SHRP-A-641

Direct Tension Test Experiments

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Contents

Acknowledgments iii
List of Figures vii
Abstract 1
Executive Summary 3
Materials and Experimental Design 5
Sample Preparation and Testing Equipment 9
Discussion of the Experiments Carried out at TAI 11
Final Notes 13
References 15
Figures 17

List of Figures

Figure 1 Alignment Jig for Direct Tension Test Samples 19

Figure 2 Diagram of the Servo-Hydraulic Machine used in the Direct Tension Test Experiments 20

Figure 3 Asphalt Concrete Sample Broken After the Direct Tension Test 21

Figure 4 Asphalt Concrete Sample Broken on One End Due to Stress Concentration 22

Figure 5 Asphalt Concrete Sample Showing the Excess of Epoxy Resin on One End Face 23

Figure 6 Diagram of the Applied Creep Load for the Asphalt Mixtures Containing Aggregate RL-1 24

Figure 7 Diagram of the Strain vs. Time in the Creep Mode Corresponding to Asphalt Mixtures Elaborated with Aggregate RL-1 25

Figure 8 Diagram of the Applied Load in the Direct Tension Mode Corresponding to Asphalt Mixtures Manufactured with Aggregate RL-1 . 26

Figure 9 Diagram of the Deformation Obtained in the Direct Tension Test Corresponding to Asphalt Mixtures Elaborated with Aggregate RL-1 . . . 27

Figure 10 Diagram of the Applied Creep Load for the Asphalt Mixtures Containing Aggregate RL-2 28

Figure 11 Diagram of the Strain vs. Time in the Creep Mode Corresponding to Asphalt Mixtures Elaborated with Aggregate RL-2 29

Figure 12 Diagram of the Applied Load in the Direct Tension Mode Corresponding to Asphalt Mixtures Manufactured with Aggregate RL-2 . 30

Figure 13 Diagram of the Deformation Obtained in the Direct Tension Test Corresponding to Asphalt Mixtures Elaborated with Aggregate RL-2 . . . 31

Figure 14 Diagram of the Applied Creep Load for the Asphalt Mixtures Containing Aggregate RL-3 32

Figure 15 Diagram of the Strain vs. Time in the Creep Mode Corresponding to Asphalt Mixtures Elaborated with Aggregate RL-3 33

Figure 16 Diagram of the Applied Load in the Direct Tension Mode Corresponding to Asphalt Mixtures Manufactured with Aggregate RL-3 . 34

Figure 17 Diagram of the Deformation Obtained in the Direct Tension Test Corresponding to Asphalt Mixtures Elaborated with Aggregate RL-3 . . . 35

Figure 18 Diagram of the Applied Creep Load for the Asphalt Mixtures Containing Aggregate RL-4 36

Figure 19 Diagram of the Strain vs. Time in the Creep Mode Corresponding to Asphalt Mixtures Elaborated with Aggregate RL-4 37

Figure 20 Diagram of the Applied Load in the Direct Tension Mode Corresponding to Asphalt Mixtures Manufactured with Aggregate RL-4 . 38

Figure 21 Diagram of the Deformation Obtained in the Direct Tension Test Corresponding to Asphalt Mixtures Elaborated with Aggregate RL-4 . . . 39

Figure 22 Asphalt Concrete Samples Manufactured with Two Different Aggregates after Direct Tension Test 40

Abstract

The Performance Based Asphalt Aggregate mixture specification, a primary product of the SHRP Asphalt Research Program, is based upon the measurement of fundamental material properties which can be used in fundamentally based performance prediction models. Two potential properties identified were tensile creep and tensile strength measured with a Direct Tension Test (DTT). A key question to be answered prior to development of a DTT was the implementability in a production laboratory.

The proposed work plan of The Asphalt Institute (TAI) was to determine the feasibility of running the DTT as a routine test suitable for Highway Agencies. If the test was feasible for implementation, it would be identified as a primary candidate test in contract research plans. Additionally, the correlation between DTT and the Diametral Indirect Tensile Test was also proposed.

DTT evaluation for several SHRP asphalt mixtures was carried out at TAI during 1991 and 1992. As a result of this work, and research carried out by other SHRP contractors, the DTT has been eliminated from consideration for mixture specification purposes. The objective of this report is to document experimental results from TAI which lead to the elimination of the direct tension test from consideration for the proposed performance based specification for asphalt mixtures.

Executive Summary

In the past, the Direct Tension Test has been researched primarily for evaluation of asphalt mixture tensile properties at low temperatures (1, 2, 3, 4, 5, 8, 9, 13, 17, 18 and 19). Haas (8) emphasized that the stiffness modulus of an asphalt mixture should be measured by direct methods to ensure that the estimated stiffness is, in fact, achieved. On the other hand, Roque (15) has pointed out that the Indirect Testing mode has the unique advantage that the failure plane is known *a priori* at low in-service temperatures.

Microcrack damage in an asphalt concrete can be assessed through DTT in the range of low temperature cracking, thermal, and load related fatigue [low, (-10°C) and ambient temperatures (25°C)].

Despite the fact that French (19) and others have reported that the DTT can be successfully conducted, there are still some difficulties in obtaining repeatability. The test in itself is very simple and of short duration, although sample preparation requires a fairly long time and a skillful technician.

Stress concentrations near the ends of the samples has been observed in many of the experiments carried out at TAI. The failure plane in some of the samples occurred at an angle with the axial direction of the sample indicating shear stresses most likely due to misalignment.

It is clear that the height/diameter ratio and the maximum aggregate particle size are related and affect the final results. The sample preparation technique (glue, alignment, etc.) is of paramount importance in order to ensure that the failure plane occurs far enough from the end caps and perpendicular to the sample axis.

Temperature is another important parameter since it affects limiting strain. In this project, the temperatures selected ranged from 4°C to 25°C; although 40°C was originally proposed, it was later considered too high a temperature for the characteristics of the test in question. The idea of performing the DTT was to evaluate the microcrack damage in the asphalt mixture in low and ambient temperature regions when those cracks are most likely to be developed affecting the fatigue resistance of the mixture.

A limited test program, including direct tensile creep and direct tensile strength experiments on SHRP asphalt mixtures, was conducted at TAI. Difficulties encountered in performing the DTT and the results obtained are reported below.

