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IV

On the Scatter in Yield Strength and Residual Stresses in Steel Members

Sur la dispersion de la limite d'élasticité et des tensions résiduelles dans les profiles d'acier

Über die Streuung der Streckgrenze und der Eigenspannungen in Stahlprofilen

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INTRODUCTION

In determining the structural behavior of steel members subjected to compressive loads, the algebraic difference between the actual yield strength of each longitudinal fiber of the cross section and the residual stress existing in those fibers is of the utmost significance. Thus, it is important to know the magnitude and distribution of these characteristics as well as their variation inside a member and between different members.

This discussion summarizes some results obtained in various phases of a continuing study of residual stresses and column strength of rolled and welded steel shapes carried out at Lehigh University during the past twenty years. The different aspects covered in the paper include: (1) statistical variation of yield strength as obtained in routine mill tests; (2) comparison between results for yield strength obtained by various testing techniques; (3) variation of longitudinal fiber yield strength over the cross section of plates and shapes; (4) influence of strain rate upon the yield strength obtained in tension specimen tests; (5) variation or scatter of residual stress distributions as measured in members of same size and manufacturing conditions; and (6) scatter of residual stress distributions measured at various sections along a particular member.

MECHANICAL PROPERTIES

A graphical representation of the typical stress-strain curve for structural carbon steel, and the definitions used, are given in Fig. 1. The region corresponding to small strains is of primary interest here, that is, the elastic region and the yield plateau. In particular, the various yield strength levels as defined in different ways will be discussed in some detail.

Mill test results

The tension specimen test normally applied as a routine acceptance test for structural steels in U.S. mills is based upon the upper yield strength level, or, where an upper yield does not exist, upon the stress corresponding to a particular strain offset. The testing is performed in accordance with the techniques specified by the ASTM Standards. [1] The speed of testing is specified for the range from half the nominal yield strength through yield strength not to exceed 1/16 inch per minute per inch of gage length or, alternatively, not to exceed a stress rate of 100 ksi per minute. [1]

Figure 2 summarizes the results of routine mill tests carried out on 3,124 specimens of low-carbon steel (ASTM A7). [2] The average yield strength is 39.4 ksi for the whole sample, as compared to the minimum specified value of 33 ksi. The distribution is skew since material that does not fulfill the specified strength of 33 ksi generally is detected in routine control tests and not included in the sample. The yield strength of all specimens varied from a low of 31.1 ksi up to a highest value of 56.6 ksi. The shape of the distribution curve in Fig. 2 is similar to those of frequency distribution curves obtained in other investigations of structural steel. [2, 3, 4]

While the upper yield strength is used in specifying the strength of the steel in the U.S., the upper yield strength is of small or no significance in determining the yield behavior of a structural steel member. To use a statistical term, the validity of the upper yield strength concept with reference to structural behavior is small. This is well-known for members that are strained in a non-homogeneous manner (for instance, bending), but the upper yield strength is insignificant also for most homogeneously strained structural members. This is because practical members contain residual stresses which cause non-homogeneous deformations for homogeneous external loading conditions. Thus, the upper yield point is normally found only in a coupon as used in a tension or compression specimen test, that is, in a test essentially on a fiber of the material. The principal difference between the load-deformation relationships of a member loaded in pure tension or compression, and stress-strain curves with or without an upper yield level, is shown in Fig. 3. While the upper yield strength for a fiber is assumed 10 per cent higher than the lower yield strength level, the two load-deformation curves for the cross section differ only by the order of one per cent.

In characterizing a steel and for material standards, the present mill testing procedures based upon the upper yield strength concept appears satisfactory, since in this connection the strength value is relative. For discussions of the safety of structures, however, the difference between various testing techniques, and the manner in which a reported yield strength value has been obtained, may be extremely important and must be considered in the determination of the real safety of structures.

Effect of strain rate on yield strength

A second factor which influences the results obtained in a tension test is the strain rate. Investigations have shown that even a "very slow" laboratory strain rate used in testing tension specimens (a strain rate of 1 microinch per inch per inch second) may raise the apparent yield strength level by as much as 5 per cent. [5]

The effect of strain rate on the yield strength level in a typical tension specimen test is shown in Fig. 4. [6] The results are given in terms of the dynamic yield strength corresponding to a certain strain rate divided by the static yield strength. Tests were made for three groups of structural steel: ASTM A36 (Fig. 4a), A441 (Fig. 4b), and A514 steel (Fig. 4c), with specified yield strengths of 36, 50, and 100 ksi, respectively. Generally, the greater the strain rate, the higher is the apparent (dynamic) yield strength. The curves of best fit to the data points in Fig. 4 were obtained by regression analysis. The boundary curves on each side of the central curves represent the 95 per cent confidence limits of σ_{yd}/σ_{ys}. The range of variation between these two limits decreases with increasing nominal strength; for instance, the variation at a strain rate of 1,000 µin/in-sec is 9.0 per cent for A36, 7.0 per cent for A441, and 2.5 per cent for A514 steel. For strain rates normally used in the plastic range of a routine mill test, that is, of the order of 1,000 µin/in-sec, the apparent (dynamic) yield strength may be as much as 15 per cent above the "static" value.

Obtaining the static yield strength

The variation in the apparent yield strength as obtained by various testing procedures, and influenced by the different interpretation of results (upper or lower yield strength) and varying testing rate has led to the suggestion of a "static yield strength" testing procedure. The procedure simply prescribes one or more "stops" of the testing machine in the plastic range, and the stress level is recorded at the resulting zero strain. The static value at a strain of 0.5 per cent is usually recorded as the "static yield strength". See Fig. 1. The duration of the "stop" normally is from 3 to 4 minutes; during this time, the stress decreases gradually to the static value. ("Stops" in the elastic range normally give no appreciable decrease in load, which indicates that the static level is not seriously affected by inevitable mechanical inaccuracies in the testing machine.) Precautions must be taken so that unloading does not occur during testing, in particular, for hydraulic machines.

