1964

Determination of the static yield level and the strain-hardening modulus, March 1964

P. F. Adams

DETERMINATION OF THE STATIC YIELD LEVEL AND THE STRAIN-HARDENING MODULUS

by P. F. Adams

A typical-load strain curve for A441 steel is shown in Fig. 1. The curve was obtained from the automatic recorder on the Tinius-Olsen Mechanical Testing Machine during Test HT-46. This test was typical of seven special coupon tests performed specifically to determine E_{st}, the strain-hardening modulus.

Work had previously been completed which involved the determination of E_{st} for A7 steel(1). This determination was based on coupon tests carried out in accordance with ASTM Specifications. The value of E_{st} was taken as the slope of the automatically recorded load-strain graph. E_{st}, for a number of specimens, had a mean value of 750 ksi and a standard deviation of 150 ksi.

The value of E_{st} depends on the relative location of load points 6 and 7 on the load-strain diagram (see Fig. 1). If both the change in load and the change in strain between the two points could be obtained precisely, a consistent value should result for E_{st} for coupons taken from the same specimen. This, however, has not been observed as a fact from the standard coupon tests for three reasons:

1. The slope of the load-strain curve for a dynamic coupon test cannot be measured with sufficient accuracy(1).

2. Even if the strain rate were decreased to zero at the two points in question, the change in load could not be measured with the required degree

---

1 "COLUMN CURVE FOR LOW SLENDERNESS RATIOS" by George J. Tamaro Jr., Master's Thesis, Lehigh University, Bethlehem, Pennsylvania, 1961

Report 297.7

LSB.

File 297

March 20, 1964

MEMORANDUM

To: Research Workers in the Structural Metals Division

From: T. V. Galambos

Re: Determination of Material Properties

Gentlemen:

Part of our work in the project "Plastic Design in High-Strength Steel" (297) is concerned with the determination of those material properties which play an important role in the inelastic stability of steel members. We were particularly interested in getting a reasonably reliable and consistent value of the strain-hardening modulus. Max Lay and Pete Adams experimented quite a lot on this problem, and Pete Adams has summarized their findings in the enclosed little report. Please examine this report, keeping in mind that in the near future we should further discuss this problem and further standardize our procedures.

Ted Galambos

TVG/va

of precision. For specimens which are greater than approximately 0.25" thick the load range necessary to strain the coupon into the strain-hardening range is such that the load at any point can only be estimated to ± 50 pounds. Since the total load change between the two points is small, the resulting E_{st} value is not consistent.

3. Coupled with the difficulty of obtaining an accurate load value is the additional problem of determining at what time the load has definitely stabilized. For the plastic range, Tall[2] states that the strain rate should be decreased to zero and a "few minutes" allowed for the load to decrease to a minimum. Current Fritz Laboratory practice is to allow between three and thirty minutes.

4. The relationship may not be linear — what should be taken?

These difficulties can be partially overcome by choosing the specimen thickness (0.25") so that the strain-hardening range can be entered using the 24 kip load range. The load at any point can then be obtained to ± 10 pounds by reading the dial. Using the largest scale on the strain axis (1" = 0.00625) with an 8" gage length the strain interval can be measured to ± 0.0003. It is recommended that the first point be taken as close as possible to the onset of strain-hardening and the second point after a strain interval of about .002. (but not at) This will give an interval large enough for accurate measurement, yet within the initial portion of the strain-hardening region[1].

However, the third difficulty still exists, that of determining the fully stabilized load. Load drop-time at zero strain rate curves for points 6 and 7 of Test HT-46 are shown in Fig. 2. The curves drawn through the two sets of points coincide. Thus if the load is measured after the same time

---

2 "MATERIAL PROPERTIES OF STRUCTURAL STEEL" by Lambert Tall, Lehigh University, Fritz Laboratory Report 220A.28A

interval for both points, and this difference in load is the basis of computing E_{st}, a consistent value should result. It is suggested that the loads be measured at both points after waiting times of 10, 20, and 30 minutes and E_{st} calculated on the basis of the average load change.

As this load relaxation also occurs in the plastic range it appears that the value of σ_{ys}, the static yield level, would show a considerable variation in view of the arbitrary waiting times used. Load drop-time at zero strain rate curves are shown in Fig. 3 for points 3, 4, and 5 of Test HT-46 which were in the plastic range. The measured points show considerably more scatter than those in the strain-hardening range. On the other hand, the accuracy required is much less than that required for the determination of E_{st}.

It appears that the fully stabilized yield stress level would be obtained by measuring the load drop at 30 min. and subtracting 1.5 times this load drop from the dynamic yield load, obtained at a crosshead speed of 0.025 I.P.M.