Materials And Experimental Design

In the experiment, four dense hot asphalt mixes (two different aggregates plus two different asphalt binders) were compacted into cylindrical samples for DTT testing. The aggregates were identified as RB and RL which were blended with asphalts AAG-1 and AAK-1. The asphalt mixtures were prepared using the data provided by the A-003A contractor for both Marshall and Hveem design methods. Mixtures were subjected to 4 hours of cure time in accordance with the short term aging proposed by SHRP (loose mix 4 hours @ 135°C, in a forced draft oven).

Optimum asphalt content was found to be 4 percent by weight of mix for RB aggregate, and 4.1 percent for RL aggregate. Air voids ranged between 3 and 4 percent. The following controlled variables and levels were included in the experiment design:

- aggregates, two types: RL (Gulf Chert, high stripping potential); RB (Watsonville Granite, low stripping potential).

- asphalts, two types: AAG-1 (AR-4000 California Valley) and AAK-1 (Boscan AC-30) and two asphalt contents depending upon aggregate type.

- compaction/air voids: one level: 4%.

- test temperatures: three levels: 4°C, 25°C and 40°C.

- testing methods: Dynamic and Static Axial Tensile Creep followed by Direct Tension Test at constant-rate-of-extension. Dynamic and Static Diametral Compression Creep followed by Indirect Tensile Test.

The response variables measured included:

- creep compliance under DTT and ITT at different loading times.
- Stress-strain-time-temperature relationships for both DTT and ITT.
- Load-deformation relationships
- Tensile Strength and Strain at Failure
- Fracture Energy

A total of 72 samples (4 mixes x 3 temperatures x 2 methods x 3 specimens) formed a full factorial design with three replicates of each combination.

A = two aggregates RB(0) and RL(1)
B = two binders AGG-1(0) and AAK-1(1)
C = two methods DTT (0) and ITT(1)
D = three temperatures 40(0), 25(1) and 4°C(2)

The experimental design results in a 2^3x3 fractional factorial,

A	B	C	D	A - C	D	A - C	D
0	0	0	0	R	1	R	2
1	0	0	0	R	1	R	2
0	1	0	0	R	1	R	2
0	0	1	0	R	1	R	2
1	0	1	0	R	1	R	2
1	1	0	0	R	1	R	2
0	1	1	0	R	1	R	2
1	1	1	0	R	1	R	2

Materials properties are listed below. Aggregate gradations are the following:

	RL	RB
1"	100.0	100.0
3/4"	97.7	95.8
1/2"	77.3	79.0
3/8"	68.3	72.1
n°4	51.4	43.9
8	32.3	37.6
16	23.9	25.4
30	20.2	18.1
50	17.9	12.5
100	8.4	9.2
200	5.8	5.7

Asphalt properties are the following:

	AAG-1	AAK-1
Viscosity, 60C	1842	3256
Viscosity, 135C	243	562
Penetration, 0, 1mm 25C, 100g, 5s	53	70
Soft. Point, °C	120	121
Visc. Ratio, 60C (TFOT)	1.75	2.98
<u>Component Analysis, %</u>		
Asphaltenes (n-heptane)	5.8	21.1
Polar Aromatics	51.2	41.8
Naphtene Aromatics	32.5	30.0
Saturates	8.5	5.1
<u>IEC separations, %</u>		
Strong Acid	18.1	3.7
Strong Base	12.0	8.0
Weak Acid	11.4	8.6
Weak Base	9.1	7.5
Neutral	50.4	52.5
<u>SEC fraction, wt, %</u>		
SEC-I	12.9	25.9
SEC-II	87.1	74.1

Sample Preparation And Testing Equipment

Asphalt concrete specimens for tension testing were prepared by gyratory compaction using 6-in.diameter by approximately 4.5-in. high cylindrical specimens. In the beginning, 1.758-in. diameter by 4.5-in. high specimens were cored from the 6-in. specimens. Later, due to problems with the maximum aggregate size, the diameter was increased to 2.8-inches. The resulting specimens were bonded to steel end caps of the same diameter with a two component epoxy adhesive of the type used for the installation of pavement markers (AASHTO Specification M 237-86, Table 3, Type IV) (Epoplex Series 500, Park Av. Maple Shade, NJ08052).

The samples were compacted at a 1 degree angle, 6 rpm and 87 psi pressure at the equiviscous temperature according to the asphalt type used.

After compaction, specimens were cored and then the ends were sawed, taking special care in the cutting of the faces in order to obtain flat parallel faces. The ends were cleaned before gluing them to the end caps with the epoxy resin.

An alignment jig was especially constructed for the gluing of the specimens to the end caps (Interlaken Tech Corp.) to ensure proper alignment between the caps and the specimen axis. A diagram of the above mentioned device is provided in Figure 1. Direct tension grips were built consisting of two screwable swivel joints along with adapters to hold the specimen. These are also noted in Figure 1.

The test system used was a servo hydraulic testing machine made by Interlaken Technology Corporation. A 6 gpm hydraulic pump with a maximum operating pressure of 3000 psi was used to power the system. The actuator of the system has a maximum stroke of 6 ± 3 inches with a maximum loading capacity of 22,000 pounds. Also contained in the actuator is a LVDT (Linear Variable Differential Transducer) to measure the displacement of the actuator and a load cell to measure and control the applied load. A schematic diagram displaying the major components of this system is shown in Figure 2.

The servo hydraulic system is controlled by a Series 3200 Controller which supplies a closed-loop servo control transducer, a signal conditioning data acquisition system, a function generator, and a hydraulic pressure control.

Interaction with the controller for function generation and test control parameters is through an IBM compatible computer via a software package. The Series 3230 Data Acquisition System is used for collecting data. Contained in the system are conversion cards that convert signals into digital output that can be stored to hard disk.

Temperature can be controlled in a conditioning unit from -30°C to 60°C.

Testing Procedure

As mentioned above, the proposed testing procedure was comprised of two different techniques: direct tension in creep followed by tensile strength and indirect diametral tension in creep followed by diametral compression (constant rate of loading). The indirect diametral tension test was planned as a subtask in order to compare tensile parameters obtained with both techniques. Actually, the ITT was never carried out due to the fact that the time consumed in this investigation was all devoted to develop a DTT procedure.