This procedure gives results which are independent of testing machine strain rate, and the "human factor". In addition, the results are relatively insensitive to inaccuracies in the alignment of the test specimen and to the effect of residual stresses which may remain in the test specimen. The method is applicable to materials with a definite yield plateau, such as structural carbon steel, as well as materials with a gradual transition from the elastic to the plastic range. Experience at Lehigh University over several years of testing has shown that this test method gives consistent and reliable results, applicable to the true yielding behavior of statically loaded structures.

Comparison between various testing techniques

A comparison between the results obtained in mill tests and in "static" tests is given in Fig. 5. [7] The different tests were performed on material from the same sample, representing steel supplied by two different companies in the form of hot-rolled H-shapes of 24 various sizes ranging from a 6WF15.5 to a 14WF426. The mill tests and the simulated mill test made on specimens from the web give average yield strength values of 42.3 and 40.6 ksi, respectively. The "static" values are 33.5 ksi for the weighted average of flange and web specimens (weighted with respect to sectional area of flange and web to furnish a yield strength value representative of the cross section of the shape) and 33.9 ksi for the stub column tests (compression test of complete cross section, tested for a member sufficiently long to retain the original residual stresses in the central portion of the member, but short enough to prevent column buckling). [2] It is of interest to note that the average mill test value for yield strength is almost 25 per cent higher than the average static yield strength obtained on the full-size member (stub column). On the other hand, the average static yield strength obtained from tension tests on flange and web specimens is very close to that of the stub column tests. The results seem to indicate that the geometrical influence of the specimen size on the static yield strength is small; also, from these results there is no apparent difference between the static yield strength in tension and compression.

Variation of yield strength over cross section

It was noted in the discussion above that representative yield strength characteristics were obtained when averaging the results of specimens from flange and web of H-shapes according to their respective areas in the cross section. The longitudinal fiber strength differs quite substantially between the flange and web elements, both with respect to yield strength (static as well as dynamic) and ultimate strength. Figure 6 gives a summary derived from previous results for flange and web specimens cut from a sample of 34 H-shapes of various sizes. [7] The average static yield strength is 33.0 ksi for the flange and 34.8 ksi for the web material, that is, a difference of 5 per cent. The difference in individual shapes is as high as 30 per cent. Only in two out of the total 34 shapes was the recorded yield strength of the flange higher than that of the web of the same shape. The difference in strength may be attributed partly to the position of the flange and web components with respect to the cross section of the ingot and the heat in the rolling process, and to the cooling behavior of the rolled member. The thinner web normally will cool faster than the flanges, resulting in a finer grain size and a higher yield strength of the web material.

The strength varies also within the individual components of the cross section. Figure 7 gives the variation recorded for yield strength obtained for 20 specimens taken from various positions in the flange of an H-shape type HE 200 B of a steel related to St 37. [8] The recorded yield strength varies between 32.8 and 41.9 ksi within the flange, that is, a variation of almost 30 per cent. Although the thickness of the flange is only 0.59 in (15 mm), the variation across it is quite significant.

Somewhat similar results were obtained in an investigation of the yield strength of tension test specimens cut from two heavy plates of ASTM A36 steel. [9] The plates studied were of dimensions 16x2 in and 24x3 1/2 in. Specimens were cut from two positions across the width of the plates, and five or seven specimens (for the 16x2 and 24x3 1/2 plates, respectively) were taken across the thickness of the plate at each position. Results for static yield strength of these tests are summarized in Fig. 8. The recorded yield strength varies between 30.7 and 34.8 ksi, for the 16x2 in plate, and between 29.5 and 33.7 ksi for the 24x3 1/2 in plate. The highest values were obtained in surface specimens, the lowest in interior specimens. This fact is consistent with the cooling conditions in the rolling process. The average static yield strength is 32.5 and 31.0 ksi for the 16x2 and 24x3 1/2 plates, respectively. These values may be compared to the reported mill test values for yield strength, 48.0 and 43.0 ksi, which are 48 and 39 per cent higher, respectively, than the average static values. The behavior of surface and interior specimens differed also in a more important manner in that the surface specimens showed a marked yield plateau and onset of strain hardening, while all the interior specimens had a gradual transition from the elastic to the strain hardening range. [9]

In conclusion, several tests indicate that the yield strength may vary over the cross section of a structural member. The variation may be quite significant, also when compared to the total variation between several different structural members manufactured from separate heats and at different mills. However, the variation is not solely statistical in nature, but to a certain extent predictable from the manufacturing conditions. The variation is of considerable importance in determining the strength of structural members; in particular, the variation must be considered when a small number of representative specimens are to be taken from the cross section of a member.

RESIDUAL STRESSES

Residual stresses exist in all practical structural members. While it would be possible theoretically to remove residual stresses from a member, for instance, by stress relieving, this is normally not practical or economical.

The residual stresses will vary inside a particular member; they will be in equilibrium. In addition, the residual stress distribution will vary from member to member of the same geometry and the same manufacturing and fabrication conditions, as well as between members of different geometry and manufacture.

A summary of all residual stress measurements performed would show a tremendous variation. A statistical treatment of the complete data from all measurements, irrespective of causes, is possible and straight-forward, however, this approach would be rather ineffective since most of the variation in results may be attributed to factors which could be controlled in the design or fabrication process. Thus, the studies of residual stresses at Lehigh University have been, in general, deterministic rather than statistical in nature. The major effort has been devoted to a study of the effect of various factors affecting the magnitude and distribution of residual stresses. Additional investigations were carried out to study the variation or scatter of residual stress distributions as measured in different members of the same geometry and manufacturing conditions and also the scatter of residual stress distributions as measured at various sections of a particular member.

