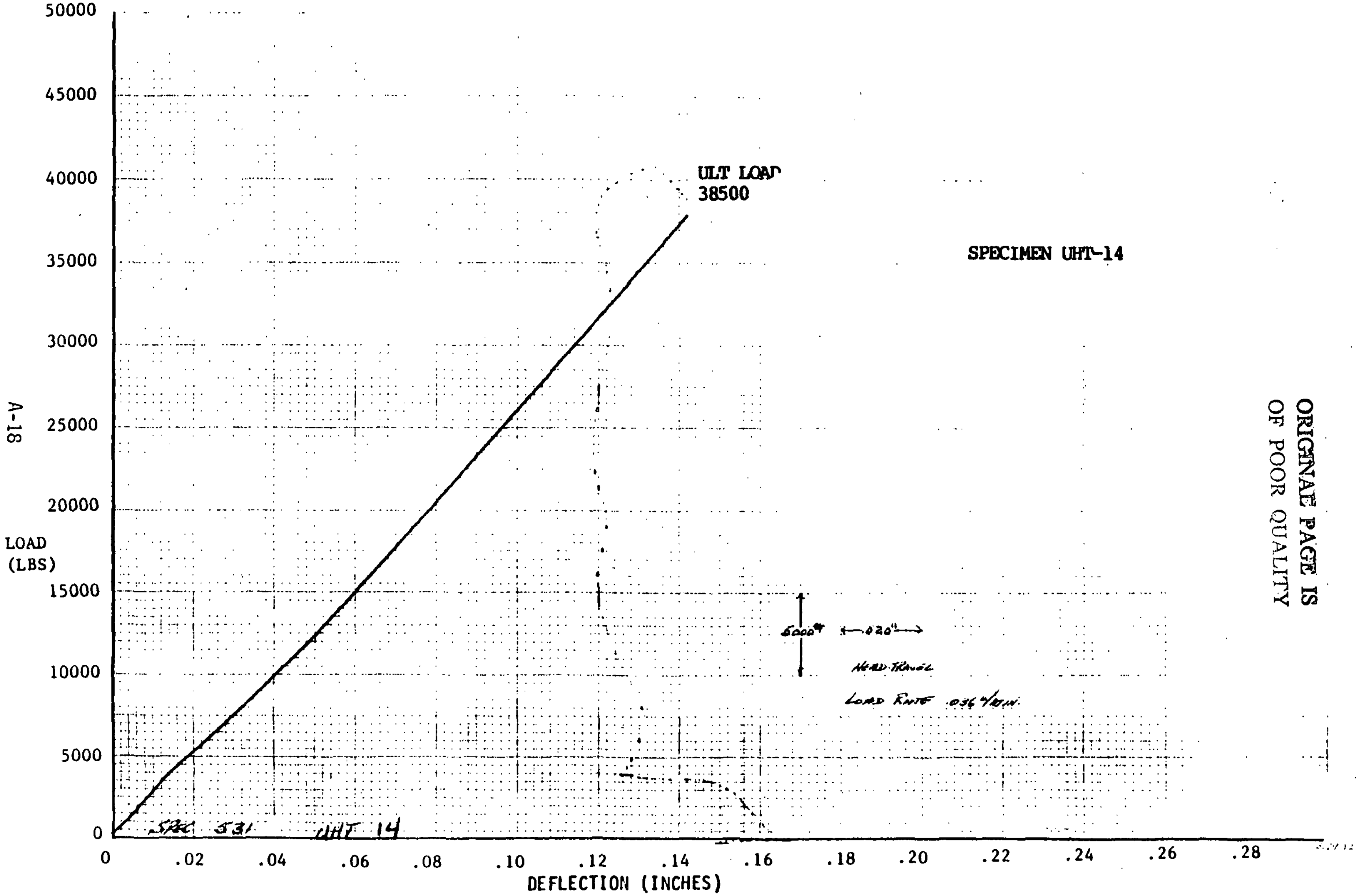
ULT LOAD
25625 #
LOAD
(LBS)
DEFLECTION (INCHES)


50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
LOAD
(LBS)
ULT LOAD
32100 #
SPECIMEN UHT-13
6000#
.020"
HEAD TRAVEL
0
.02
.04
.06
.08
.10
.12
.14
.16
.18
.20
.22
.24
.26
.28
DEFLECTION (INCHES)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38500
SPECIMEN UHT-14
LOAD
(LBS)
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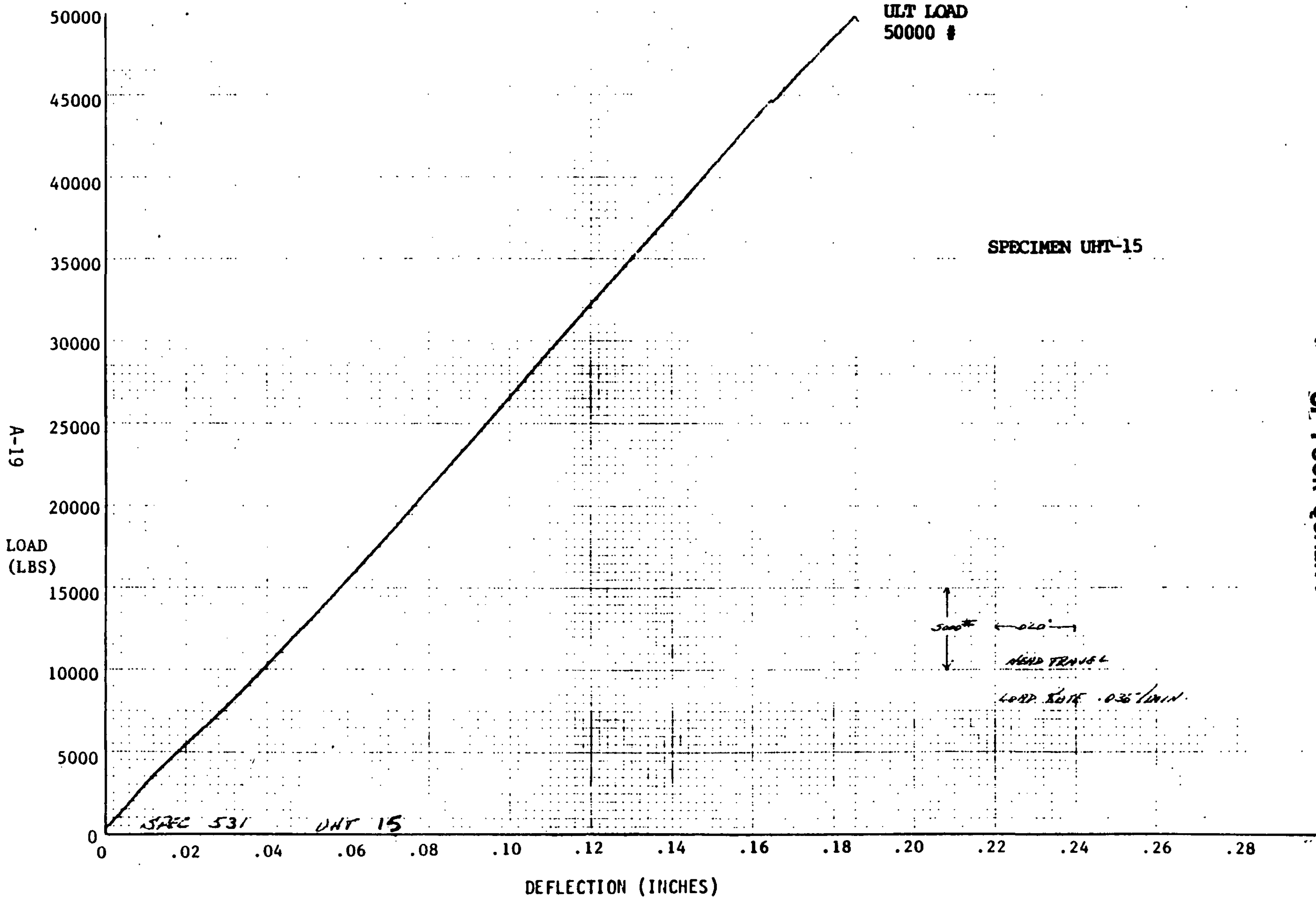
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
0
.02
.04
.06
.08
.10
.12
.14
.16
.18
.20
.22
.24
.26
.28
DEFLECTION (INCHES)
SPEC 531
UHT 14
5000#
.020"
HEAD TRAVEL
LOAD RATE .036"/MIN.



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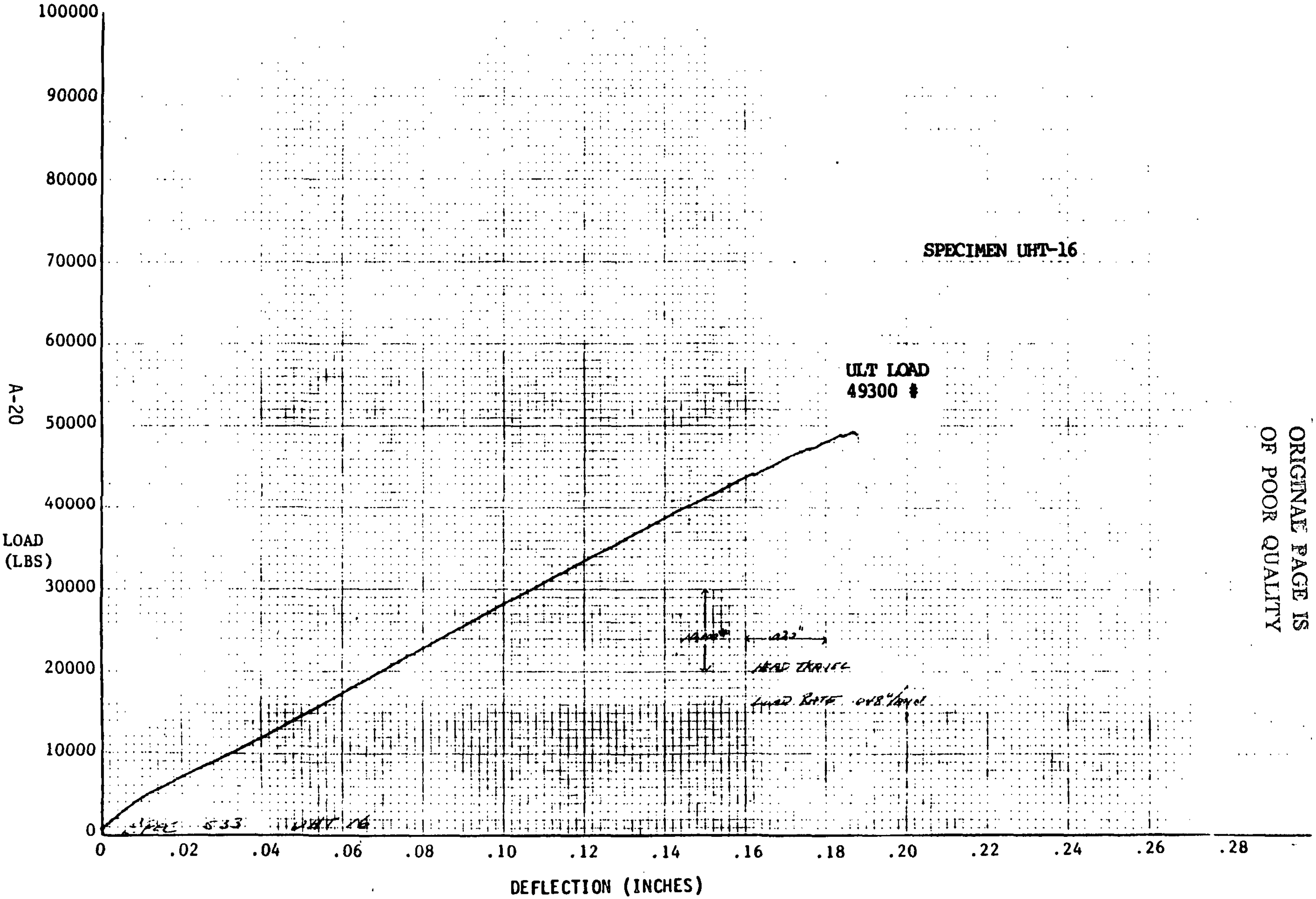
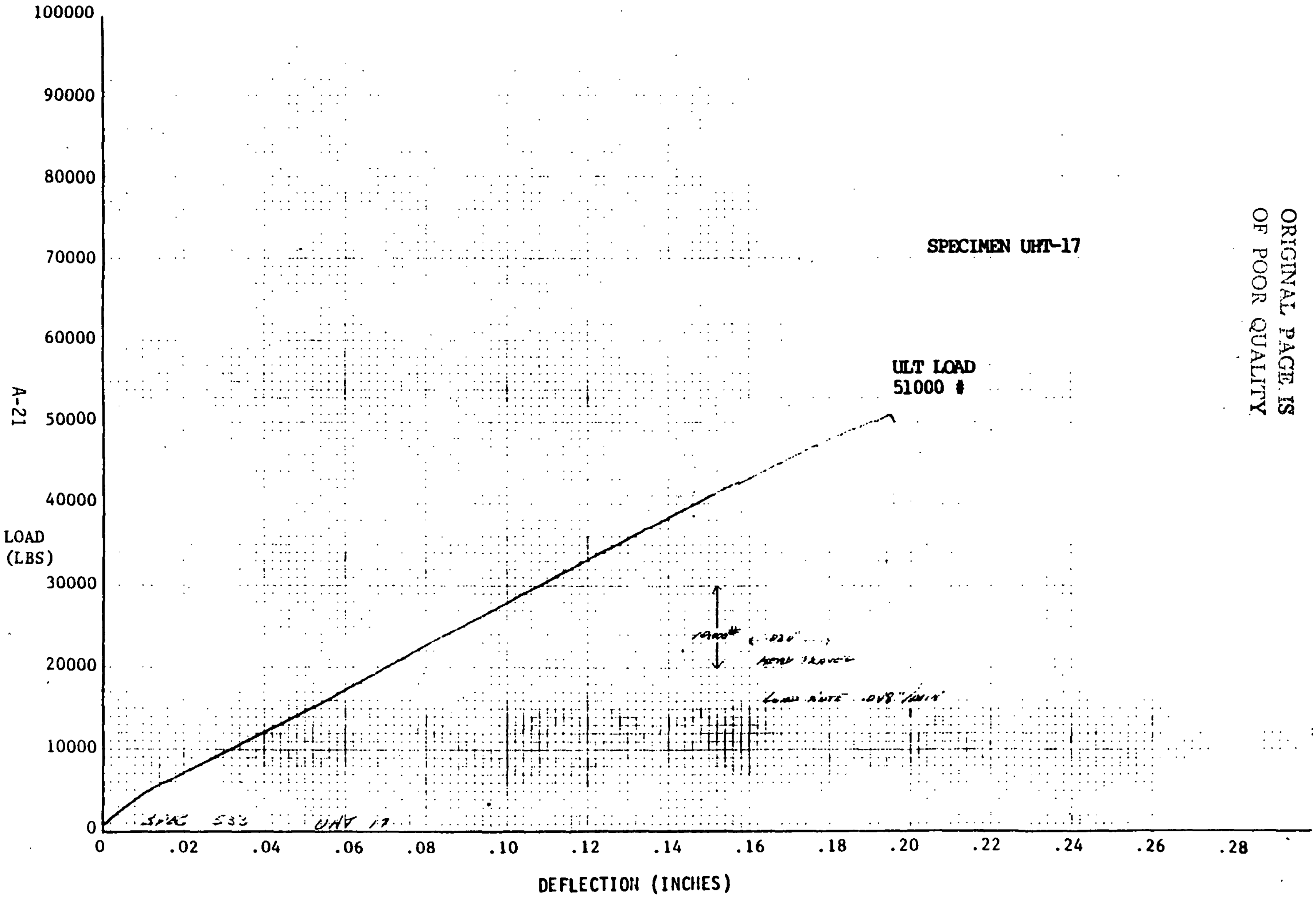
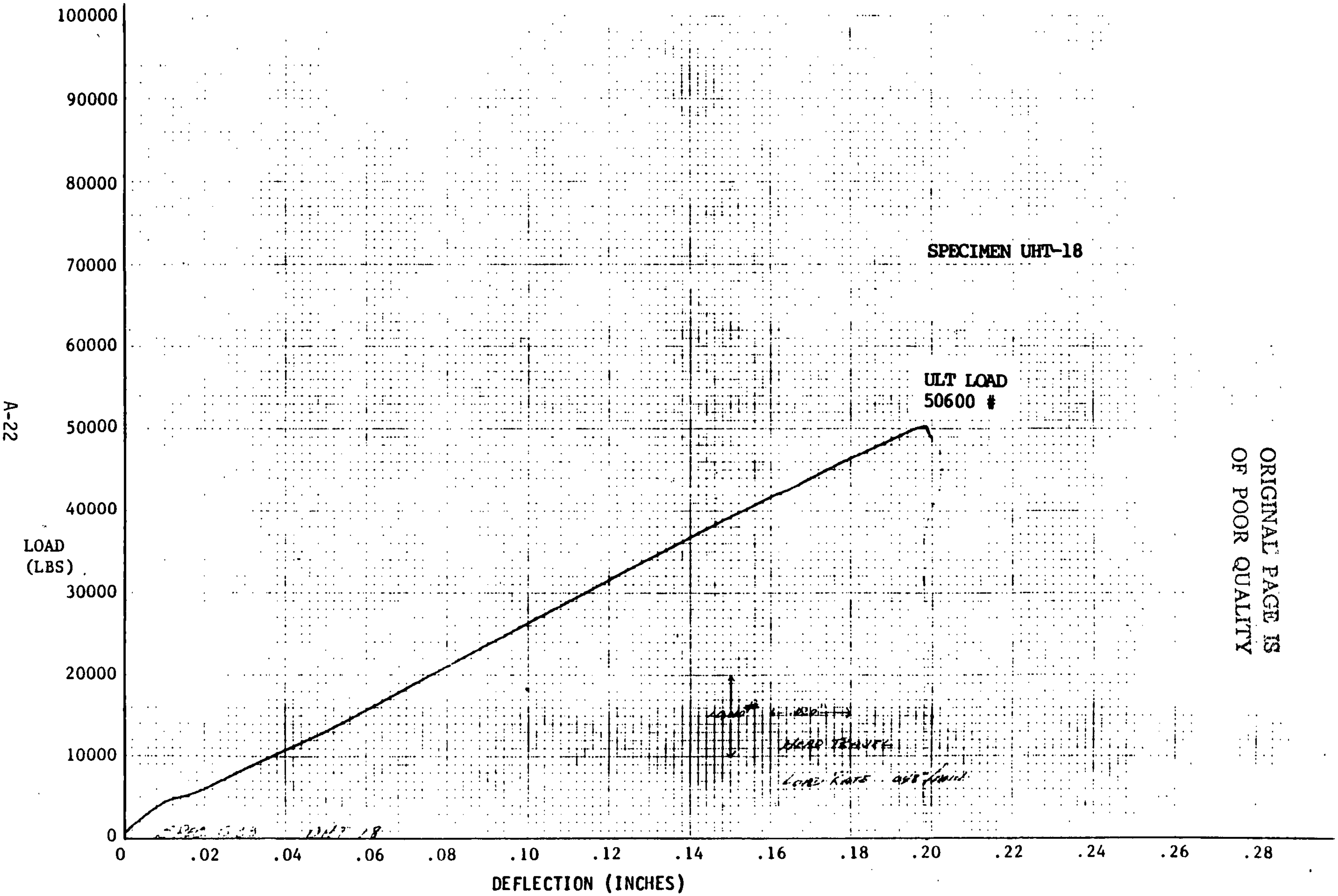
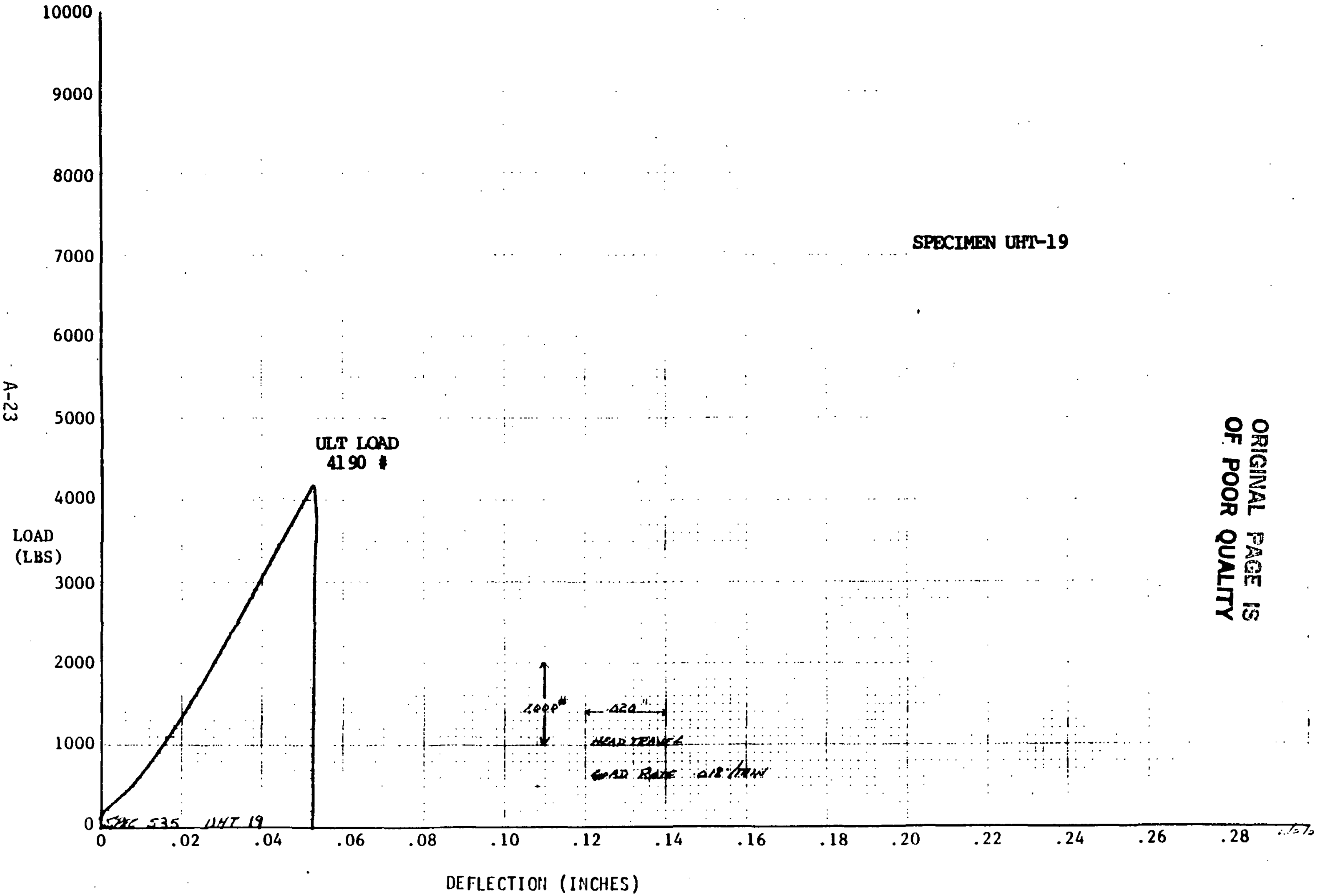
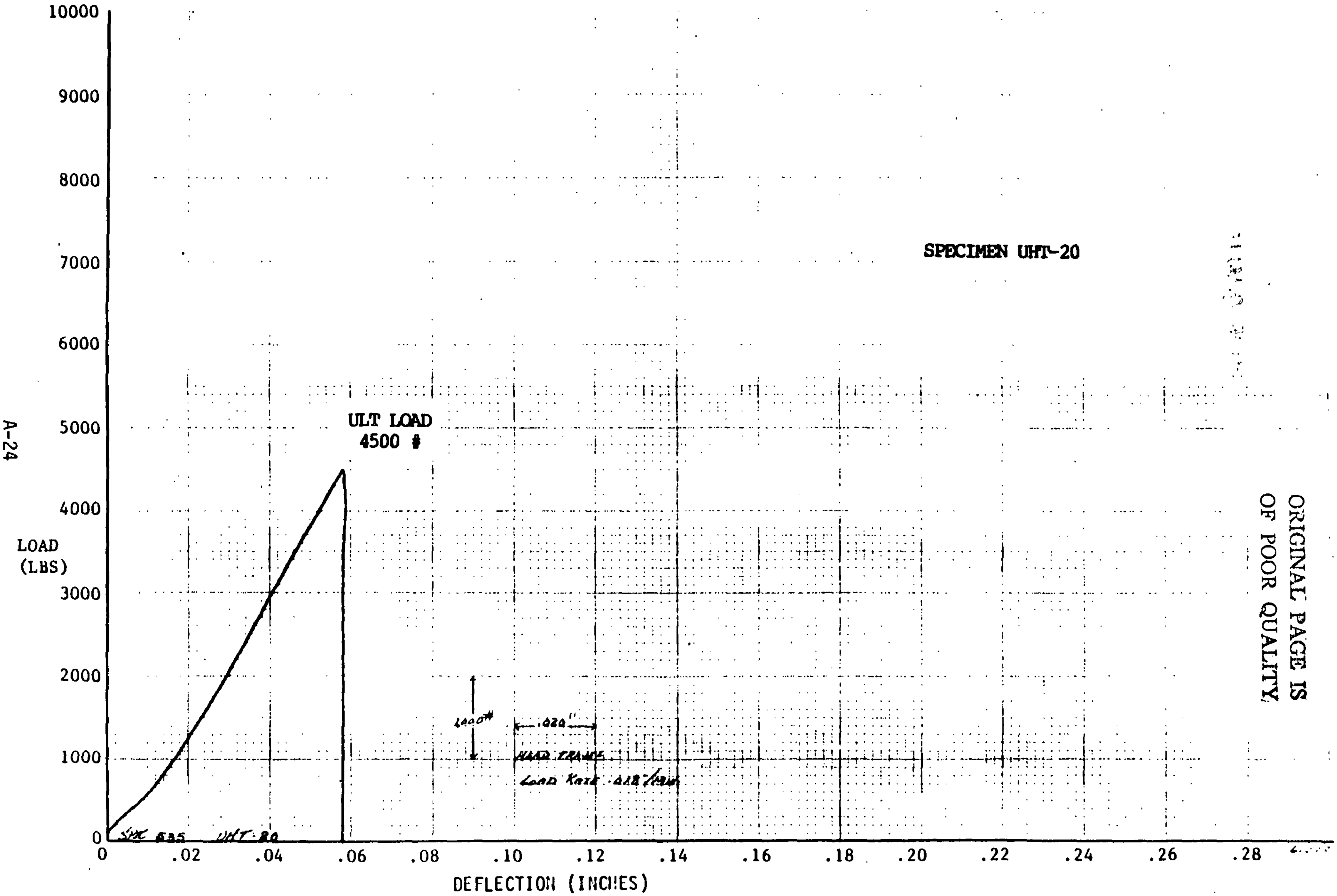
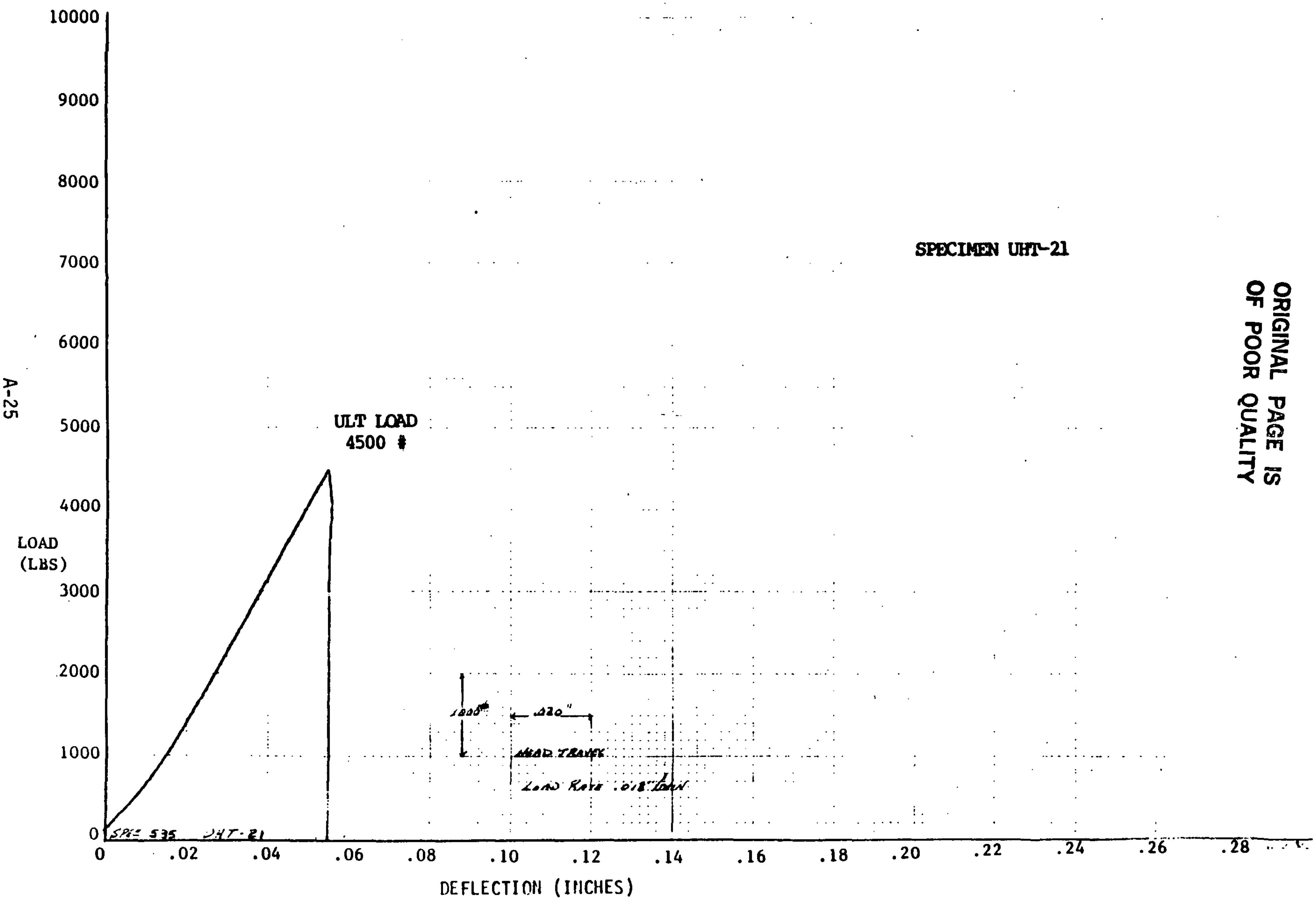

SPECIMEN UHT-16
ULT LOAD
49300 #
LOAD (LBS)
DEFLECTION (INCHES)
0
10000
20000
30000
40000
50000
60000
70000
80000
90000
100000
.02
.04
.06
.08
.10
.12
.14
.16
.18
.20
.22
.24
.26
.28

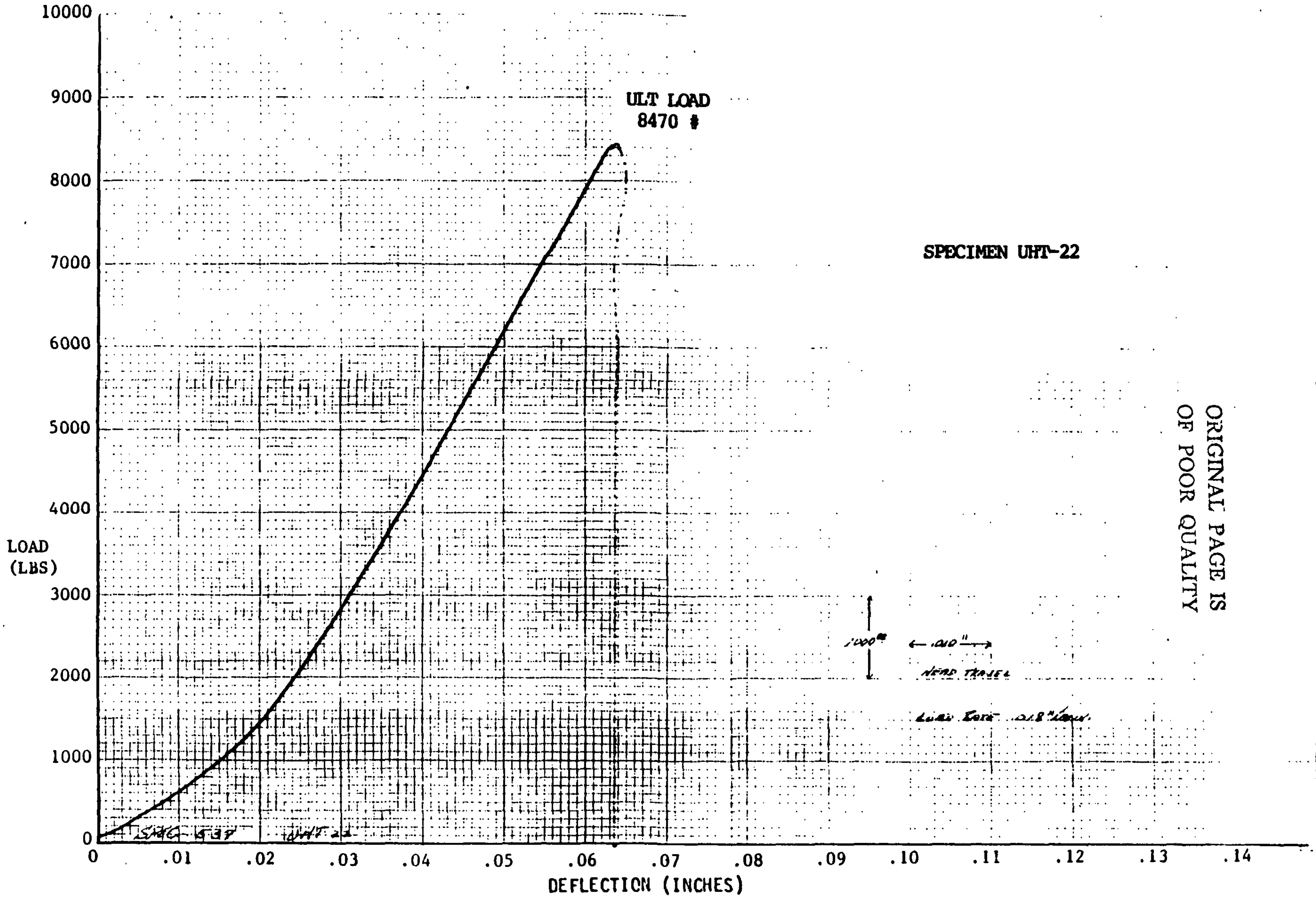

SPECIMEN UHT-17
ULT LOAD
51000 #
LOAD
(LBS)
100000
90000
80000
70000
60000
50000
40000
30000
20000
10000
0
0
.02
.04
.06
.08
.10
.12
.14
.16
.18
.20
.22
.24
.26
.28
DEFLECTION (INCHES)


SPECIMEN UHT-18
ULT LOAD
50600 #
LOAD (LBS)
100000
90000
80000
70000
60000
50000
40000
30000
20000
10000
0
0
.02
.04
.06
.08
.10
.12
.14
.16
.18
.20
.22
.24
.26
.28
DEFLECTION (INCHES)

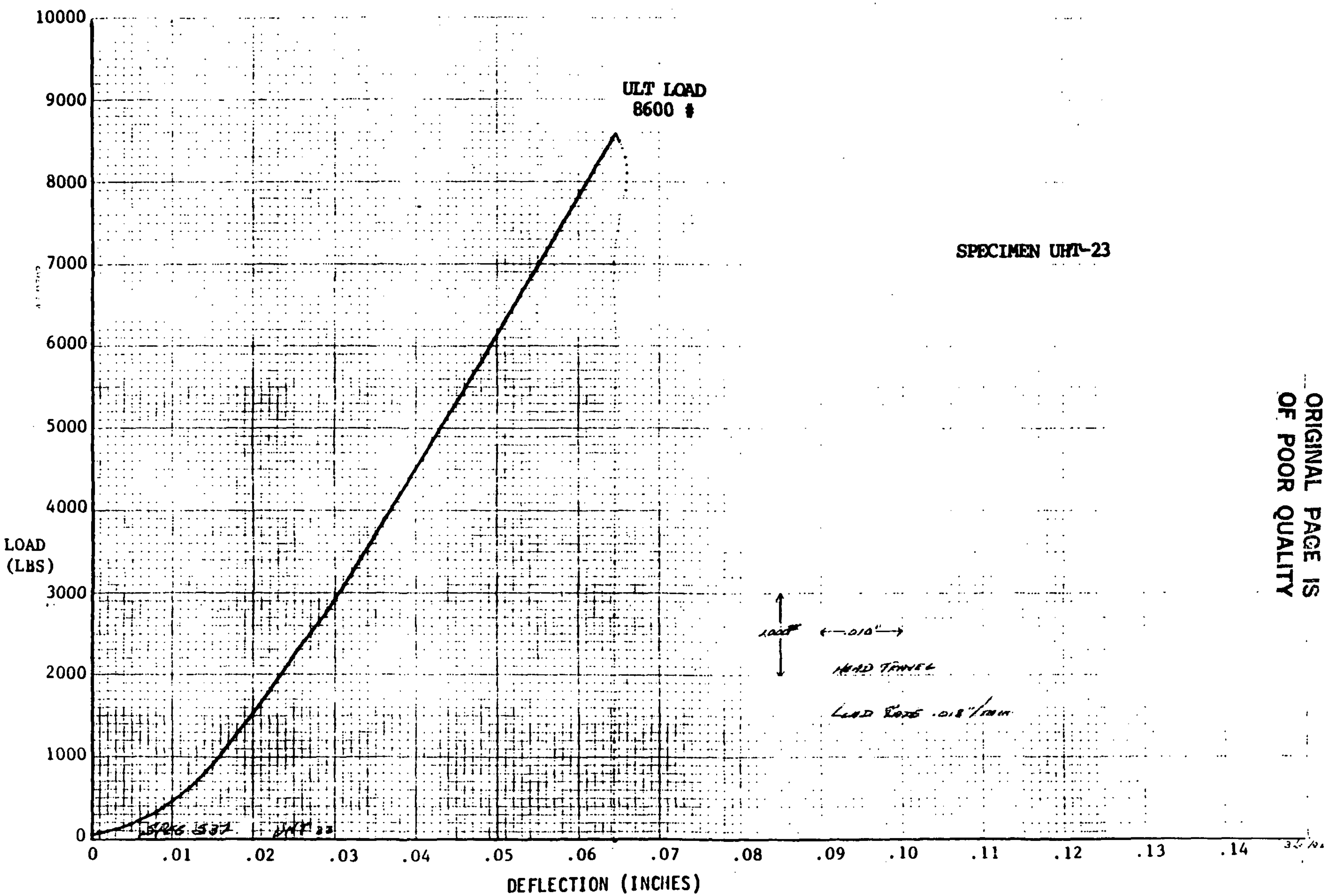

SPECIMEN UHT-19
ULT LOAD
4190 #
LOAD
(LBS)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
0
.02
.04
.06
.08
.10
.12
.14
.16
.18
.20
.22
.24
.26
.28
DEFLECTION (INCHES)
2000#
.020"
HEAD TRAVEL

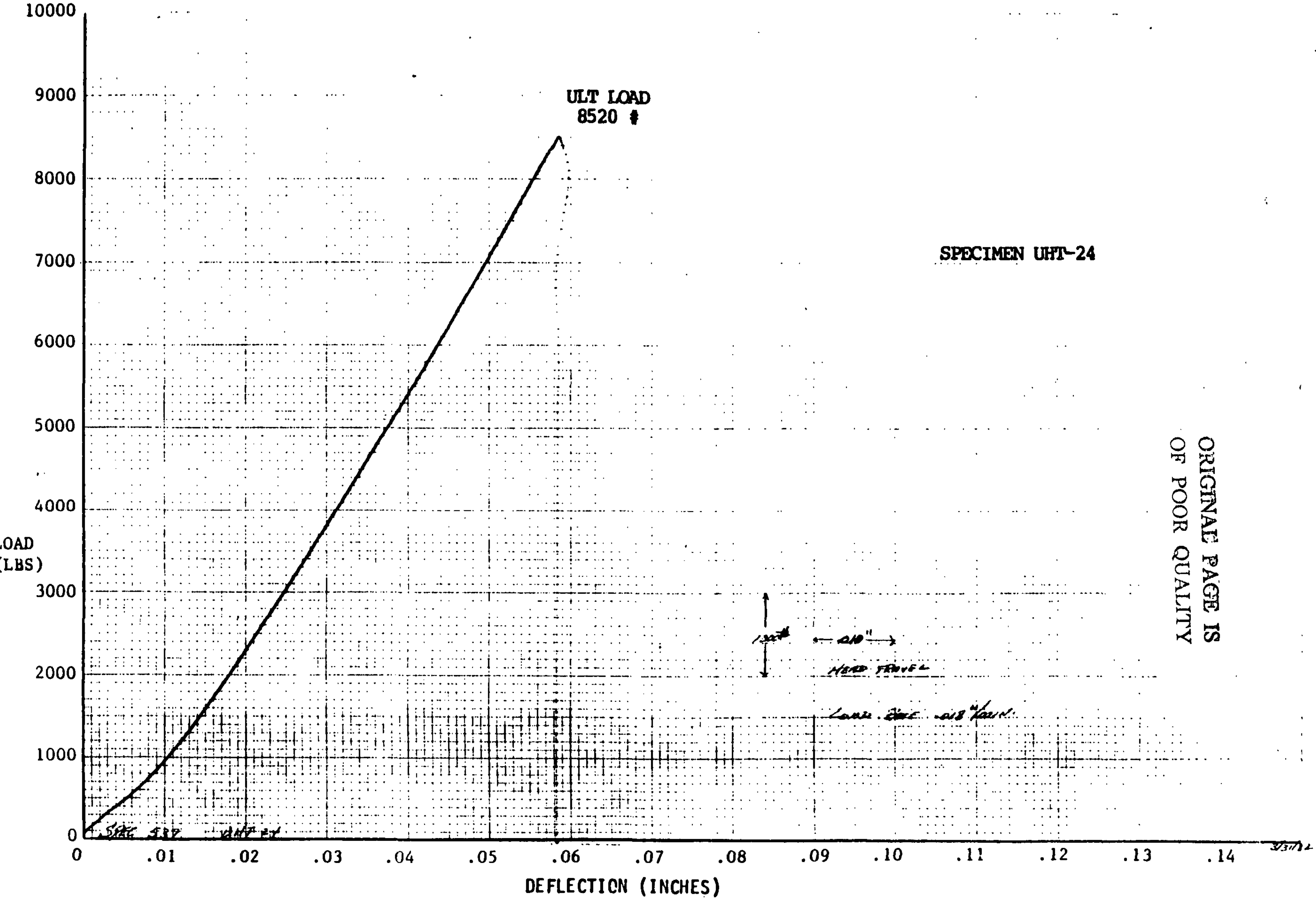

SPECIMEN UHT-20
ULT LOAD
4500 #
LOAD
(LBS)
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
0
.02
.04
.06
.08
.10
.12
.14
.16
.18
.20
.22
.24
.26
.28
DEFLECTION (INCHES)

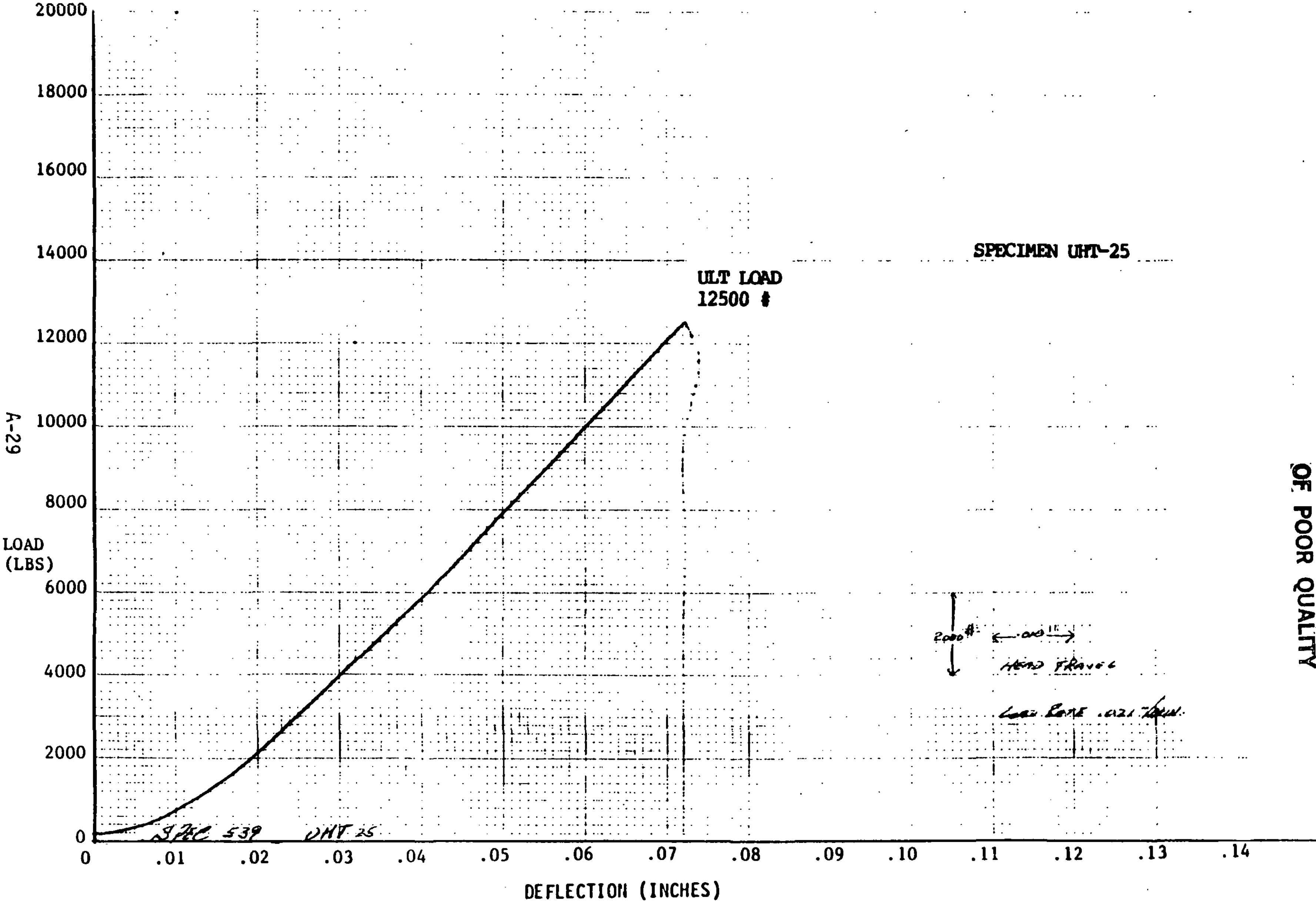

SPECIMEN UHT-21
ULT LOAD
4500 #
LOAD
(LBS)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
0
.02
.04
.06
.08
.10
.12
.14
.16
.18
.20
.22
.24
.26
.28
DEFLECTION (INCHES)



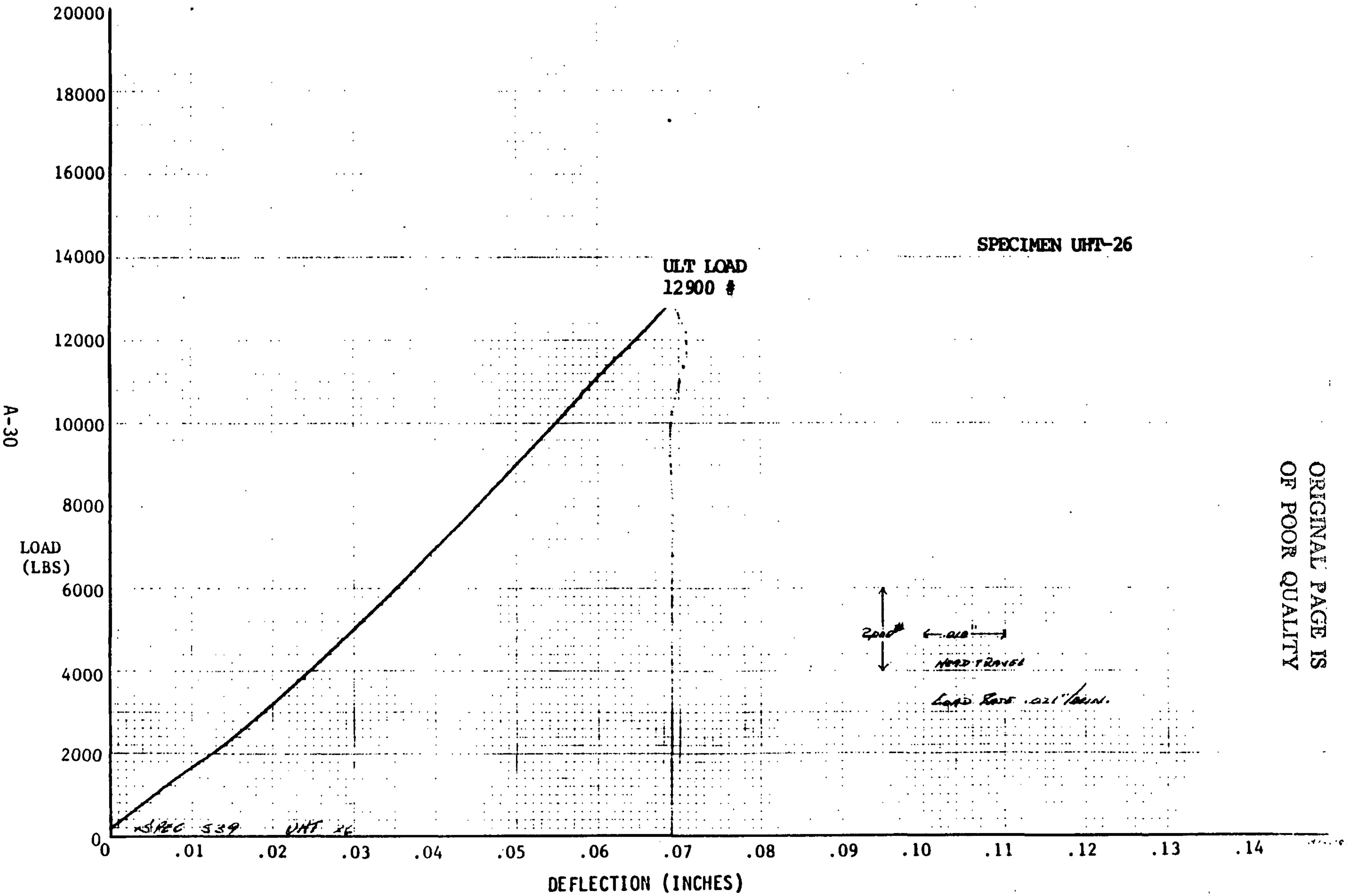
SPECIMEN UHT-22
ULT LOAD
8470 #
LOAD
(LBS)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
.01
.02
.03
.04
.05
.06
.07
.08
.09
.10
.11
.12
.13
.14
DEFLECTION (INCHES)

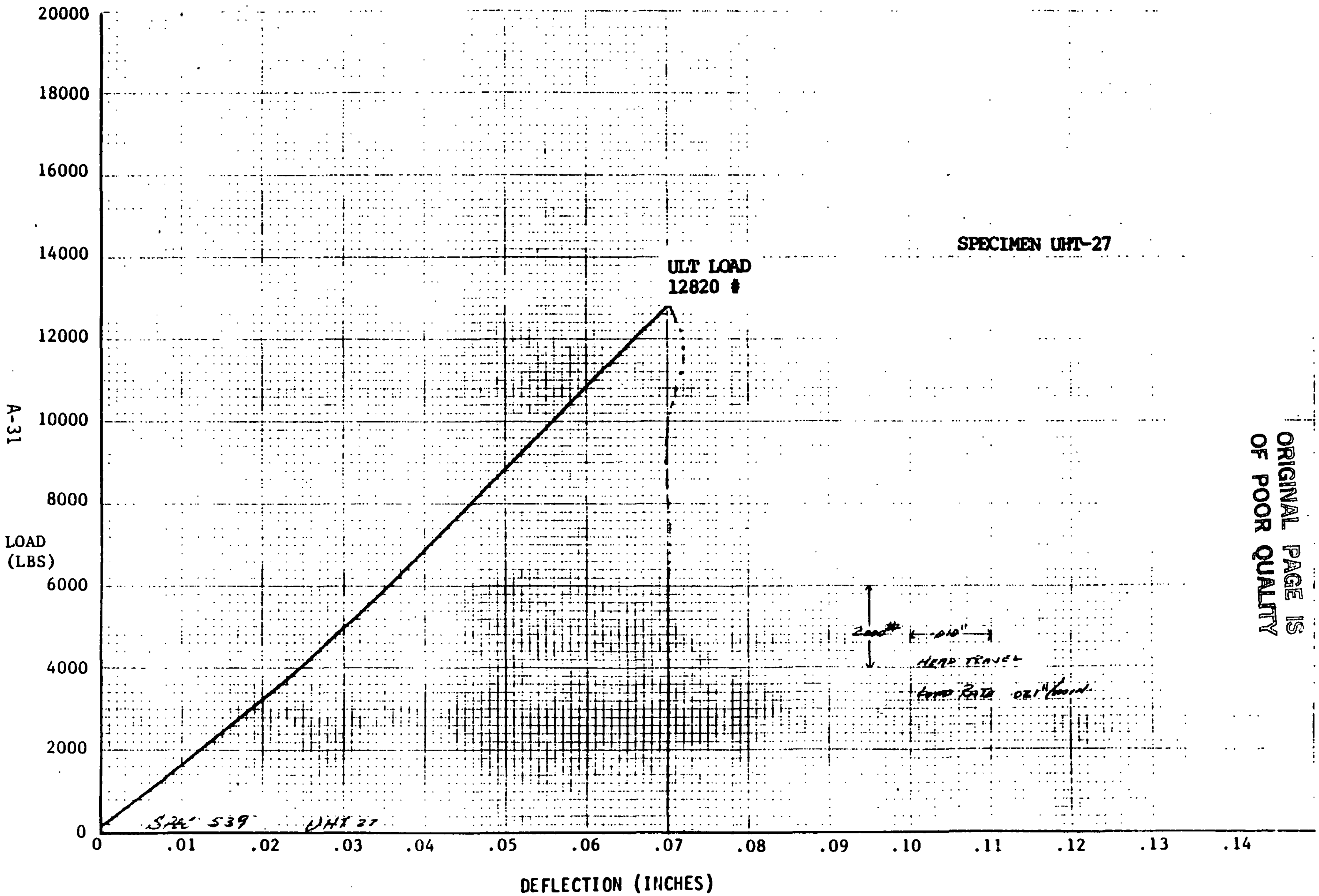

ULT LOAD
8600 #
SPECIMEN UHT-23
LOAD
(LBS)
DEFLECTION (INCHES)
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
.01
.02
.03
.04
.05
.06
.07
.08
.09
.10
.11
.12
.13
.14
1000#
.010"
HEAD TRAVEL

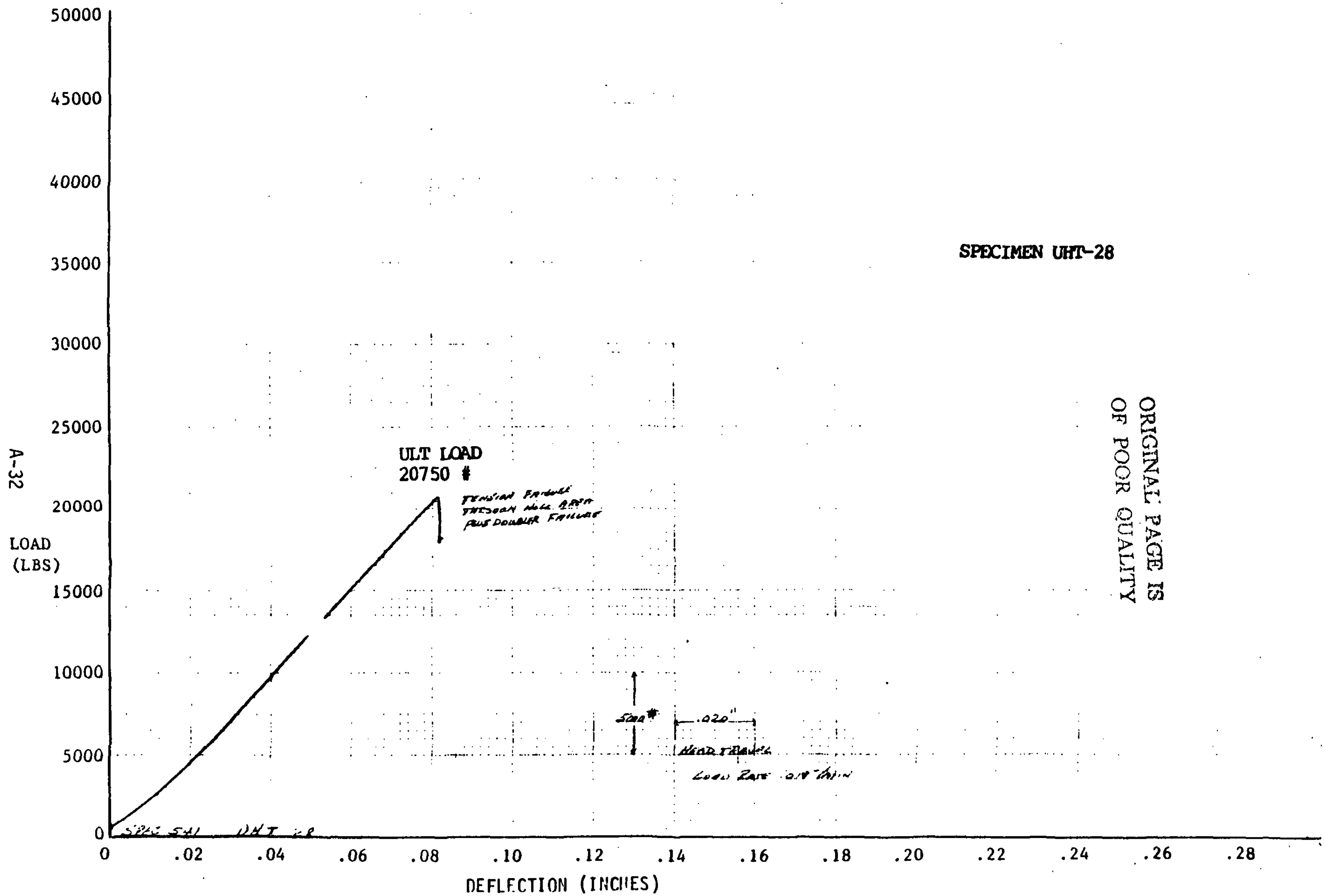

ULT LOAD
8520 #
SPECIMEN UHT-24
LOAD
(LBS)
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
0
.01
.02
.03
.04
.05
.06
.07
.08
.09
.10
.11
.12
.13
.14
DEFLECTION (INCHES)
HEAD TRAVEL

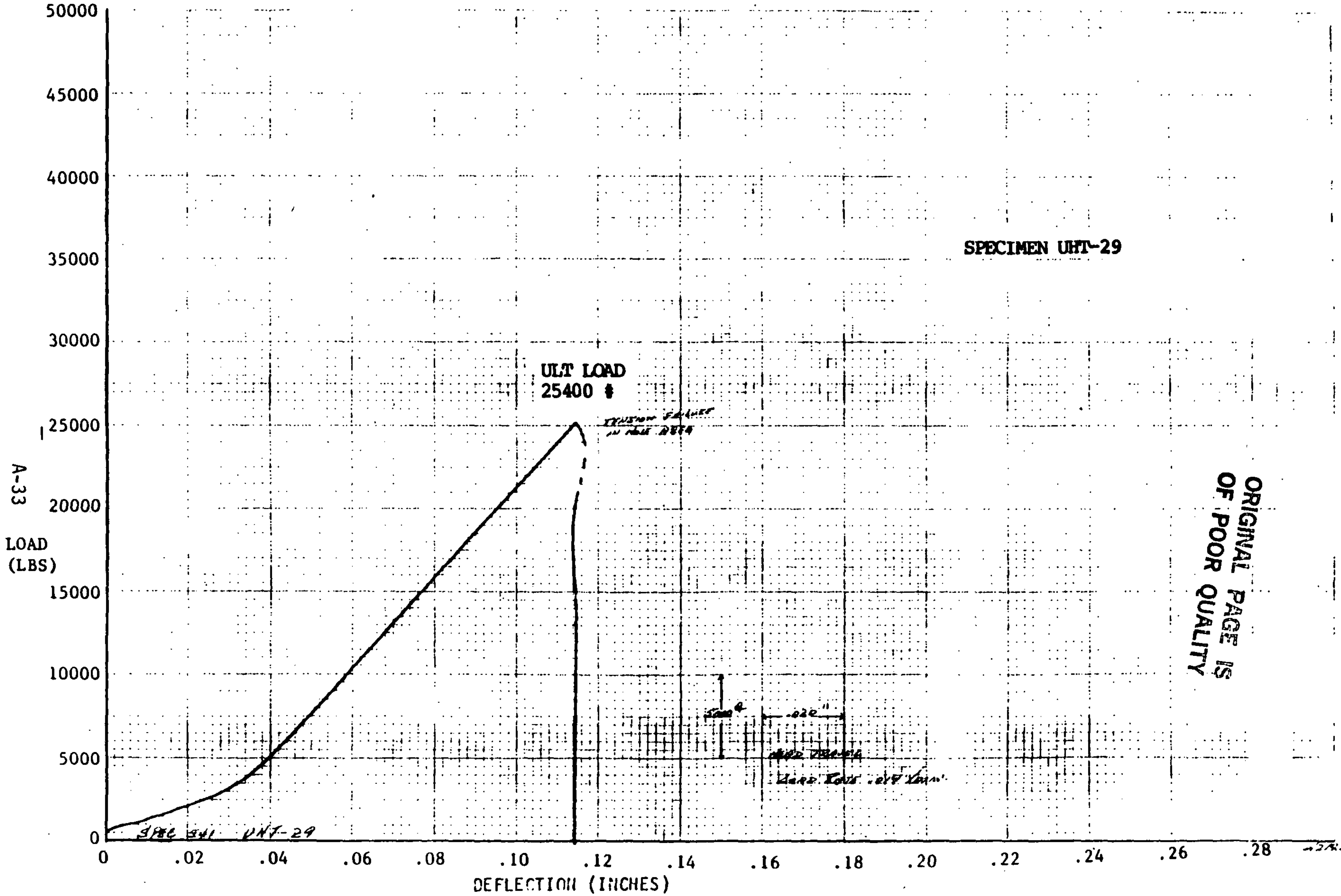


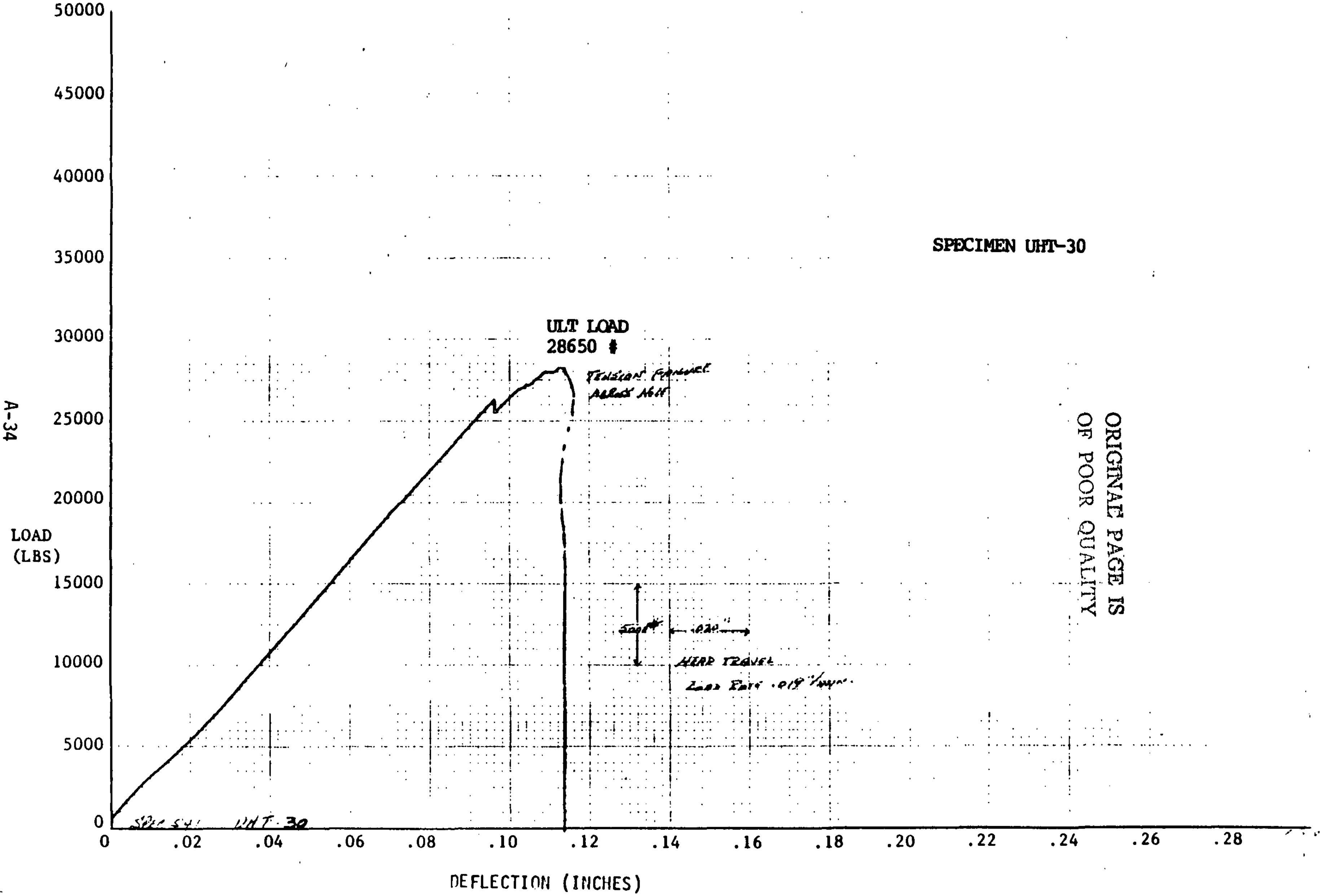
SPECIMEN UHT-25
ULT LOAD
12500 #
LOAD
(LBS)
DEFLECTION (INCHES)
0
2000
4000
6000
8000
10000
12000
14000
16000
18000
20000
.01
.02
.03
.04
.05
.06
.07
.08
.09
.10
.11
.12
.13
.14
SPEC 539
UHT 25
2000#
HEAD TRAVEL

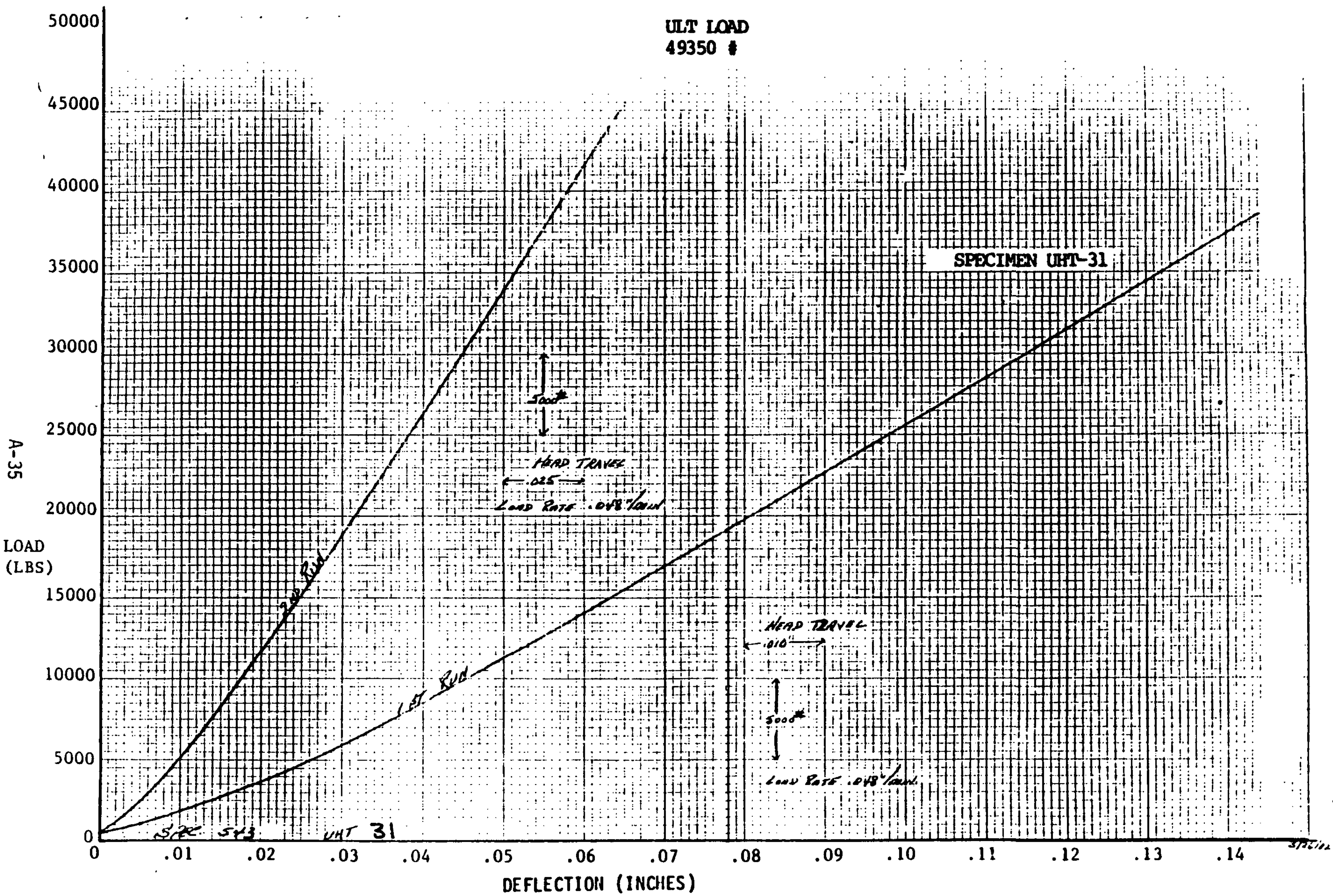

SPECIMEN UHT-26
ULT LOAD
12900 #
LOAD
(LBS)
DEFLECTION (INCHES)
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
0
.01
.02
.03
.04
.05
.06
.07
.08
.09
.10
.11
.12
.13
.14
2000#
.010"
HEAD TRAVEL
LOAD RATE .021"/MIN.
SPEC 539
UHT 26

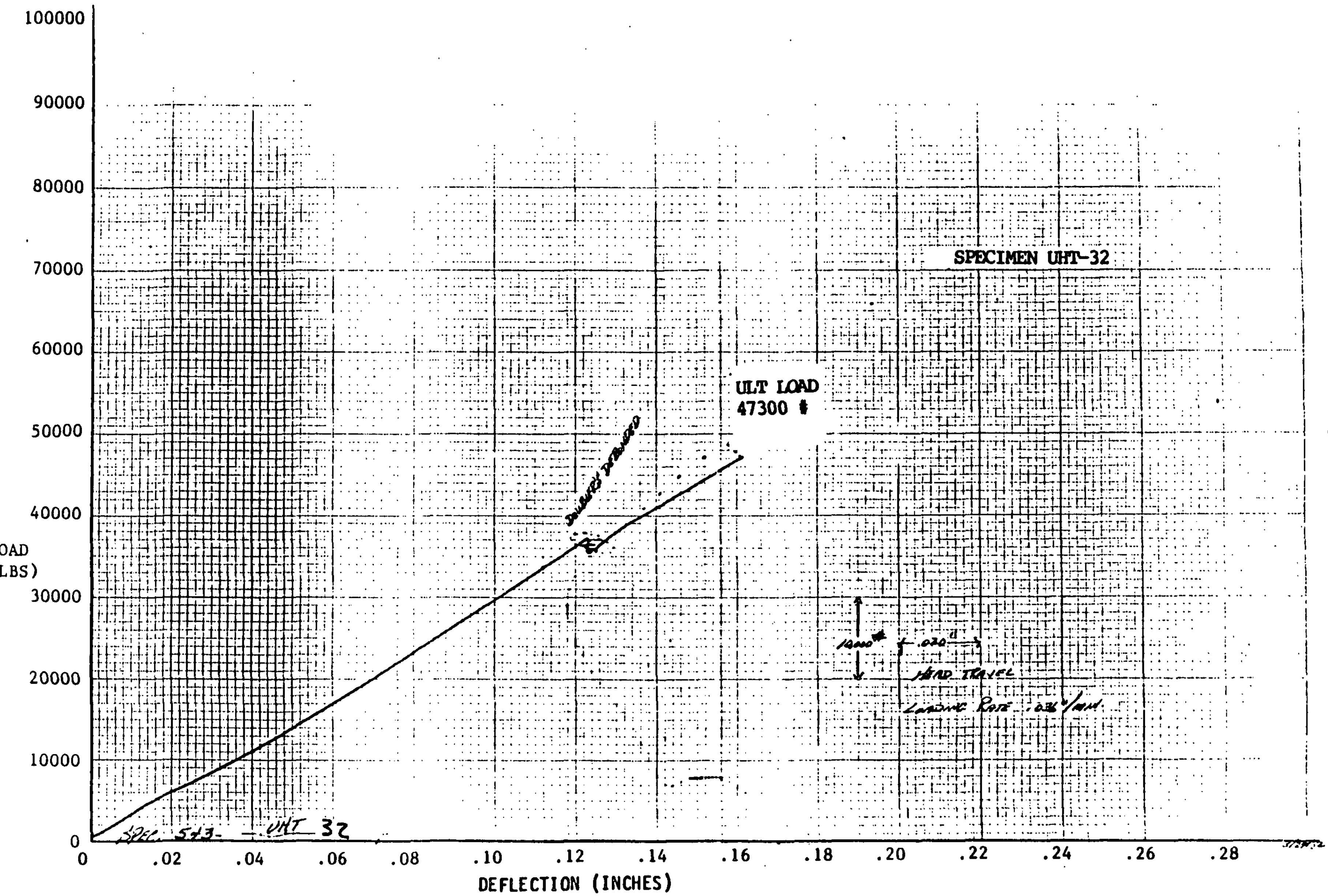

SPECIMEN UHT-27
ULT LOAD
12820 #
LOAD
(LBS)
DEFLECTION (INCHES)
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
.01
.02
.03
.04
.05
.06
.07
.08
.09
.10
.11
.12
.13
.14


SPECIMEN UHT-28
ULT LOAD
20750 #
LOAD
(LBS)
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
.02
.04
.06
.08
.10
.12
.14
.16
.18
.20
.22
.24
.26
.28
DEFLECTION (INCHES)


SPECIMEN UHT-29
ULT LOAD
25400 #
LOAD
(LBS)
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
0
.02
.04
.06
.08
.10
.12
.14
.16
.18
.20
.22
.24
.26
.28
DEFLECTION (INCHES)


SPECIMEN UHT-30
ULT LOAD
28650 #
500#
.020"
HEAD TRAVEL
UHT-30
LOAD
(LBS)
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
0
.02
.04
.06
.08
.10
.12
.14
.16
.18
.20
.22
.24
.26
.28
DEFLECTION (INCHES)


ULT LOAD
49350 #
SPECIMEN UHT-31
LOAD (LBS)
DEFLECTION (INCHES)
2nd Run
1st Run
5000#
HEAD TRAVEL
.025
LOAD RATE .048"/MIN
HEAD TRAVEL
.010"
5000#
LOAD RATE .048"/MIN
UHT 31



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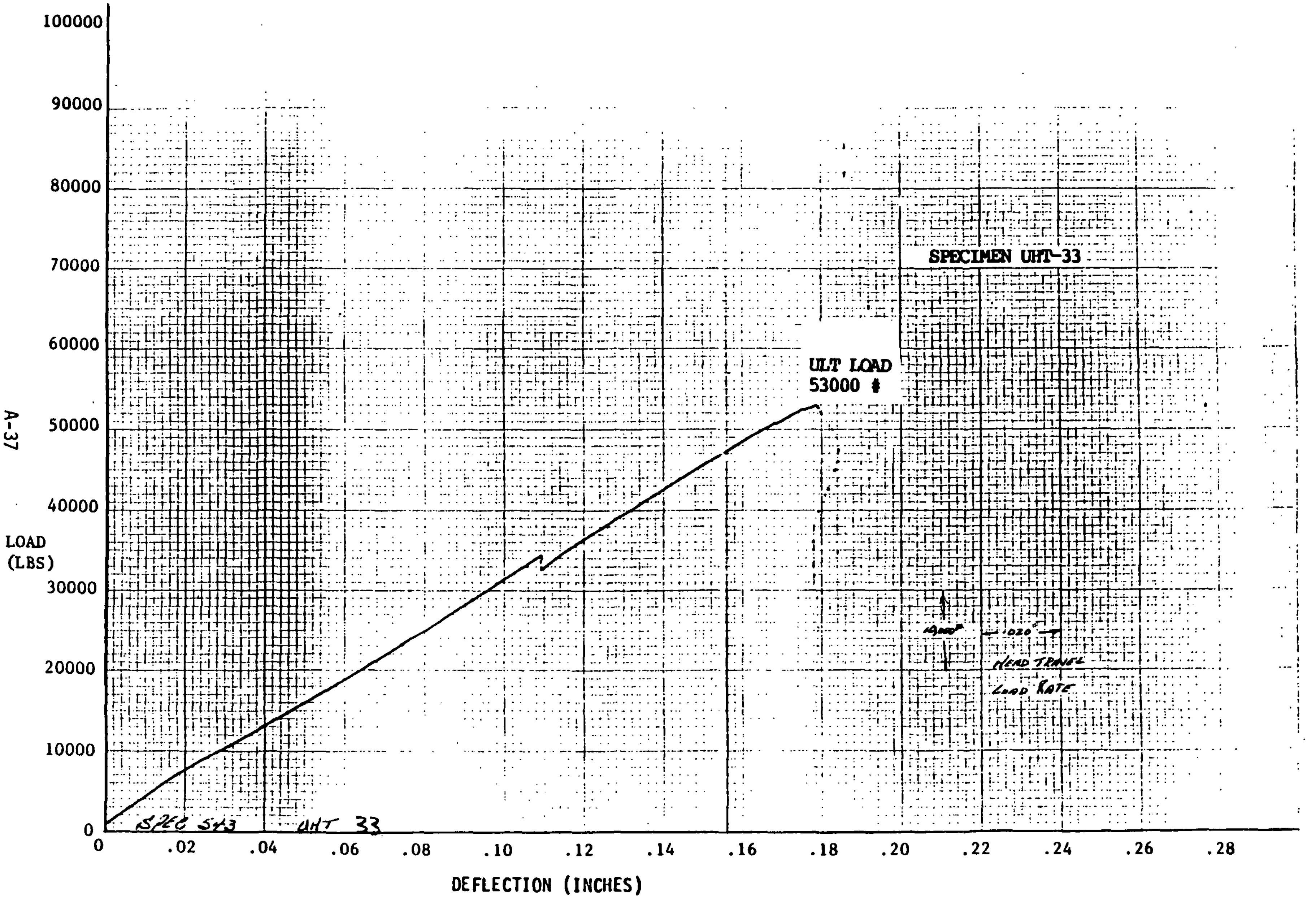
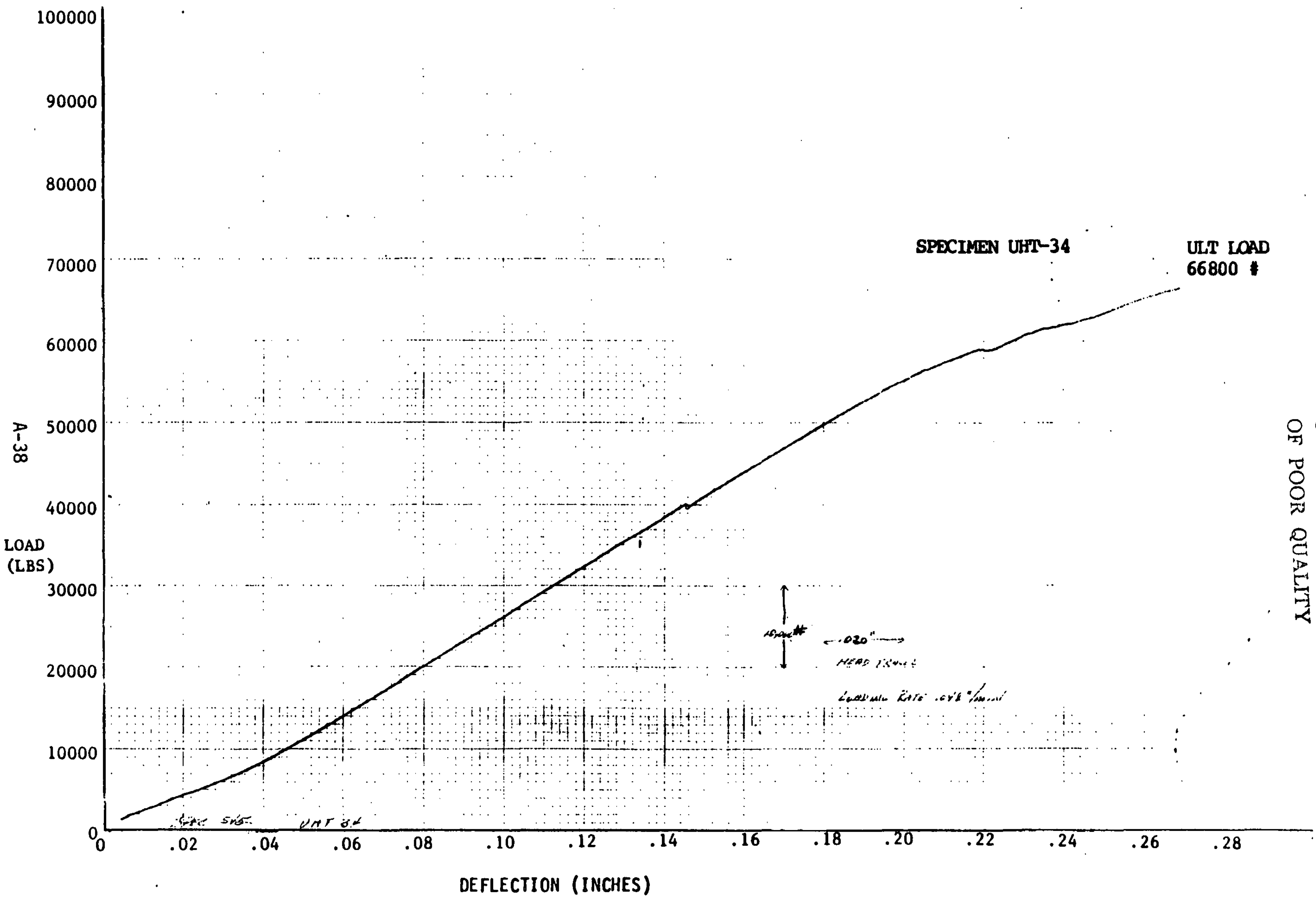
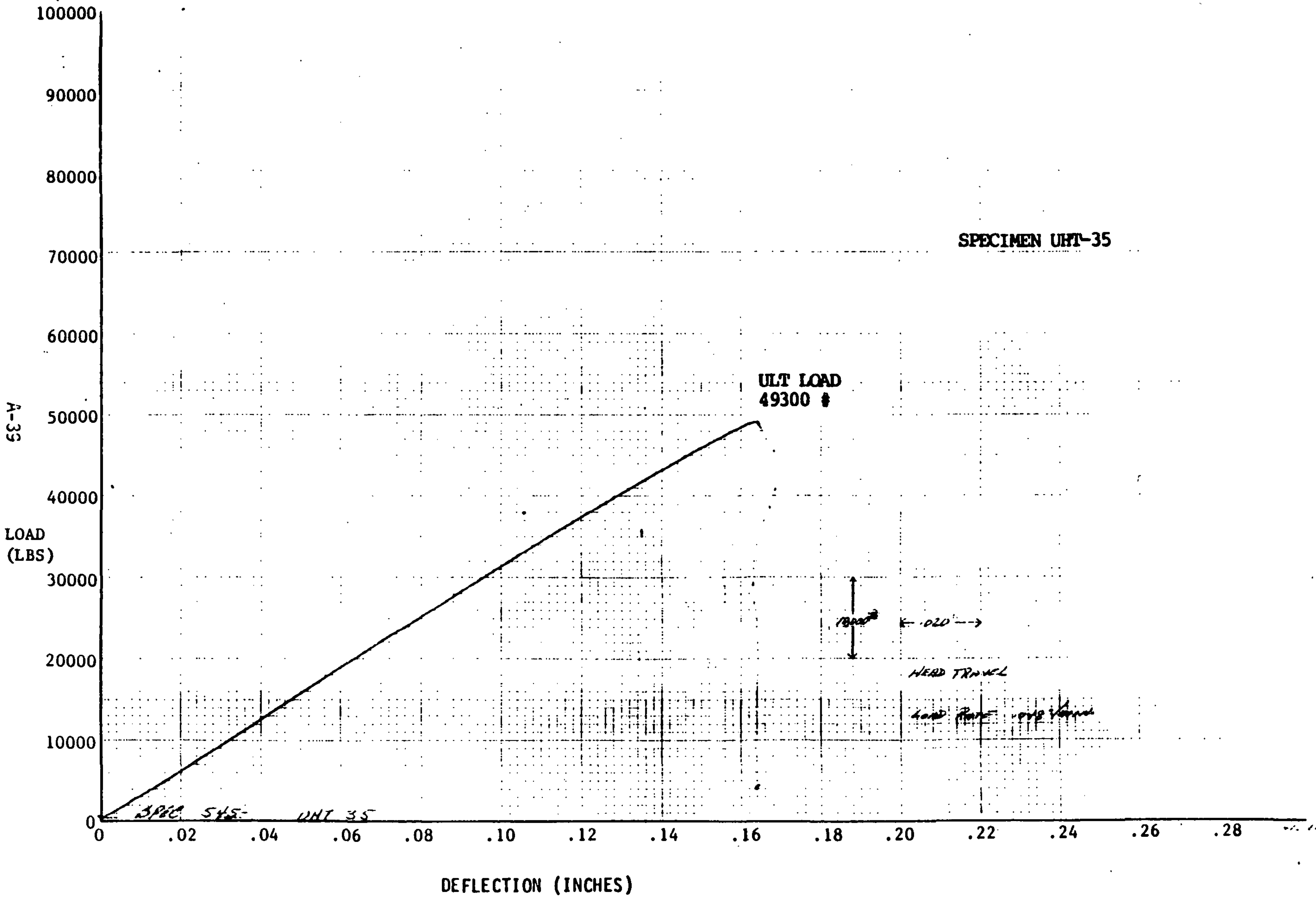

SPECIMEN UHT-33
ULT LOAD
53000 #
LOAD
(LBS)
100000
90000
80000
70000
60000
50000
40000
30000
20000
10000
0
0
.02
.04
.06
.08
.10
.12
.14
.16
.18
.20
.22
.24
.26
.28
DEFLECTION (INCHES)
SPEC 543
UHT 33
HEAD TRAVEL
LOAD RATE


SPECIMEN UHT-34
ULT LOAD
66800 #
LOAD
(LBS)
100000
90000
80000
70000
60000
50000
40000
30000
20000
10000
0
DEFLECTION (INCHES)
0
.02
.04
.06
.08
.10
.12
.14
.16
.18
.20
.22
.24
.26
.28
.020"
HEAD TRAVEL
UHT 34