The sequence of the test was as follows: a) a preload of approximately 10% of the static load was applied throughout the test to prevent an impact load, to minimize the effect of seating of the loading strips (in the indirect tension test) and to avoid movements in the sample; b) a static load (25% of the ultimate load) was applied during 1000 seconds followed by removal and observation of the recoverable deformation obtained by an equal period and, c) a constant-rate-of-extension (controlled strain) was also applied immediately after the creep experiment until the specimen failed. In the DTT, the rate of loading was 0.017 in/min. while in the ITT it was 2 in/min.

During the direct tension test, resulting loads and strains were recorded. Load was measured by the load cell in the actuator and the deformation was measured by the extensometer connected to the Series 3230 Data Acquisition System. The extensometer used has a gauge length of 1-inch and a range of $\pm$ 20%.

Discussion Of The Experiments Carried Out At TAI

Specimen preparation comprised several steps before the specimen was tested. First, the 6-in. diameter specimens were produced in the gyratory compactor from materials that had been selected and blended in accordance with the mix design. Coring of the 1.75-in. or the 2.8-in. cylindrical samples followed. This operation normally takes 20 minutes plus 30 minutes more for the sawing of the ends (for which a jig device was used to hold a sample).

The alignment and gluing takes approximately 3 hours. The DTT itself lasts 15 minutes. After capping, the specimens have to be conditioned to the testing temperature for at least two hours (depending upon the temperature). All in all, only one or two samples can be tested a day if only one jig is available; because of this, the experiment was time consuming. The capping operation is the most complicated. As previously mentioned, an alignment jig was tailor-made for gripping the samples and keeping the end faces perpendicular to the specimens axial direction.

In the beginning, the preparation of the 1.75-in. diameter specimens was simpler than the 2.8-in. ones. Two problems were addressed: 1) the ratio of nominal maximum aggregate size and diameter were not correct, and 2) the failure plane was influenced by the aggregate particle size and it was very difficult to obtain a separation plane either perpendicular to the direction of the principal tensile stress or sufficiently far from the ends. Additionally, some problems with the coring of samples containing RL aggregate were also found. The adoption of 1.75-in. diameter by 4.55-in. high dimensions are based on the dimension of the gyratory specimens and the need to keep a sufficient diameter to height ratio to avoid stress concentrations near the ends.

After reviewing the results obtained, a decision to shift to larger diameter specimens was made. A 2.85-inch diameter specimen was cored through a 6 inch molded specimen, the final height of the sample was approximately 5 inches due to the fact that this was the approximate length obtainable in the gyratory machine.

This procedure improved the preparation of the samples but did little to enhance repeatability. Stress concentrations near one of the ends continued to occur. Shear failure, probably due to misalignment, was the common factor encountered in the samples tested, as Figures 3 and 4 clearly show.

Another factor that may influence the type of failure was the glue used, both its content and type. In some of the samples, it was observed that there was an excessive amount of epoxy and non-uniform gluing (see Figure 5).

A total of 35 samples of the thin specimens and 25 samples of the thicker ones were tested to failure at room temperature using a constant rate of extension equal to 0.017 in/min. as previously stated. During the tension test on the specimens, load and deformation (extensometers) were recorded at periodic intervals (5 seconds interval was used in this research). Some typical plots obtained from tensile creep and strength tests are shown in Figures 6 through 22. Tests were performed with samples prepared with mixtures containing aggregates RL-1 and asphalt AAG-1. In Figure 23, two examples with two different aggregates which show a successful failure in DTT can be observed.

Figures 6 and 7 display the creep load used and the deformation recorded after 1000 seconds constant stress for the RL-AAK-1, RL-1 mixtures as indicated on the Figures. Originally 25% of the ultimate load had been proposed, but due to the fact that this load turned out to be too low for the capacity of the load cell used, a 12 pound load was finally adopted.

In creep, tensile strain vs. time data was recorded during 1000 seconds. The curve reveals a viscoelastic behavior displaying linearity between 0.6 (250 seconds approximately) and 1.0% (500 seconds approximately) strain. Beyond 600 seconds the strain increased more rapidly at longer times indicating non-linearity. At the end of the test, after 1000 seconds, the strain recorded was 1.62%. for a constant stress of 1.62 psi.

After the creep test, a constant-rate-of-strain test was performed (0.017in/in.) reaching failure at approximately 8 seconds. The strain at the peak load (about 26 pounds) was 1.2%.

The ultimate strain is nearly the same in the four cases presented, around 1%. The creep response, however, showed some differences in behavior partly due to the application of the load and partly due to differences in the room temperature at the time of testing. The tensile peak load was nearly 26 pounds for samples RL-1 (RL-AAK-1) and RL-2 (RL-AAG-1); and 32 pounds for samples RL-3 and RL-4. The former showed strains between 1.6 and 1.8% in creep after 1000 seconds loading while the latter displayed strains of 0.45% approximately, for the same loading time. They are four replicates manufactured with one aggregate type (RL-1) and asphalt AAG-1. Stress concentrations near the ends of many of the specimens were unavoidable, therefore no further calculations or variables analysis were carried out on them.

It is suggested, as a consequence, that the alignment device be reviewed to check the parallelism of the end faces and their alignment with regard to the axial direction of the sample in order to obtain failures in the middle of the specimens and consistently away from the end caps like ones shown in Figure 5.

Likewise, gluing has to be done very carefully in order to obtain an evenly distributed thin film thickness on each face of the sample.

Final Notes

Sample preparation seems to be the key to many of the problems encountered. Special care should be taken in cutting the ends and in gluing the specimen to the end plates. It is suggested that a minimum amount of epoxy resin be used that is compatible with the required stress and that a uniform compressive pressure be applied on the end caps to obtain a uniform film of epoxy binder. Any broken corners should be avoided, since refilling them with epoxy resin could create stress concentrations. Excess glue at the sides of the specimen should be wiped off.

With regard to the sample dimensions, from the literature review it was found that the most common ratio between length and diameter is approximately 2:1, sometimes higher, while the TAI sample ratio was 1.6:1. In addition, the relationship between nominal maximum aggregate size and diameter are important. For instance, a ratio of 4 is considered sufficient in order to avoid a fracture influenced by the aggregate size.