The most important factors in the formation of residual stresses are the manufacturing and fabrication processes used, and the size and geometry of the structural member. [10] Any type of thermal or mechanical procedure used in the manufacture and fabrication, will affect, in general, the final residual stress distribution in the structural member. Thus, a hot-rolled shape normally will show a residual stress distribution quite different from that encountered in a welded shape of similar size. Residual stresses measured in various types of structural members have been discussed extensively in several papers. [2, 5, 7 through 17]

The variation or scatter in the residual stress distribution as measured at various positions along different members of same geometry and manufacturing conditions is exemplified in Fig. 9 for a hot-rolled H-shape, [11] in Fig. 10 for a welded box-shape, [13] and in Fig. 11 for a welded H-shape fabricated from flame-cut plates of A572(50) steel (σ_y = 50 ksi). [17] Figure 12 summarizes in histograms, the deviation between individually measured results in the component plates of the welded box-shape 10□65, and the average for the two different component plates, 10x1/2 in and 9x1/2 in, of all ten sections investigated.

In conclusion, the experimental studies summarized in Figs. 9 through 12 indicate that the variation or scatter in the residual stress distribution along a particular member or between different members of the same geometry and manufacturing conditions is reasonably small, that is, as long as the factors influencing the formation of residual stresses are uniform. On the other hand, it is obvious that discontinuous manufacturing or fabrication conditions, such as intermittent welding or local cold-straightening will lead to a wider scatter in residual stress characteristics.

From the above, it follows that residual stresses in a particular member may be predicted from information obtained on a similar member of the same geometry, provided the manufacturing and fabrication conditions are the same. An idea of the possible variation due to uncontrolled factors could be obtained from the results given in Figs. 9 through 12. The prediction might be obtained also from a theoretical study of the thermal-mechanical history during the manufacture and fabrication. [15]

The magnitude of residual stresses will affect the structural behavior of columns, and the important variable is the ratio between the residual stress and the static yield strength. For columns of hot-rolled H-shapes, the residual stresses at the flange tips are of primary interest. [2] Figure 13 gives an example of results obtained for 26 rolled wide-flange H-shapes; the sample is approximately the same as that of Fig. 6.

CONCLUSIONS

Various aspects on the scatter of yield strength and residual stresses in structural steel members have been covered in the paper. From the discussion, it is concluded that:

1. There is a significant difference between the apparent yield strength as obtained by various testing procedures. The variation is due to different interpretations of results (upper or lower yield stress), testing rate, and size and location of test specimen relative to the full-size member (that is, small specimen from a particular location of a member, or a test on a full-size member). Results obtained by the routine ASTM acceptance test normally used as the mill test in the United States may be 30% higher than the lower yield strength obtained in a very slow ("static") test.

2. Tests have shown that there is a functional relationship between the apparent yield strength level and the strain rate; the greater the strain rate, the higher the yield strength. The increase in the yield strength above the "static" value may be as much as 15 per cent for strain rates normally used in practice.

3. Based upon the variations in results obtained in different test procedures and at various strain rates, a "static" testing procedure was suggested to furnish test results which are independent of testing machine and strain rate. The procedure simply prescribes one or more "stops" of the testing machine in the plastic range, and the stress level is recorded at the resulting zero strain ("static yield strength"). Experience over several years of testing has shown that this test method gives consistent and reliable results, applicable to the true yield behavior of statically loaded structures.

4. There is a difference in yield strength between the various elements of a rolled shape, the thinner web normally being stronger than the flanges (the difference may be 5 to 20 per cent). There is also a variation in yield strength over the cross section of the elements of a structural member, in particular, for thick component plates. The variation in yield strength over the thickness of two thick plates (2 and 3-1/2 inches thick) was measured to be 10-15 per cent for A36 steel (σ_y = 36 ksi). In addition, the appearance of the stress-strain relationship was somewhat different between specimens taken from the surface or from the interior of the plates. Generally, the interior specimens showed no marked plastic plateau but rather a gradual transition from the elastic to the strain-hardening range. The surface specimens, on the other hand, followed the usual behavior with a separated elastic range, a yield plateau, and a

strain-hardening range. This variation must be considered when a small number of representative tension specimens are to be taken from a structural member.

5. The scatter of residual stress distributions measured at various sections along the length of a particular member appears to be small, as long as the factors influencing the formation of residual stresses are uniform. Thus, thermal residual stresses in hot-rolled plates and shapes or residual stresses due to continuous welding are more or less constant along the member. Measured variations in such members are of the same order of magnitude as the accuracy of the measurements. On the other hand, it is obvious that discontinuous manufacturing or fabrication conditions, such as intermittent welding or local cold-straightening will lead to a wider scatter in residual stress characteristics.

6. The variation between residual stress distributions measured in various members of the same size and fabrication conditions is reasonably small. Repeated measurements on different members, both hot-rolled and welded, have resulted in consistent results, the deviation between results normally being less than 5 ksi. Thus, residual stresses in a particular member can be predicted from information obtained on a similar member, provided the manufacturing and fabrication conditions are the same.

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REFERENCES

1. American Society for Testing and Materials
ASTM STANDARDS, ASTM Designation A370-68, Part 4, January 1969.

2. L.S. Beedle and L. Tall
BASIC COLUMN STRENGTH, Journal of the Structural Division, Proc. ASCE, Proc. Paper 2555, Vol. 86 (ST-7), July 1960.