In many instances, the fully stabilized yield stress level will not be desired (for comparison with test results, for example). However, it should be remembered that the static yield stress level is time-dependent, particularly in the range of 0-30 minutes and a standard interval should be used for all tests in any particular series.

Table I summarizes the results of seven coupon tests performed primarily to determine E_{st}. Tests HT-45 and HT-46 were allowed to fully stabilize at each load point while the properties of the remaining tests were calculated by the methods outlined above. In test HT-44, the first of the series, the small scale was used on the strain axis, thus the values of E_{st} and ε_{st} are open to question.

The conclusions drawn from these tests are strictly applicable only to A441 specimens of the size tested, however, it is felt that the trends developed may be extended to other situations. A more detailed investigation is needed before more general conclusions can be drawn.

TABLE I MODIFIED CUPON TEST RESULTS

(CROSSHEAD SPEED 0.025 I.P.M.)

(KIP-IN. UNITS)

ALL CUPONS CUT FROM FLANGE OF 10WF25 HEAT 143G540. CUPONS STD. EXCEPT MACHINED TO 0.25" THICK.

TEST	σ_{YS} (30 MIN.)	σ_{YS}	ϵ_{ST}	E_{ST}
HT-44	54.3	52.4	0.0188	605
HT-45	54.5	52.6	.0196	692
HT-46	53.3	51.4	.0191	701
HT-48	55.3	51.7	.0193	708
HT-49	53.1	51.7	.0196	815
HT-50	54.1	52.4	.0202	697
HT-51	53.2	51.8	.0200	708