From the type of failure obtained in many of the samples in which shear stress is evident (failure at the end caps), a check out of the alignment device is needed. In fact, this was a task in which TAI was focusing its efforts at the time the testing was discontinued.

Additional effort is needed in the following areas:

- specimen geometry (length/diameter ratio, maximum nominal aggregate size/diameter ratio),
- specimen preparation,
- perpendicularity between end faces and axial direction,
- sample configuration,
- alignment device,
- glue type,
- amount of film thickness;
- contact pressure between sample faces and end caps,
- cure time,
- testing temperature and load;
- loading system capability suitable for the loading range used.

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Figures

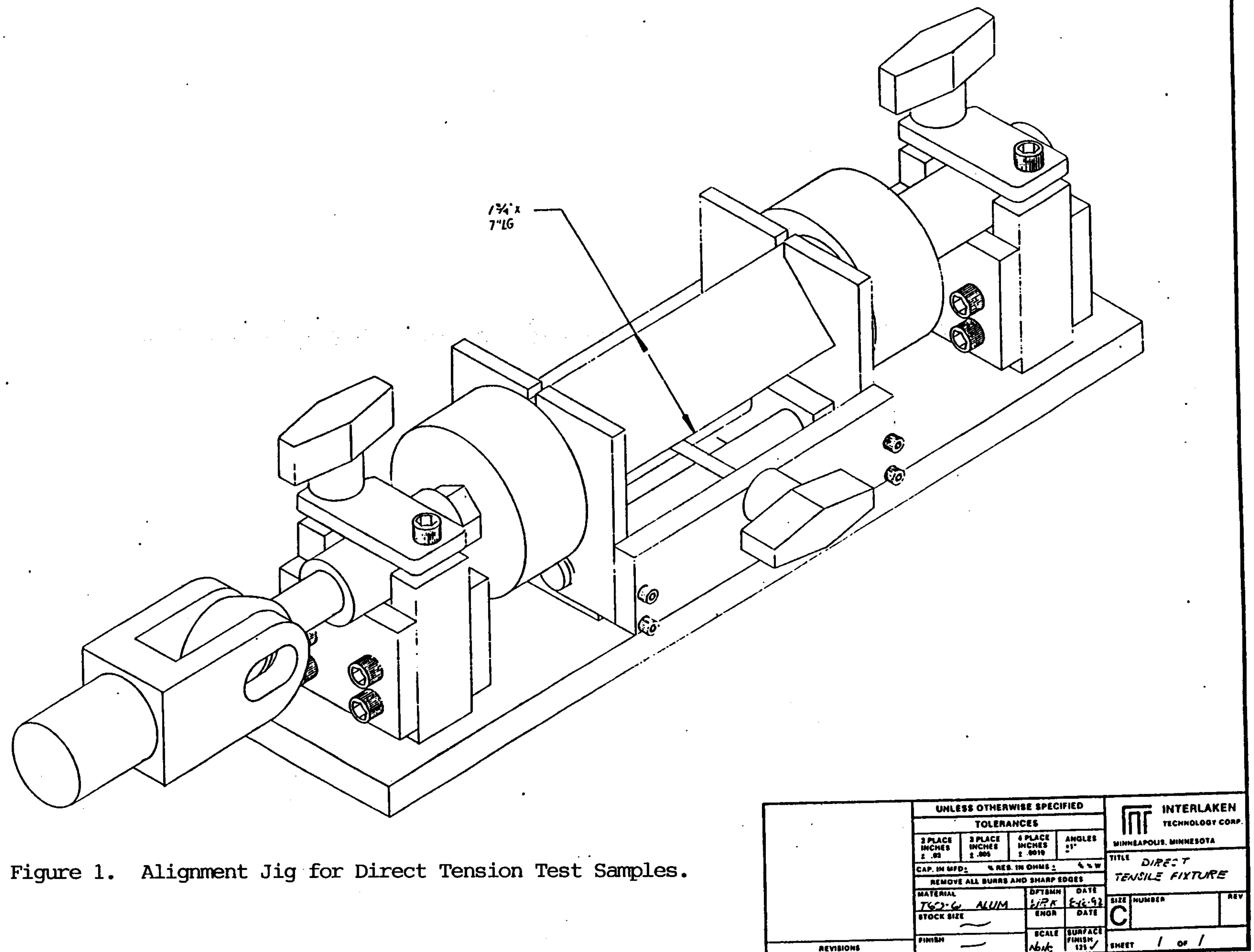


Figure 1. Alignment Jig for Direct Tension Test Samples.