3. G. Winter
PROPERTIES OF STEEL AND CONCRETE AND THE BEHAVIOR OF STRUCTURES, Proc. ASCE, Vol. 86 (ST-2), February 1960.

4. Deutscher Stahlbau-Verband
STAHLBAU, Band 1, 2nd Ed., Stahlbau-Verlags-GmbH, Köln, 1961.

5. A.T. Gozum and A.W. Huber
MATERIAL PROPERTIES, RESIDUAL STRESSES AND COLUMN STRENGTH, Fritz Engrg. Lab. Report No. 220A.14, Lehigh University, May 1955.

6. N.R. Nagaraja Rao, M. Lohrmann, and L. Tall
EFFECT OF STRAIN RATE ON THE YIELD STRESS OF STRUCTURAL STEELS, ASTM Journal of Materials, Vol. 1, No. 1, March 1966.

7. L. Tall
MATERIAL PROPERTIES OF STRUCTURAL STEEL, Fritz Engrg. Lab. Report No. 220A.28A, Lehigh University, April 1958.

8. G. A. Alpsten
EGENSPÄNNINGAR I VARMVALSADE STALPROFILER ("RESIDUAL STRESSES IN HOT-ROLLED STEEL PROFILES"), Institution of Structural Engineering and Bridge Building, Royal Institute of Technology, Stockholm, June 1967.

9. G. A. Alpsten
RESIDUAL STRESS IN A HEAVY WELDED SHAPE 23H681, Fritz Engrg. Lab. Report No. 337.9, Lehigh University, In Preparation.

10. G.A. Alpsten and L. Tall
RESIDUAL STRESSES IN HEAVY WELDED SHAPES, Fritz Engrg. Lab. Report No. 337.12, Lehigh University, January 1969; to be published in the Welding Journal.

11. A.W. Huber and L.S. Beedle
RESIDUAL STRESS AND THE COMPRESSIVE STRENGTH OF STEEL, Welding Journal, Vol. 33, December 1954.

12. F.R. Estuar and L.Tall
EXPERIMENTAL INVESTIGATION OF WELDED BUILT-UP COLUMNS, Welding Journal, Vol. 42, April 1963.

13. N.R. Nagaraja Rao, F.R. Estuar, and L. Tall
RESIDUAL STRESSES IN WELDED SHAPES, Welding Journal, Vol. 43, July 1964.

14. E. Odar, F. Nishino, and L. Tall
RESIDUAL STRESSES IN "T-1" CONSTRUCTIONAL ALLOY STEEL PLATES; RESIDUAL STRESSES IN WELDED BUILT-UP "T-1" SHAPES; RESIDUAL STRESSES IN ROLLED HEAT-TREATED "T-1" SHAPES, Welding Research Council Bulletin No. 121, April 1967.

15. G.A. Alpsten
THERMAL RESIDUAL STRESSES IN HOT-ROLLED STEEL MEMBERS, Fritz Engrg. Lab. Report No. 337.3, December 1968; to be published in the Welding Journal.

16. R.K. McFalls and L. Tall
A STUDY OF WELDED COLUMNS MANUFACTURED FROM FLAME-CUT PLATES, Welding Journal, Vol. 48, April 1969.

17. Y. Kishima, G.A. Alpsten, and L. Tall
RESIDUAL STRESSES IN WELDED SHAPES OF FLAME-CUT PLATES IN ASTM A572(50) STEEL, Fritz Engrg. Lab. Report No. 321.2, Lehigh University, June 1969.

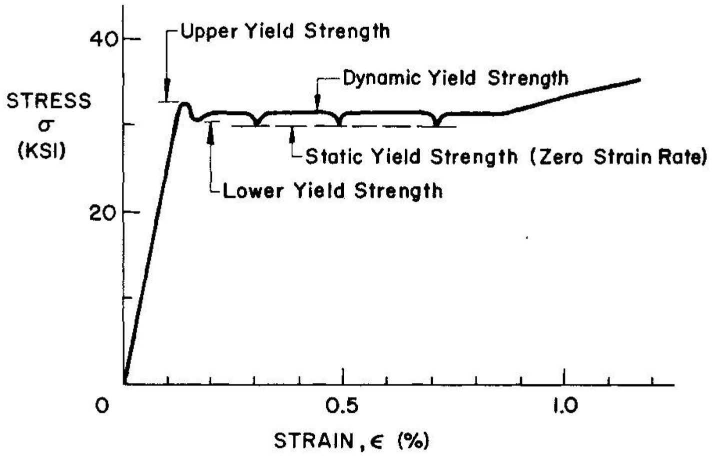
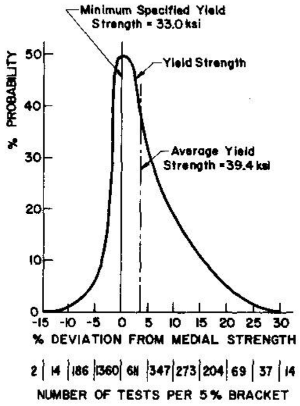


Fig. 1 Typical stress-strain curve of a structural carbon steel and definition of terms



No. of Mill Tests	3124
High	56.65 ksi
Low	31.09 ksi
Average	39.4 ksi
Standard Deviation	3.13 ksi
Probability Error	2.11 ksi 5.5 %
Coefficient of Variation	7.8 %