Table 1 Modified Coupon Test Results

FIG. 1 LOAD-STRAIN RELATIONSHIP TEST HT-46

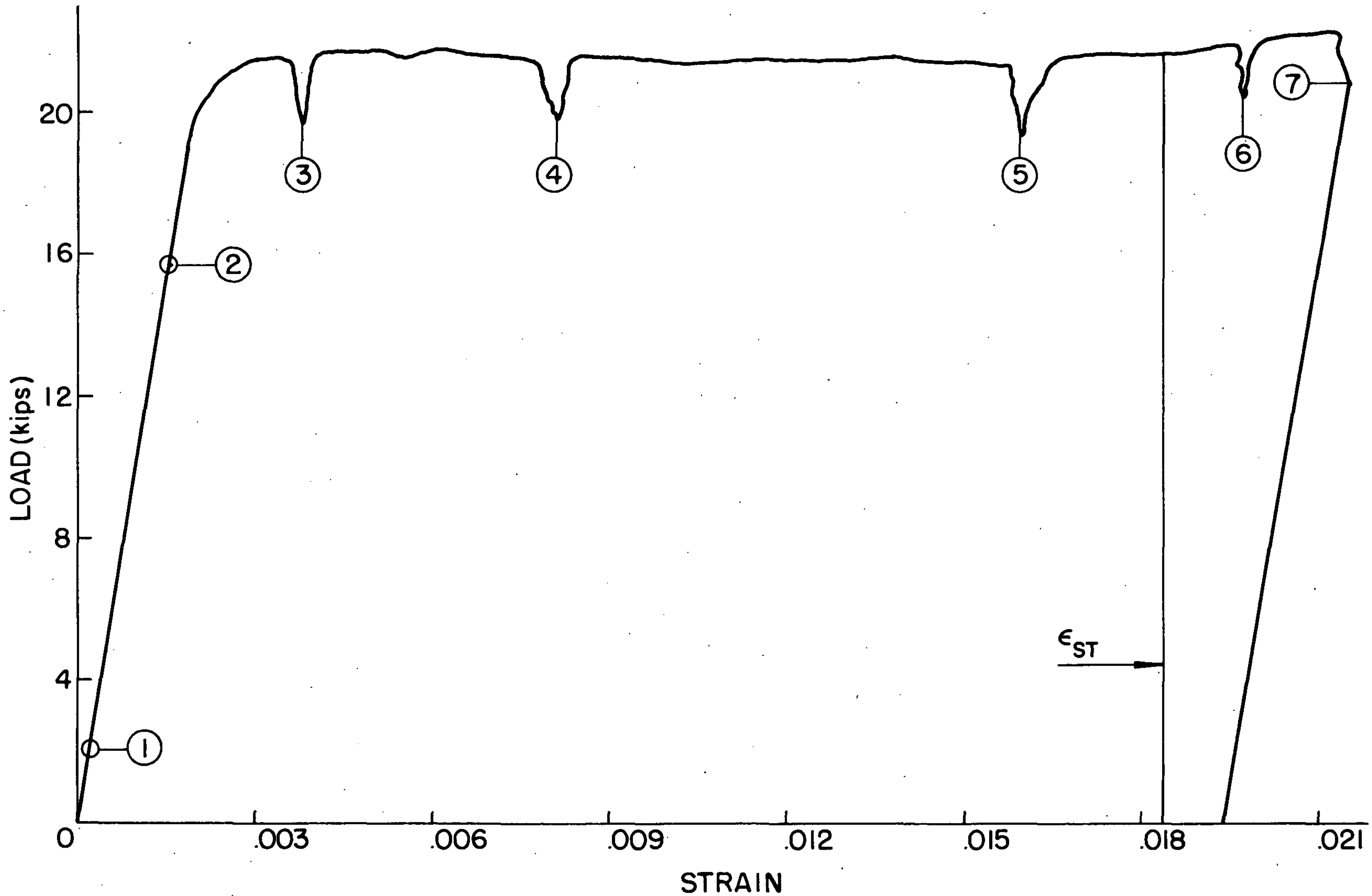

Fig. 1 Load-Strain Relationship Test HT-46

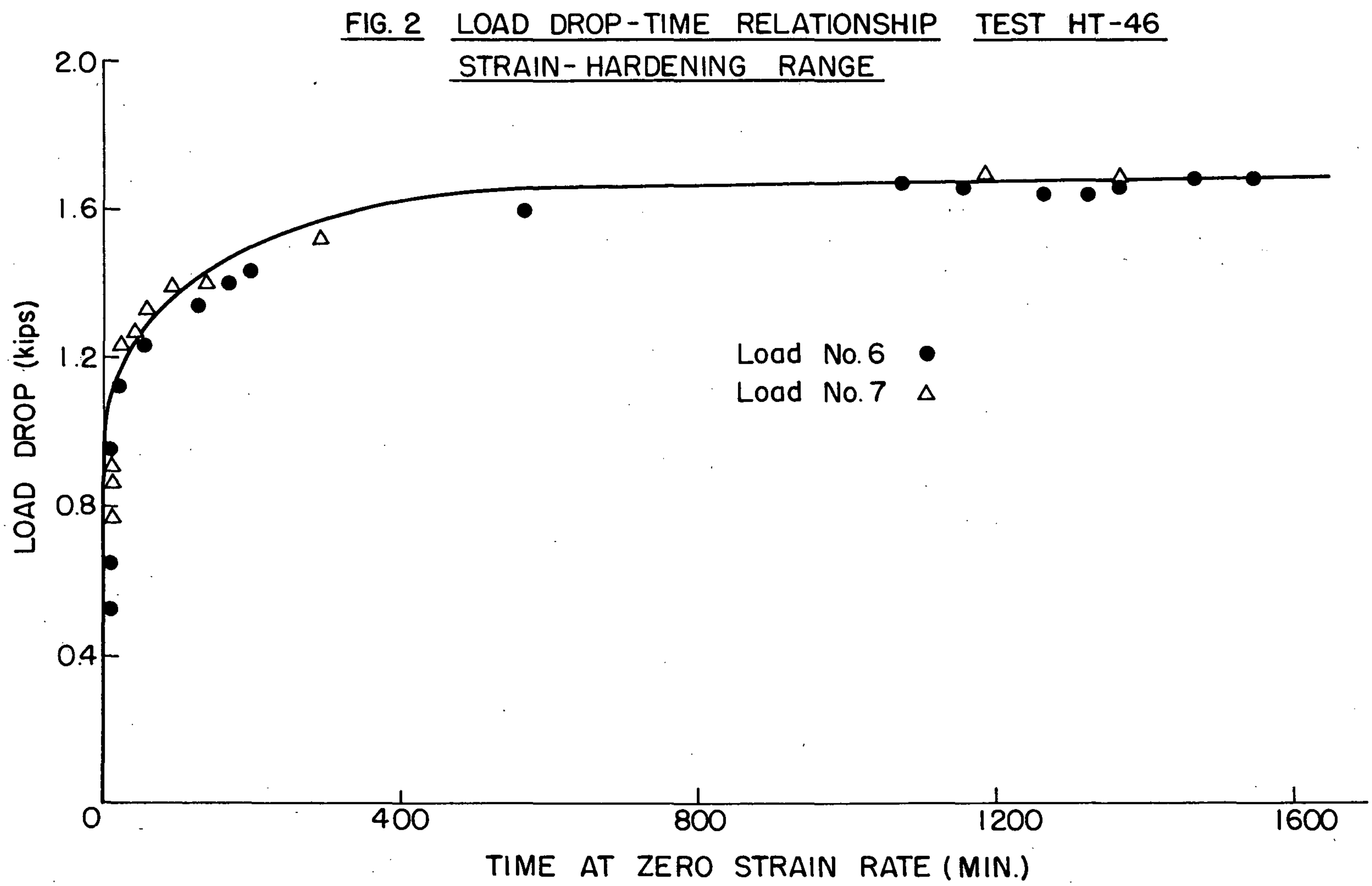