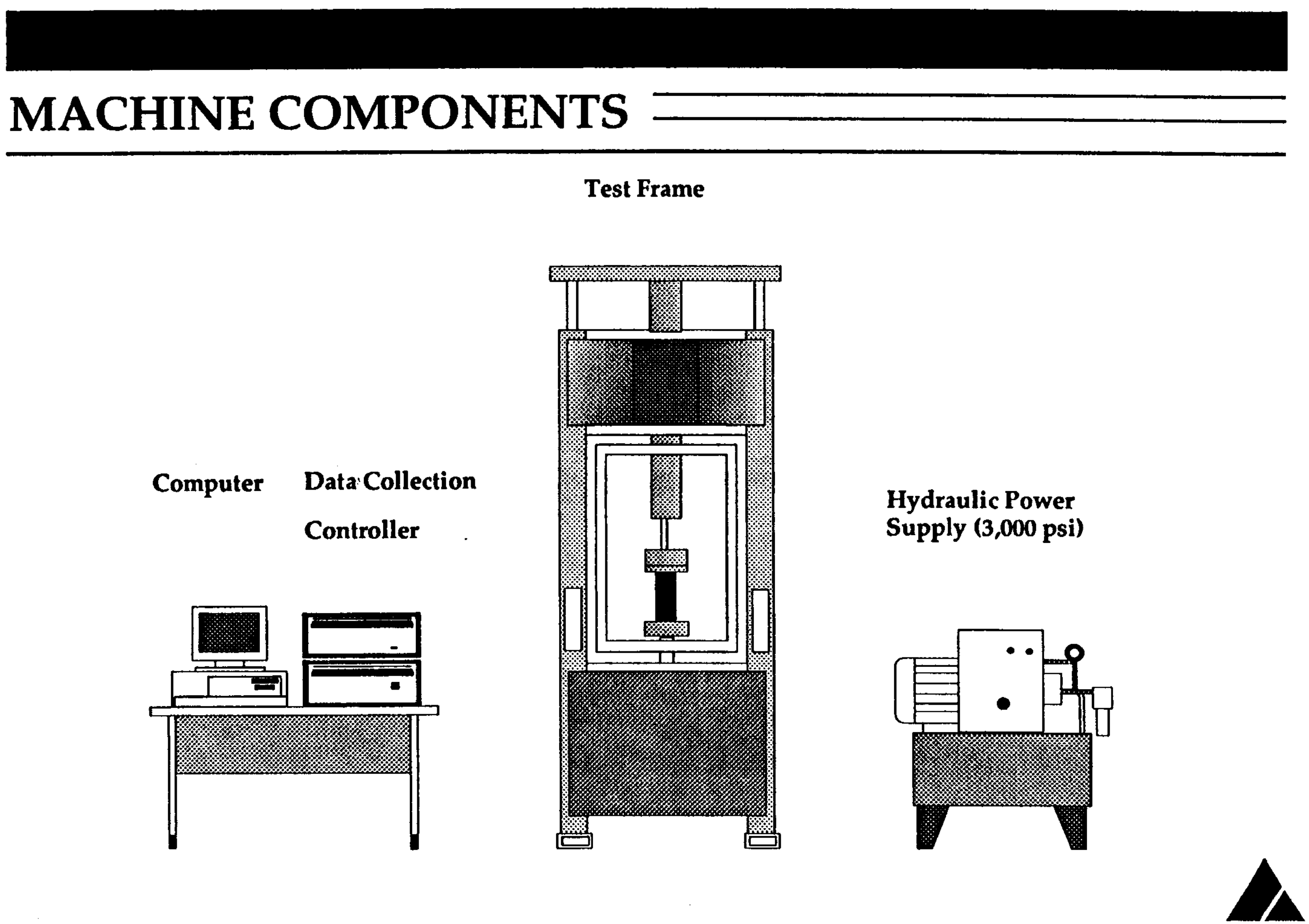


Figure 2. Diagram of the Servo-Hydraulic Machine used in the Direct Tension Test Experiments.

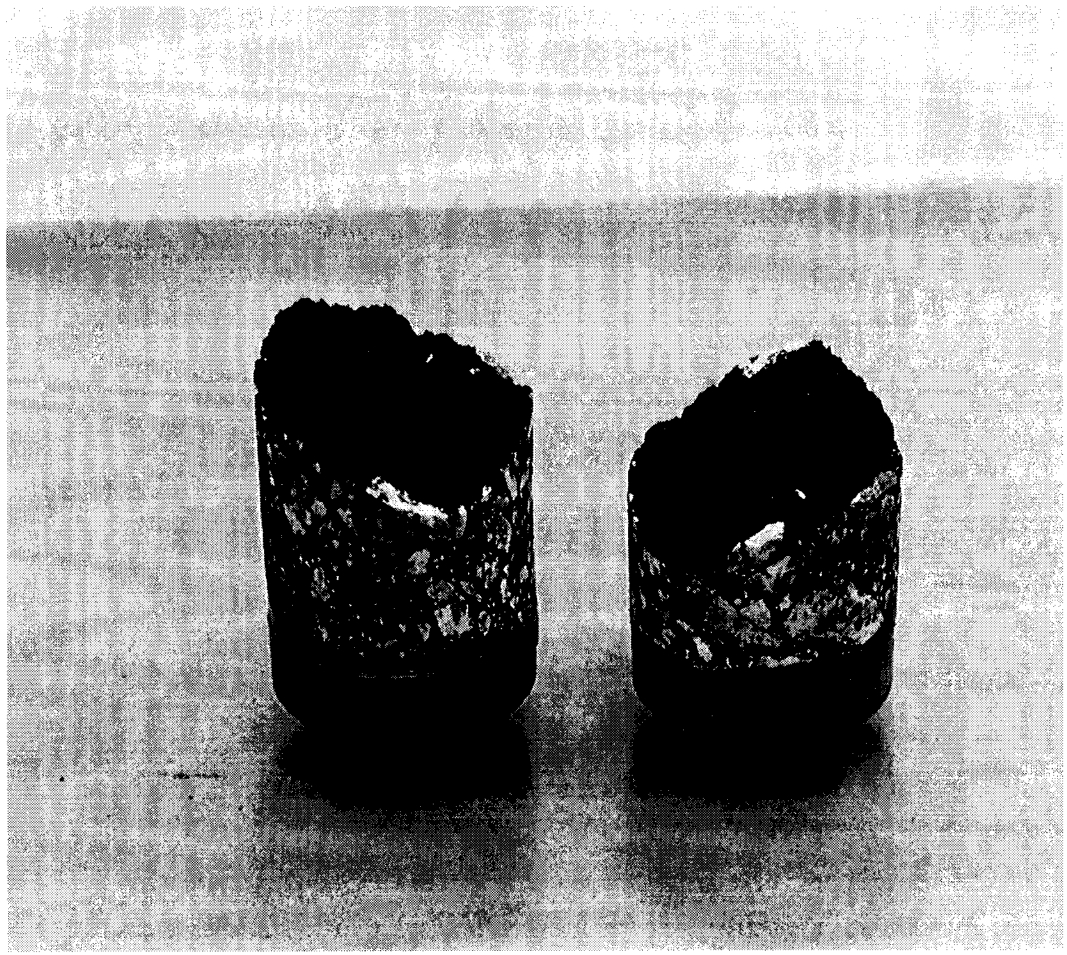


Figure 3. Asphalt Concrete Sample Broken After the Direct Tension Test.