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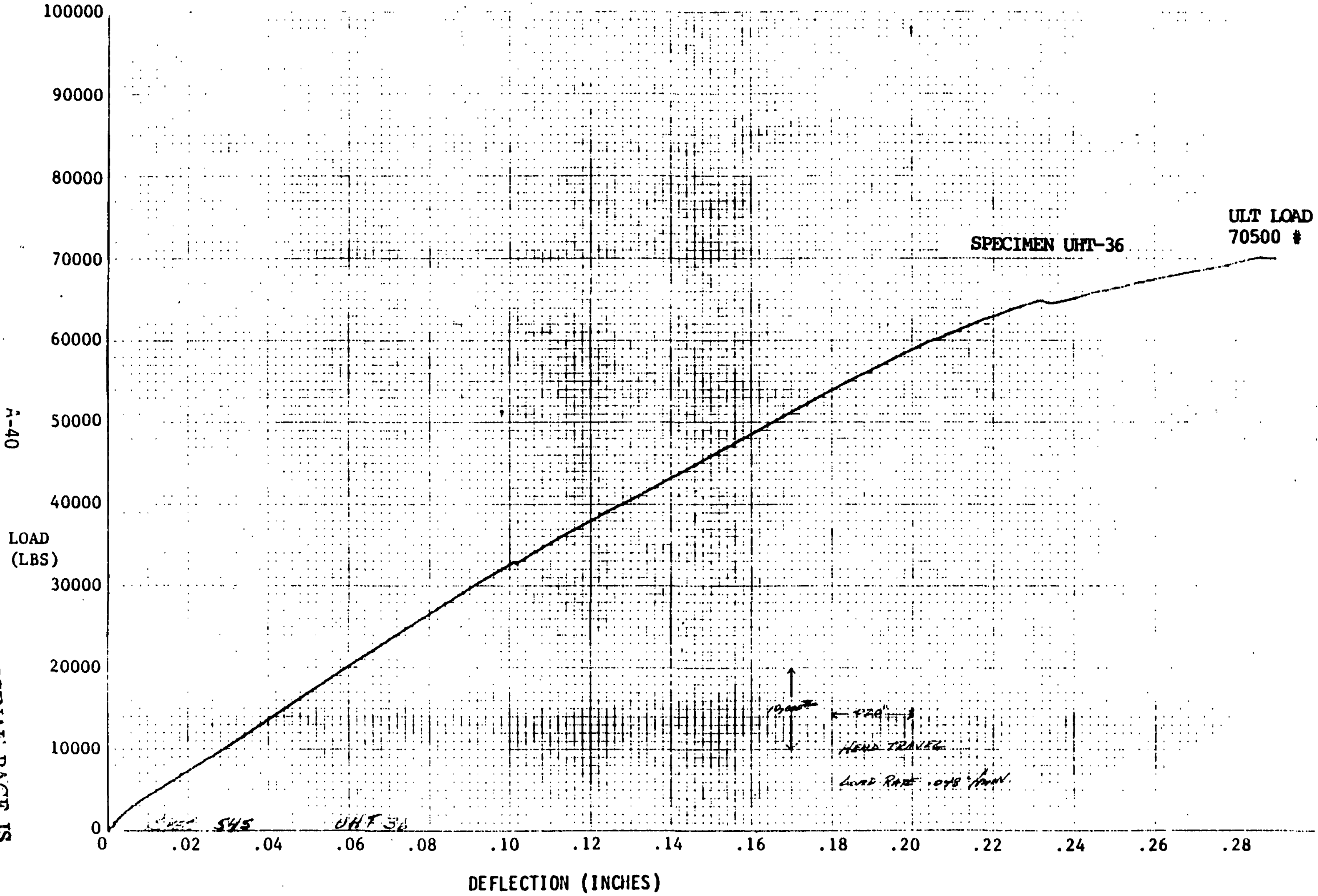
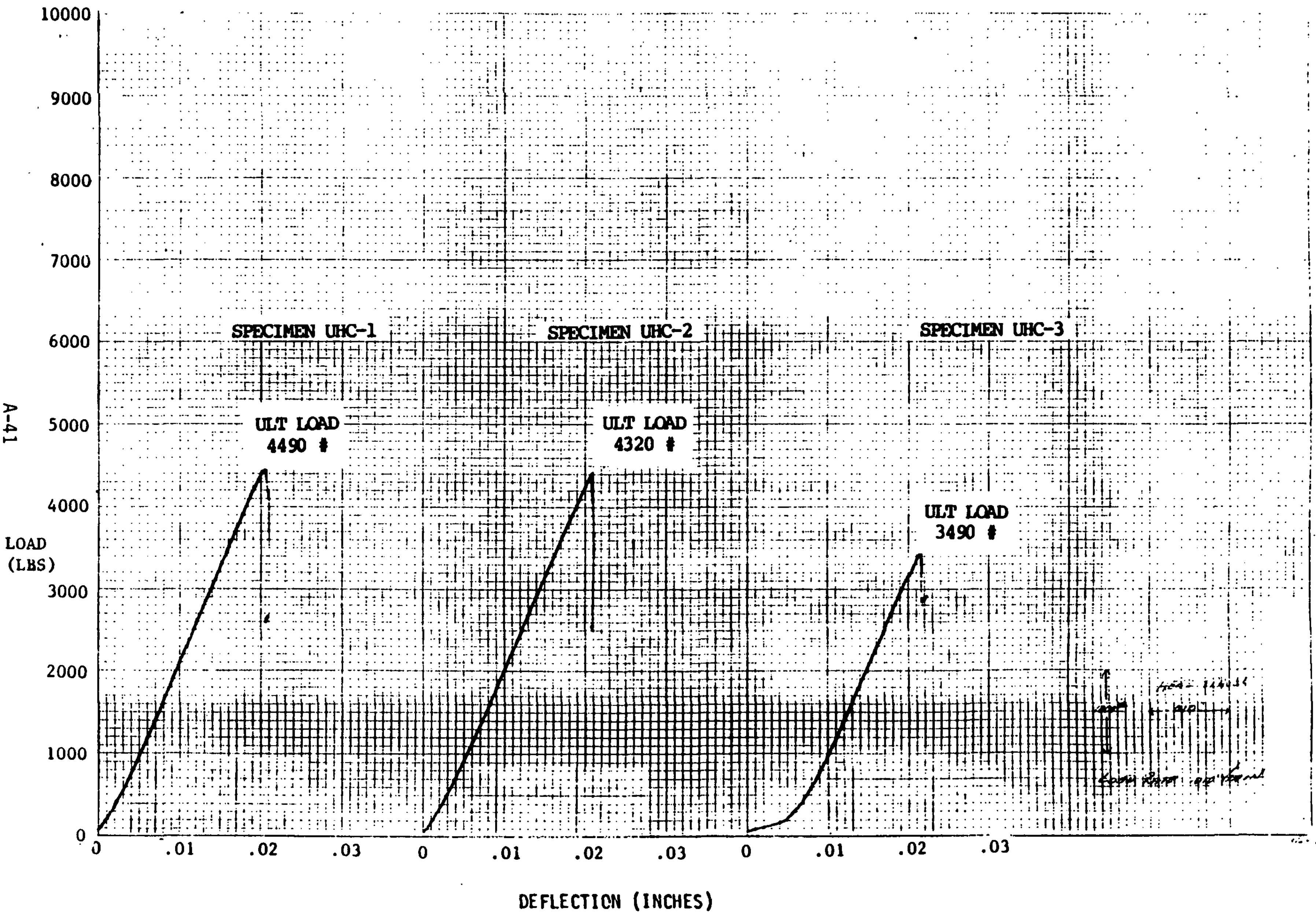
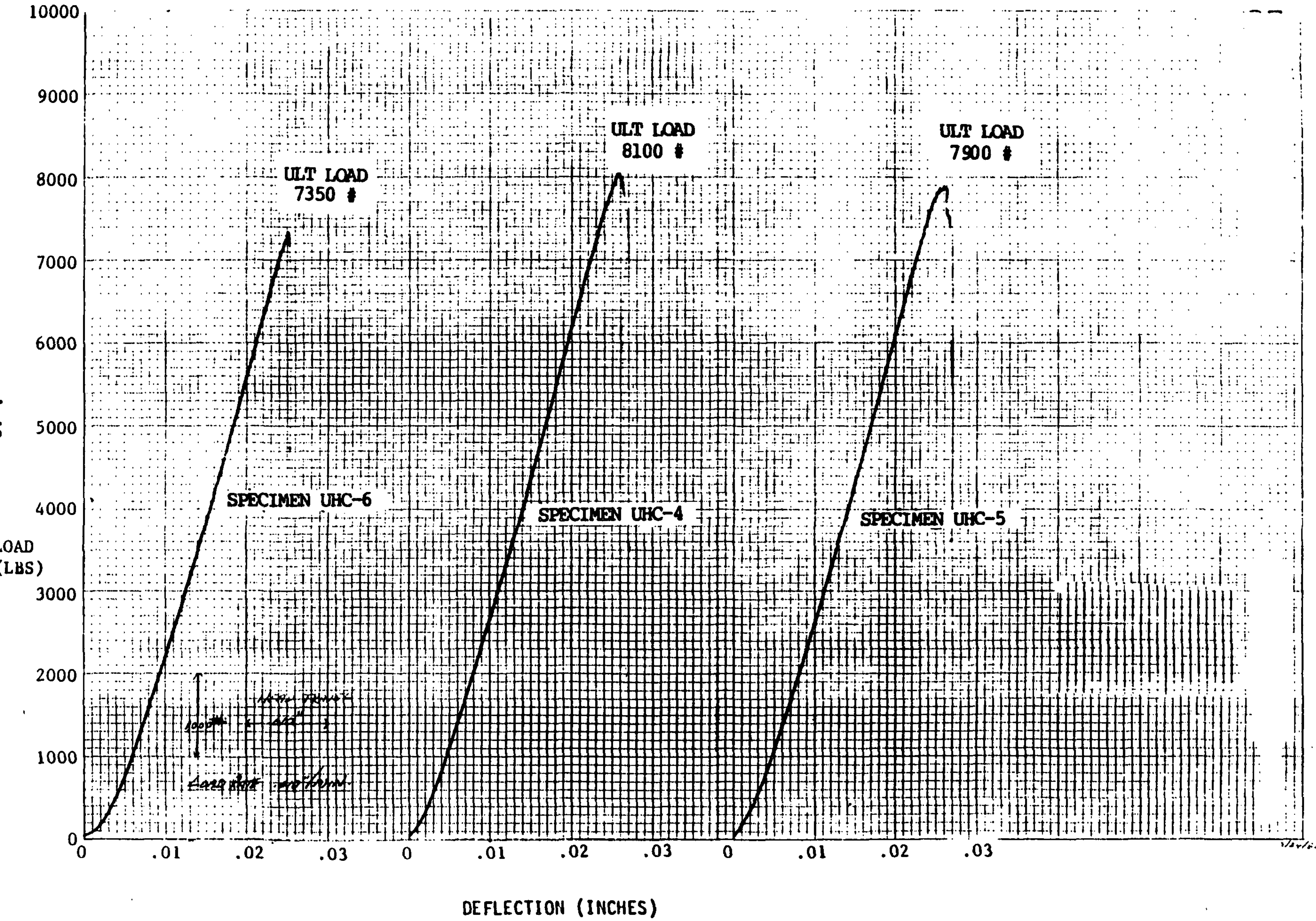
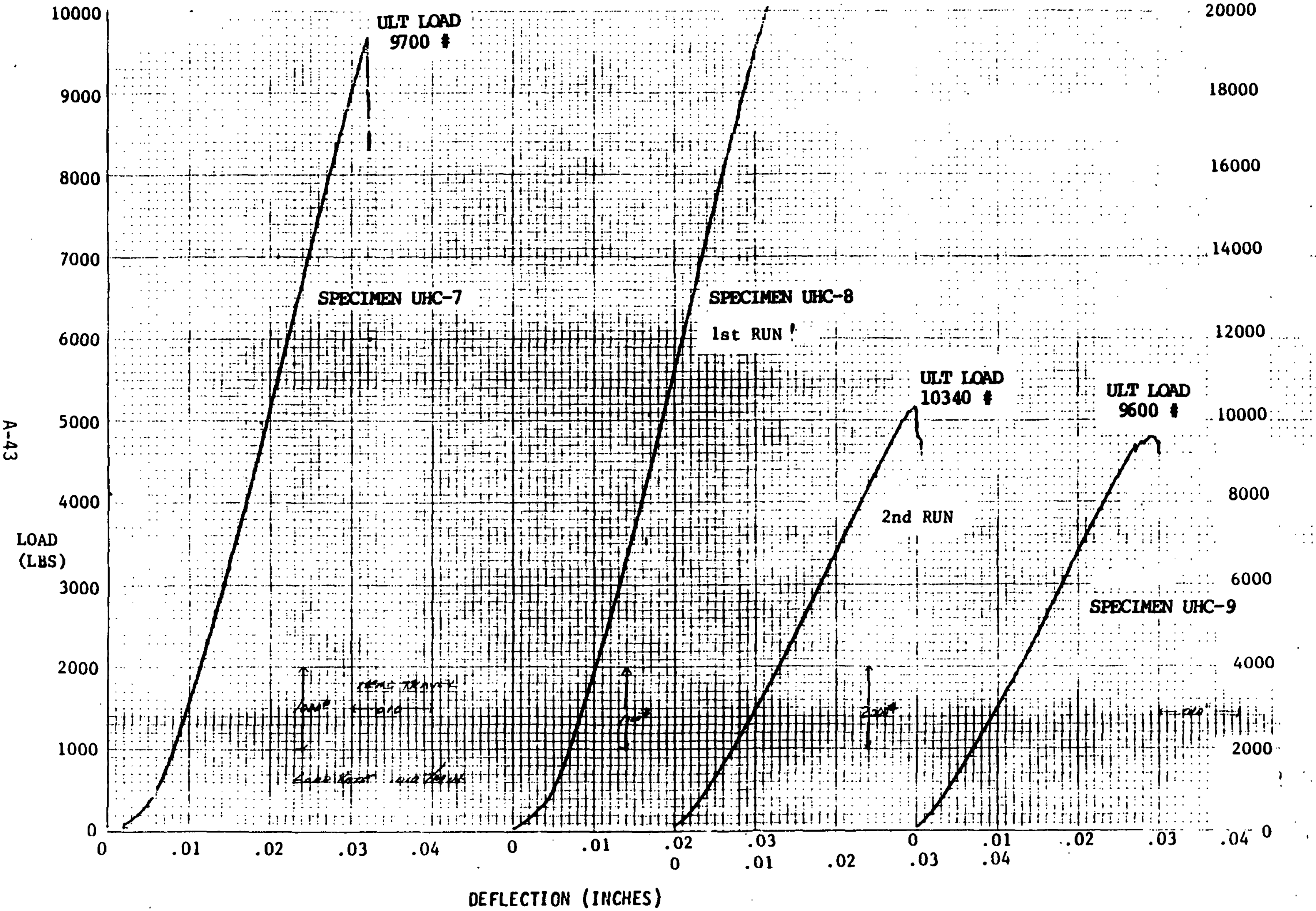
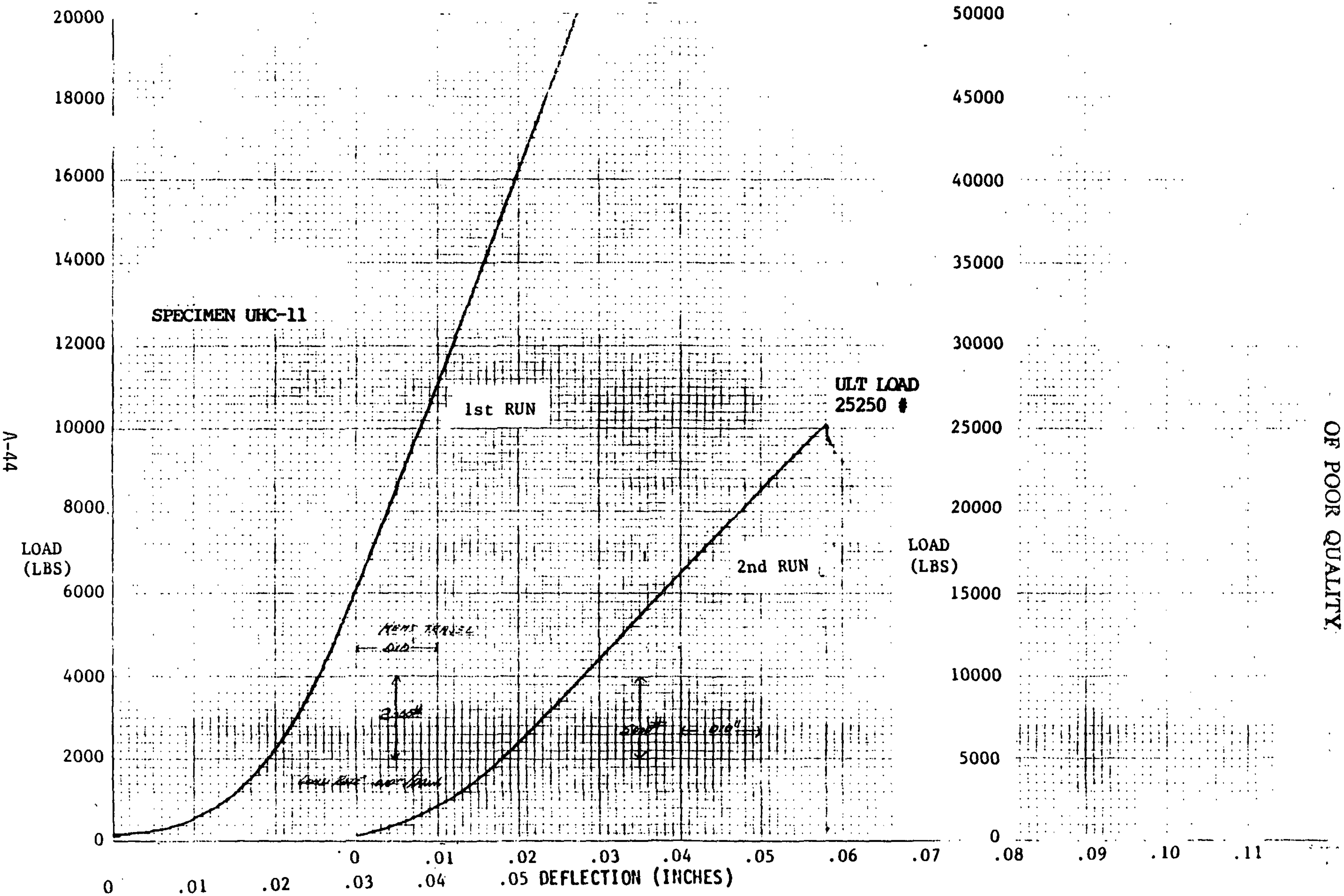

SPECIMEN UHT-36
ULT LOAD
70500 #
LOAD
(LBS)
DEFLECTION (INCHES)


SPECIMEN UHC-1
SPECIMEN UHC-2
SPECIMEN UHC-3
ULT LOAD
4490 #
ULT LOAD
4320 #
ULT LOAD
3490 #
LOAD
(LBS)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
0
.01
.02
.03
0
.01
.02
.03
0
.01
.02
.03
DEFLECTION (INCHES)

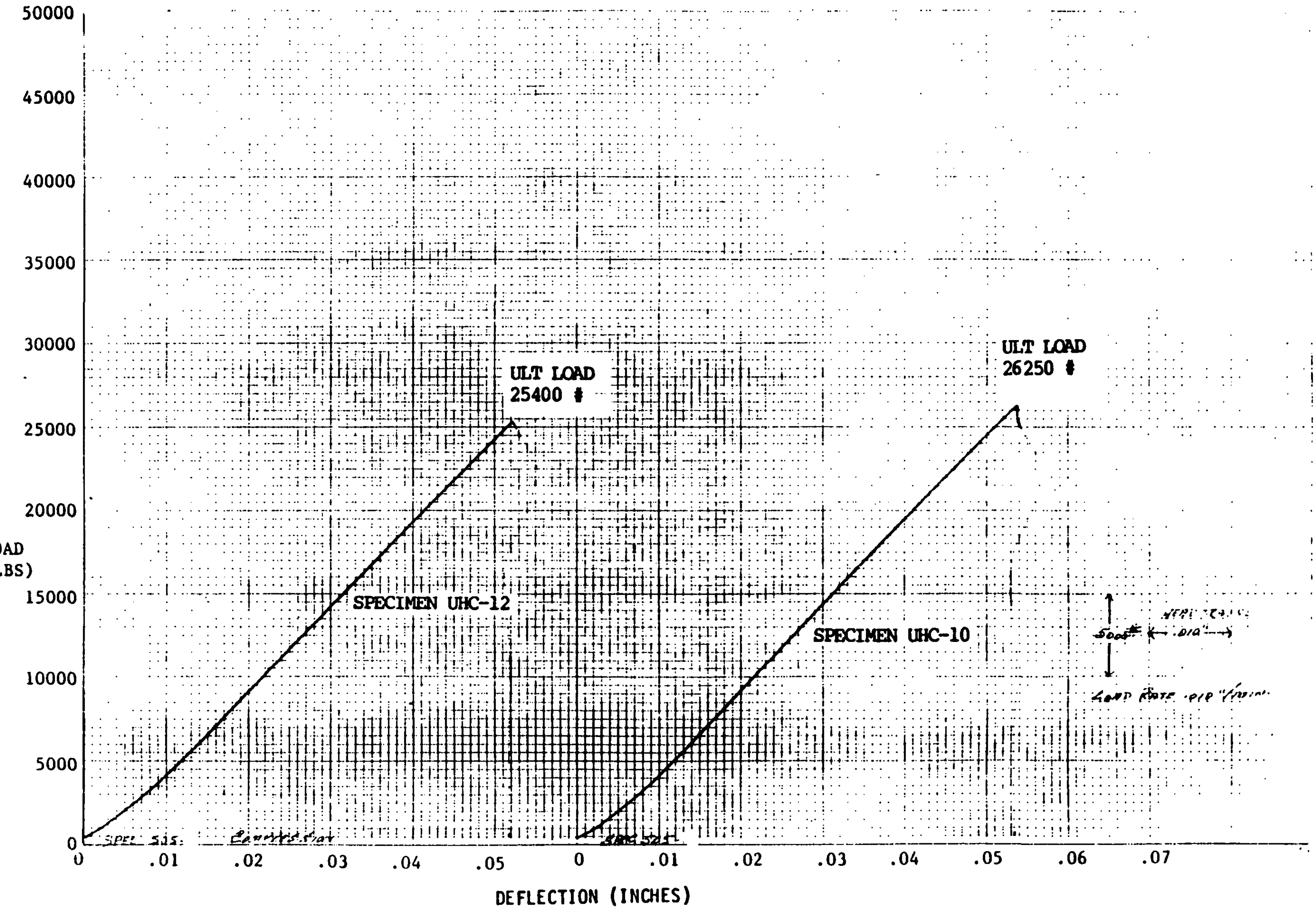

ULT LOAD
7350 #
ULT LOAD
8100 #
ULT LOAD
7900 #
SPECIMEN UHC-6
SPECIMEN UHC-4
SPECIMEN UHC-5
LOAD
(LBS)
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
0
.01
.02
.03
DEFLECTION (INCHES)



ULT LOAD
9700 #
SPECIMEN UHC-7
SPECIMEN UHC-8
1st RUN
ULT LOAD
10340 #
2nd RUN
ULT LOAD
9600 #
SPECIMEN UHC-9
LOAD
(LBS)
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
DEFLECTION (INCHES)



SPECIMEN UHC-11
1st RUN
2nd RUN
ULT LOAD
25250 #
LOAD (LBS)
LOAD (LBS)
DEFLECTION (INCHES)



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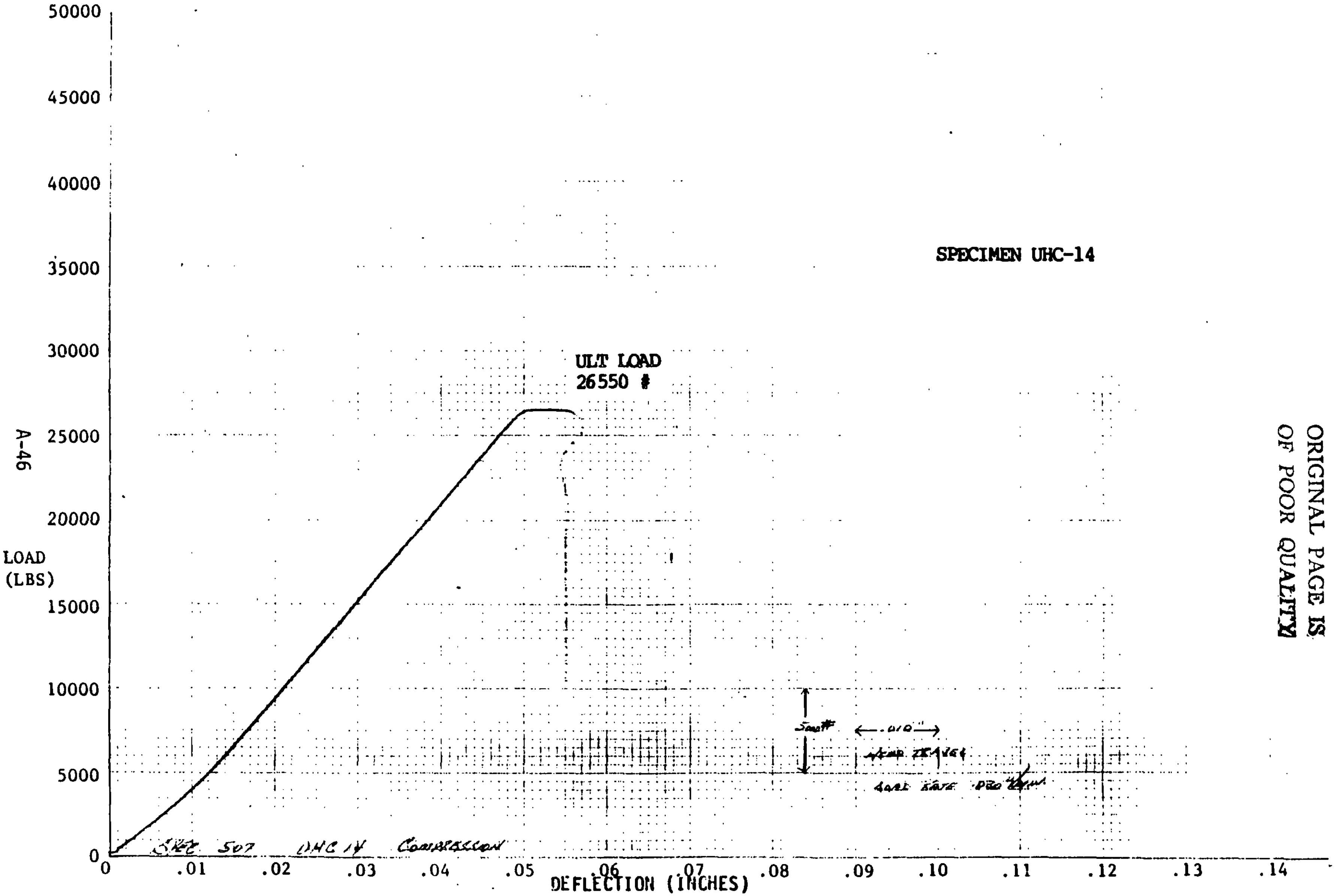

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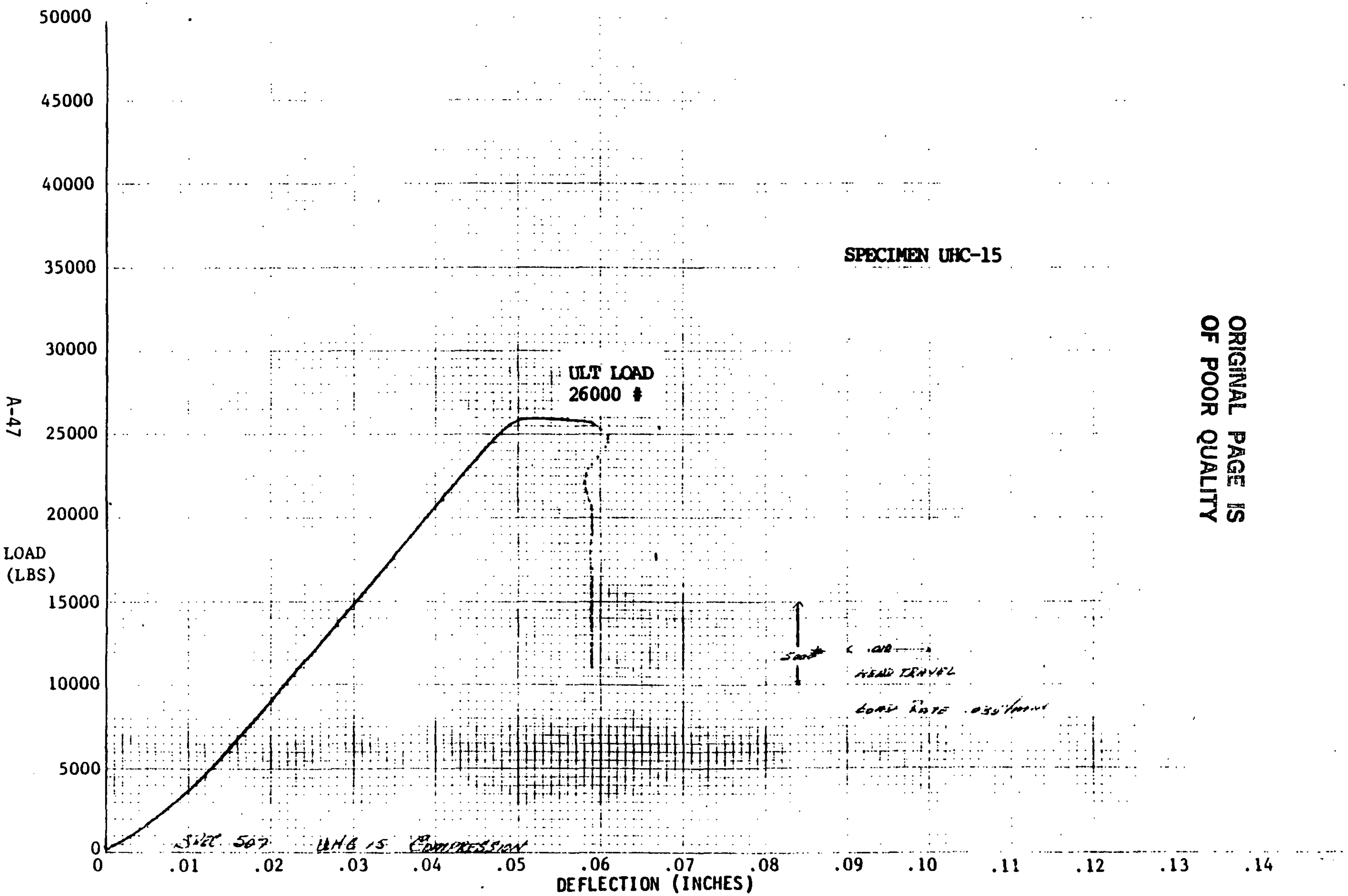

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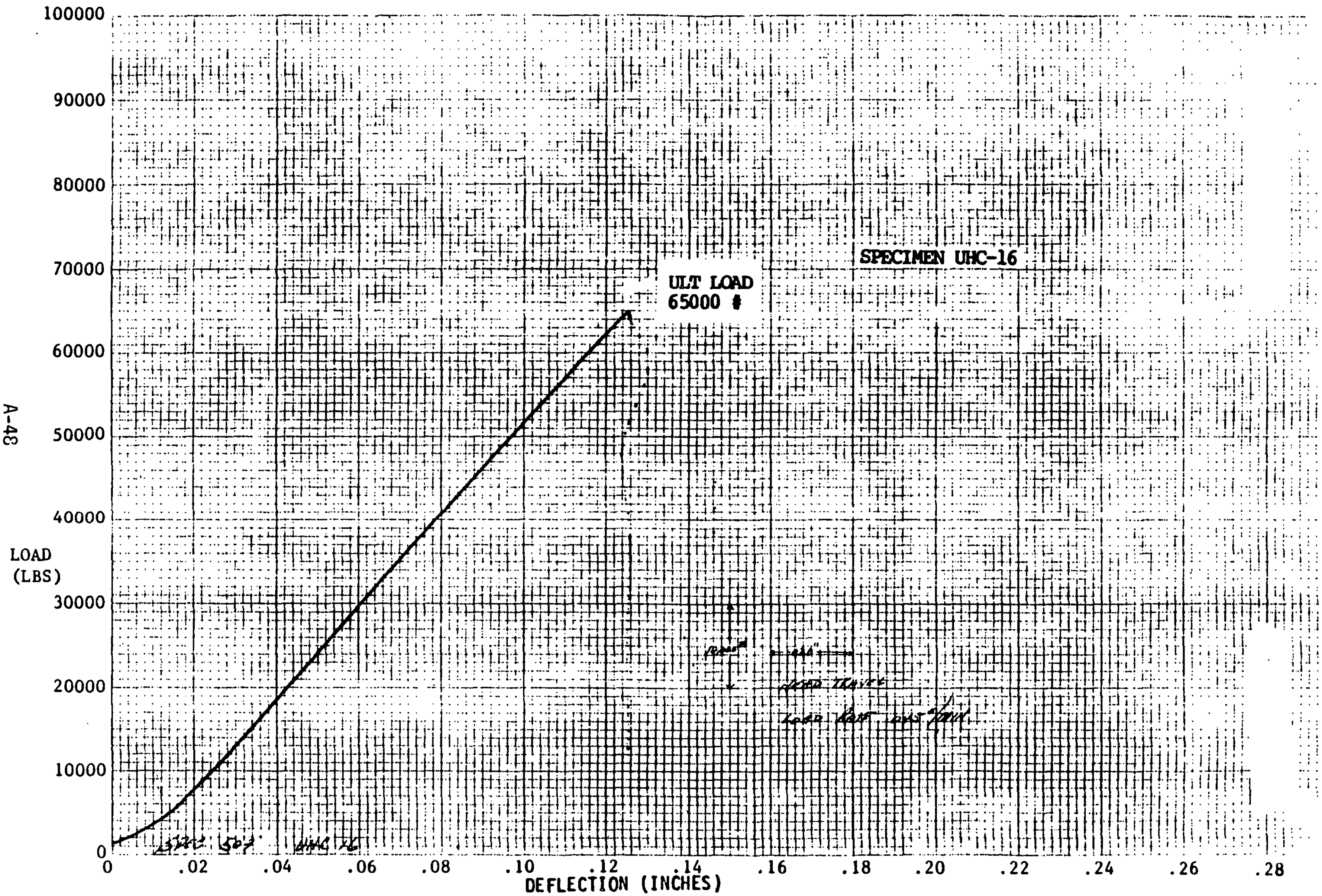
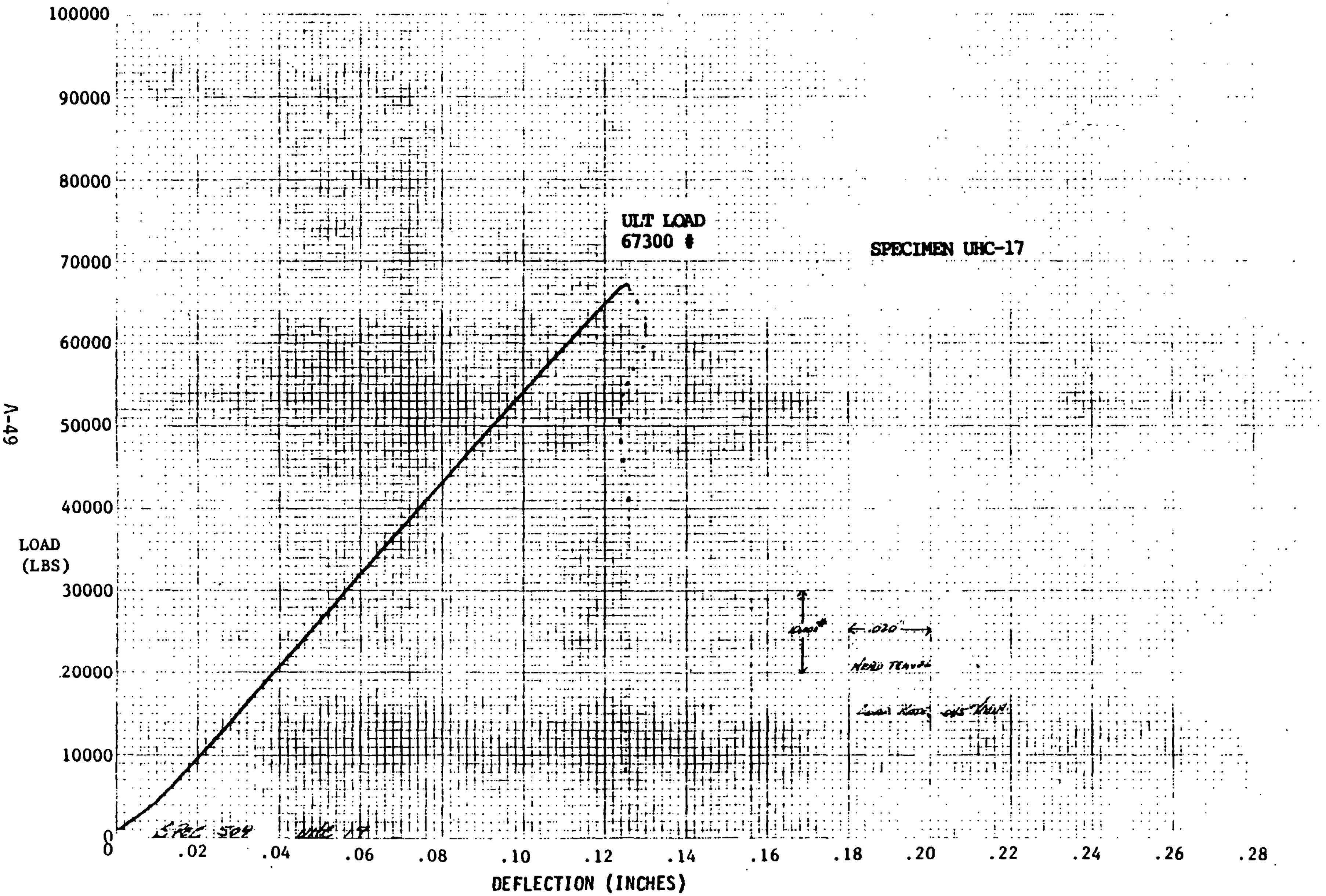
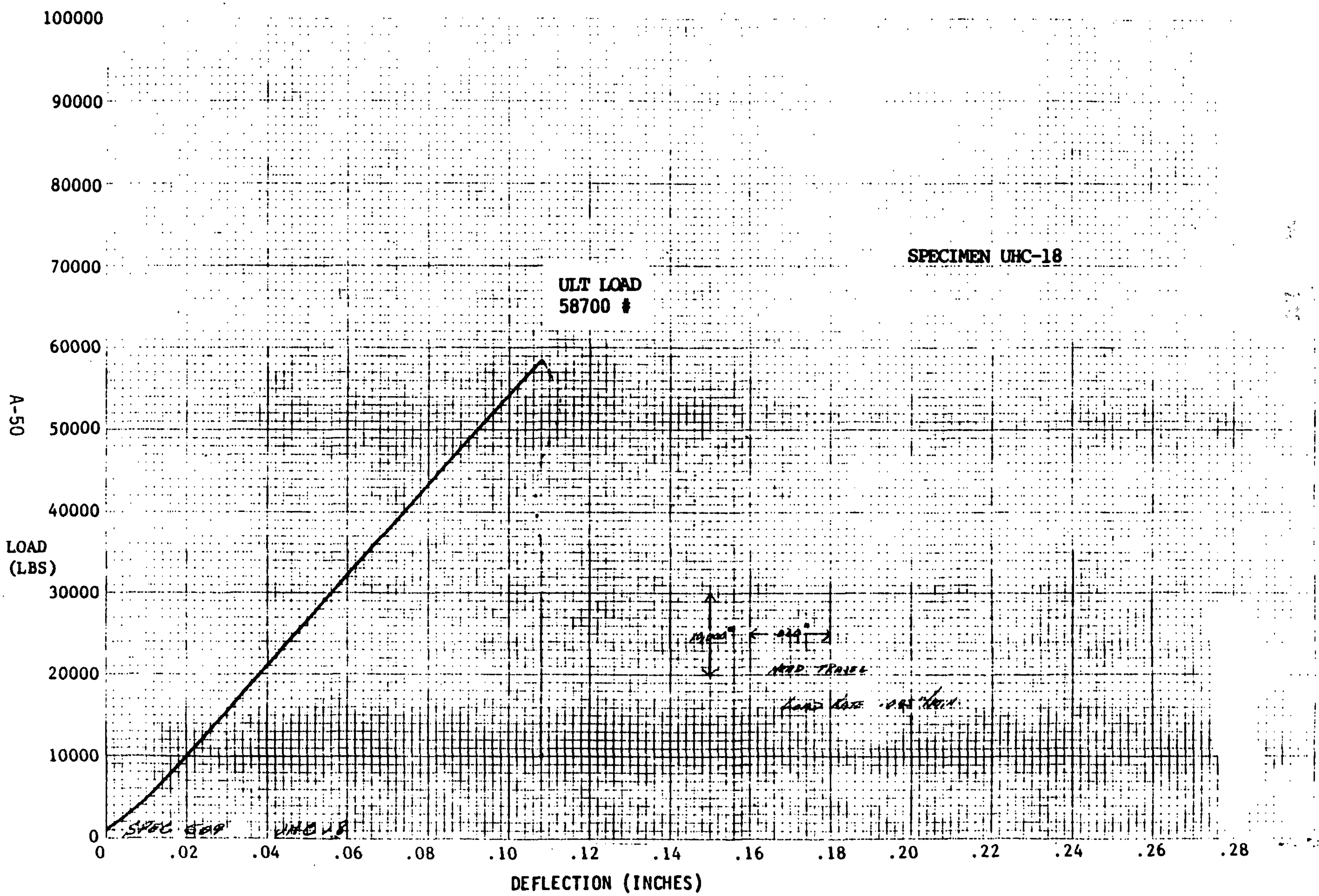
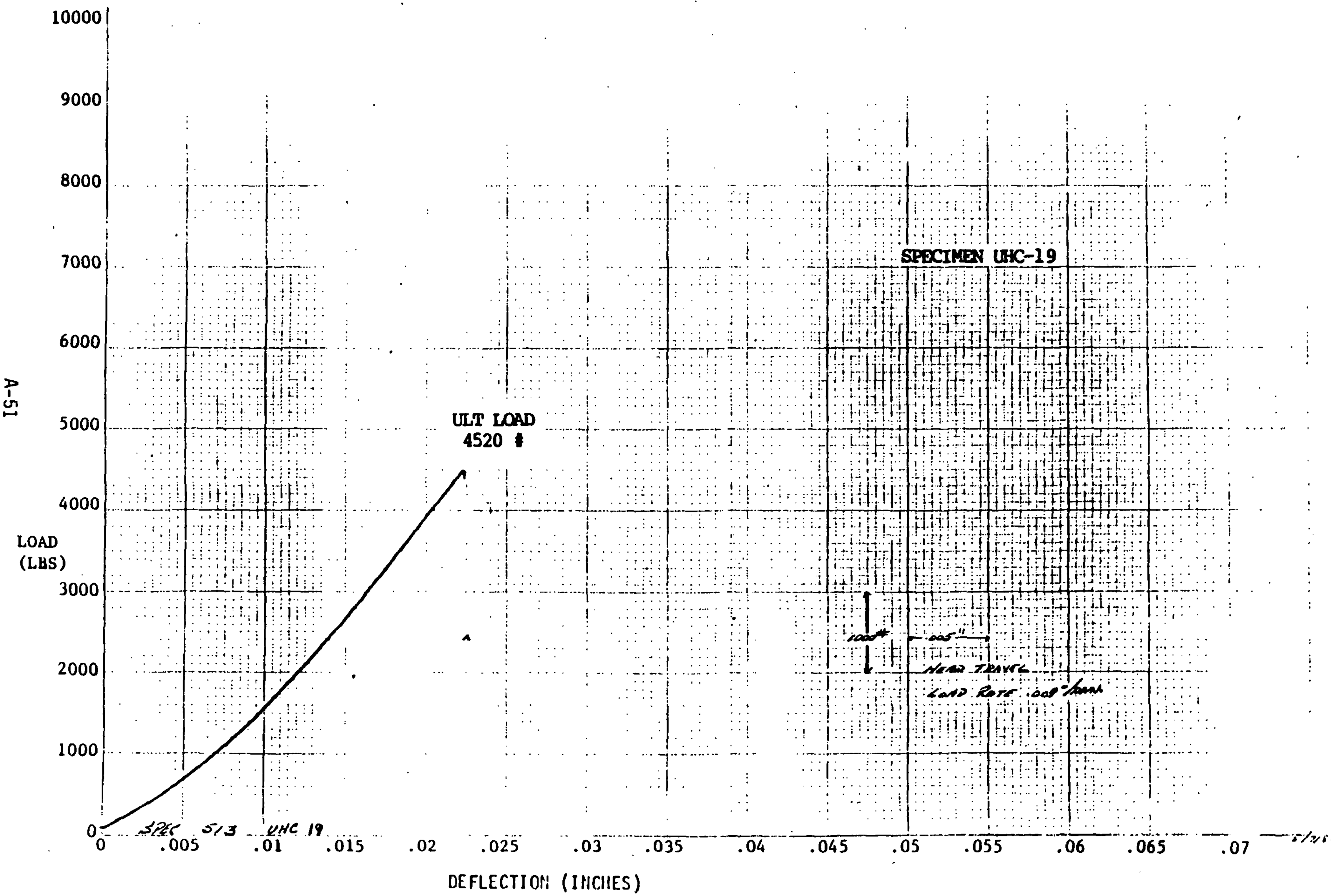

SPECIMEN UHC-16
ULT LOAD
65000 #
LOAD
(LBS)
100000
90000
80000
70000
60000
50000
40000
30000
20000
10000
0
0
.02
.04
.06
.08
.10
.12
.14
.16
.18
.20
.22
.24
.26
.28
DEFLECTION (INCHES)

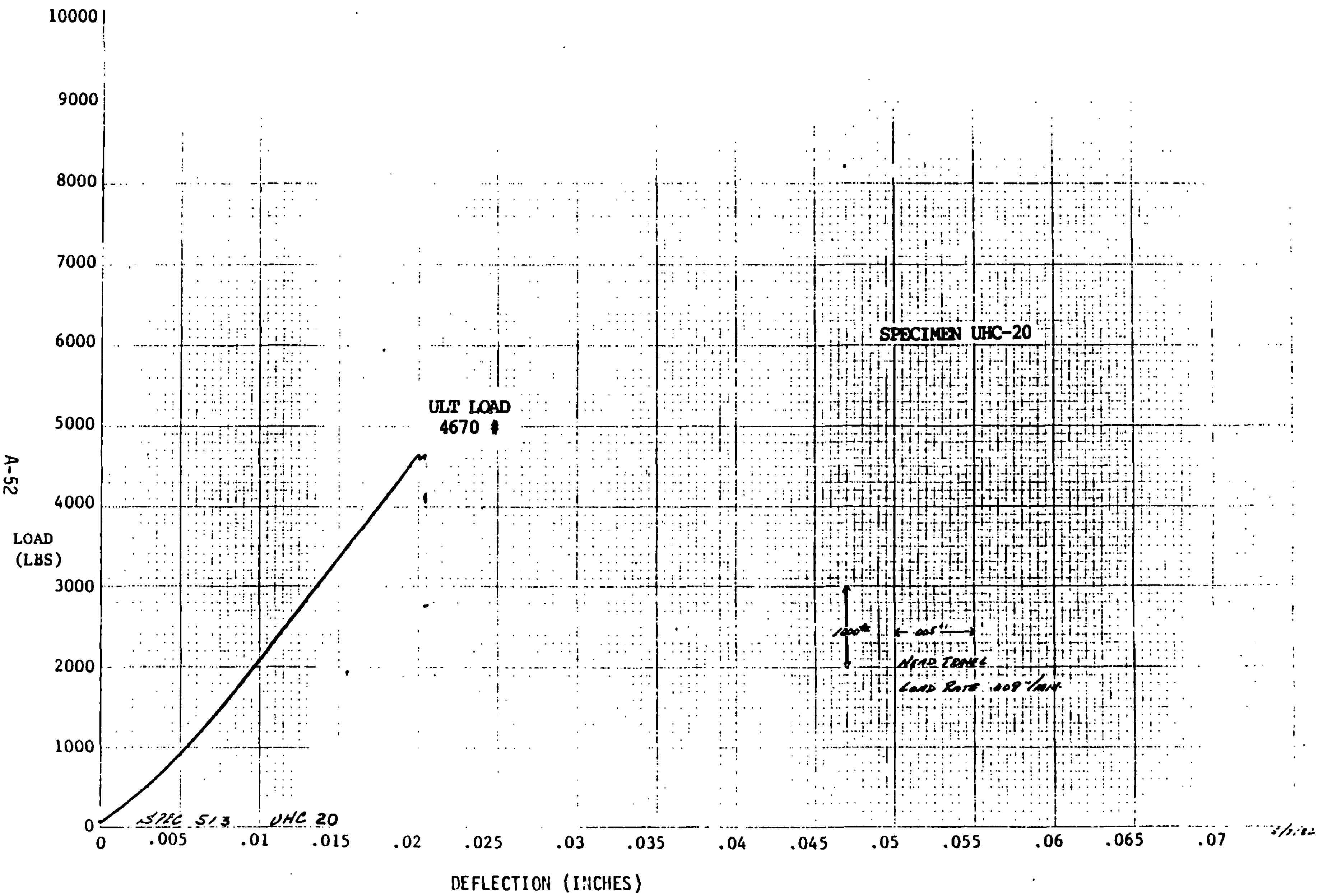

ULT LOAD
67300 #
SPECIMEN UHC-17
LOAD
(LBS)
100000
90000
80000
70000
60000
50000
40000
30000
20000
10000
0
0
.02
.04
.06
.08
.10
.12
.14
.16
.18
.20
.22
.24
.26
.28
DEFLECTION (INCHES)
.020"

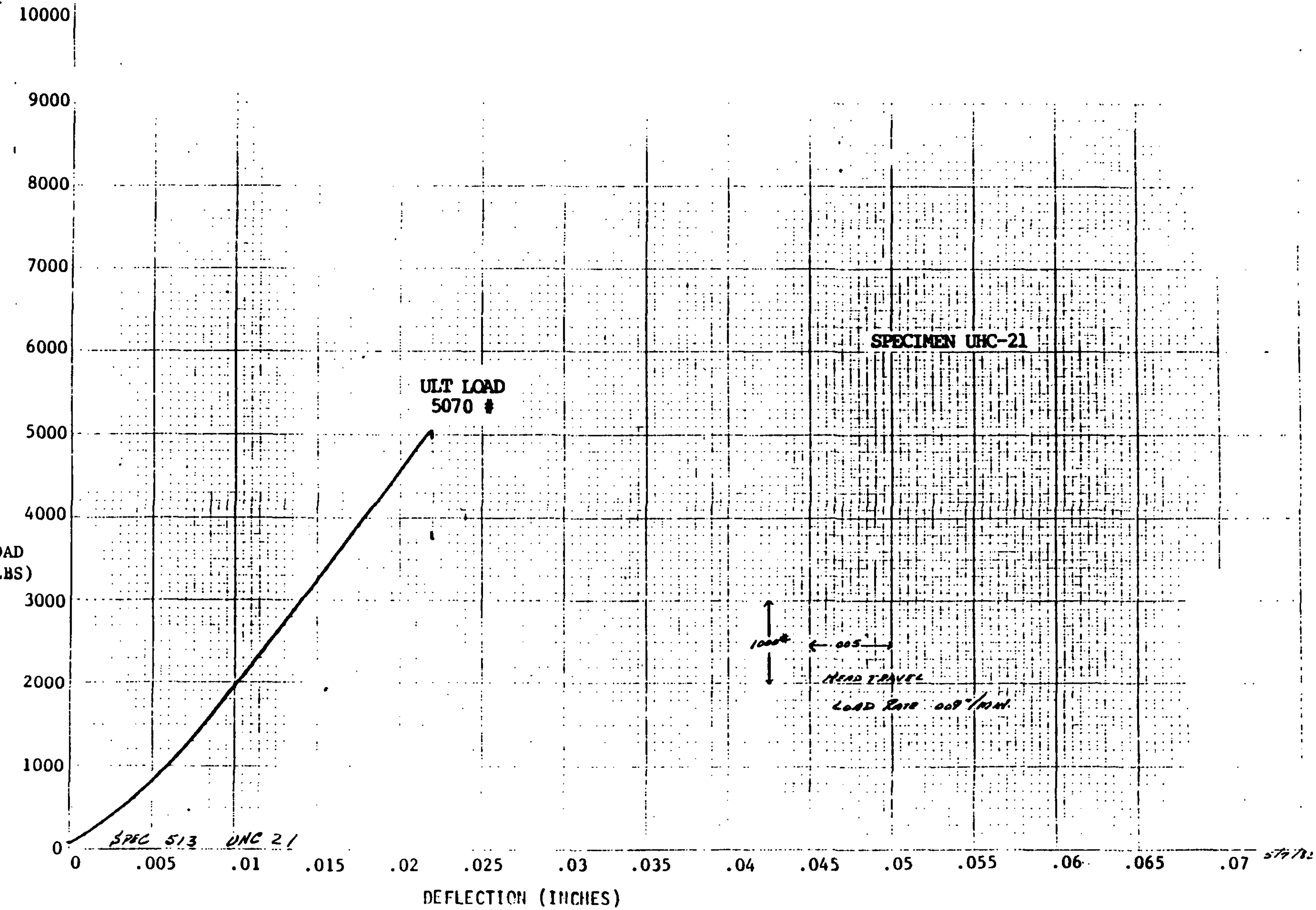


SPECIMEN UHC-18
ULT LOAD
58700 #
LOAD
(LBS)
100000
90000
80000
70000
60000
50000
40000
30000
20000
10000
0
0
.02
.04
.06
.08
.10
.12
.14
.16
.18
.20
.22
.24
.26
.28
DEFLECTION (INCHES)

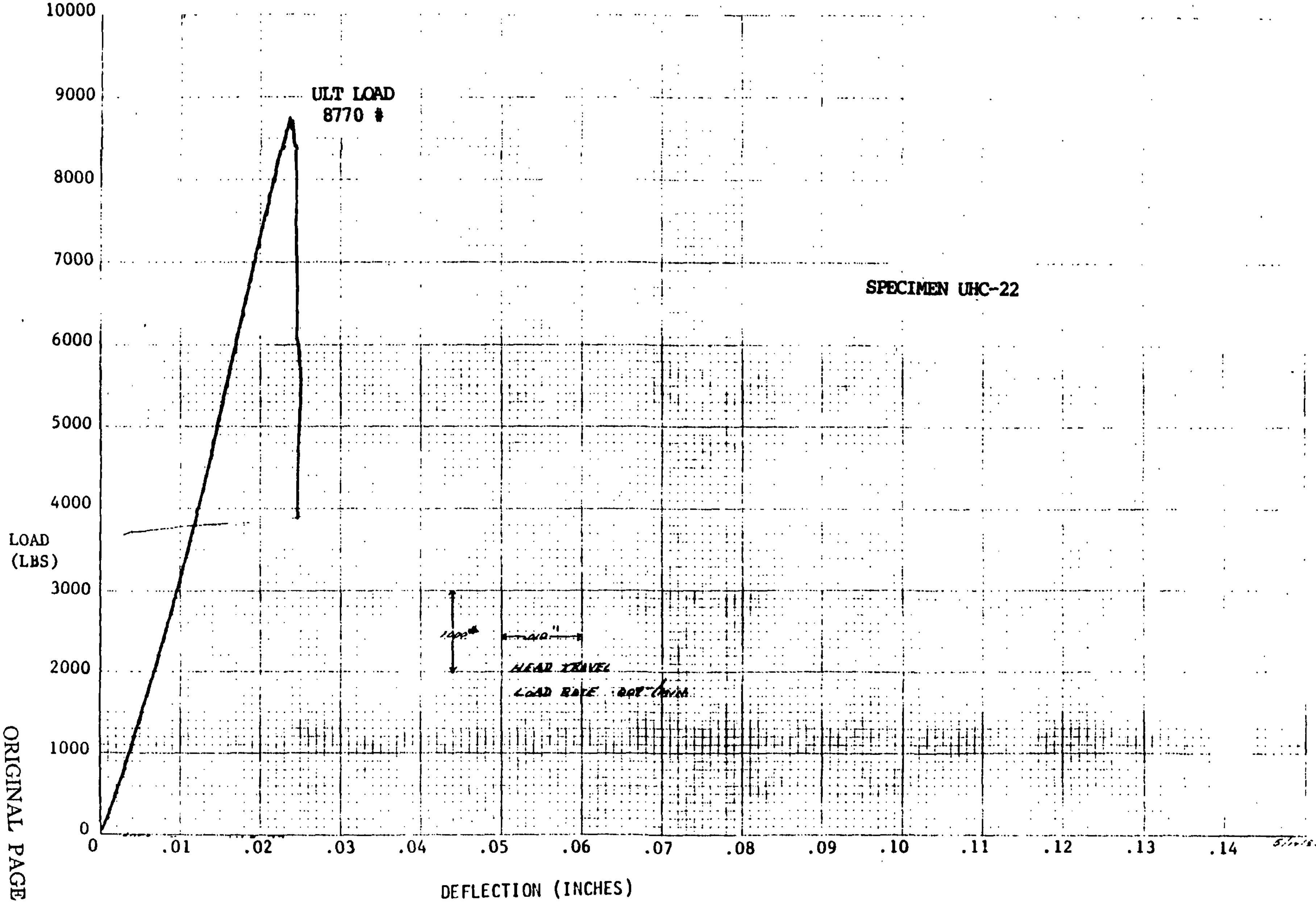


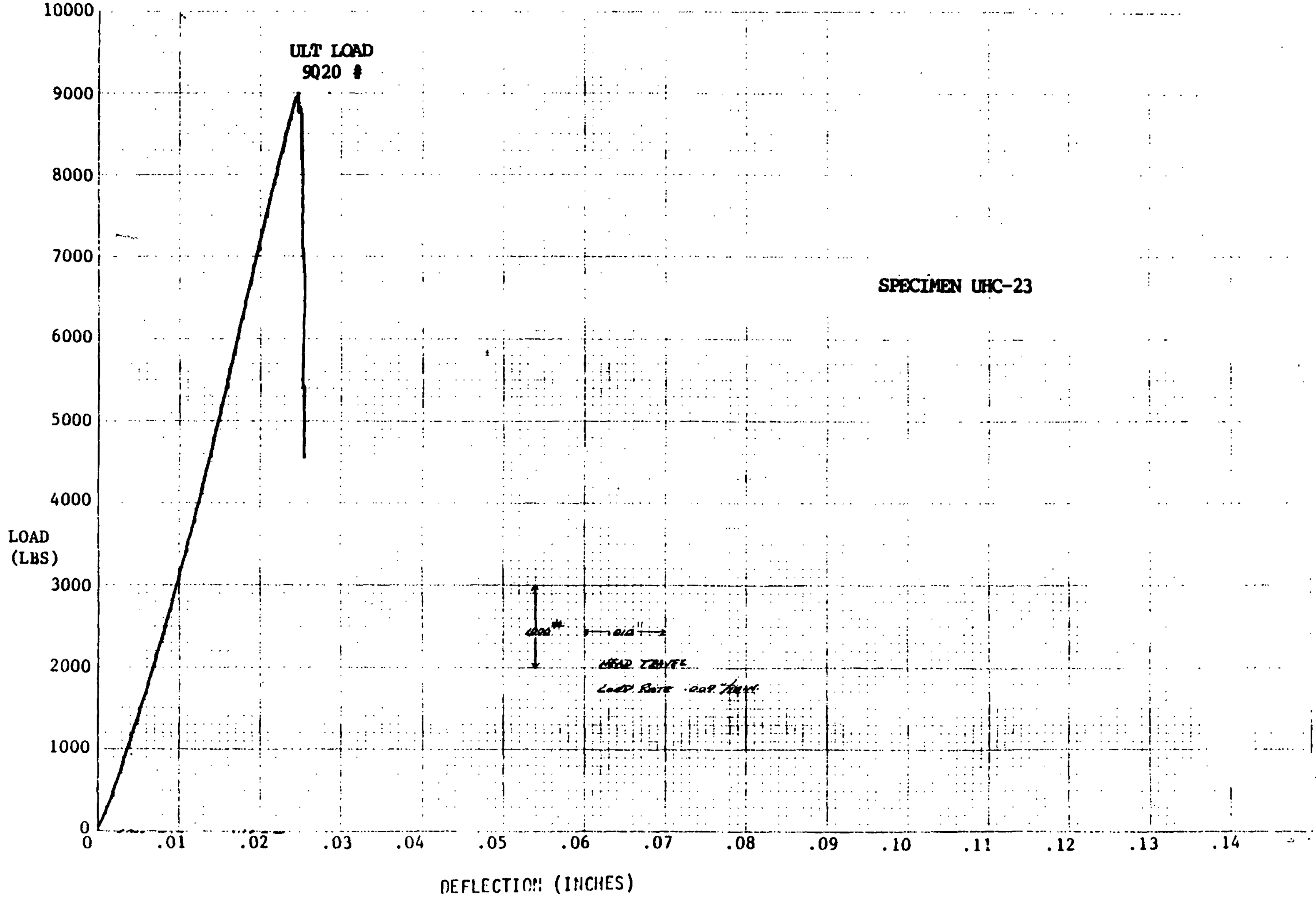
SPECIMEN UHC-19
ULT LOAD
4520 #
LOAD
(LBS)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
0
.005
.01
.015
.02
.025
.03
.035
.04
.045
.05
.055
.06
.065
.07
DEFLECTION (INCHES)
SPEC 513 UHC 19
1000#
.005"
HEAD TRAVEL
LOAD RATE .008"/MIN


SPECIMEN UHC-20
ULT LOAD
4670 #
LOAD
(LBS)
DEFLECTION (INCHES)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
0
.005
.01
.015
.02
.025
.03
.035
.04
.045
.05
.055
.06
.065
.07
SPEC 513
UHC 20
HEAD TRAVEL
LOAD RATE .009"/MIN

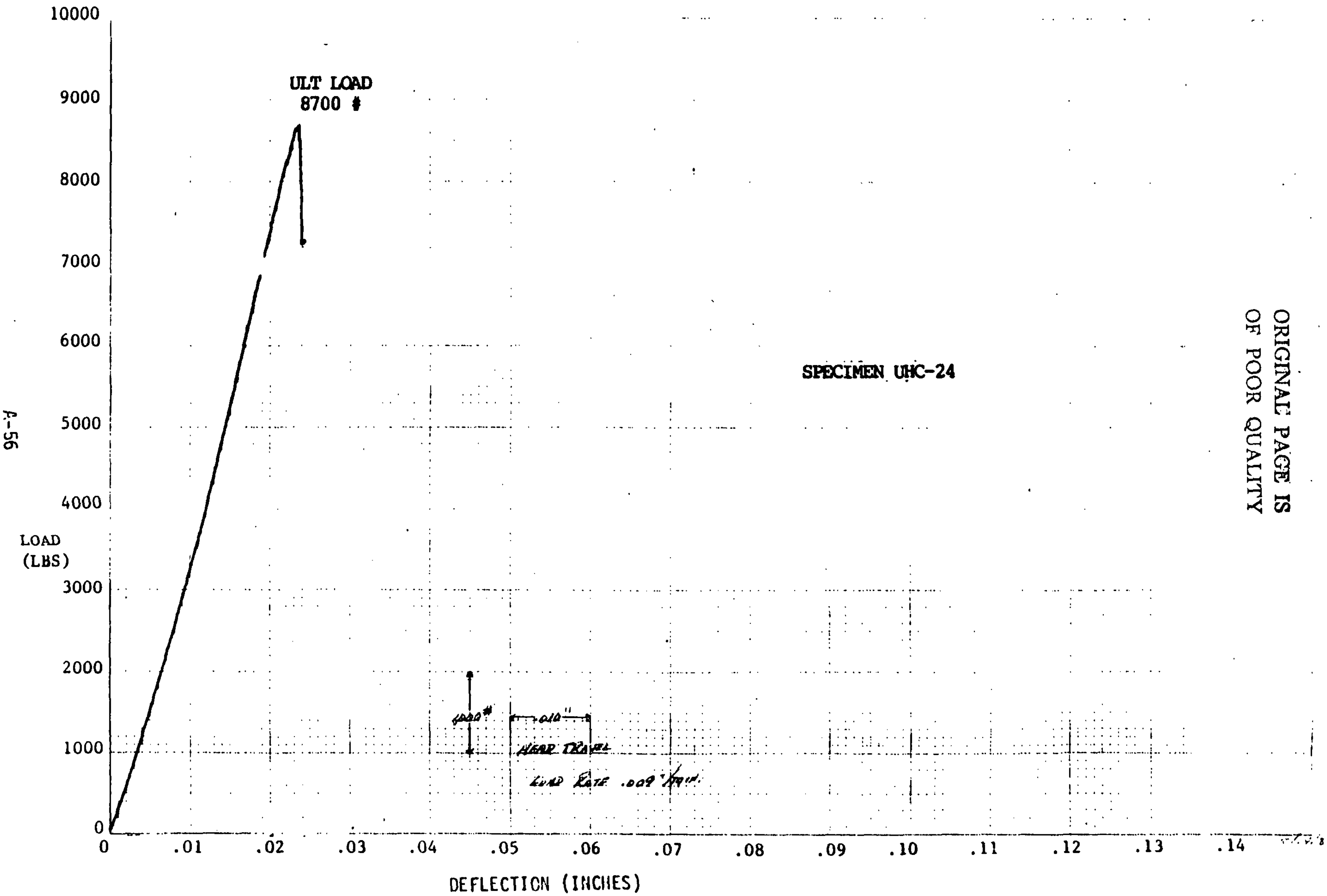


10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
LOAD
(LBS)
ULT LOAD
5070 #
SPECIMEN UHC-21
1000#
.005
HEAD TRAVEL
LOAD RATE .009"/MIN.
SPEC 513 UHC 21
0
.005
.01
.015
.02
.025
.03
.035
.04
.045
.05
.055
.06
.065
.07
DEFLECTION (INCHES)


ULT LOAD
8770 #
SPECIMEN UHC-22
LOAD
(LBS)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
0
.01
.02
.03
.04
.05
.06
.07
.08
.09
.10
.11
.12
.13
.14
HEAD TRAVEL
DEFLECTION (INCHES)



ULT LOAD
9020 #
SPECIMEN UHC-23
LOAD (LBS)
DEFLECTION (INCHES)



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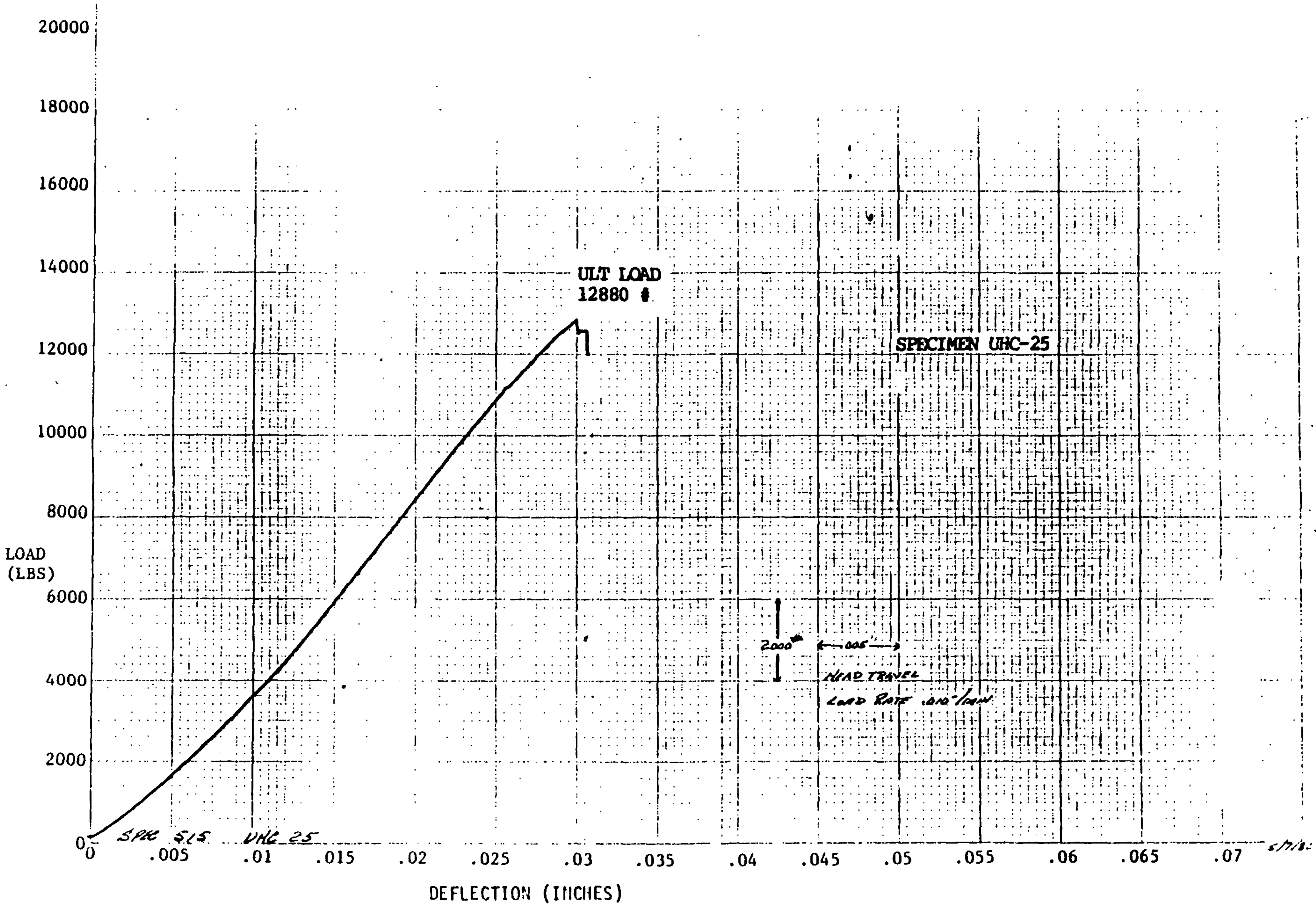
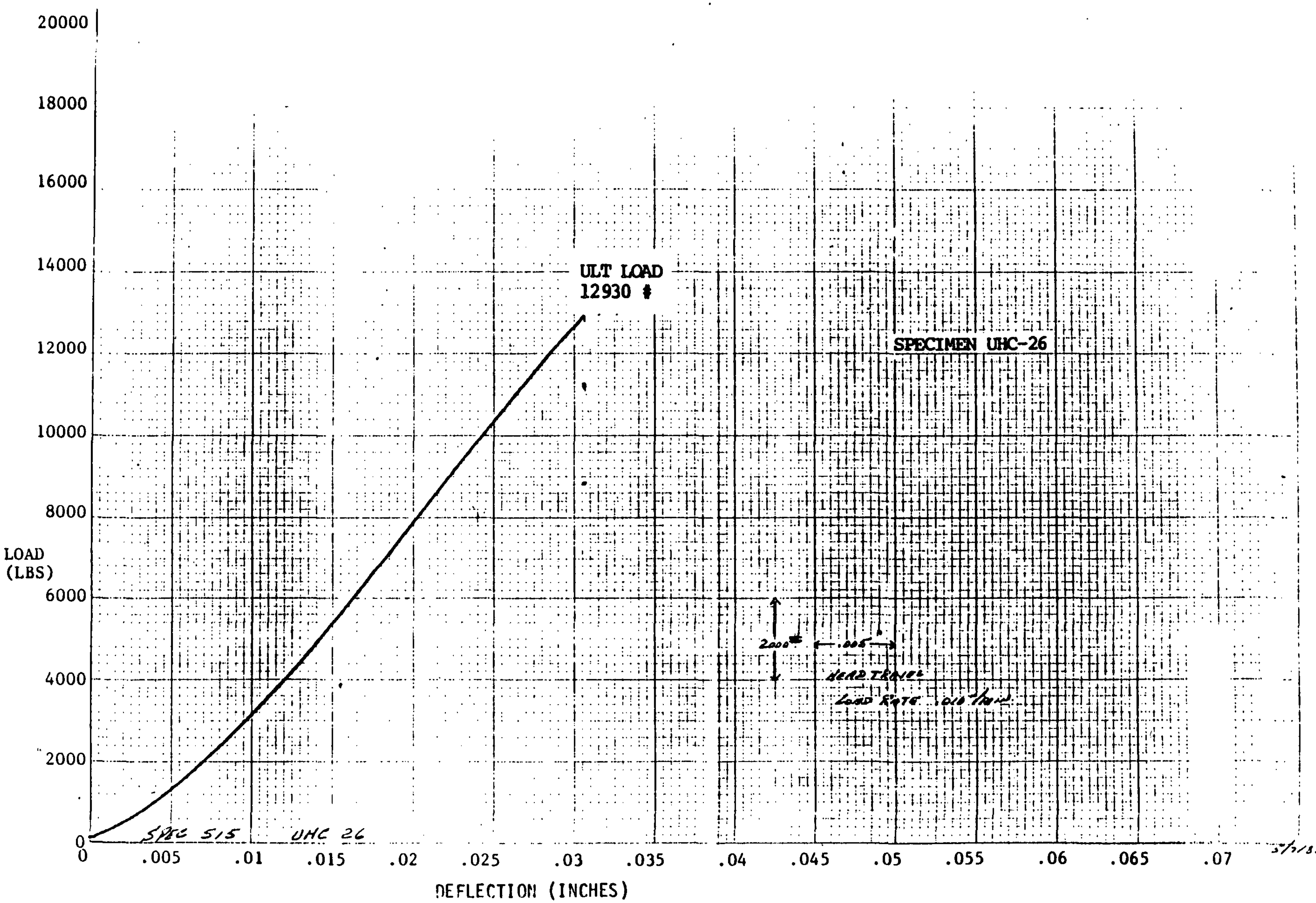
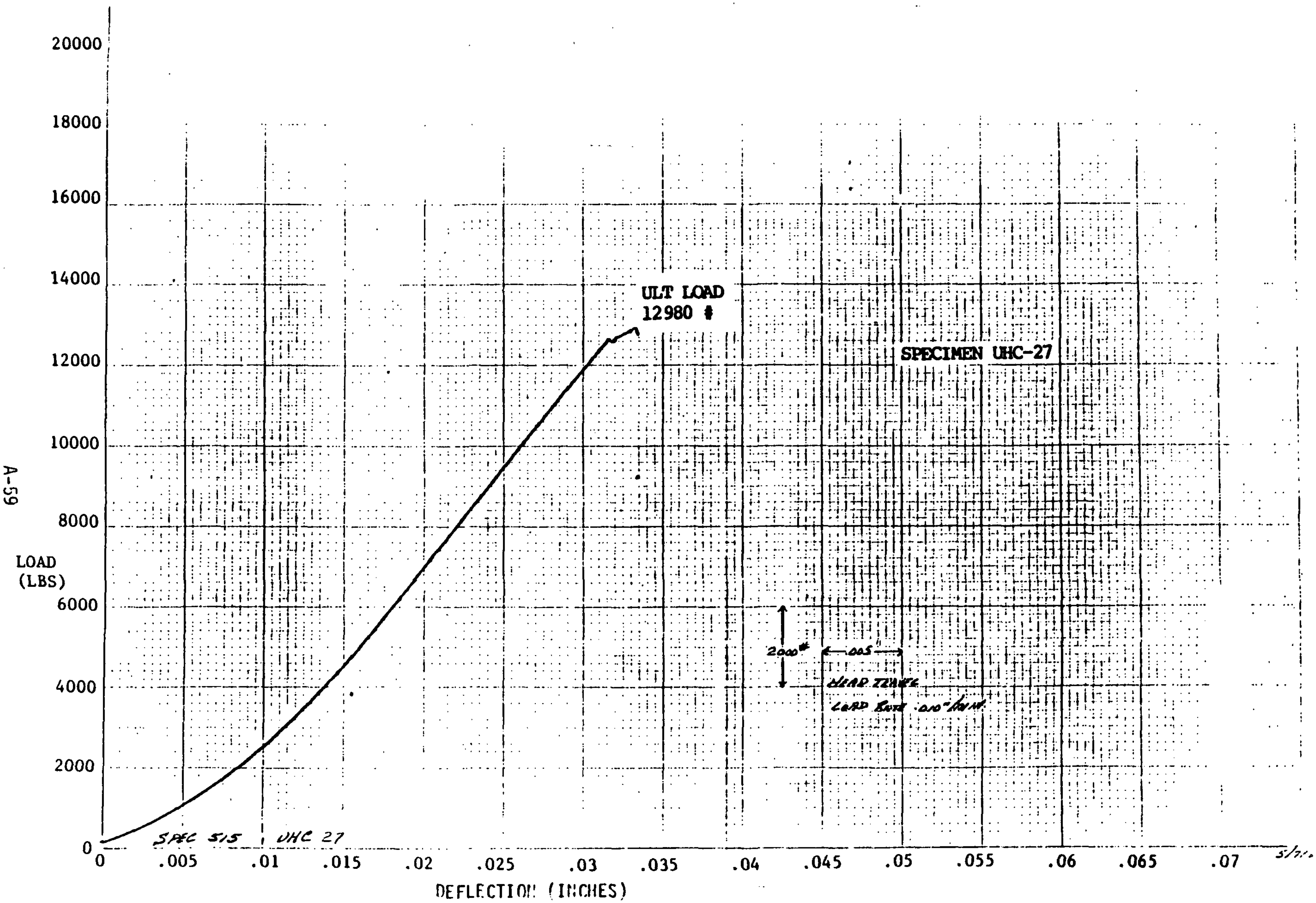
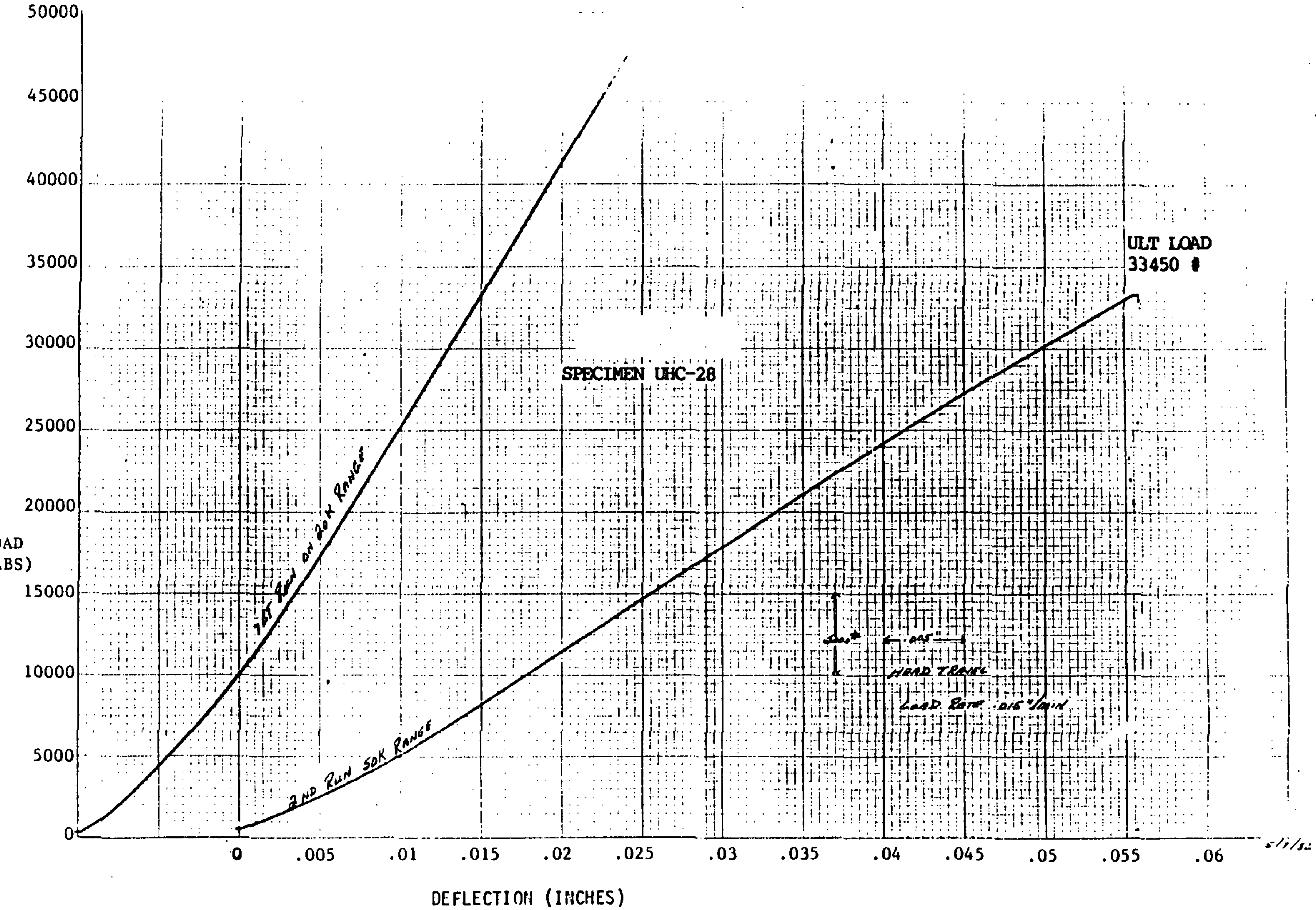

ULT LOAD
12880 #
SPECIMEN UHC-25
LOAD
(LBS)
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
0
.005
.01
.015
.02
.025
.03
.035
.04
.045
.05
.055
.06
.065
.07
DEFLECTION (INCHES)
SPEC 515 UHC 25
2000#
.005
HEAD TRAVEL
LOAD RATE .010"/MIN



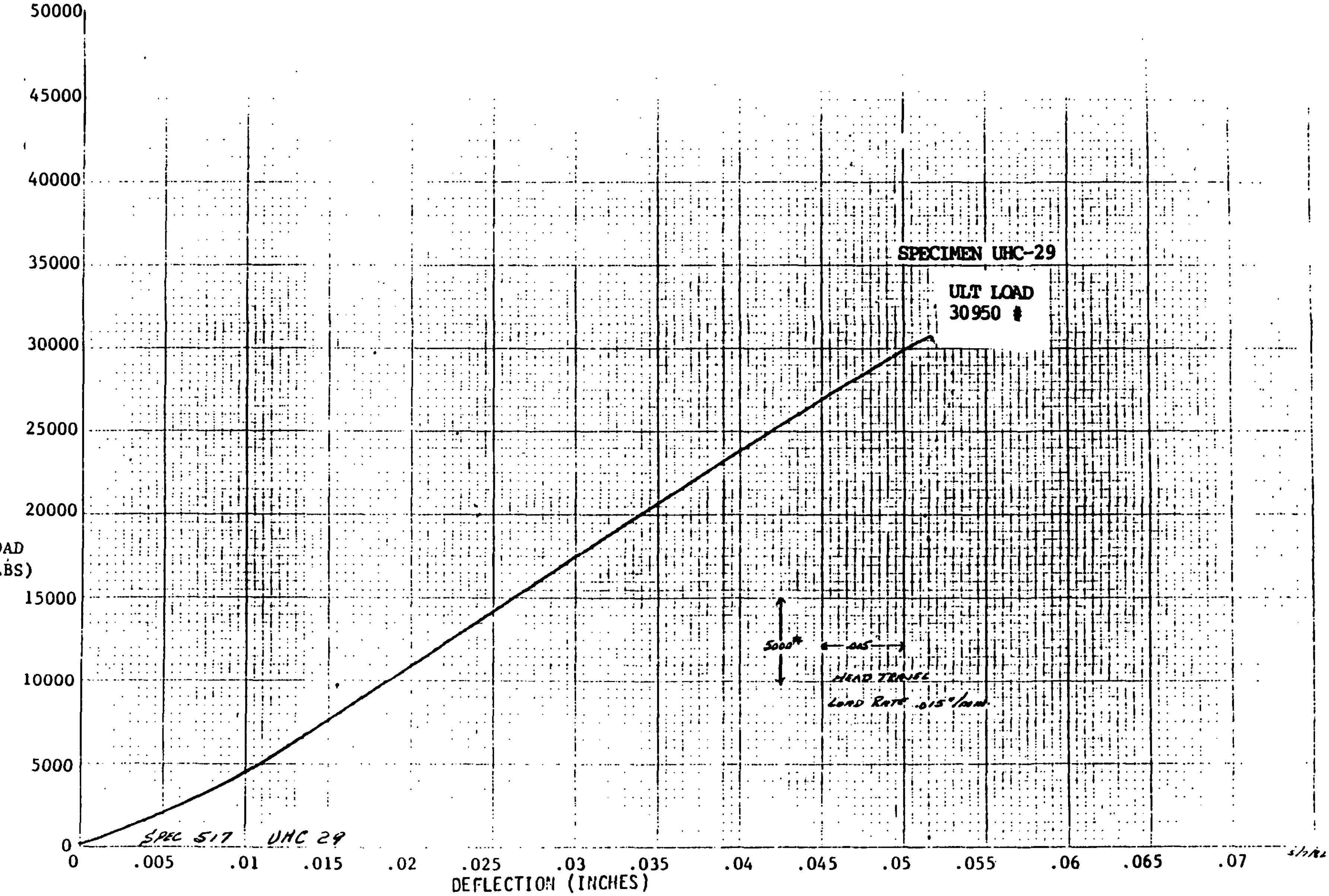
ULT LOAD
12930 #
SPECIMEN UHC-26
LOAD
(LBS)
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
0
.005
.01
.015
.02
.025
.03
.035
.04
.045
.05
.055
.06
.065
.07
DEFLECTION (INCHES)
SPEC 515
UHC 26
2000#
.005
HEAD TRAVEL
LOAD RATE .010"/MIN



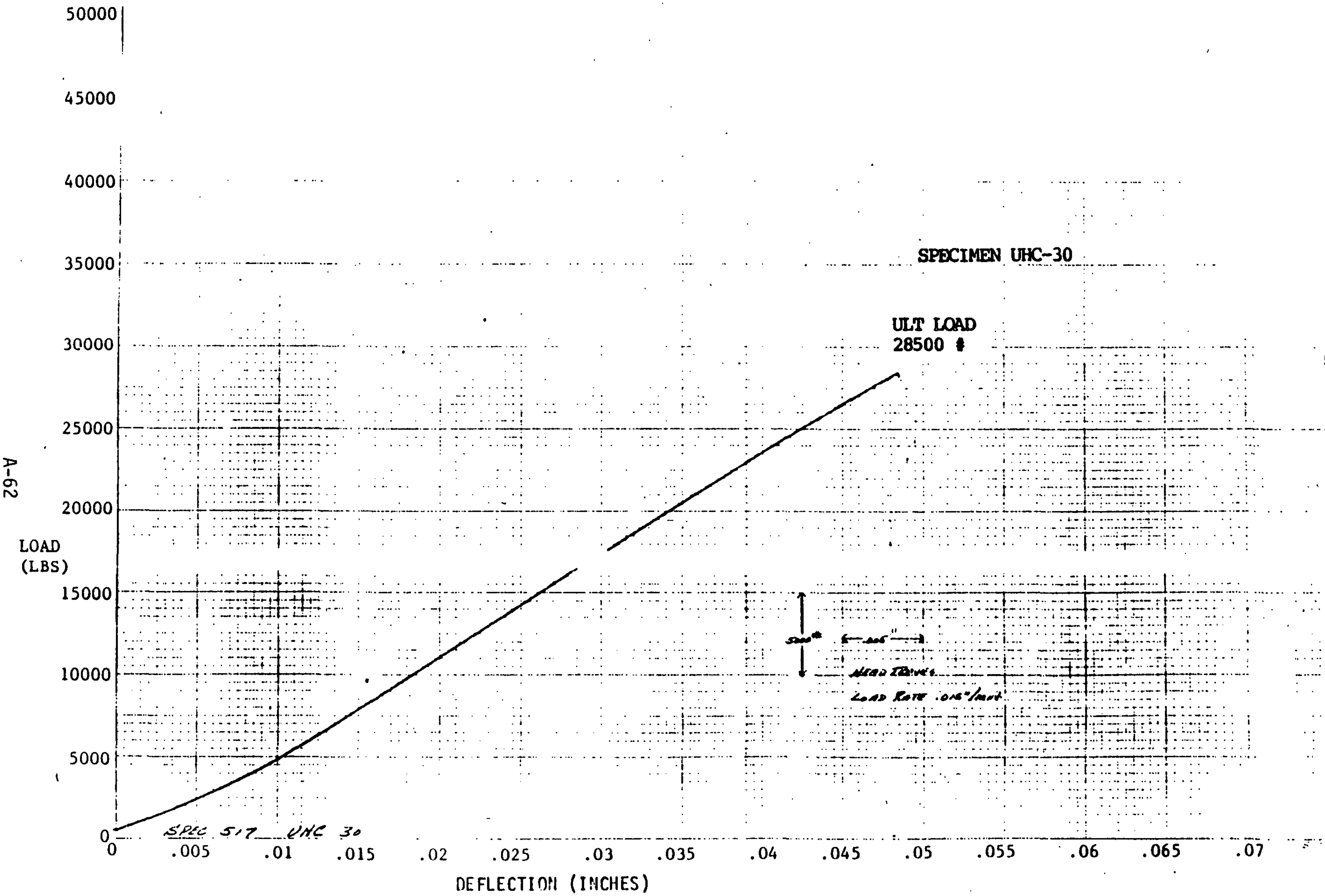
ULT LOAD
12980 #
SPECIMEN UHC-27
LOAD
(LBS)
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
0
.005
.01
.015
.02
.025
.03
.035
.04
.045
.05
.055
.06
.065
.07
DEFLECTION (INCHES)
SPEC 515
UHC 27
2000#
.005"
HEAD TRAVEL



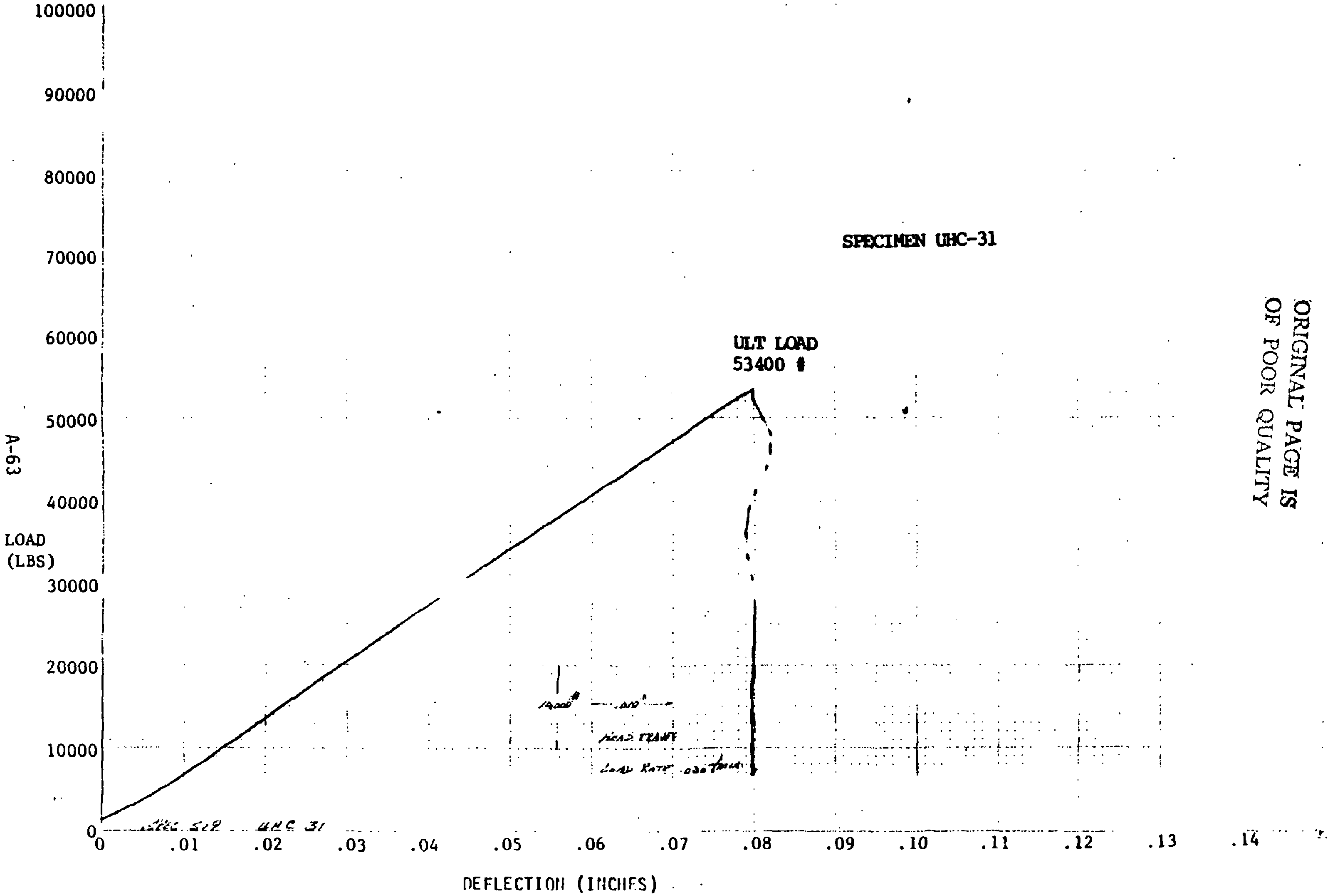
SPECIMEN UHC-28
ULT LOAD
33450 #
1ST RUN ON 20K RANGE
2ND RUN 50K RANGE
HEAD TRAVEL
LOAD (LBS)
DEFLECTION (INCHES)

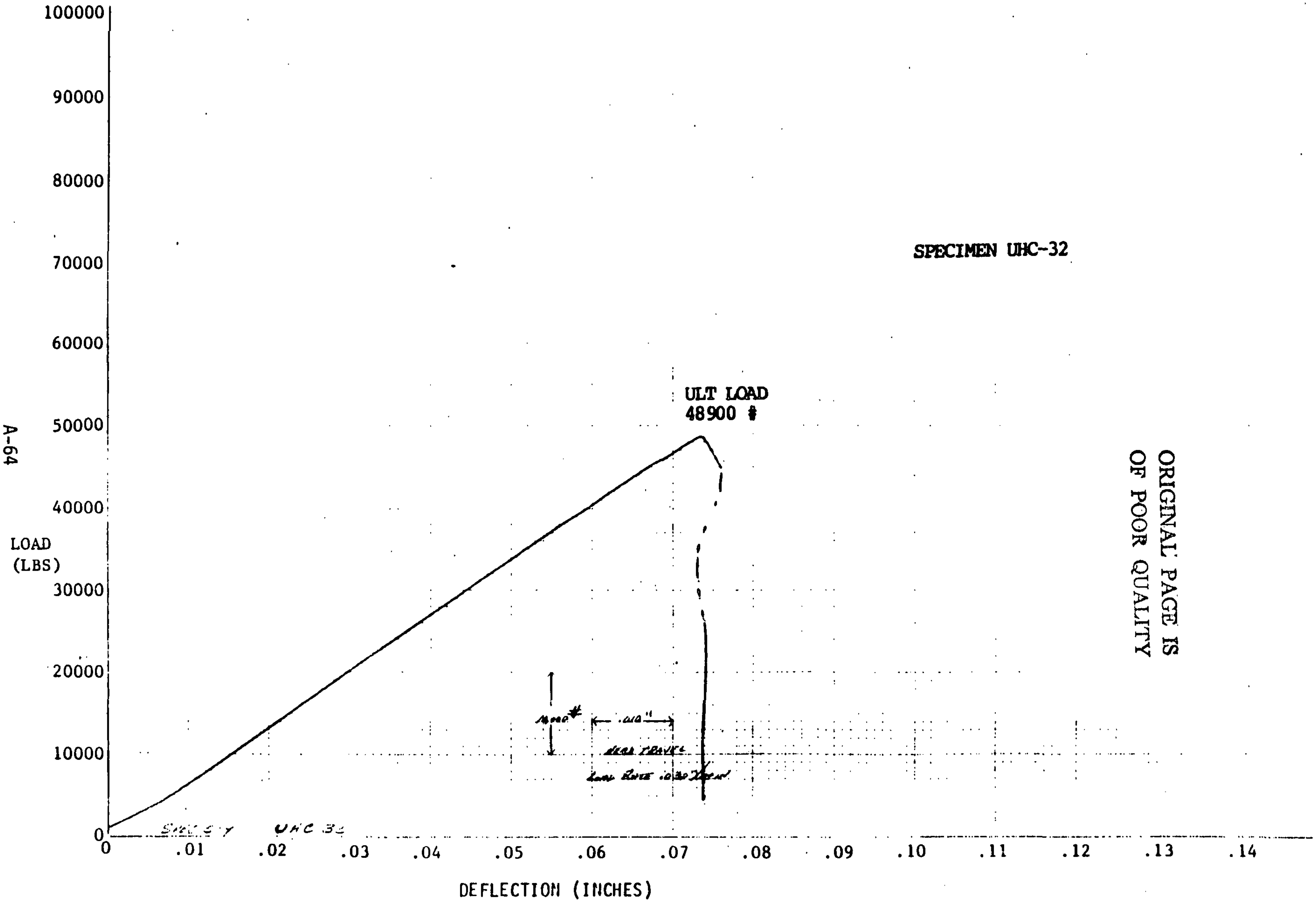


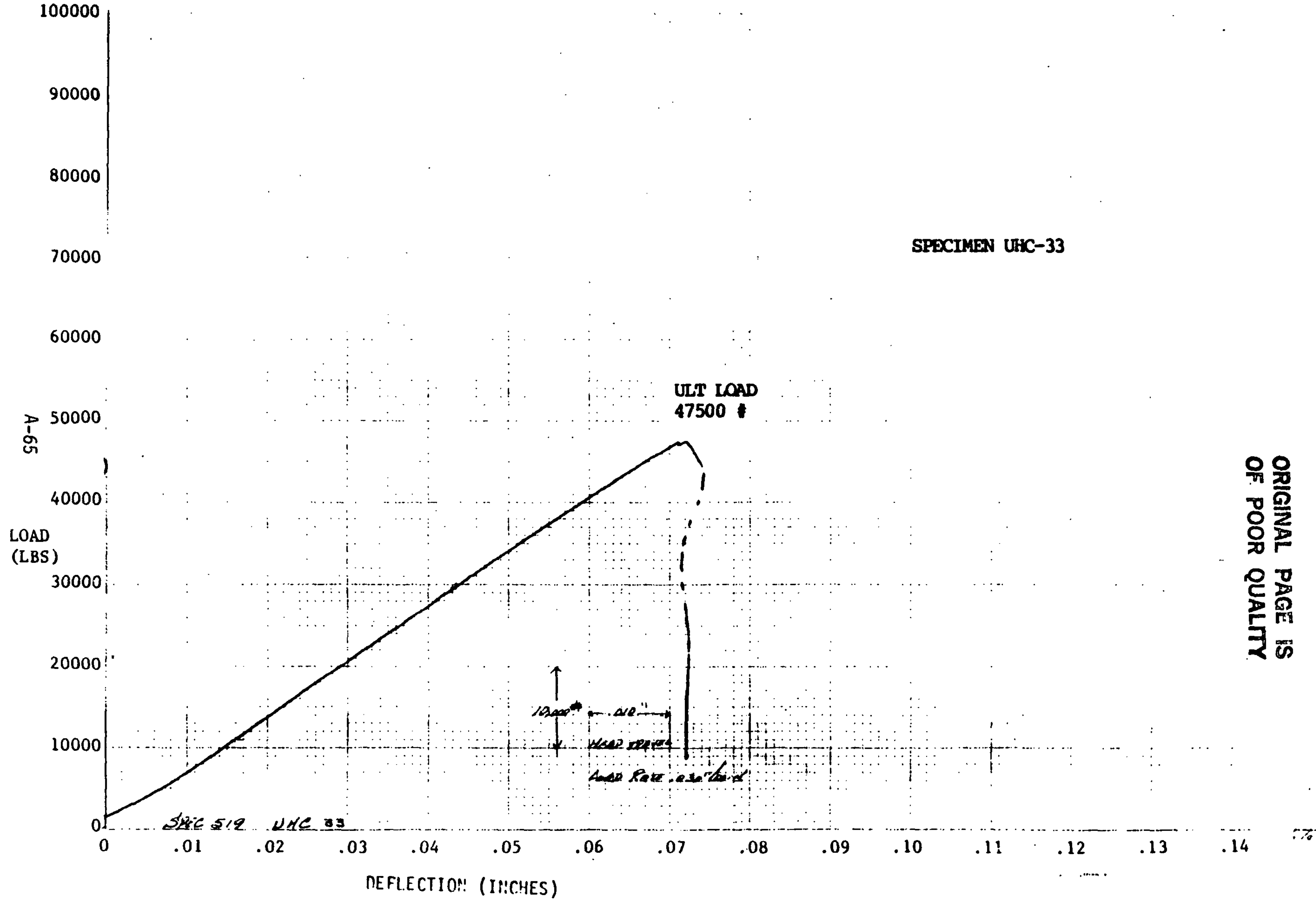
SPECIMEN UHC-29
ULT LOAD
30950 #
5000#
.005
HEAD TRAVEL
LOAD RATE .015"/MIN
SPEC 517 UHC 29
LOAD
(LBS)
DEFLECTION (INCHES)
0
5000
10000
15000
20000
25000
30000
35000
40000
45000
50000
0
.005
.01
.015
.02
.025
.03
.035
.04
.045
.05
.055
.06
.065
.07

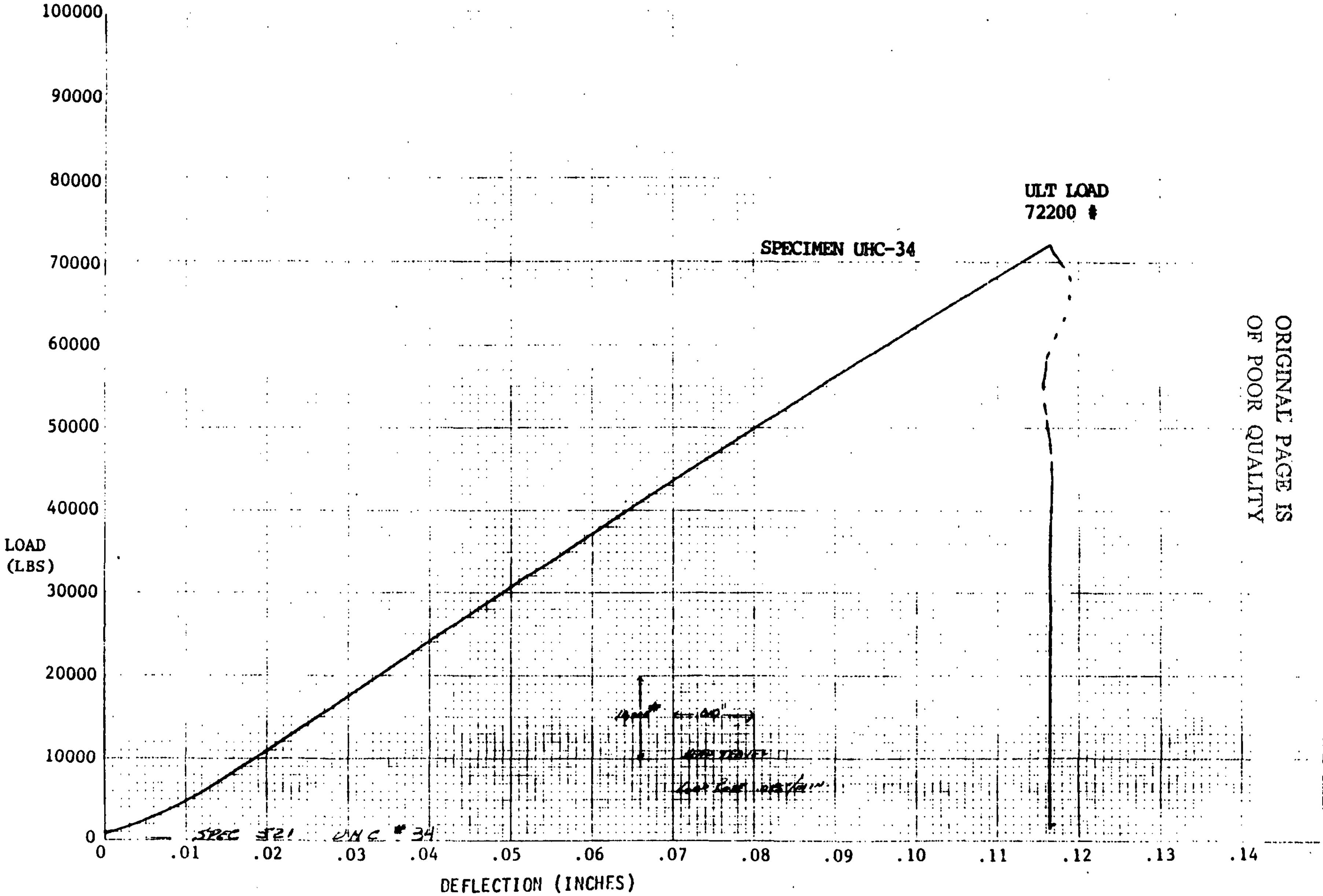


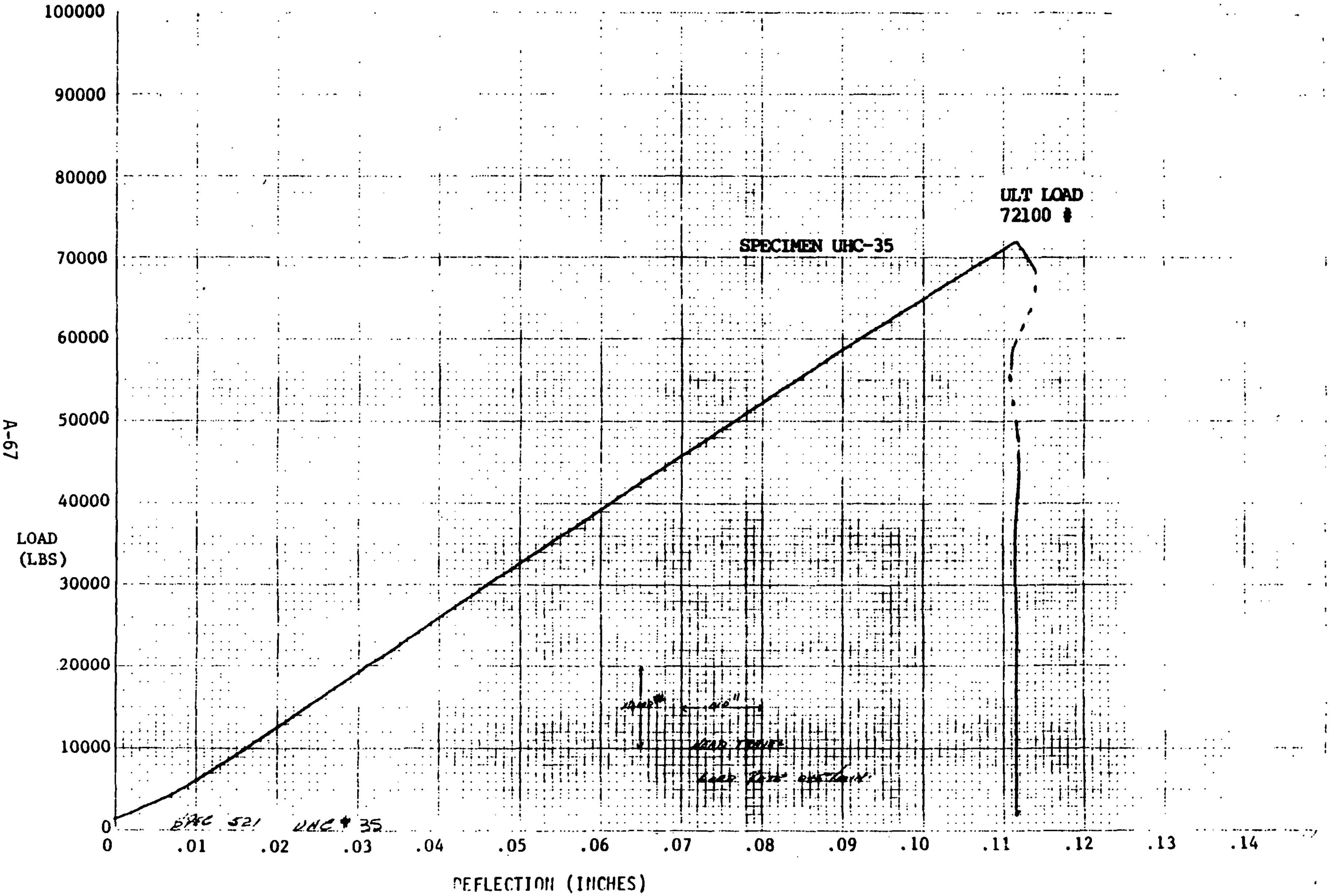
SPECIMEN UHC-30
ULT LOAD
28500 #
LOAD (LBS)
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
0
.005
.01
.015
.02
.025
.03
.035
.04
.045
.05
.055
.06
.065
.07
DEFLECTION (INCHES)
SPEC 517 UHC 30

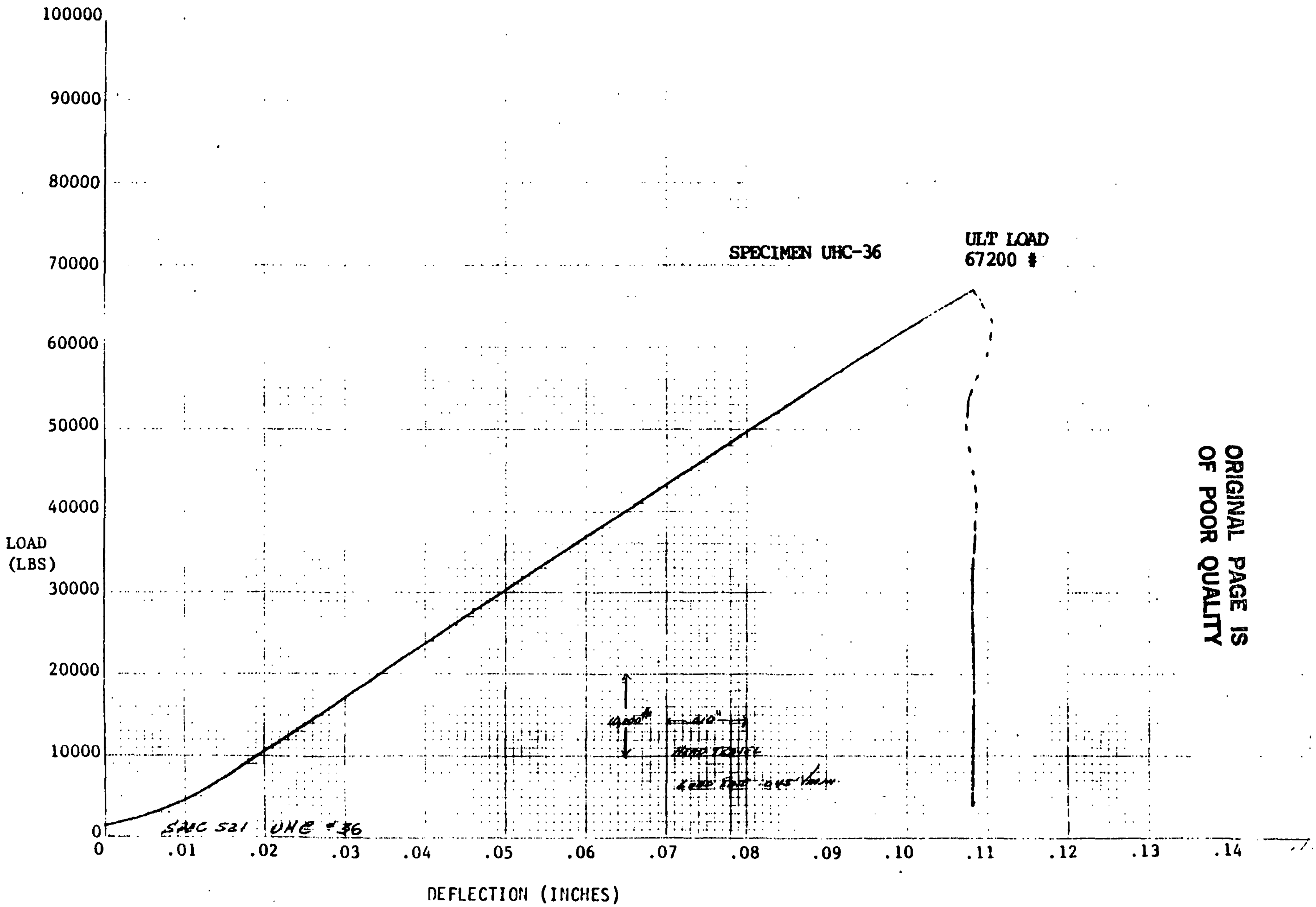

SPECIMEN UHC-31
ULT LOAD
53400 #
LOAD
(LBS)
100000
90000
80000
70000
60000
50000
40000
30000
20000
10000
0
0
.01
.02
.03
.04
.05
.06
.07
.08
.09
.10
.11
.12
.13
.14
DEFLECTION (INCHES)
UHC 31


SPECIMEN UHC-32
ULT LOAD
48900 #
LOAD
(LBS)
100000
90000
80000
70000
60000
50000
40000
30000
20000
10000
0
0
.01
.02
.03
.04
.05
.06
.07
.08
.09
.10
.11
.12
.13
.14
DEFLECTION (INCHES)


SPECIMEN UHC-33
ULT LOAD
47500 #
LOAD
(LBS)
100000
90000
80000
70000
60000
50000
40000
30000
20000
10000
0
0
.01
.02
.03
.04
.05
.06
.07
.08
.09
.10
.11
.12
.13
.14
DEFLECTION (INCHES)


ULT LOAD
72200 #
SPECIMEN UHC-34
LOAD
(LBS)
100000
90000
80000
70000
60000
50000
40000
30000
20000
10000
0
0
.01
.02
.03
.04
.05
.06
.07
.08
.09
.10
.11
.12
.13
.14
DEFLECTION (INCHES)


SPECIMEN UHC-35
ULT LOAD
72100 #
LOAD
(LBS)
DEFLECTION (INCHES)
BAC 521 UHC # 35
0
10000
20000
30000
40000
50000
60000
70000
80000
90000
100000
0
.01
.02
.03
.04
.05
.06
.07
.08
.09
.10
.11
.12
.13
.14



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APPENDIX B

PHASE I DOUBLE SHEAR TESTS

SPECIMEN CODING:

DST - DOUBLE SHEAR TENSION
DSC - DOUBLE SHEAR COMPRESSION

FAILURE MODES

DST	
1	Net-section failure. Most 0° plies sheared out. Cross plies failed in inter-fiber tension/shear. Some bolt bending.
2	Net-section failure. Most 0° plies sheared out. Cross plies failed in inter-fiber tension/shear. Some bolt bending.
3	1st run - doubler initiated de-bond but no catastrophic failure. 2nd run - net-section failure and doubler failure leading to net-section failure of specimen at load pin. Net-section failure at bolt occurred on nut side. Failure at load pin occurred on opposite side.
4	Net-section failure. Slightly more damage on head side of bolt. Some shear-out of 0° plies.
5	Bearing failure. Slight washer dig-in.
6	Net-section failure. Slightly more damage on head side. Some shear-out of 0° plies.
7	Tapered doubler failure and net-section failure at load pin.
8	Tapered doubler failure and net-section failure at load pin.
9	Tapered doubler failure and net-section failure at load pin. Slight buckling of plies on head side of bolt.
10	Bolt bending failure with bearing damage. Washer dig-in.
11	Bolt bending failure with bearing damage. Washer dig-in. Adhesive failure occurred on doubler (1 side) between outer plates.
12	Bolt bending and slight bearing failure
13	Bearing failure. Washer dig-in, both sides.
14	Doubler bond failure (adhesive failure). Some bearing damage in outer plates.
15	Bearing failure. Slight washer dig in. Buckling of outer plies.
16	Bearing failure. Hole elongated approximately 3d (3/4" dia). Extensive brooming and bearing damage.
17	Bearing failure. Washer dig in.
18	Bearing failure. Washer dig in.
19	Net-section failure. Bolt bending. Most of the 0° plies sheared out and cross plies failed in inter-fiber tension/shear along 45° and 90° lines.
20	Net-section failure. Bolt bending. Most of the 0° plies sheared out and cross plies failed in inter-fiber tension/shear along 45° and 90° lines.