Fig. 2 Load Drop-Time Relationship Test HT-46
Strain Hardening Range

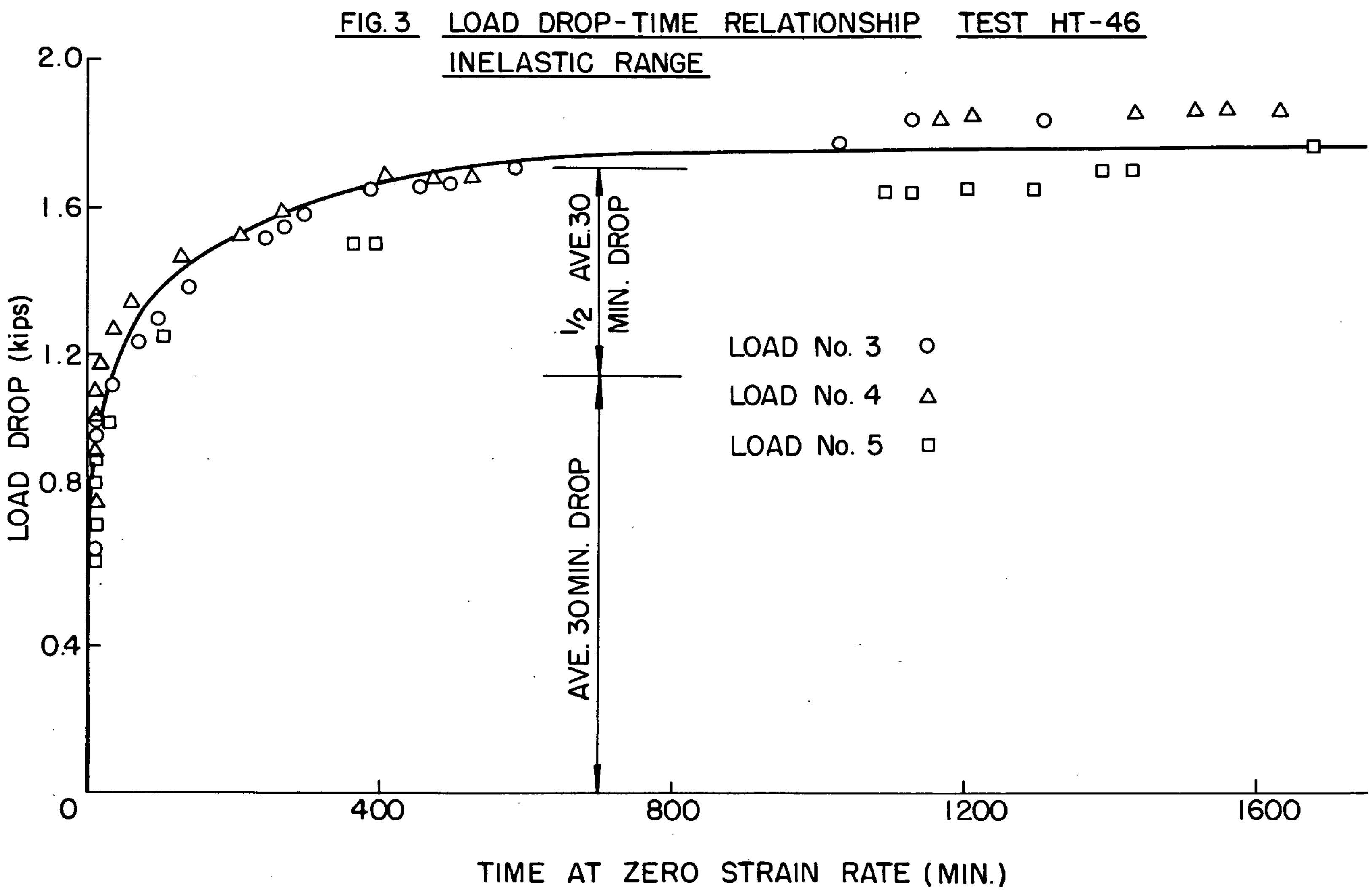

Fig. 3 Load Drop-Time Relationship Test HT-46
Inelastic Range