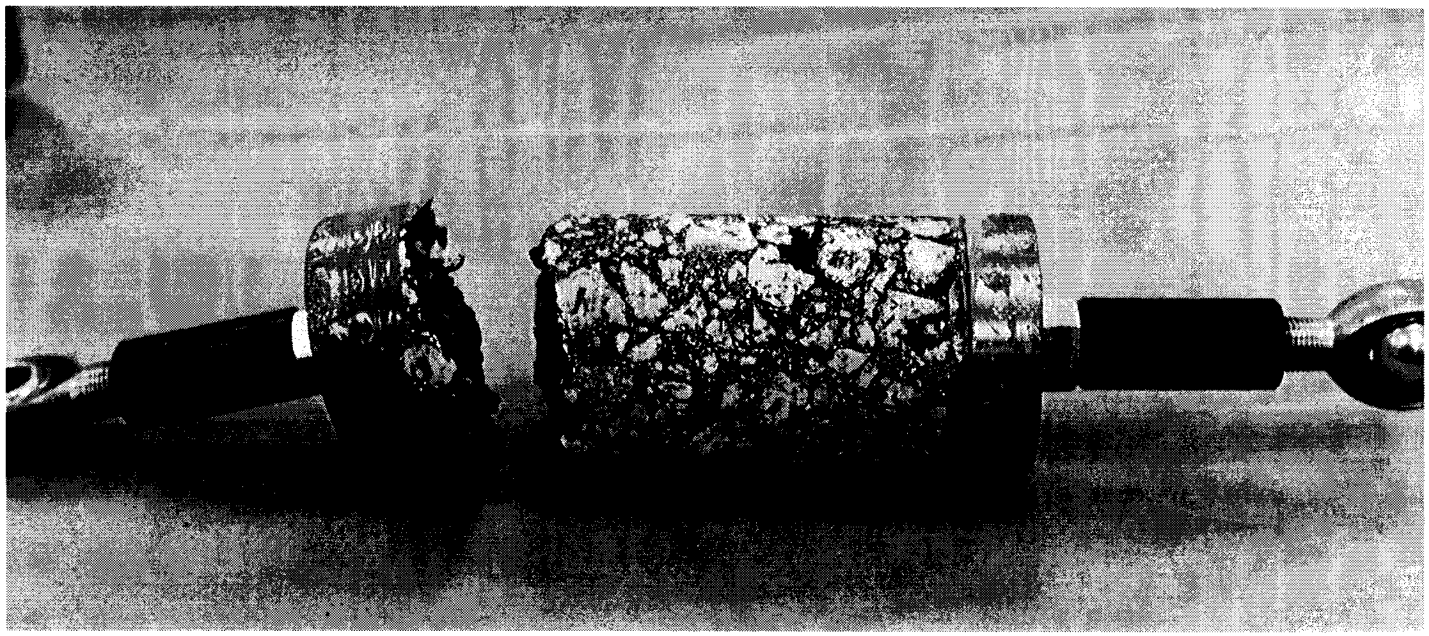


Figure 4. Asphalt Concrete Sample Broken on One End Due to Stress Concentration.

Figure 5. Asphalt Concrete Sample Showing the Excess of Epoxy Resin on One End Face.

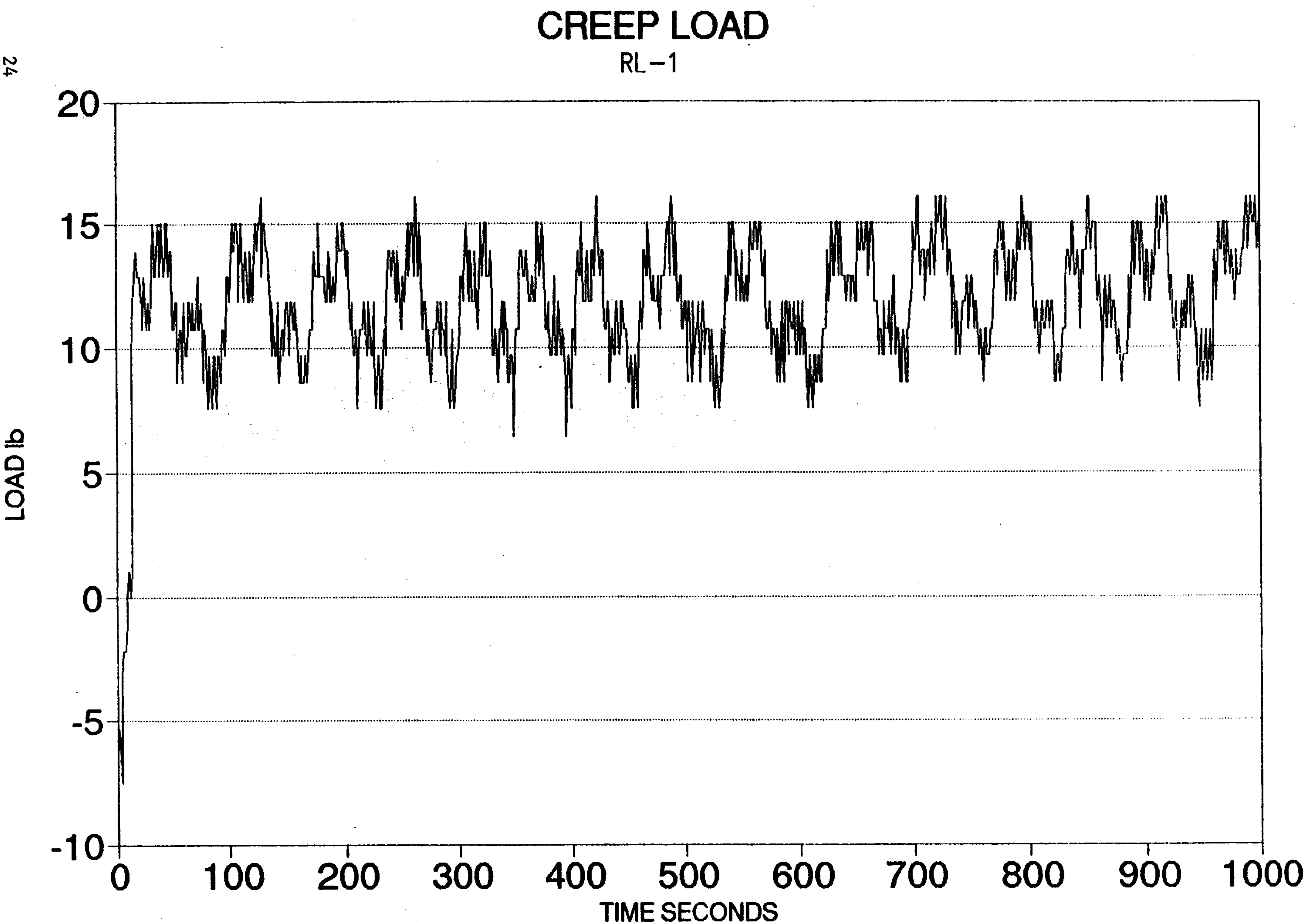

CREEP LOAD
RL-1
LOAD lb
20
15
10
5
0
-5
-10
0
100
200
300
400
500
600
700
800
900
1000
TIME SECONDS

Figure 6.