DST (Continued)

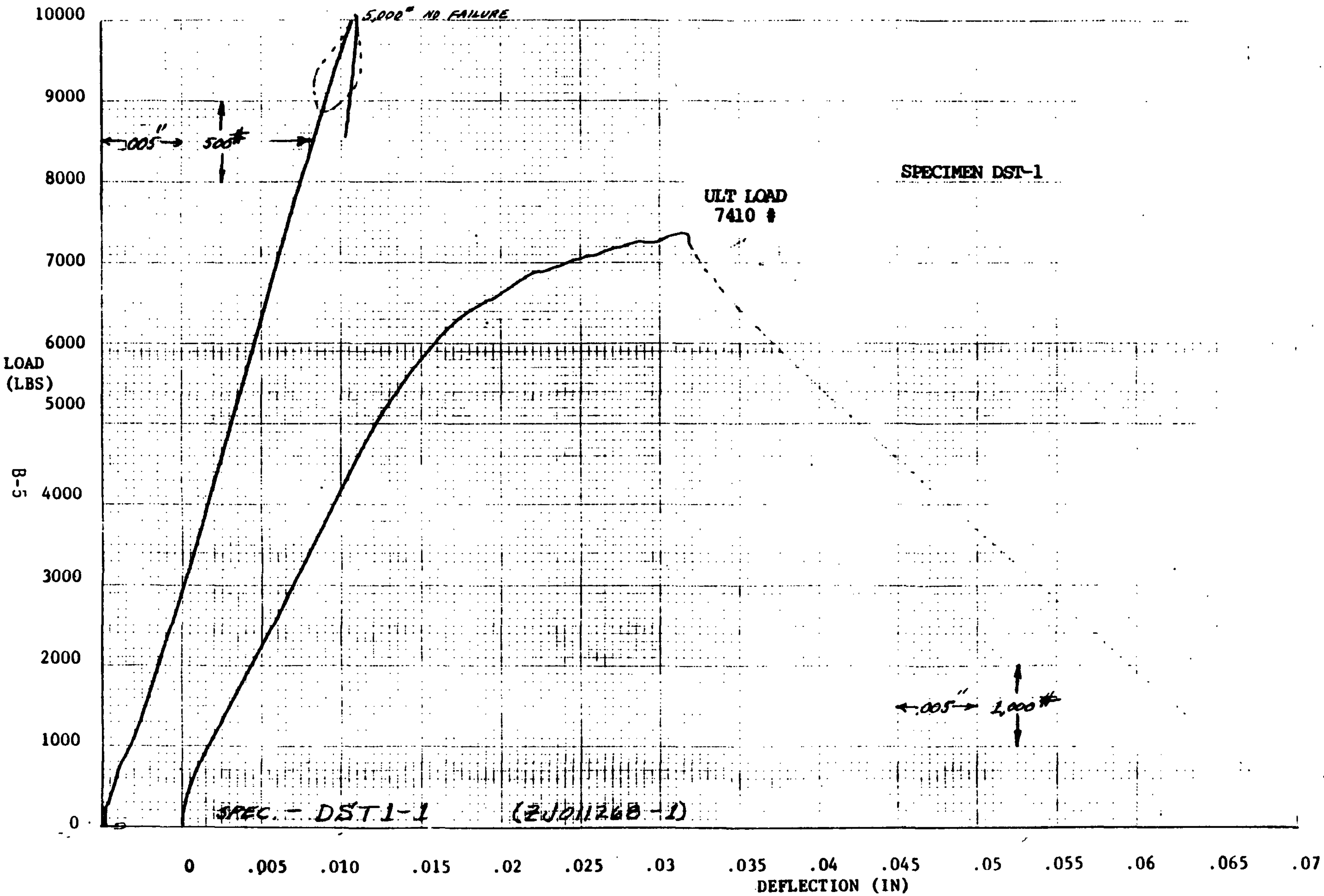
21	Net-section failure. Bolt bending. Most of the 0° plies sheared out and cross plies failed in inter-fiber tension/shear along 45° and 90° lines.
22	Apparent bearing failure. No ply buckling or delaminations on nut side. Outer ply buckling and delaminations on bolt side head. Inner ply buckling.
23	Tapered doubler failure and net-section failure at load pin
24	Net-section failure on nut side. Inner and outer 0° plies sheared out. Washer dig-in with outer buckling on head side. Also inner ply delaminations.
25	Bearing failure. Head-side - washer dig-in. Nut side - slight washer dig-in. Outer ply delaminated to edge of plate.
26	Tapered doubler failure
27	Tapered doubler failure.
28	Bolt bending failure. Slight bearing damage. Some washer dig-in.
29	Bolt bending failure. Slight bearing damage. Some washer dig-in.
30	Bolt bending failure. Slight bearing damage. Some washer dig-in.
31	Bearing failure. Not much visible damage besides cracks in outer plies and slight hole elongation.
32	Bearing failure. Washer dig-in both sides.
33	Bearing failure. Washer dig-in. Buckled plies.
34	Bearing failure. Washer dig-in. Damaged primarily in outer plates.
35	Bearing failure. Washer dig-in. Damaged primarily in outer plates.
36	Bearing failure. Washer dig-in. Damaged primarily in outer plates.

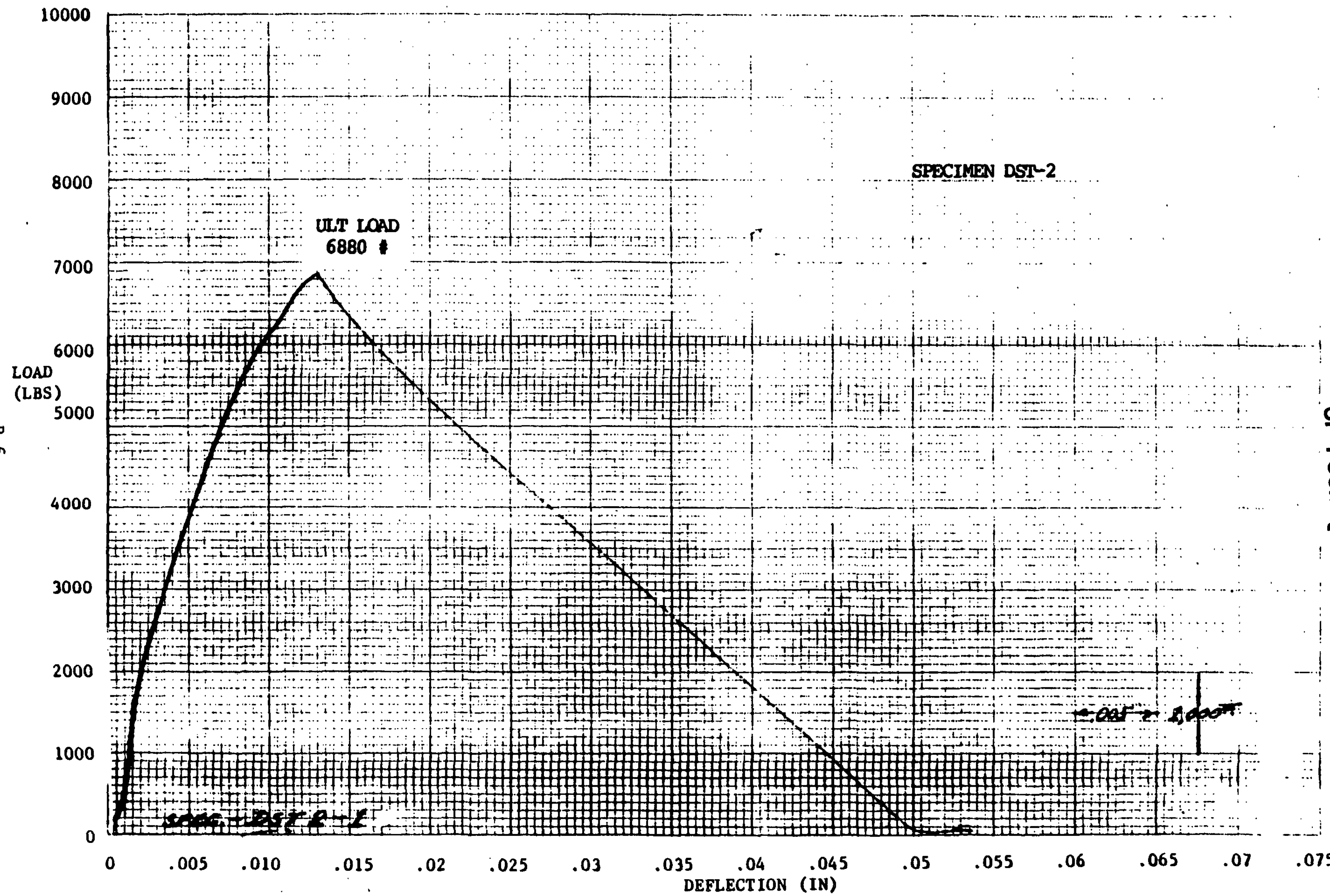
DSC

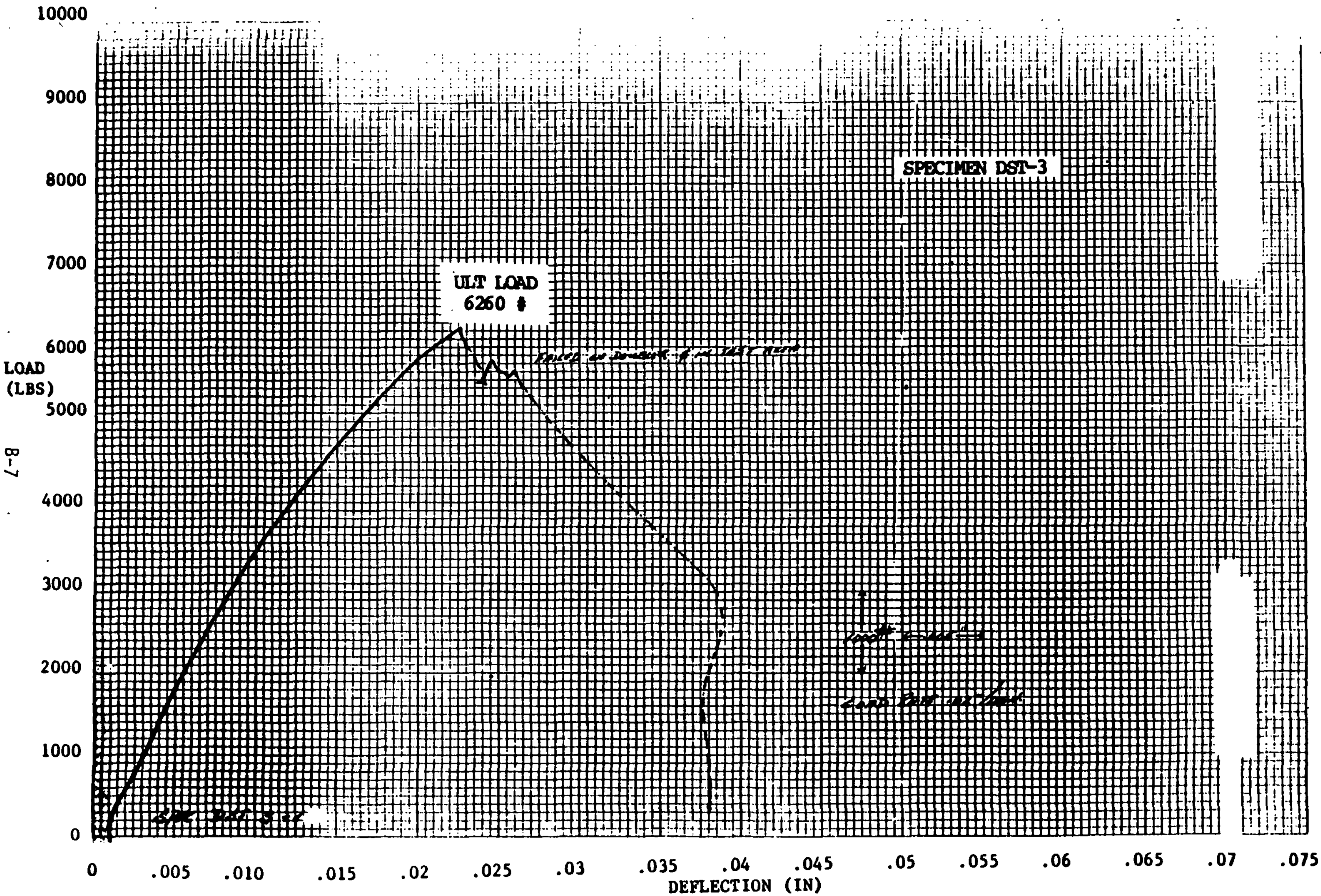
1	Failed below washer in compression on head side of outer plate. Bolt bending also occurred.
2	Failed below washer in compression on head side of outer plate. Slight bolt bending.
3	Bolt bending and some bearing damage showing.
4	Buckling of outer plies with moderate shear/buckling failure. Occurred away from hole at edge of washer.
5	Apparent bearing failure. Slight fiber splitting and delaminations of plies.
6	Buckling and delamination of outer plies with shear/buckling failure. Occurred away from hole at edge of washer.

<u>DSC</u> (Continued)

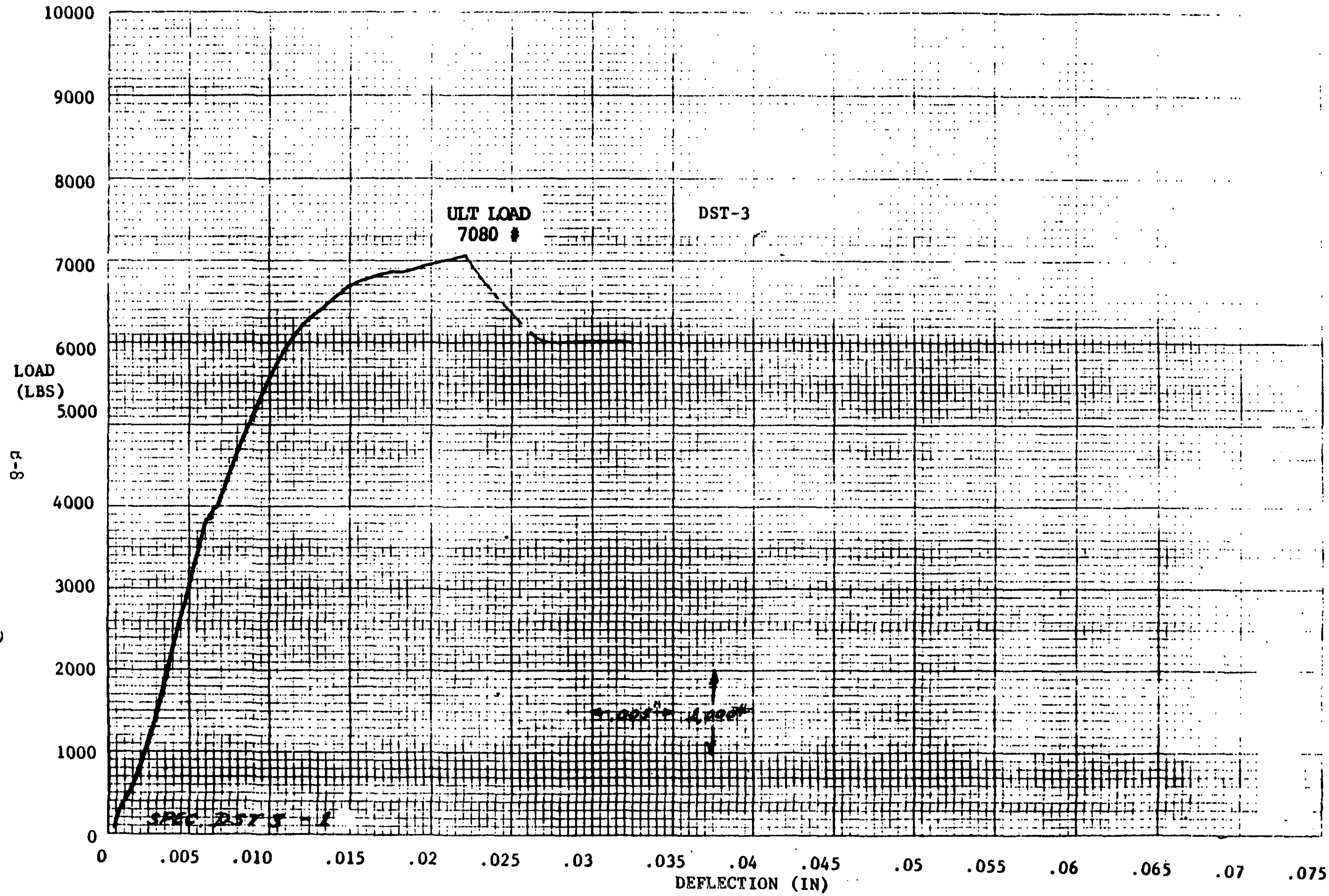
7	Bearing failure
8	Bearing failure
9	Bearing failure
10	Bearing failure
11	Bearing failure
12	Bearing failure
13	Bearing failure
14	Bearing failure
15	Bearing failure
16	Bearing failure
17	Bearing failure
18	Bearing failure
19	Failed in compression above bolt, somewhat along 45° line. Slight bolt bending.
20	Failed in compression above bolt, somewhat along 45° line. Slight bolt bending.
21	Failed in compression above bolt, somewhat along 45° line. Slight bolt bending.
22	Outer plates buckled, delaminated and failed in shear/buckling below bolt at edge of washer.
23	Outer plates buckled, delaminated and failed in shear/buckling below bolt at edge of washer. Damage on head side of bolt.
24	Bearing failure. Some plies failed along 45° line.
25	Bearing failure.
26	Bearing failure.
27	Bearing failure.
28	Bolt bending and bearing failure
29	Bolt bending and bearing failure
30	Bolt bending and bearing failure
31	Bearing failure
32	Bearing failure
33	Bearing failure
34	Bearing failure
35	Bearing failure
36	Bearing failure.


5,000# NO FAILURE
.005"
500#
SPECIMEN DST-1
ULT LOAD
7410 #
LOAD
(LBS)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
.005"
1,000#
SPEC. - DST1-1
(ZJ011268-1)
0
.005
.010
.015
.02
.025
.03
.035
.04
.045
.05
.055
.06
.065
.07
DEFLECTION (IN)


SPECIMEN DST-2
ULT LOAD
6880 #
LOAD
(LBS)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
0
.005
.010
.015
.02
.025
.03
.035
.04
.045
.05
.055
.06
.065
.07
.075
DEFLECTION (IN)



SPECIMEN DST-3
ULT LOAD
6260 #
LOAD
(LBS)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
0
.005
.010
.015
.02
.025
.03
.035
.04
.045
.05
.055
.06
.065
.07
.075
DEFLECTION (IN)


ULT LOAD
7080 #
DST-3
LOAD
(LBS)
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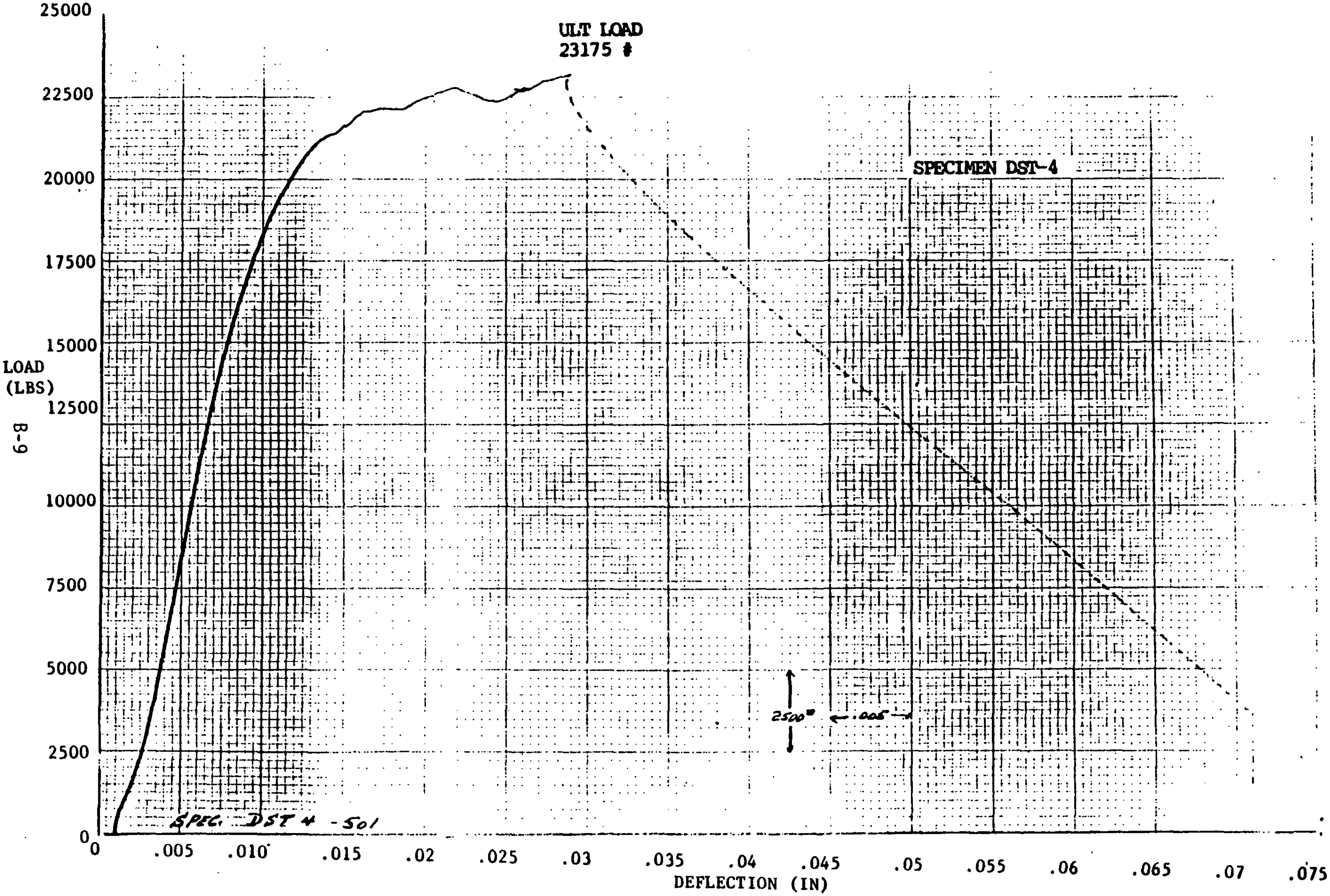
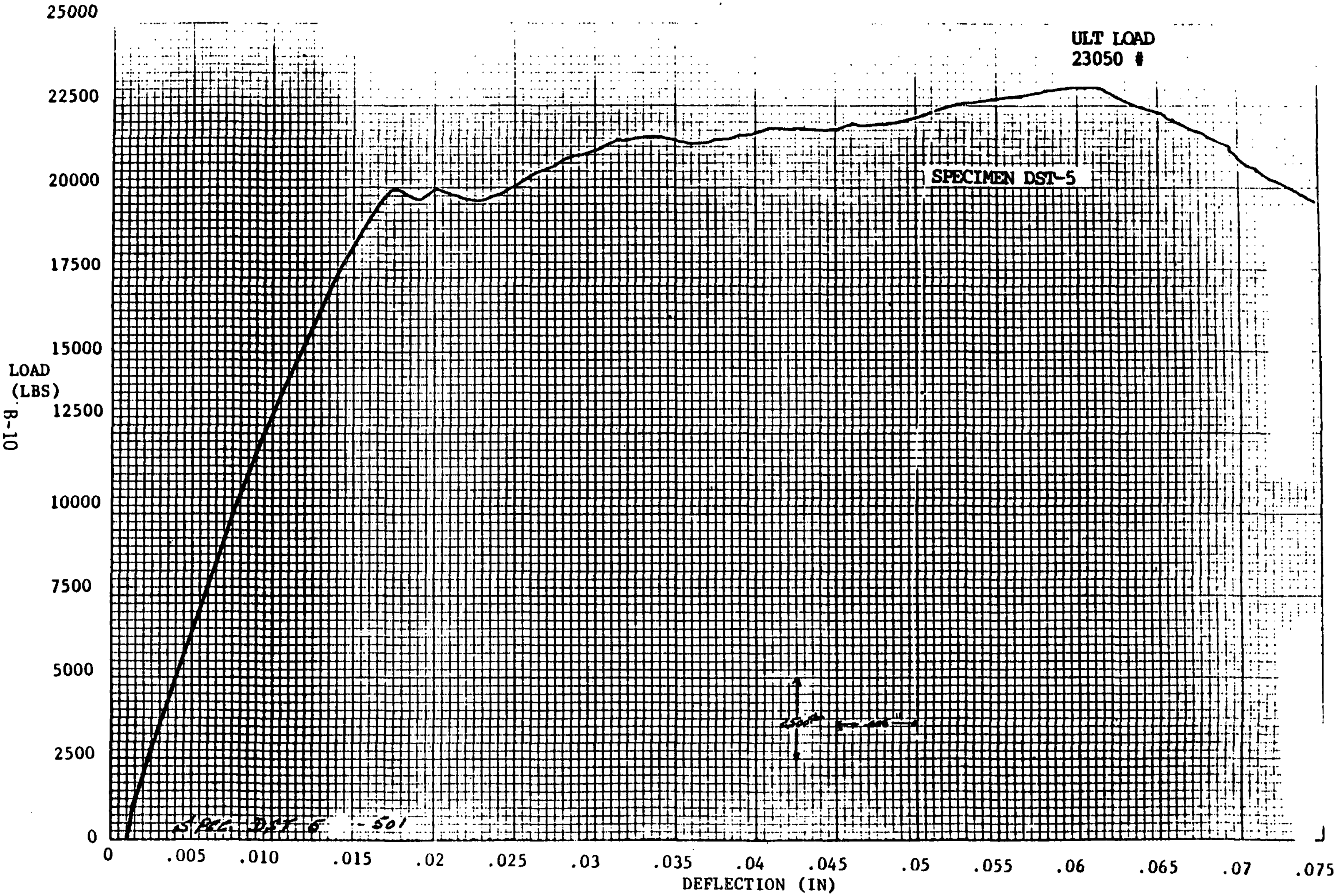
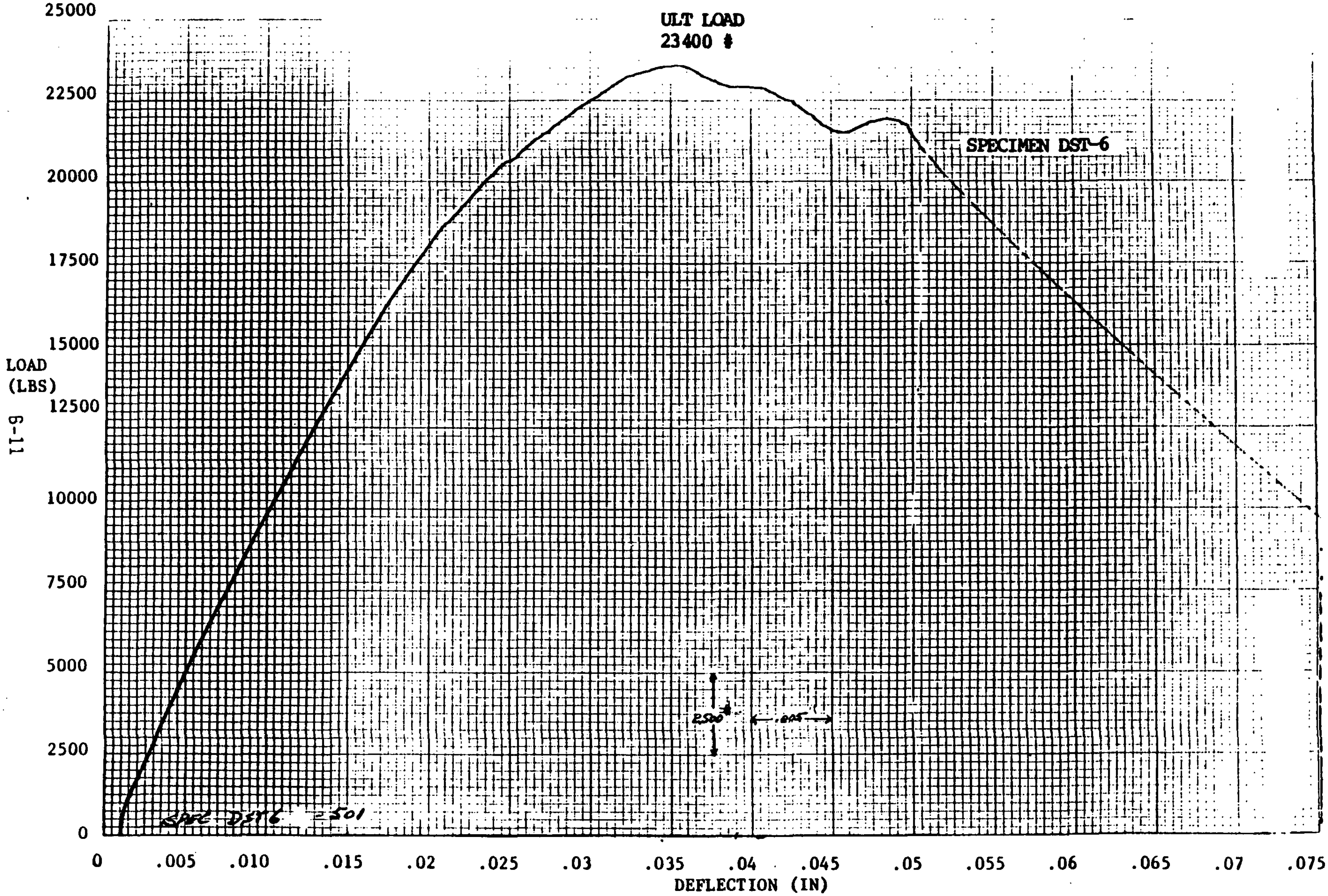
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
0
.005
.010
.015
.02
.025
.03
.035
.04
.045
.05
.055
.06
.065
.07
.075
DEFLECTION (IN)



ULT LOAD
23175 #
SPECIMEN DST-4
SPEC. DST 4 -501
2500#
.005
LOAD (LBS)
DEFLECTION (IN)
25000
22500
20000
17500
15000
12500
10000
7500
5000
2500
0
0
.005
.010
.015
.02
.025
.03
.035
.04
.045
.05
.055
.06
.065
.07
.075


ULT LOAD
23050 #
SPECIMEN DST-5
LOAD
(LBS)
25000
22500
20000
17500
15000
12500
10000
7500
5000
2500
0
0
.005
.010
.015
.02
.025
.03
.035
.04
.045
.05
.055
.06
.065
.07
.075
DEFLECTION (IN)



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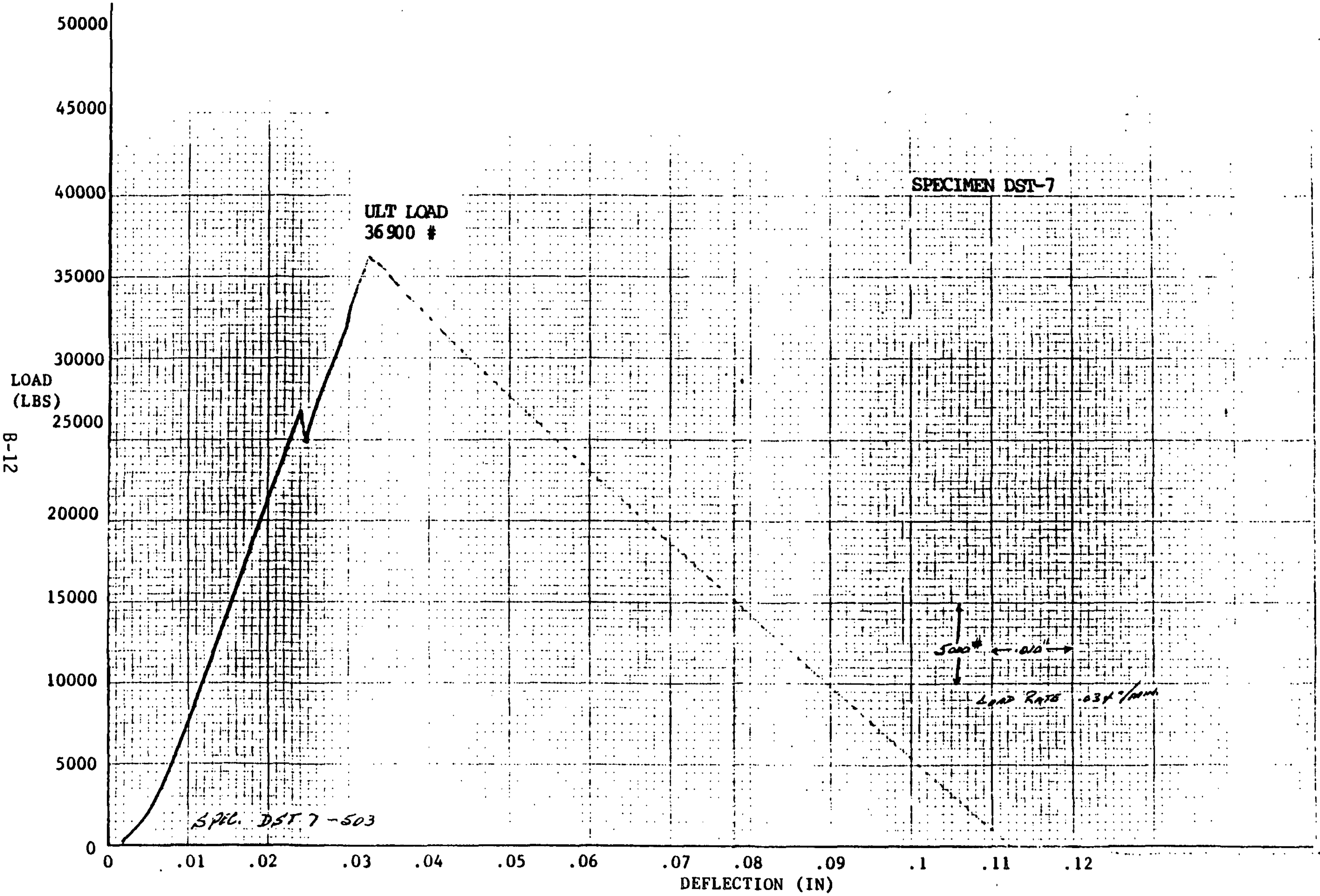

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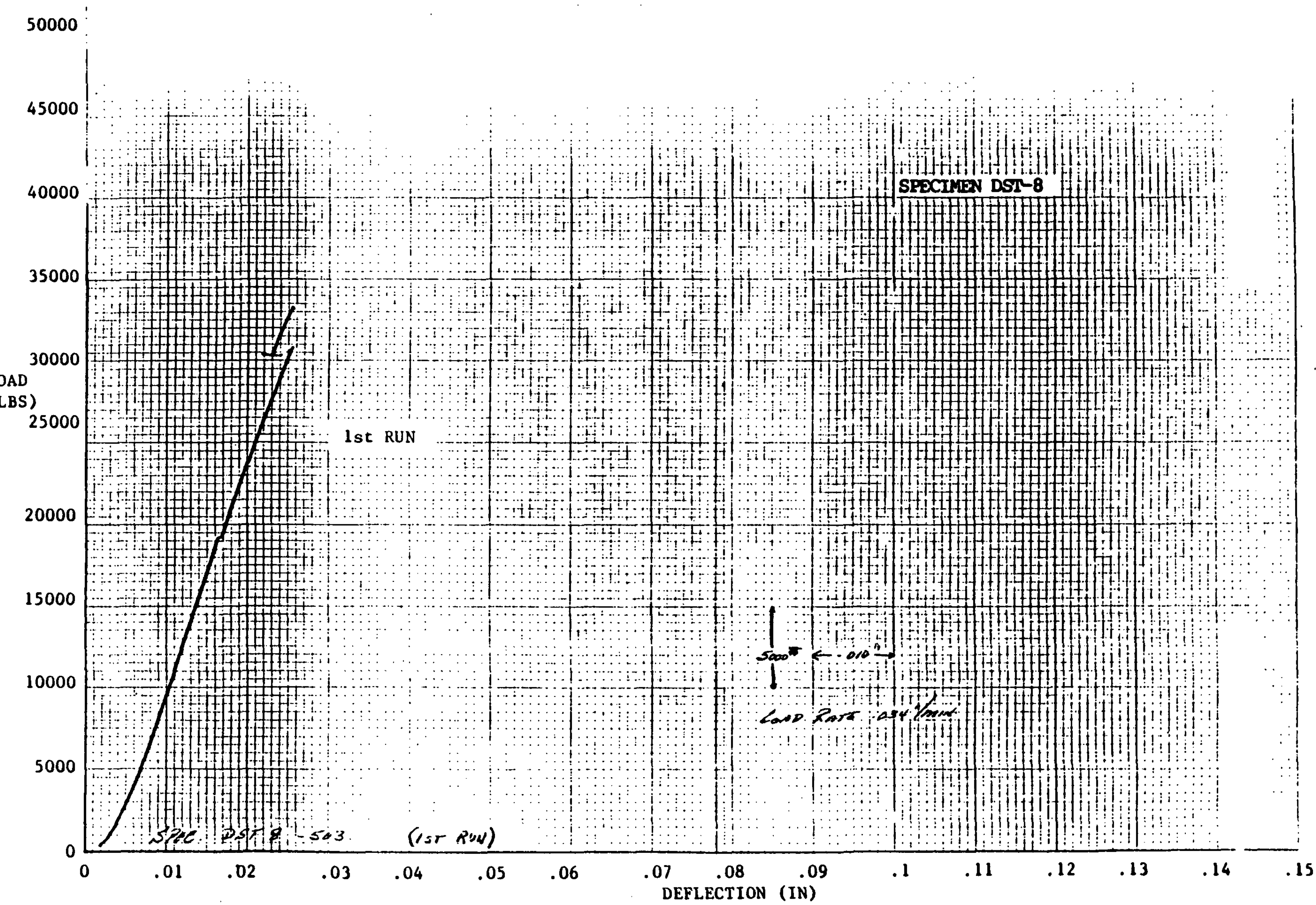

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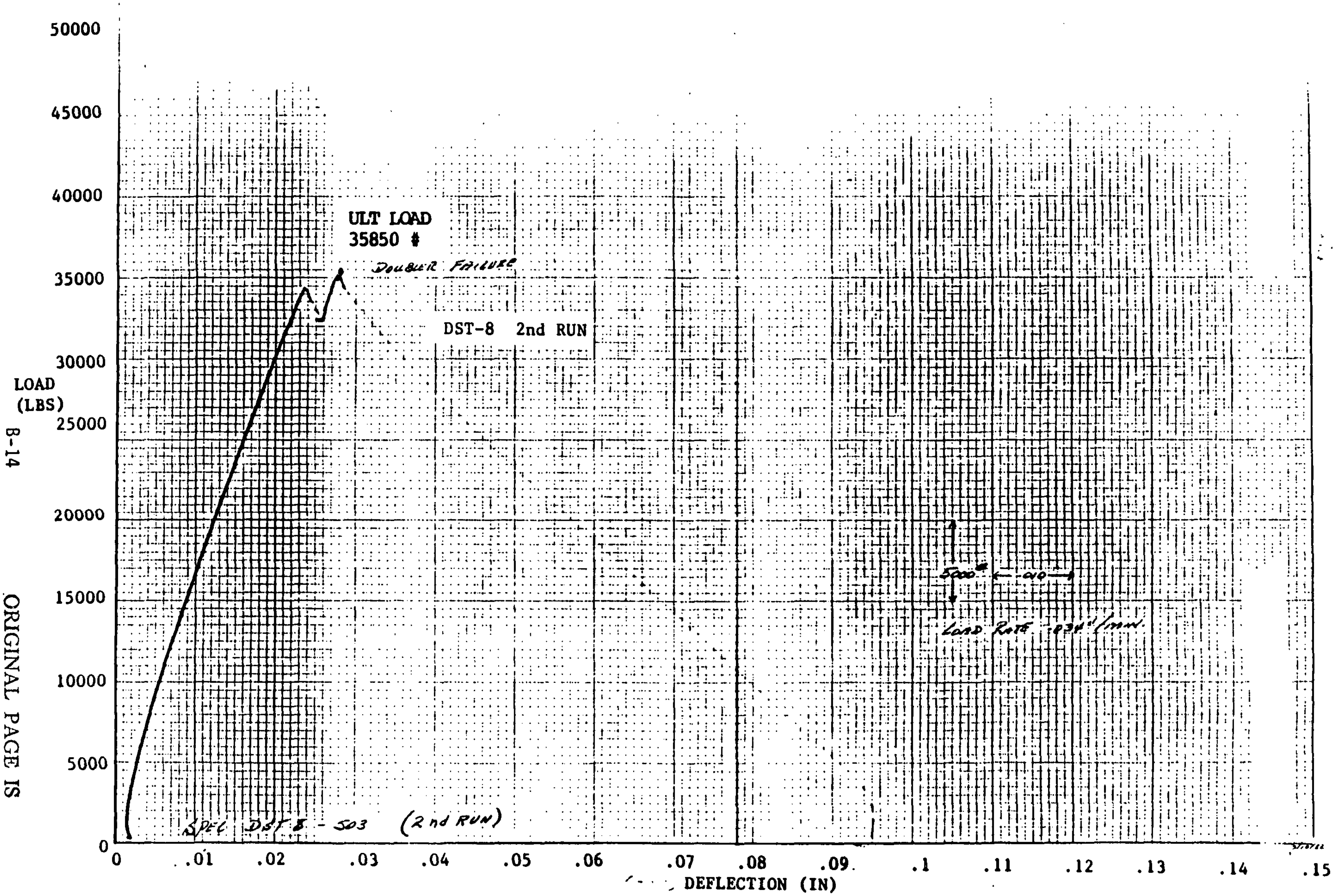
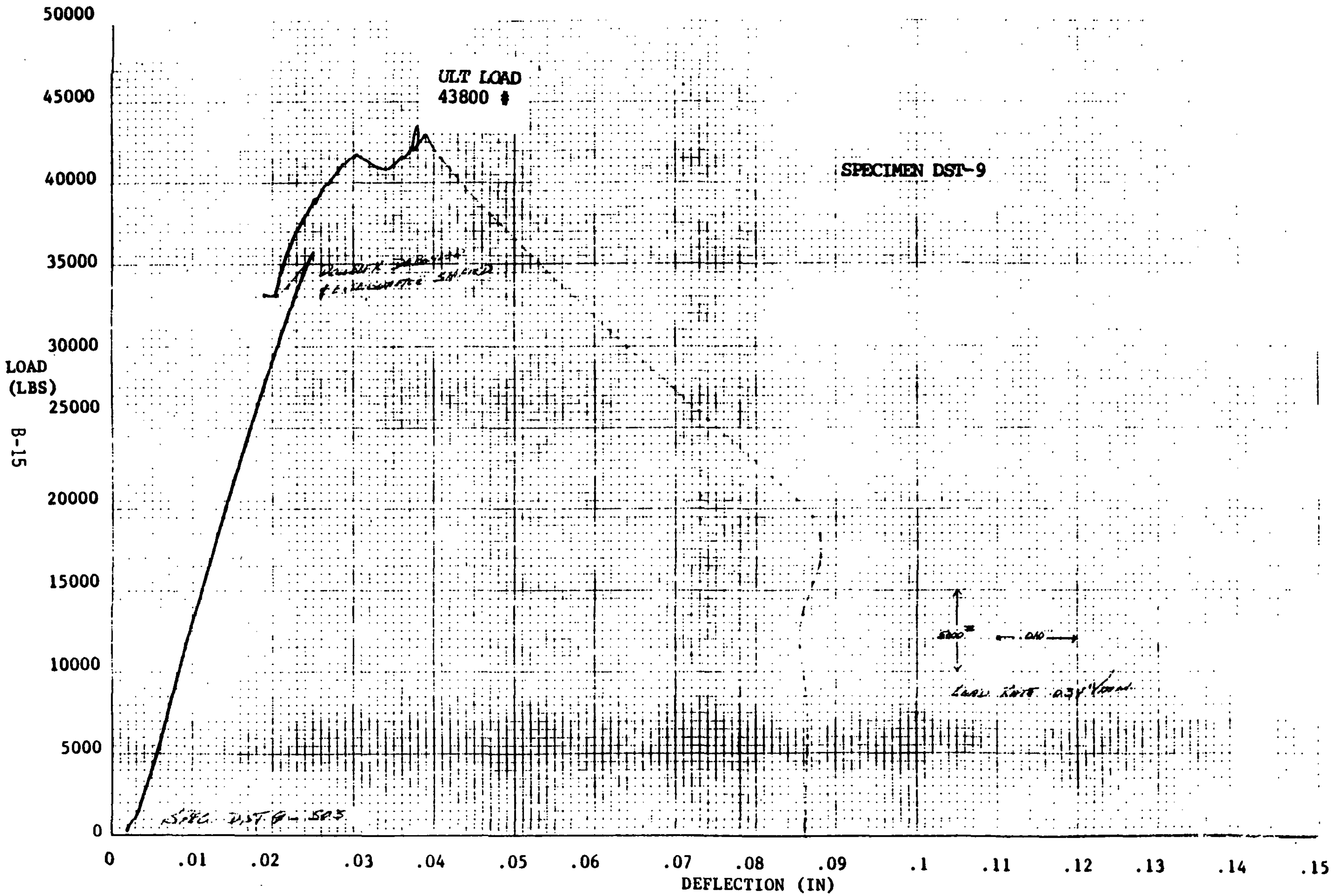

ULT LOAD
35850 #
DOUBLER FAILURE
DST-8 2nd RUN
LOAD
(LBS)
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
0
.01
.02
.03
.04
.05
.06
.07
.08
.09
.1
.11
.12
.13
.14
.15
DEFLECTION (IN)
5000#
.010
LOAD RATE .034"/MIN.
SPEC DST 8 - 503 (2nd RUN)


ULT LOAD
43800 #
SPECIMEN DST-9
LOAD (LBS)
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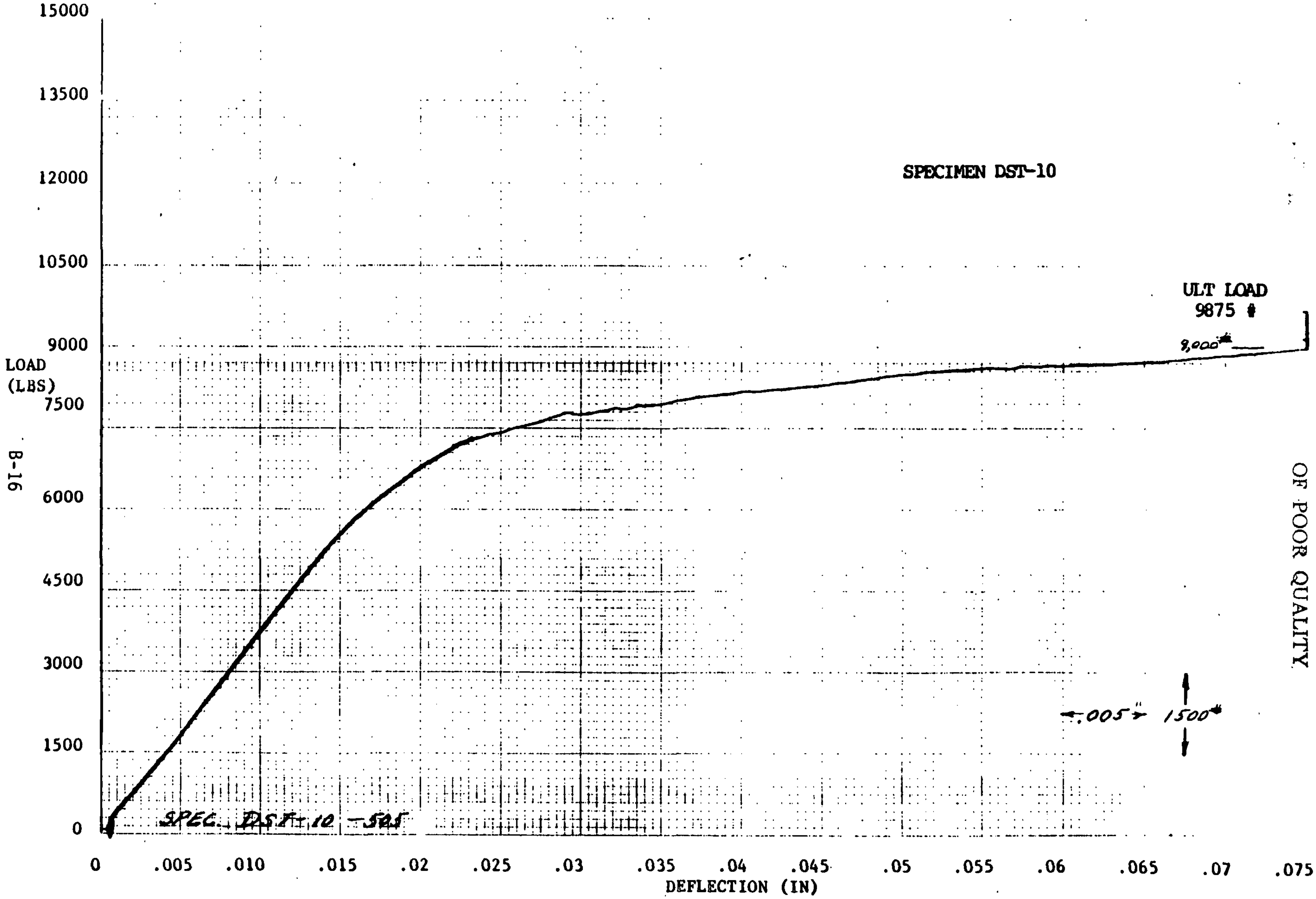
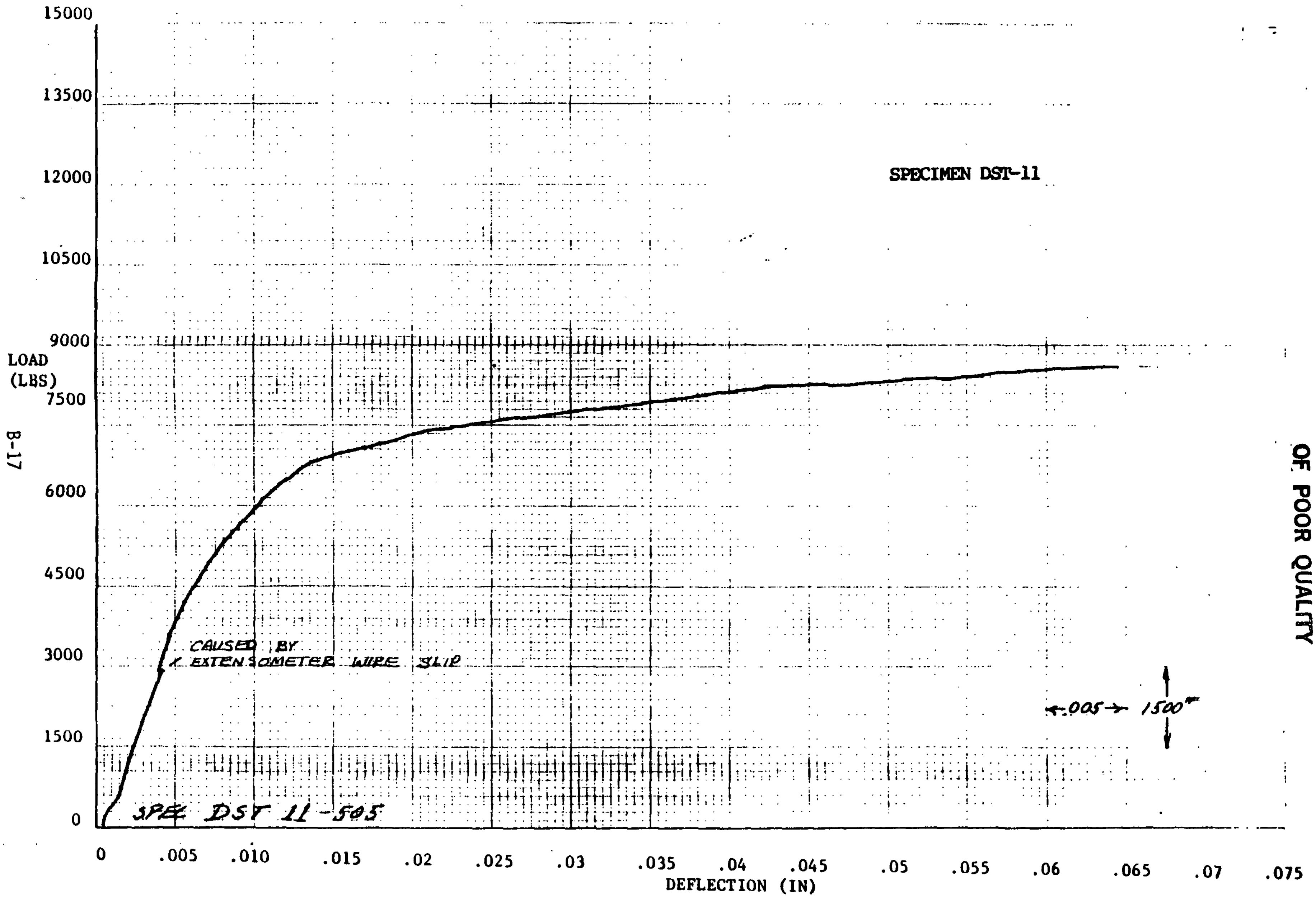
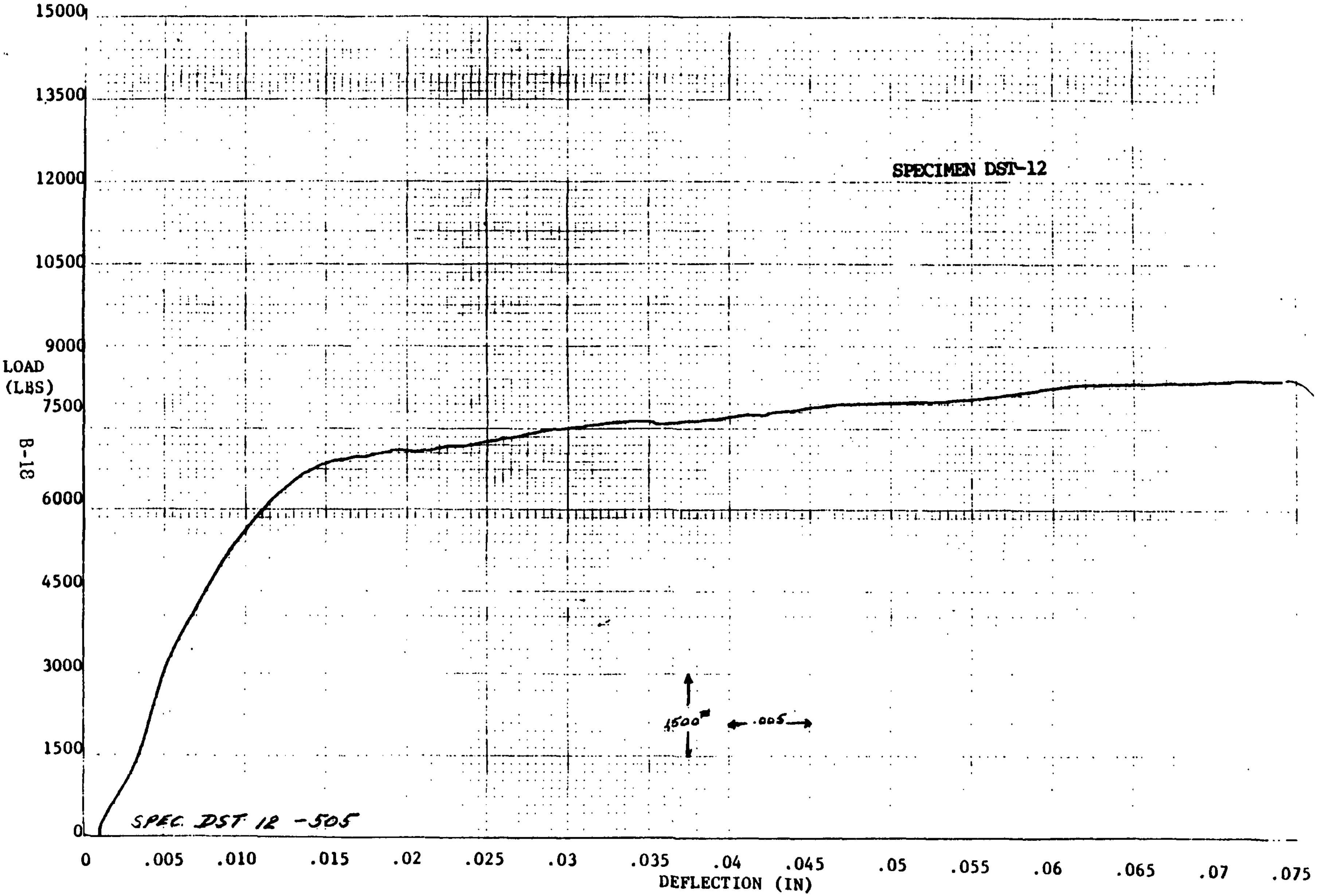
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
DEFLECTION (IN)
0
.01
.02
.03
.04
.05
.06
.07
.08
.09
.1
.11
.12
.13
.14
.15


SPECIMEN DST-10
ULT LOAD
9875 #
9,000#
LOAD (LBS)
15000
13500
12000
10500
9000
7500
6000
4500
3000
1500
0
0
.005
.010
.015
.02
.025
.03
.035
.04
.045
.05
.055
.06
.065
.07
.075
DEFLECTION (IN)
.005"
1500#
SPEC. DST-10 -505


SPECIMEN DST-11
15000
13500
12000
10500
9000
7500
6000
4500
3000
1500
0
LOAD (LBS)
0
.005
.010
.015
.02
.025
.03
.035
.04
.045
.05
.055
.06
.065
.07
.075
DEFLECTION (IN)
CAUSED BY
X EXTENSOMETER WIRE SLIP
.005
1500
SPEC DST 11-505

B-17



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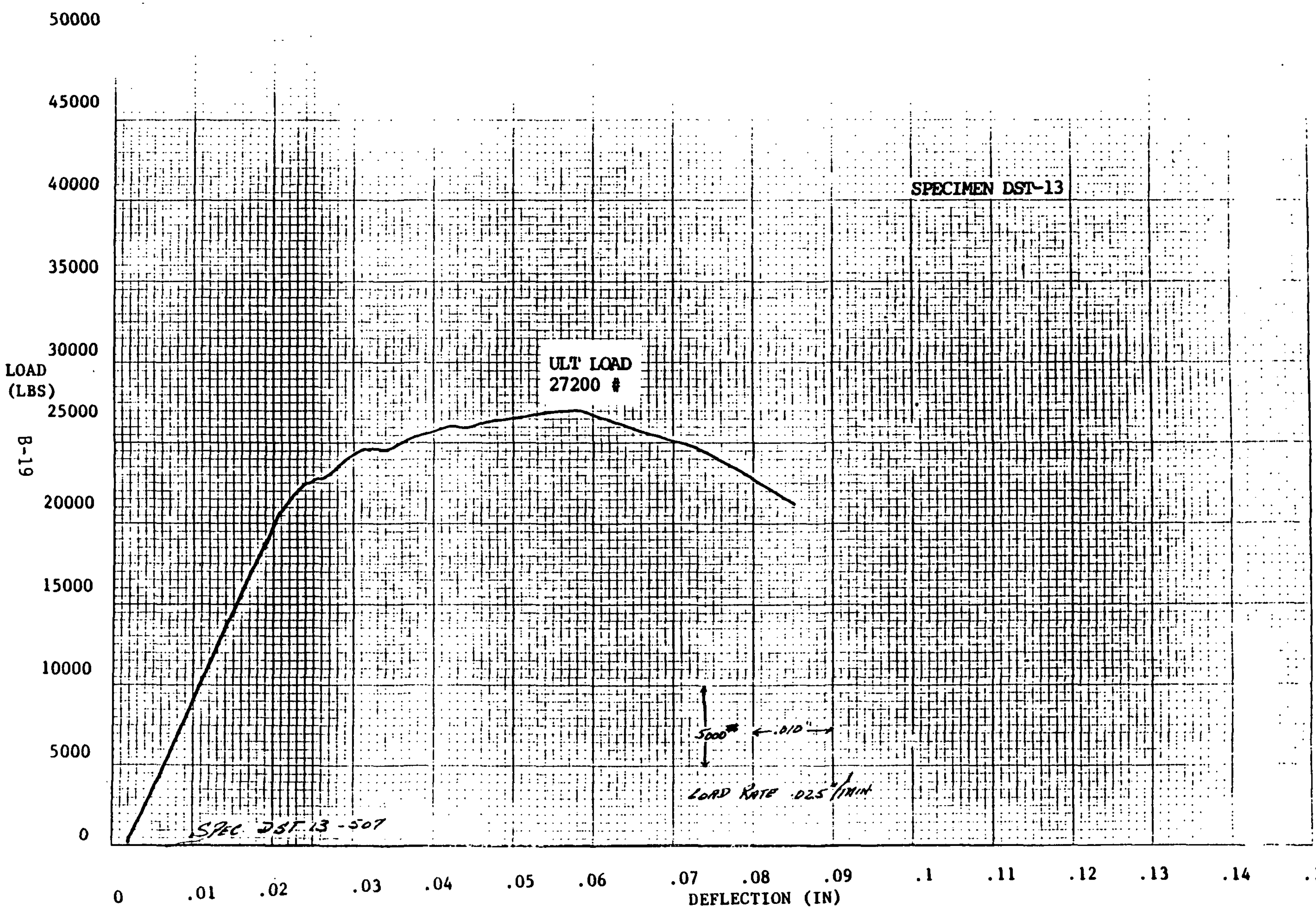
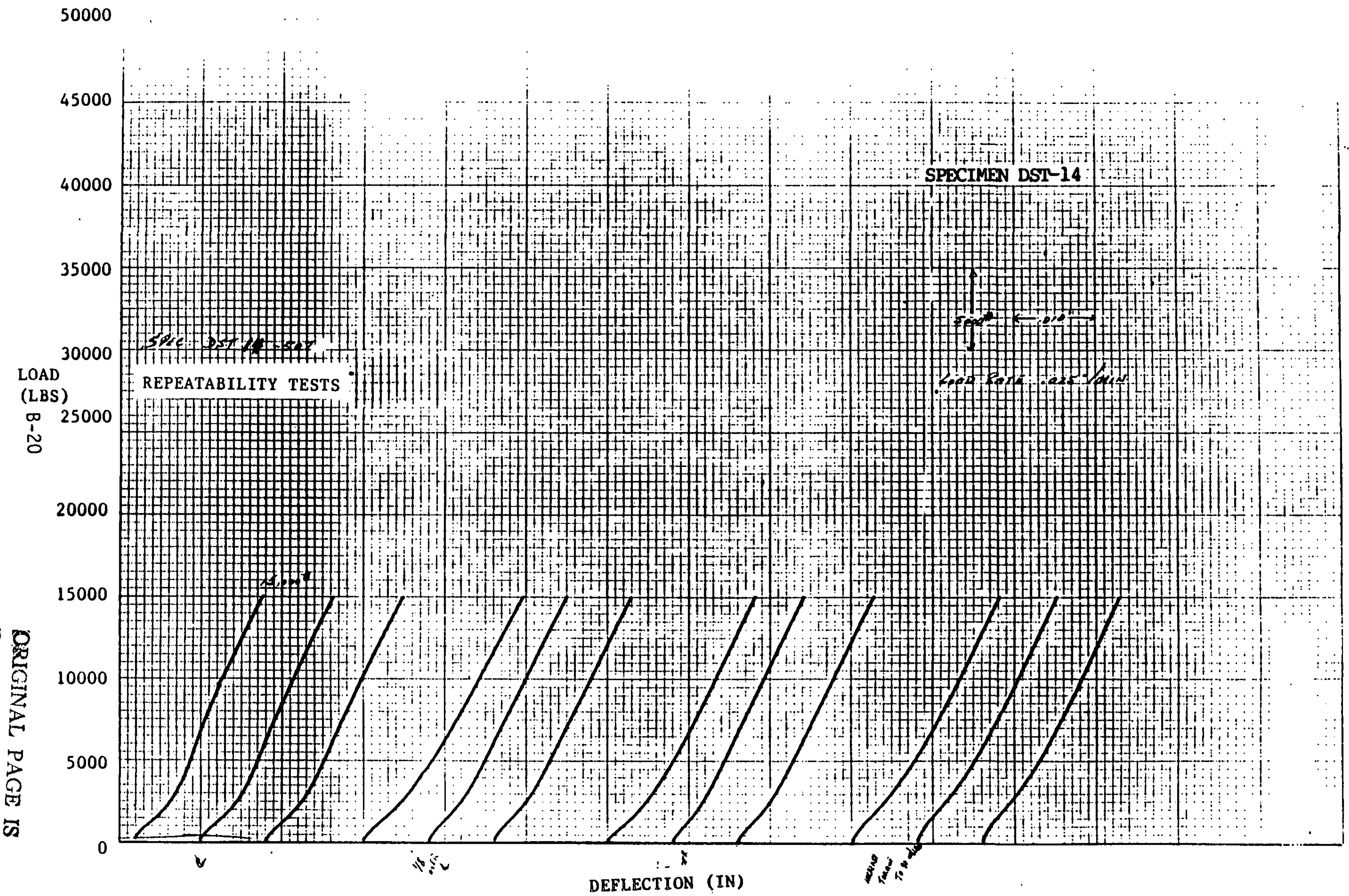
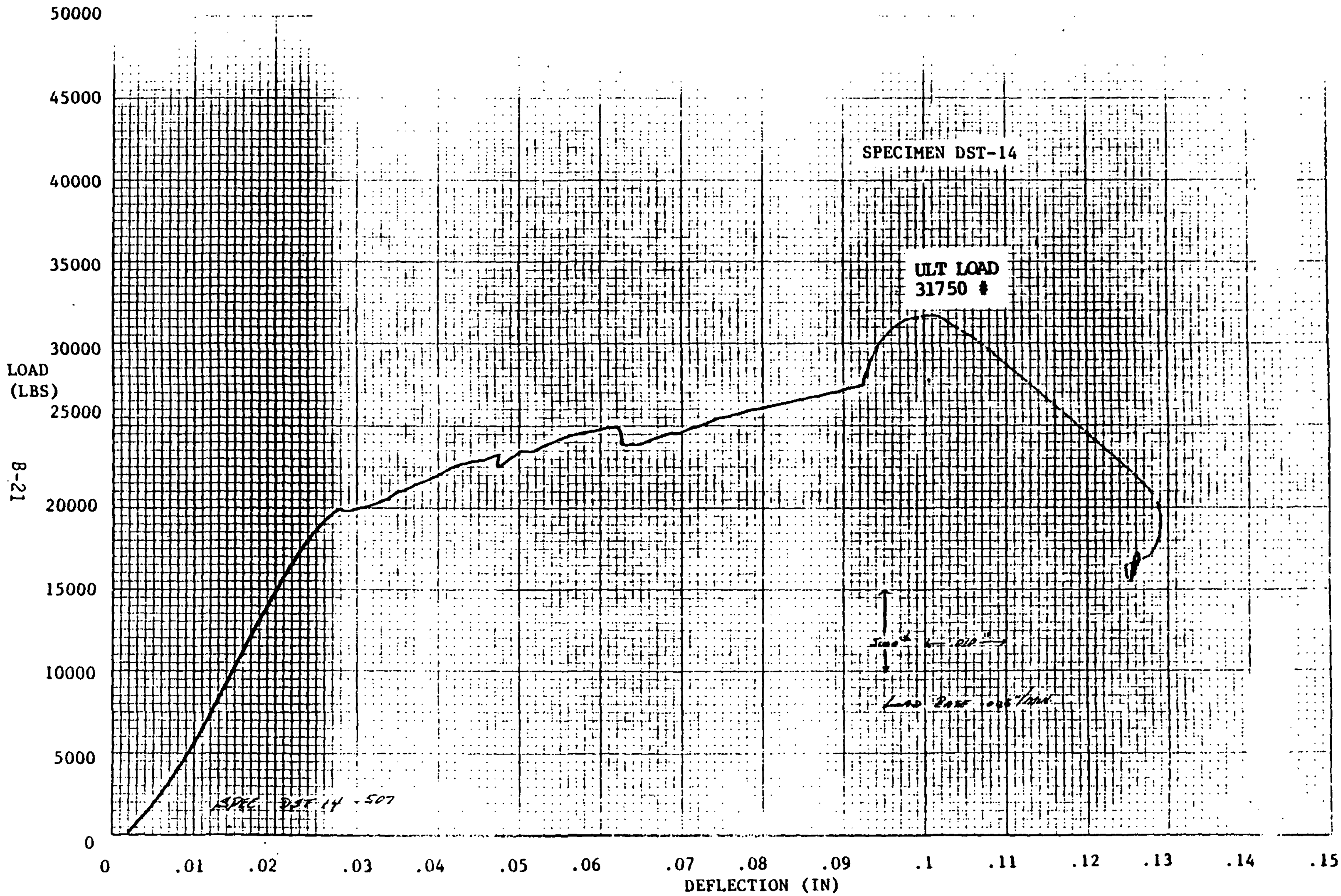

SPECIMEN DST-13
ULT LOAD
27200 #
LOAD
(LBS)
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
0
.01
.02
.03
.04
.05
.06
.07
.08
.09
.1
.11
.12
.13
.14
.15
DEFLECTION (IN)
5000#
.010"
LOAD RATE .025"/MIN
SPEC. DST-13-507



SPECIMEN DST-14
REPEATABILITY TESTS
LOAD
(LBS)
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
DEFLECTION (IN)



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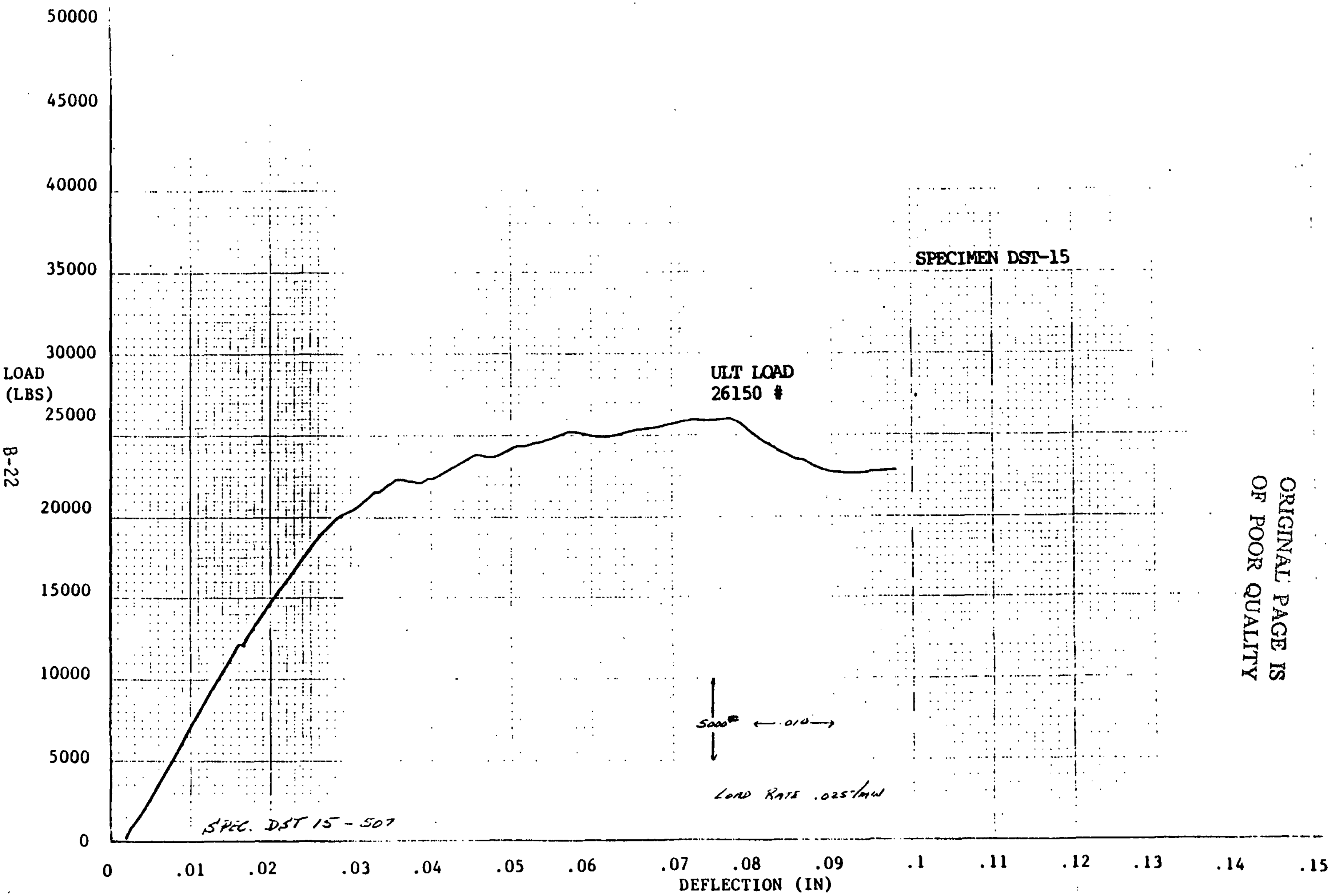

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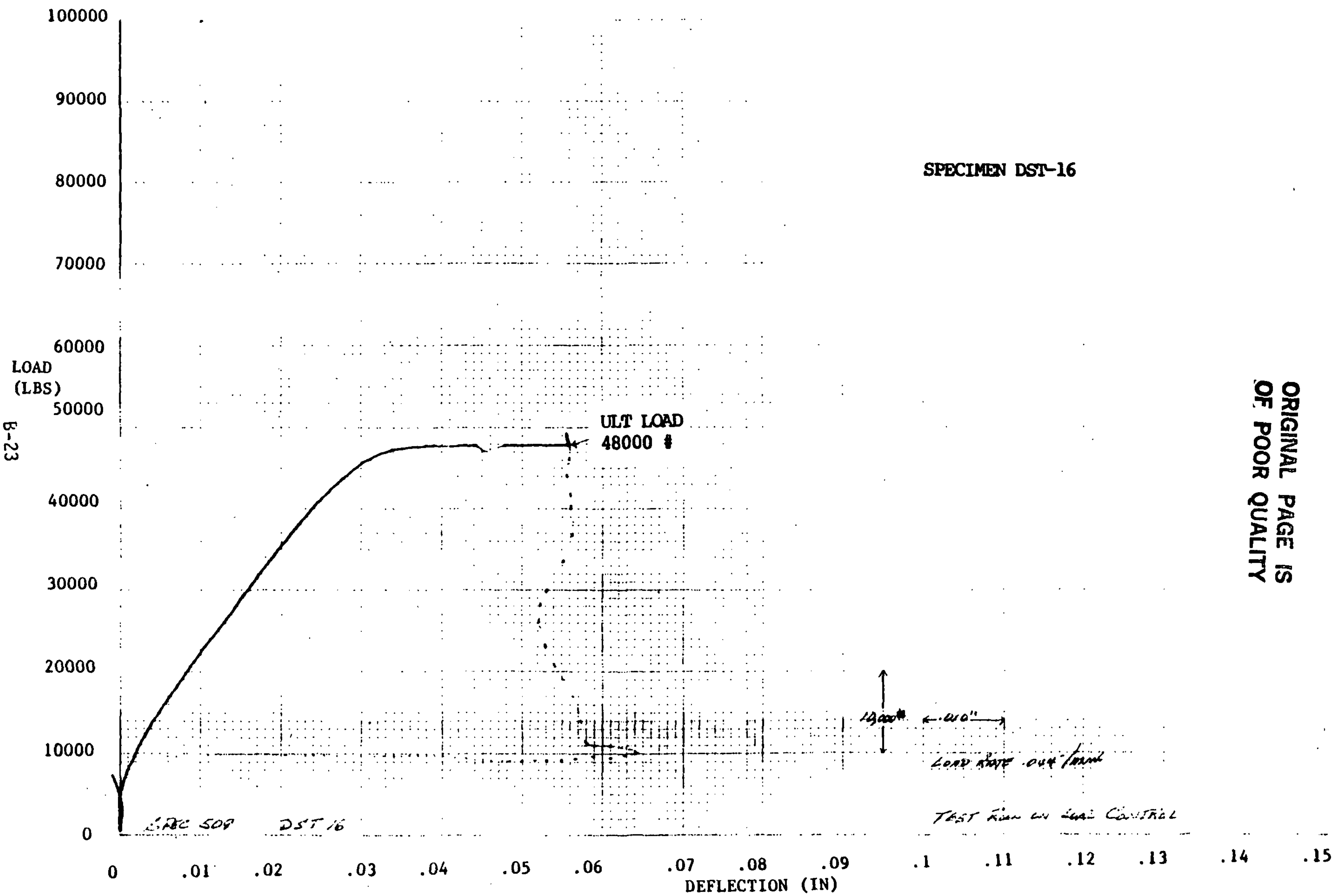
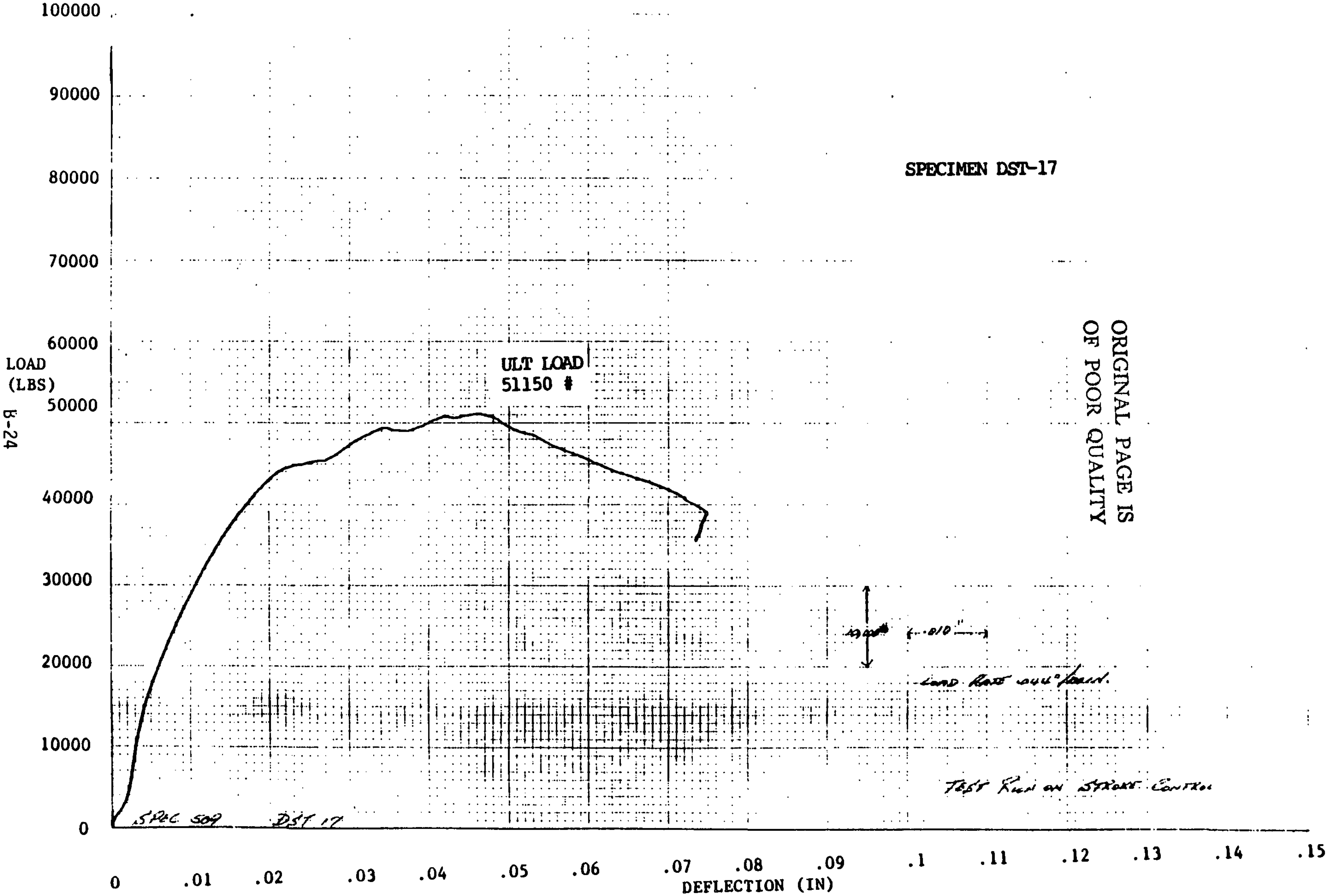


SPECIMEN DST-16
LOAD (LBS)
100000
90000
80000
70000
60000
50000
40000
30000
20000
10000
0
ULT LOAD 48000 #
DST 16
LOAD RATE .004"/min
DEFLECTION (IN)
0
.01
.02
.03
.04
.05
.06
.07
.08
.09
.1
.11
.12
.13
.14
.15



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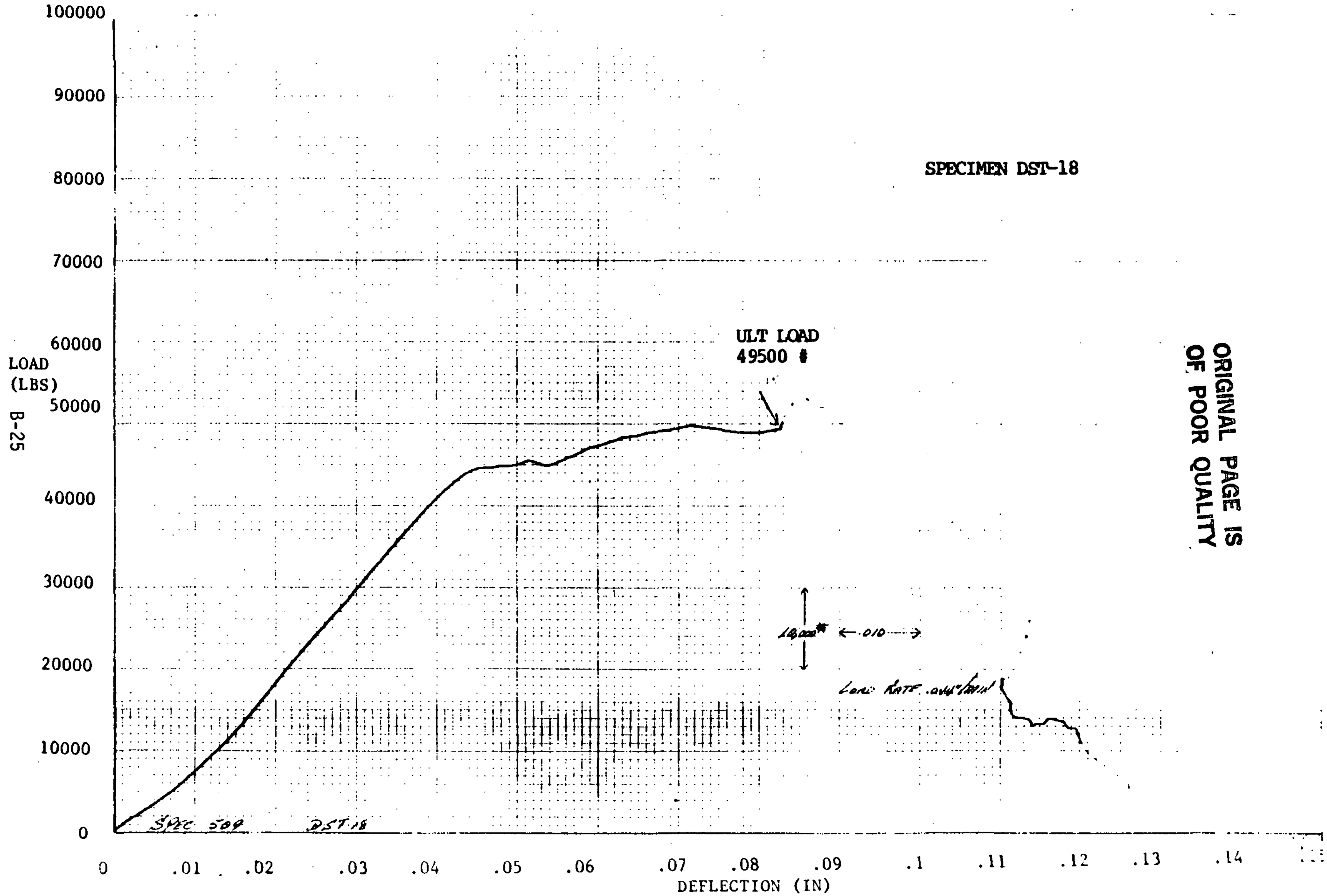