Fig. 2 Frequency distribution of yield strength obtained in 3124 mill tests

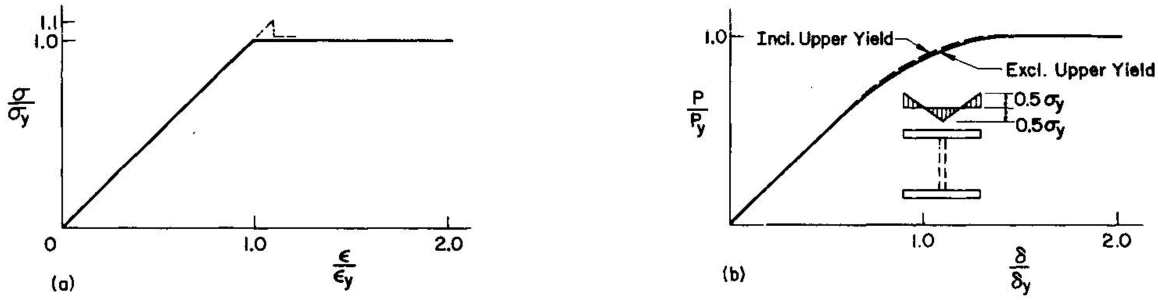
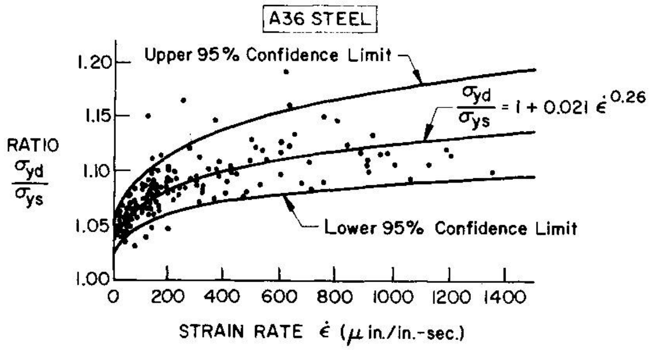


Fig. 3 Influence of an upper yield level upon the load-deformation behavior of a structural member containing residual stresses and loaded in pure tension (schematic)



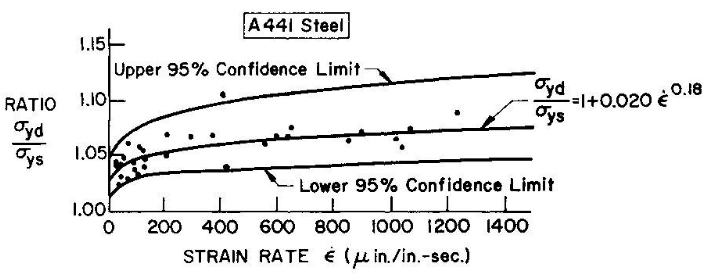
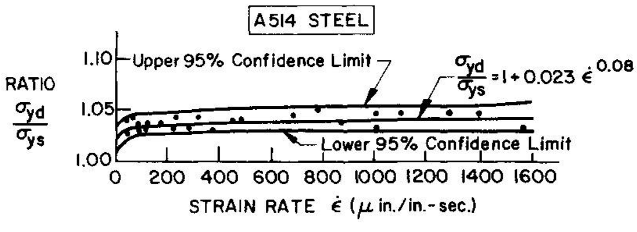


Fig. 4 Relationship between ratio of dynamic to static yield strength level and strain rate for ASTM A36, A441, and A514 steels



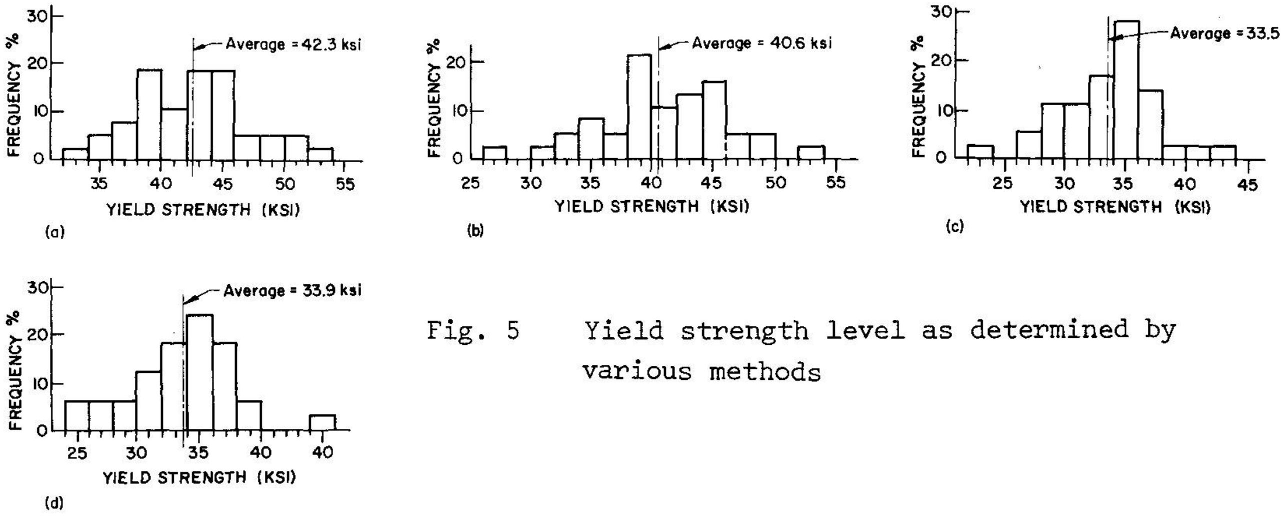
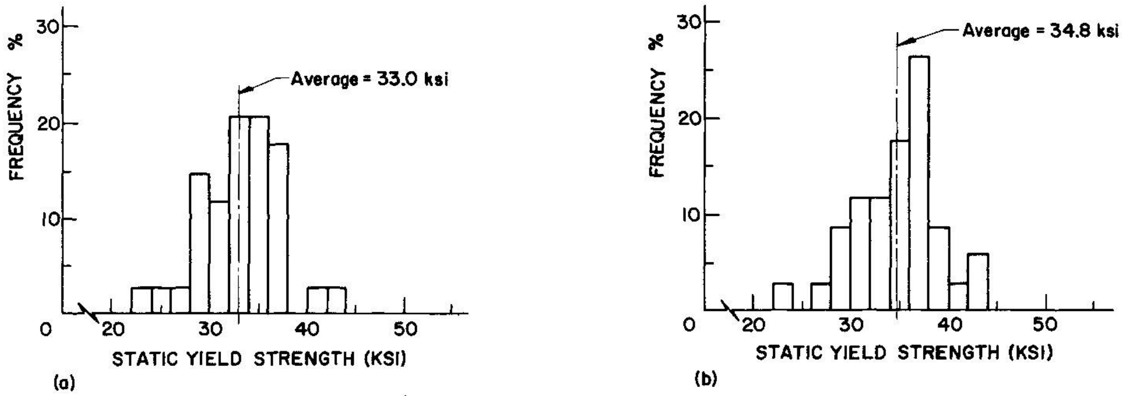
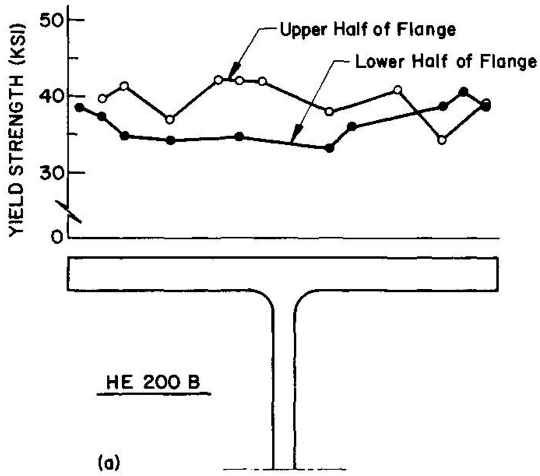