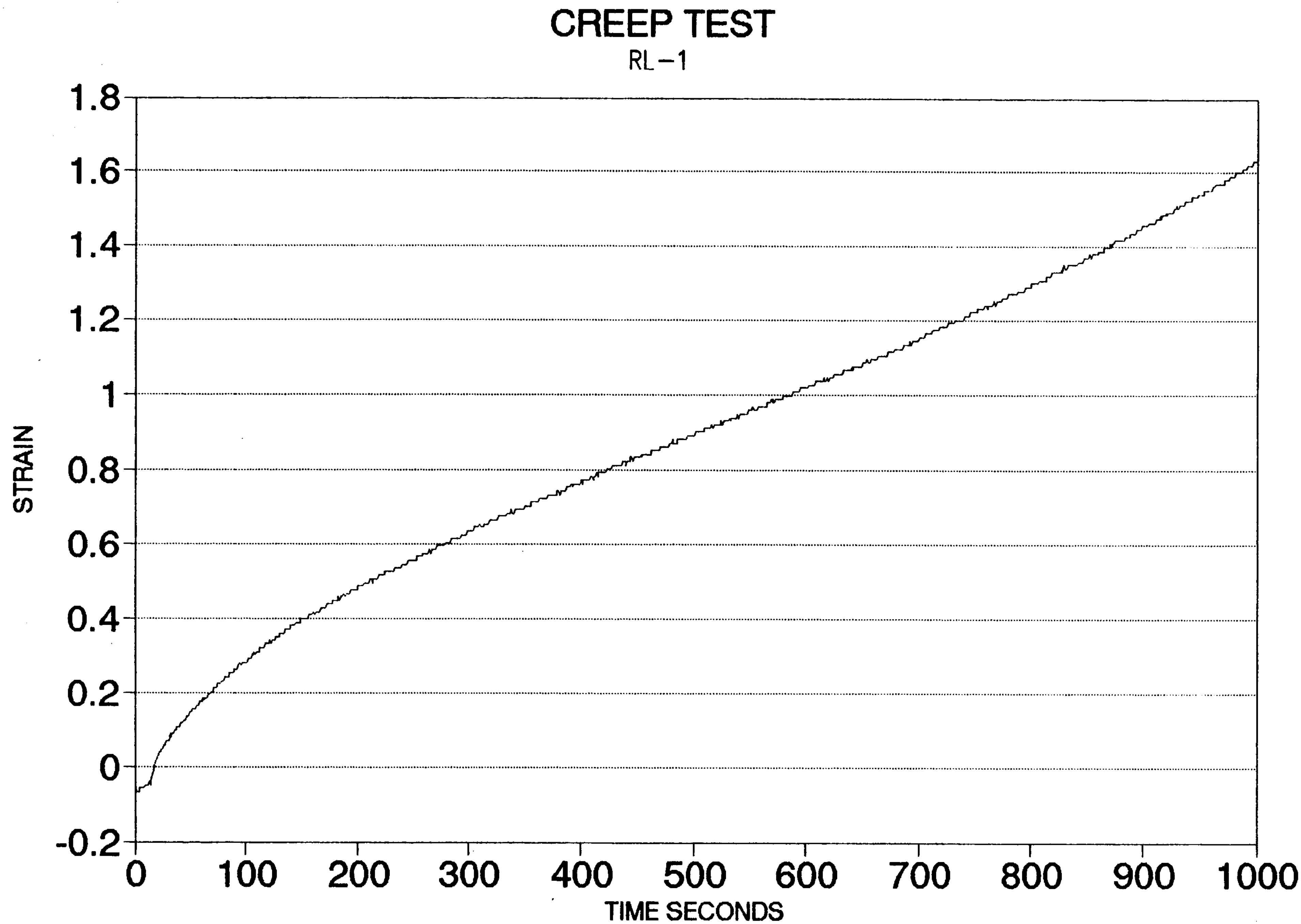

CREEP TEST
RL-1
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
STRAIN
0
100
200
300
400
500
600
700
800
900
1000
TIME SECONDS

Figure 7.