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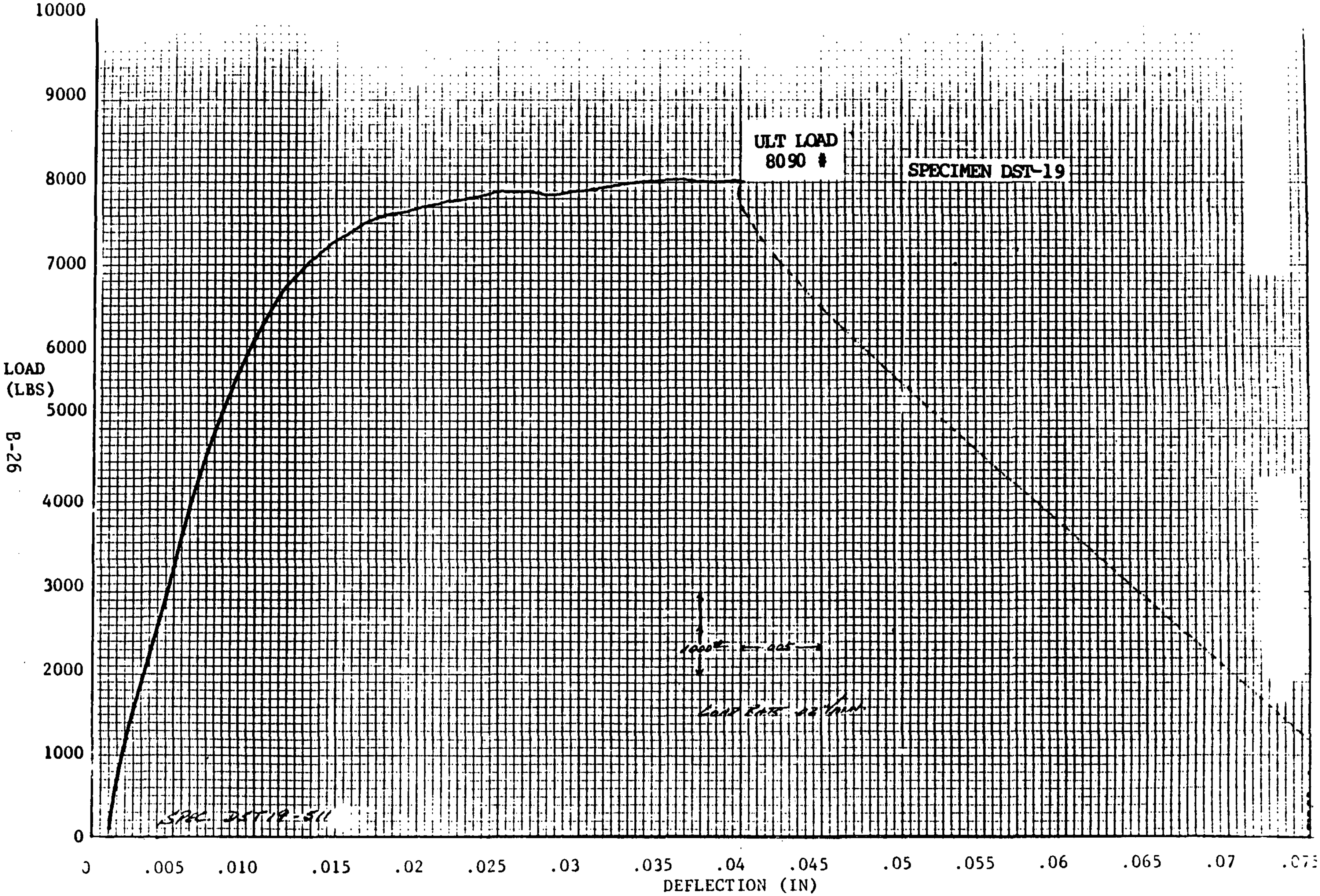

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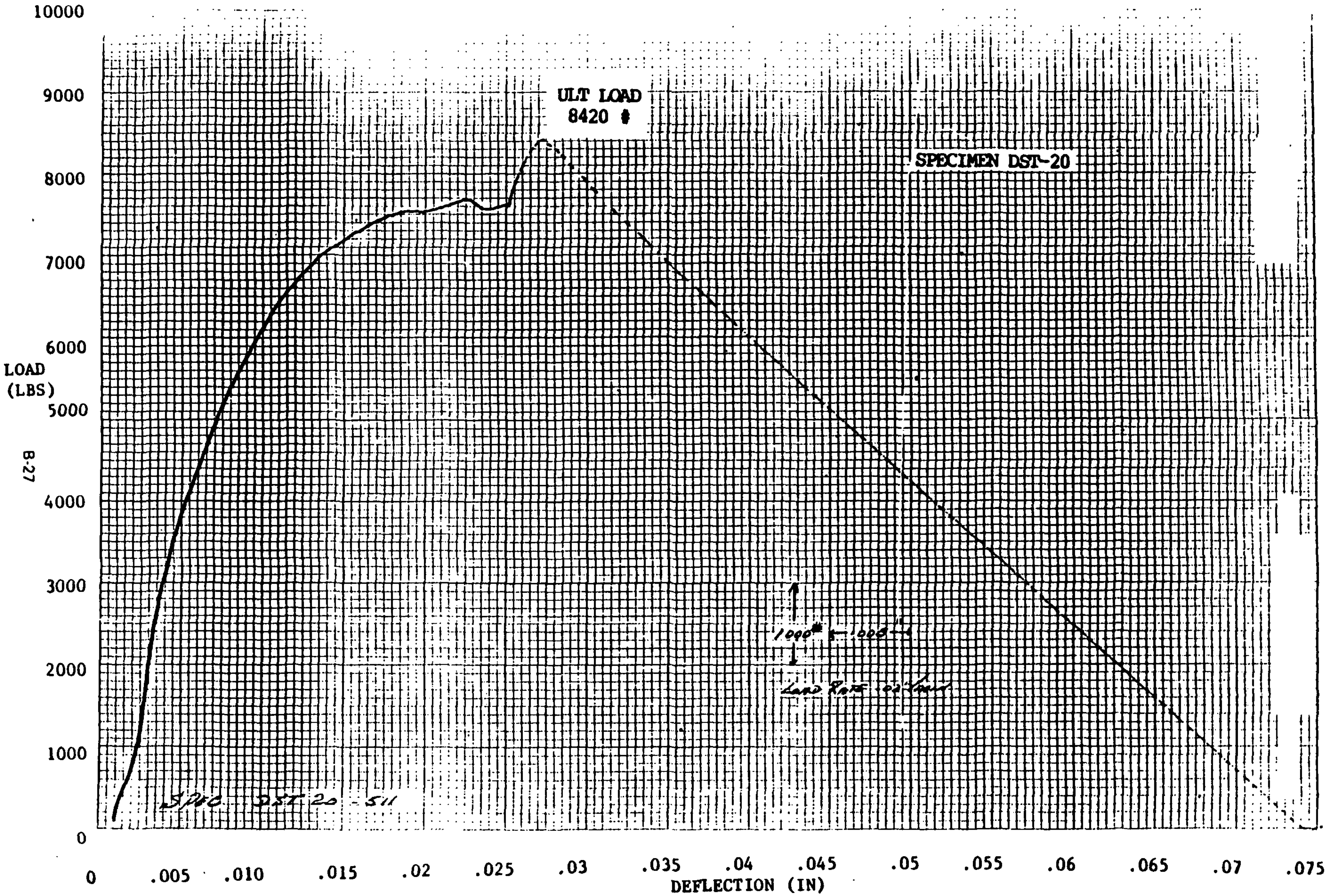
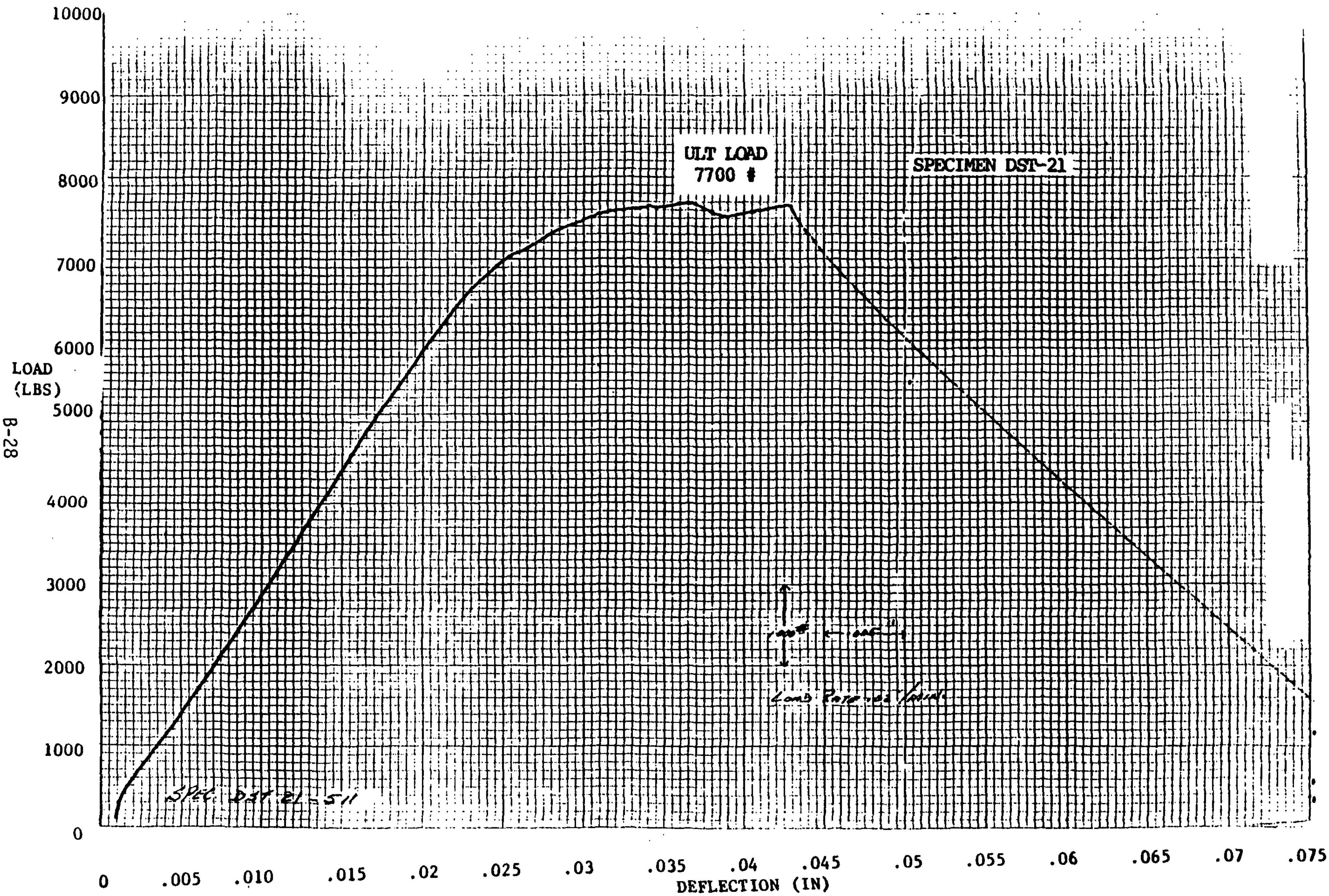
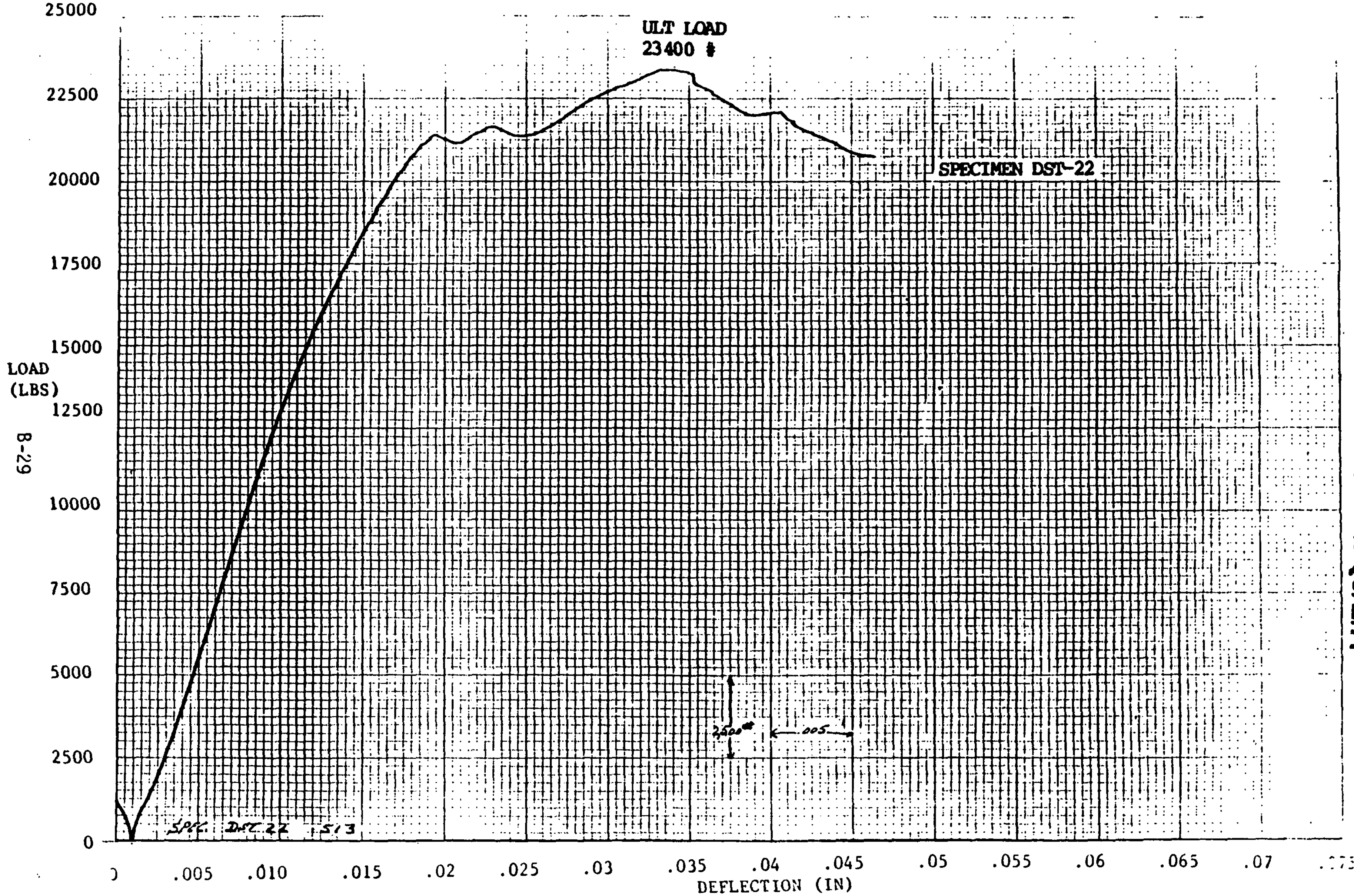
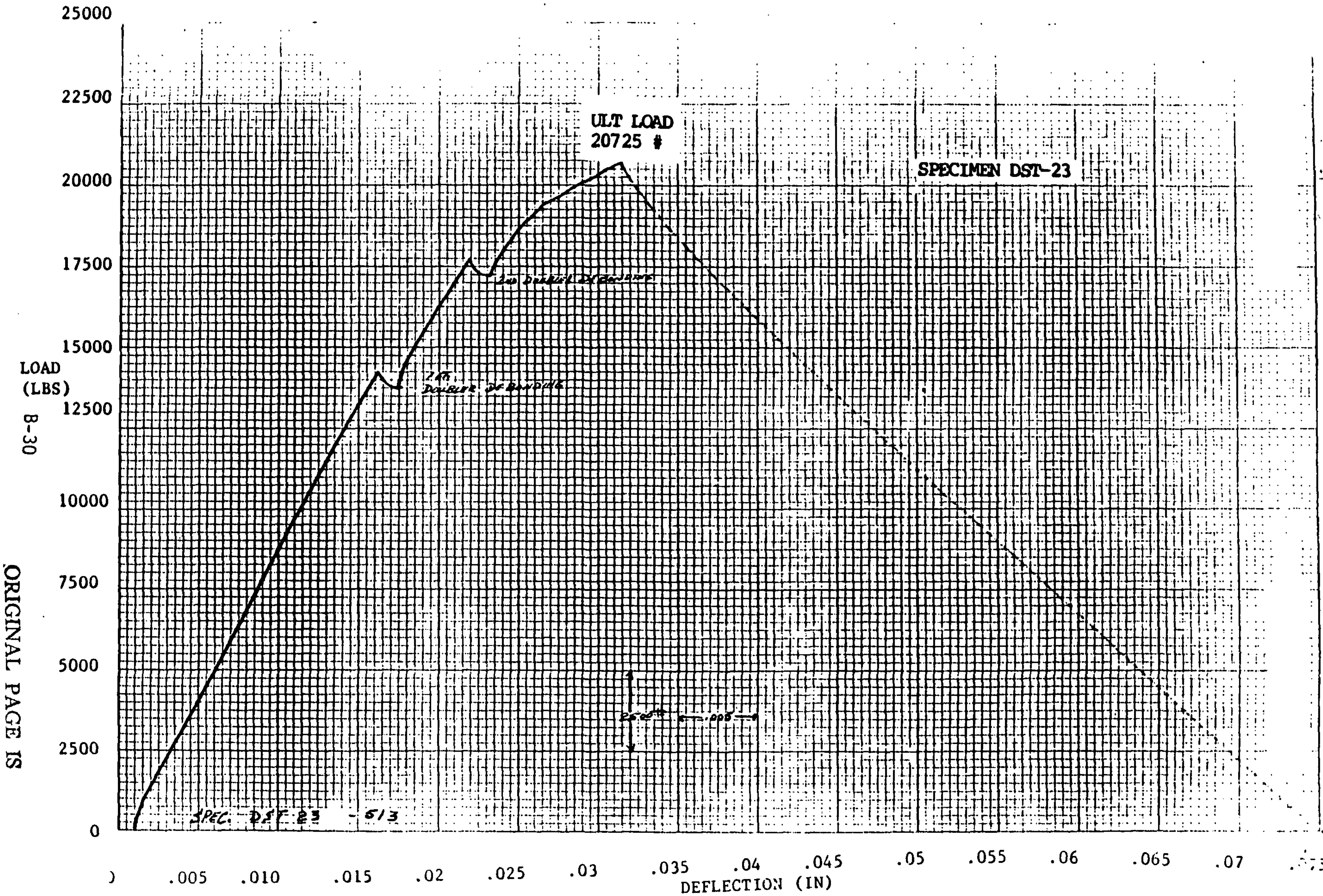

ULT LOAD
8420 #
SPECIMEN DST-20
LOAD
(LBS)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
0
.005
.010
.015
.02
.025
.03
.035
.04
.045
.05
.055
.06
.065
.07
.075
DEFLECTION (IN)
SPEC DST 20 - 511
1000#
.005



ULT LOAD
7700 #
SPECIMEN DST-21
LOAD
(LBS)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
0
.005
.010
.015
.02
.025
.03
.035
.04
.045
.05
.055
.06
.065
.07
.075
DEFLECTION (IN)
SPEC. DST 21-511


ULT LOAD
23400 #
SPECIMEN DST-22
LOAD
(LBS)
25000
22500
20000
17500
15000
12500
10000
7500
5000
2500
0
2500#
.005
SPEC. DST 22 .513
0
.005
.010
.015
.02
.025
.03
.035
.04
.045
.05
.055
.06
.065
.07
DEFLECTION (IN)



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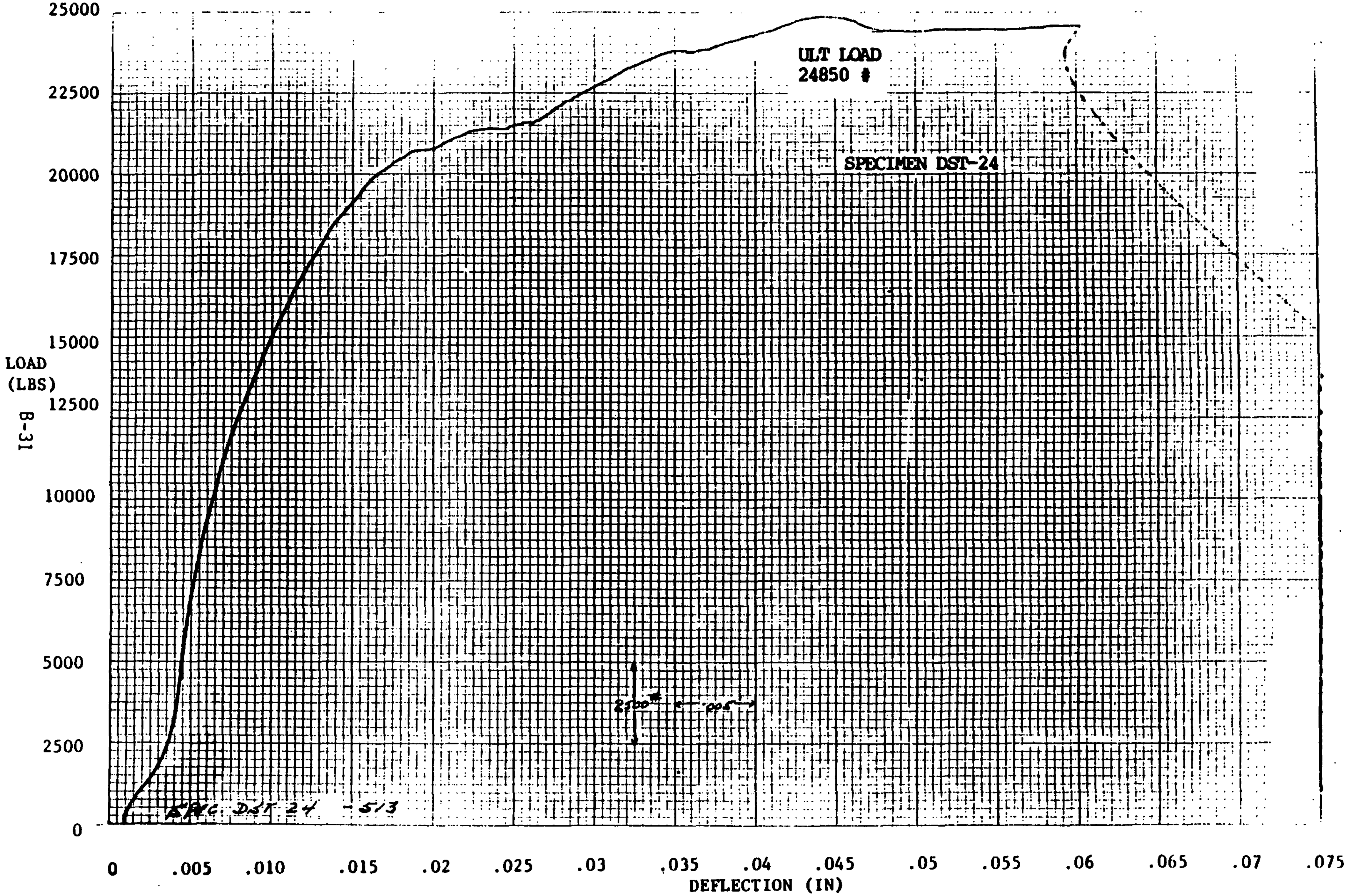

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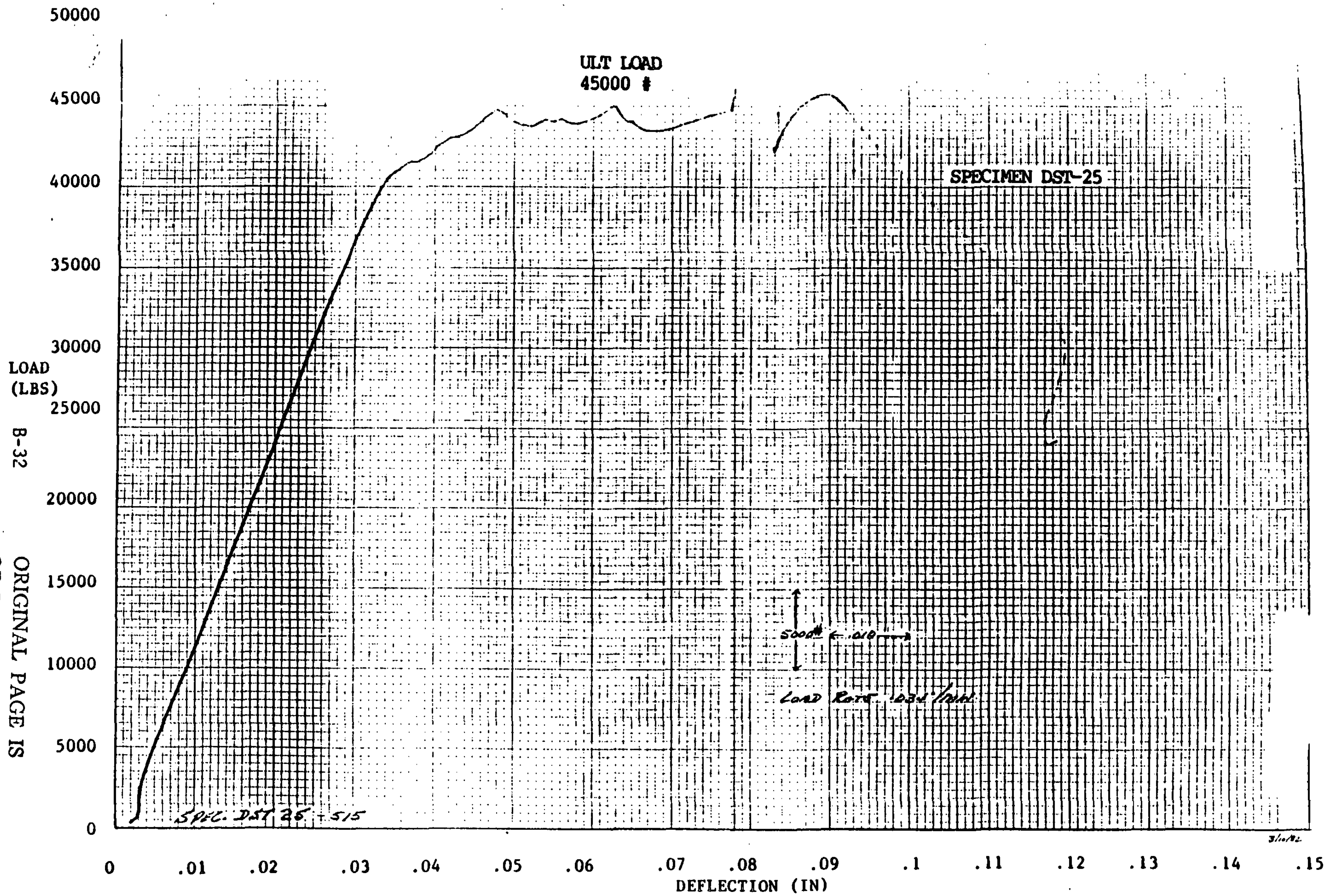

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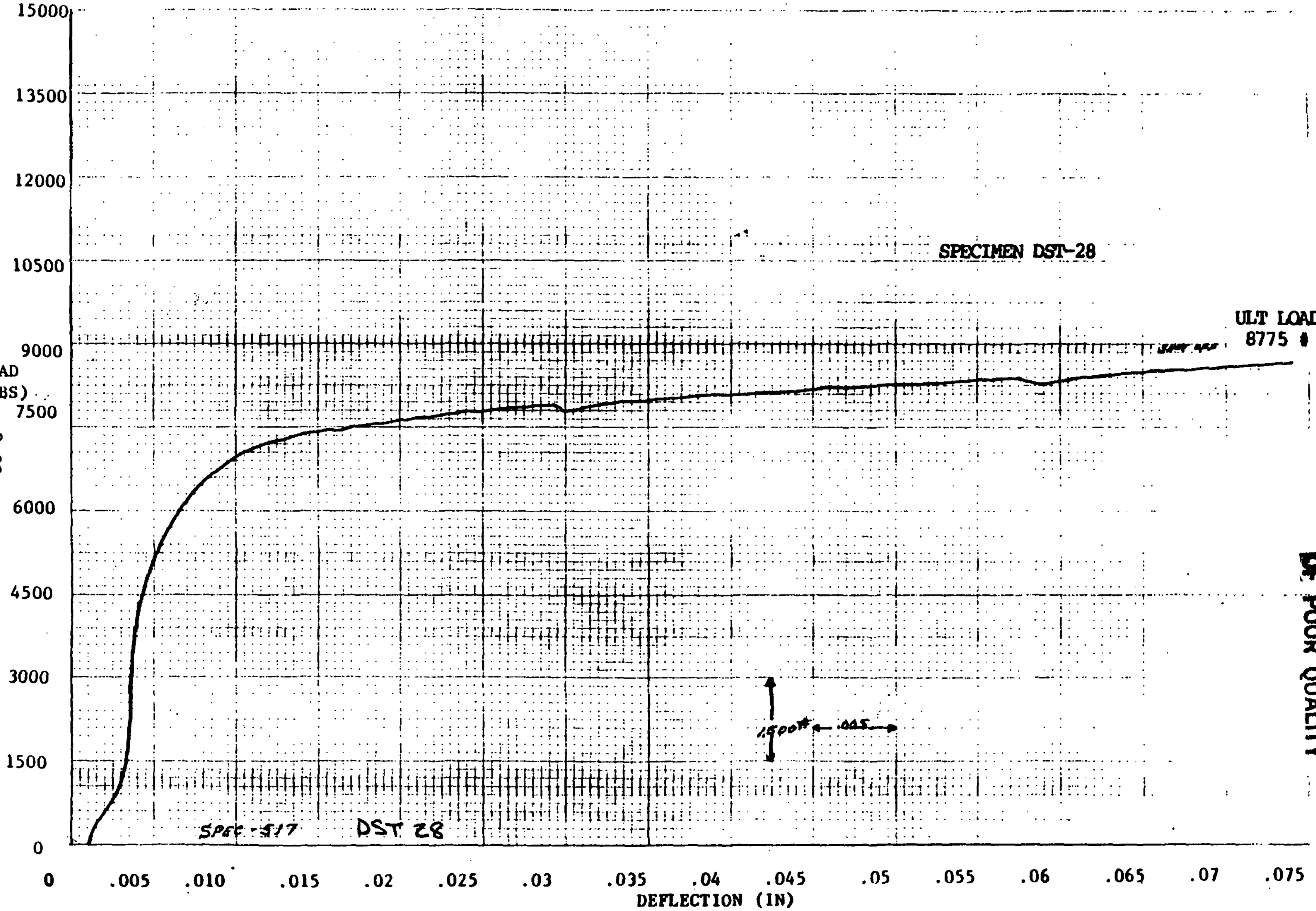
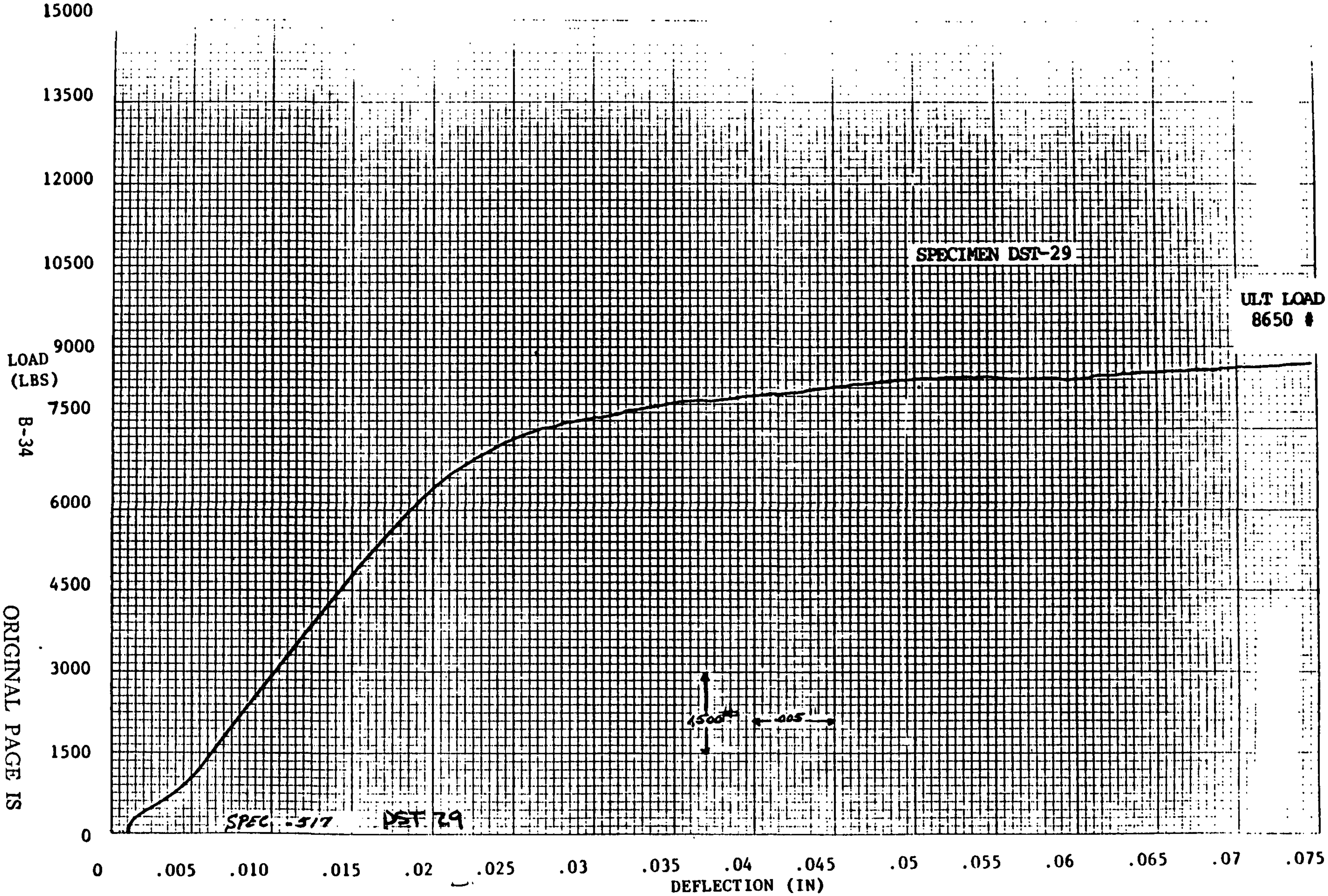

SPECIMEN DST-28
ULT LOAD
8775 #
LOAD
(LBS)
15000
13500
12000
10500
9000
7500
6000
4500
3000
1500
0
0
.005
.010
.015
.02
.025
.03
.035
.04
.045
.05
.055
.06
.065
.07
.075
DEFLECTION (IN)
1500#
.005
SPEC-517
DST 28



B-34

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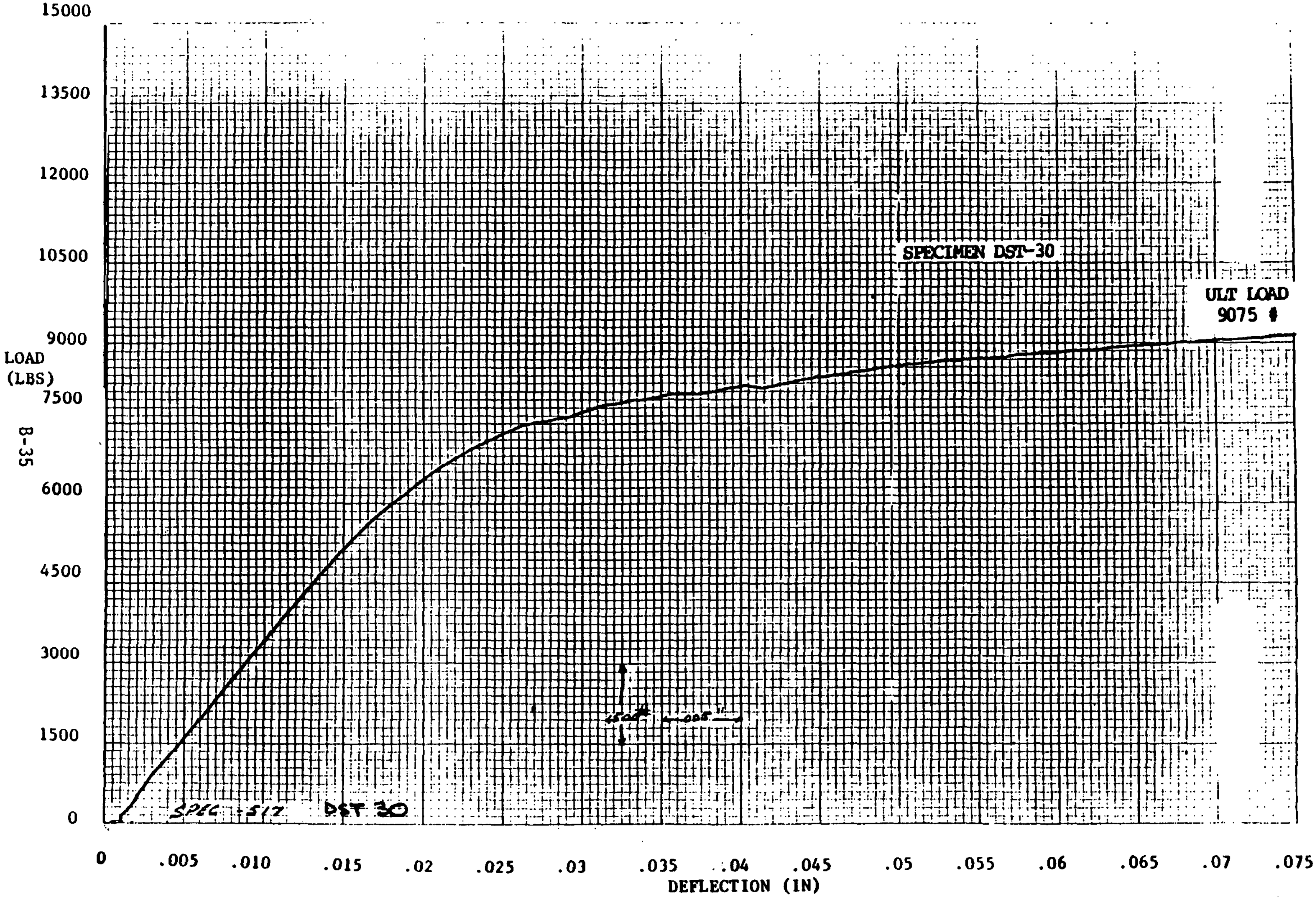
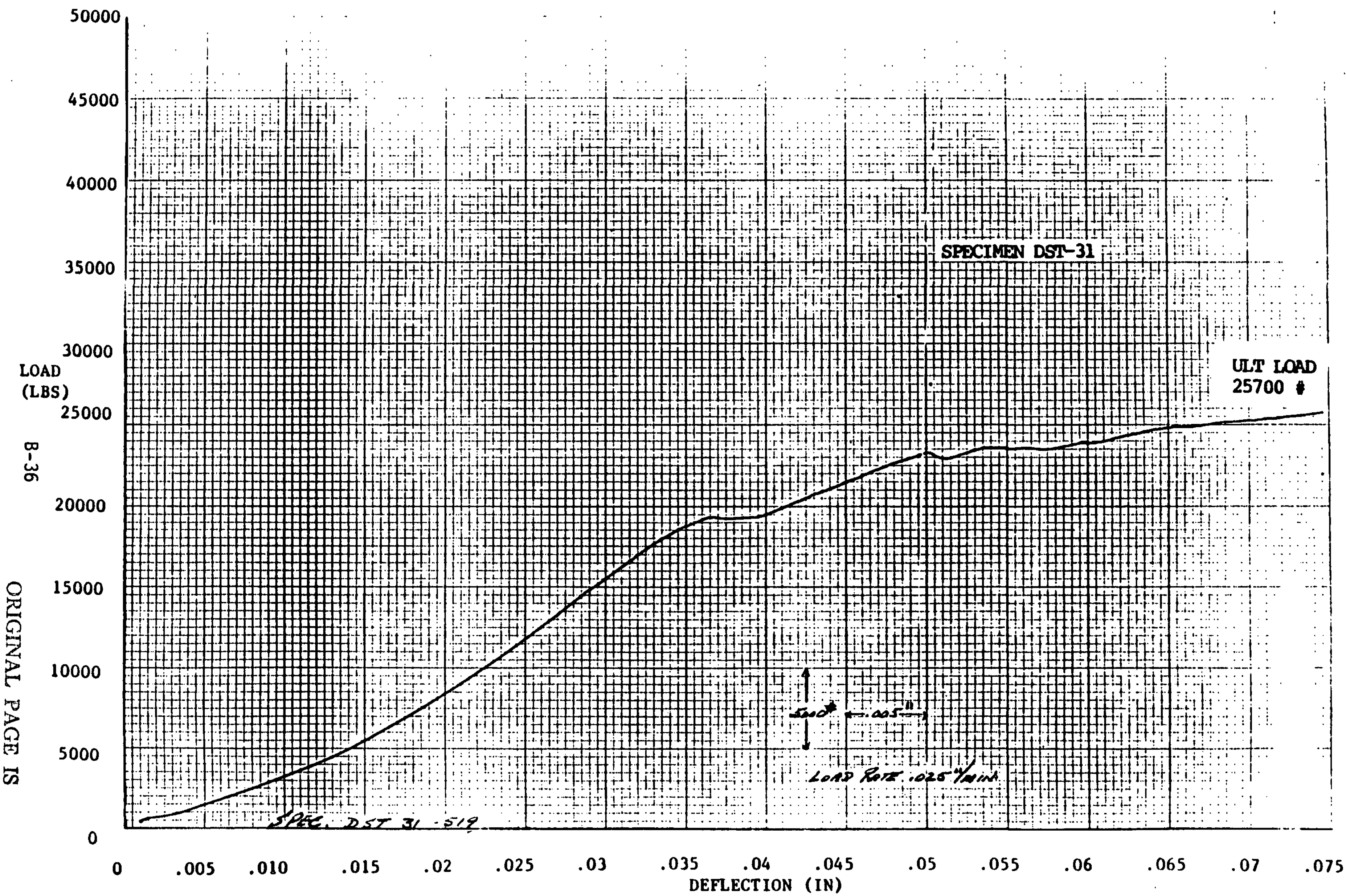
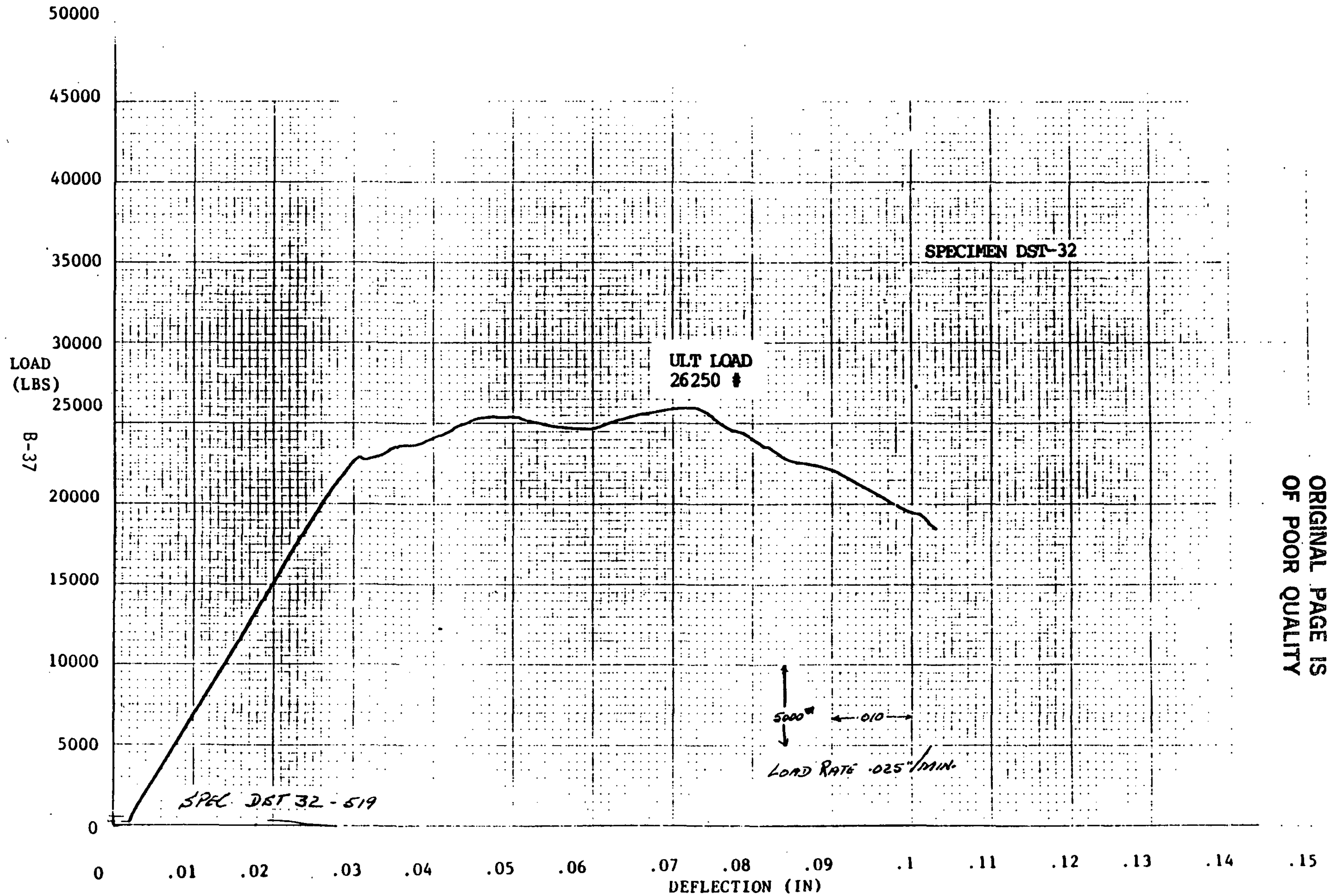
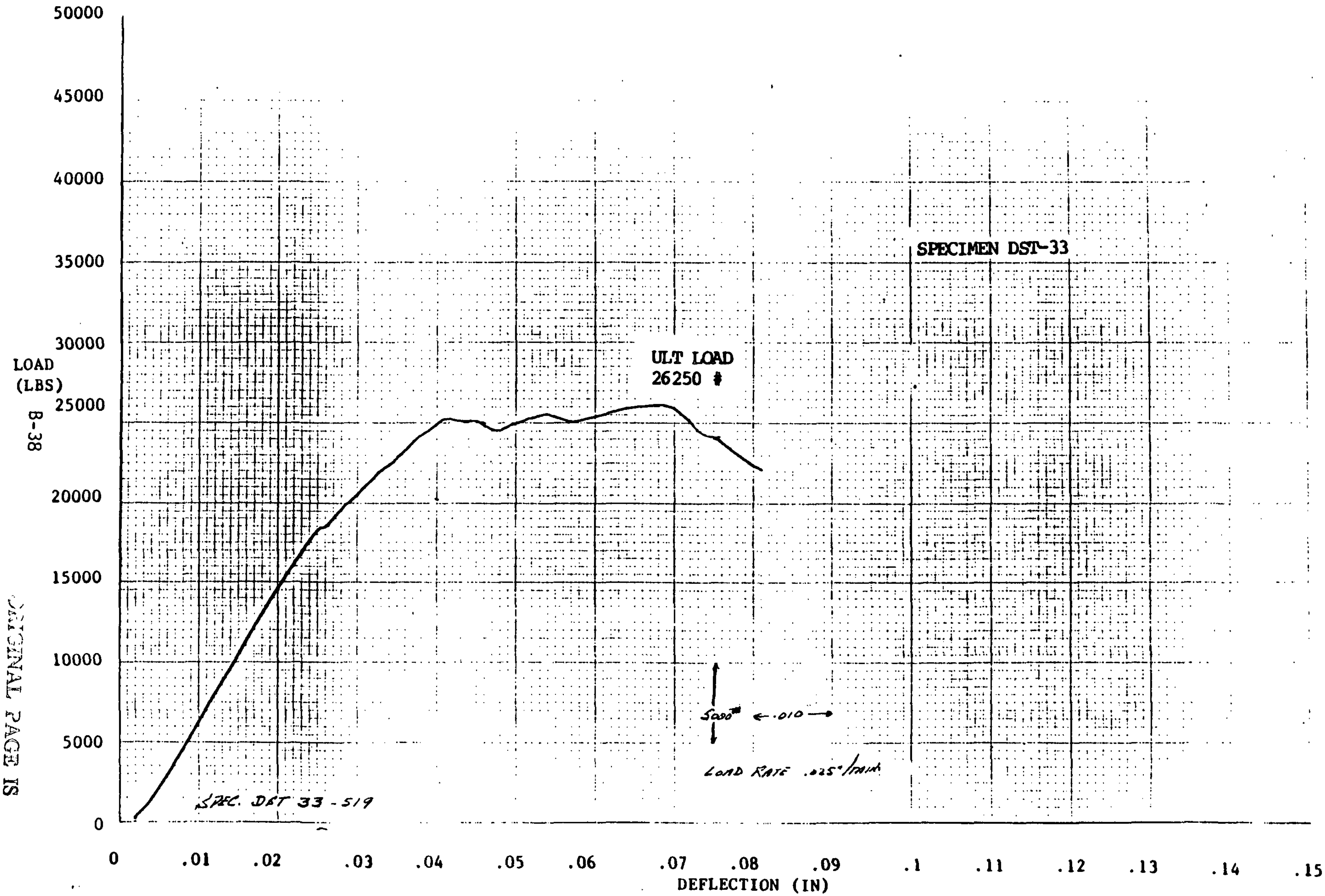
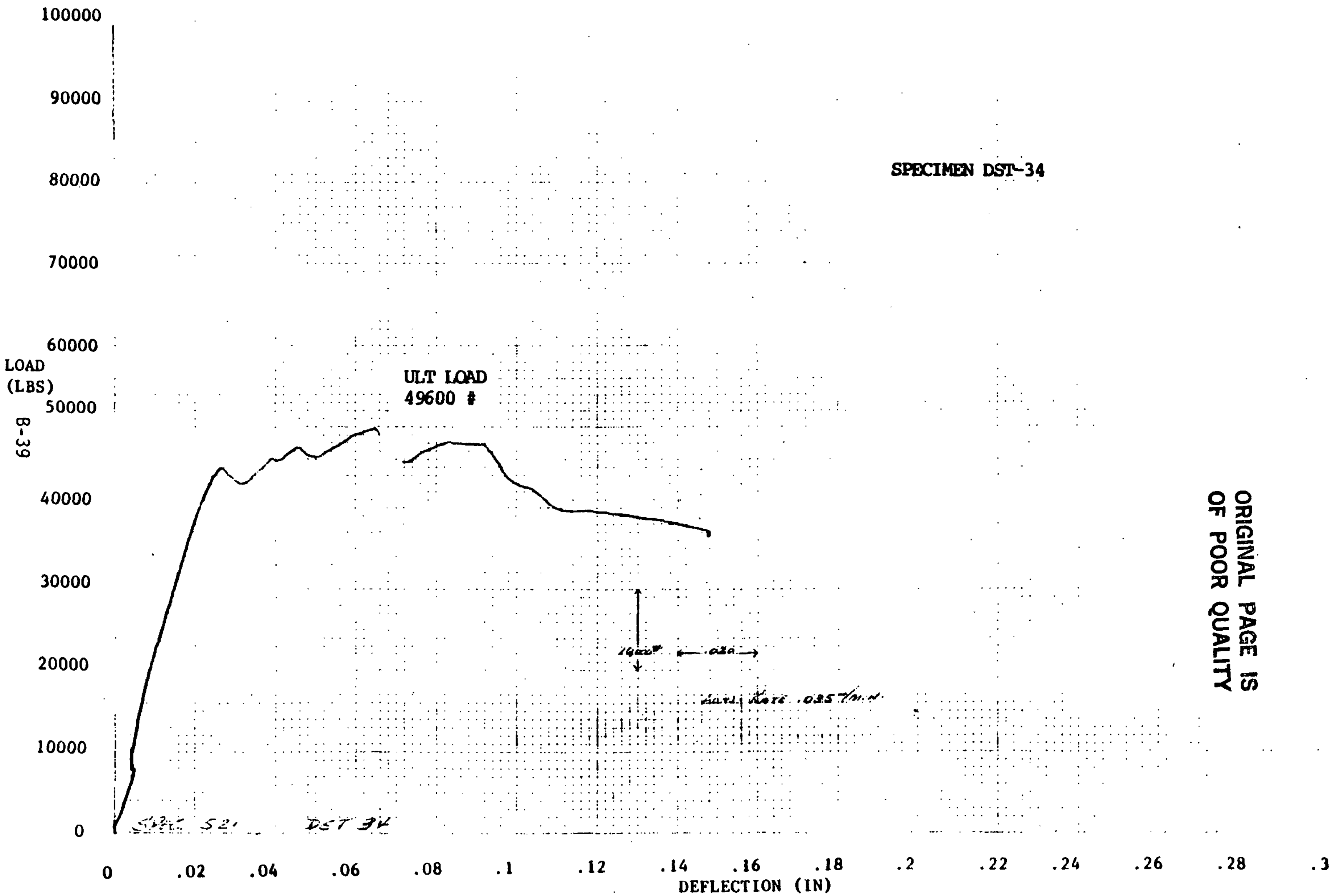

SPECIMEN DST-30
ULT LOAD
9075 #
LOAD
(LBS)
15000
13500
12000
10500
9000
7500
6000
4500
3000
1500
0
0
.005
.010
.015
.02
.025
.03
.035
.04
.045
.05
.055
.06
.065
.07
.075
DEFLECTION (IN)
SPEC -517
DST 30


SPECIMEN DST-31
ULT LOAD
25700 #
LOAD
(LBS)
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
DEFLECTION (IN)
0
.005
.010
.015
.02
.025
.03
.035
.04
.045
.05
.055
.06
.065
.07
.075
5000#
.005"
LOAD RATE .025"/MIN
SPEC. DST 31 -519


SPECIMEN DST-32
ULT LOAD
26250 #
LOAD
(LBS)
DEFLECTION (IN)
5000#
.010
LOAD RATE .025"/MIN.
SPEC DST 32 - 519



LOAD
(LBS)
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
0
.01
.02
.03
.04
.05
.06
.07
.08
.09
.1
.11
.12
.13
.14
.15
DEFLECTION (IN)
SPECIMEN DST-33
ULT LOAD
26250 #
5000#
← .010 →
LOAD RATE .025"/min
SPEC. DST 33 - 519



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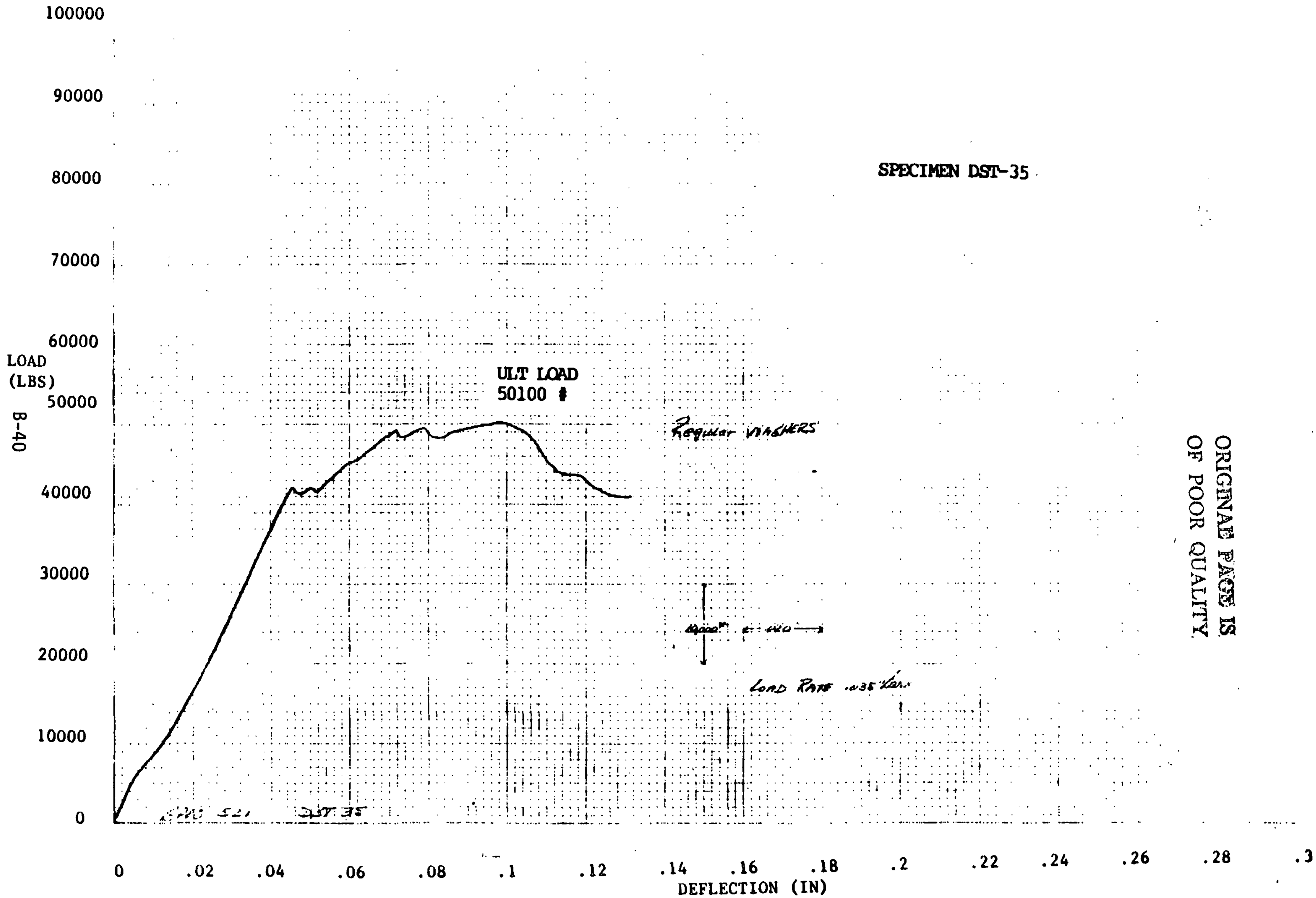
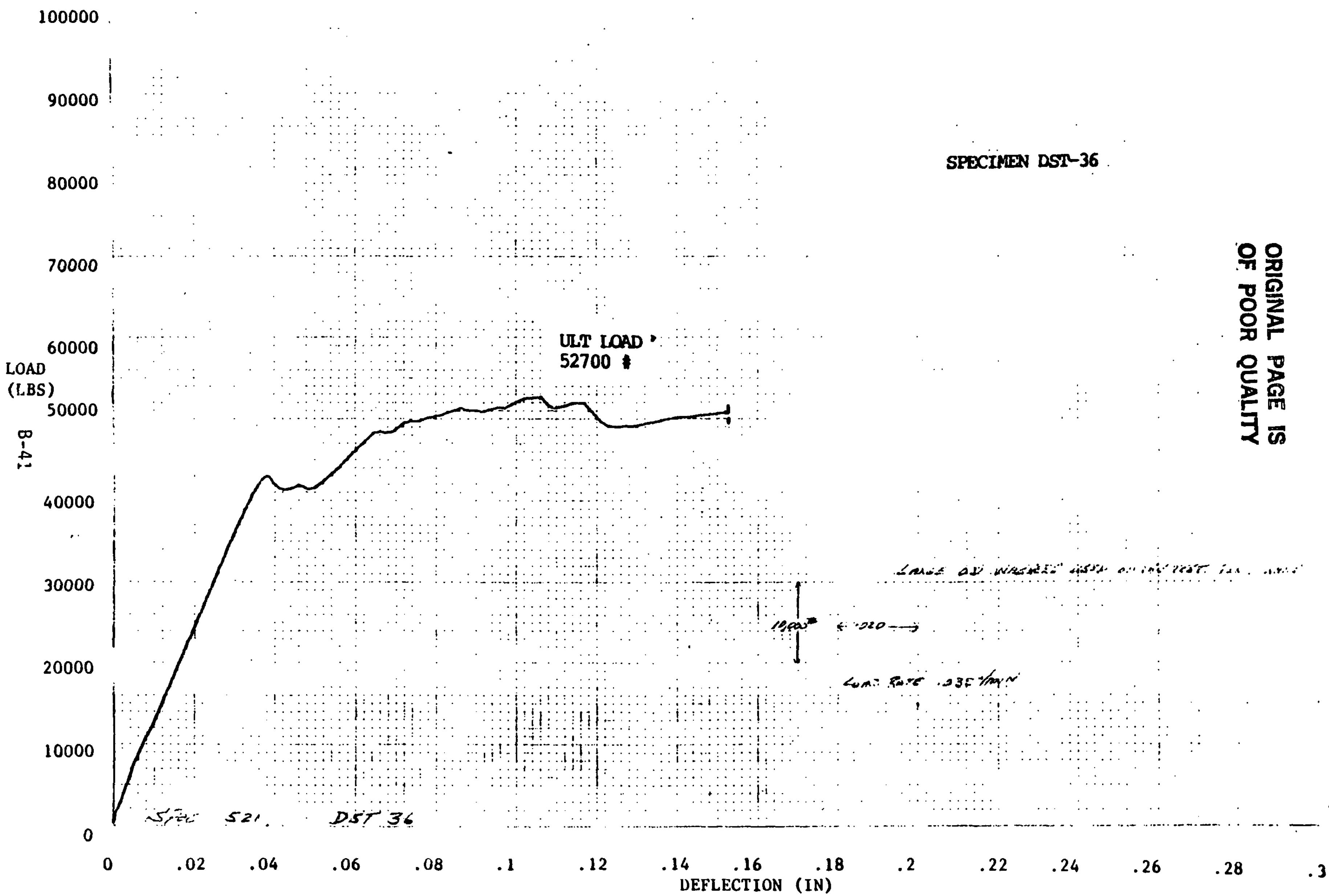
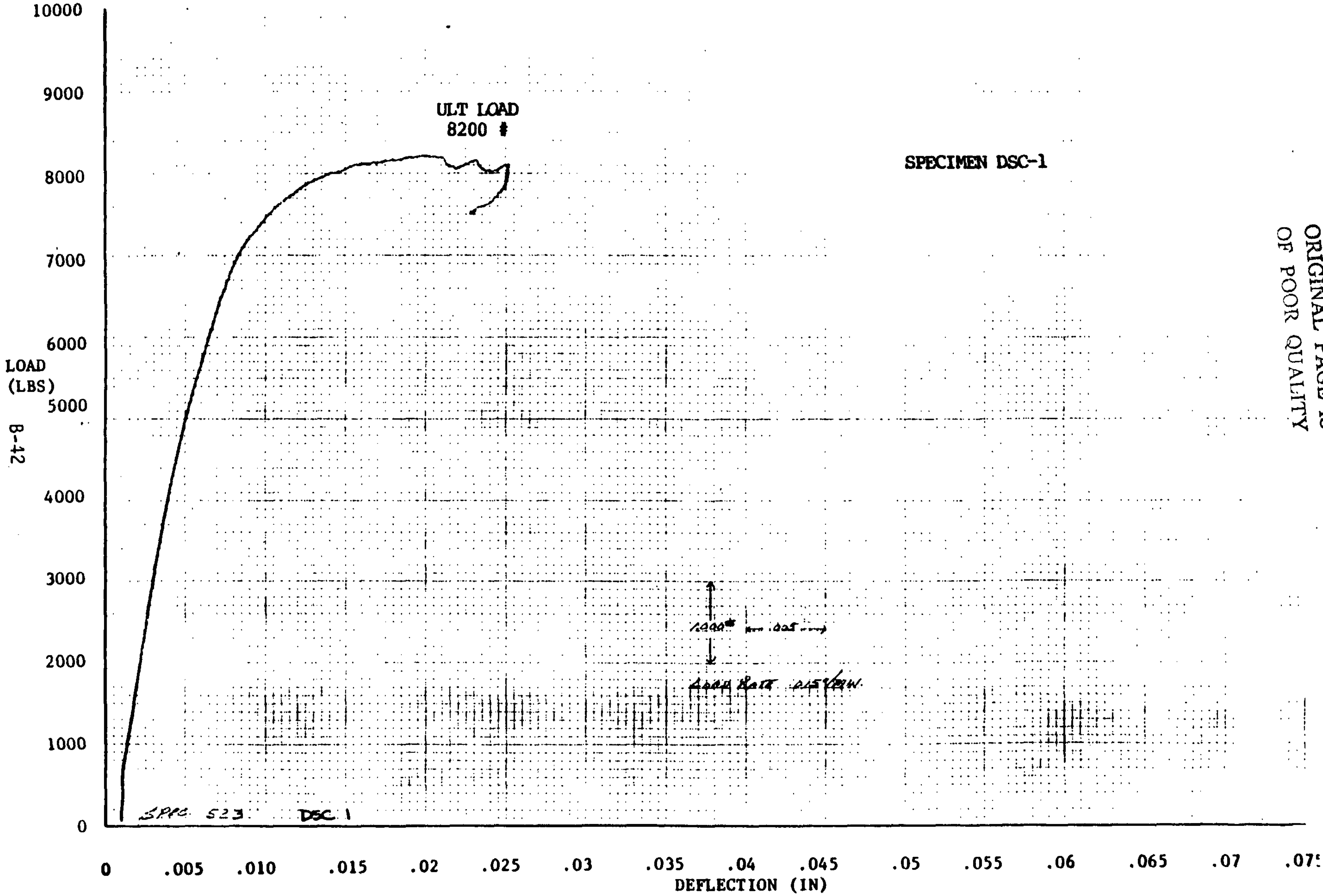

SPECIMEN DST-35
LOAD (LBS)
100000
90000
80000
70000
60000
50000
40000
30000
20000
10000
0
ULT LOAD
50100 #
Regular WASHERS
LOAD RATE .035
DST 35
0
.02
.04
.06
.08
.1
.12
.14
.16
.18
.2
.22
.24
.26
.28
.3
DEFLECTION (IN)



SPECIMEN DST-36
ULT LOAD
52700 #
LOAD
(LBS)
100000
90000
80000
70000
60000
50000
40000
30000
20000
10000
0
0
.02
.04
.06
.08
.1
.12
.14
.16
.18
.2
.22
.24
.26
.28
.3
DEFLECTION (IN)
DST 36



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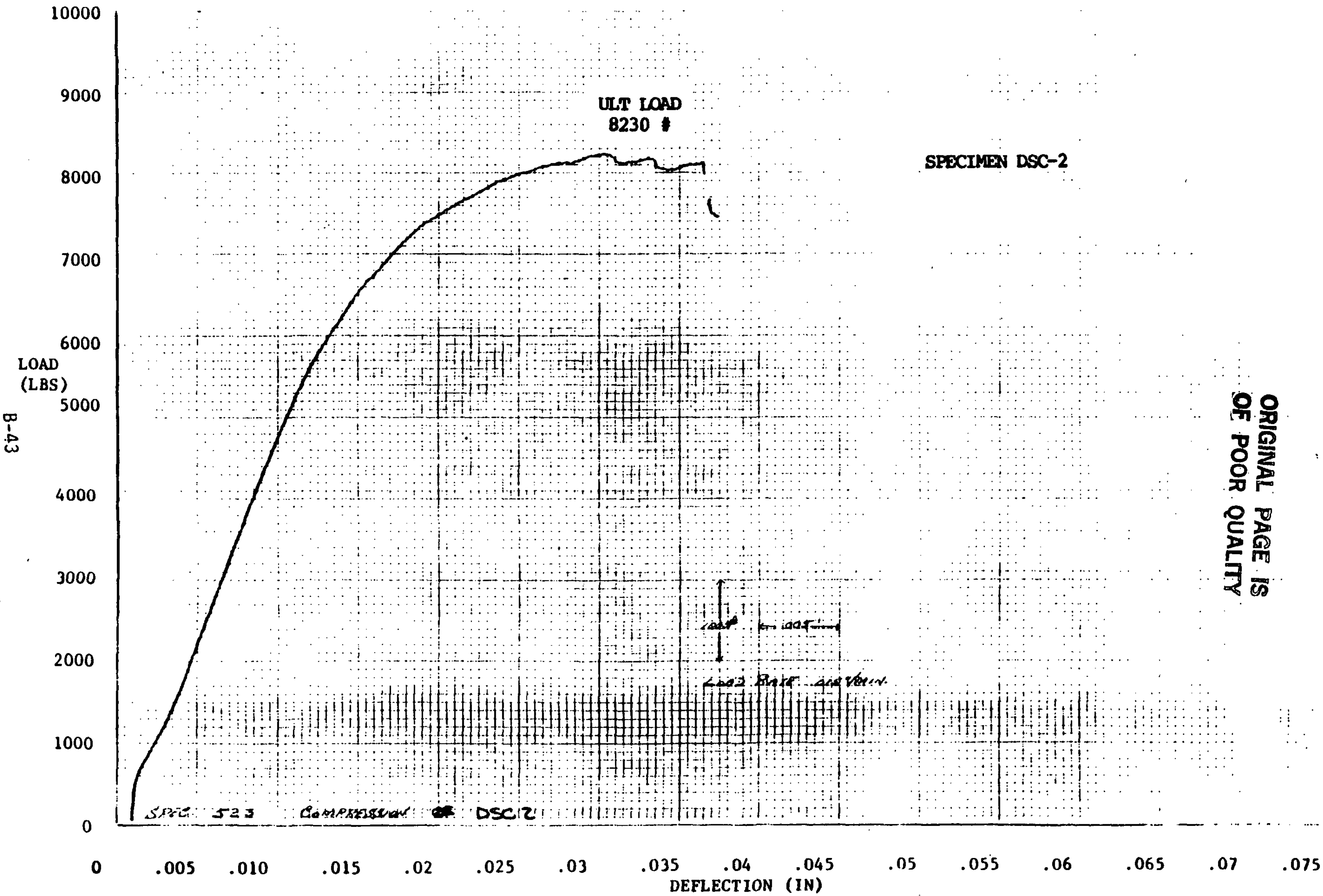
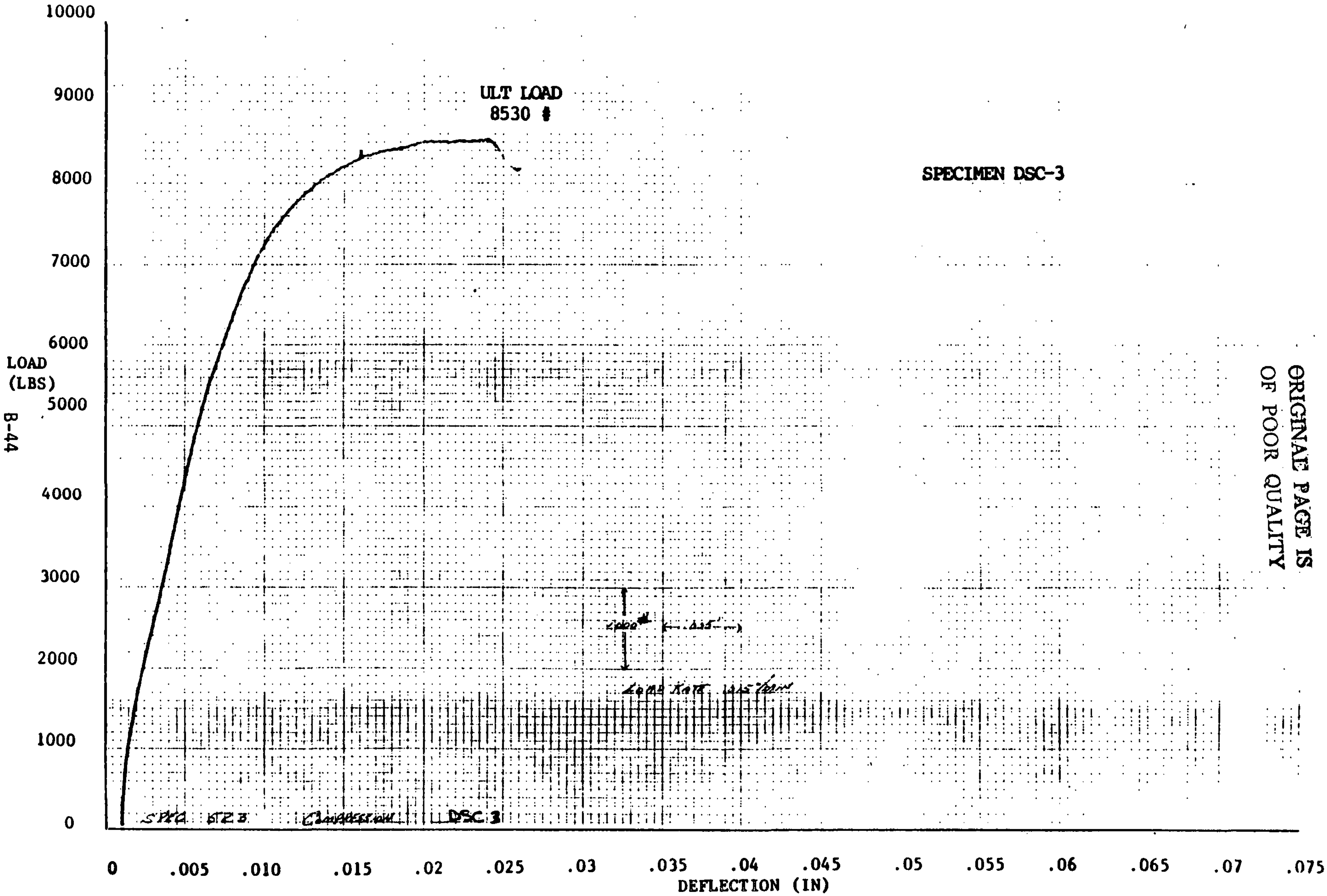
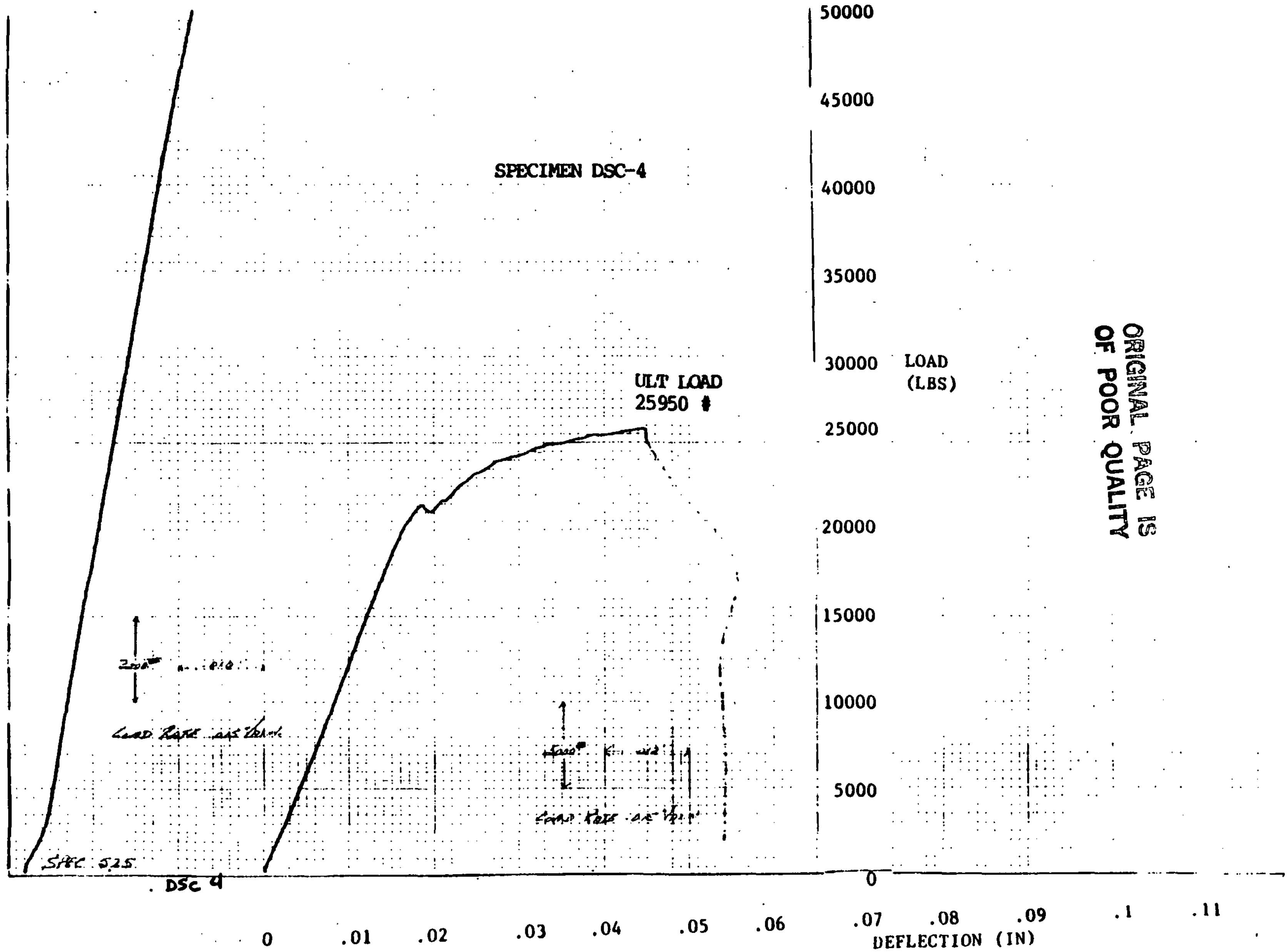
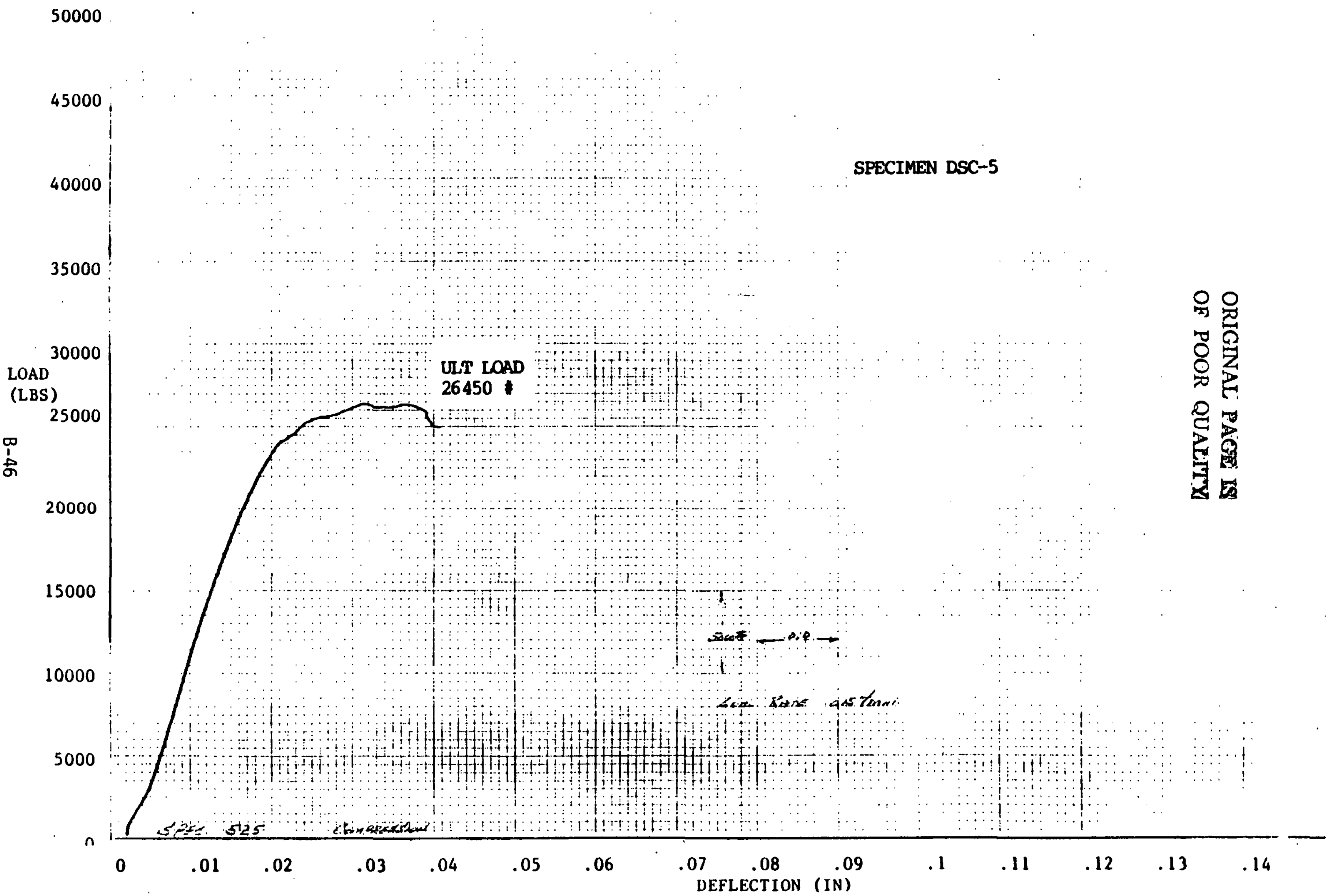

ULT LOAD
8230 #
SPECIMEN DSC-2
LOAD (LBS)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
0
.005
.010
.015
.02
.025
.03
.035
.04
.045
.05
.055
.06
.065
.07
.075
DEFLECTION (IN)

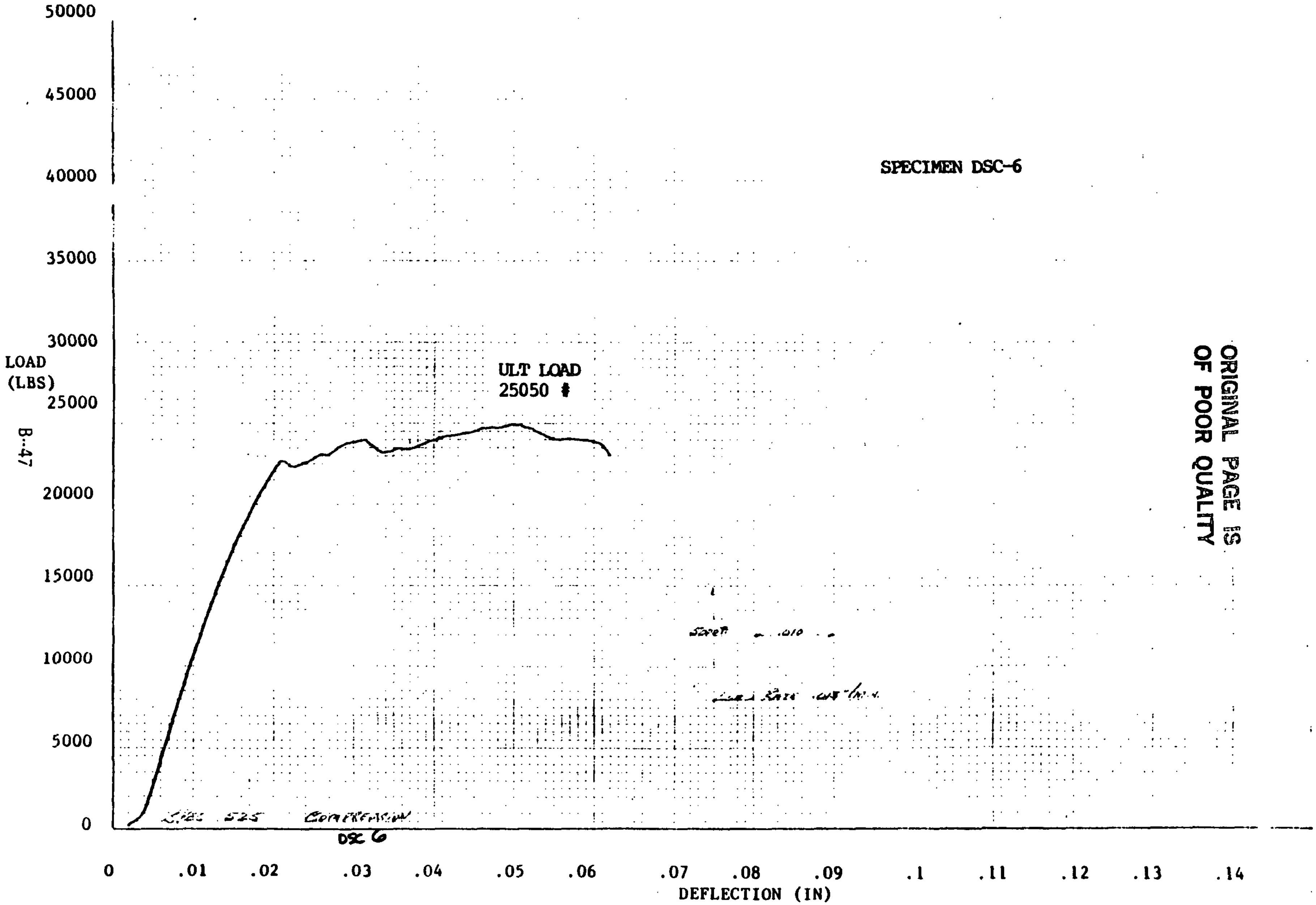


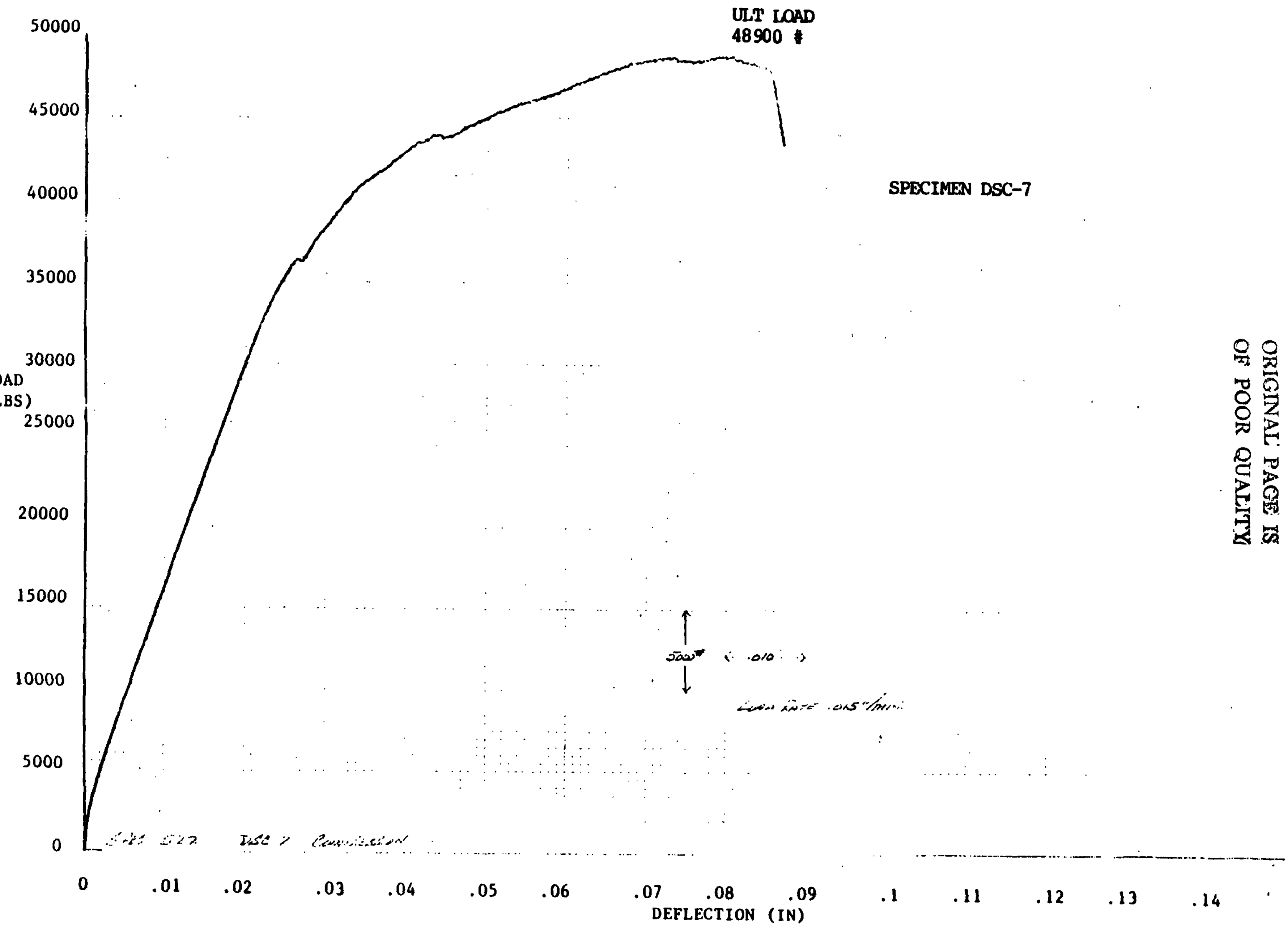
ULT LOAD
8530 #
SPECIMEN DSC-3
LOAD (LBS)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
0
.005
.010
.015
.02
.025
.03
.035
.04
.045
.05
.055
.06
.065
.07
.075
DEFLECTION (IN)
DSC 3

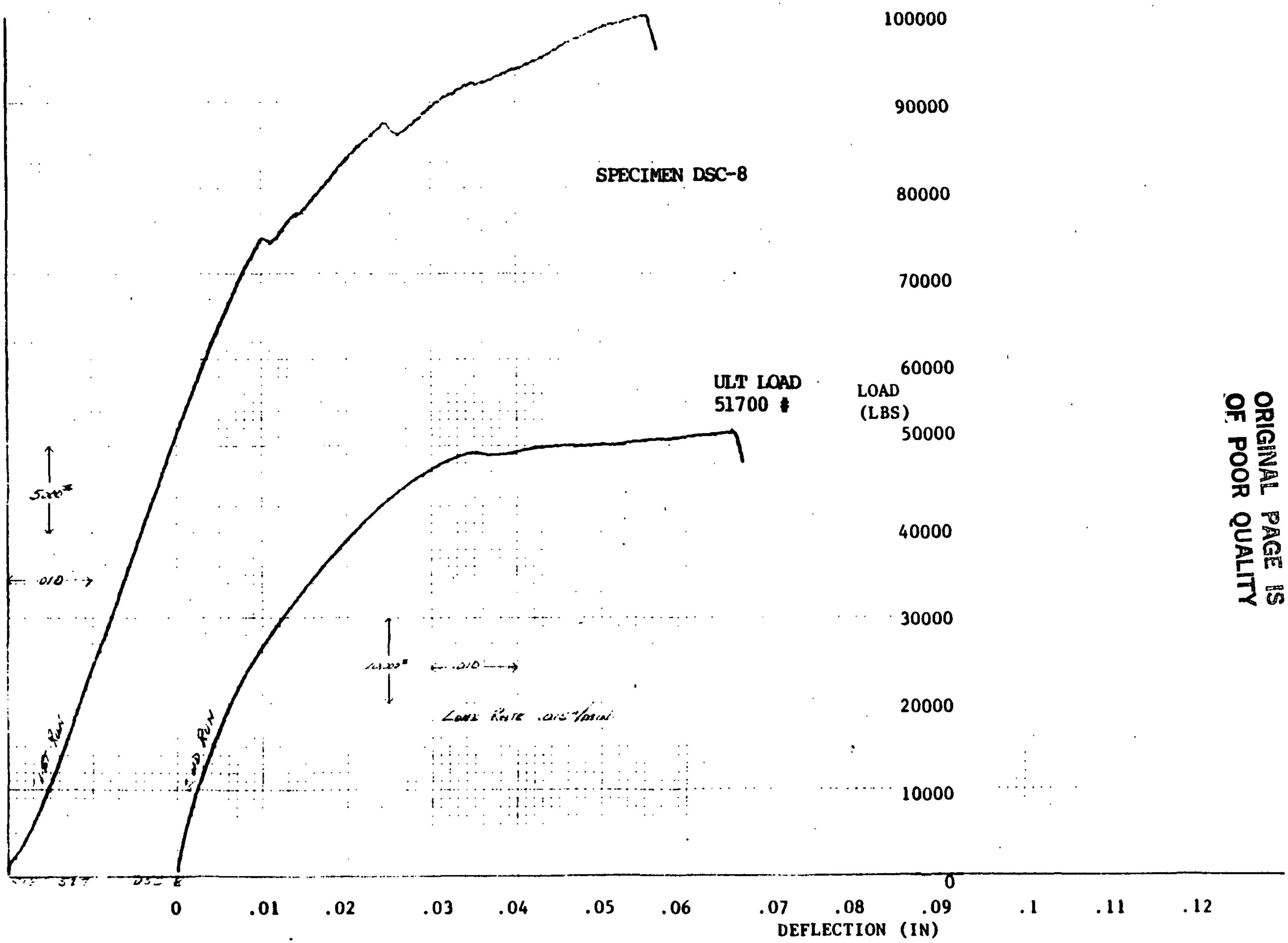

SPECIMEN DSC-4
ULT LOAD
25950 #
LOAD
(LBS)
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
0
.01
.02
.03
.04
.05
.06
.07
.08
.09
.1
.11
DEFLECTION (IN)
SPEC 525
DSC 4



SPECIMEN DSC-5
ULT LOAD
26450 #
LOAD
(LBS)
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
0
.01
.02
.03
.04
.05
.06
.07
.08
.09
.1
.11
.12
.13
.14
DEFLECTION (IN)


SPECIMEN DSC-6
ULT LOAD
25050 #
LOAD
(LBS)
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
0
.01
.02
.03
.04
.05
.06
.07
.08
.09
.1
.11
.12
.13
.14
DEFLECTION (IN)
DSC 6


ULT LOAD
48900 #
SPECIMEN DSC-7
LOAD
(LBS)
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
0
.01
.02
.03
.04
.05
.06
.07
.08
.09
.1
.11
.12
.13
.14
DEFLECTION (IN)



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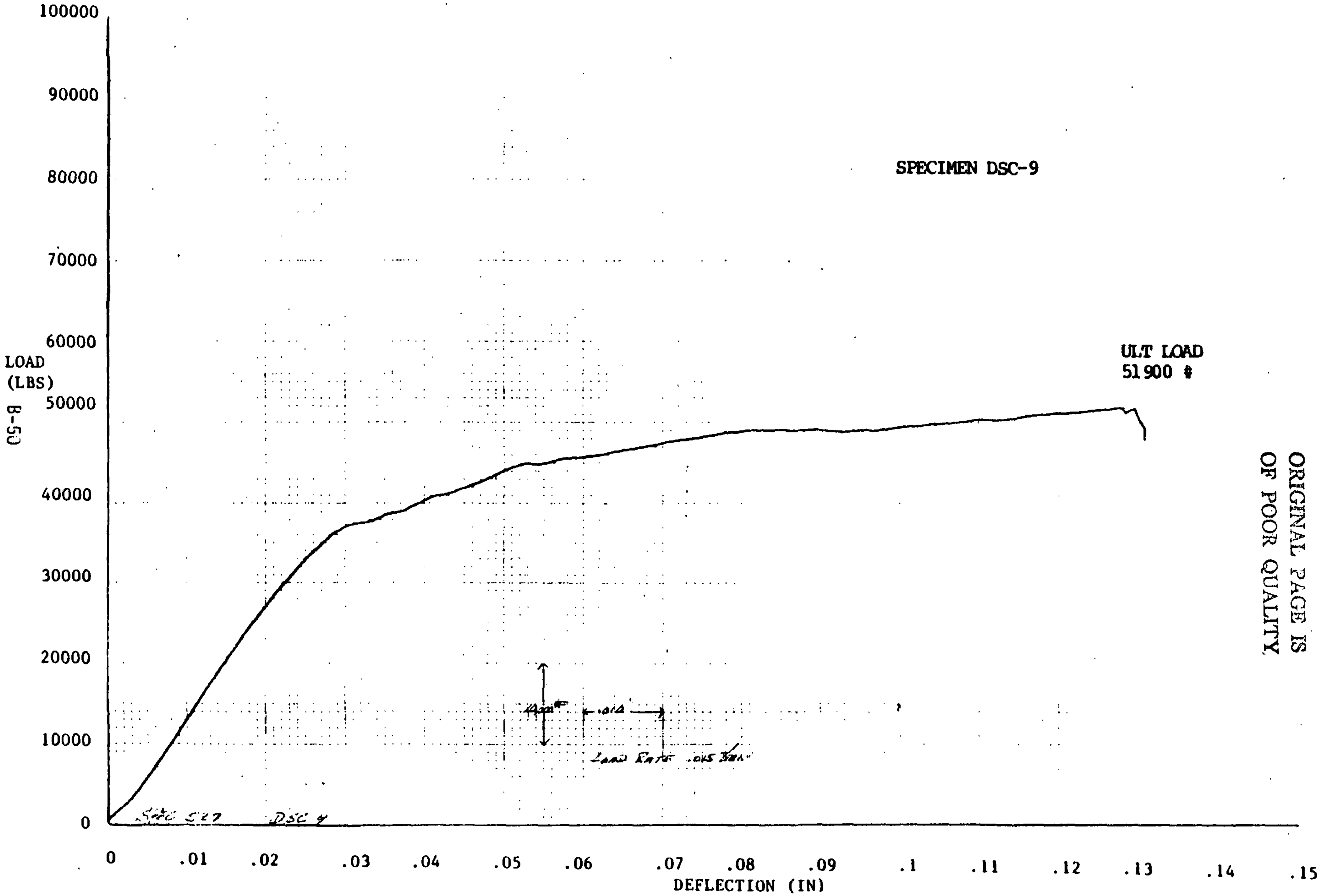