Fig. 5 Yield strength level as determined by various methods

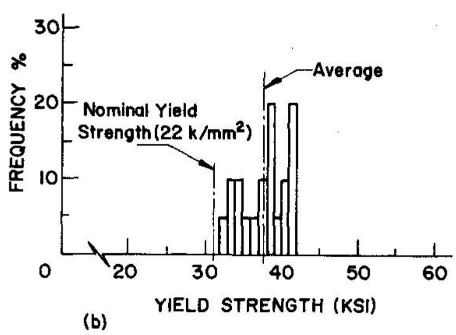


(a) Specimens from Flange (b) Specimens from Web

Fig. 6 Static yield strength of specimens cut from the flange and web of 34 H-shapes

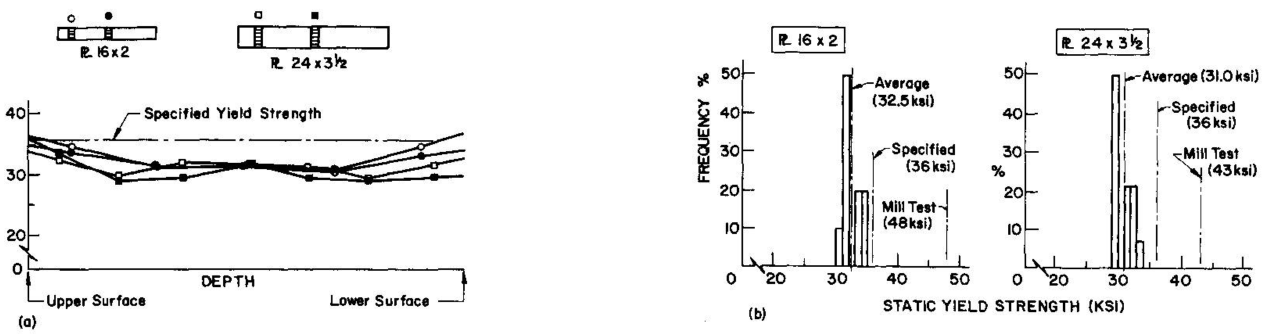


(a) Relationship between location and yield strength



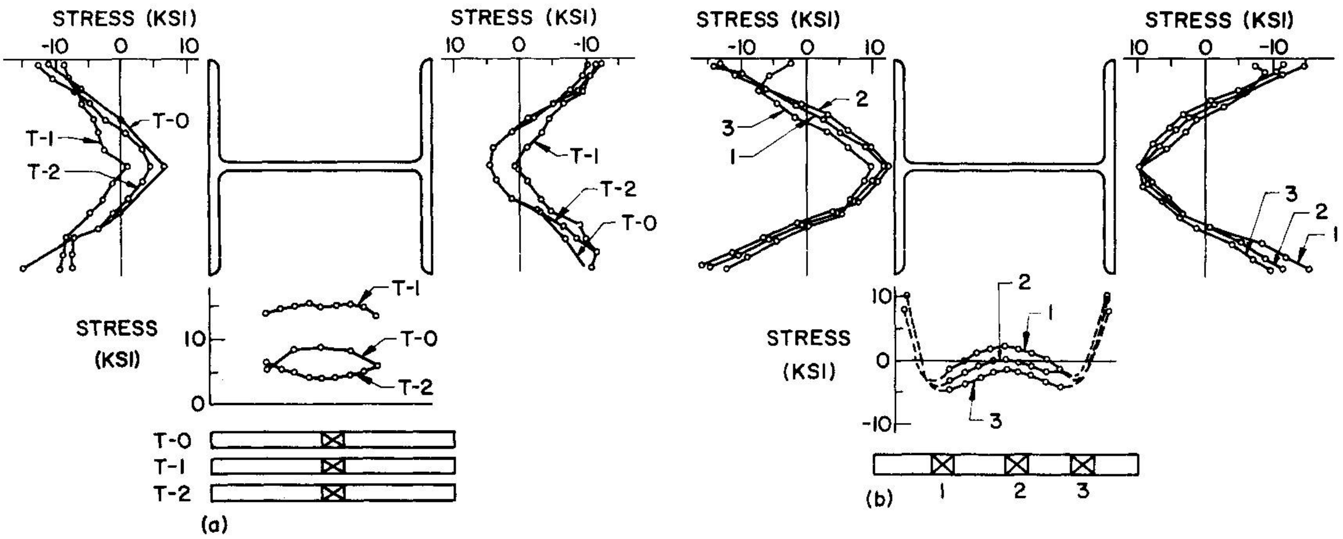
(b) Histogram

Fig. 7 Variation of yield strength for specimens from various positions in the flange of an HE 200 B shape



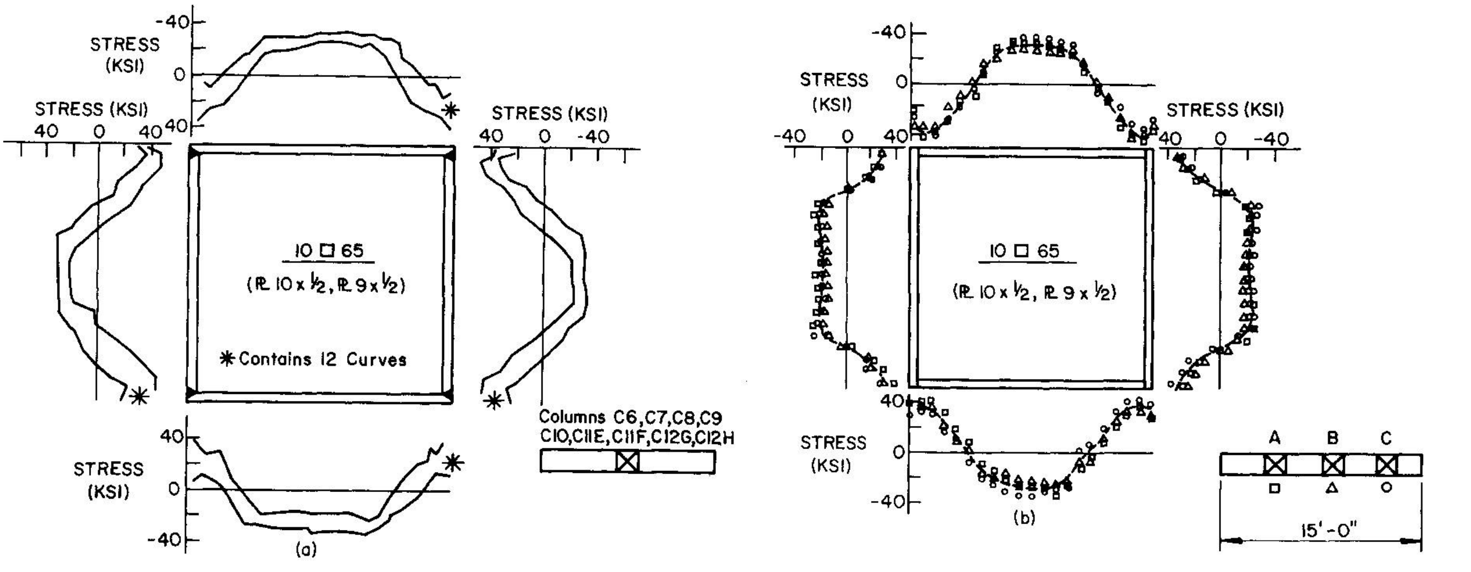
(a) Relationship between location and yield strength (b) Histograms