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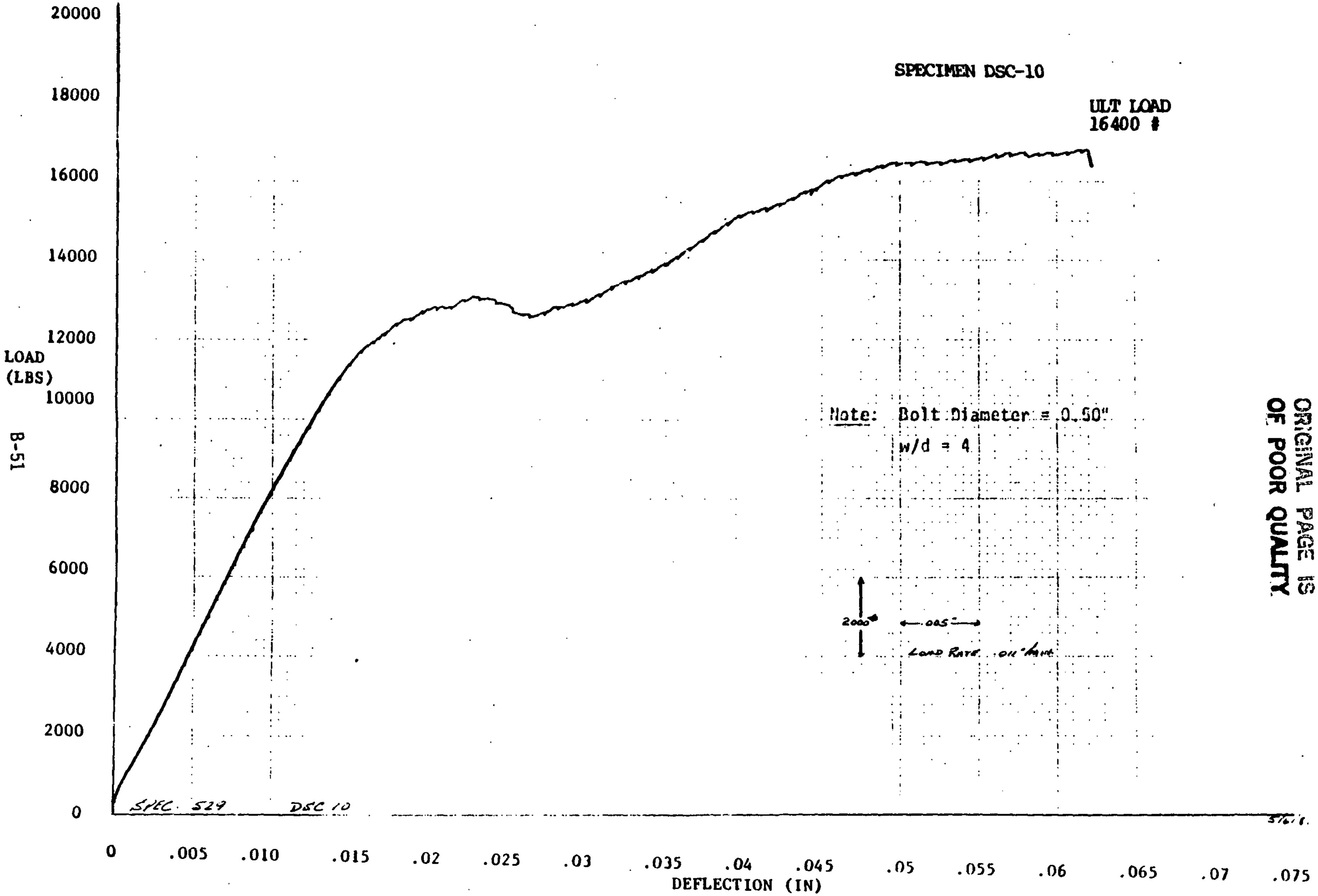
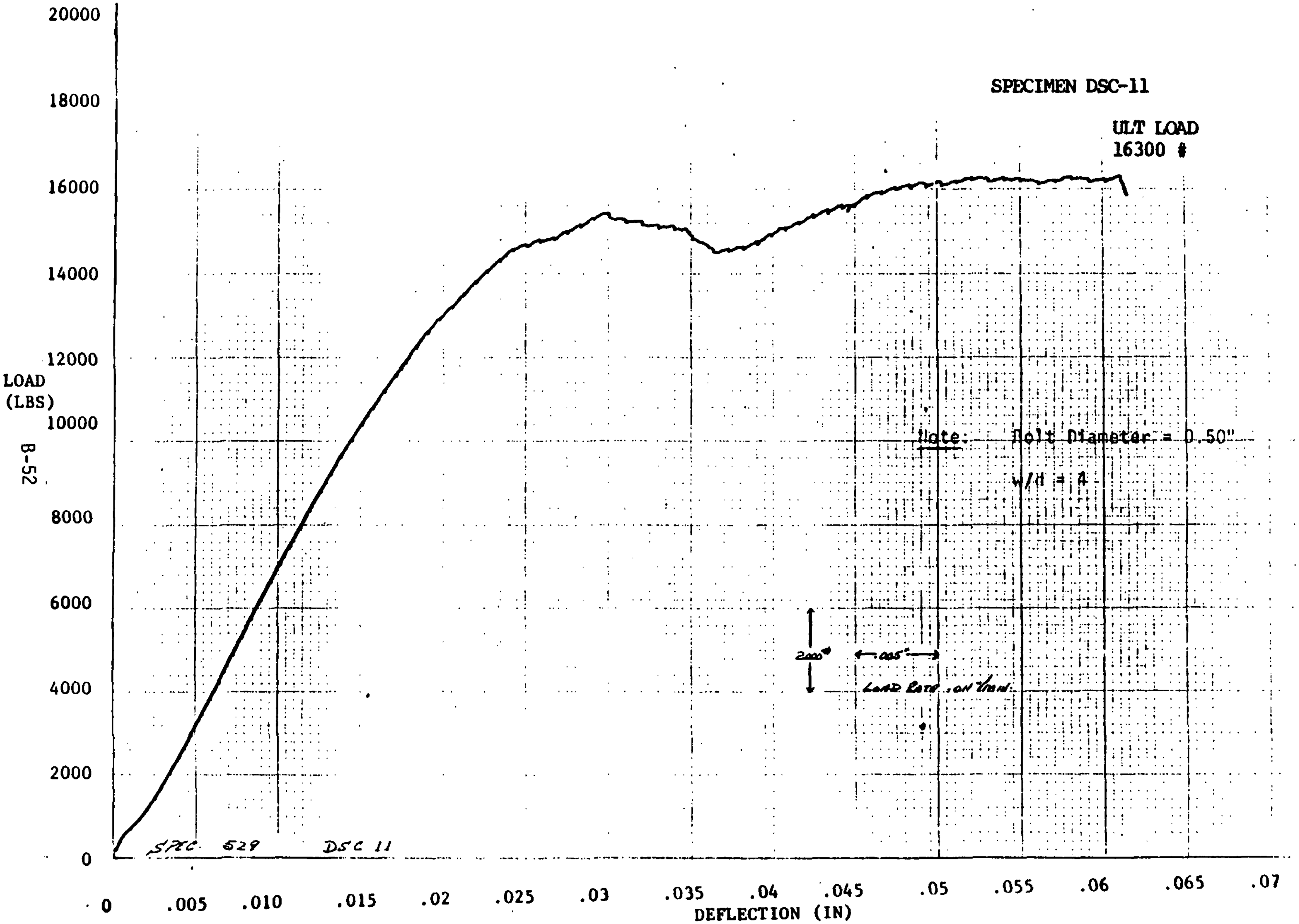
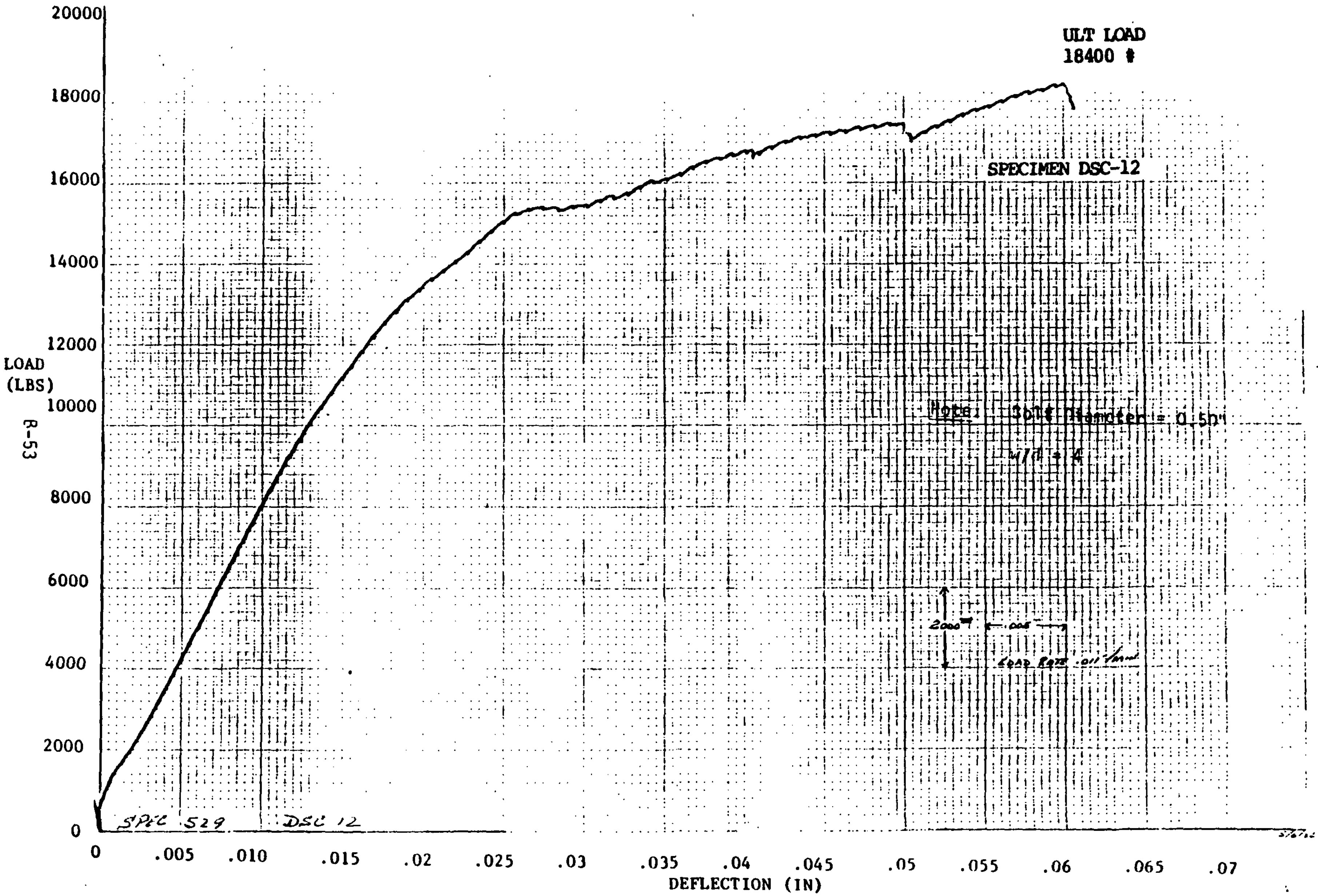
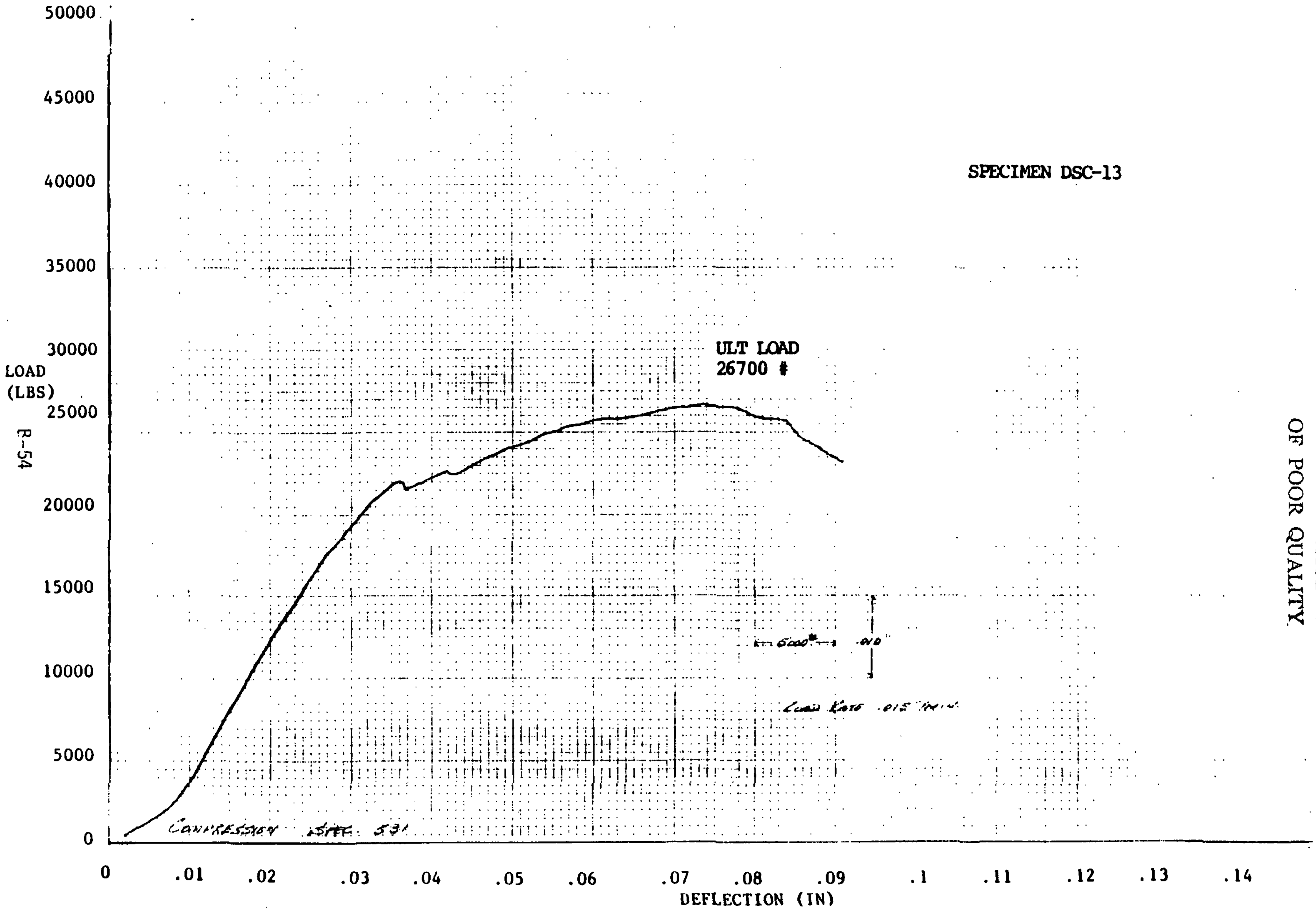

SPECIMEN DSC-10
ULT LOAD
16400 #
Note: Bolt Diameter = 0.50"
w/d = 4
2000
.005
LOAD RATE .011"/MIN
SPEC. 529
DSC 10
LOAD
(LBS)
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
0
.005
.010
.015
.02
.025
.03
.035
.04
.045
.05
.055
.06
.065
.07
.075
DEFLECTION (IN)

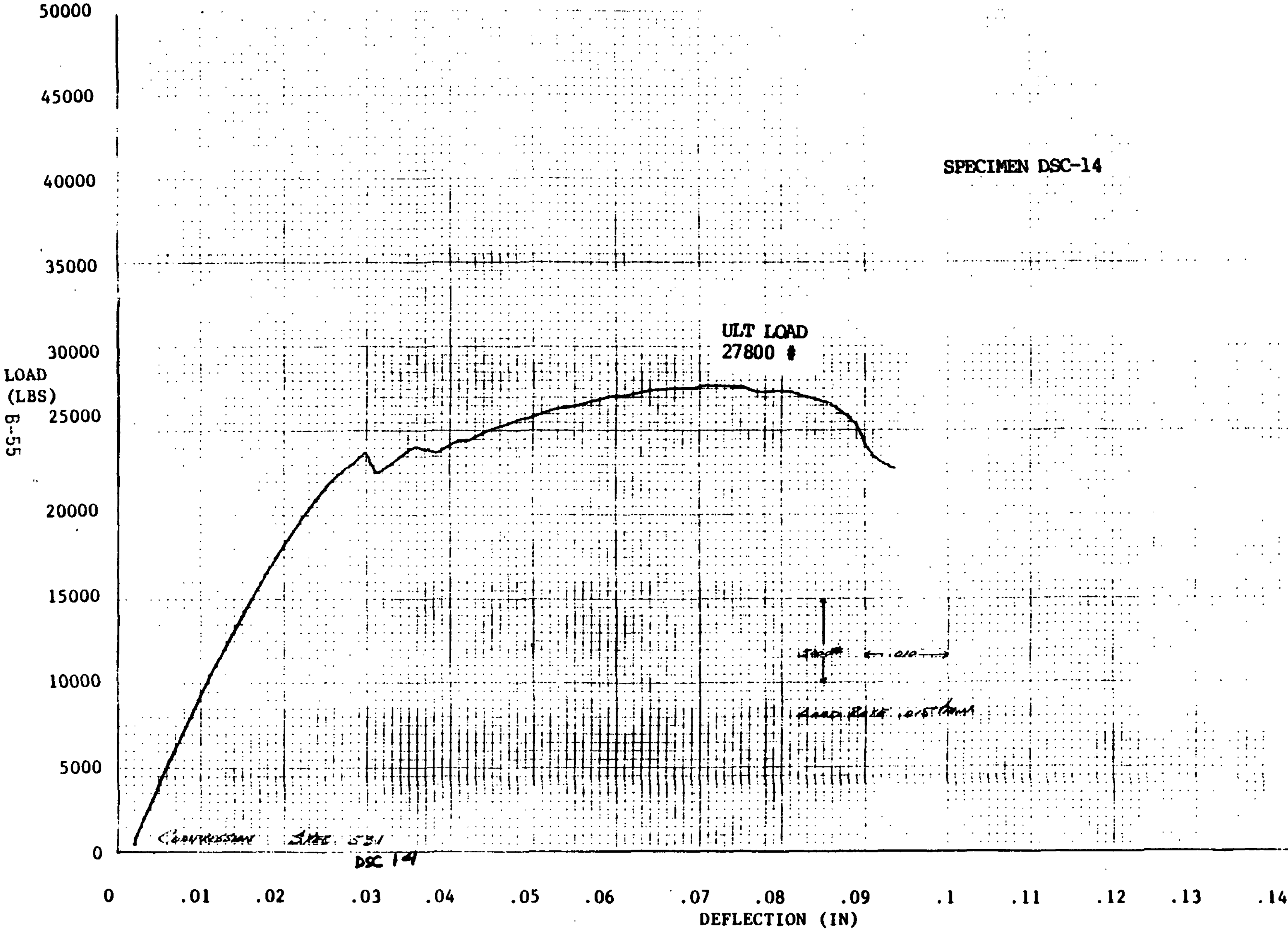


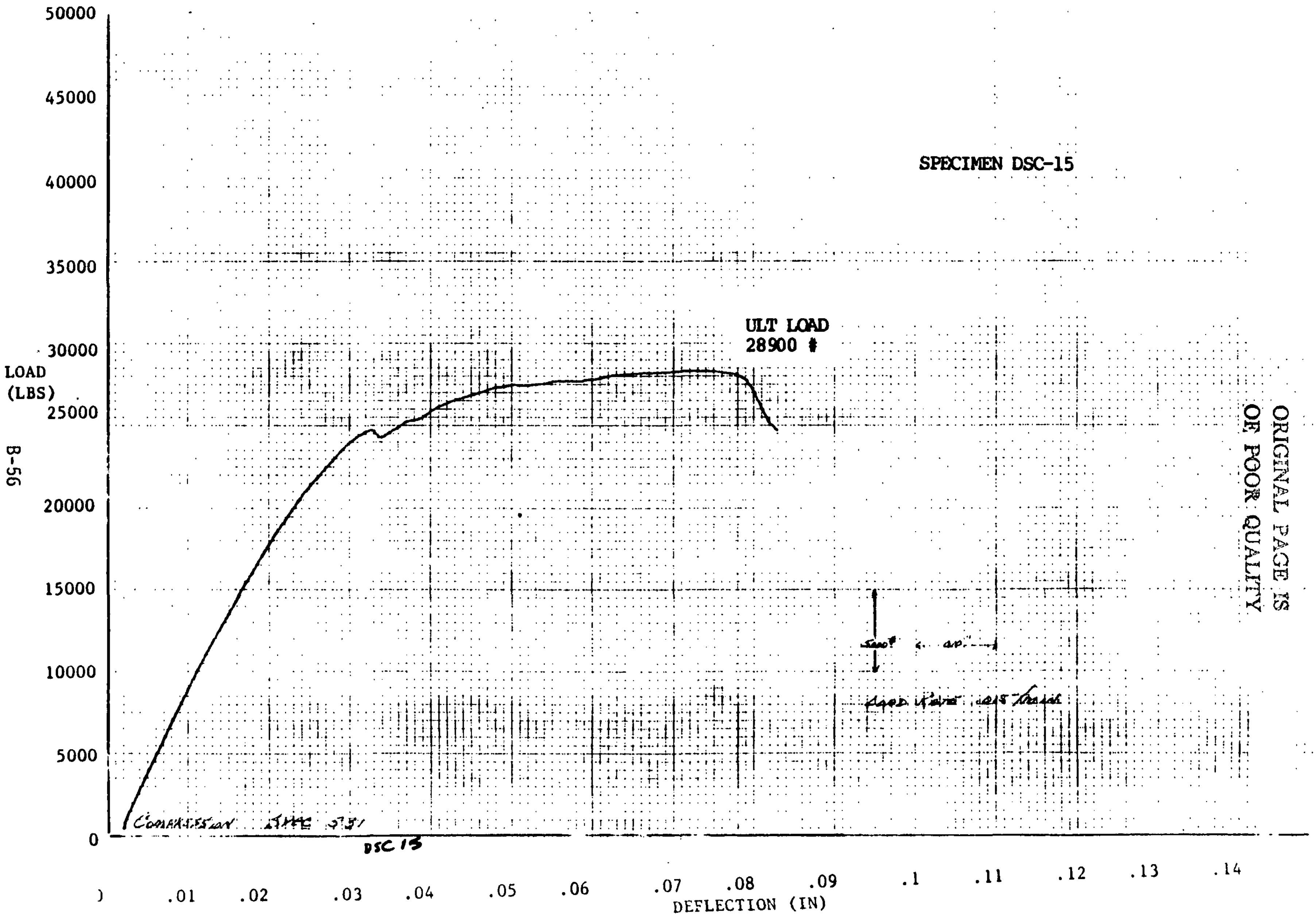
SPECIMEN DSC-11
ULT LOAD
16300 #
Note: Bolt Diameter = 0.50"
w/d = 4
LOAD (LBS)
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
0
.005
.010
.015
.02
.025
.03
.035
.04
.045
.05
.055
.06
.065
.07
DEFLECTION (IN)
SPEC 529
DSC 11

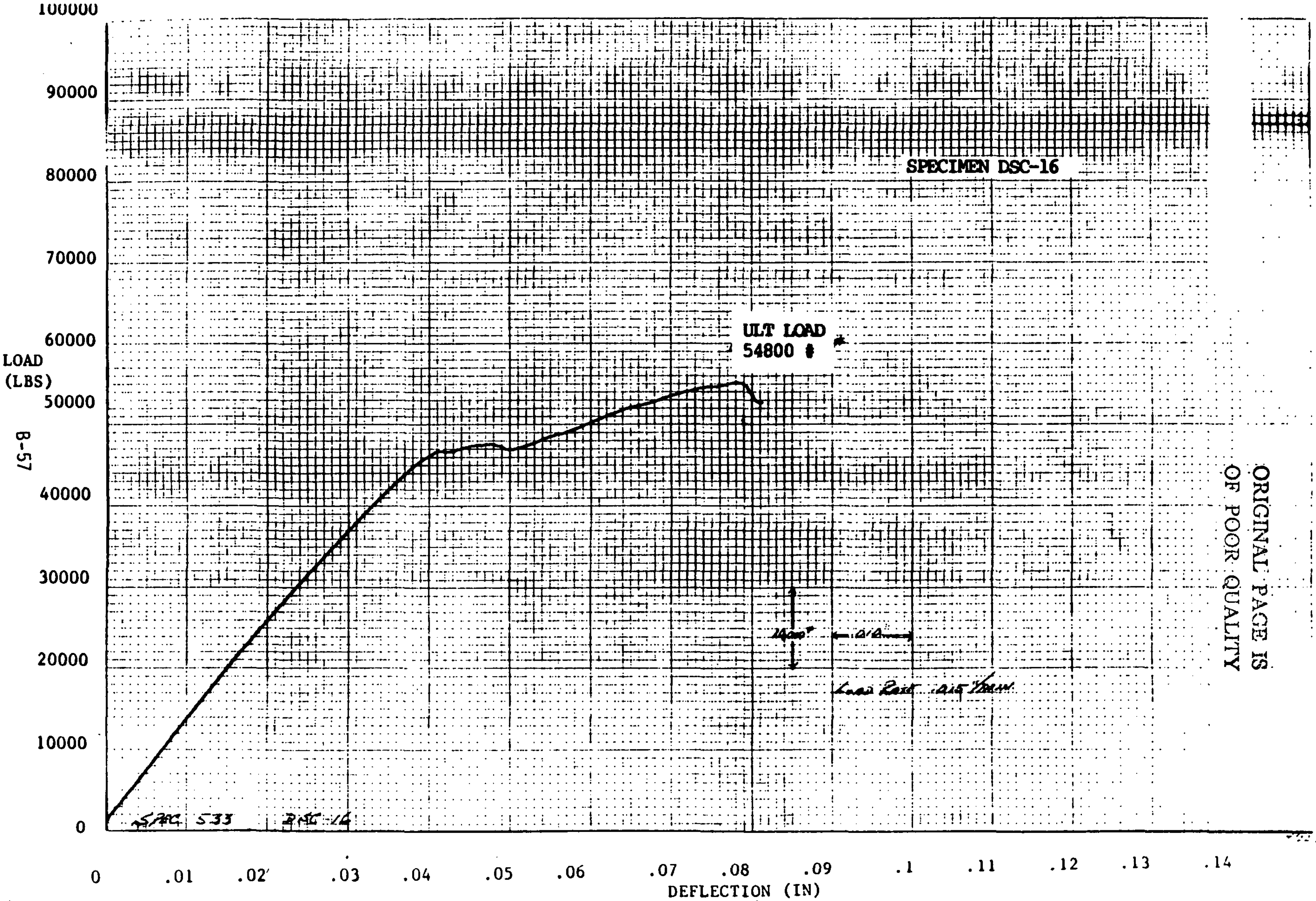


ULT LOAD
18400 #
SPECIMEN DSC-12
LOAD
(LBS)
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
0
.005
.010
.015
.02
.025
.03
.035
.04
.045
.05
.055
.06
.065
.07
DEFLECTION (IN)
SPEC 529
DSC 12
2000#

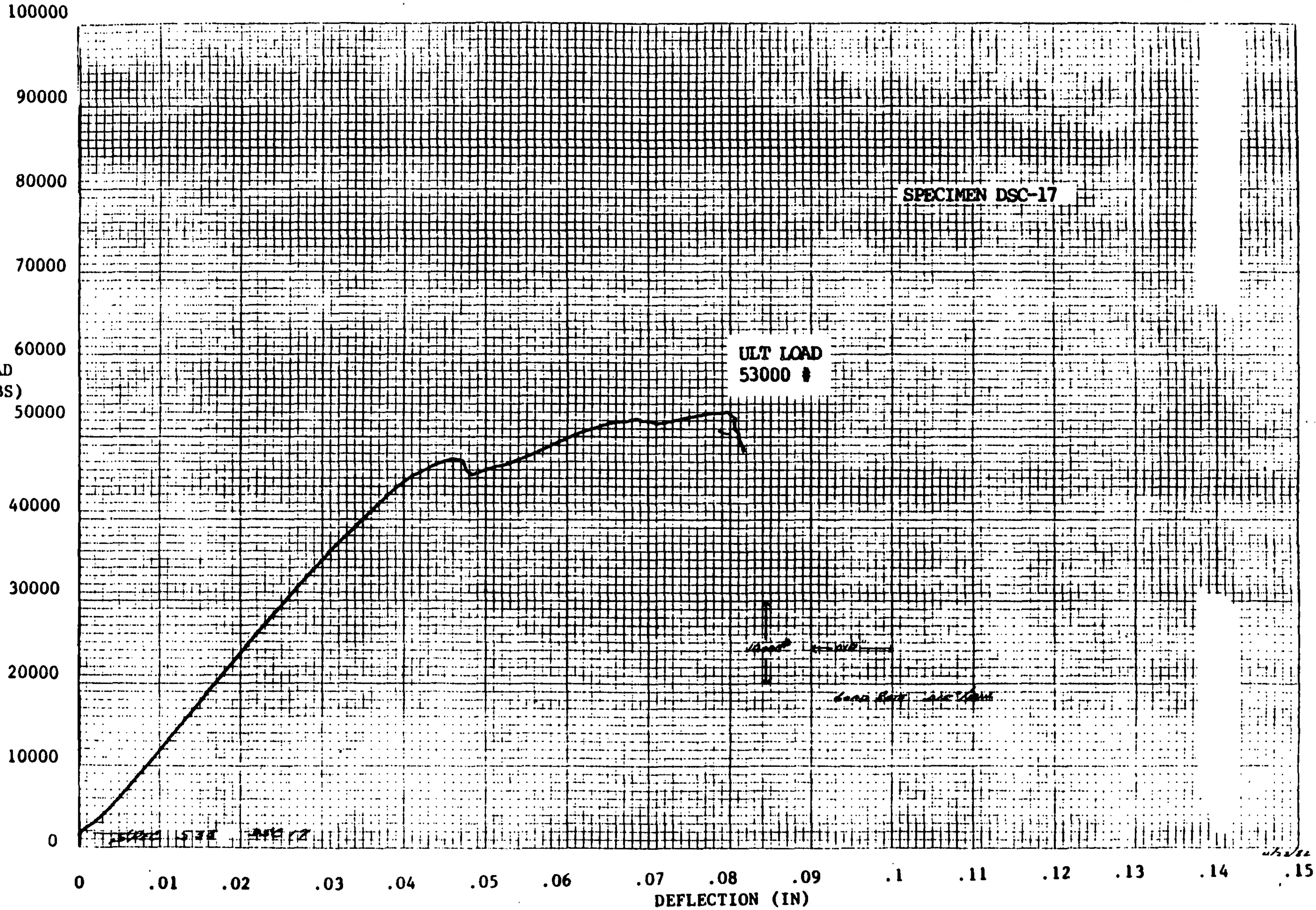

SPECIMEN DSC-13
ULT LOAD
26700 #
LOAD
(LBS)
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
0
.01
.02
.03
.04
.05
.06
.07
.08
.09
.1
.11
.12
.13
.14
DEFLECTION (IN)
6000#
.010"

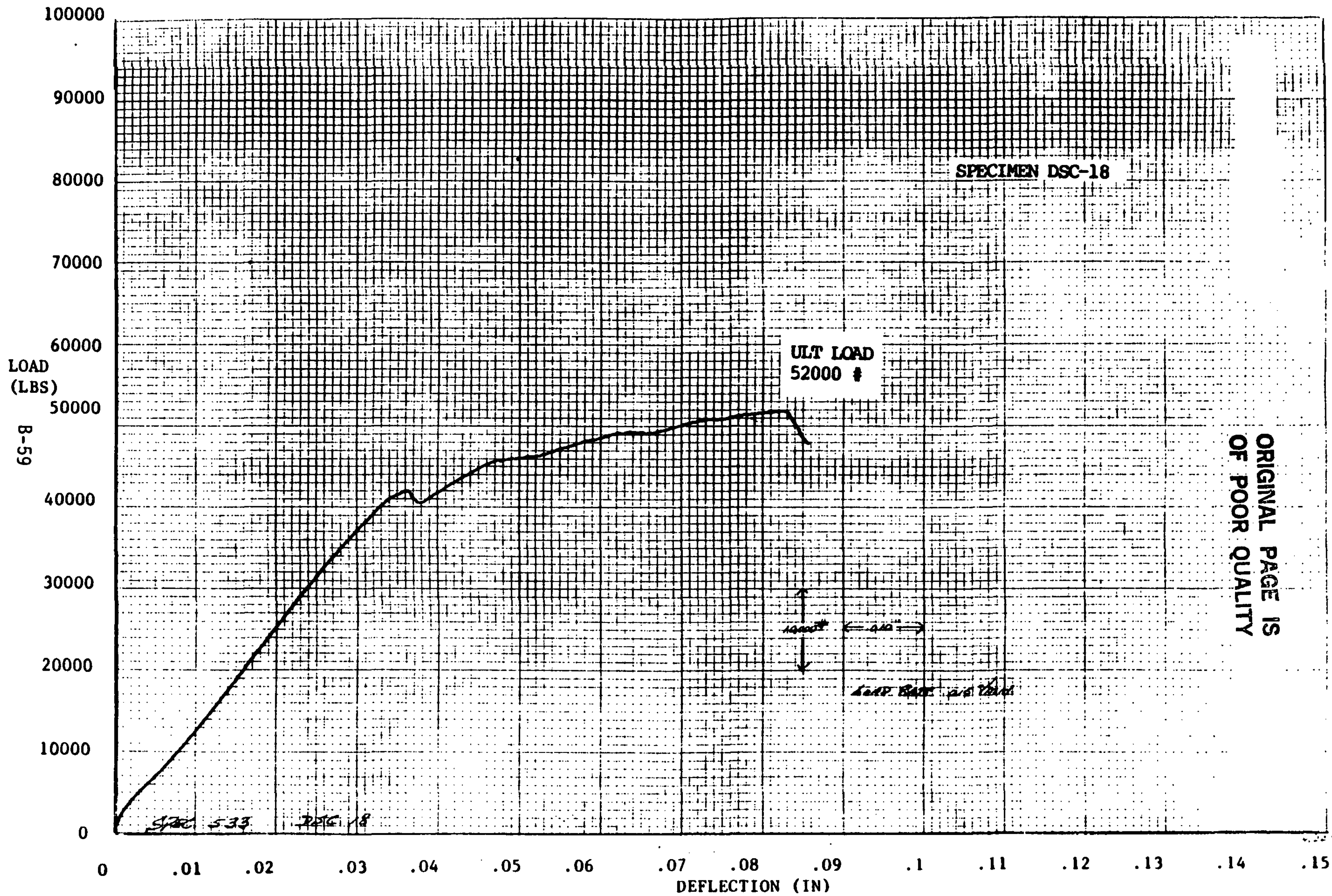

SPECIMEN DSC-14
ULT LOAD
27800 #
LOAD
(LBS)
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
0
.01
.02
.03
.04
.05
.06
.07
.08
.09
.1
.11
.12
.13
.14
DEFLECTION (IN)
DSC 14

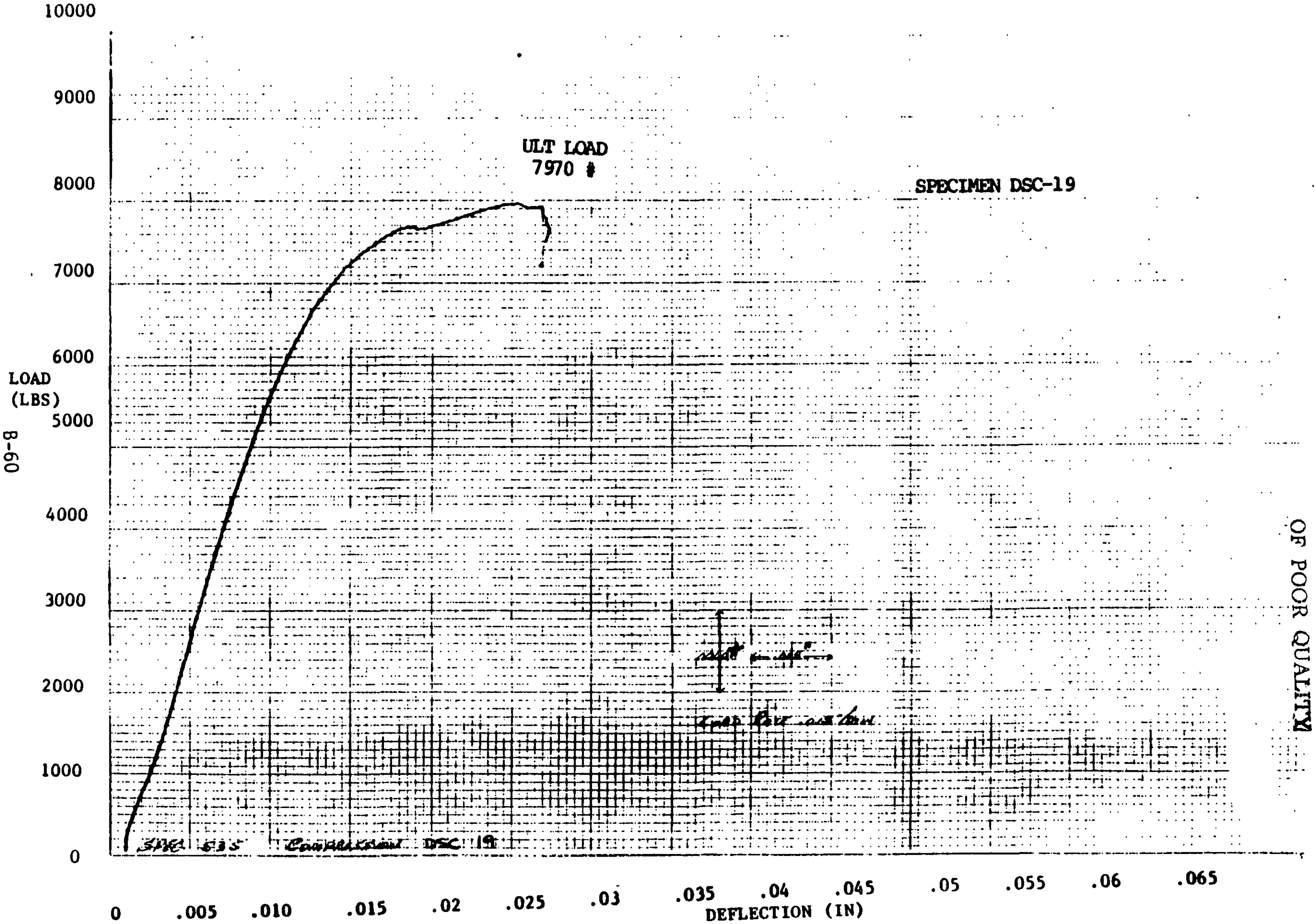

SPECIMEN DSC-15
ULT LOAD
28900 #
LOAD
(LBS)
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
.01
.02
.03
.04
.05
.06
.07
.08
.09
.1
.11
.12
.13
.14
DEFLECTION (IN)
DSC 15



SPECIMEN DSC-16
ULT LOAD
54800 #
LOAD
(LBS)
100000
90000
80000
70000
60000
50000
40000
30000
20000
10000
0
0
.01
.02
.03
.04
.05
.06
.07
.08
.09
.1
.11
.12
.13
.14
DEFLECTION (IN)


SPECIMEN DSC-17
ULT LOAD
53000 #
LOAD
(LBS)
100000
90000
80000
70000
60000
50000
40000
30000
20000
10000
0
0
.01
.02
.03
.04
.05
.06
.07
.08
.09
.1
.11
.12
.13
.14
.15
DEFLECTION (IN)


SPECIMEN DSC-18
ULT LOAD
52000 #
LOAD
(LBS)
100000
90000
80000
70000
60000
50000
40000
30000
20000
10000
0
0
.01
.02
.03
.04
.05
.06
.07
.08
.09
.1
.11
.12
.13
.14
.15
DEFLECTION (IN)



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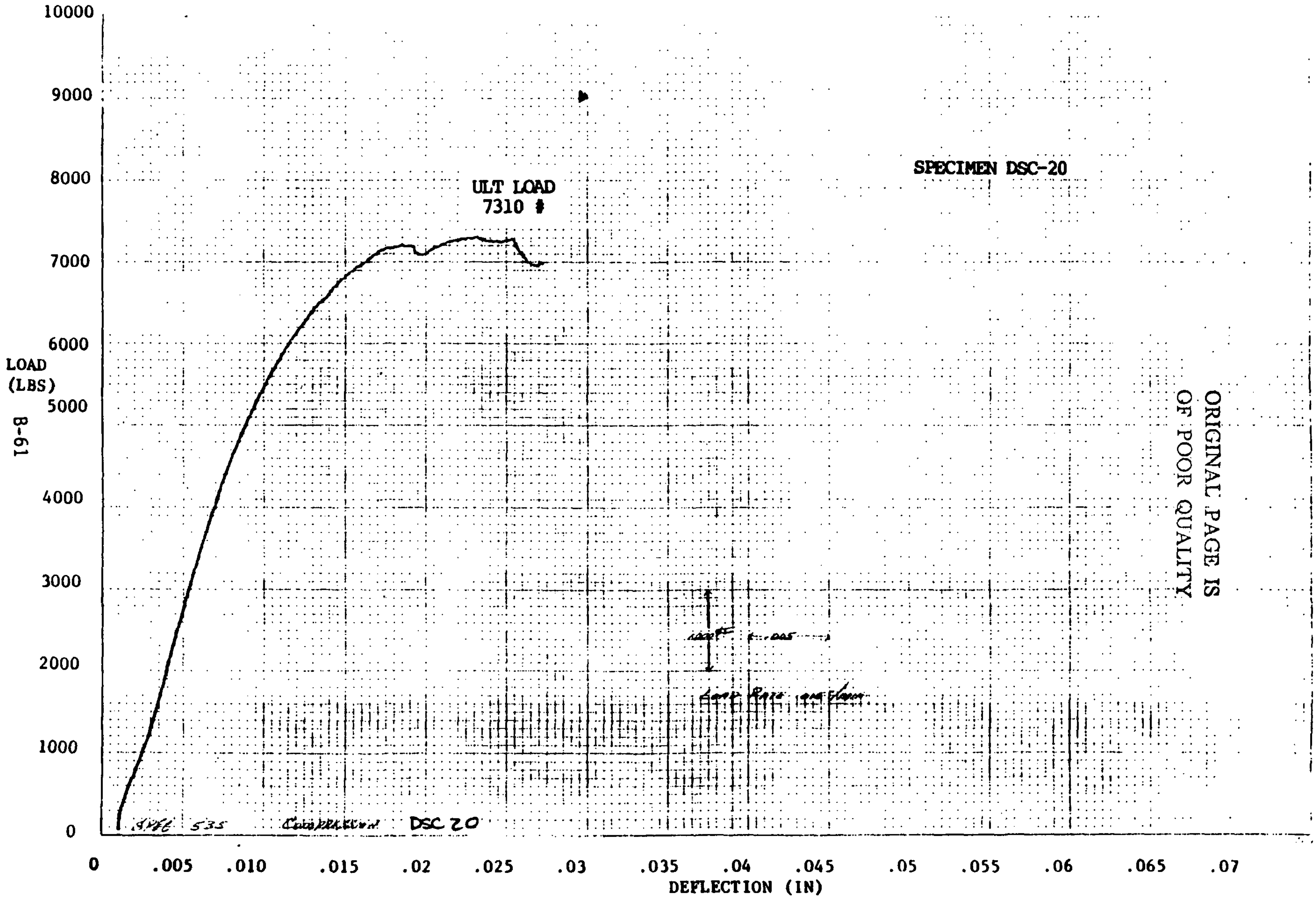
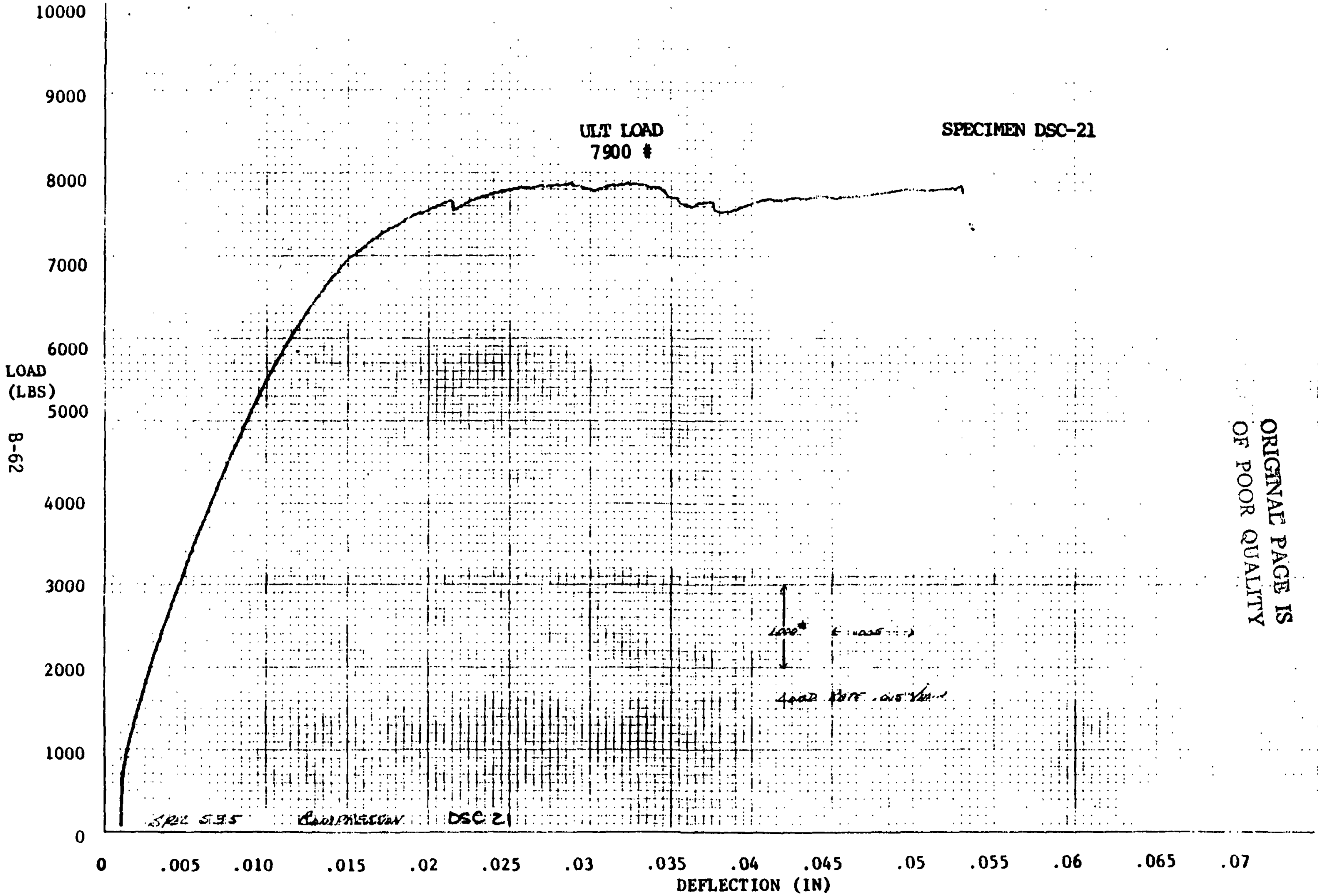

ULT LOAD
7310 #
SPECIMEN DSC-20
LOAD
(LBS)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
0
.005
.010
.015
.02
.025
.03
.035
.04
.045
.05
.055
.06
.065
.07
DEFLECTION (IN)
DSC 20



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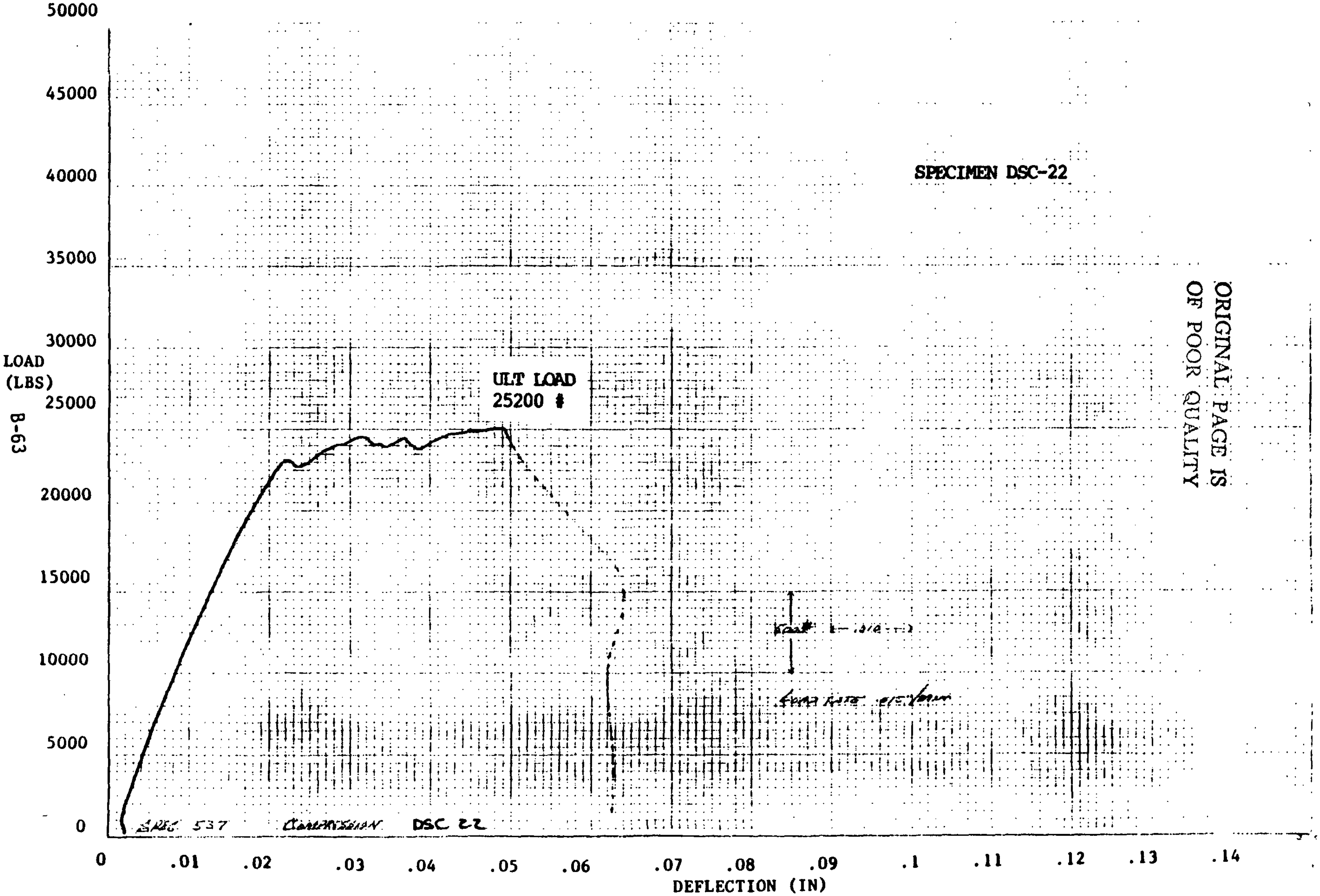
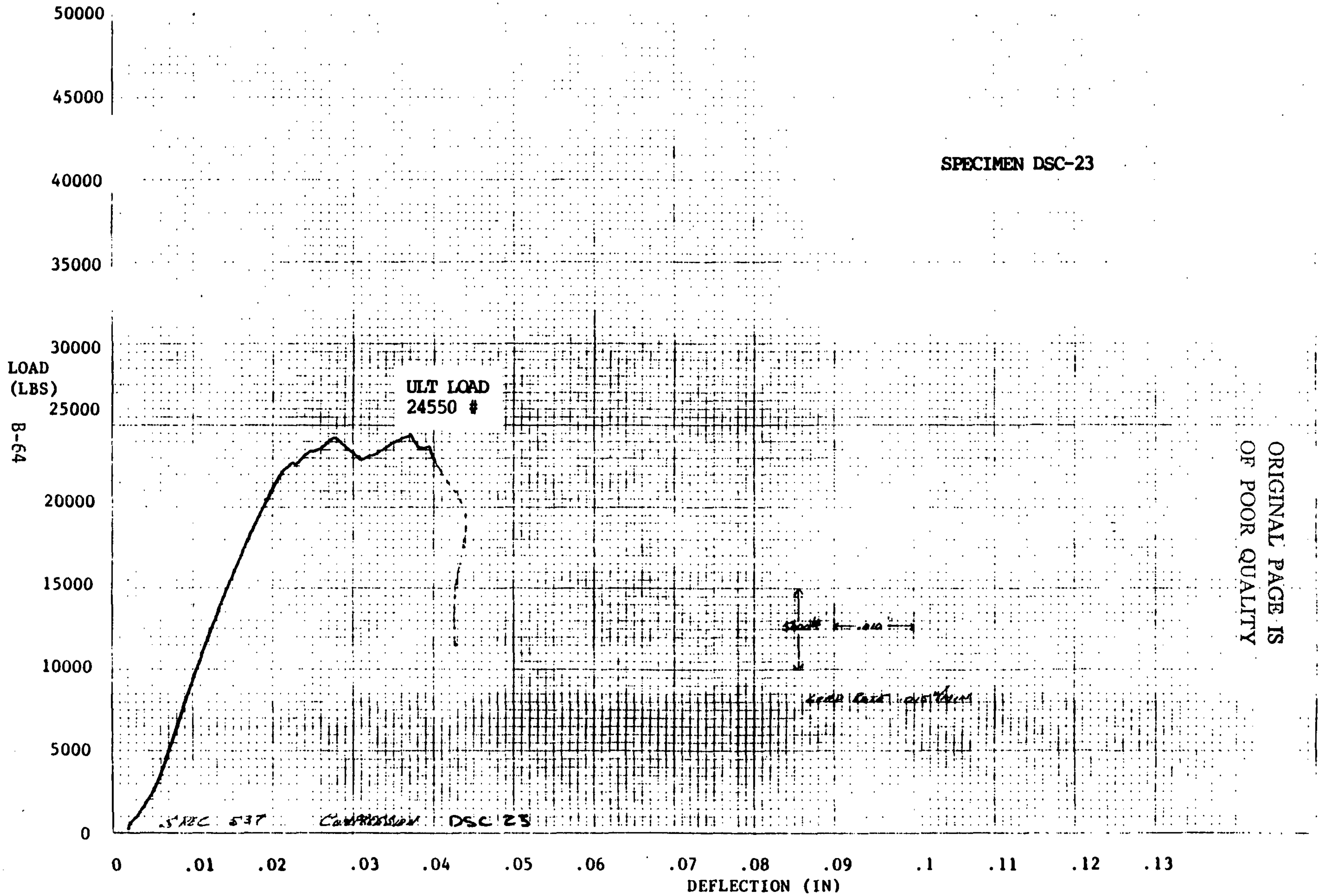
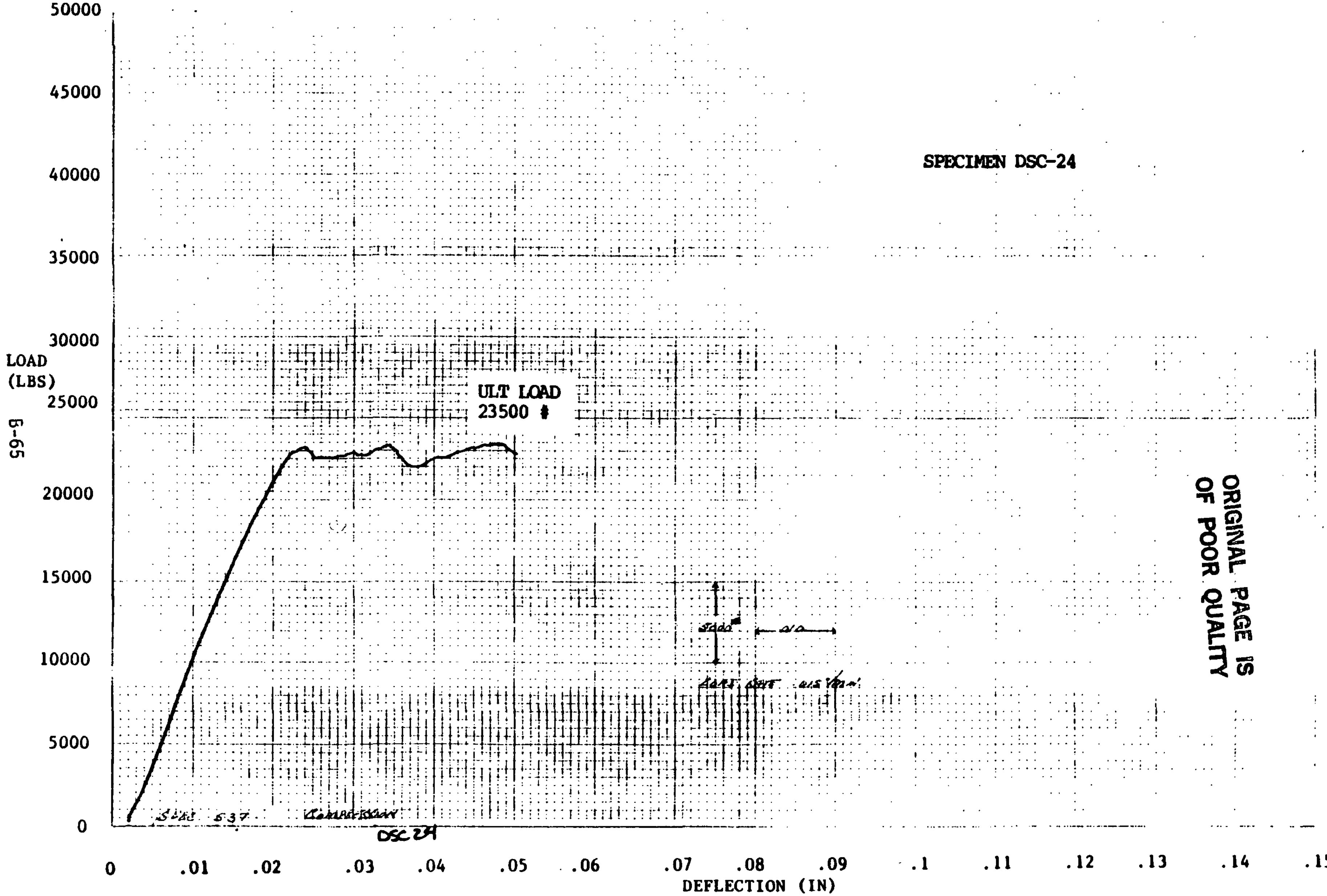
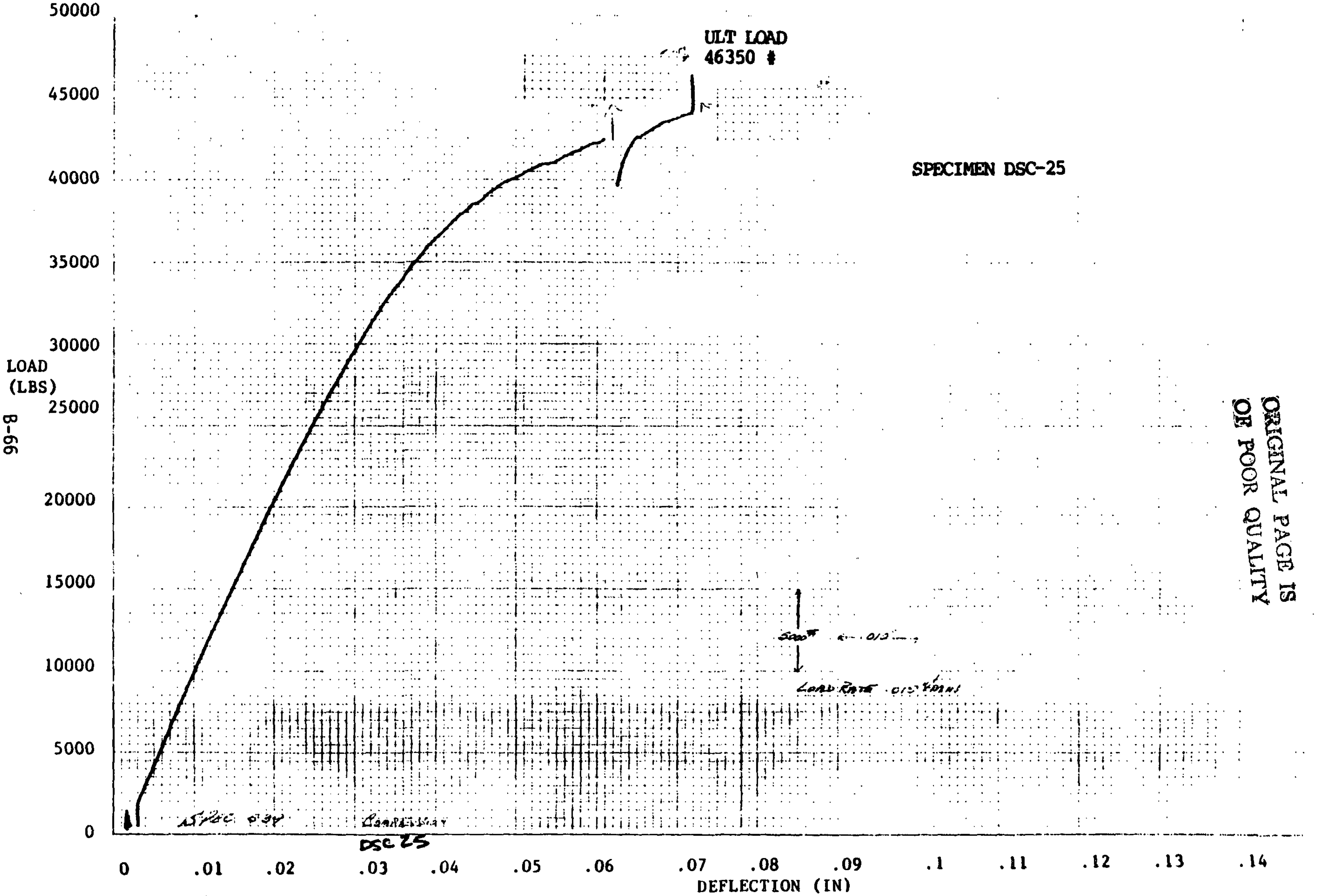
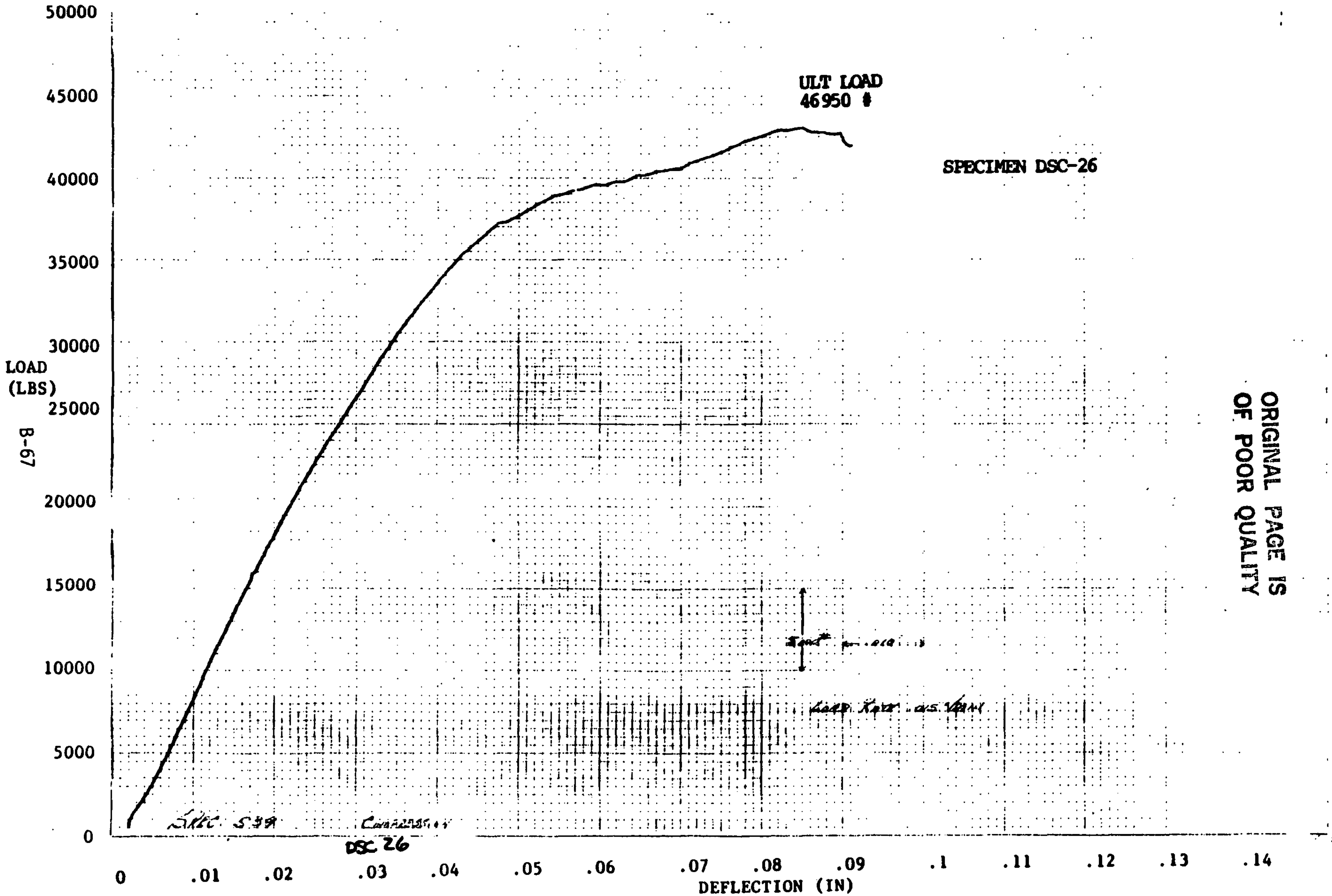

SPECIMEN DSC-22
ULT LOAD
25200 #
LOAD
(LBS)
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
0
.01
.02
.03
.04
.05
.06
.07
.08
.09
.1
.11
.12
.13
.14
DEFLECTION (IN)
DSC 22

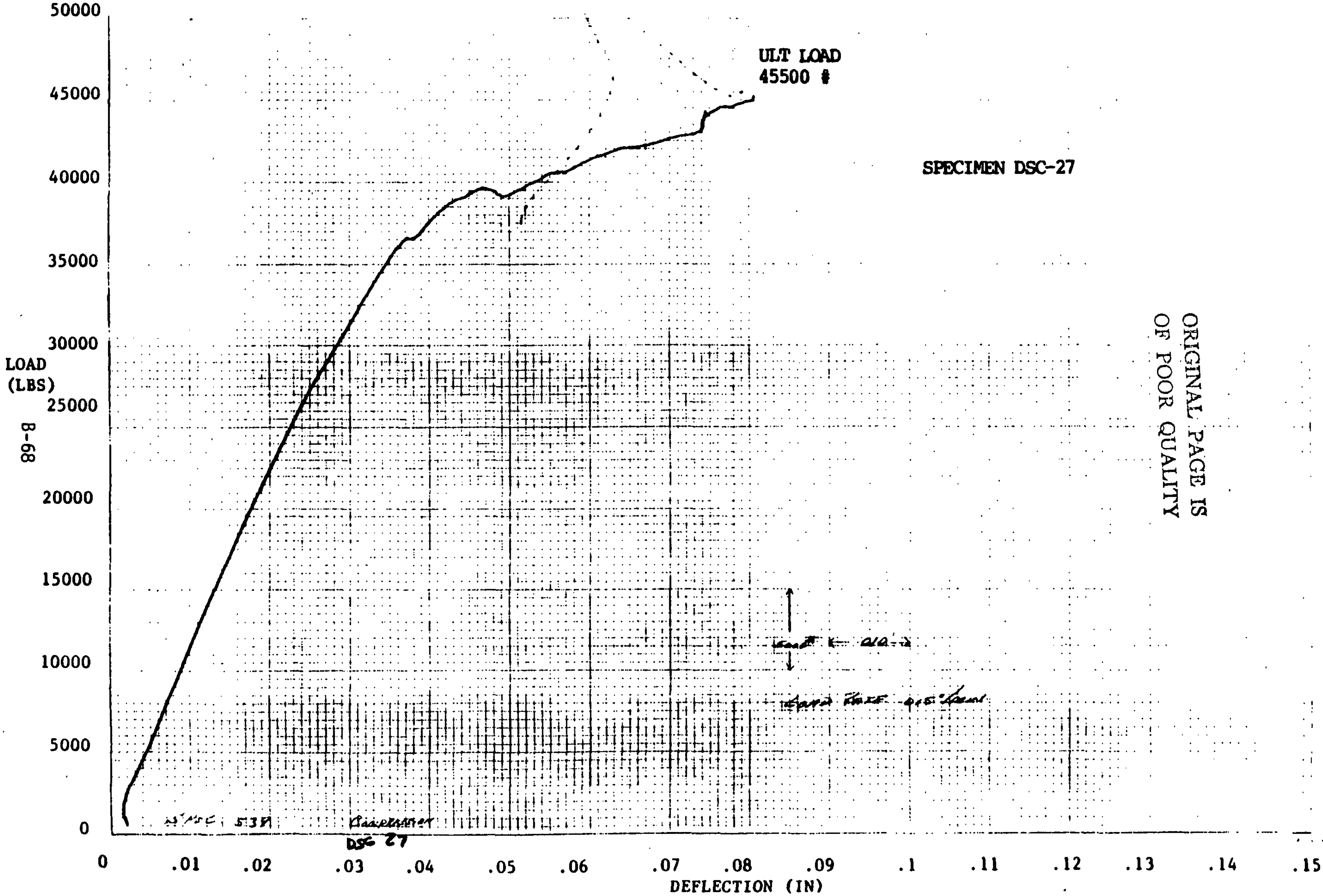

SPECIMEN DSC-23
ULT LOAD
24550 #
LOAD
(LBS)
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
0
.01
.02
.03
.04
.05
.06
.07
.08
.09
.1
.11
.12
.13
DEFLECTION (IN)

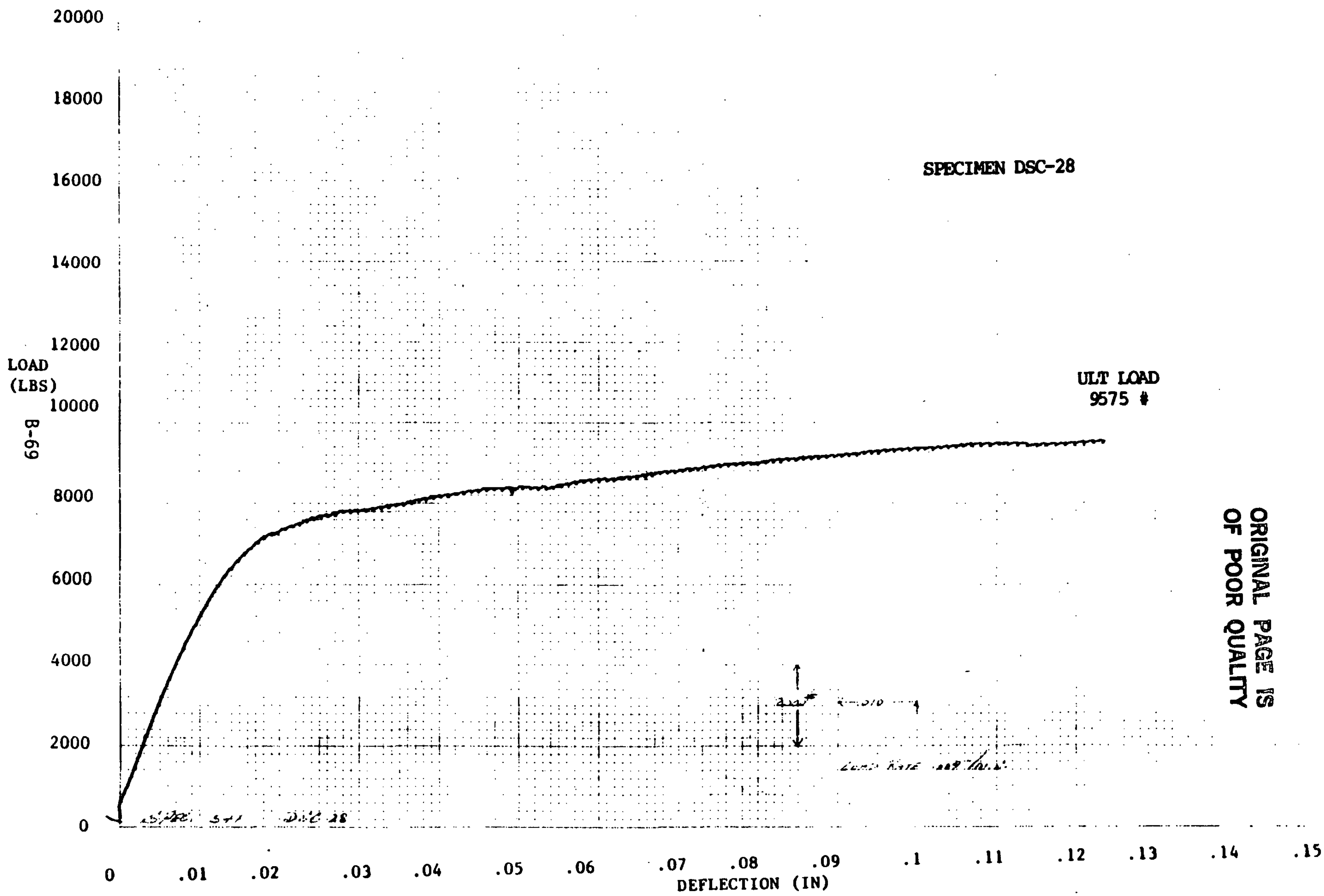

SPECIMEN DSC-24
LOAD (LBS)
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
ULT LOAD
23500 #
DSC 24
0
.01
.02
.03
.04
.05
.06
.07
.08
.09
.1
.11
.12
.13
.14
.15
DEFLECTION (IN)


ULT LOAD
46350 #
SPECIMEN DSC-25
LOAD
(LBS)
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
0
.01
.02
.03
.04
.05
.06
.07
.08
.09
.1
.11
.12
.13
.14
DEFLECTION (IN)
DSC 25



ULT LOAD
46950 #
SPECIMEN DSC-26
LOAD
(LBS)
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
0
.01
.02
.03
.04
.05
.06
.07
.08
.09
.1
.11
.12
.13
.14
DEFLECTION (IN)
DSC 26


ULT LOAD
45500 #
SPECIMEN DSC-27
LOAD
(LBS)
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
0
.01
.02
.03
.04
.05
.06
.07
.08
.09
.1
.11
.12
.13
.14
.15
DEFLECTION (IN)
DSC 27



B-69

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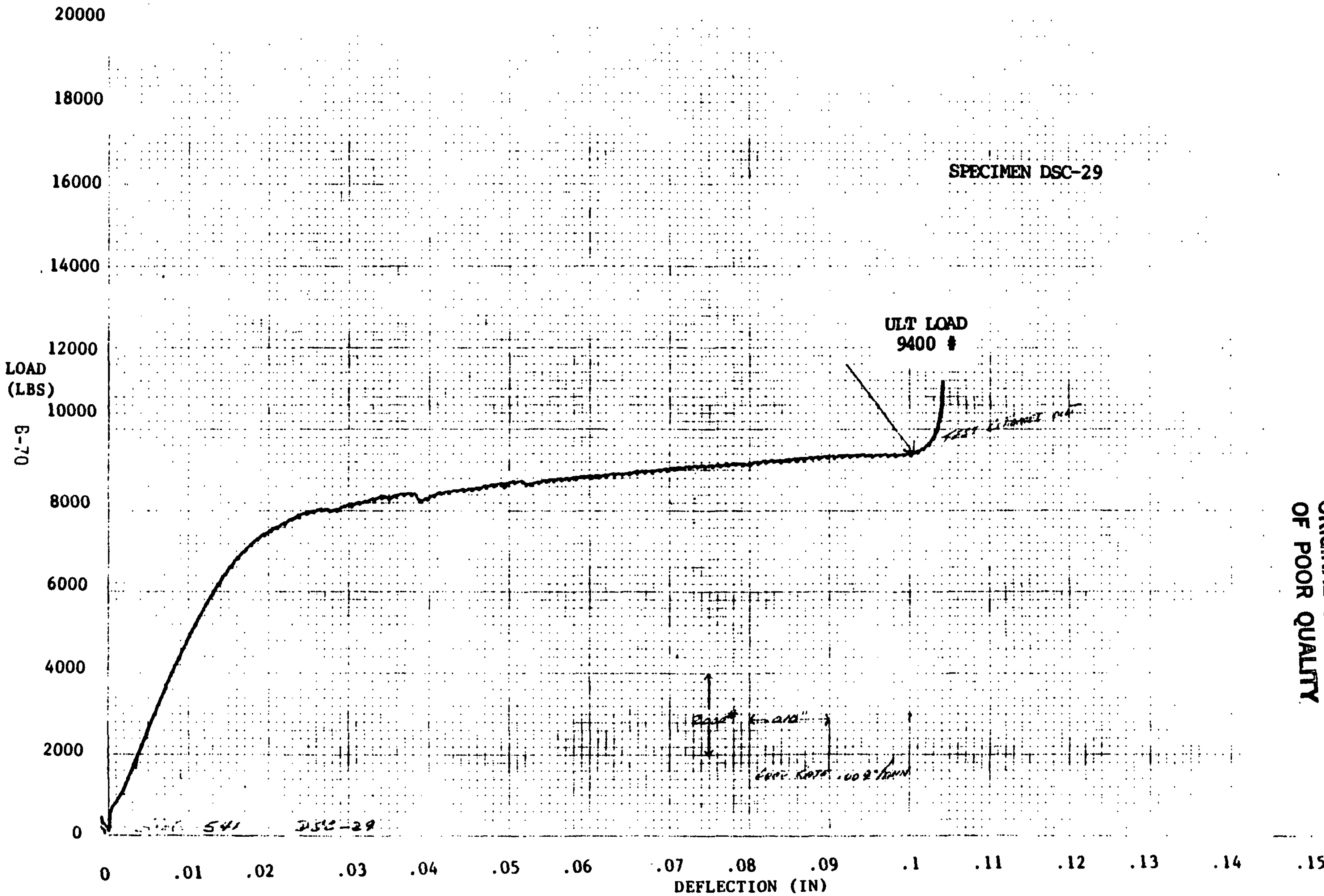
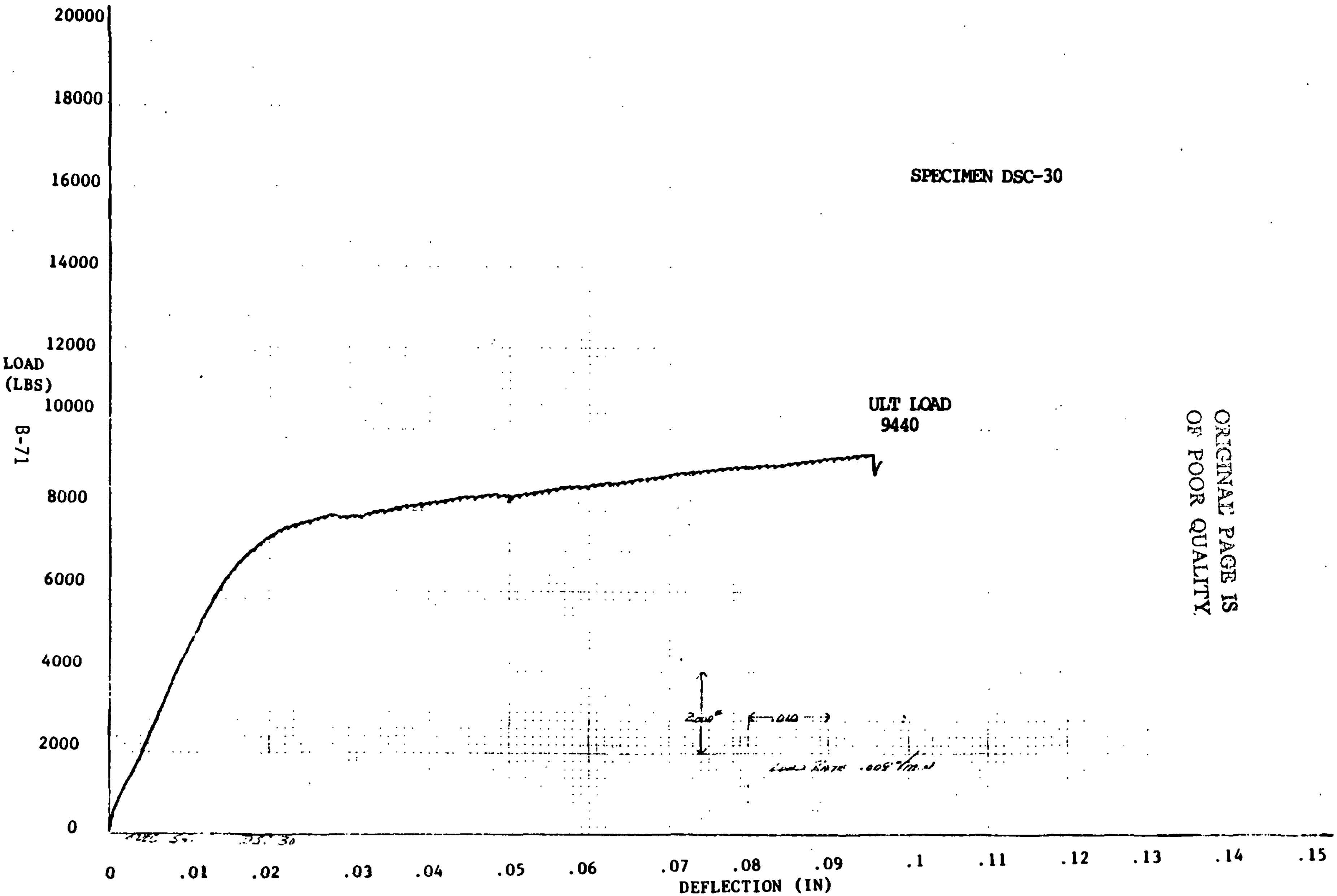
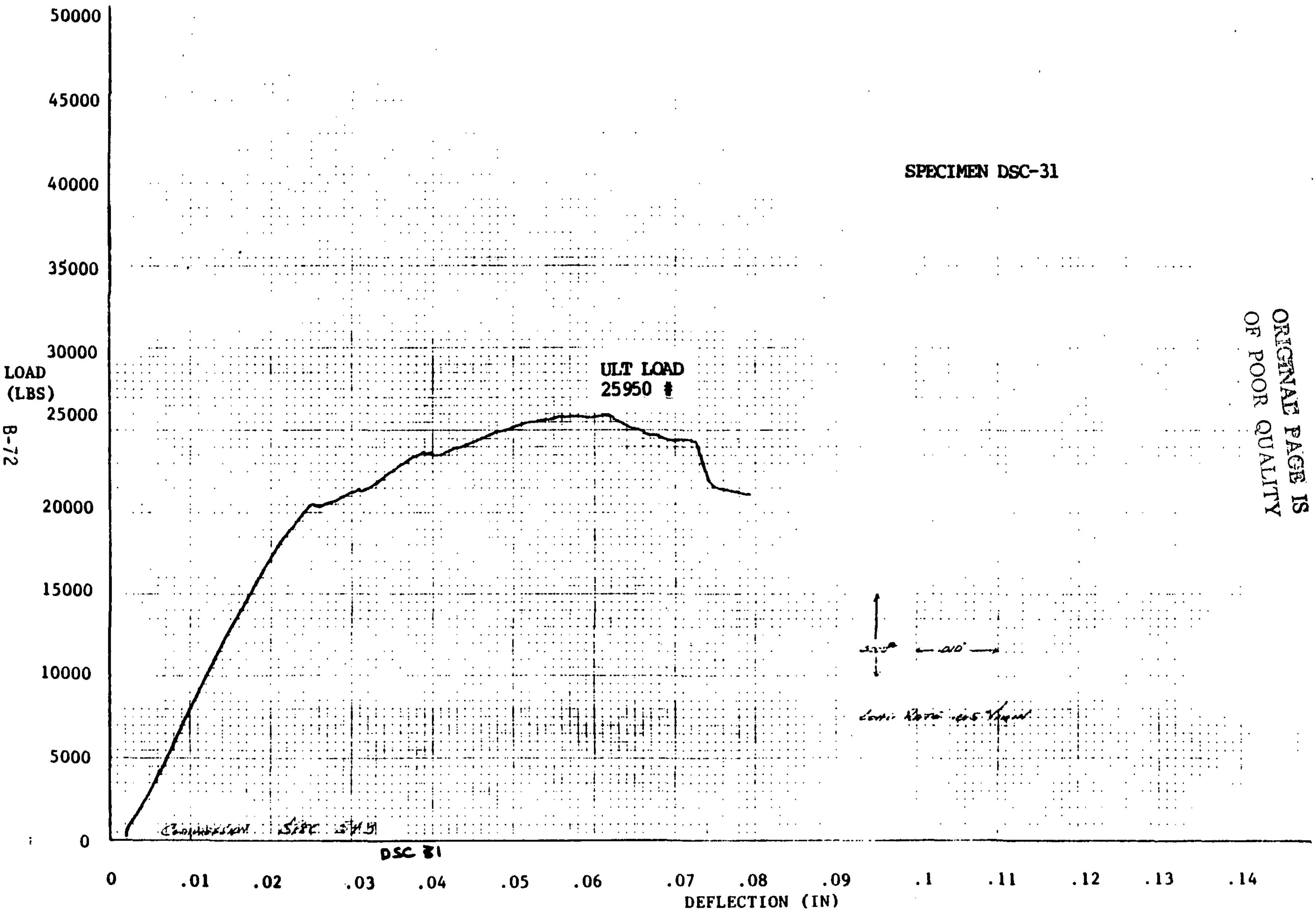
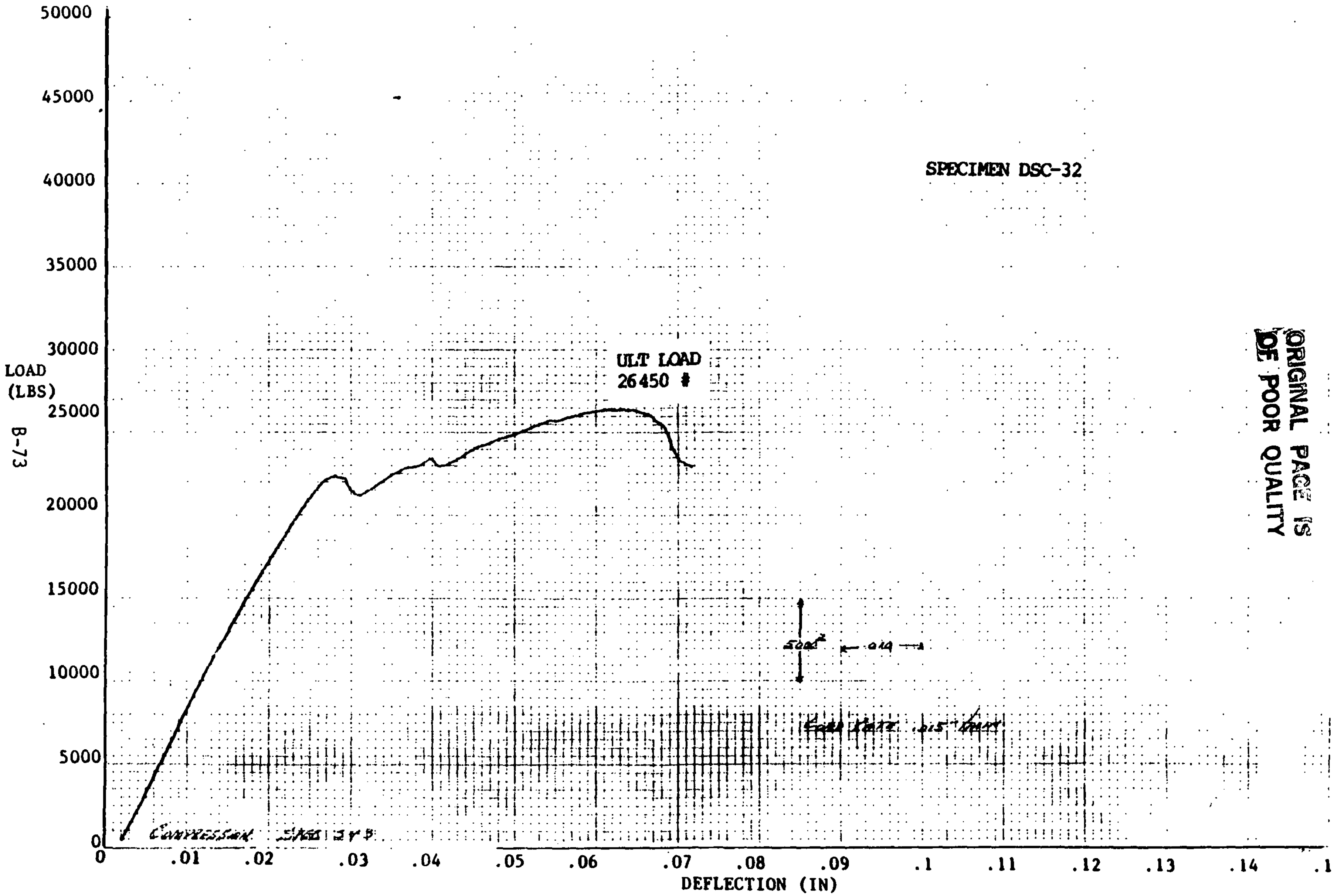

SPECIMEN DSC-29
ULT LOAD
9400 #
LOAD
(LBS)
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
0
.01
.02
.03
.04
.05
.06
.07
.08
.09
.1
.11
.12
.13
.14
.15
DEFLECTION (IN)


SPECIMEN DSC-30
ULT LOAD
9440
LOAD
(LBS)
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
0
.01
.02
.03
.04
.05
.06
.07
.08
.09
.1
.11
.12
.13
.14
.15
DEFLECTION (IN)


SPECIMEN DSC-31
ULT LOAD
25950 #
LOAD
(LBS)
DEFLECTION (IN)
DSC 31
0
5000
10000
15000
20000
25000
30000
35000
40000
45000
50000
0
.01
.02
.03
.04
.05
.06
.07
.08
.09
.1
.11
.12
.13
.14



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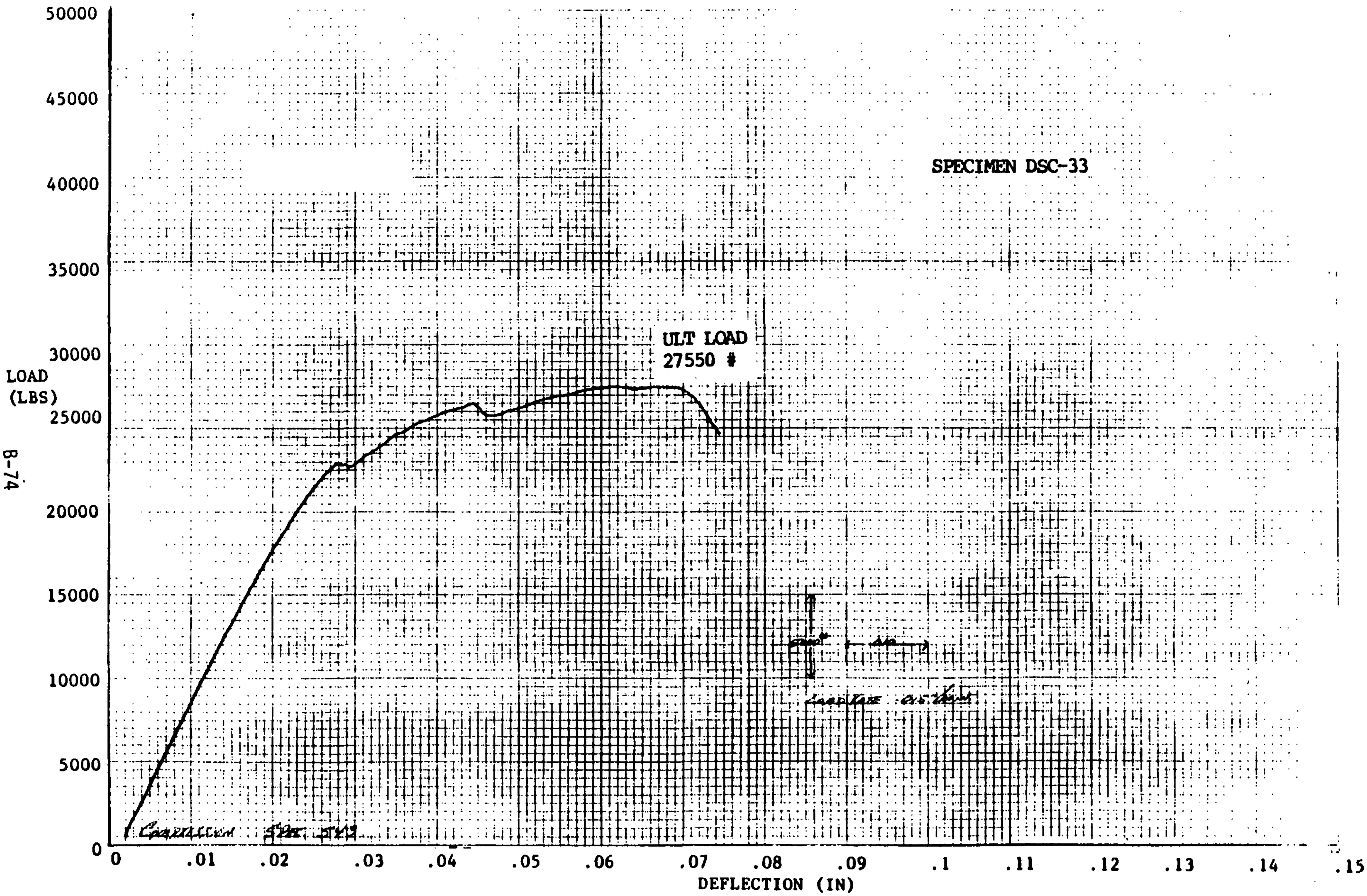