Fig. 8 Variation of static yield strength for specimens from various postitions of two thick steel plates



(a) Members T-0, T-1, and T-2 (b) Three sections of member T-6

Fig. 9 Residual stress distributions in four lengths of a hot-rolled H-shape, 8WF31



(a) Scatter between various fabricated lengths (b) Scatter within one fabricated length

Fig. 10 Residual stress distributions in several lengths of a welded box-shape, 10 □ 65

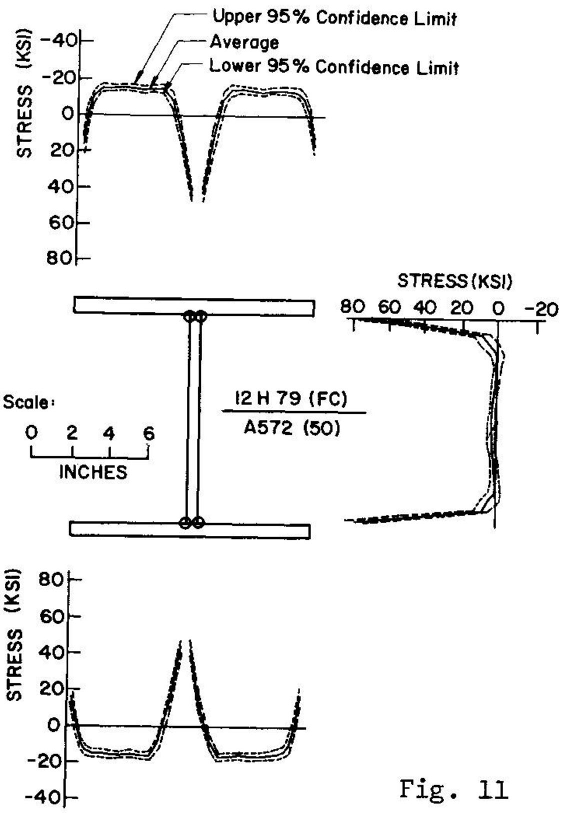


Fig. 11

Residual stress distributions in three fabricated lengths of a welded H-shape 12H79. ASTM A572 (50) steel with nominal yield strength of 50 ksi

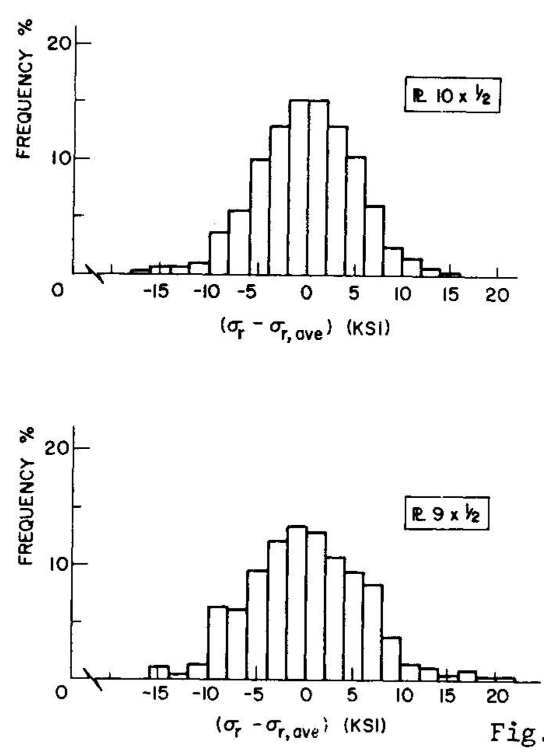


Fig. 12

Histograms of residual stress results obtained from 10 different fabricated lengths of a welded box-shape 10☐ 65 (same results as in Fig. 10)

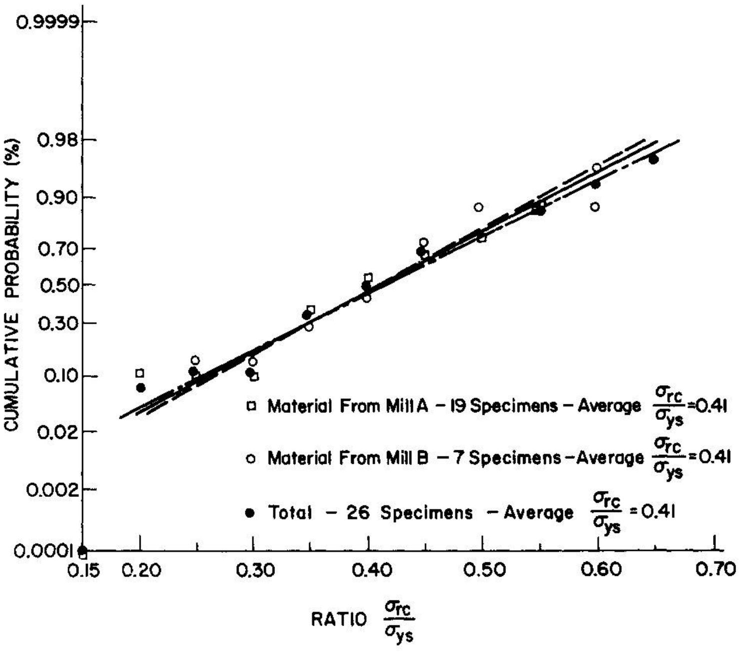


Fig. 13 Distribution of the ratio of maximum compressive residual stress to static yield strength for 26 hot-rolled wide-flange shapes

SUMMARY

The discussion summarizes some results obtained in a study of residual stresses and column strength of rolled and welded shapes. The different aspects covered include (1) statistical variation of yield strength in mill tests, (2) comparison of tension testing techniques, (3) variation of yield strength over the cross section of plates and shapes, (4) influence of strain rate upon yield strength, (5) variation or scatter of residual stress as measured in members of same size and manufacturing conditions, and (6) scatter of residual stress in various sections along a particular member.

RESUME

On présente ici les résultats obtenus lors d'une étude sur les contraintes résiduelles et la résistance des profilés laminés ou assemblés. Les différents aspects traités comprennent: (1) L'étude statistique de la variation de la limite d'élasticité donnée par les essais des laminoirs, (2) Comparaison des techniques des essais de traction, (3) Variation de la limite d'élasticité dans les sections droites des plaques et des profilés, (4) Influence de la vitesse de déformation sur la limite d'écoulement, (5) Variation ou dispersion des contraintes résiduelles pour des éléments de mêmes dimensions et de même provenance, et (6) Dispersion des contraintes résiduelles le long du même élément.

ZUSAMMENFASSUNG

Es wird über einige Untersuchungsergebnisse von Eigen- und Stützenspannungen an Walz- und geschweissten Profilen berichtet. Gesichtspunkte, die besondere Beachtung fanden, sind (1) die statistische Streuung der Streckgrenze bei Zugversuchen aus der laufenden Produktion , (2) der Vergleich zwischen Ergebnissen der verschiedenen Verfahren für Zugversuche, (3) die Streuung der Streckgrenze über den Querschnitt von Band- und Profilstahl, (4) der Einfluss der Dehnungsgeschwindigkeit auf die Streckgrenze, (5) die Streuung der Eigenspannungen bei Profilen gleicher Form und Herstellung und (6) die Streuung der Eigenspannungen in verschiedenen Schnitten einzelner Profile.

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