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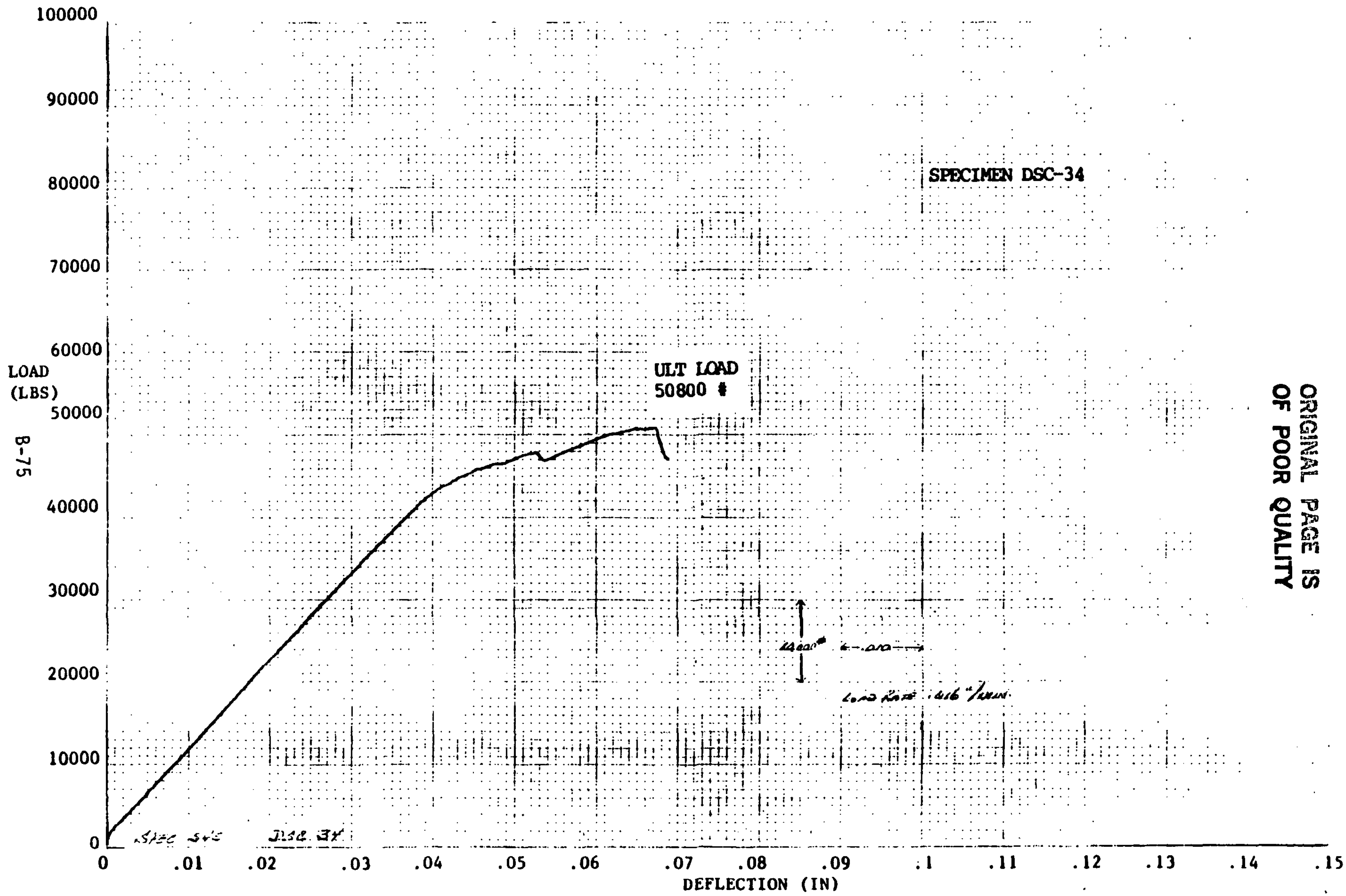
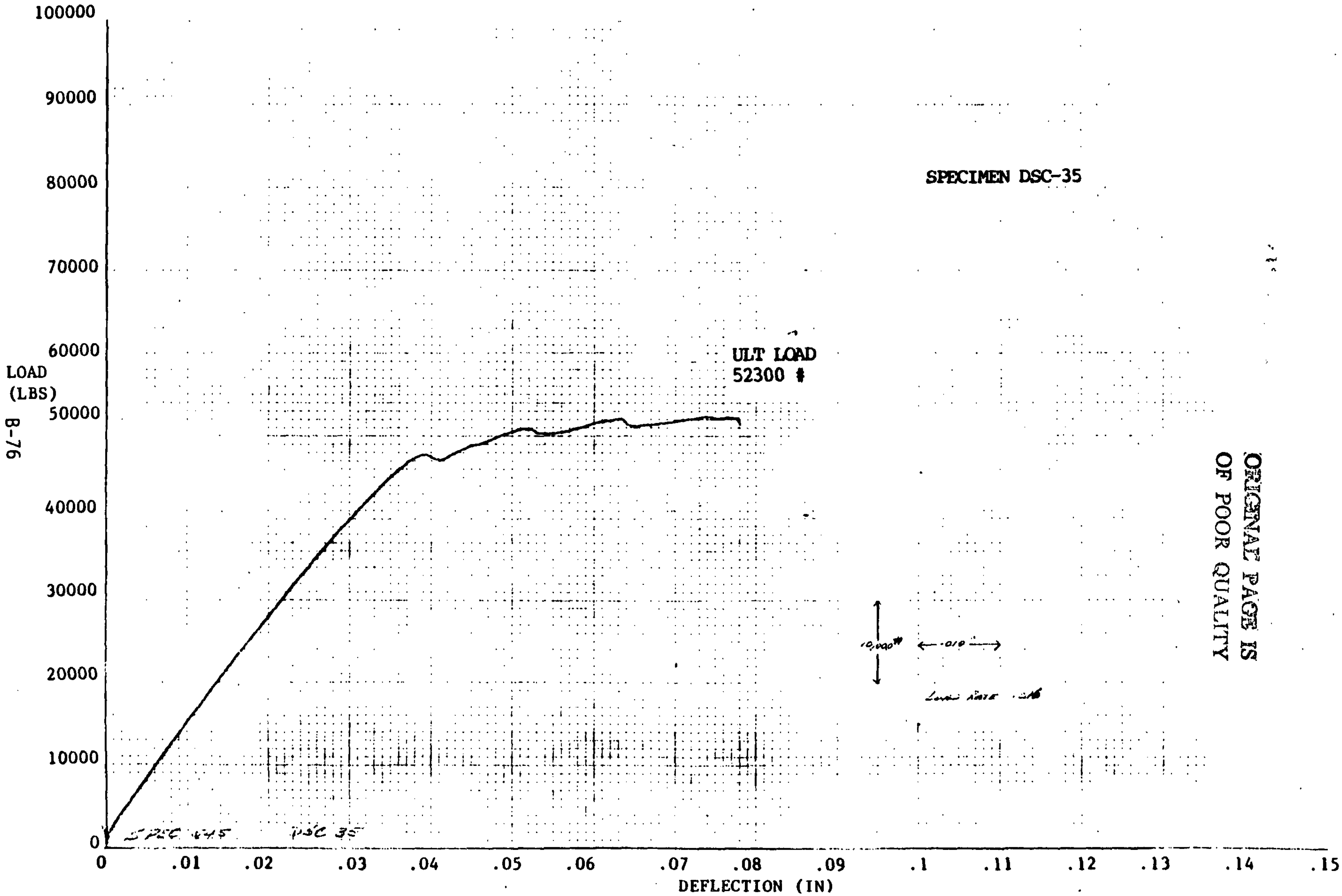

LOAD (LBS)
100000
90000
80000
70000
60000
50000
40000
30000
20000
10000
0
0
.01
.02
.03
.04
.05
.06
.07
.08
.09
.1
.11
.12
.13
.14
.15
DEFLECTION (IN)
SPECIMEN DSC-34
ULT LOAD
50800 #



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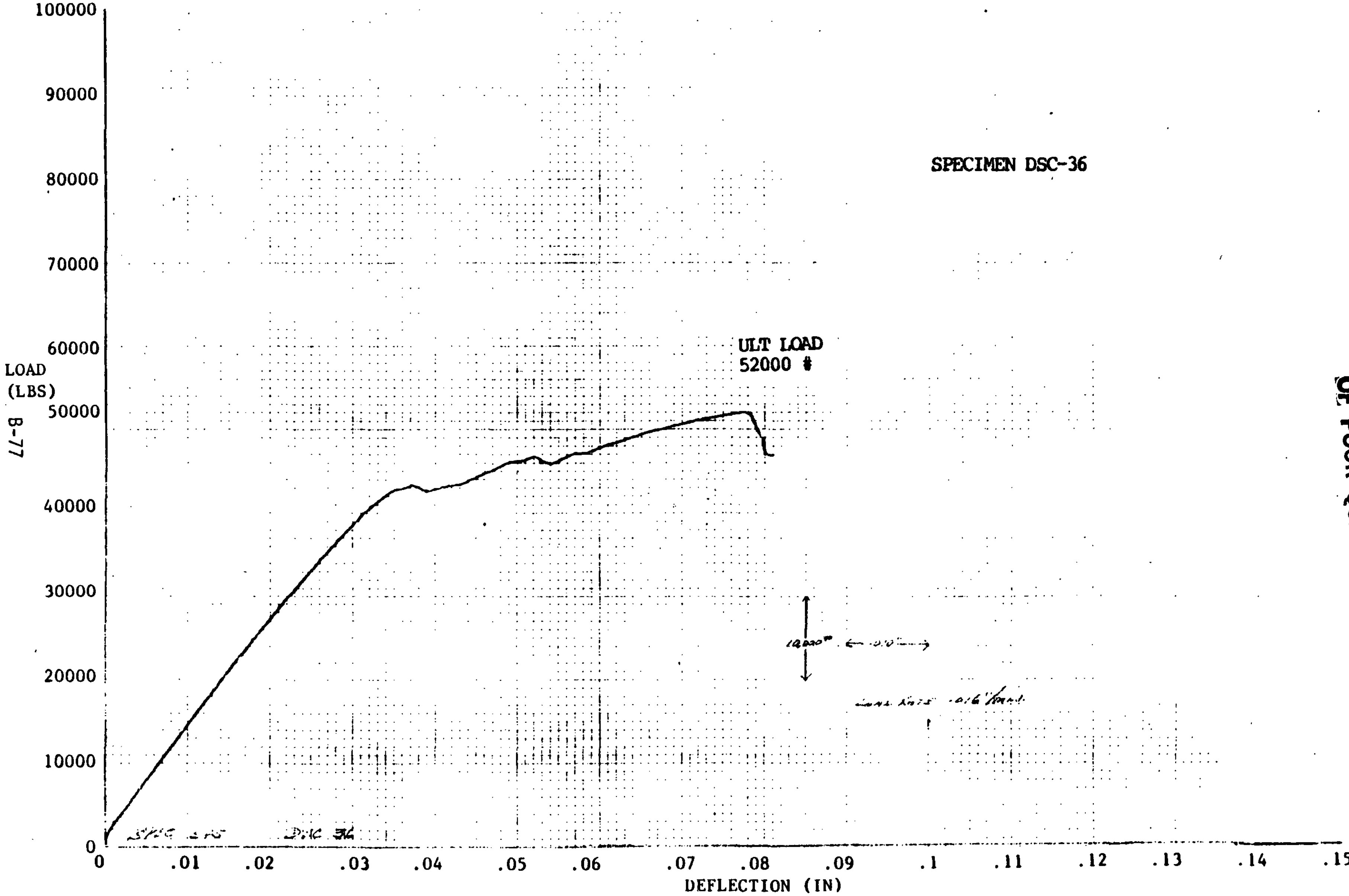

B-77

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APPENDIX C

PHASE I SINGLE SHEAR TESTS

SPECIMEN CODING:

SST - SINGLE SHEAR TENSION
SSC - SINGLE SHEAR COMPRESSION

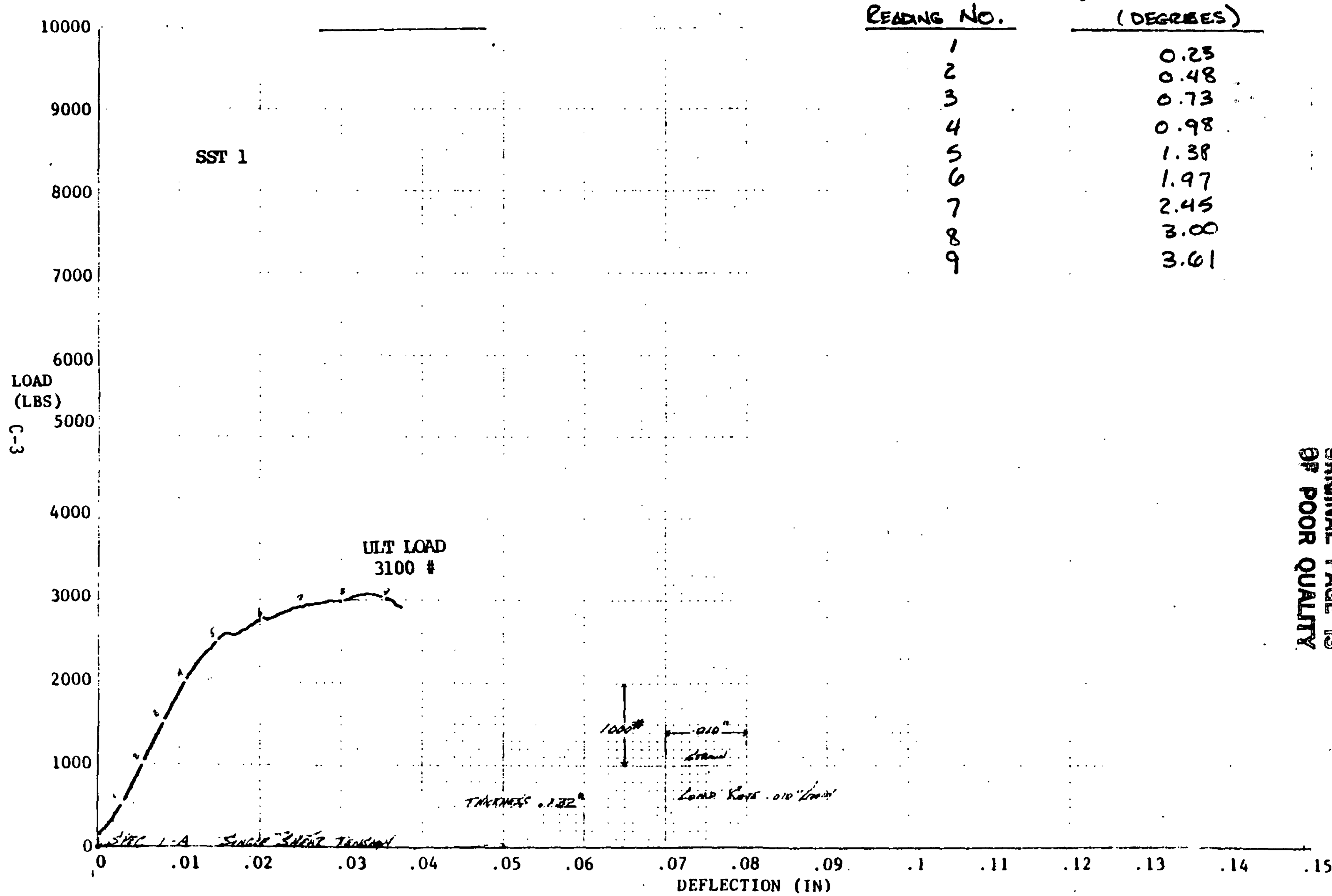
FAILURE MODES

SST

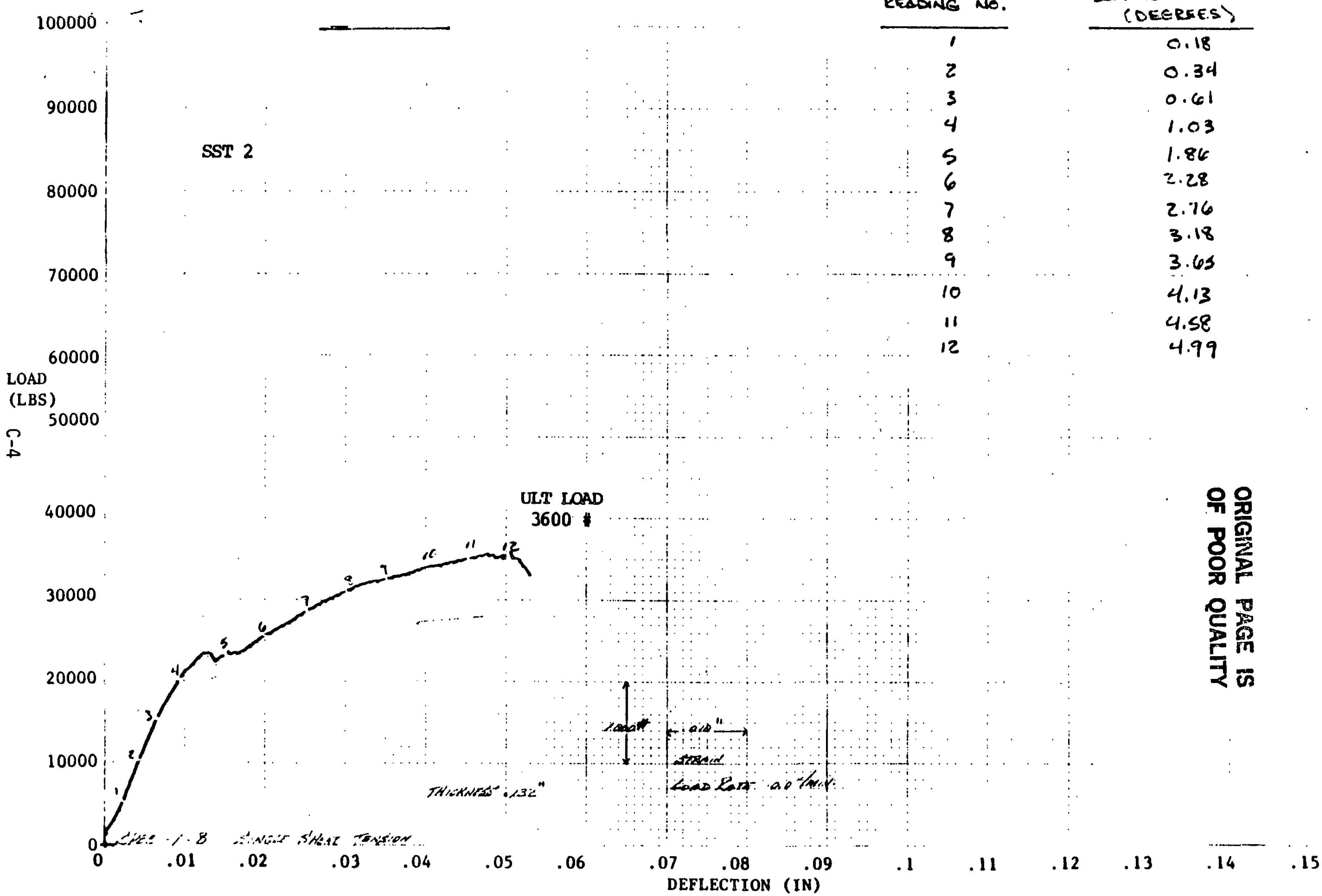
1 - 18 Bearing Failures.

SSC

1 - 18 Bearing Failures.



READING NO.	BOLT HEAD ROTATION (DEGREES)
1	0.25
2	0.48
3	0.73
4	0.98
5	1.38
6	1.97
7	2.45
8	3.00
9	3.61



READING NO.	BOLT HEAD ROTATION (DEGREES)
1	0.18
2	0.34
3	0.61
4	1.03
5	1.86
6	2.28
7	2.76
8	3.18
9	3.65
10	4.13
11	4.58
12	4.99

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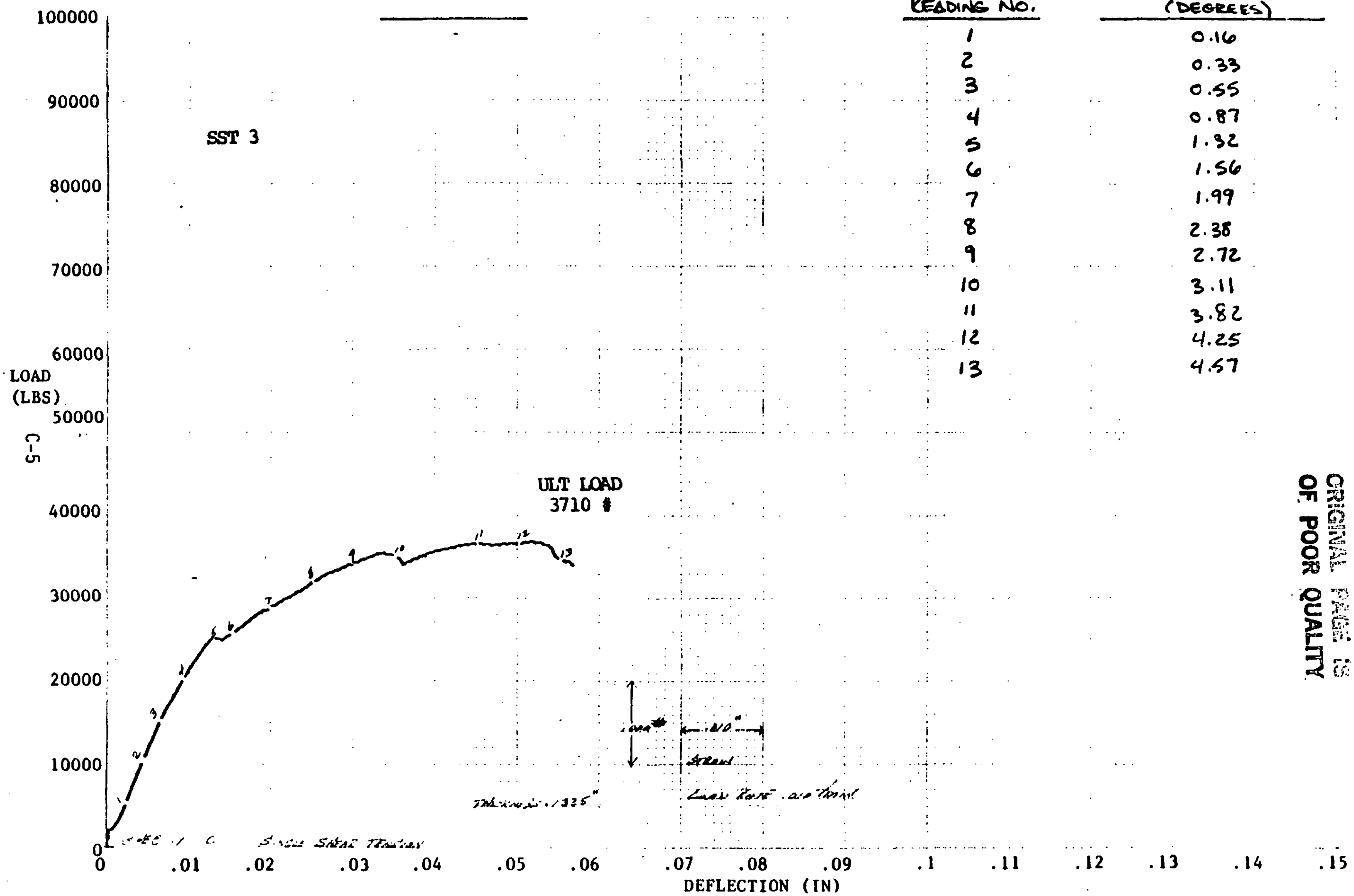
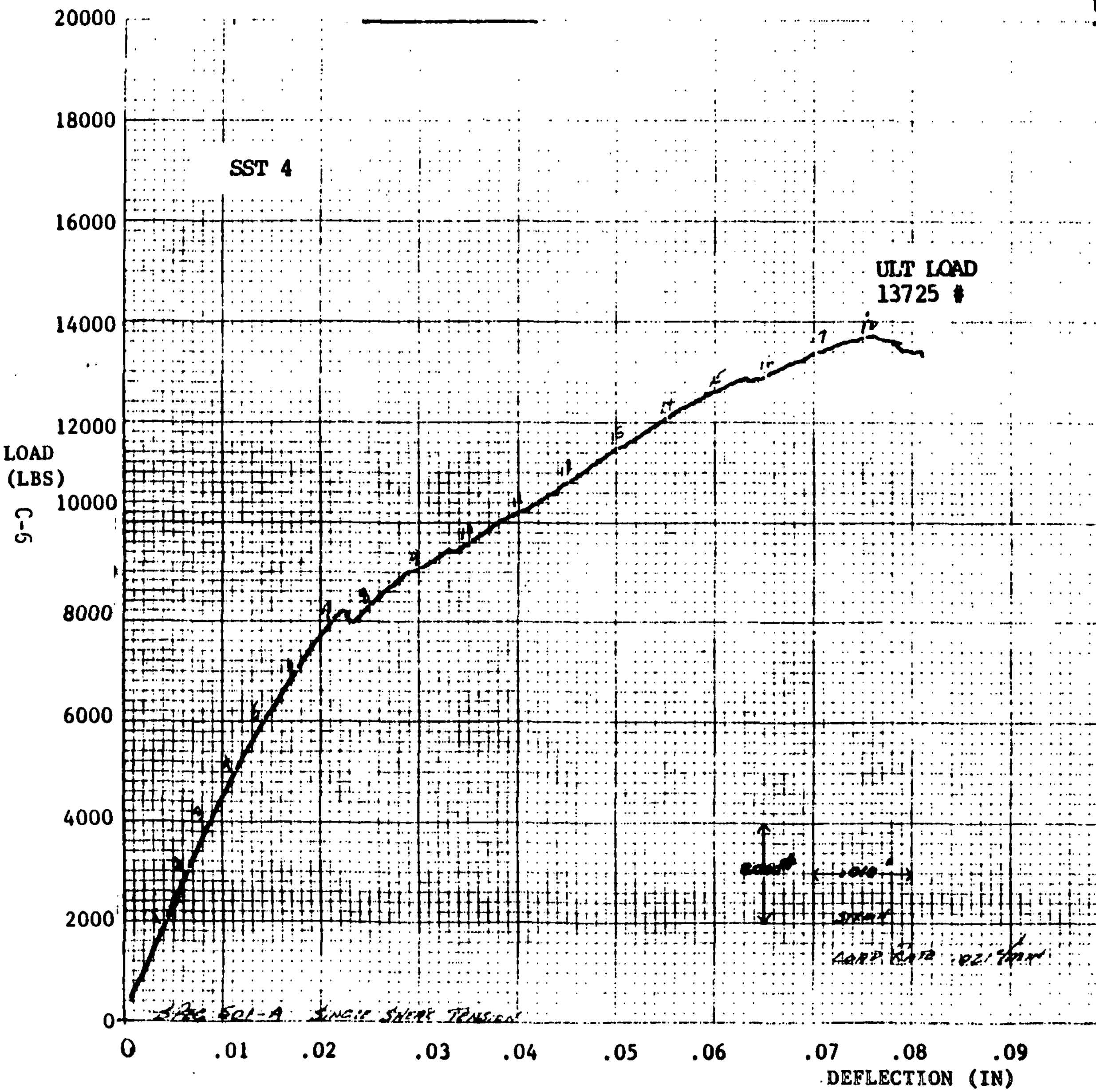


READING NO.	BOLT HEAD ROTATION (DEGREES)
1	0.16
2	0.33
3	0.55
4	0.87
5	1.32
6	1.56
7	1.99
8	2.38
9	2.72
10	3.11
11	3.82
12	4.25
13	4.57



READING NO.	BOLT HEAD ROTATION (DEGREES)
1	0.30
2	0.46
3	0.63
4	0.79
5	1.00
6	1.23
7	1.48
8	1.69
9	1.99
10	2.18
11	2.41
12	2.60
13	2.83
14	3.06
15	3.27
16	3.48
17	3.65
18	3.83

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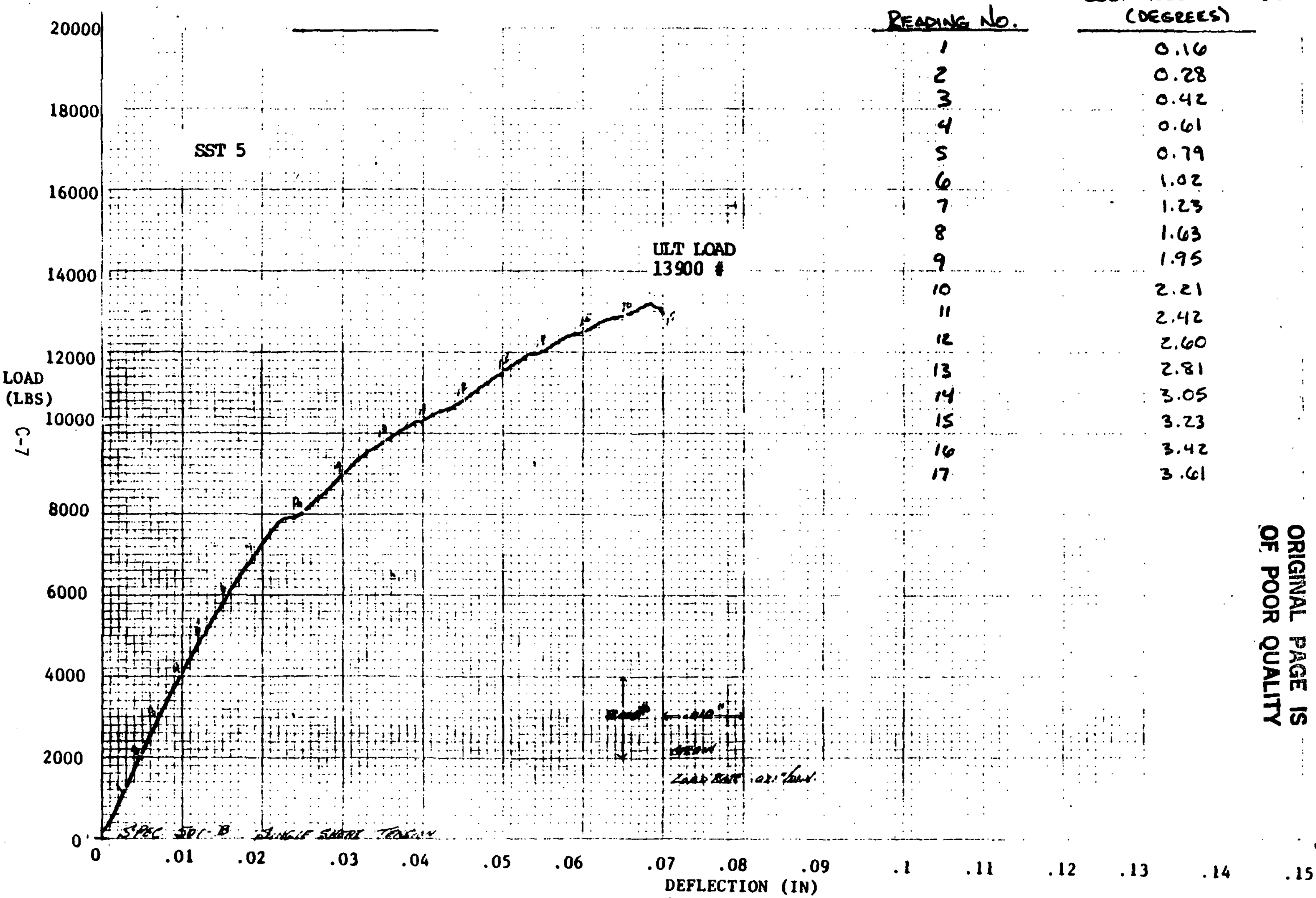

Reading No.	Bolt Head Rotation (Degrees)
1	0.16
2	0.28
3	0.42
4	0.61
5	0.79
6	1.02
7	1.23
8	1.63
9	1.95
10	2.21
11	2.42
12	2.60
13	2.81
14	3.05
15	3.23
16	3.42
17	3.61

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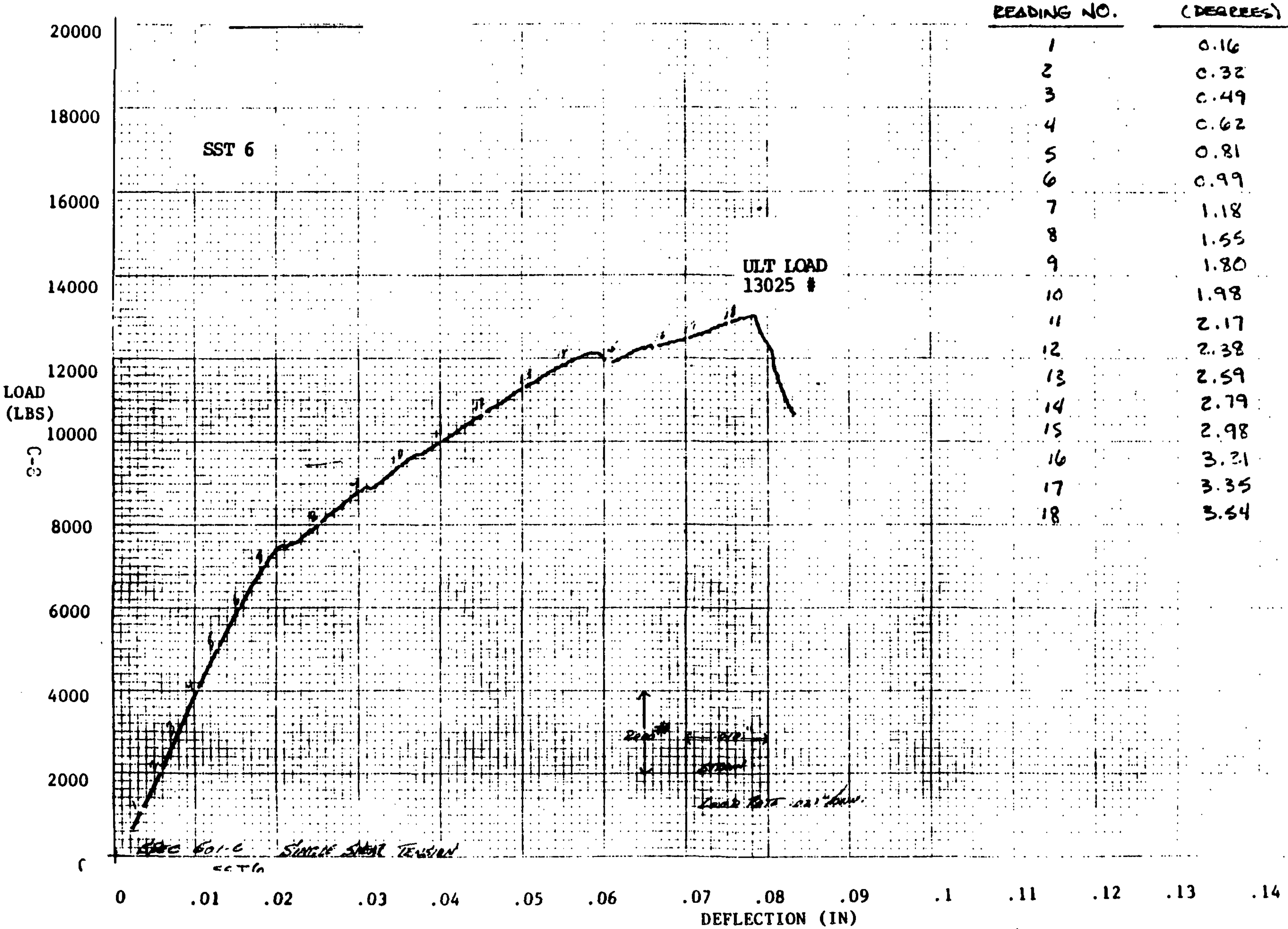

READING NO.	BOLT HEAD ROTATION (DEGREES)
1	0.16
2	0.32
3	0.49
4	0.62
5	0.81
6	0.99
7	1.18
8	1.55
9	1.80
10	1.98
11	2.17
12	2.38
13	2.59
14	2.79
15	2.98
16	3.21
17	3.35
18	3.54

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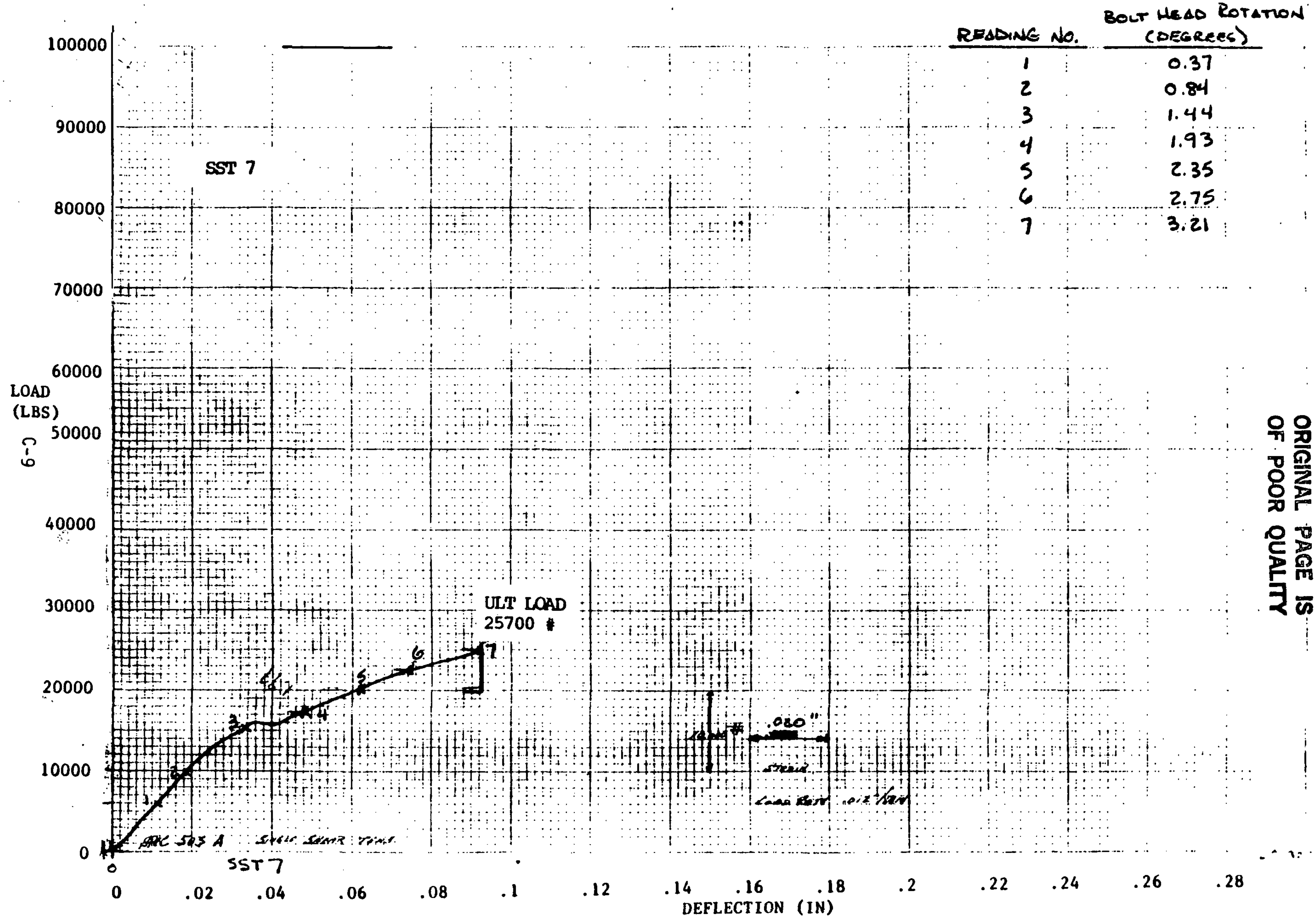
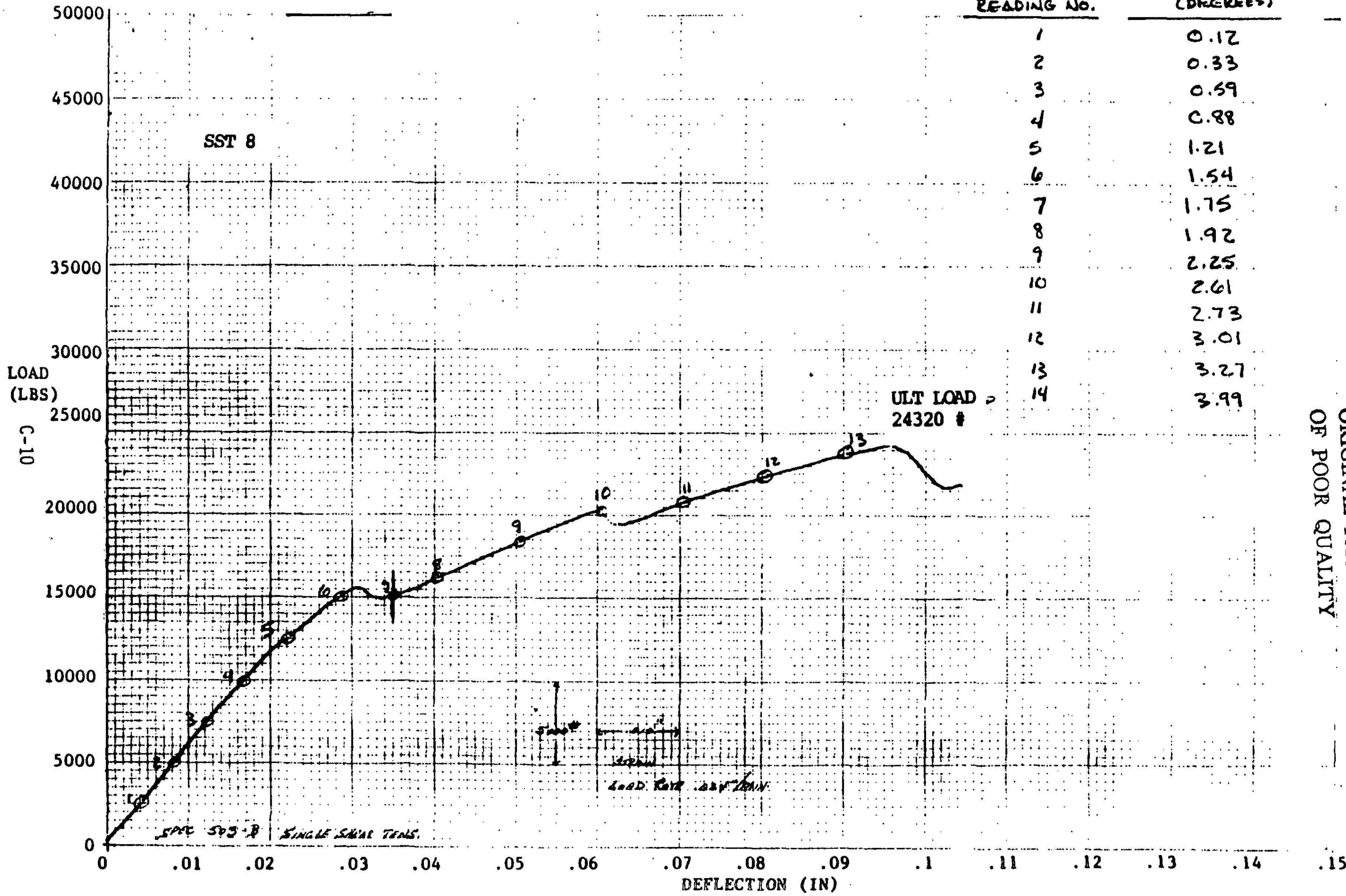
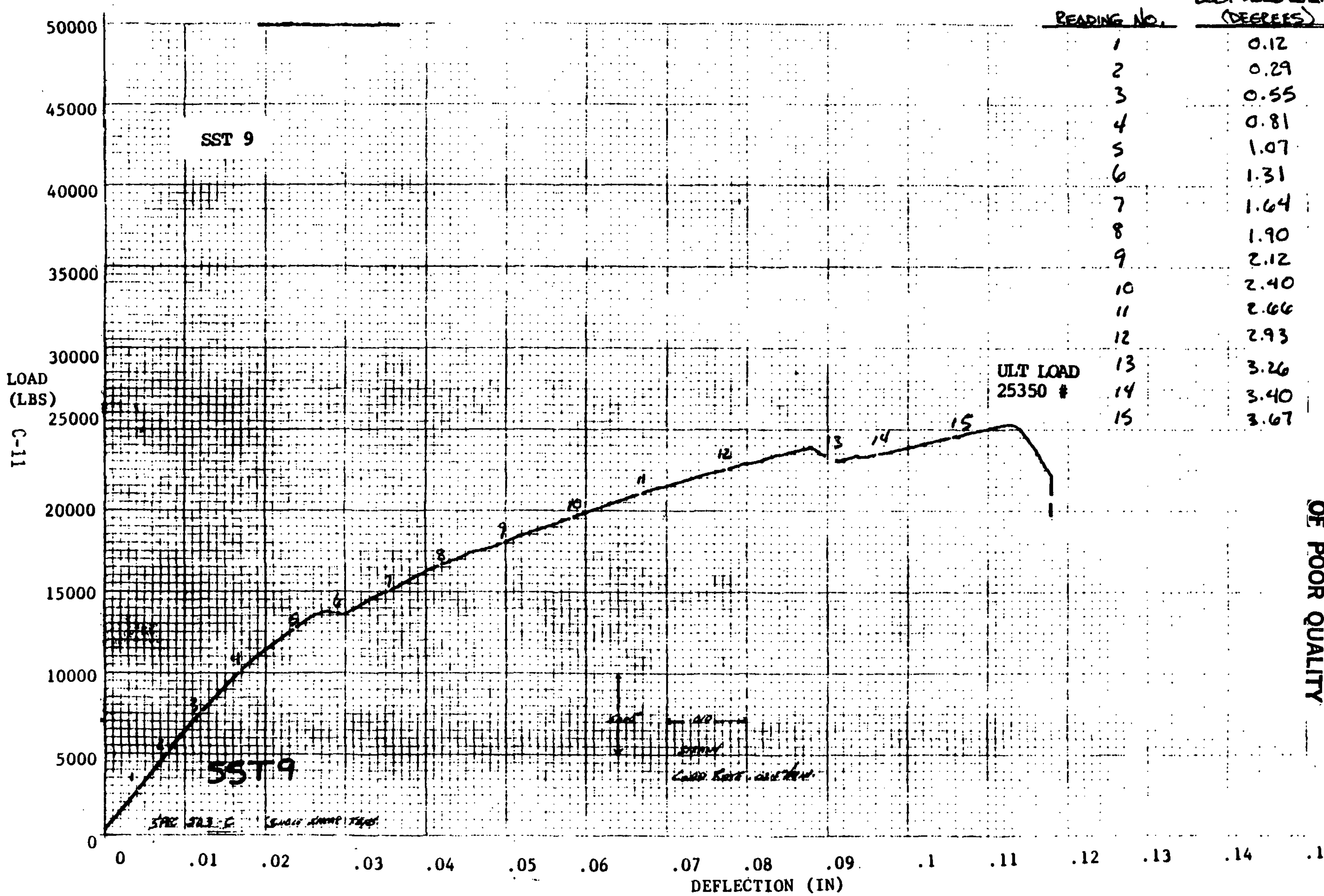
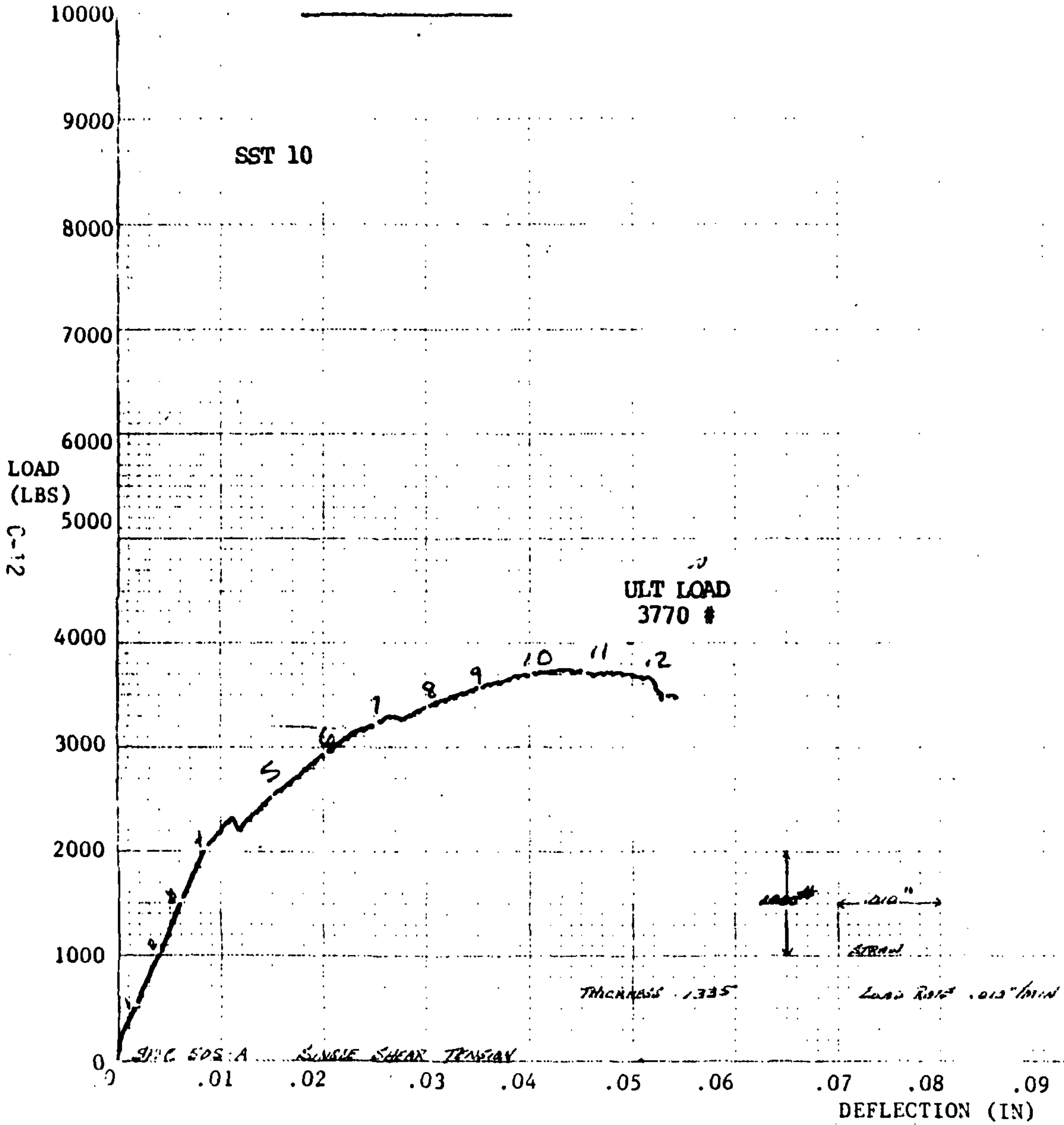

SST 7
READING NO.
BOLT HEAD ROTATION (DEGREES)
1 0.37
2 0.84
3 1.44
4 1.93
5 2.35
6 2.75
7 3.21
ULT LOAD
25700 #
LOAD (LBS)
100000
90000
80000
70000
60000
50000
40000
30000
20000
10000
0
0 .02 .04 .06 .08 .1 .12 .14 .16 .18 .2 .22 .24 .26 .28
DEFLECTION (IN)
.080"
SST 7



READING NO.	BOLT HEAD ROTATION (DEGREES)
1	0.12
2	0.33
3	0.59
4	0.88
5	1.21
6	1.54
7	1.75
8	1.92
9	2.25
10	2.61
11	2.73
12	3.01
13	3.27
14	3.99



READING NO.	BOLT HEAD ROTATION (DEGREES)
1	0.12
2	0.29
3	0.55
4	0.81
5	1.07
6	1.31
7	1.64
8	1.90
9	2.12
10	2.40
11	2.66
12	2.93
13	3.26
14	3.40
15	3.67



READING NO.	BOLT HEAD ROTATION (DEGREES)
1	0.15
2	0.45
3	0.72
4	1.11
5	1.88
6	2.37
7	2.73
8	3.01
9	3.35
10	3.71
11	4.10
12	4.69

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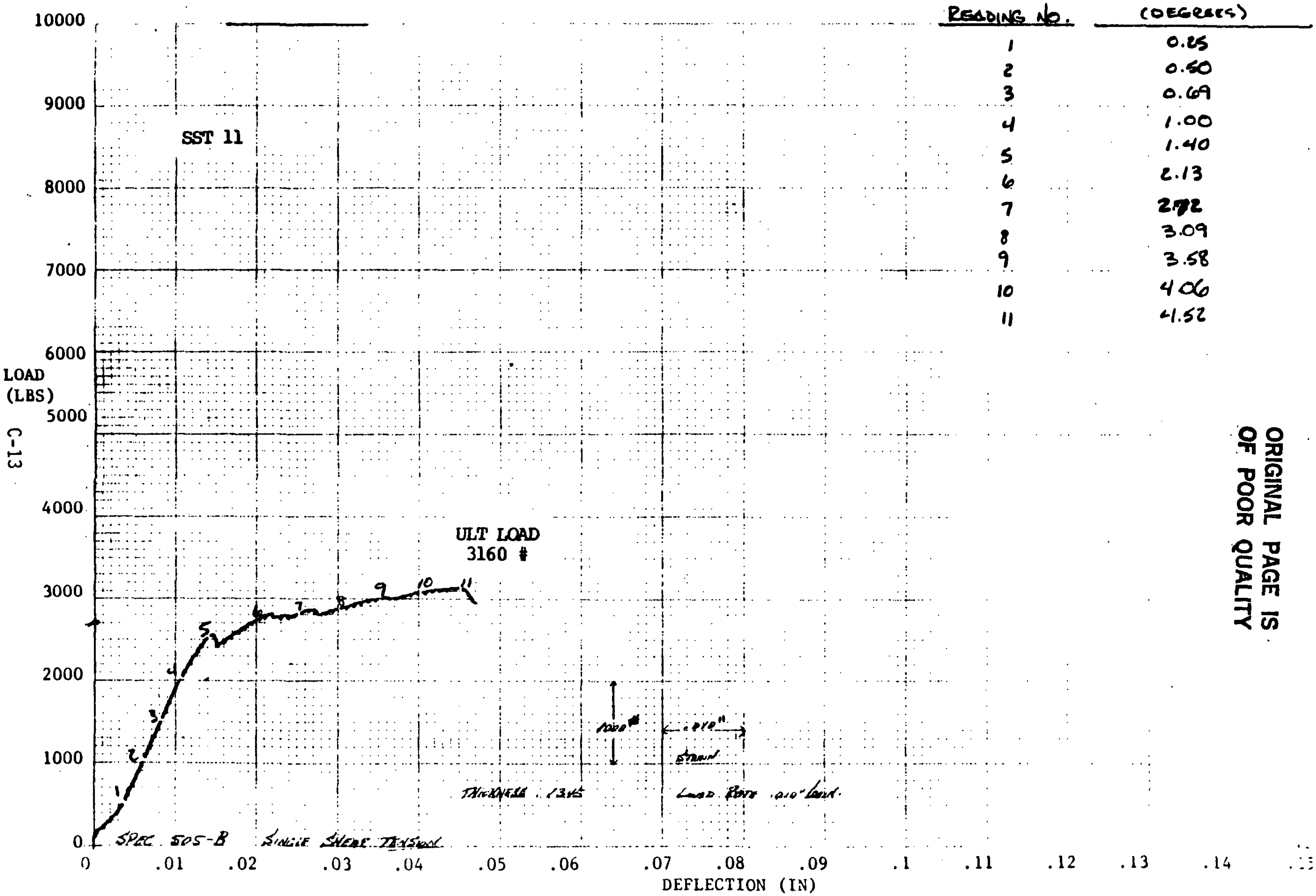

READING NO.	BOLT HEAD ROTATION (DEGREES)
1	0.25
2	0.50
3	0.69
4	1.00
5	1.40
6	2.13
7	2.72
8	3.09
9	3.58
10	4.06
11	4.52

C-13

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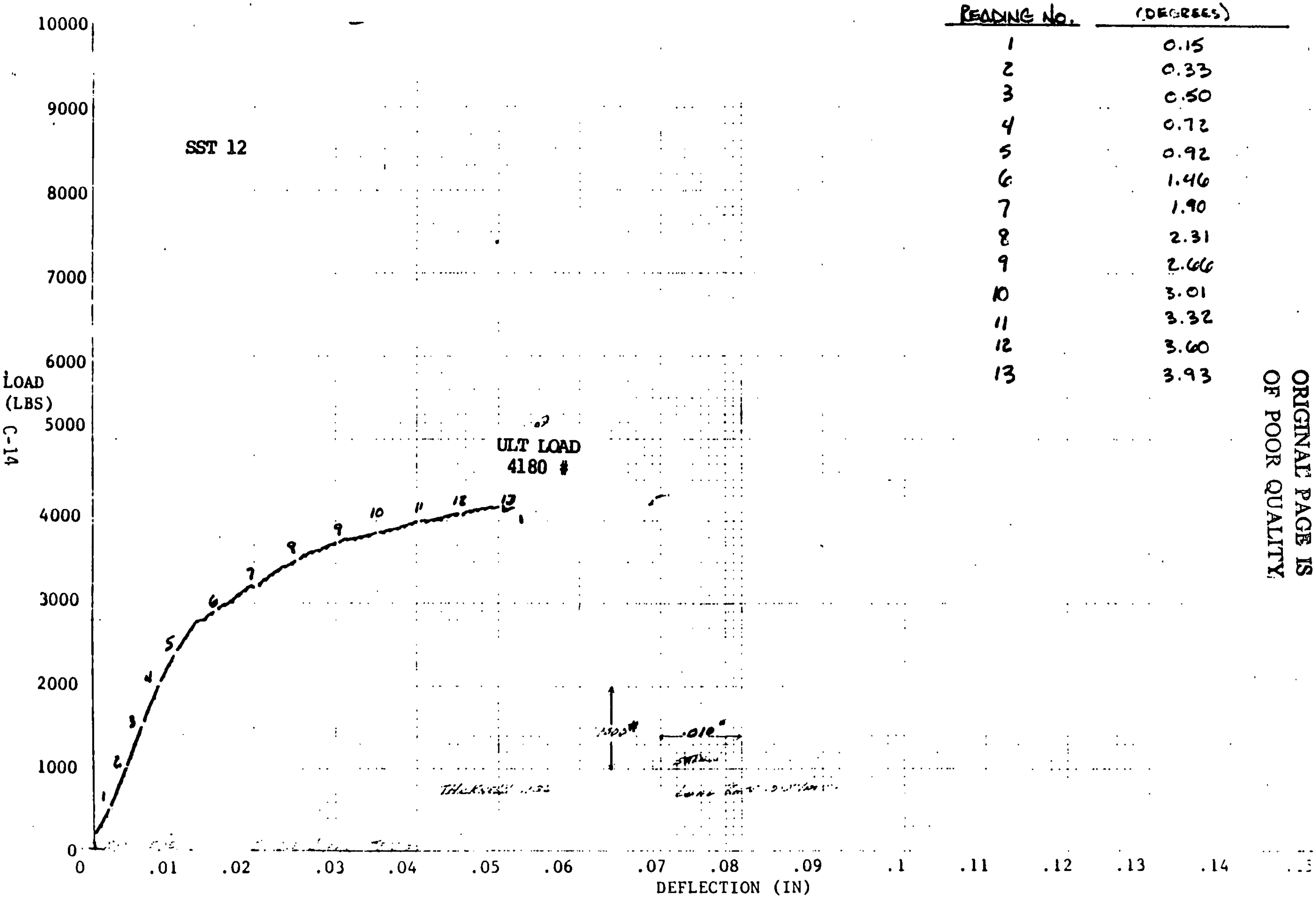
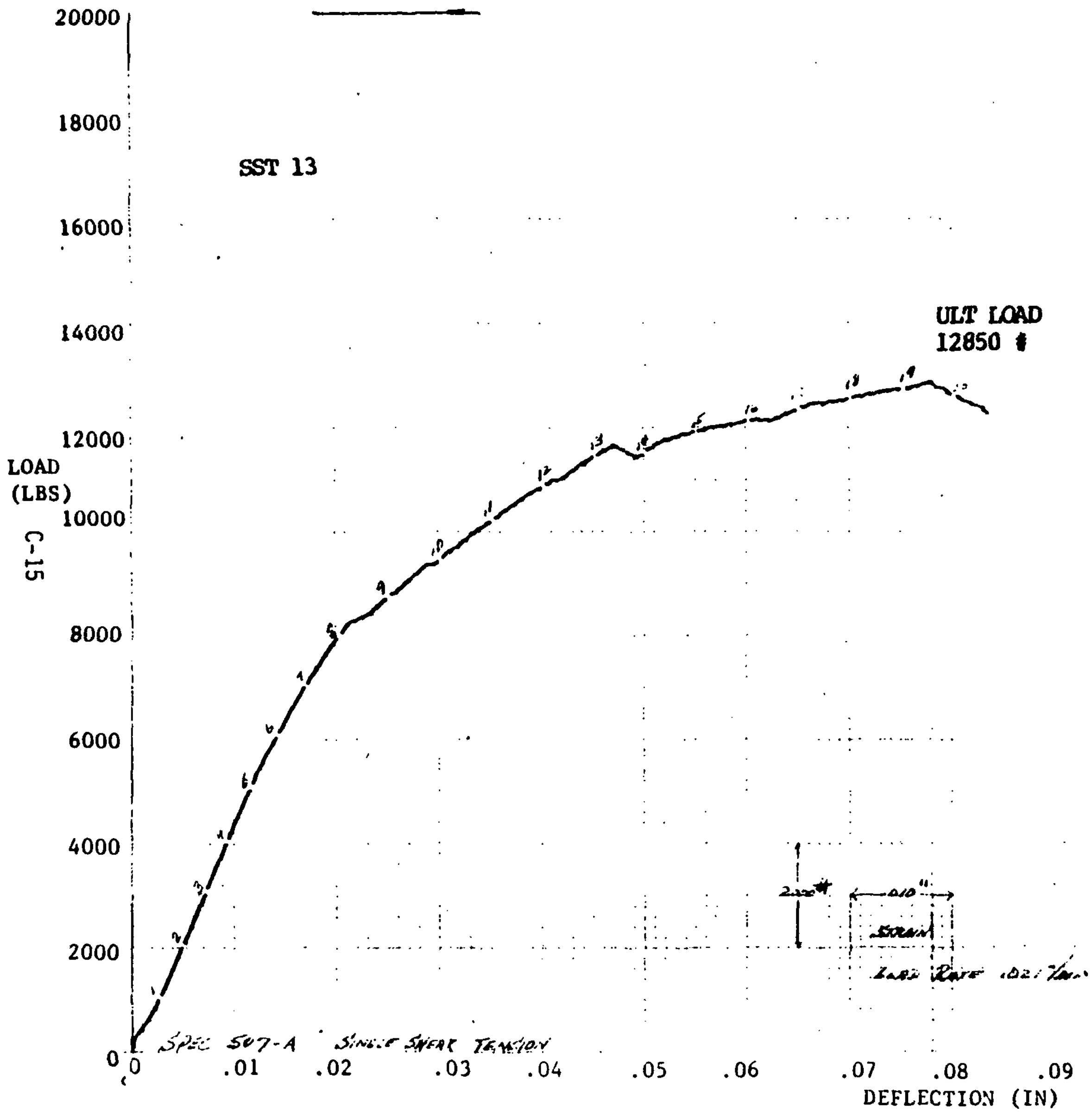
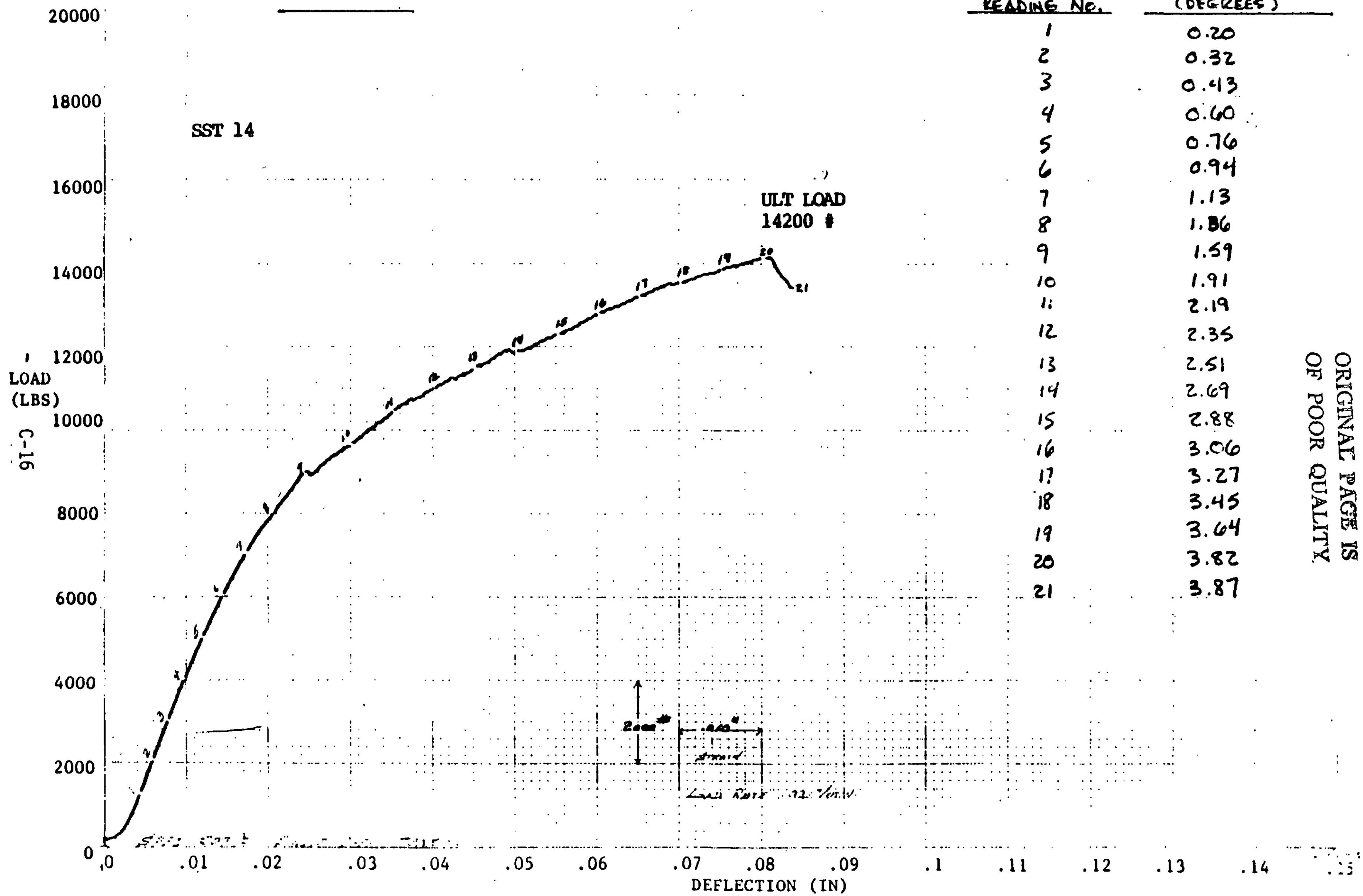


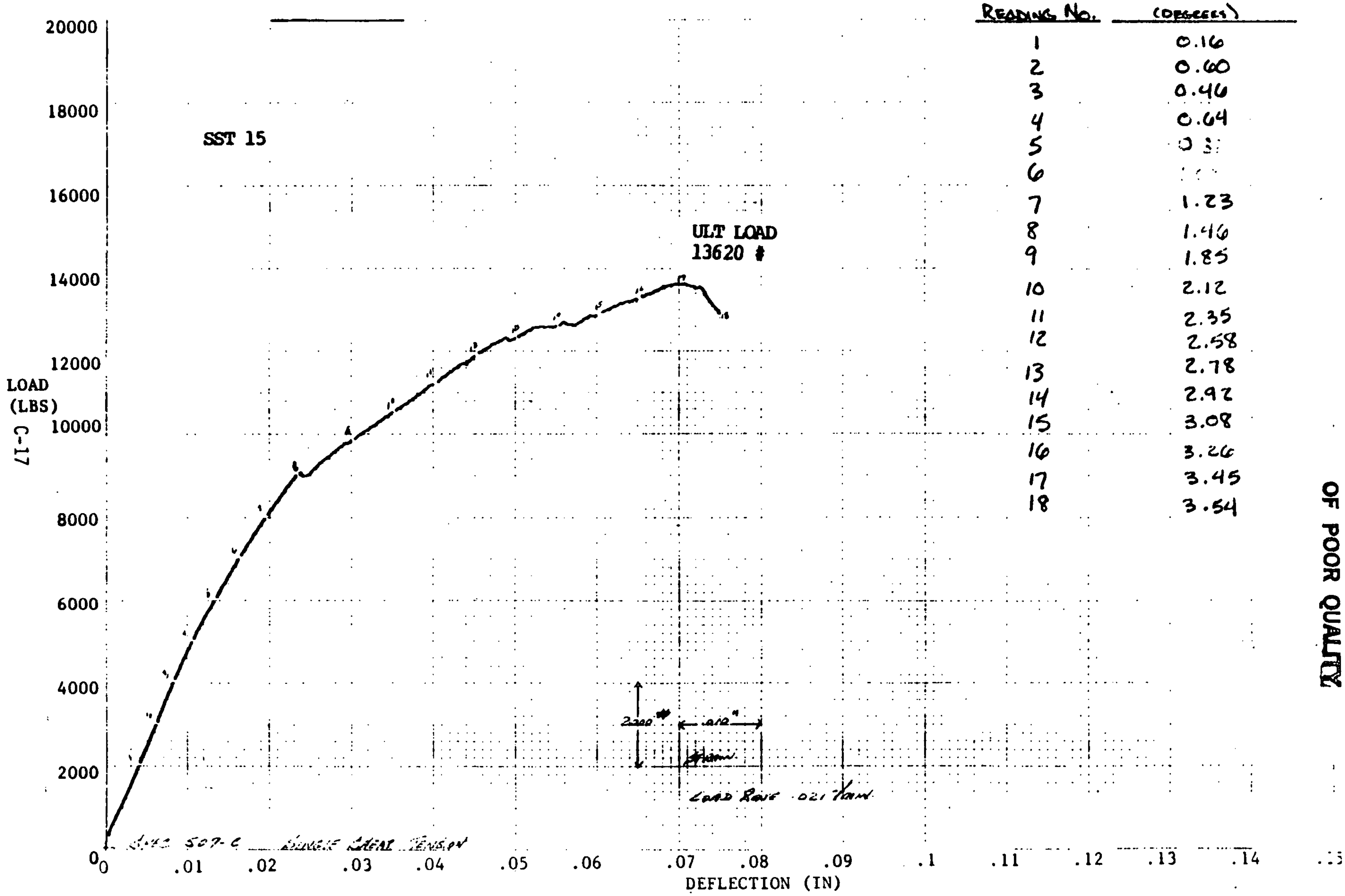
READING No.	BOLT HEAD ROTATION (DEGREES)
1	0.15
2	0.33
3	0.50
4	0.72
5	0.92
6	1.46
7	1.90
8	2.31
9	2.66
10	3.01
11	3.32
12	3.60
13	3.93



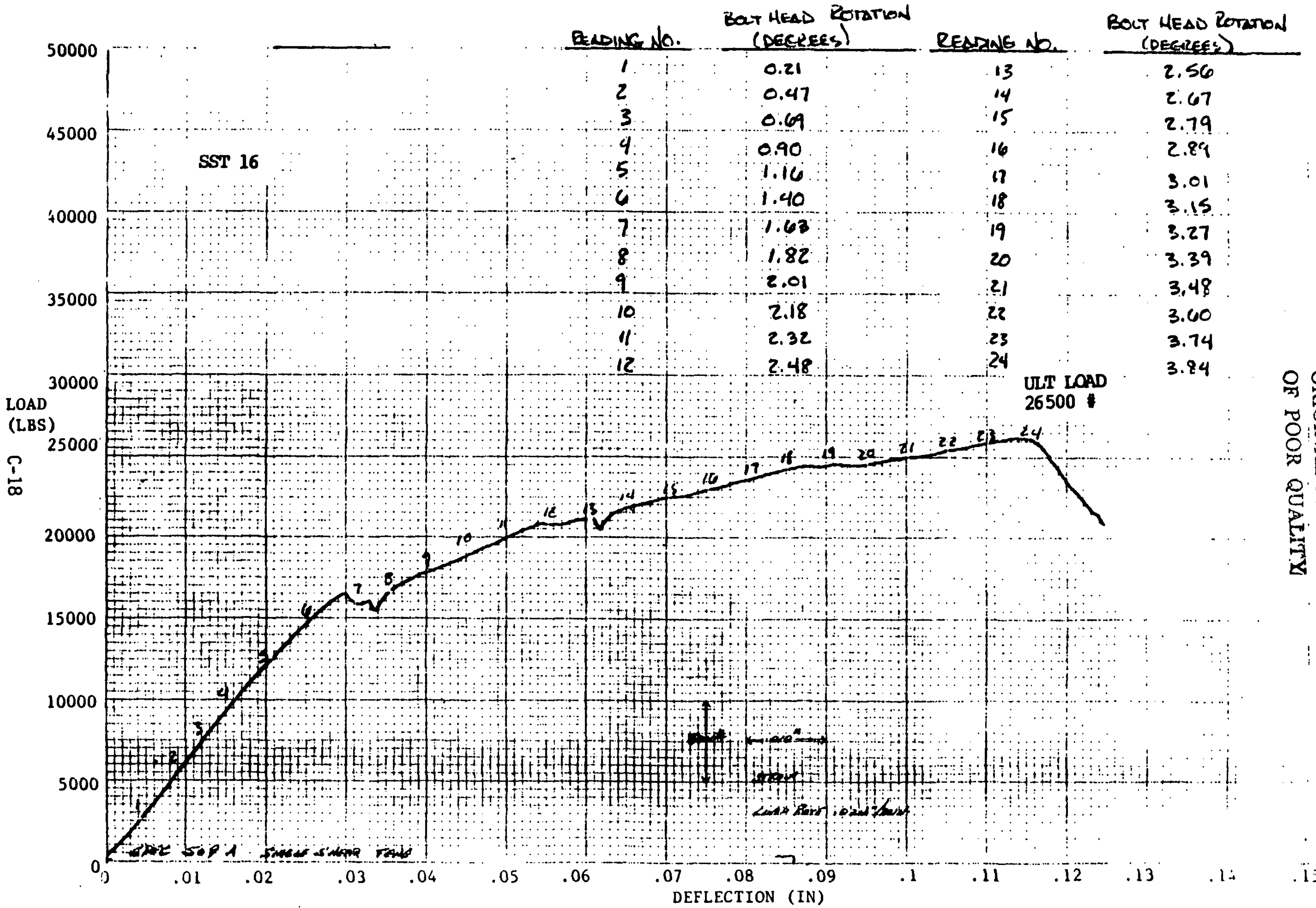
READING NO.	BOLT HEAD ROTATION (DEGREES)
1	0.16
2	0.32
3	0.44
4	0.60
5	0.76
6	0.92
7	1.11
8	1.32
9	1.62
10	1.87
11	2.15
12	2.38
13	2.61
14	2.73
15	2.89
16	3.05
17	3.24
18	3.40
19	3.56
20	3.65



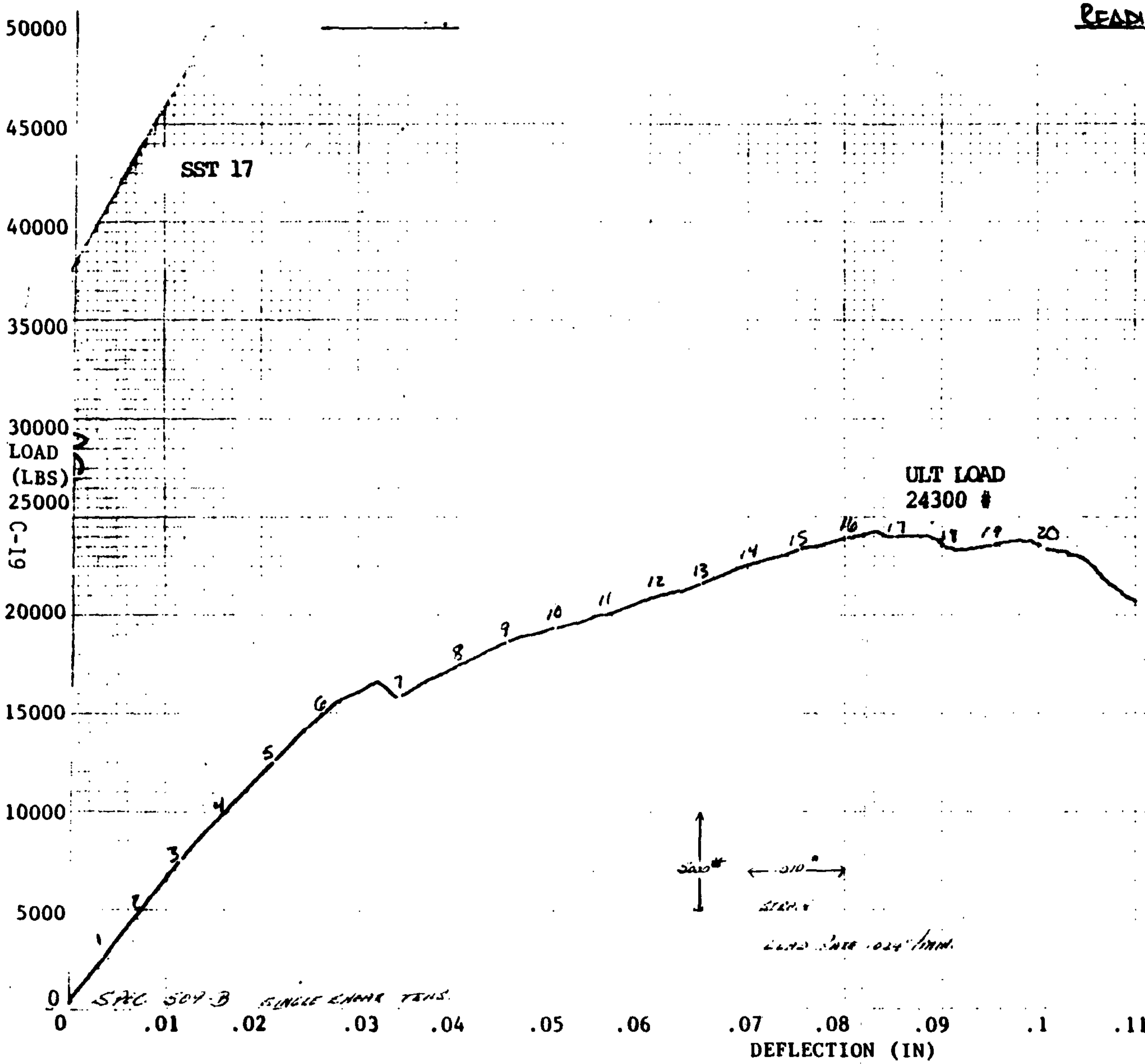
READING No.	BOLT HEAD ROTATION (DEGREES)
1	0.20
2	0.32
3	0.43
4	0.60
5	0.76
6	0.94
7	1.13
8	1.36
9	1.59
10	1.91
11	2.19
12	2.35
13	2.51
14	2.69
15	2.88
16	3.06
17	3.27
18	3.45
19	3.64
20	3.82
21	3.87



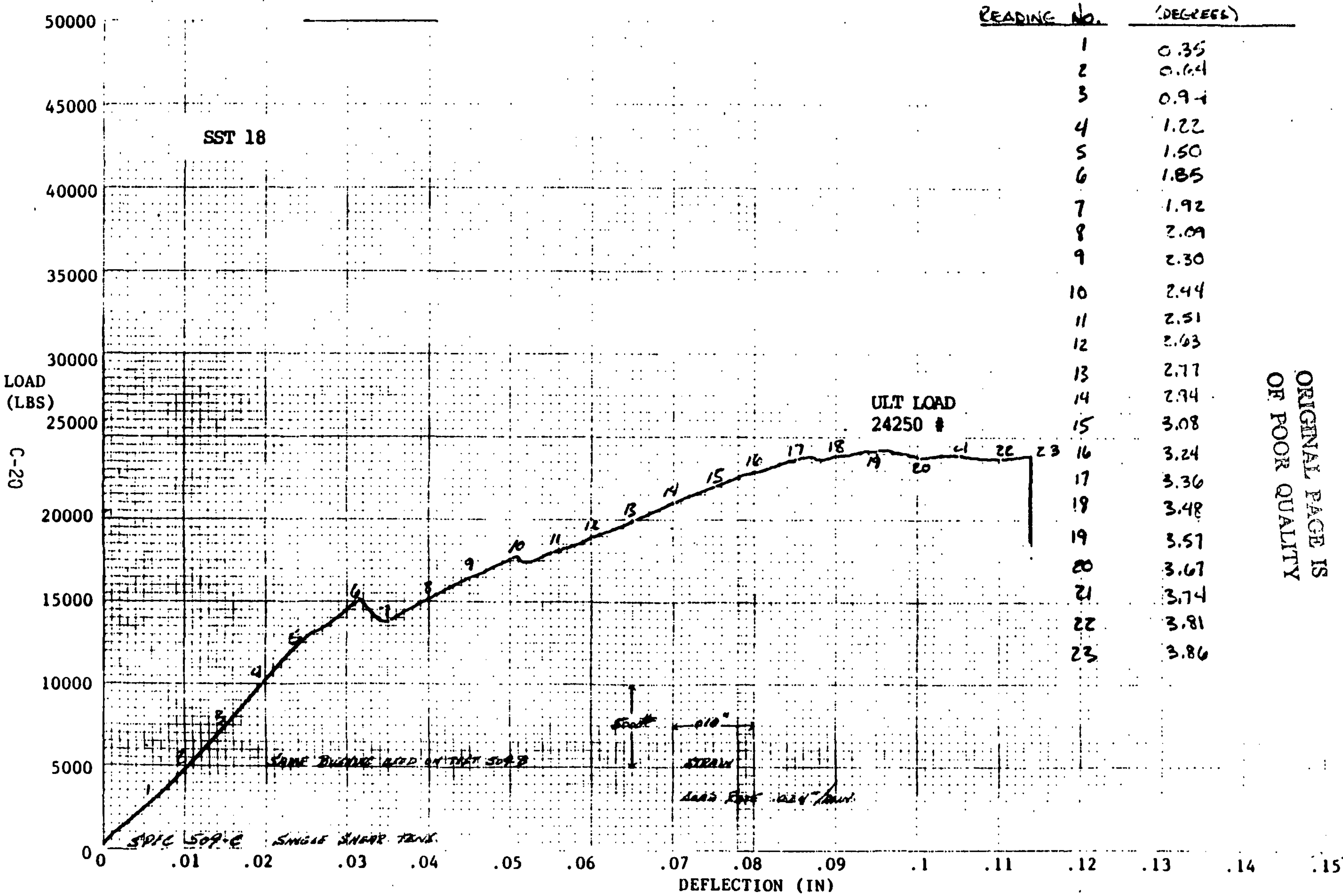
Reading No.	Bolt Head Rotation (Degrees)
1	0.16
2	0.60
3	0.46
4	0.64
5	[illegible]
6	[illegible]
7	1.23
8	1.46
9	1.85
10	2.12
11	2.35
12	2.58
13	2.78
14	2.92
15	3.08
16	3.26
17	3.45
18	3.54



READING NO.	BOLT HEAD ROTATION (DEGREES)	READING NO.	BOLT HEAD ROTATION (DEGREES)
1	0.21	13	2.56
2	0.47	14	2.67
3	0.69	15	2.79
4	0.90	16	2.89
5	1.16	17	3.01
6	1.40	18	3.15
7	1.63	19	3.27
8	1.82	20	3.39
9	2.01	21	3.48
10	2.18	22	3.60
11	2.32	23	3.74
12	2.48	24	3.84



READING NO.	BOLT HEAD ROTATION (DEGREES)
1	0.14
2	0.35
3	0.58
4	0.86
5	1.14
6	1.45
7	1.75
8	2.05
9	2.26
10	2.38
11	2.52
12	2.66
13	2.80
14	2.96
15	3.10
16	3.25
17	3.34
18	3.46
19	3.53
20	3.64



Reading No.	Bolt Head Rotation (Degrees)
1	0.35
2	0.64
3	0.94
4	1.22
5	1.50
6	1.85
7	1.92
8	2.09
9	2.30
10	2.44
11	2.51
12	2.63
13	2.77
14	2.94
15	3.08
16	3.24
17	3.36
18	3.48
19	3.57
20	3.67
21	3.74
22	3.81
23	3.86

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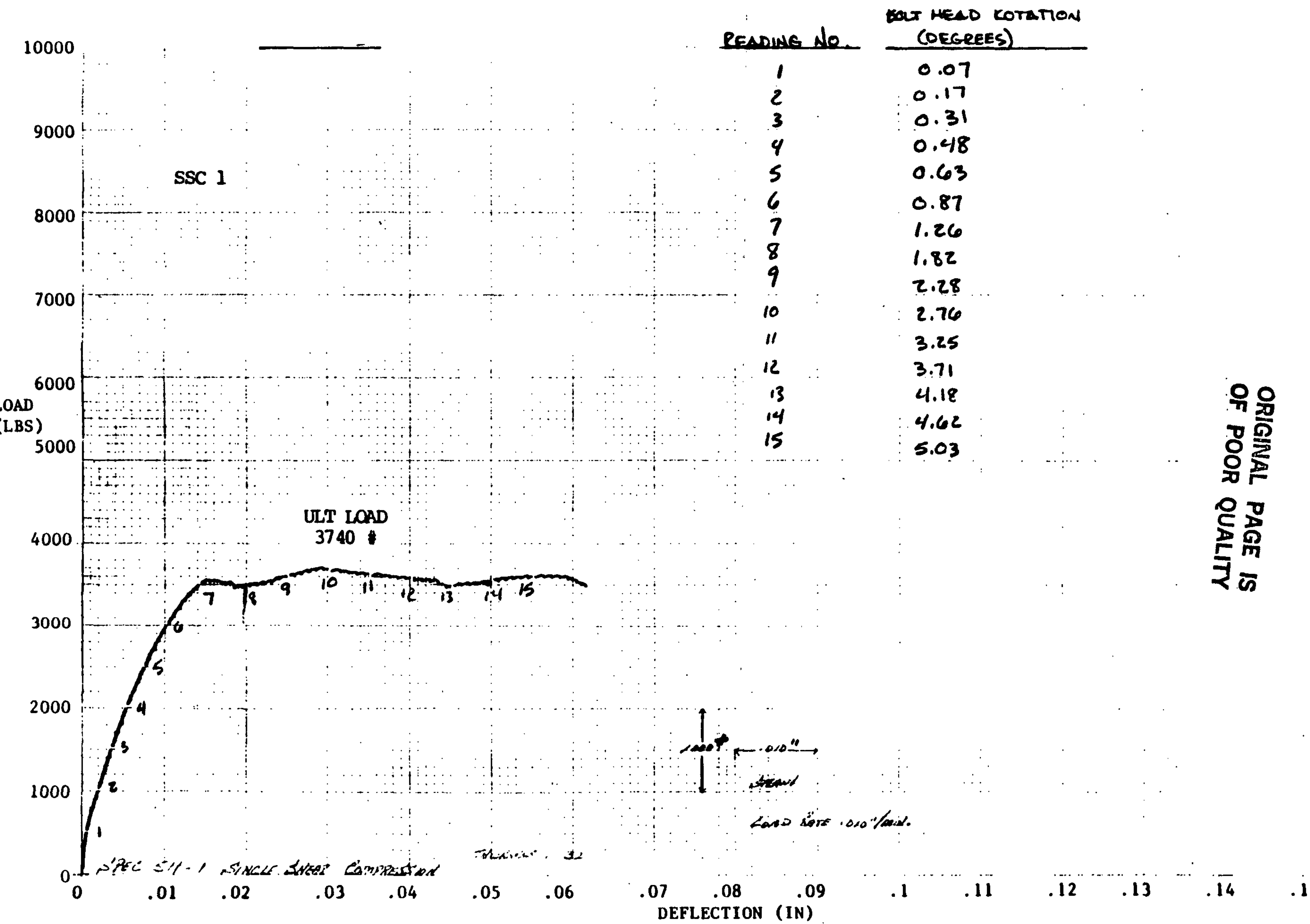
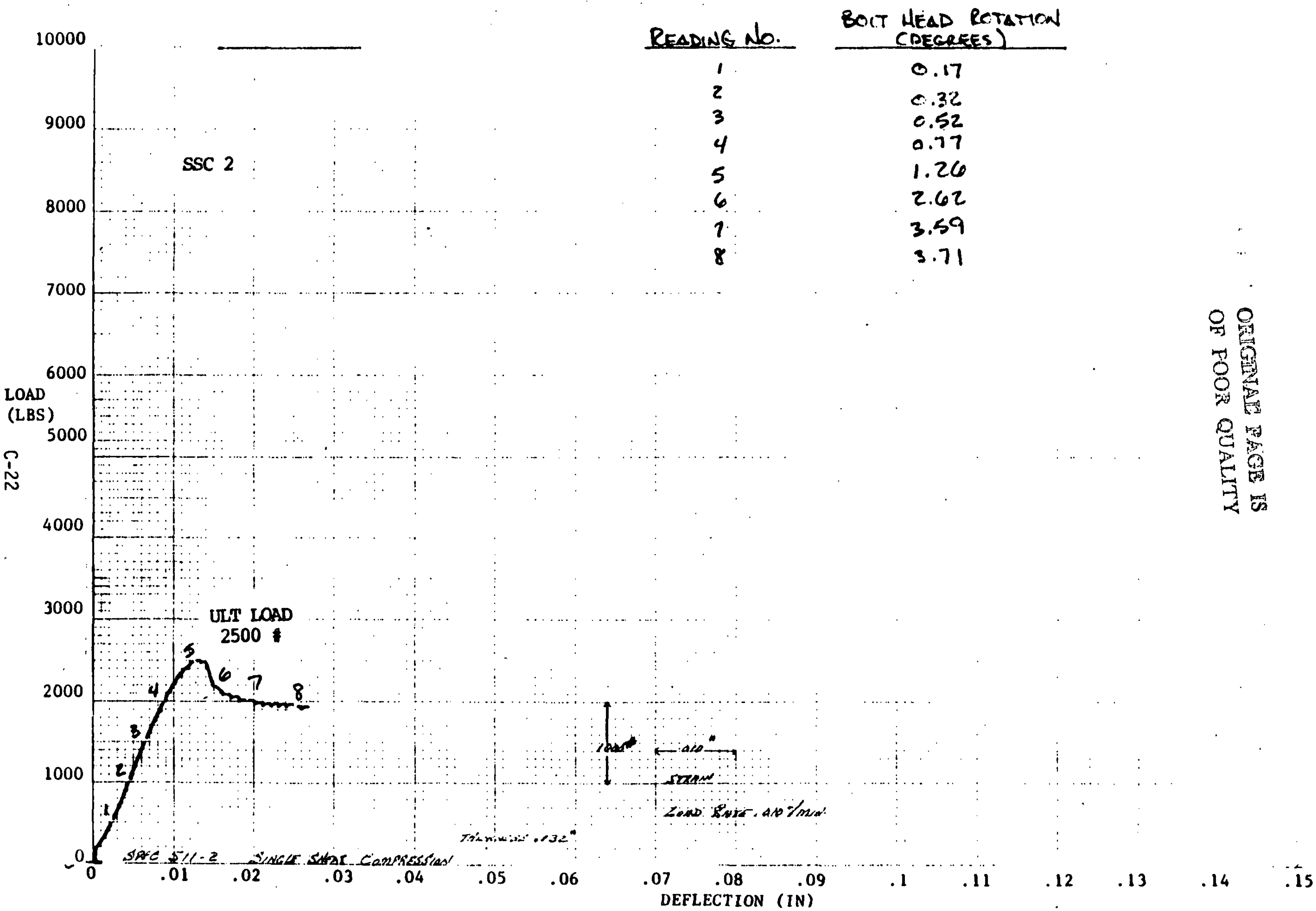
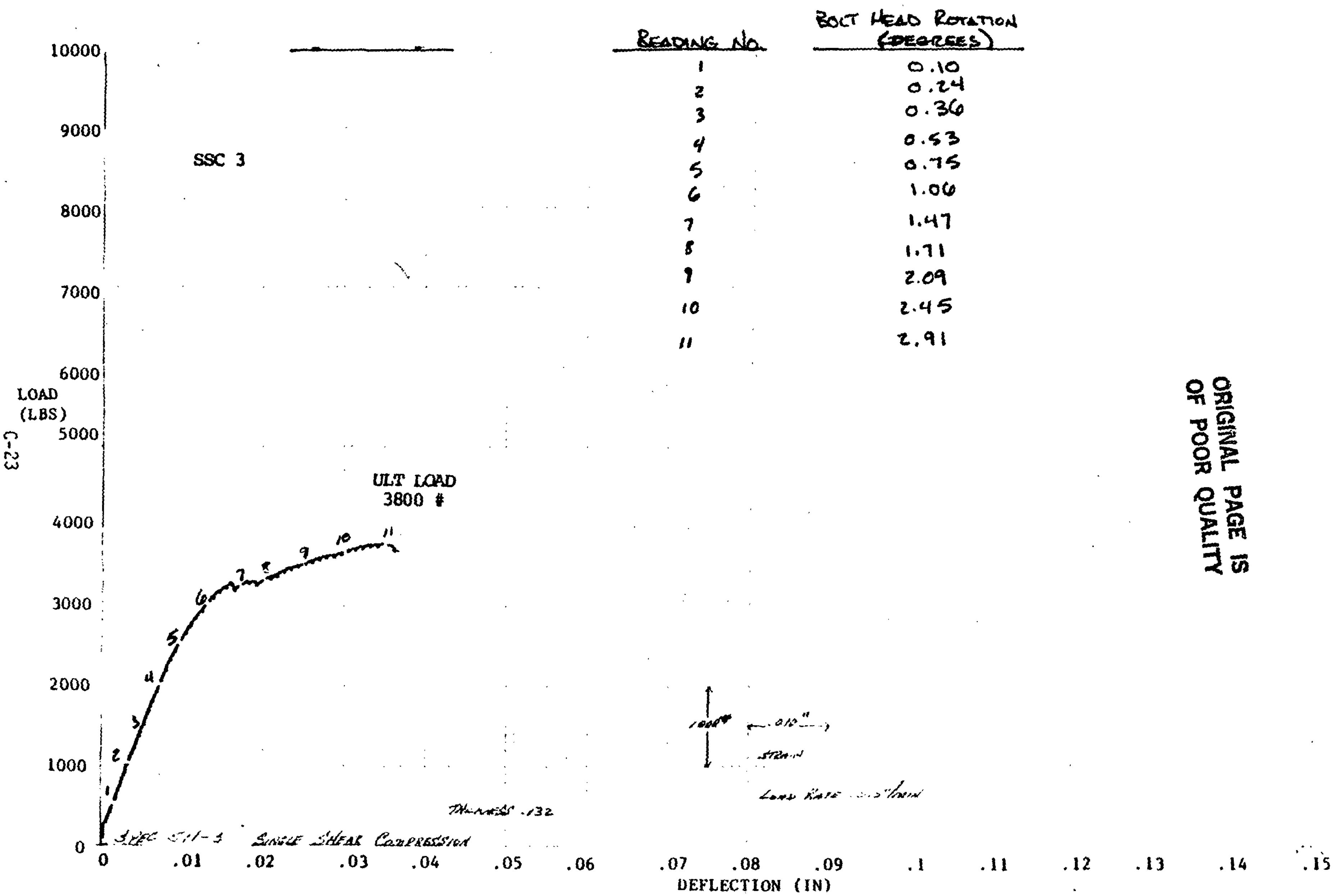


SSC 1
ULT LOAD
3740 #
LOAD (LBS)
DEFLECTION (IN)
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
0
.01
.02
.03
.04
.05
.06
.07
.08
.09
.1
.11
.12
.13
.14
.15
READING NO.
BOLT HEAD ROTATION (DEGREES)
1 0.07
2 0.17
3 0.31
4 0.48
5 0.63
6 0.87
7 1.26
8 1.82
9 2.28
10 2.76
11 3.25
12 3.71
13 4.18
14 4.62
15 5.03
1000#
.010"
LOAD RATE .010"/MIN.
SPEC SV-1 SINGLE SHEET COMPRESSION



SSC 2
LOAD (LBS)
DEFLECTION (IN)
ULT LOAD 2500 #
READING NO.
BOLT HEAD ROTATION (DEGREES)
1 0.17
2 0.32
3 0.52
4 0.77
5 1.26
6 2.62
7 3.59
8 3.71
SPEC 511-2 SINGLE SHEAR COMPRESSION
STRAIN



READING NO.	BOLT HEAD ROTATION (DEGREES)
1	0.10
2	0.24
3	0.36
4	0.53
5	0.75
6	1.06
7	1.47
8	1.71
9	2.09
10	2.45
11	2.91

C-23

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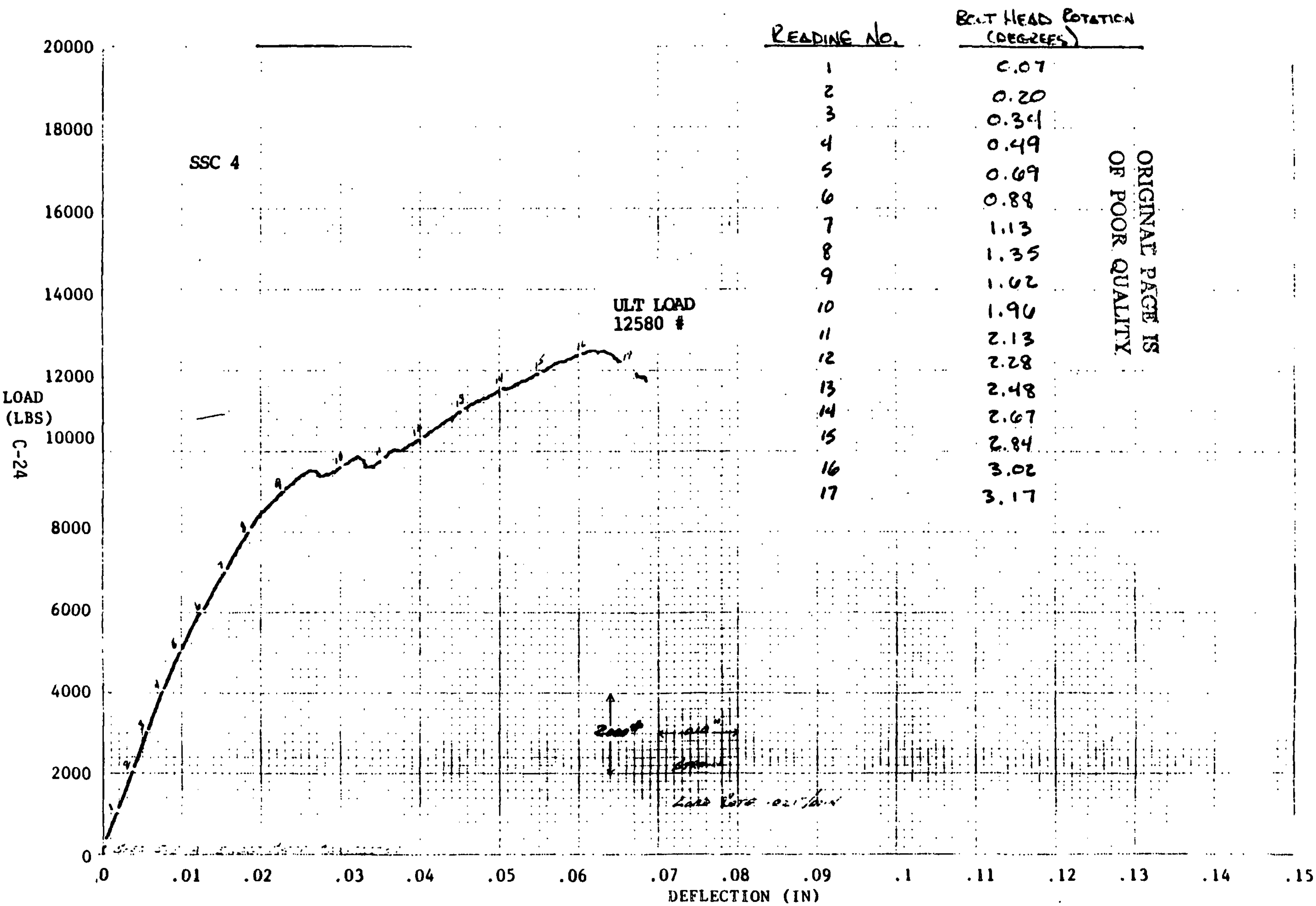

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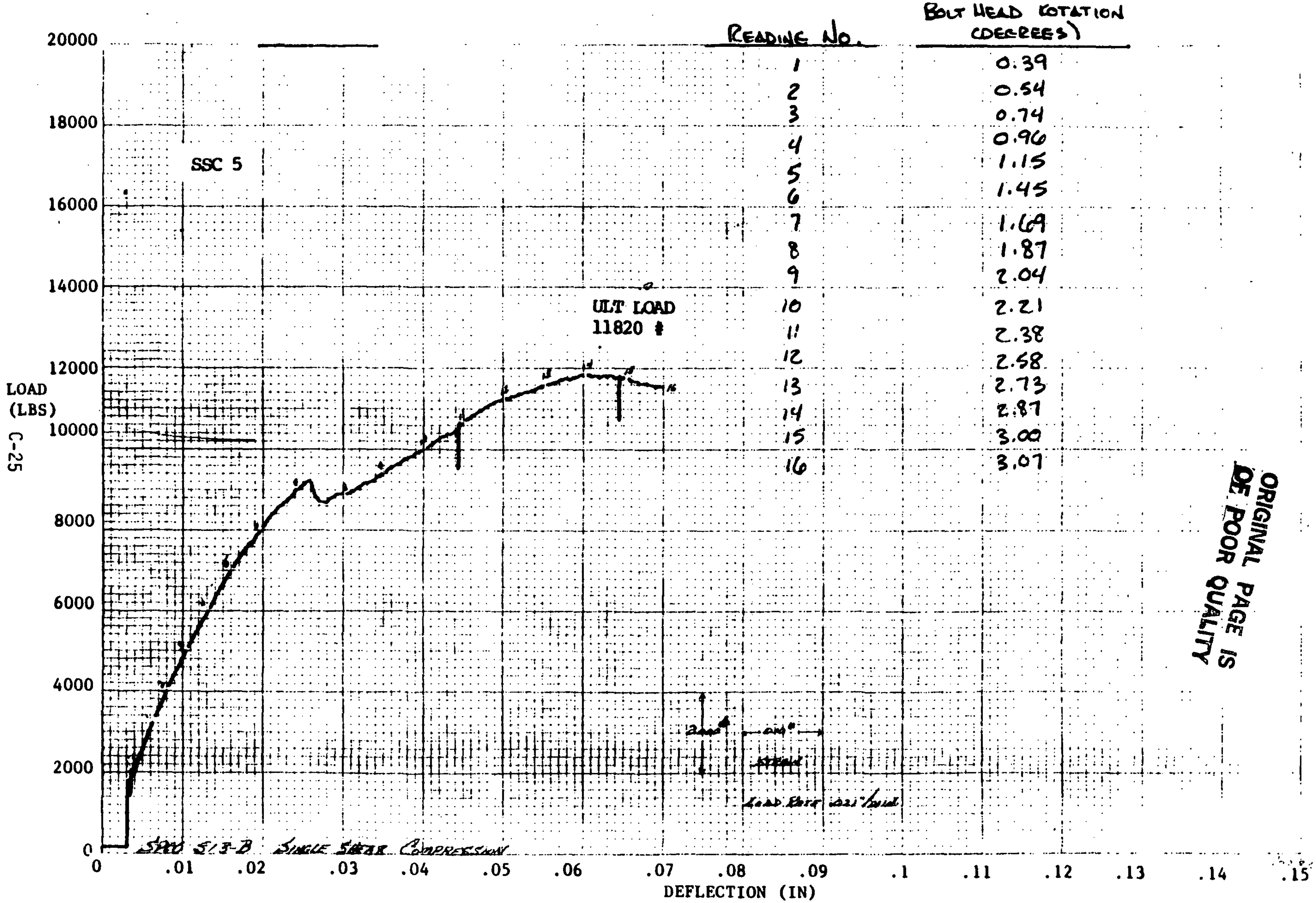
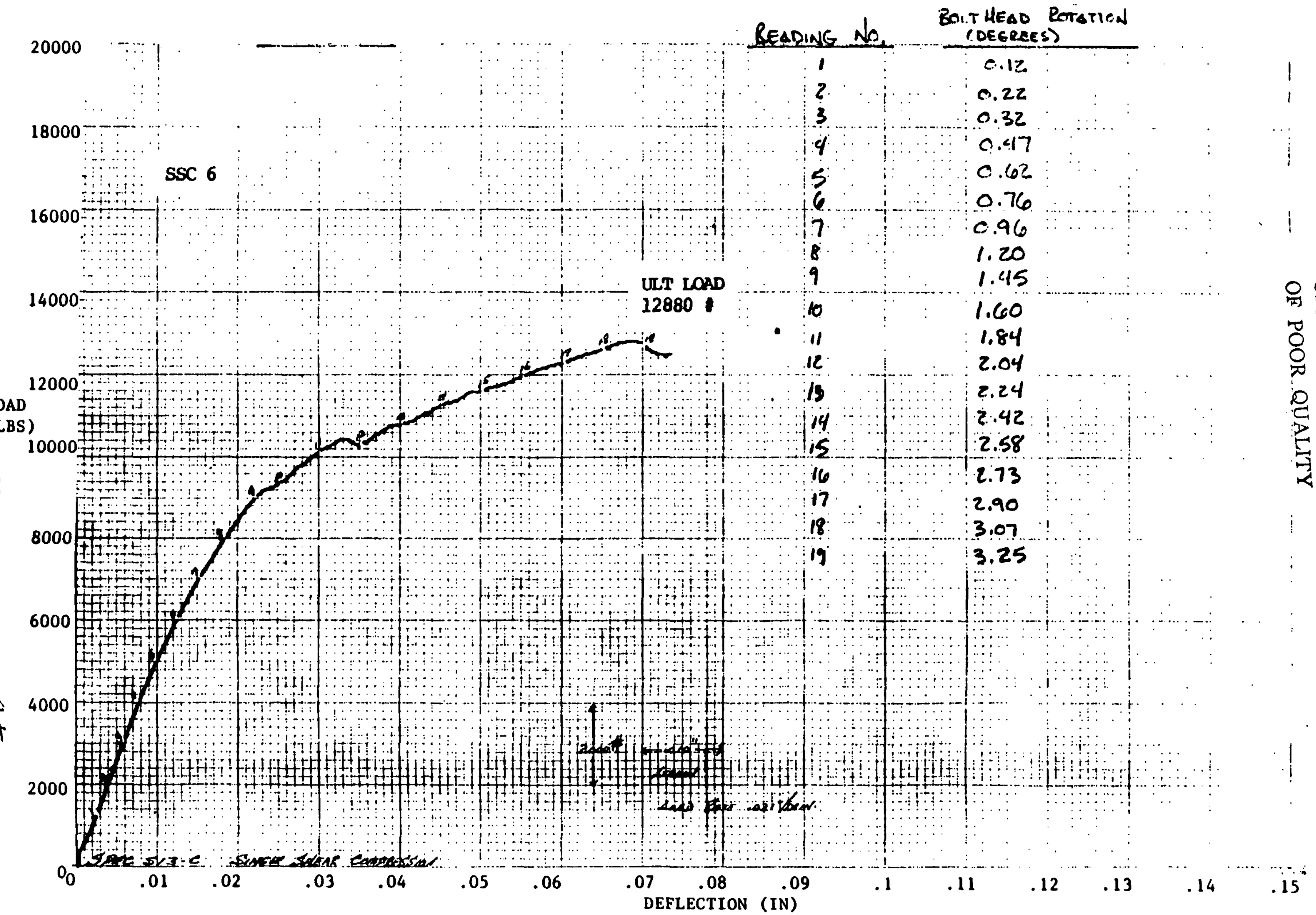
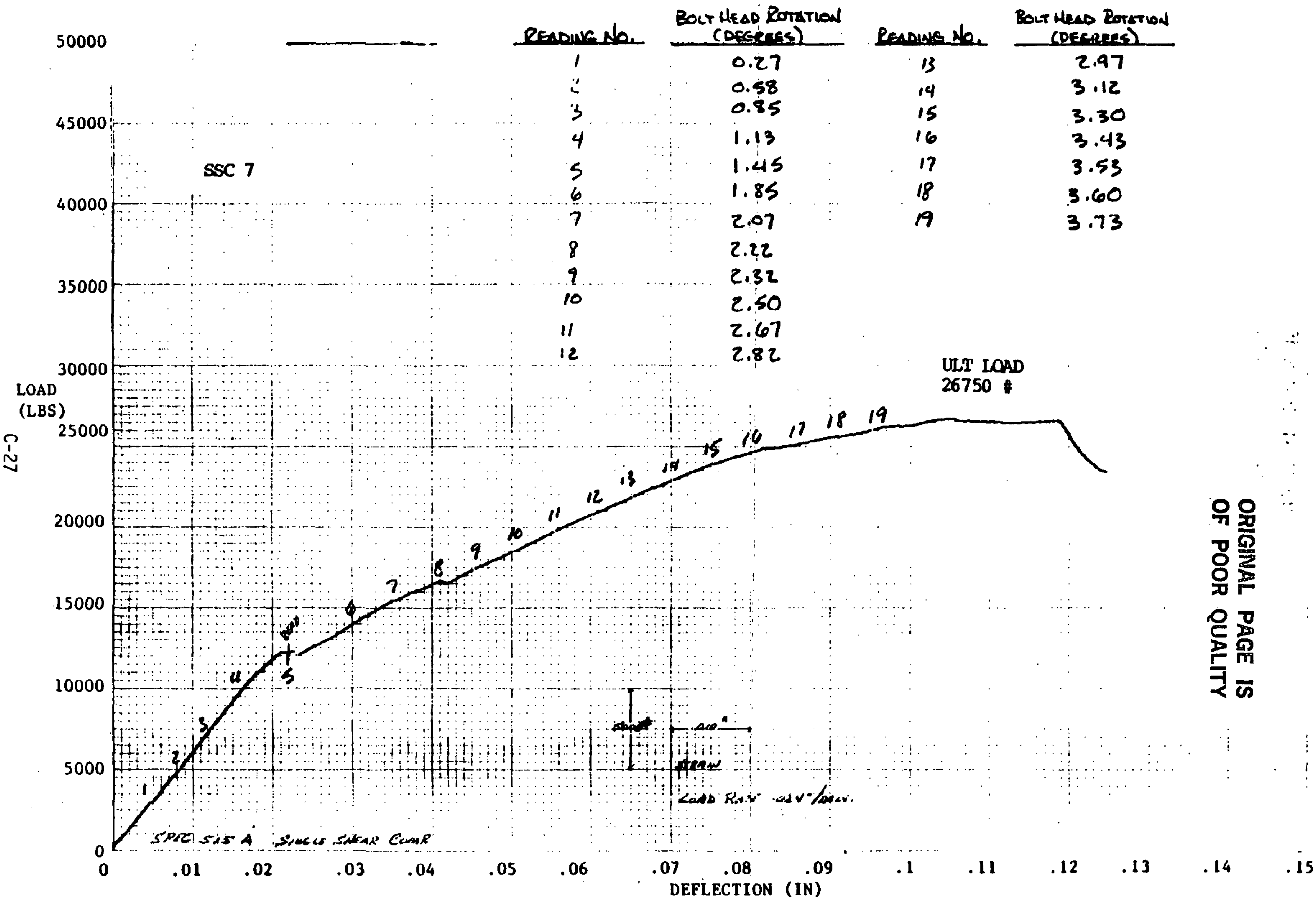
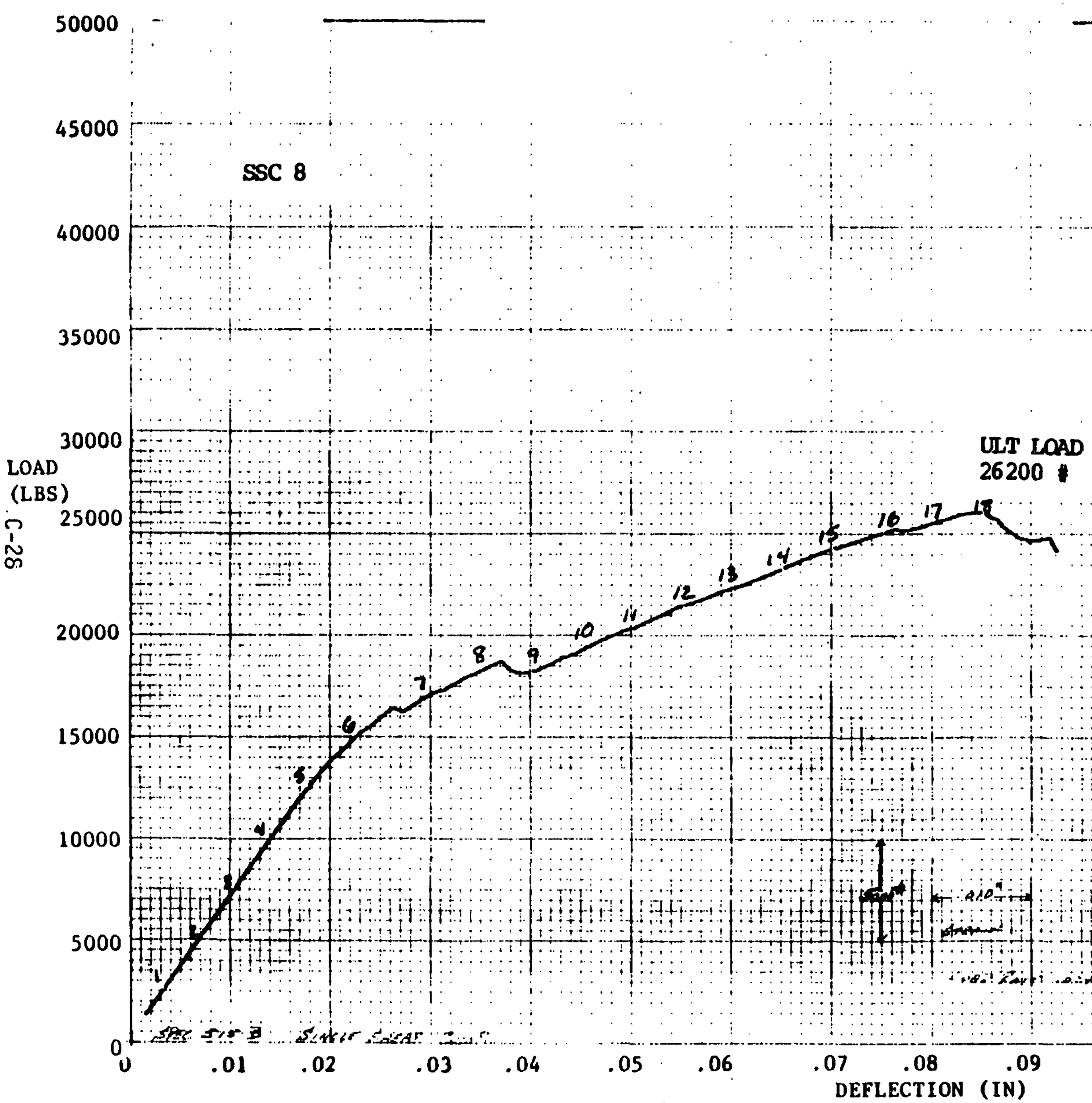

SSC 5
ULT LOAD
11820 #
LOAD (LBS)
DEFLECTION (IN)
SPEC 5/3-B SINGLE SHEAR COMPRESSION
Load Rate .021"/min
Reading No.
Bolt Head Rotation (Degrees)
1 0.39
2 0.54
3 0.74
4 0.96
5 1.15
6 1.45
7 1.69
8 1.87
9 2.04
10 2.21
11 2.38
12 2.58
13 2.73
14 2.87
15 3.00
16 3.07



READING NO.	BOLT HEAD ROTATION (DEGREES)
1	0.12
2	0.22
3	0.32
4	0.47
5	0.62
6	0.76
7	0.96
8	1.20
9	1.45
10	1.60
11	1.84
12	2.04
13	2.24
14	2.42
15	2.58
16	2.73
17	2.90
18	3.07
19	3.25



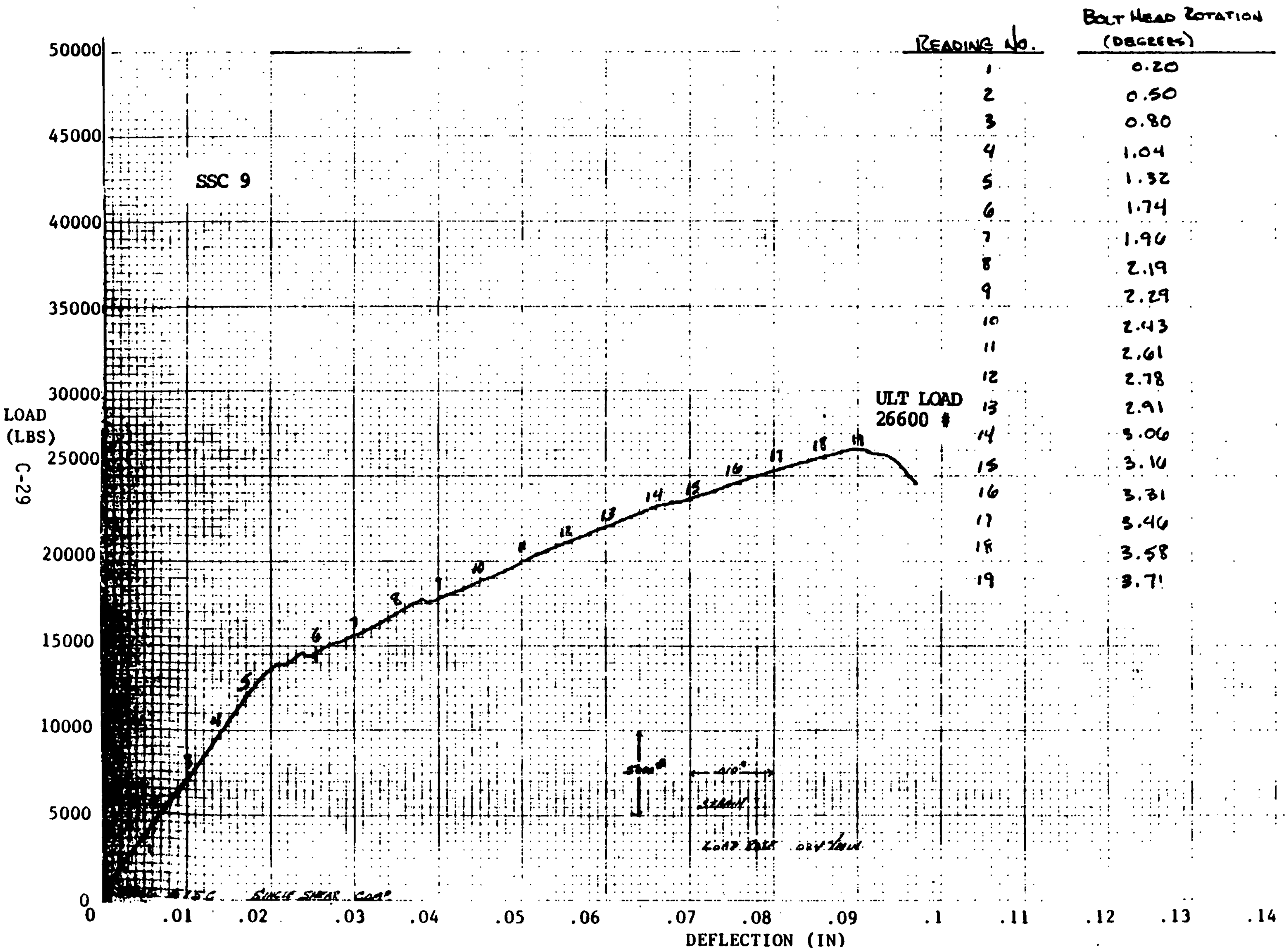
SSC 7
READING NO.
BOLT HEAD ROTATION (DEGREES)
1 0.27
2 0.58
3 0.85
4 1.13
5 1.45
6 1.85
7 2.07
8 2.22
9 2.32
10 2.50
11 2.67
12 2.82
13 2.97
14 3.12
15 3.30
16 3.43
17 3.53
18 3.60
19 3.73
ULT LOAD
26750 #
LOAD (LBS)
0
5000
10000
15000
20000
25000
30000
35000
40000
45000
50000
0 .01 .02 .03 .04 .05 .06 .07 .08 .09 .1 .11 .12 .13 .14 .15
DEFLECTION (IN)
SPEC 515 A SINGLE SHEAR COMP.
LOAD RATE .02" /MIN.



READING NO.	BOLT HEAD ROTATION (DEGREES)
1	0.20
2	0.39
3	0.62
4	0.84
5	1.03
6	1.33
7	1.77
8	1.99
9	2.12
10	2.27
11	2.41
12	2.61
13	2.76
14	2.93
15	3.08
16	3.20
17	3.30
18	3.45

C-28

C-4



SSC 9
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DEFLECTION (IN)
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35000
30000
25000
20000
15000
10000
5000
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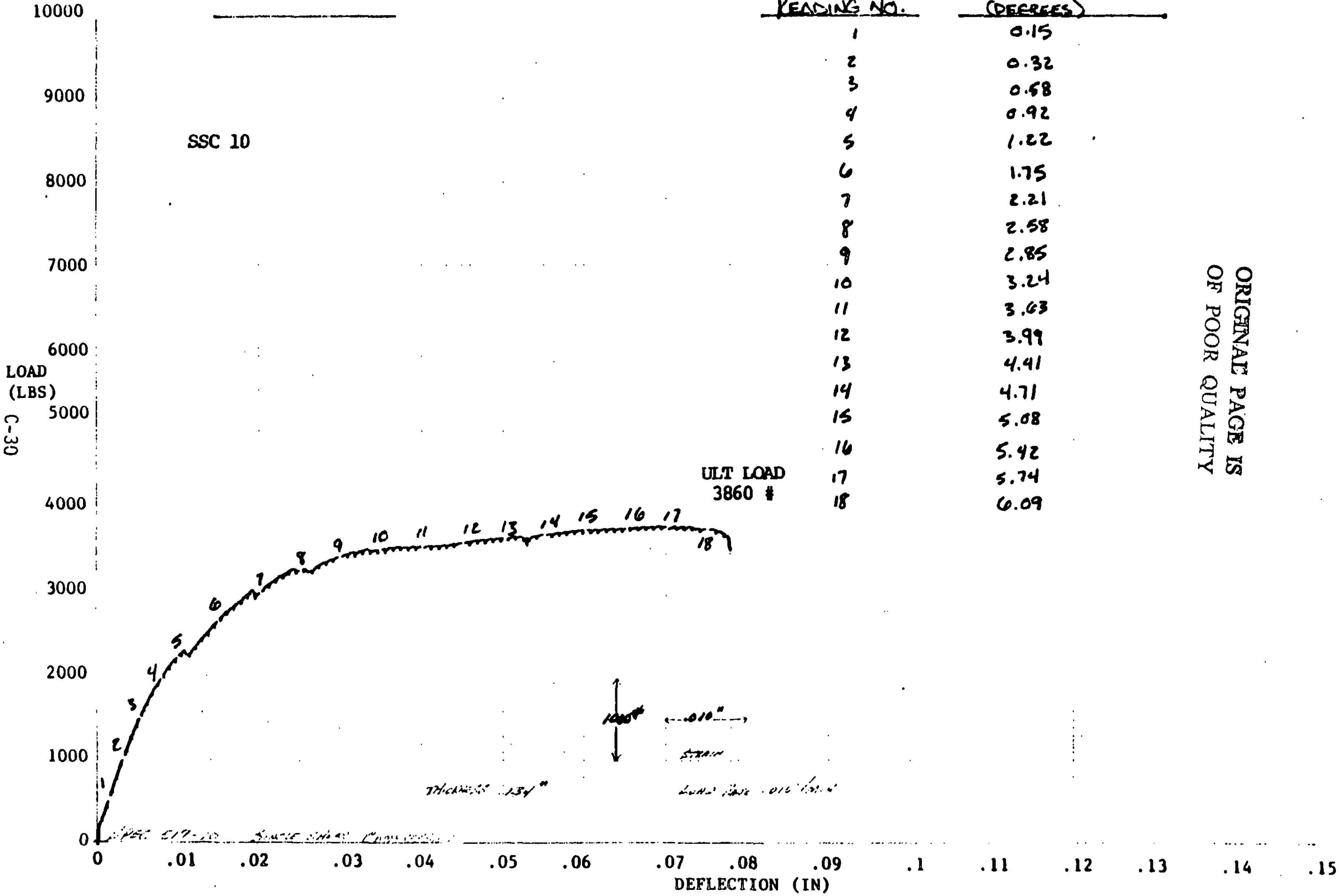
.01
.02
.03
.04
.05
.06
.07
.08
.09
.1
.11
.12
.13
.14
.15
READING NO.
BOLT HEAD ROTATION (DEGREES)
1 0.20
2 0.50
3 0.80
4 1.04
5 1.32
6 1.74
7 1.96
8 2.19
9 2.29
10 2.43
11 2.61
12 2.78
13 2.91
14 3.06
15 3.16
16 3.31
17 3.46
18 3.58
19 3.71



READING NO.	BOLT HEAD ROTATION (DEGREES)
1	0.15
2	0.32
3	0.58
4	0.92
5	1.22
6	1.75
7	2.21
8	2.58
9	2.85
10	3.24
11	3.63
12	3.99
13	4.41
14	4.71
15	5.08
16	5.42
17	5.74
18	6.09

C-30

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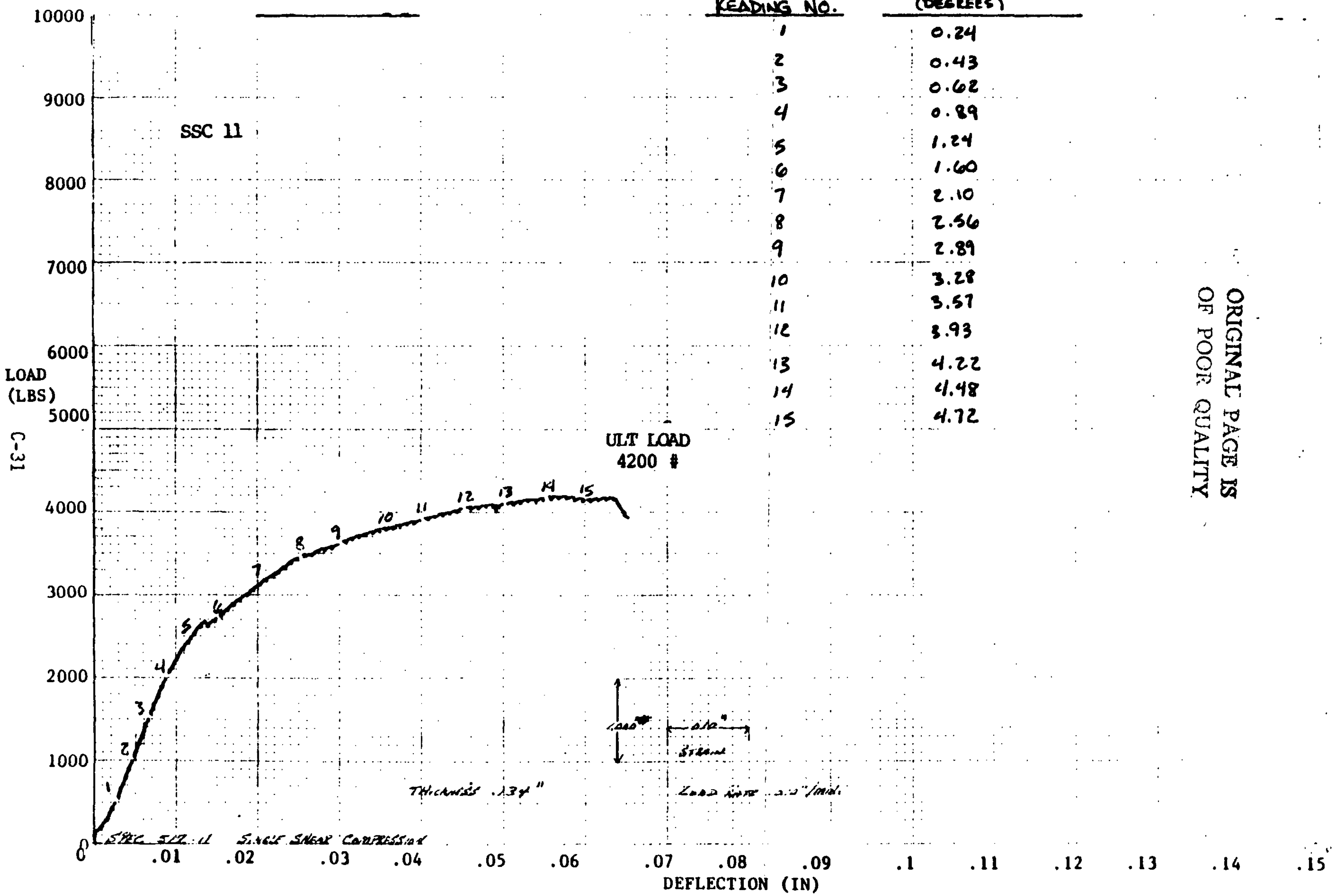
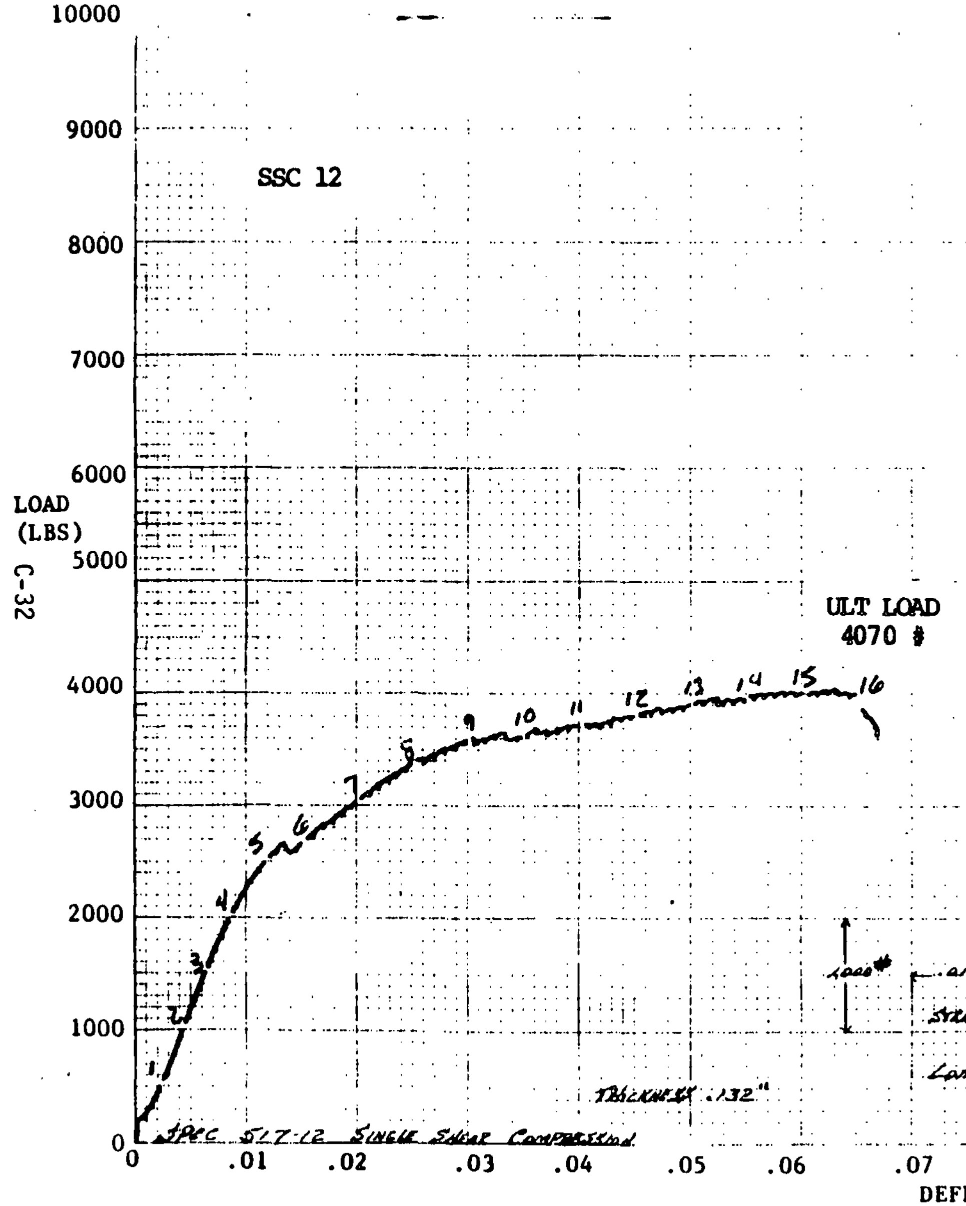


READING NO.	BOLT HEAD ROTATION (DEGREES)
1	0.24
2	0.43
3	0.62
4	0.89
5	1.24
6	1.60
7	2.10
8	2.56
9	2.89
10	3.28
11	3.57
12	3.93
13	4.22
14	4.48
15	4.72



READING NO.	BOLT HEAD ROTATION (DEGREES)
1	0.19
2	0.36
3	0.58
4	0.82
5	1.23
6	1.61
7	2.07
8	2.50
9	2.84
10	3.15
11	3.42
12	3.68
13	3.95
14	4.24
15	4.58
16	4.87

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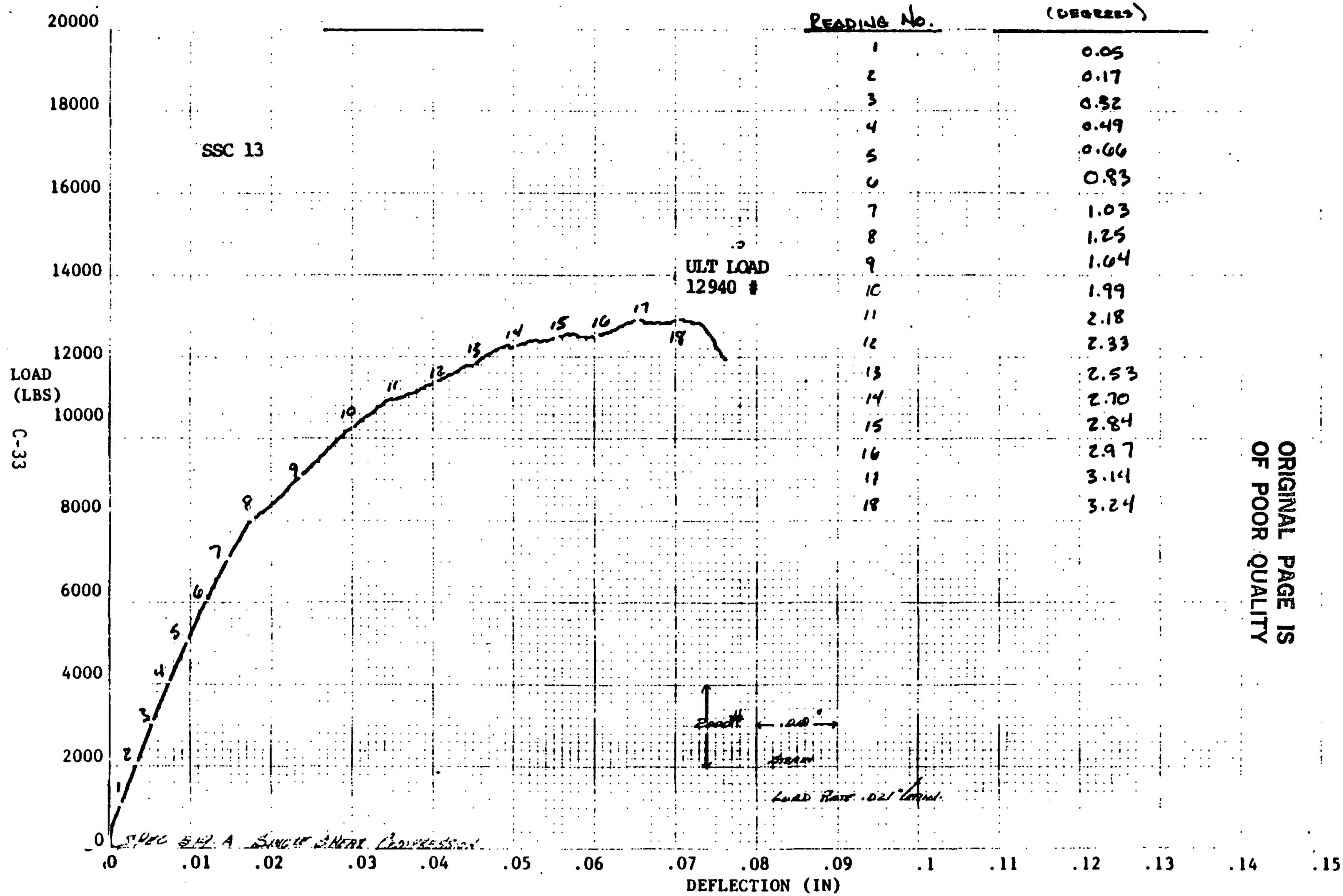
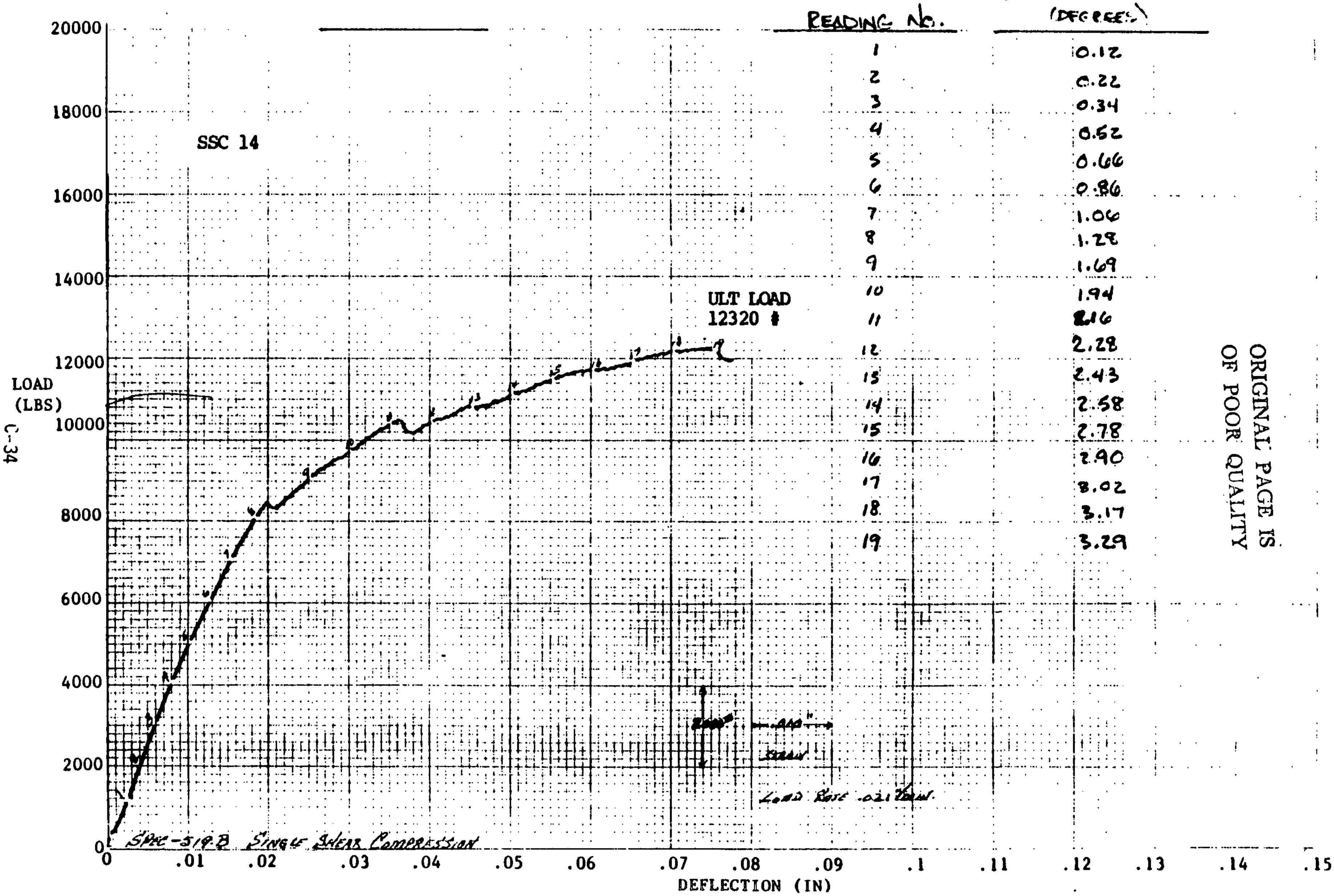
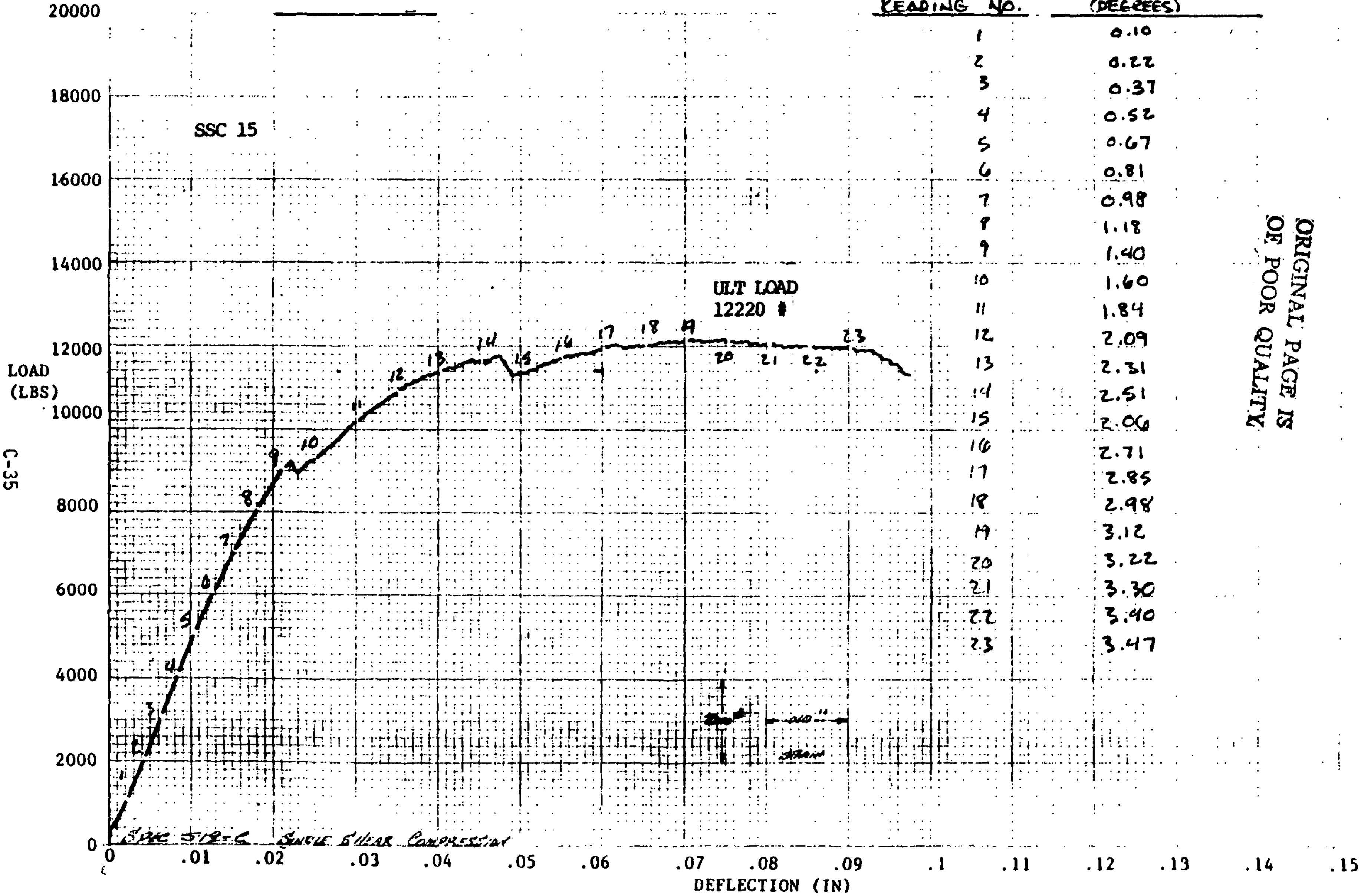


READING NO.	BOLT HEAD ROTATION (DEGREES)
1	0.05
2	0.17
3	0.32
4	0.49
5	0.66
6	0.83
7	1.03
8	1.25
9	1.64
10	1.99
11	2.18
12	2.33
13	2.53
14	2.70
15	2.84
16	2.97
17	3.14
18	3.24



READING NO.	BOLT HEAD ROTATION (DEGREES)
1	0.12
2	0.22
3	0.34
4	0.52
5	0.66
6	0.86
7	1.06
8	1.28
9	1.69
10	1.94
11	2.16
12	2.28
13	2.43
14	2.58
15	2.78
16	2.90
17	3.02
18	3.17
19	3.29



Reading No.	Bolt Head Rotation (Degrees)
1	0.10
2	0.22
3	0.37
4	0.52
5	0.67
6	0.81
7	0.98
8	1.18
9	1.40
10	1.60
11	1.84
12	2.09
13	2.31
14	2.51
15	2.06
16	2.71
17	2.85
18	2.98
19	3.12
20	3.22
21	3.30
22	3.40
23	3.47

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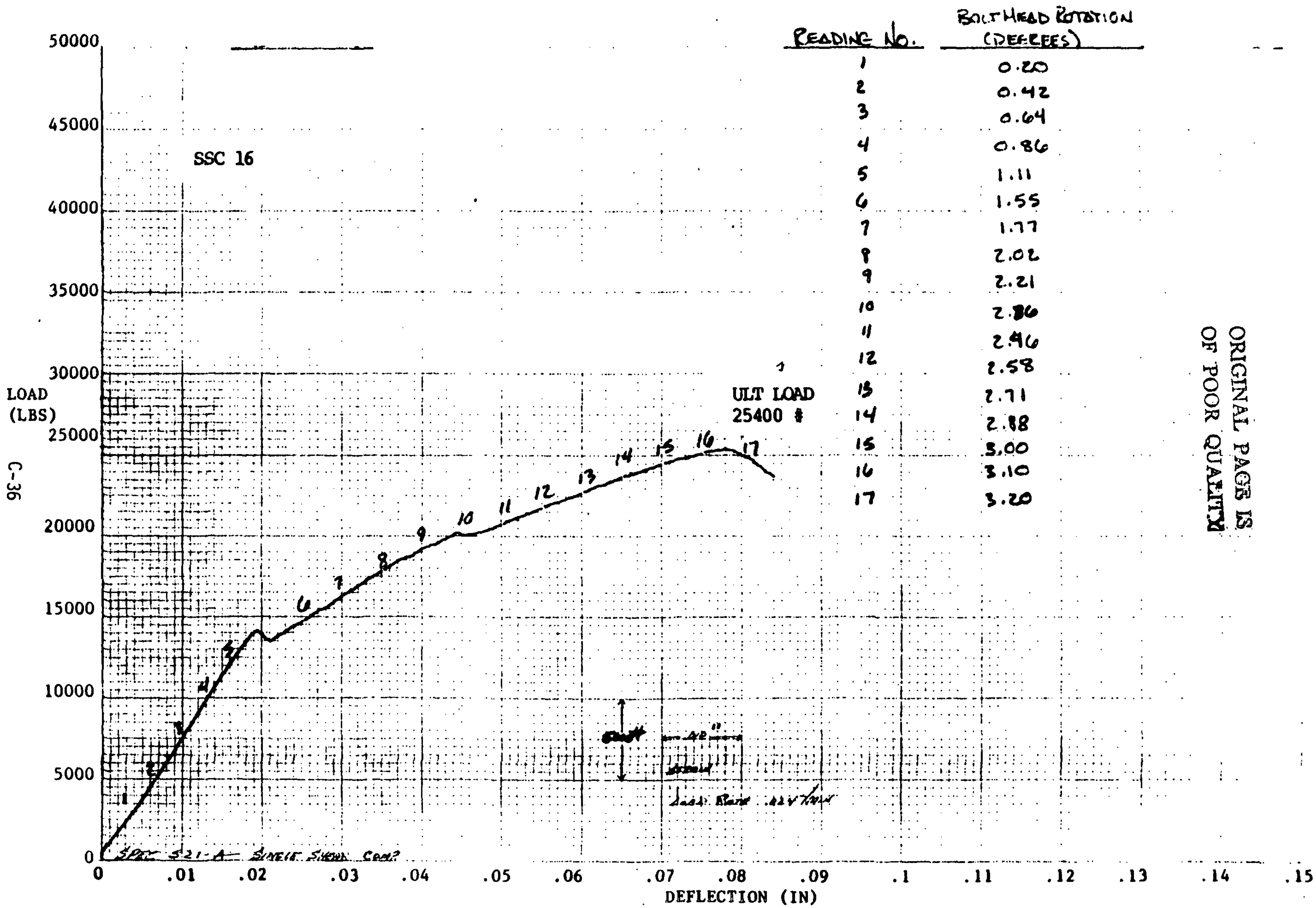

READING NO.	BOLT HEAD ROTATION (DEGREES)
1	0.20
2	0.42
3	0.64
4	0.86
5	1.11
6	1.55
7	1.77
8	2.02
9	2.21
10	2.36
11	2.46
12	2.58
13	2.71
14	2.88
15	3.00
16	3.10
17	3.20

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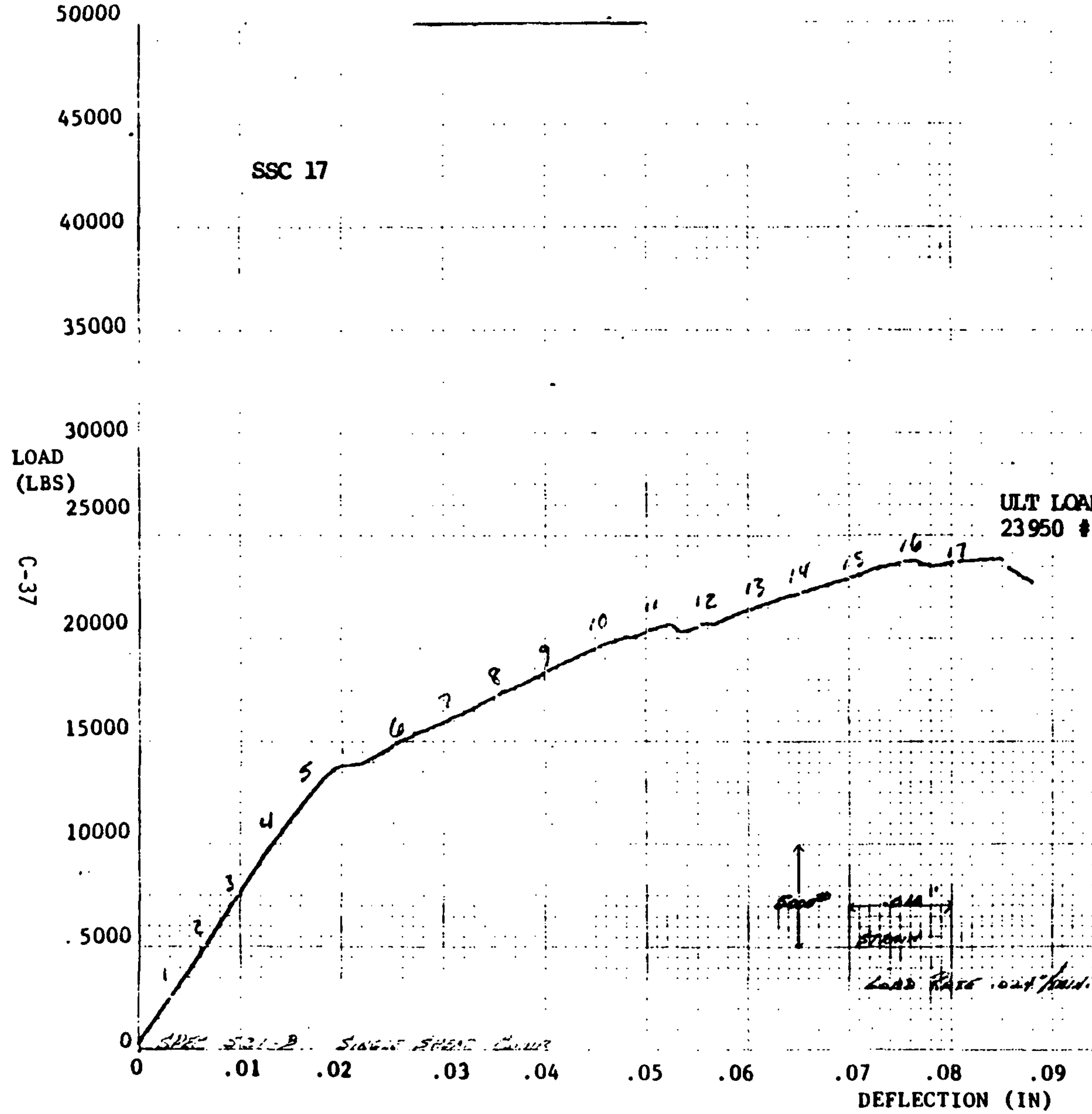

READING NO.	BOLT HEAD ROTATION (DEGREES)
1	0.15
2	0.35
3	0.54
4	0.79
5	1.06
6	1.48
7	1.73
8	1.93
9	2.12
10	2.30
11	2.42
12	2.50
13	2.59
14	2.74
15	2.84
16	2.99
17	3.09
18	3.19

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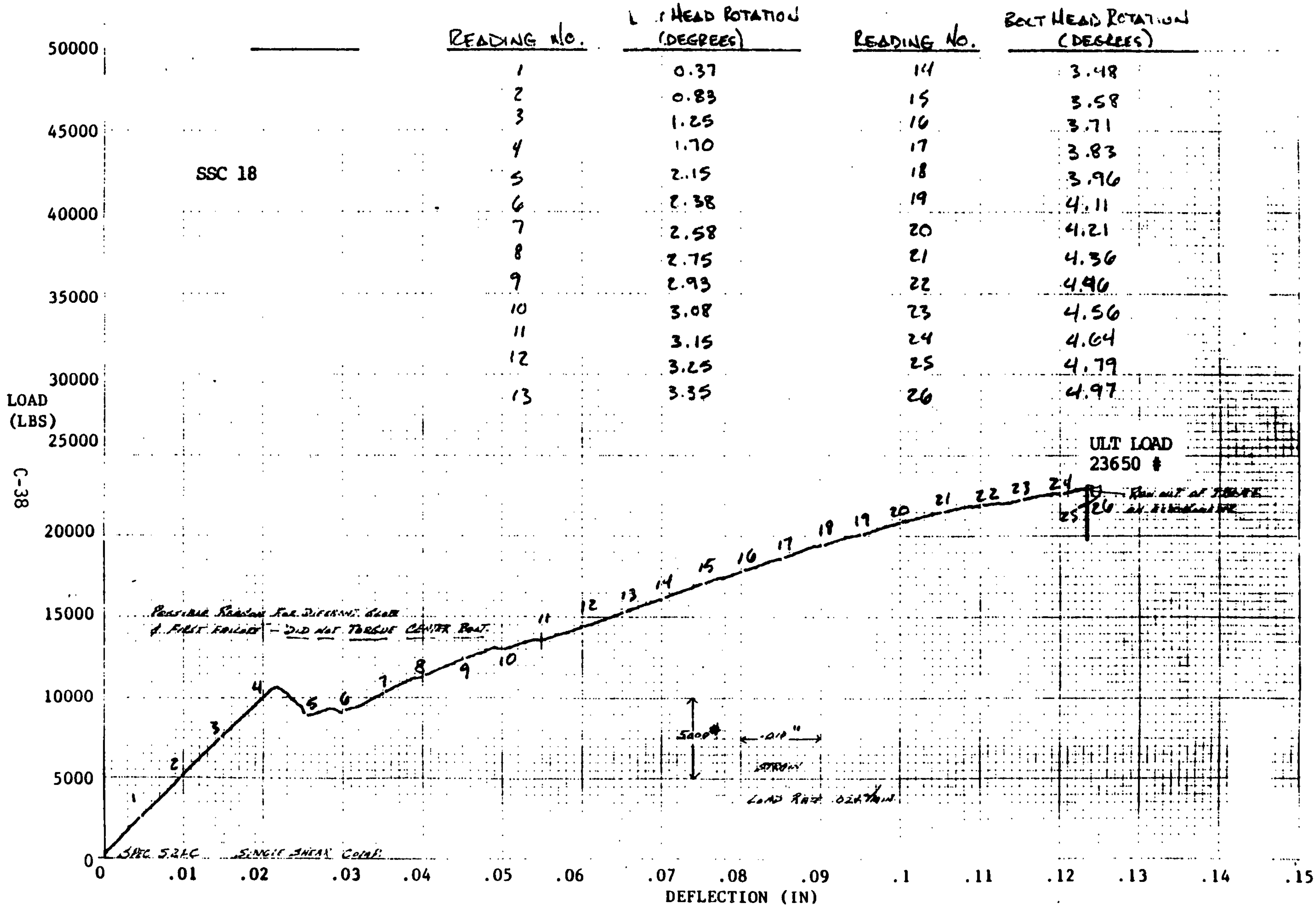
C-38



Reading No.	[illegible] Head Rotation (Degrees)	Reading No.	Bolt Head Rotation (Degrees)
1	0.37	14	3.48
2	0.83	15	3.58
3	1.25	16	3.71
4	1.70	17	3.83
5	2.15	18	3.96
6	2.38	19	4.11
7	2.58	20	4.21
8	2.75	21	4.36
9	2.93	22	4.46
10	3.08	23	4.56
11	3.15	24	4.64
12	3.25	25	4.79
13	3.35	26	4.97

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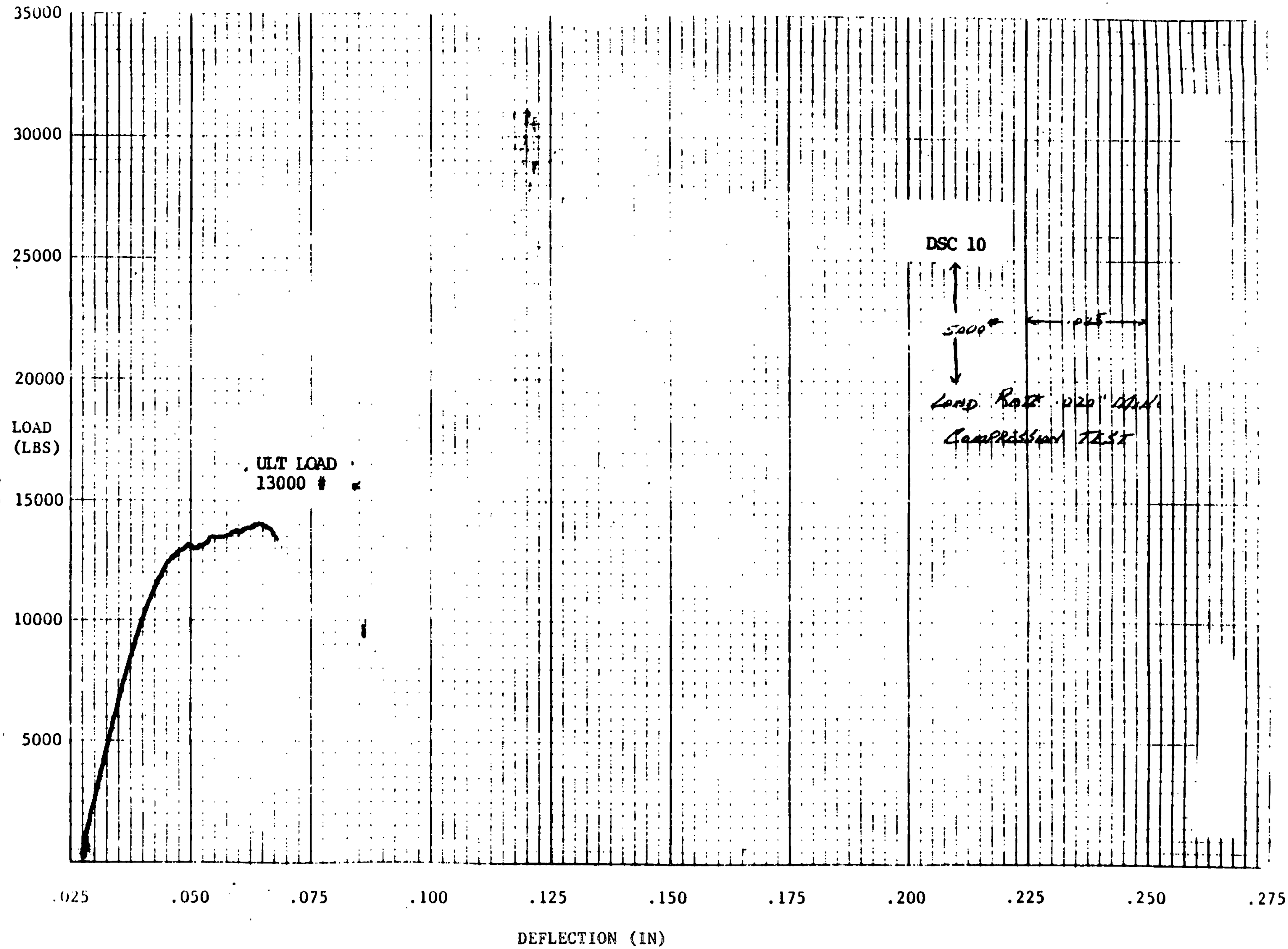
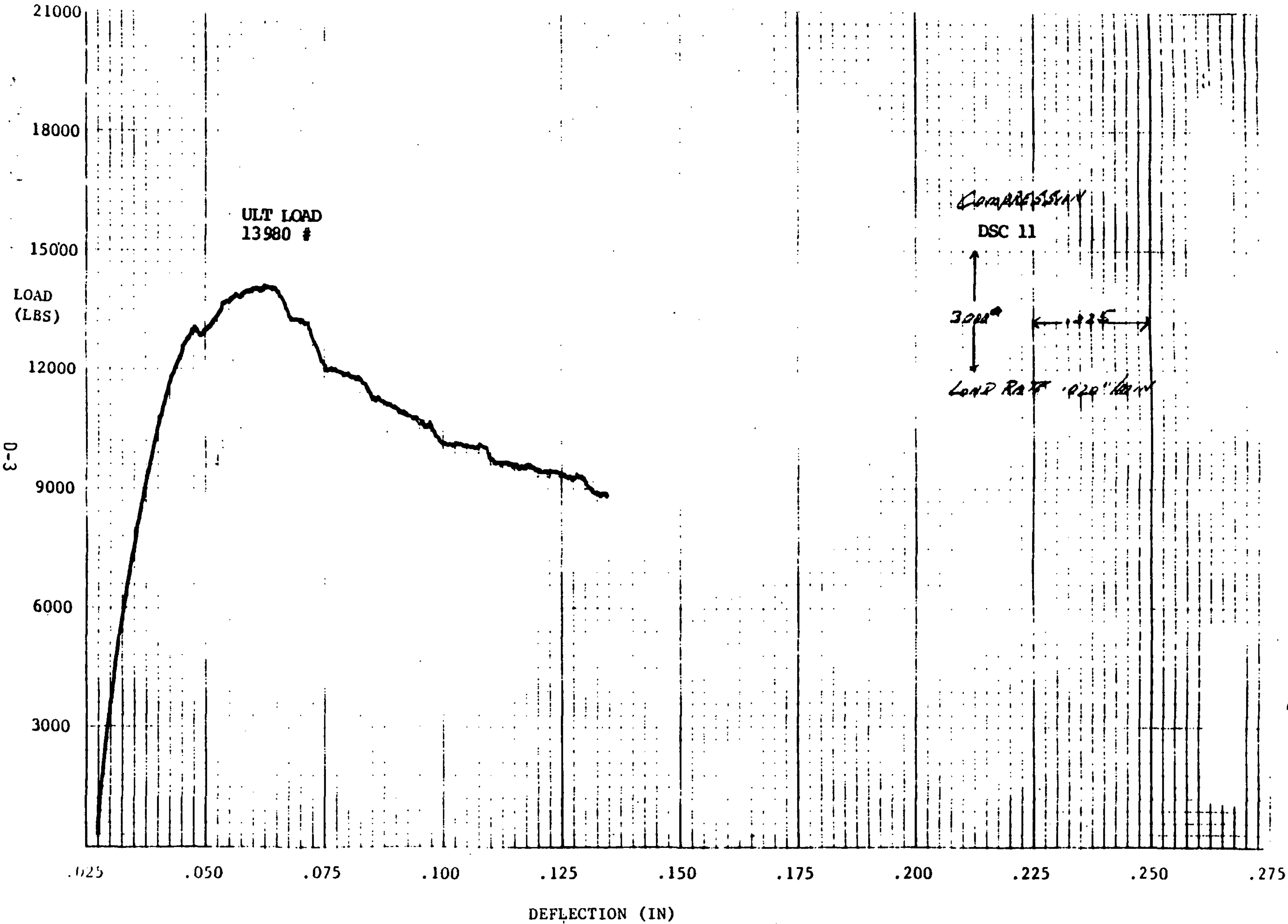
APPENDIX D

ANCILLARY TEST DATA

PHASE II TESTS



35000
30000
25000
20000
LOAD (LBS)
15000
10000
5000
ULT LOAD 13000 #
DSC 10
5000#
.025
.025
.050
.075
.100
.125
.150
.175
.200
.225
.250
.275
DEFLECTION (IN)


ULT LOAD
13980 #
COMPRESSION
DSC 11
300#
.225
LOAD RATE .020"/min
LOAD (LBS)
21000
18000
15000
12000
9000
6000
3000
.025
.050
.075
.100
.125
.150
.175
.200
.225
.250
.275
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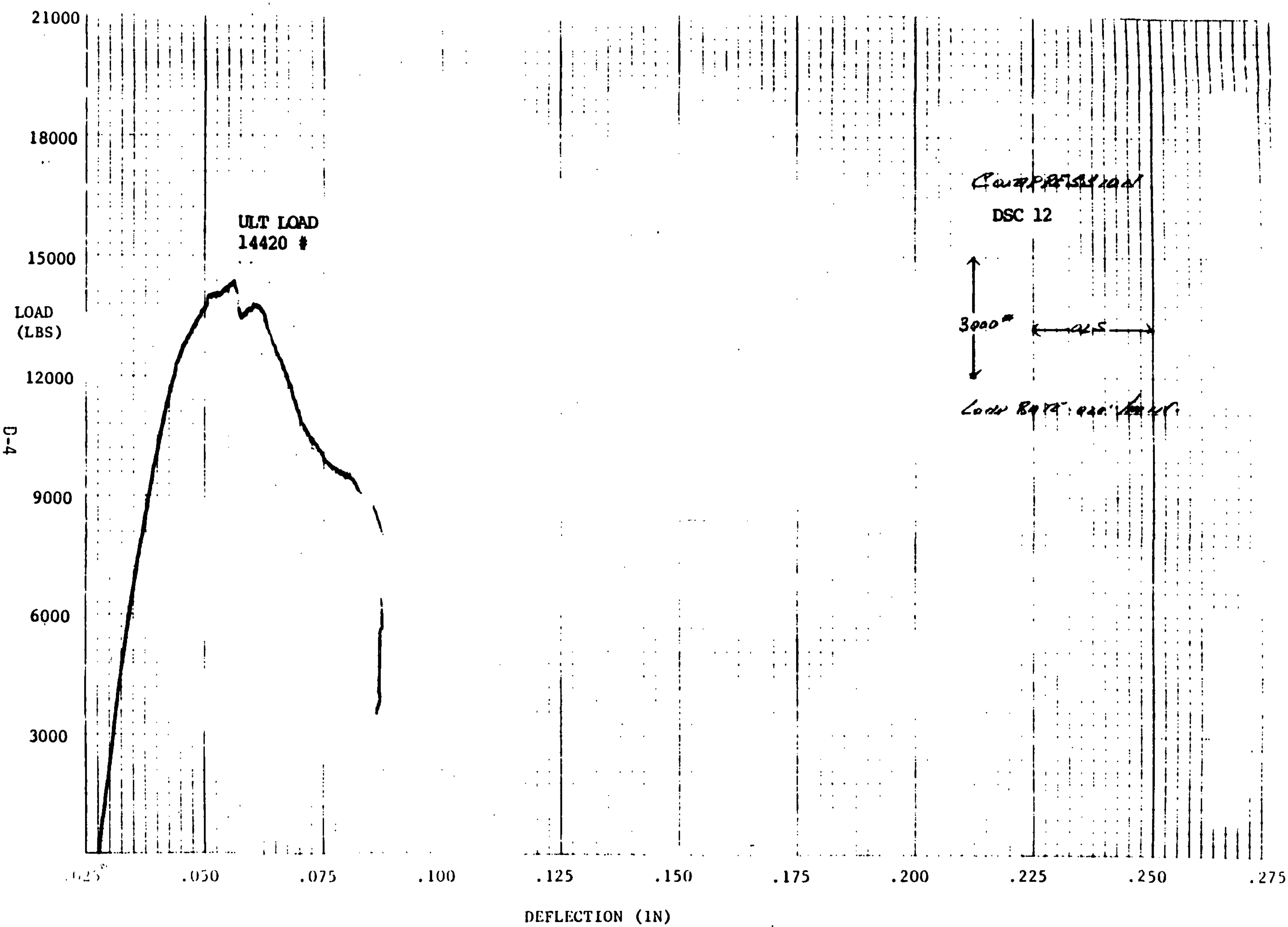
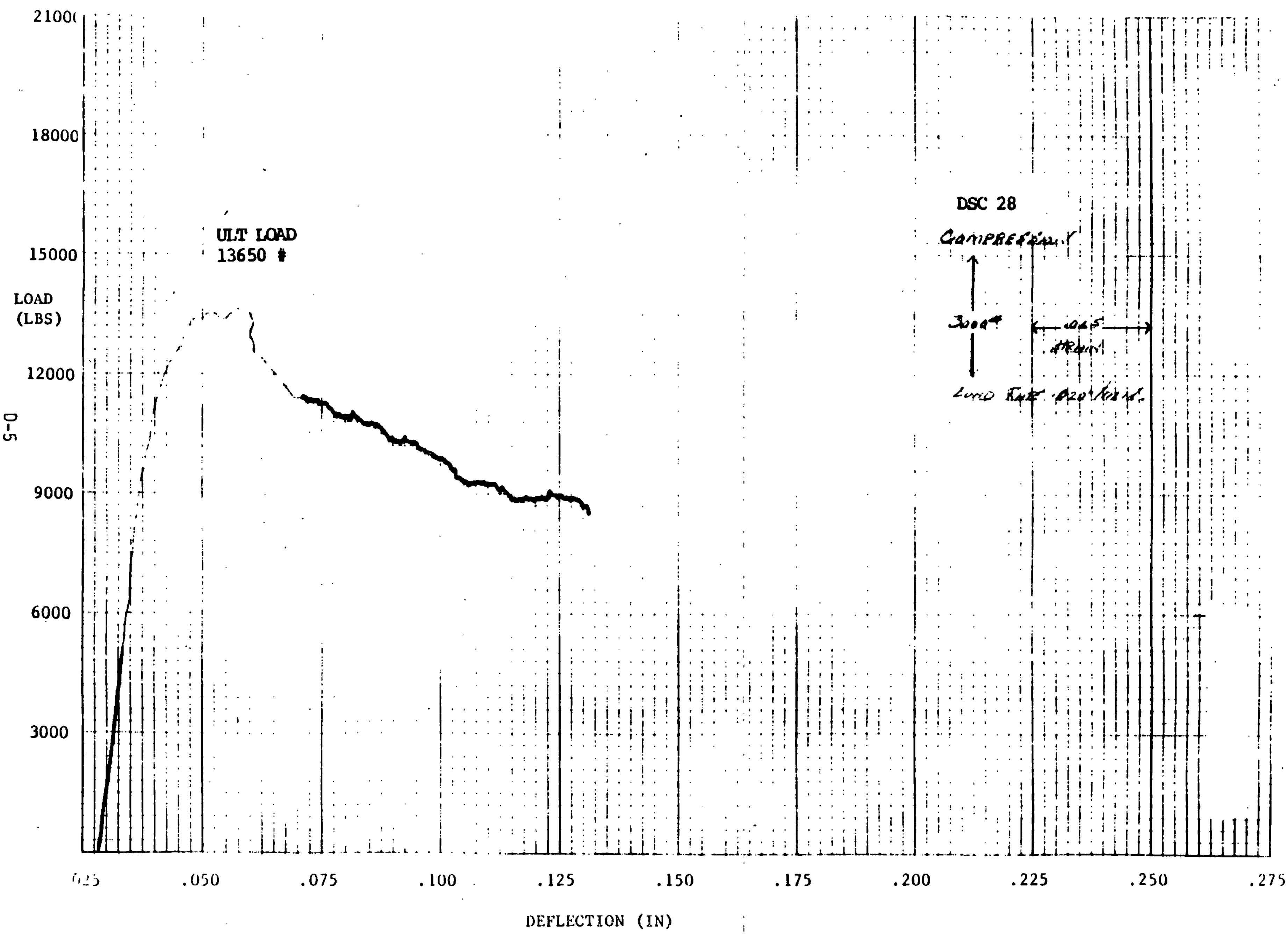
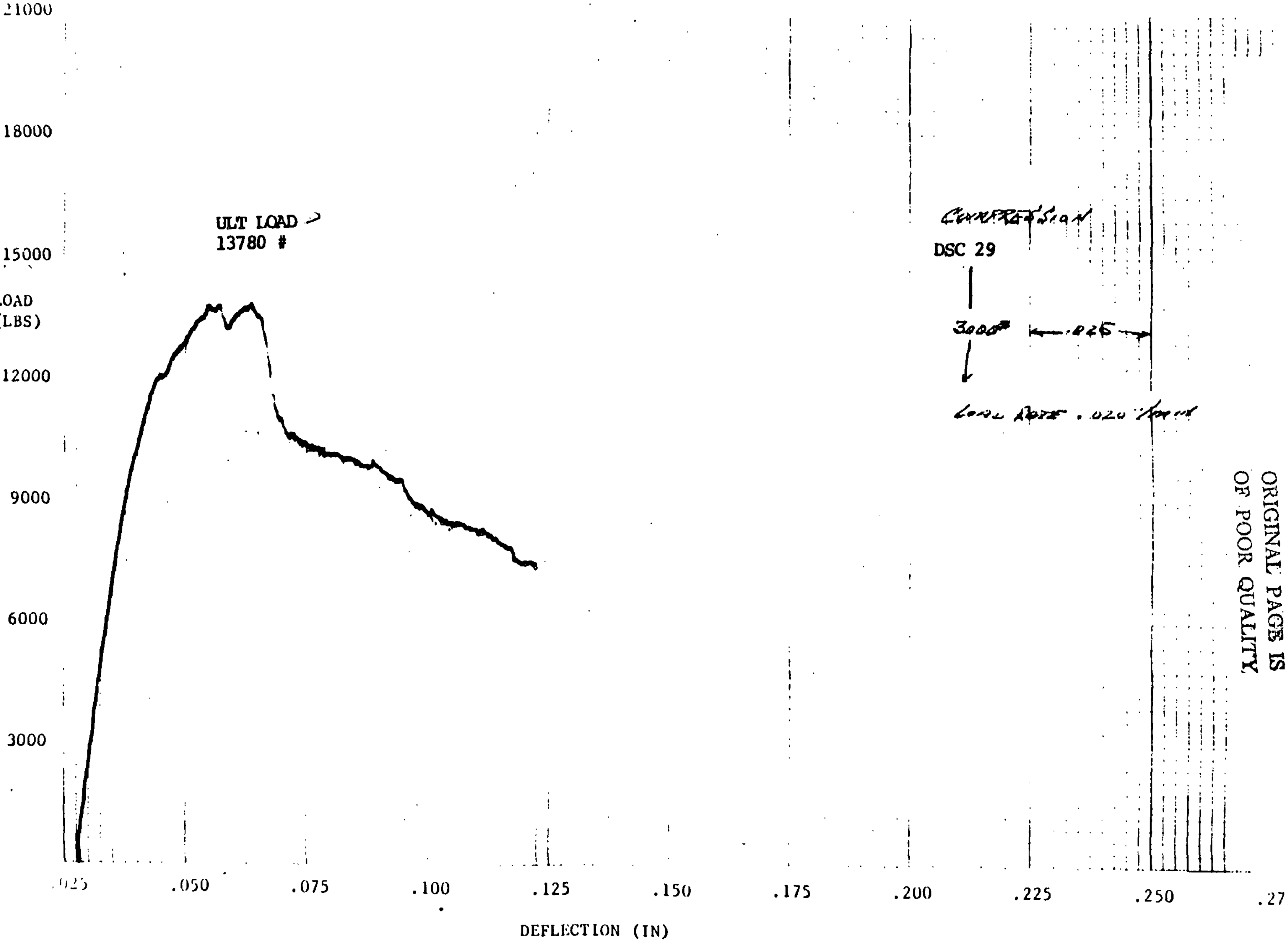
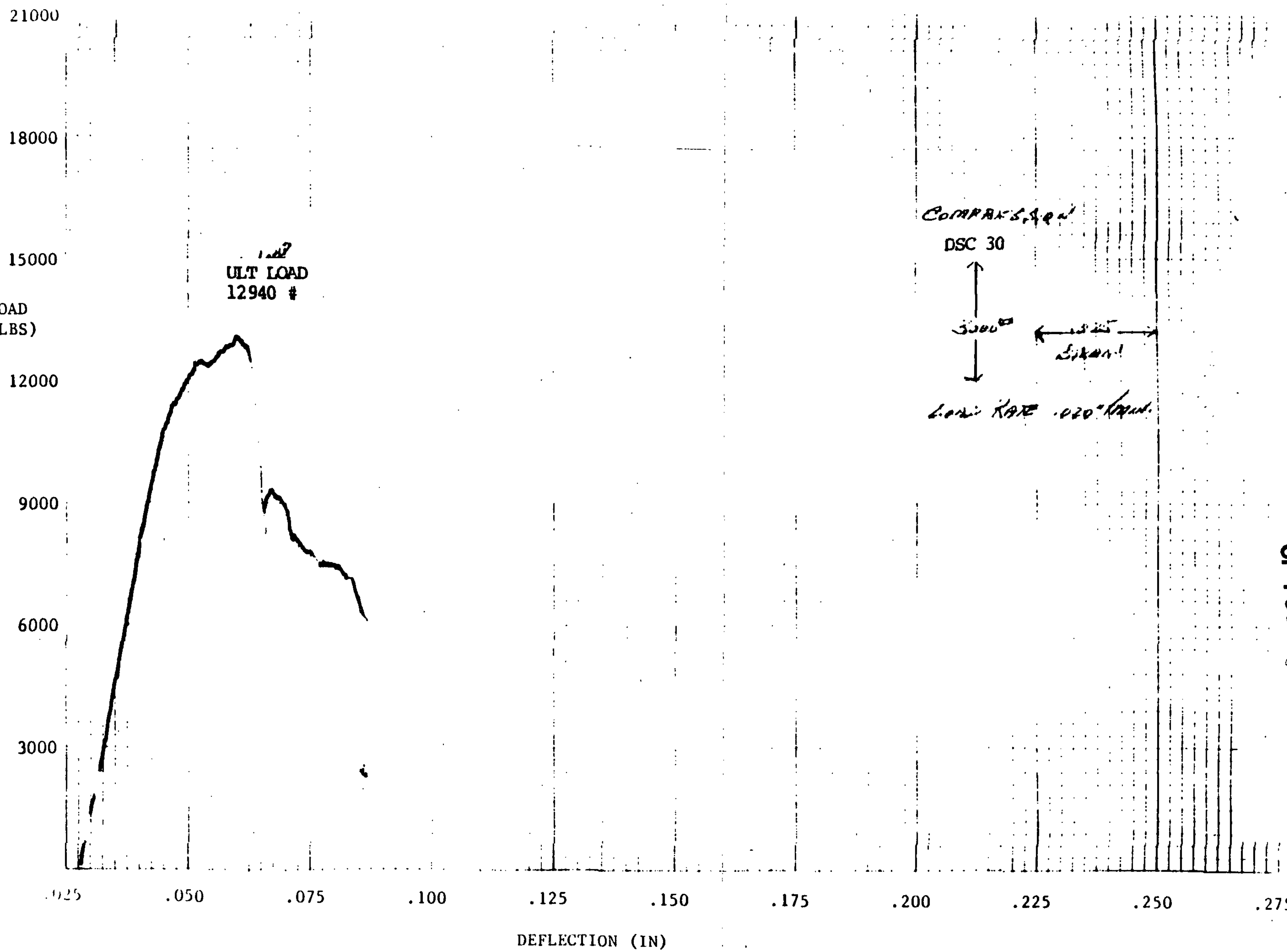

21000
18000
15000
12000
9000
6000
3000
LOAD
(LBS)
ULT LOAD
14420 #
COMPRESSION
DSC 12
3000#
.025
.050
.075
.100
.125
.150
.175
.200
.225
.250
.275
DEFLECTION (IN)



ULT LOAD
13650 #
DSC 28
LOAD
(LBS)
21000
18000
15000
12000
9000
6000
3000
.025
.050
.075
.100
.125
.150
.175
.200
.225
.250
.275
DEFLECTION (IN)


21000
18000
15000
12000
9000
6000
3000
LOAD
(LBS)
ULT LOAD
13780 #
COMPRESSION
DSC 29
3000#
.025
.025
.050
.075
.100
.125
.150
.175
.200
.225
.250
.275
DEFLECTION (IN)



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18000
15000
12000
9000
6000
3000
LOAD
(LBS)
ULT LOAD
12940 #
DSC 30
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.050
.075
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.200
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.275
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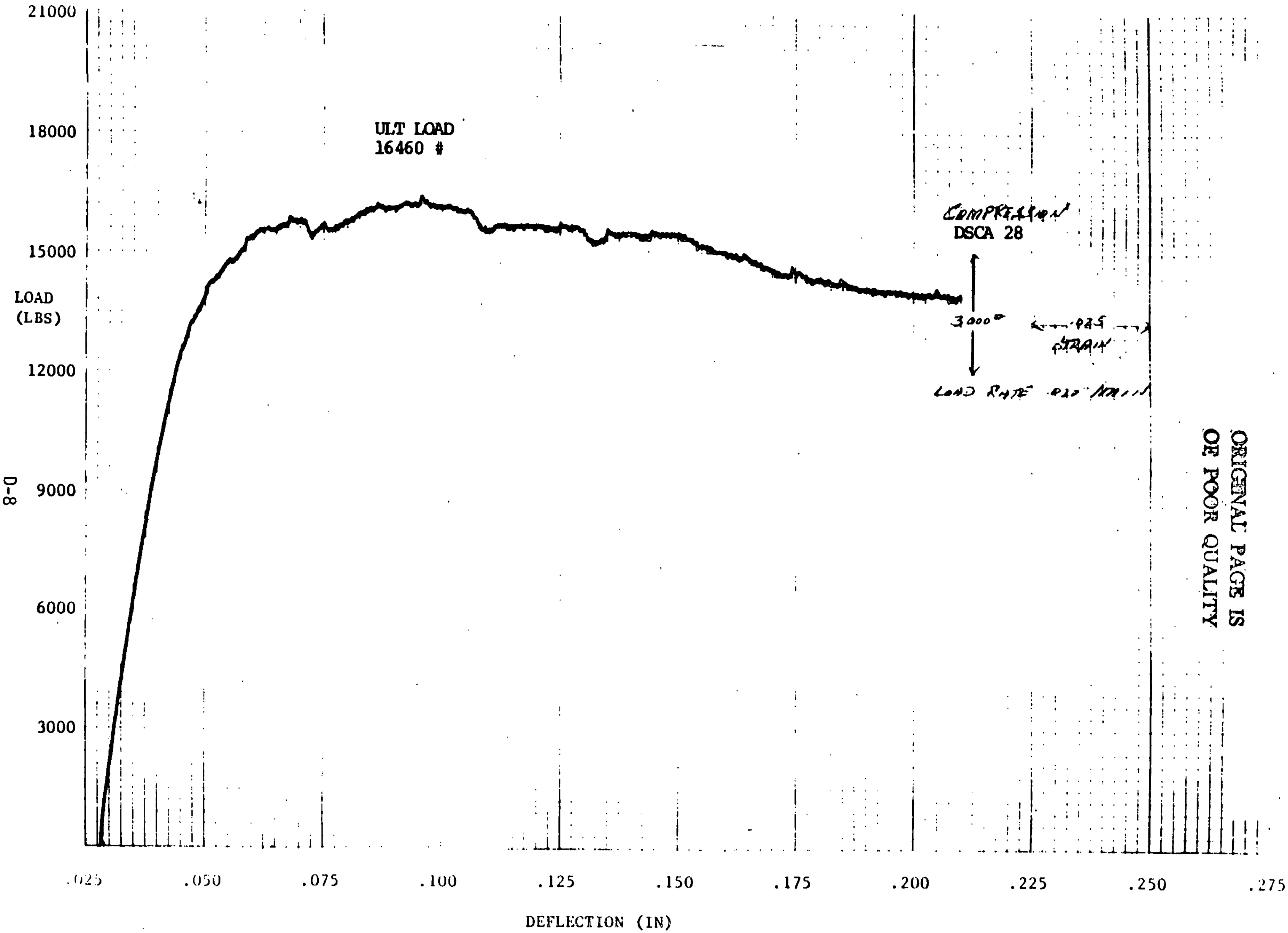
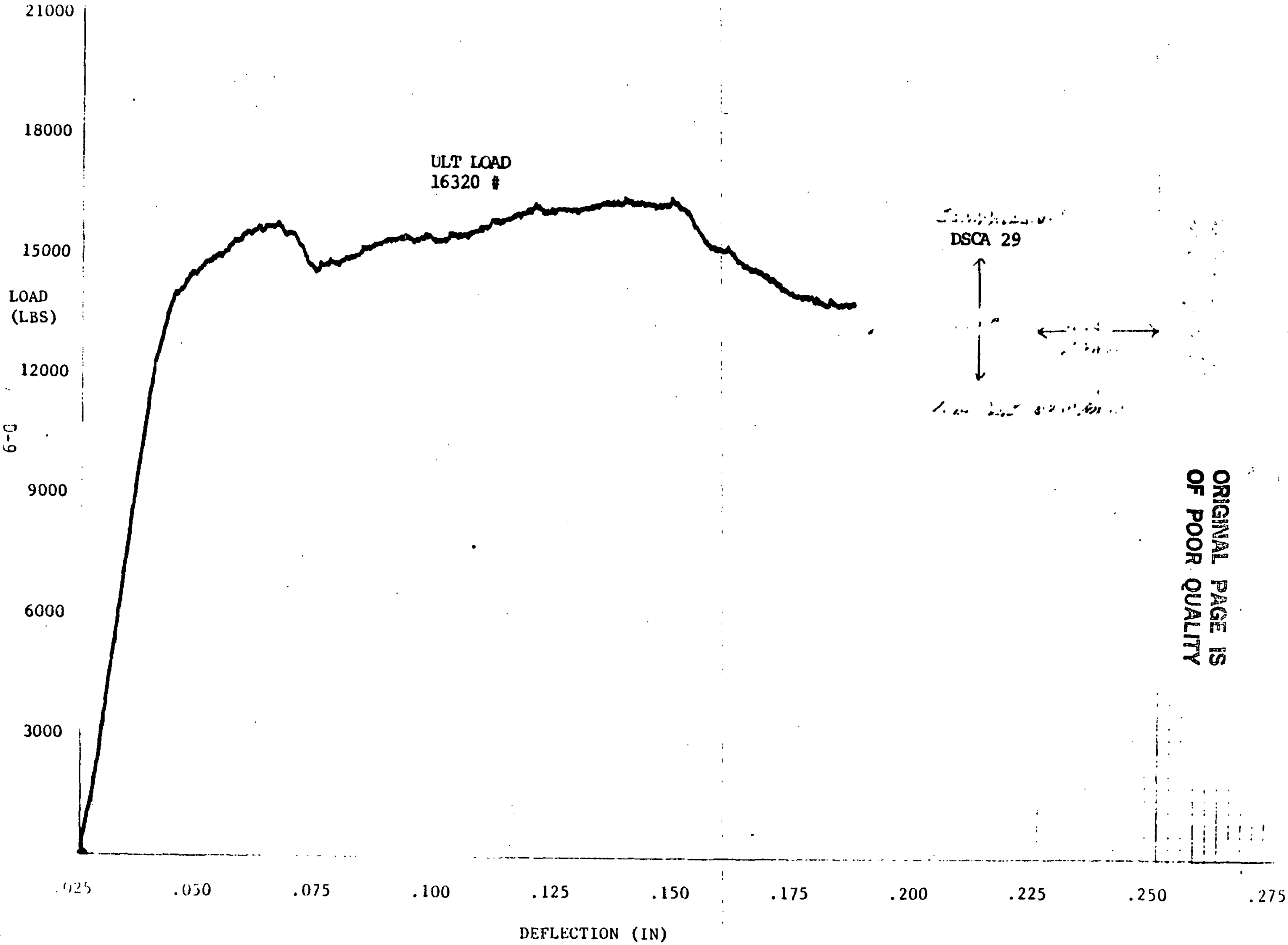

21000
18000
15000
12000
9000
6000
3000
LOAD
(LBS)
ULT LOAD
16460 #
COMPRESSION
DSCA 28
3000#
.025
STRAIN
LOAD RATE
.025
.050
.075
.100
.125
.150
.175
.200
.225
.250
.275
DEFLECTION (IN)


ULT LOAD
16320 #
DSCA 29
LOAD
(LBS)
21000
18000
15000
12000
9000
6000
3000
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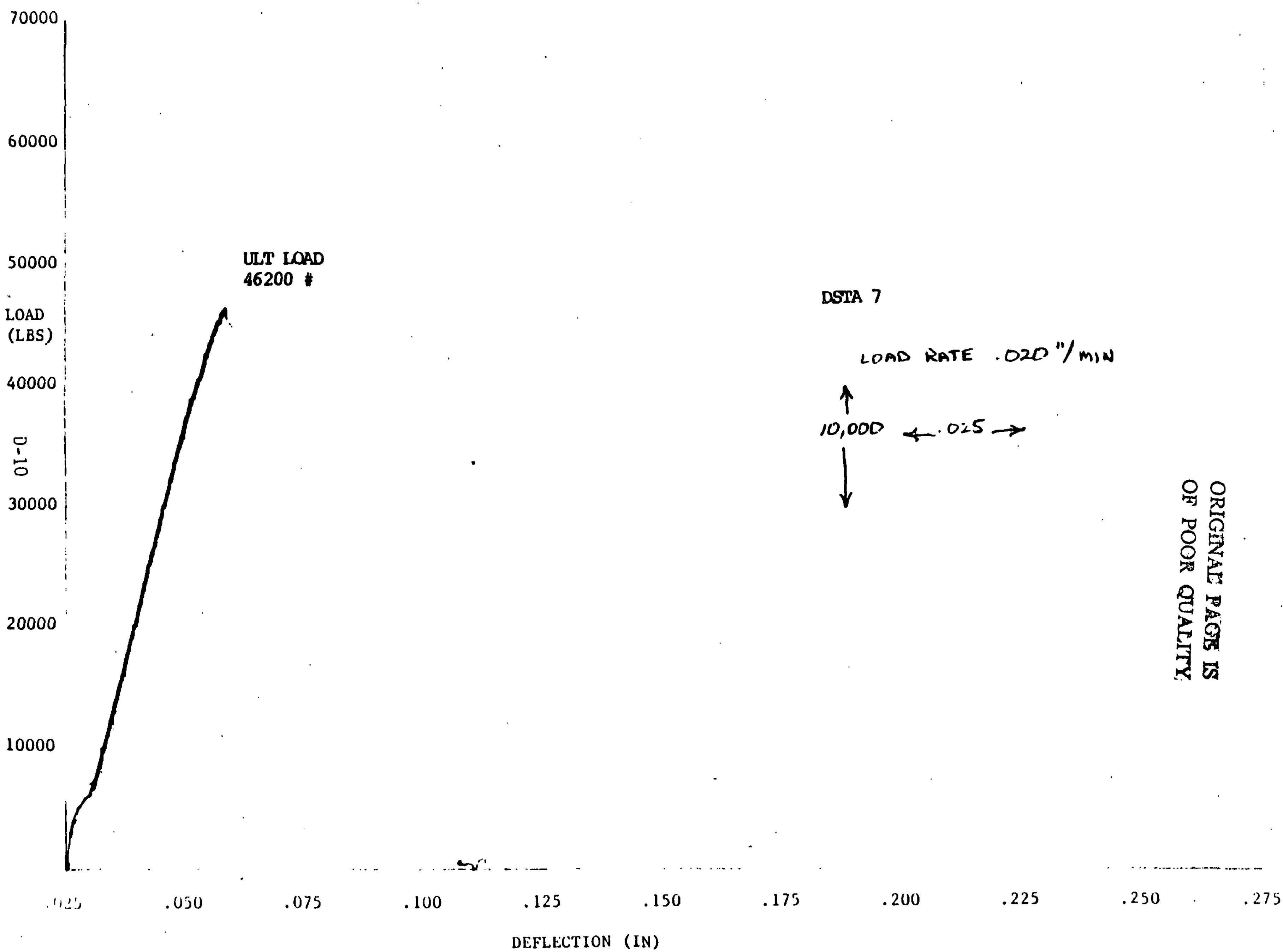
.050
.075
.100
.125
.150
.175
.200
.225
.250
.275
DEFLECTION (IN)



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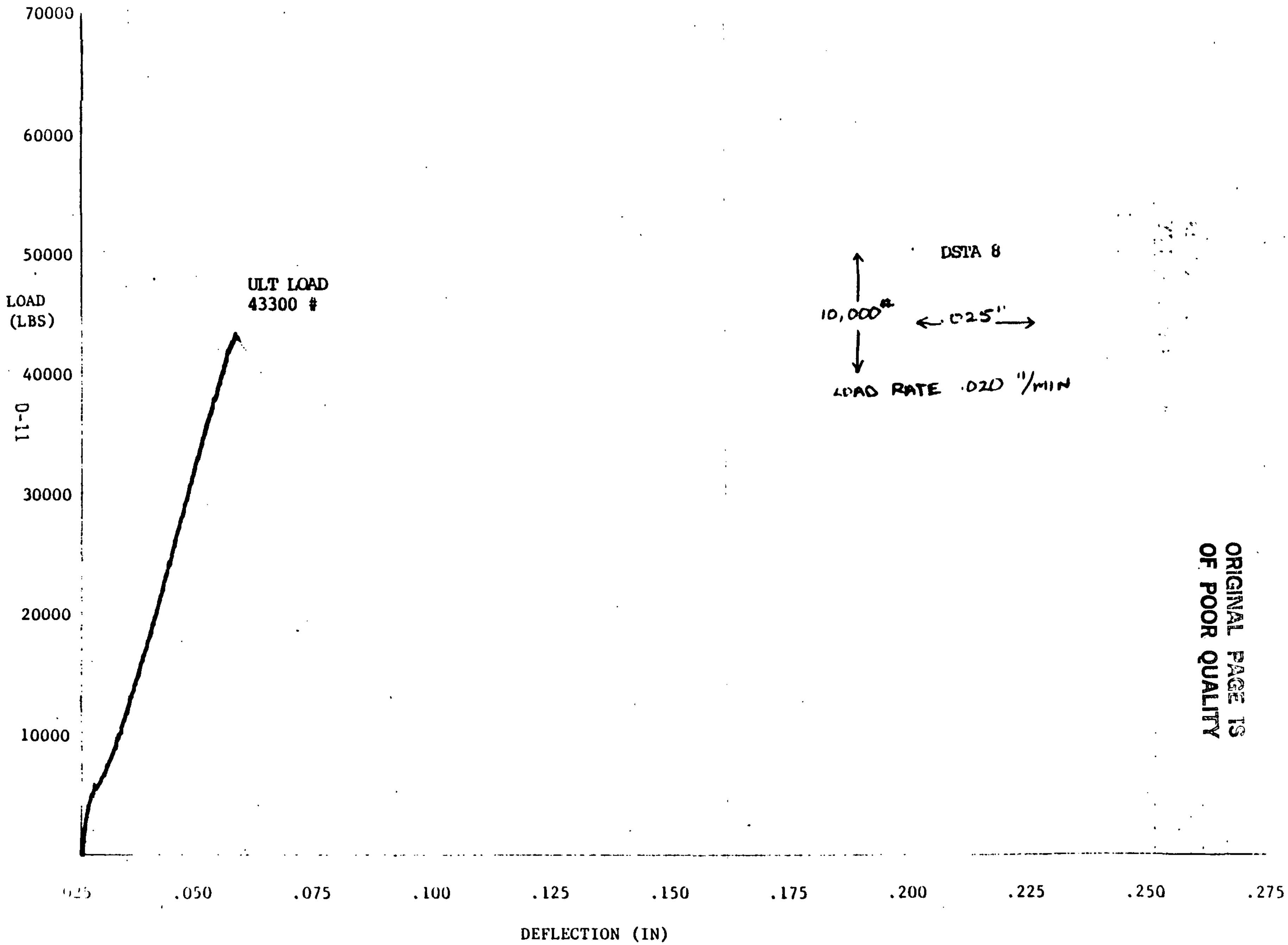
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60000
50000
40000
30000
20000
10000
LOAD
(LBS)
ULT LOAD
43300 #
DSTA 8
10,000#
.025"
LOAD RATE .020 "/MIN
.025
.050
.075
.100
.125
.150
.175
.200
.225
.250
.275
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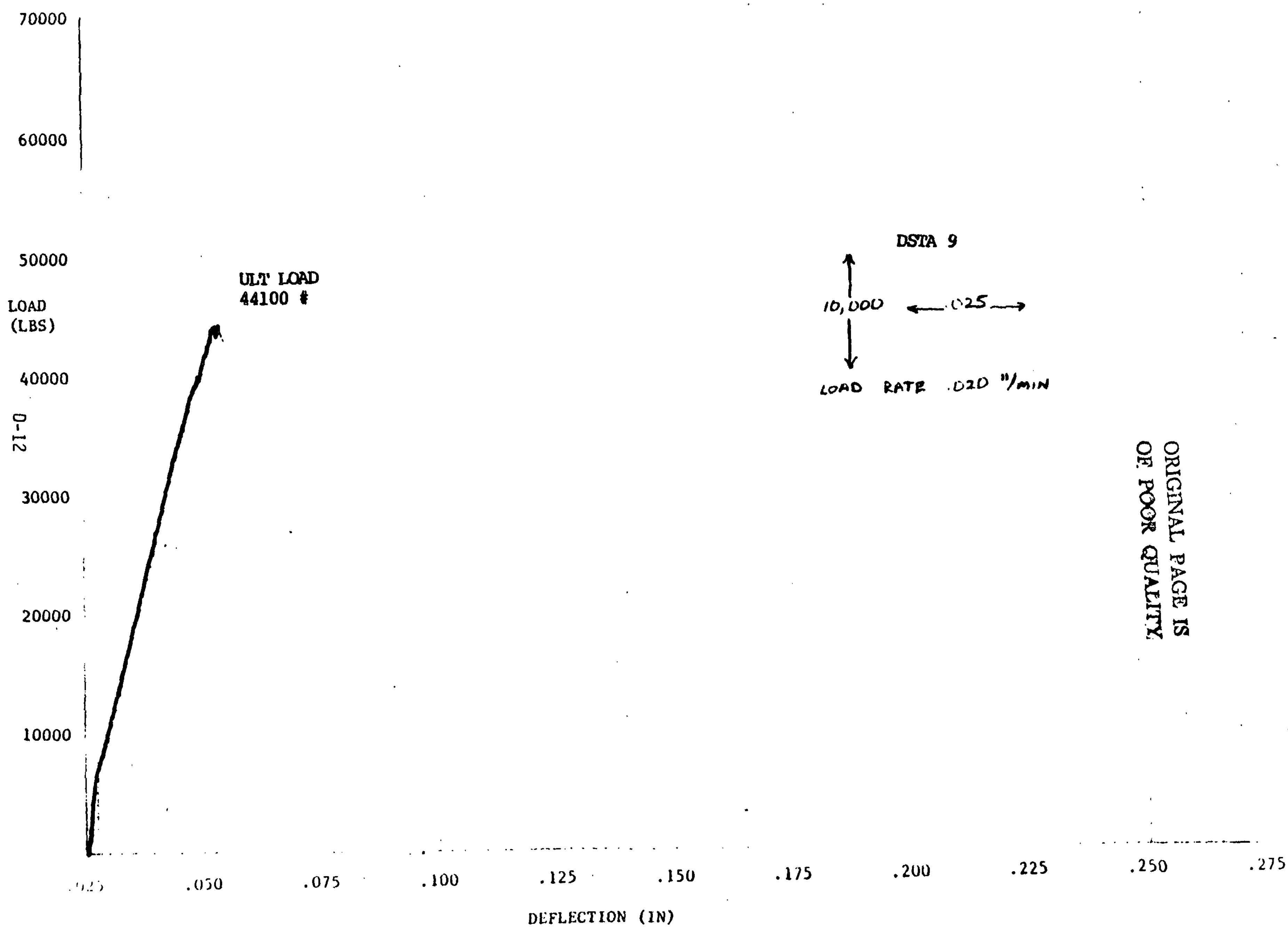
DSTA 9
ULT LOAD
44100 #
LOAD
(LBS)
70000
60000
50000
40000
30000
20000
10000
10,000
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LOAD RATE .020 "/MIN
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.075
.100
.125
.150
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.200
.225
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.275
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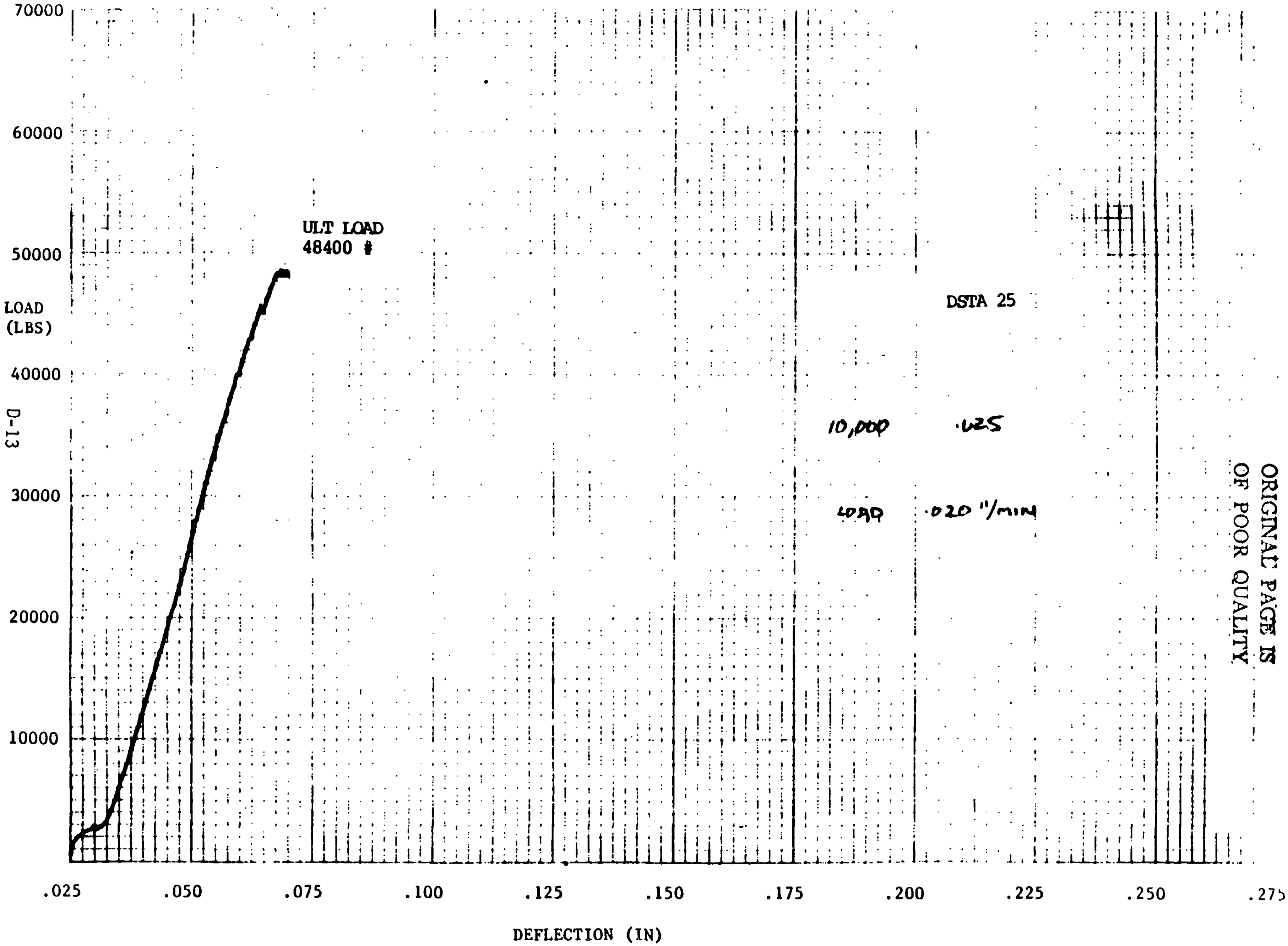
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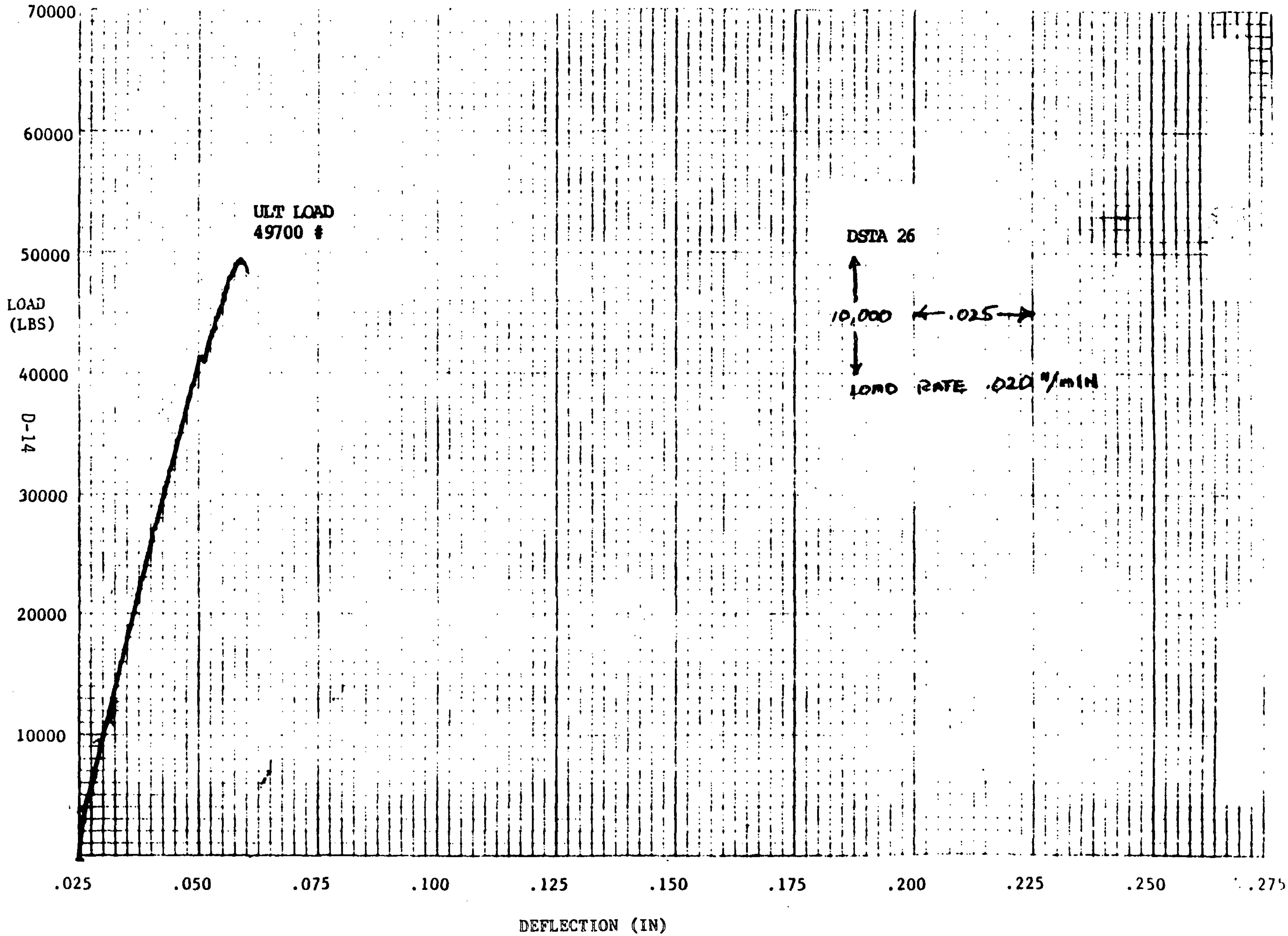
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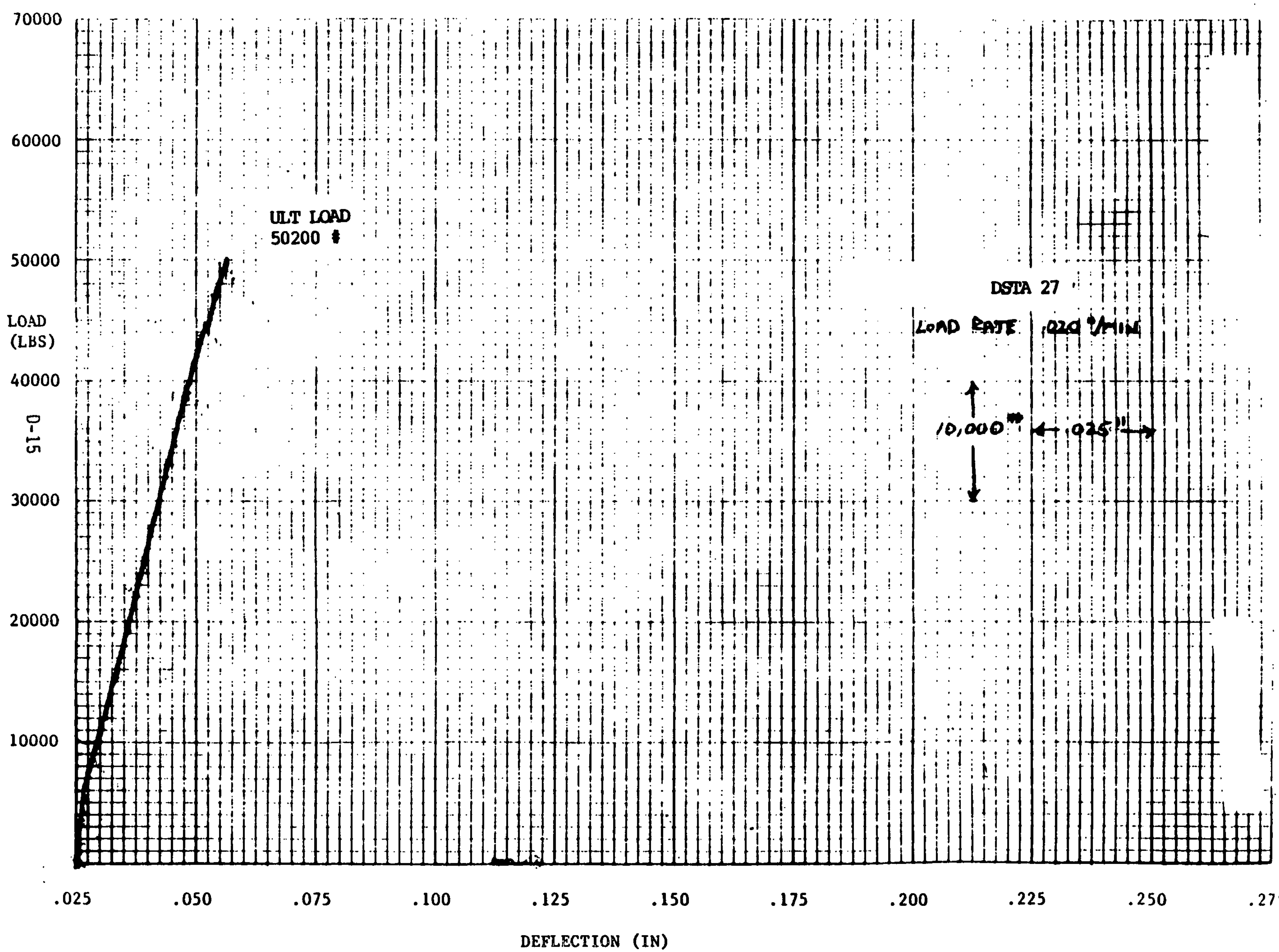
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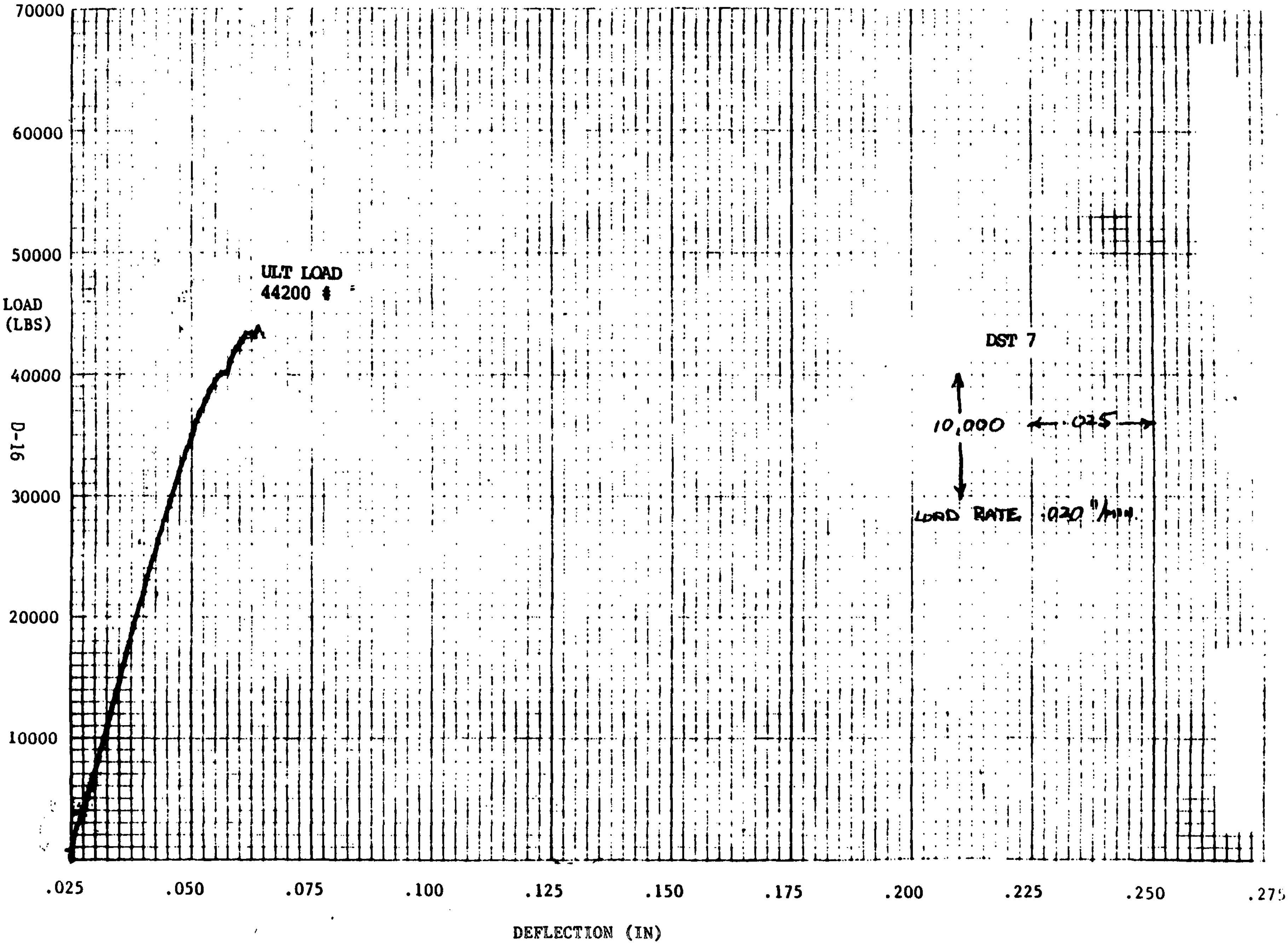
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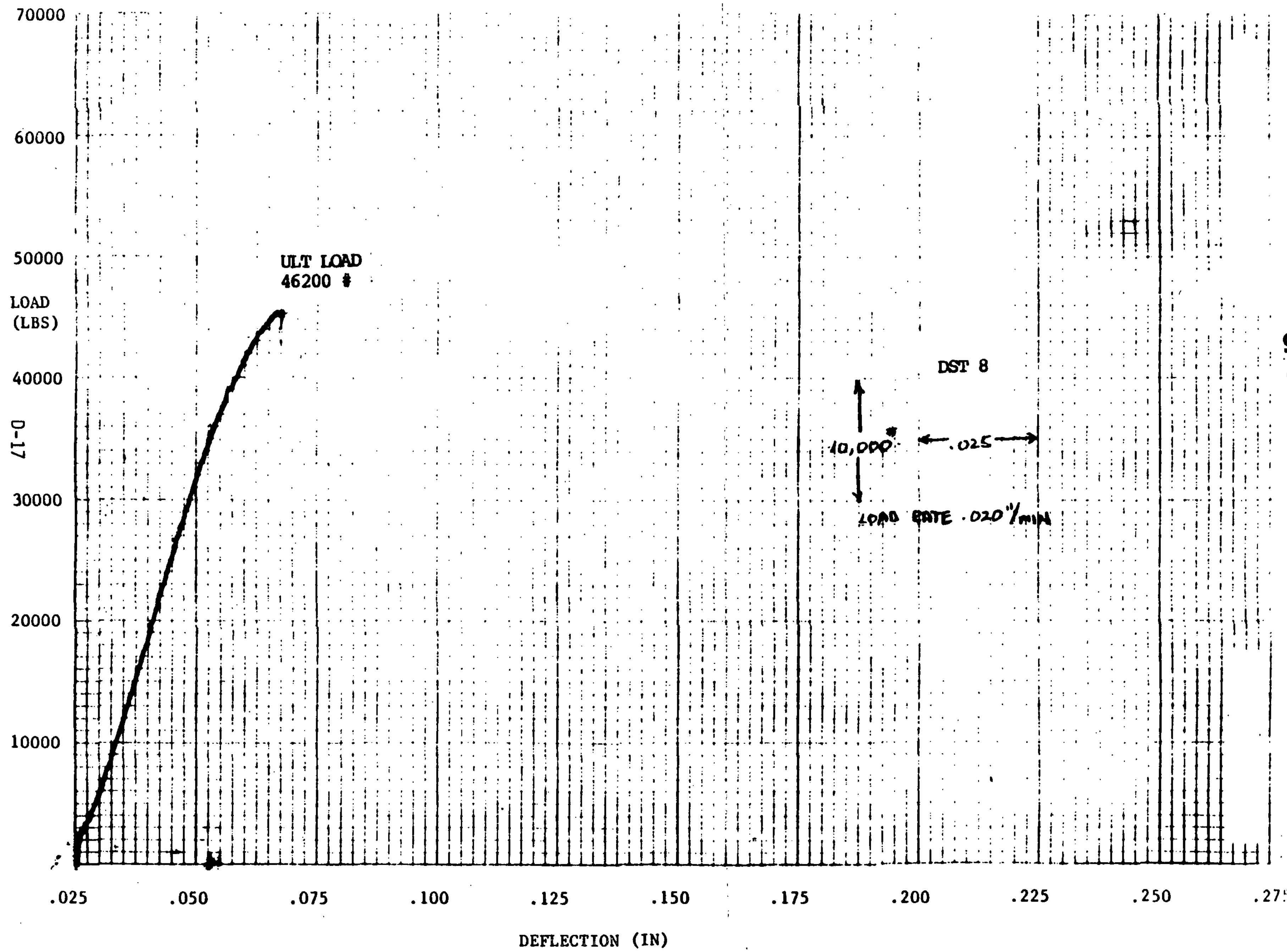
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DST 8
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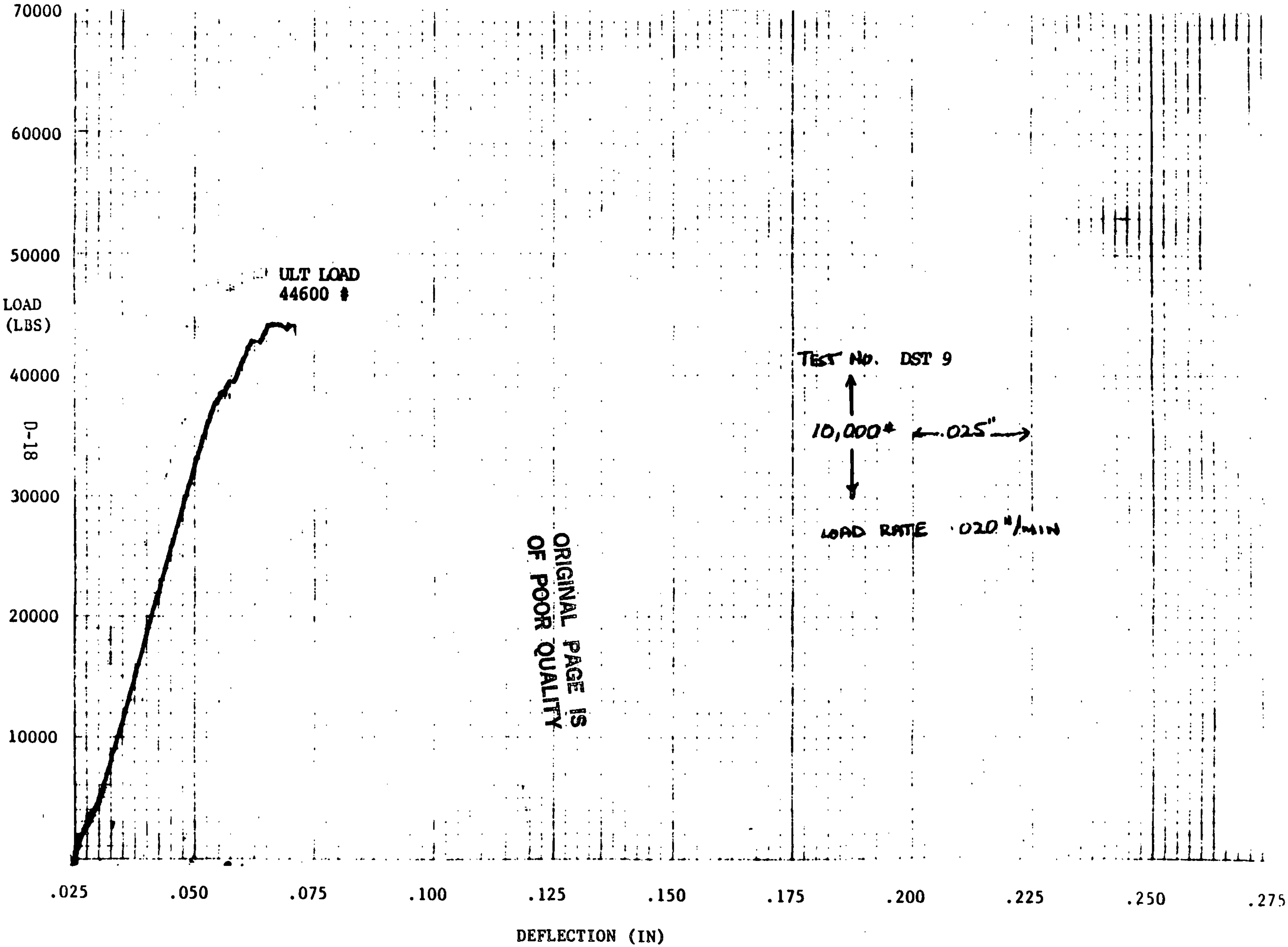
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10000
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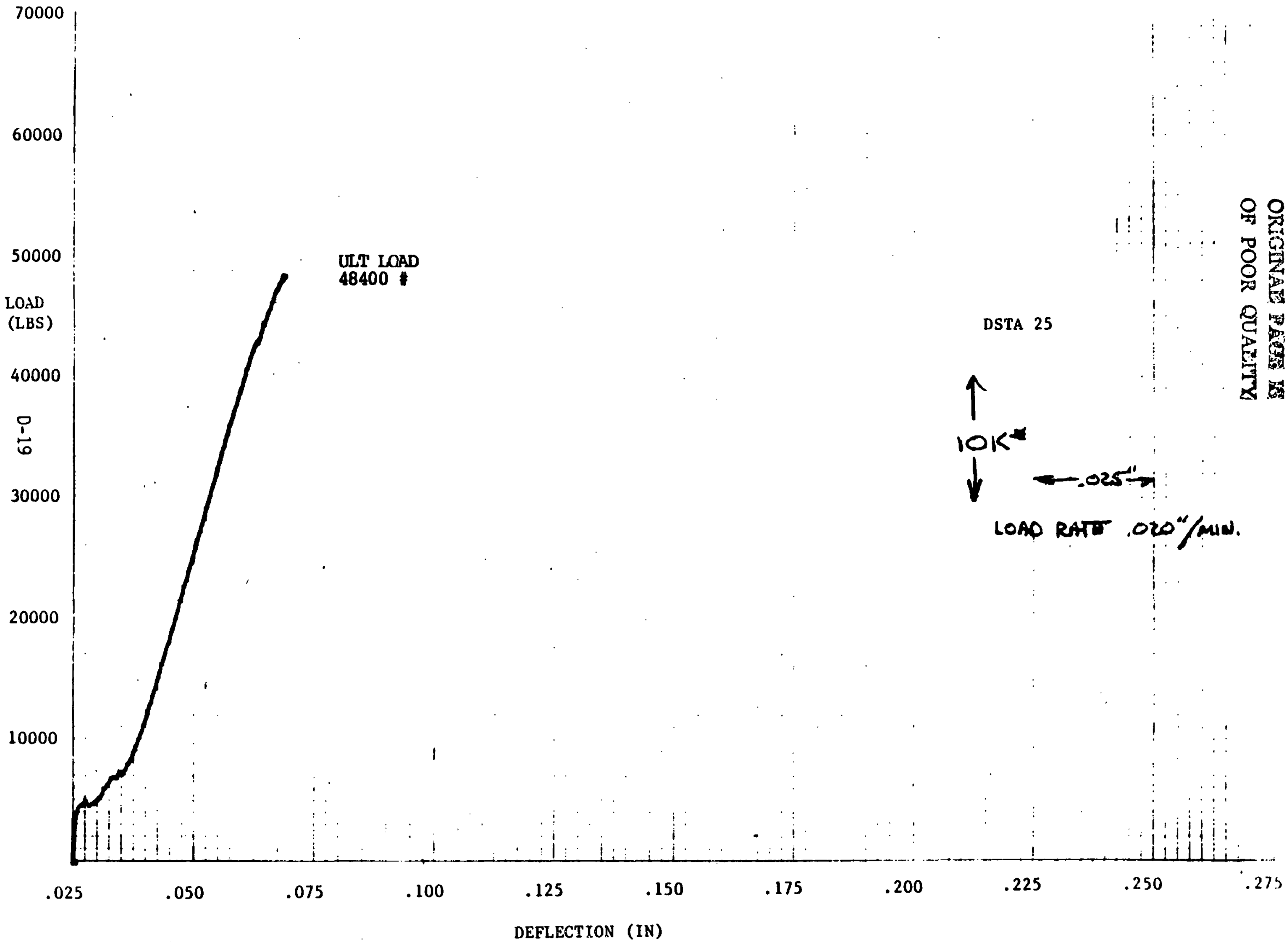
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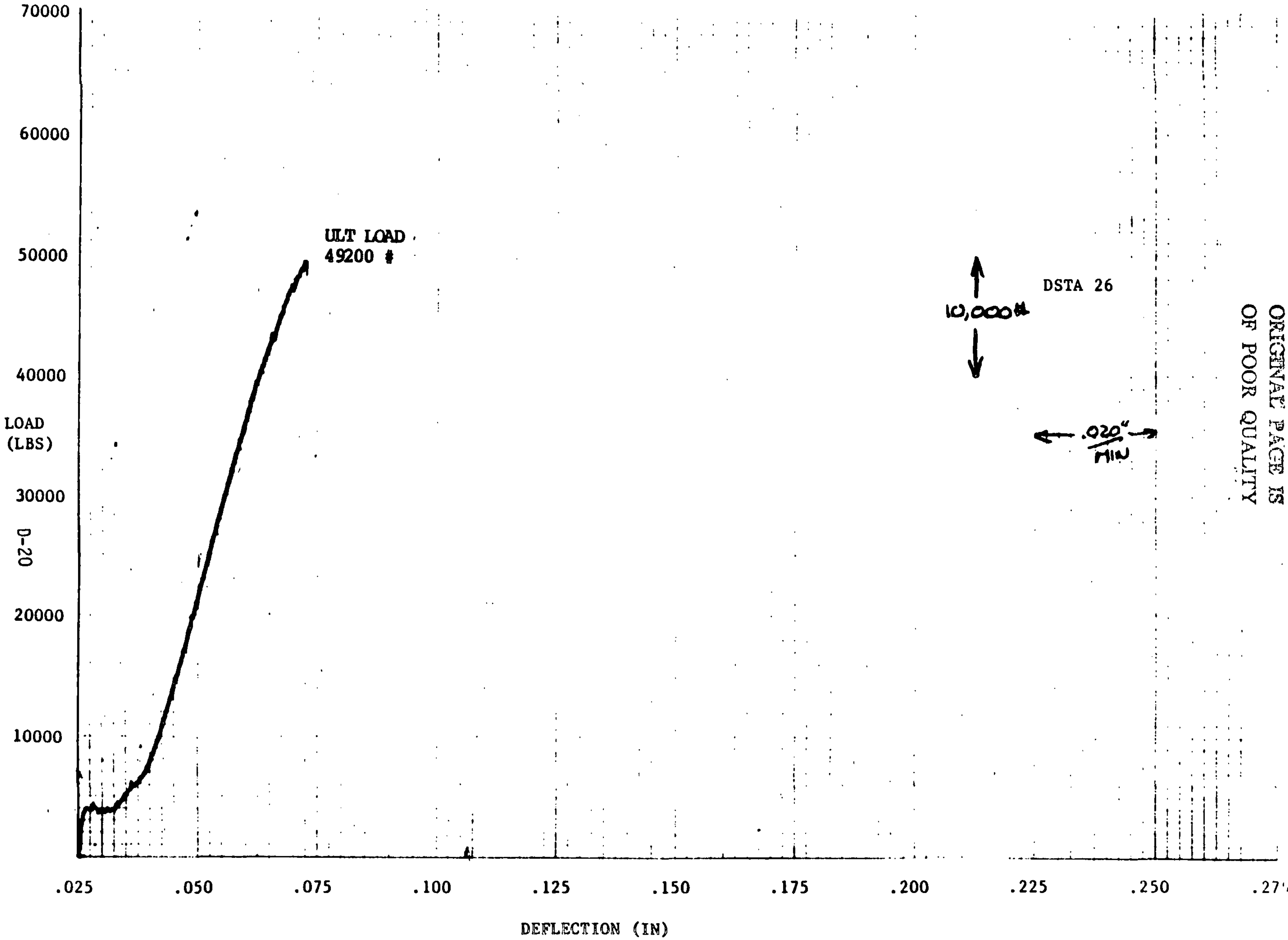
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20000
10000
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ULT LOAD
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DSTA 26
10,000#
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MIN
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.050
.075
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.125
.150
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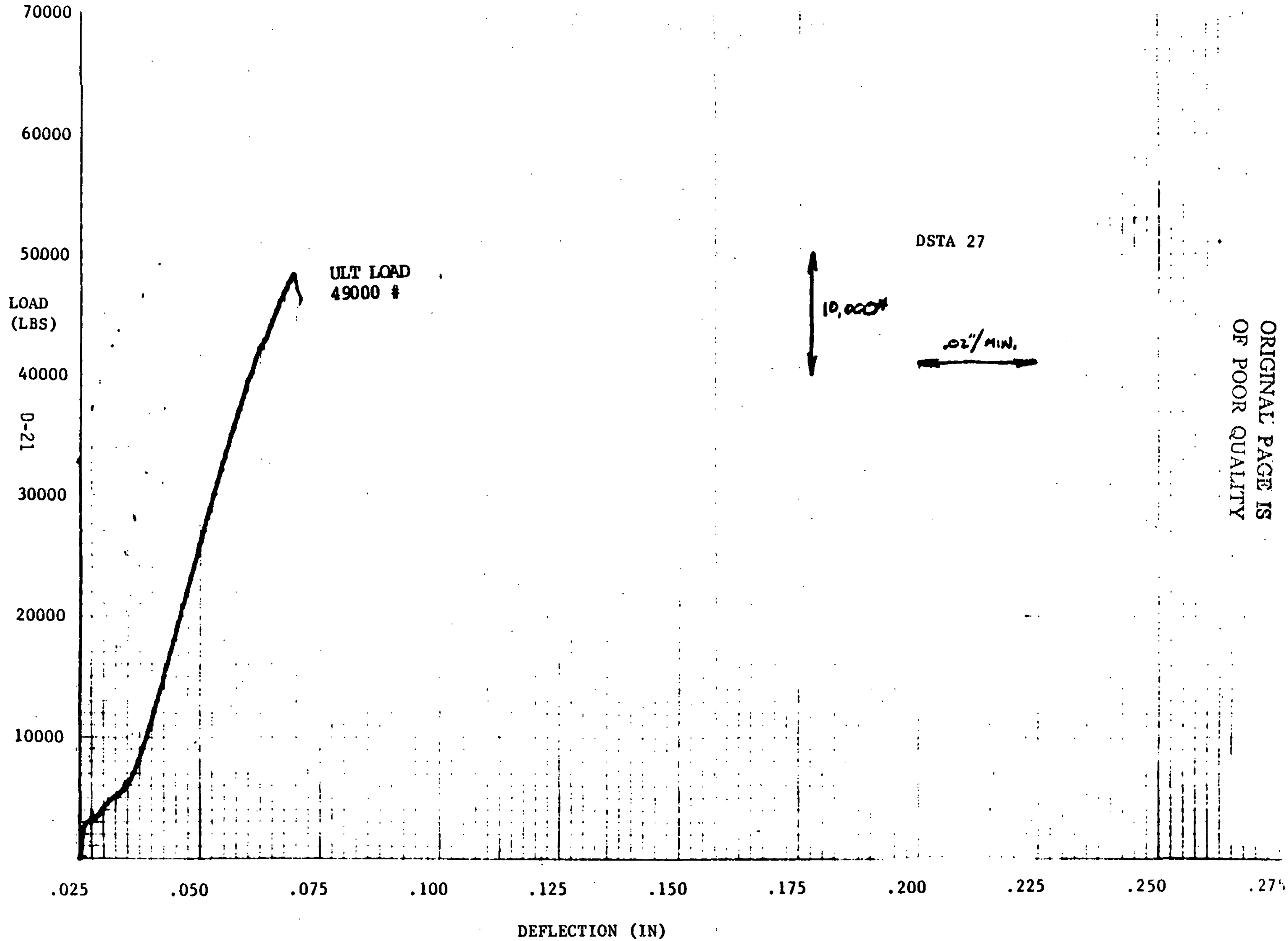
.200
.225
.250
.27
DEFLECTION (IN)



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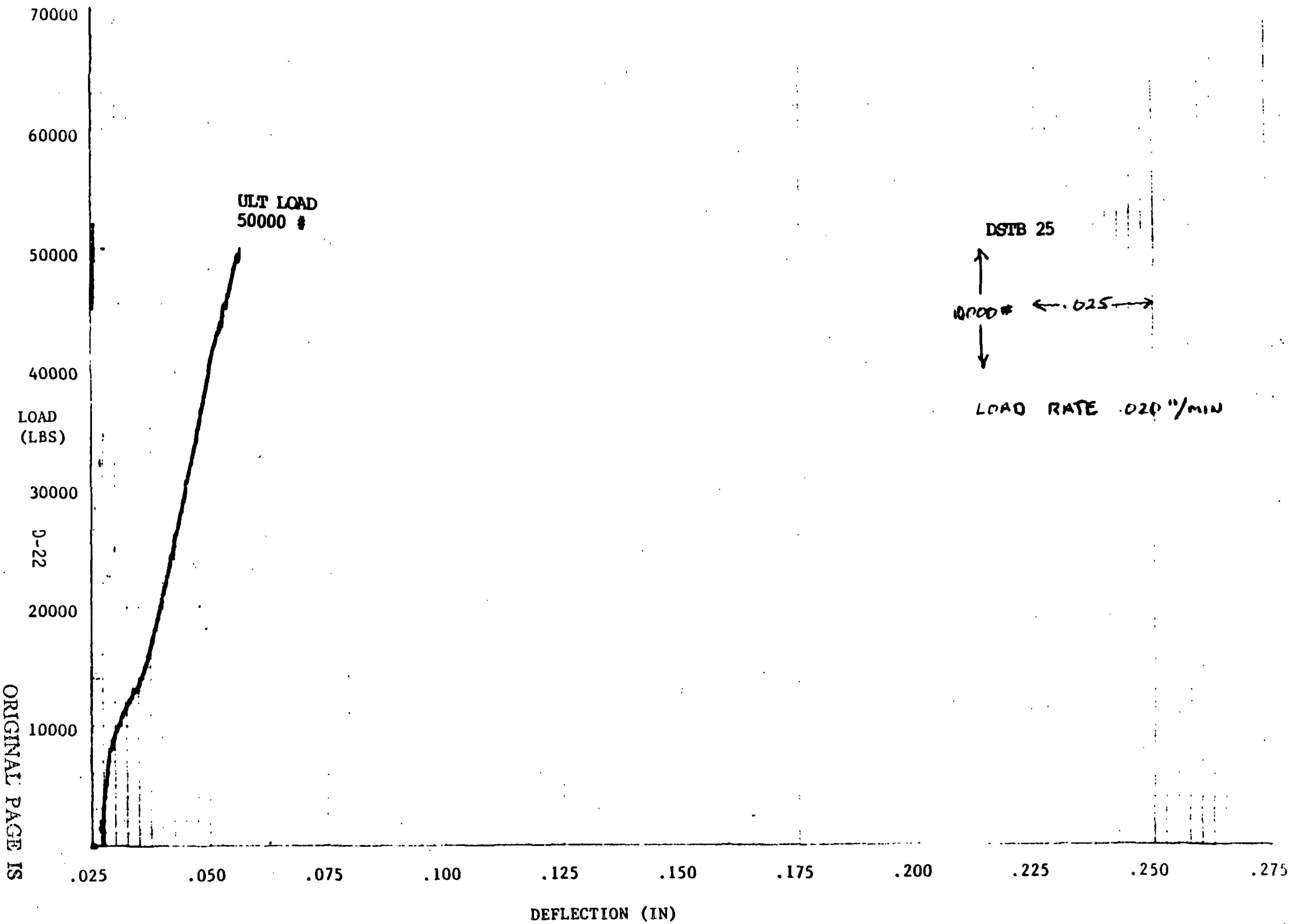

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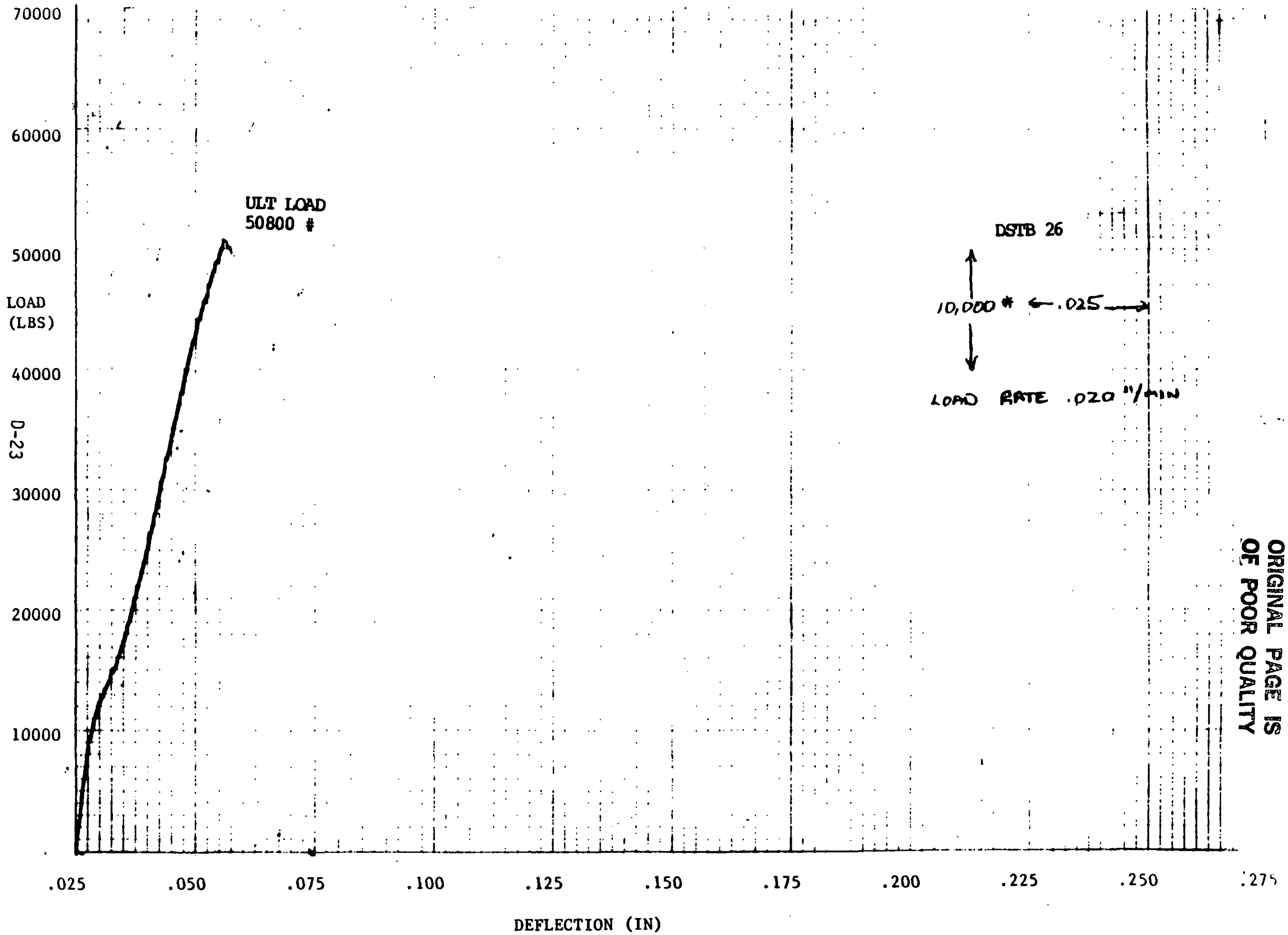

D-23

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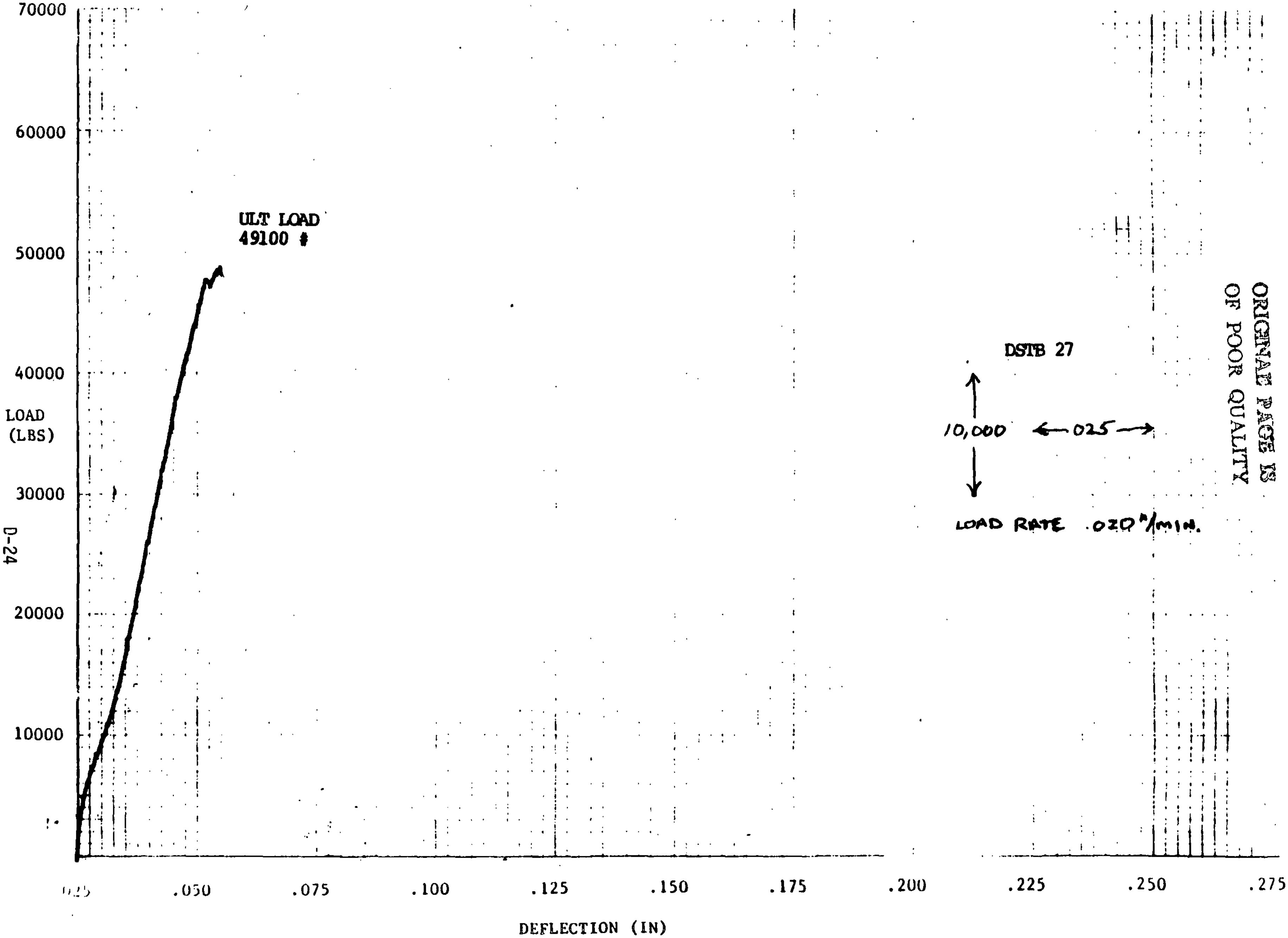
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50000
40000
30000
20000
10000
LOAD
(LBS)
ULT LOAD
49100 #
DSTB 27
10,000
.025
LOAD RATE .020"/MIN.
.025
.050
.075
.100
.125
.150
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.200
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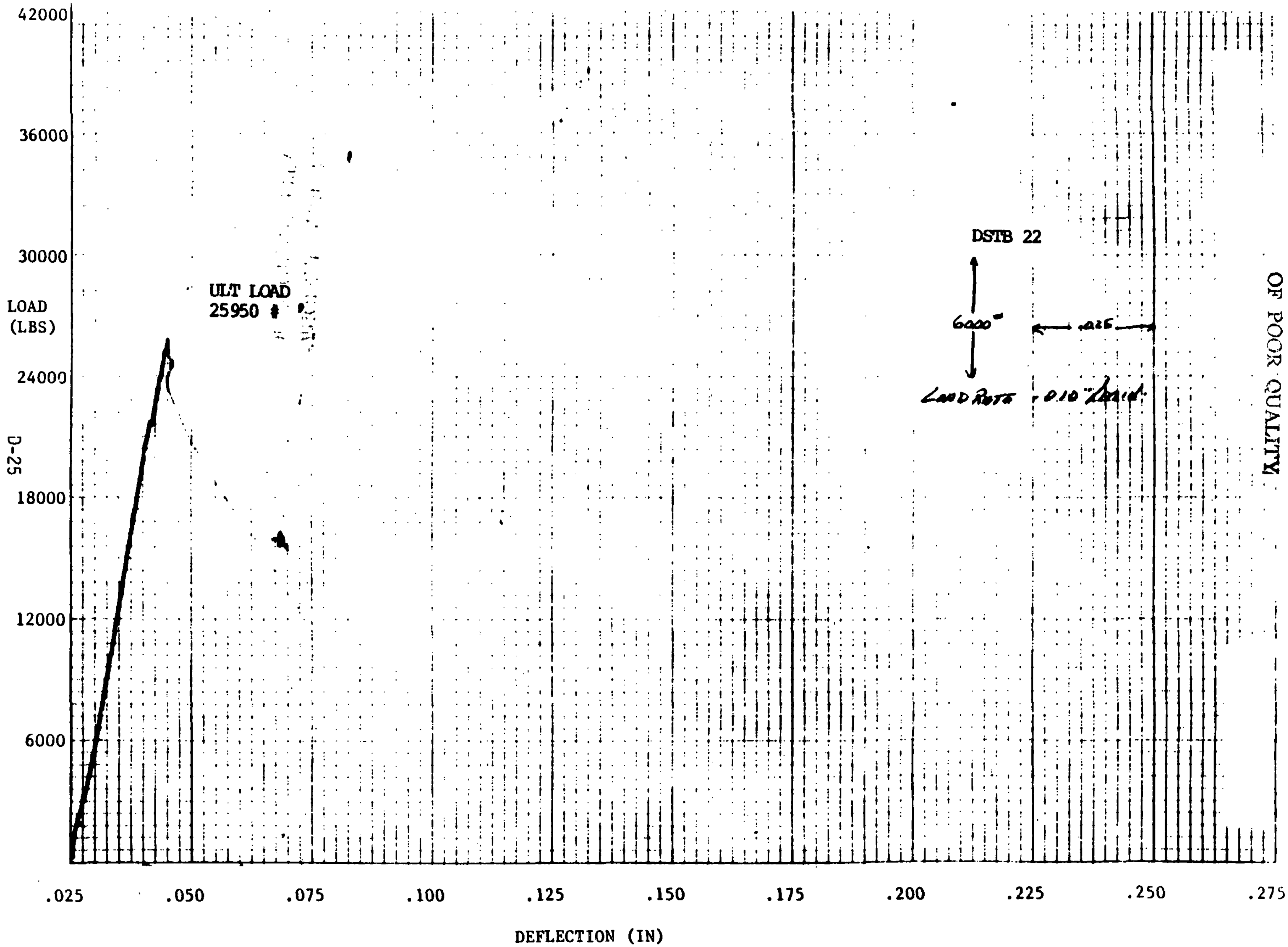
DEFLECTION (IN)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30000
24000
18000
12000
6000
LOAD (LBS)
ULT LOAD 25950 #
DSTB 22
6000#
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LOAD RATE .010"/MIN
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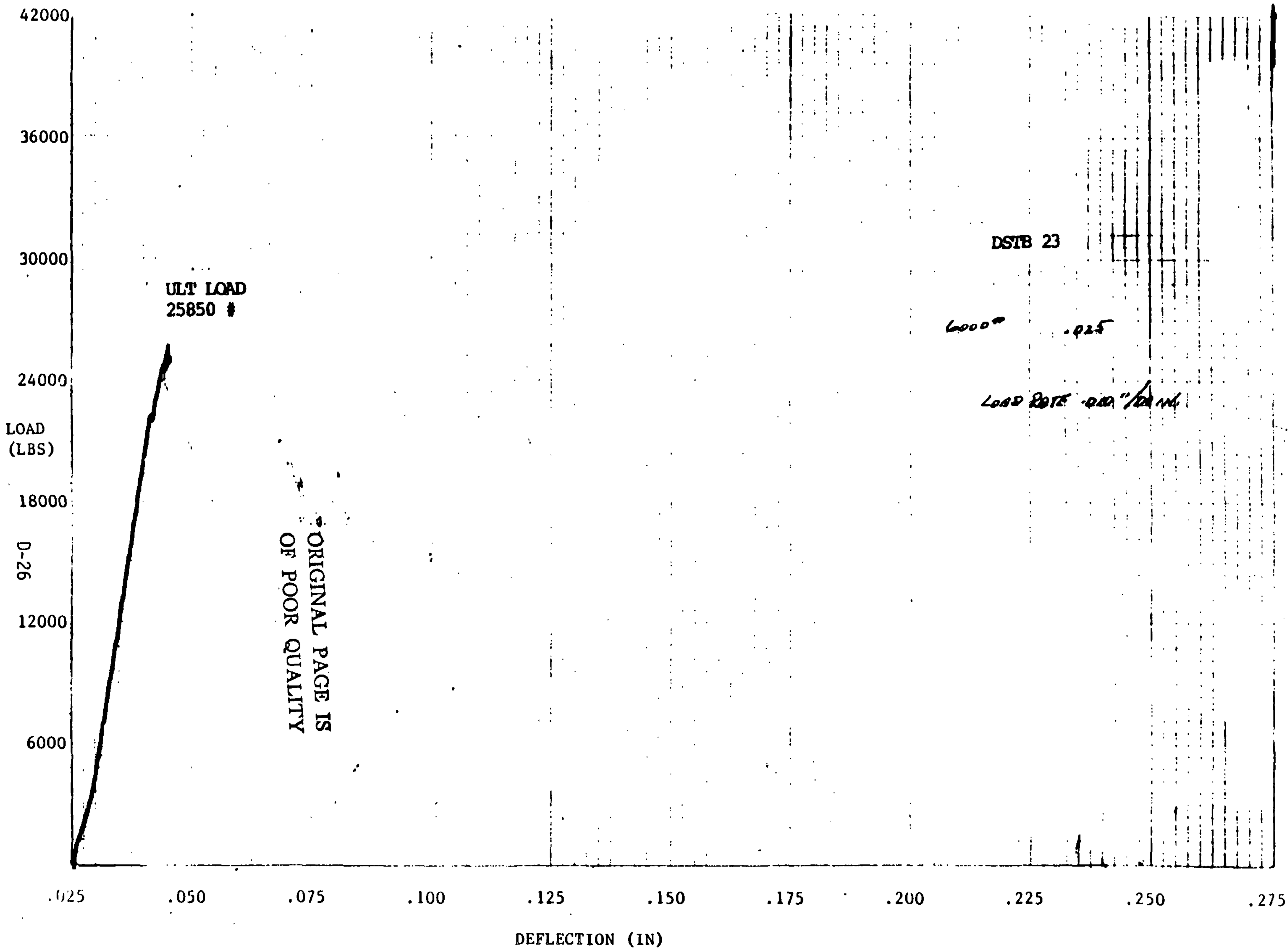
.275
DEFLECTION (IN)

D-25



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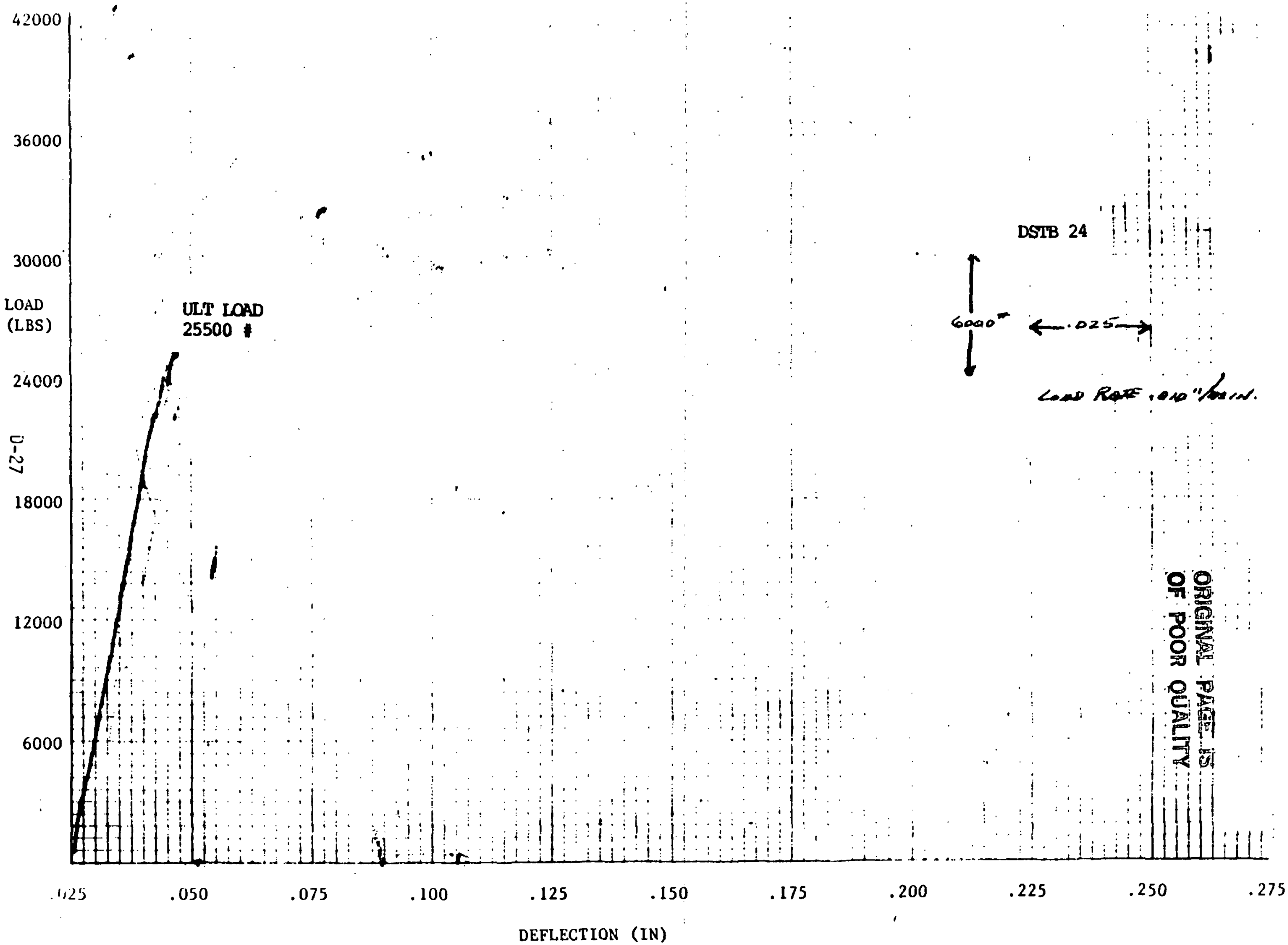

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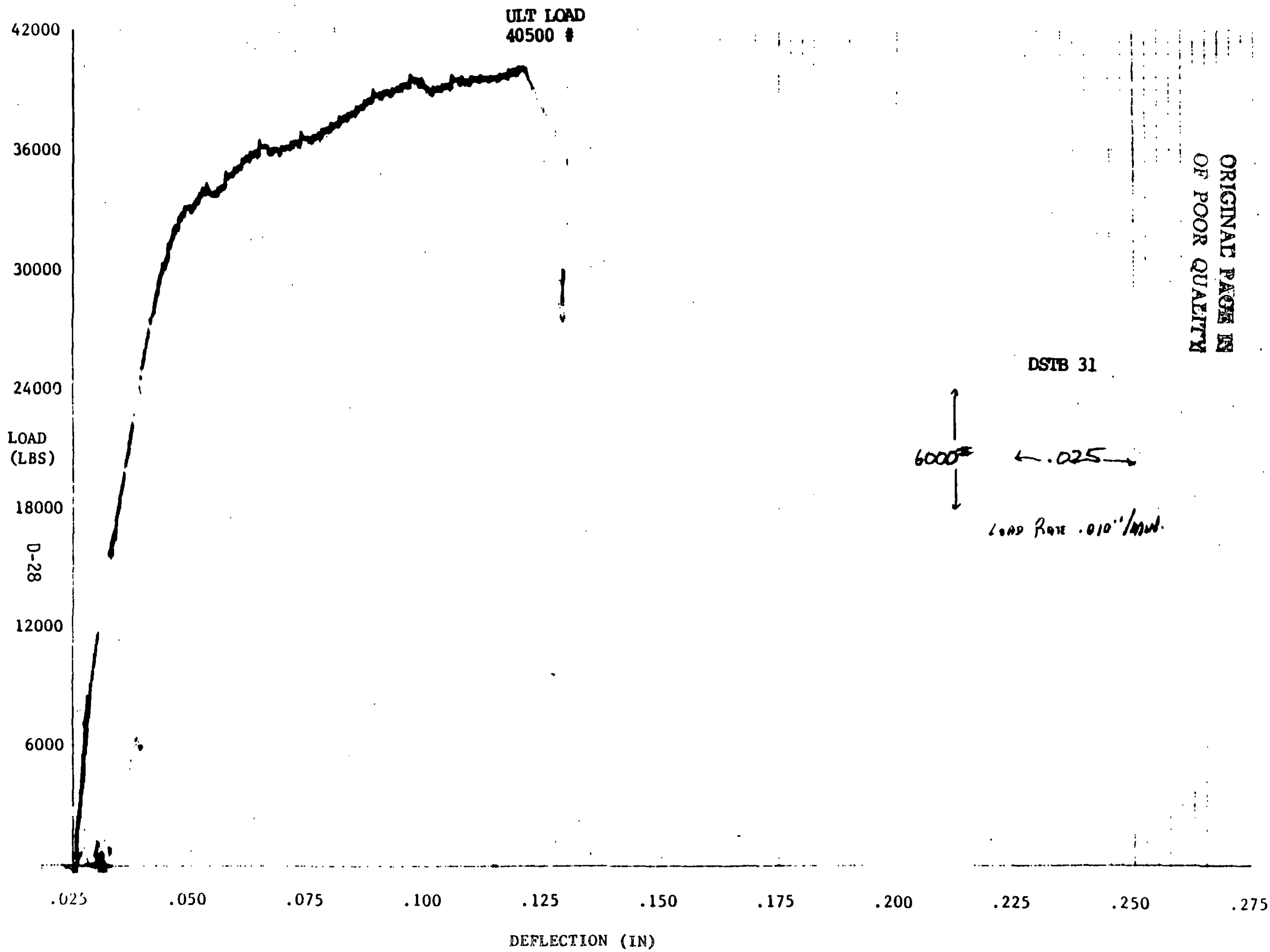

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36000
30000
24000
LOAD
(LBS)
18000
D-28
12000
6000
.025
.050
.075
.100
.125
.150
.175
.200
.225
.250
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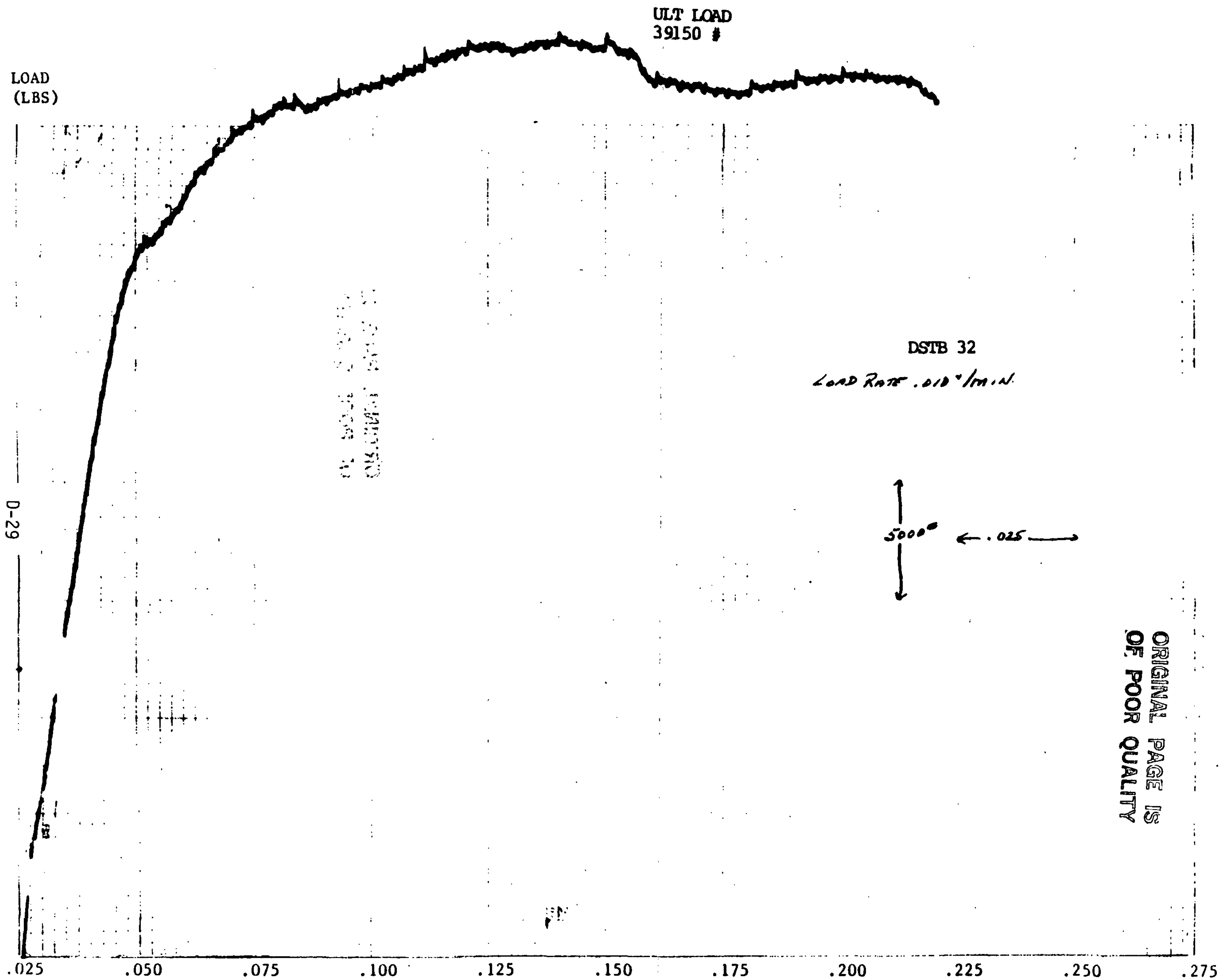

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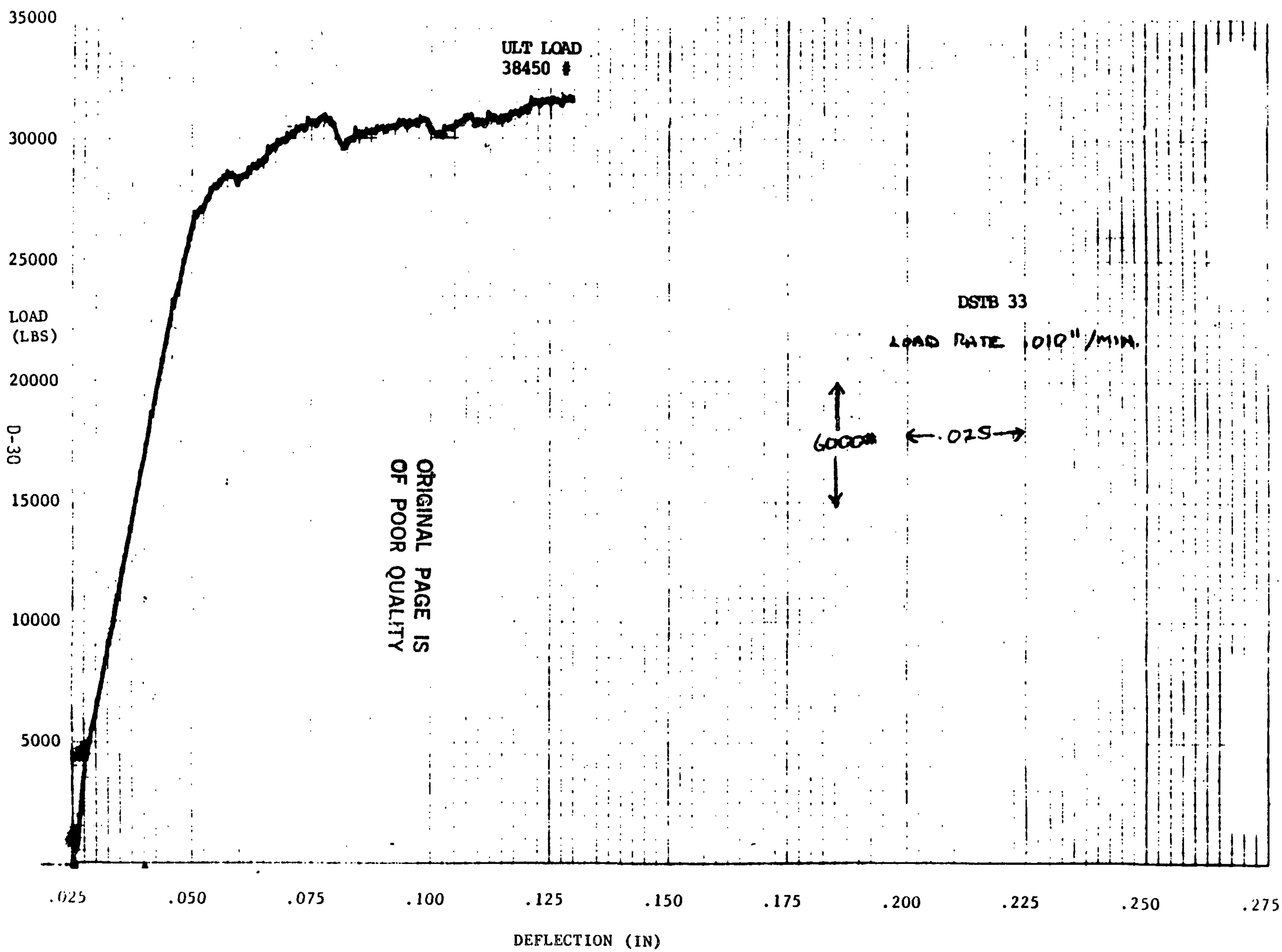
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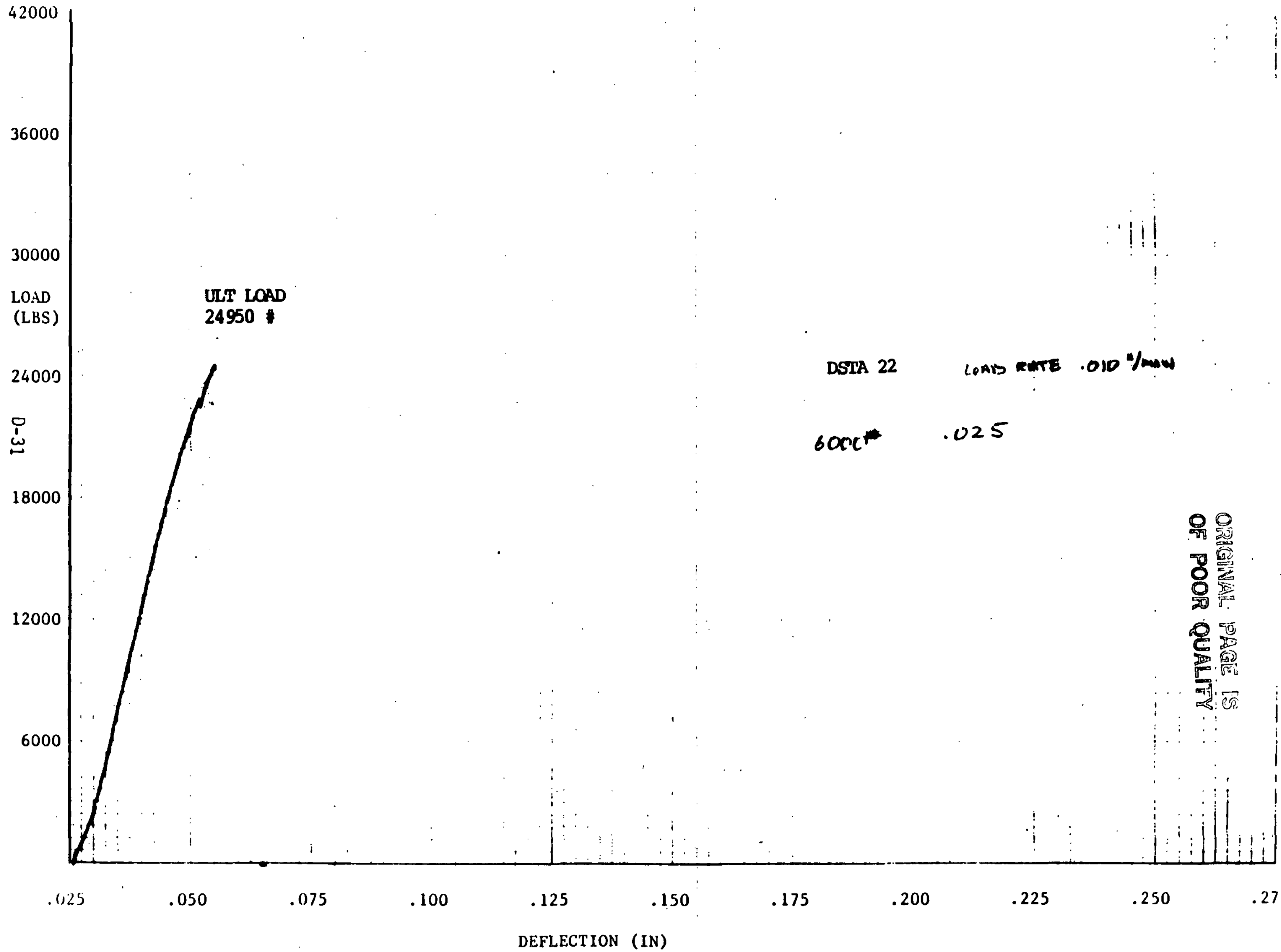
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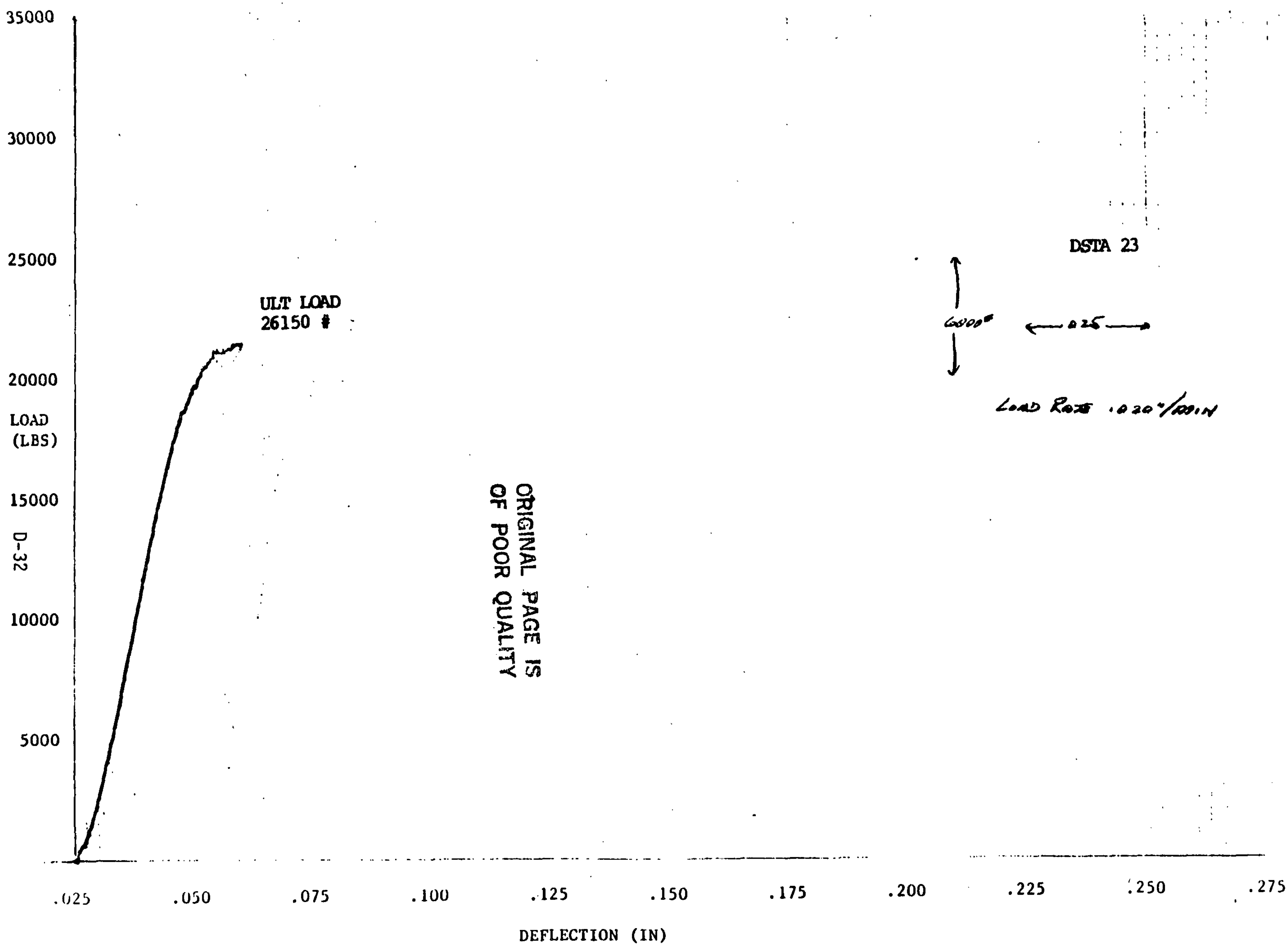
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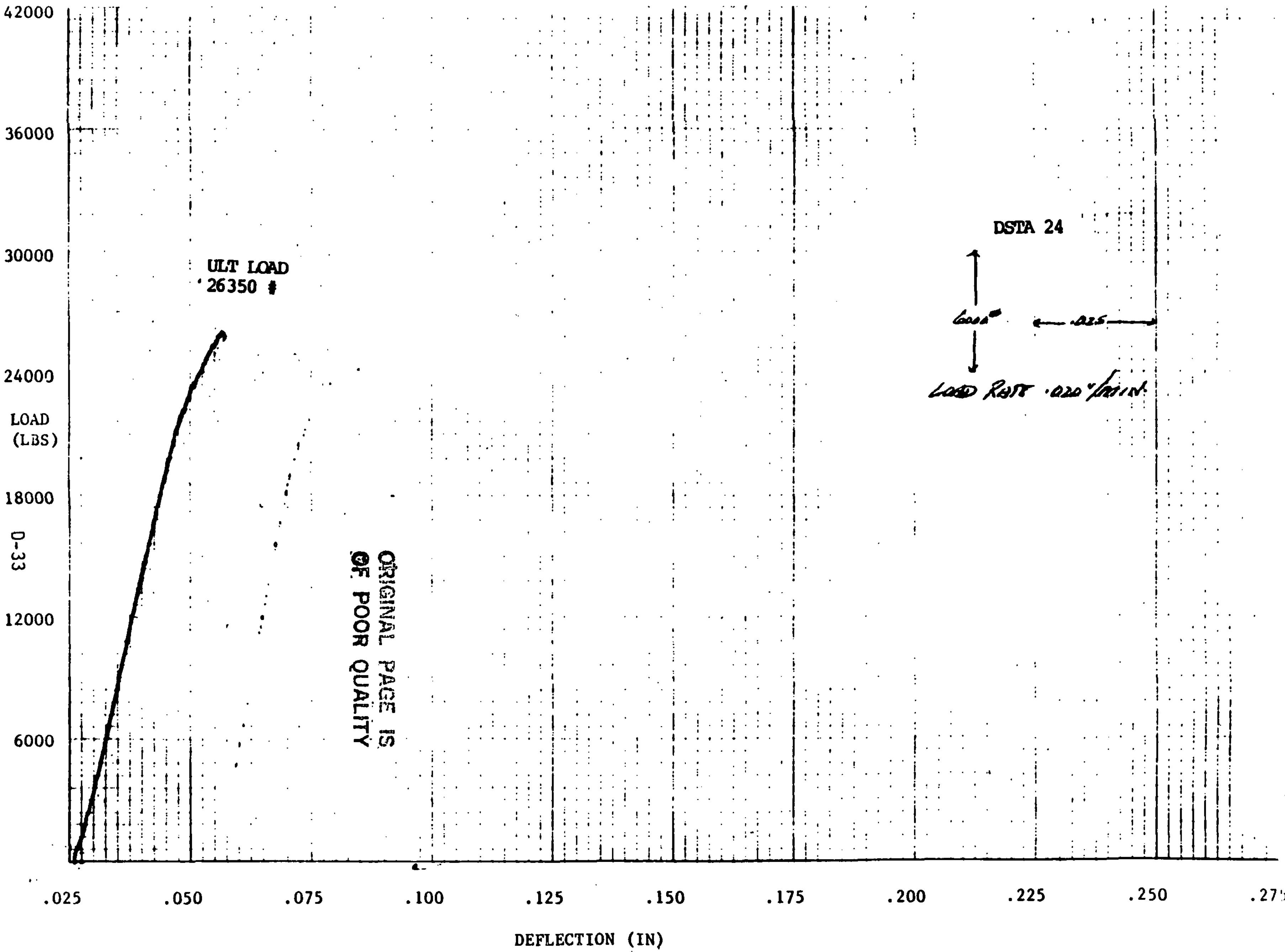

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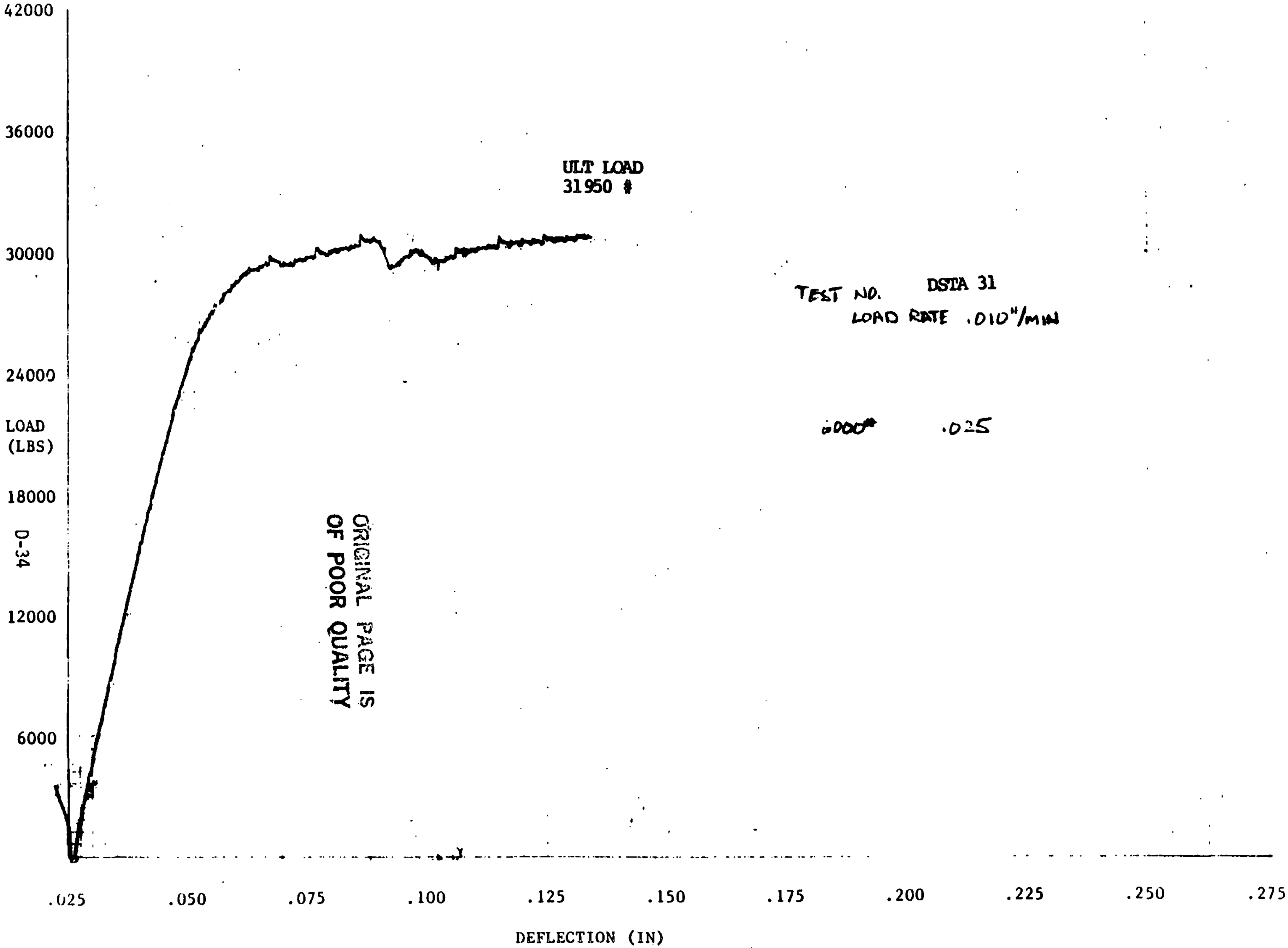
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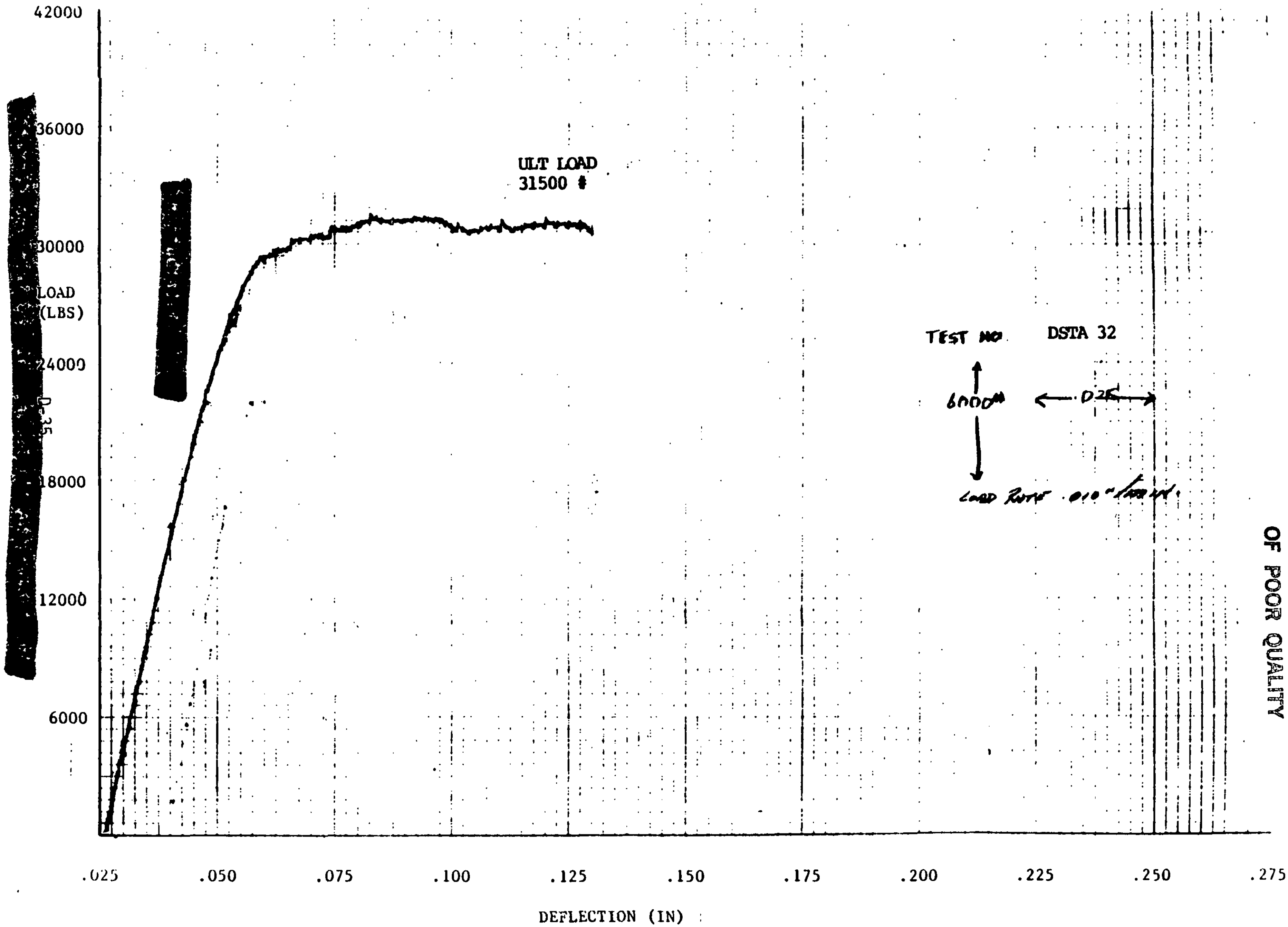

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15. Supplementary Notes

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16. Abstract

A program was conducted at Douglas Aircraft Company to develop the technology for critical structural joints for composite wing structure that meets all the design requirements of a 1990 commercial transport aircraft. This report summarizes the results of a comprehensive ancillary test program, consisting of single-bolt composite joint specimens tested in a variety of configurations. These tests were conducted to characterize the strength and load-deflection properties that are required for multirow joint analysis. The composite material was Toray 300 fiber and Ciba-Geigy 914 resin, in the form of 0.005 and 0.010-inch thick unidirectional tape. Tests were conducted in single and double shear for loaded and unloaded hole configurations under both tensile and compressive loading. Two different layup patterns were examined. All tests were conducted at room temperature. In addition, the results of NASA Standard Toughness Tests (NASA RP 1092) are reported, which were conducted for several material systems.

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