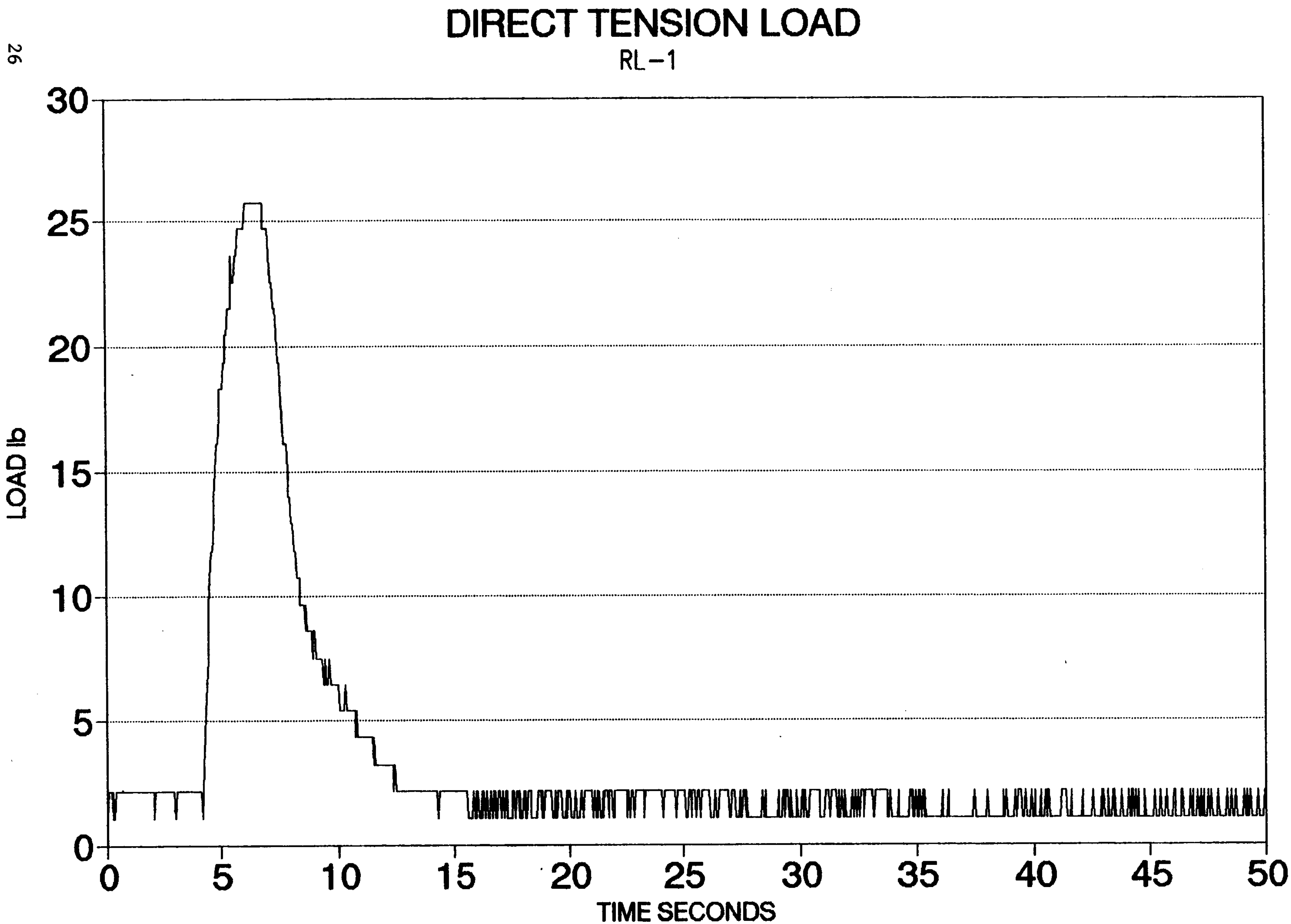

DIRECT TENSION LOAD
RL-1
LOAD lb
30
25
20
15
10
5
0
0
5
10
15
20
25
30
35
40
45
50
TIME SECONDS

Figure 8.

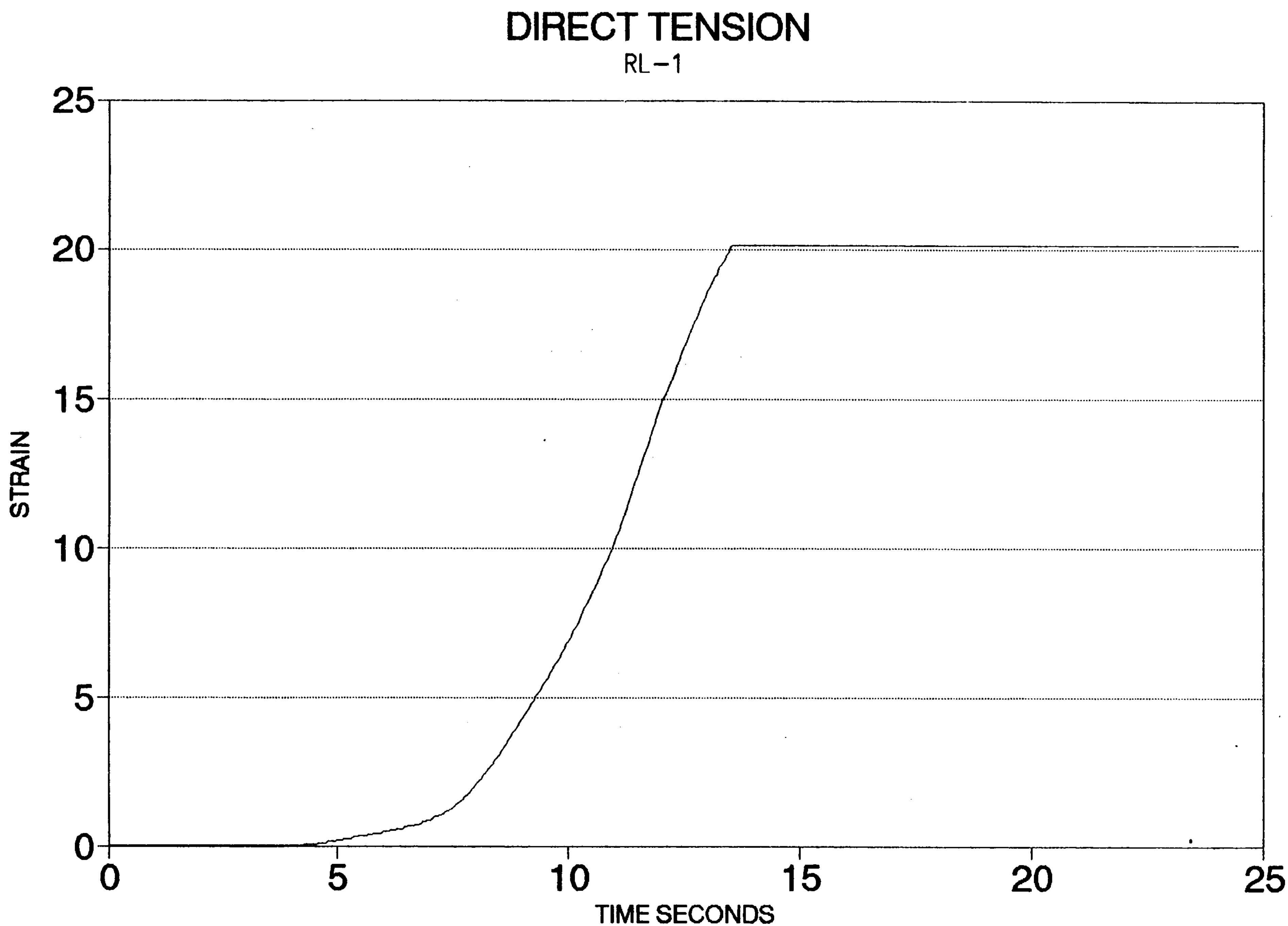
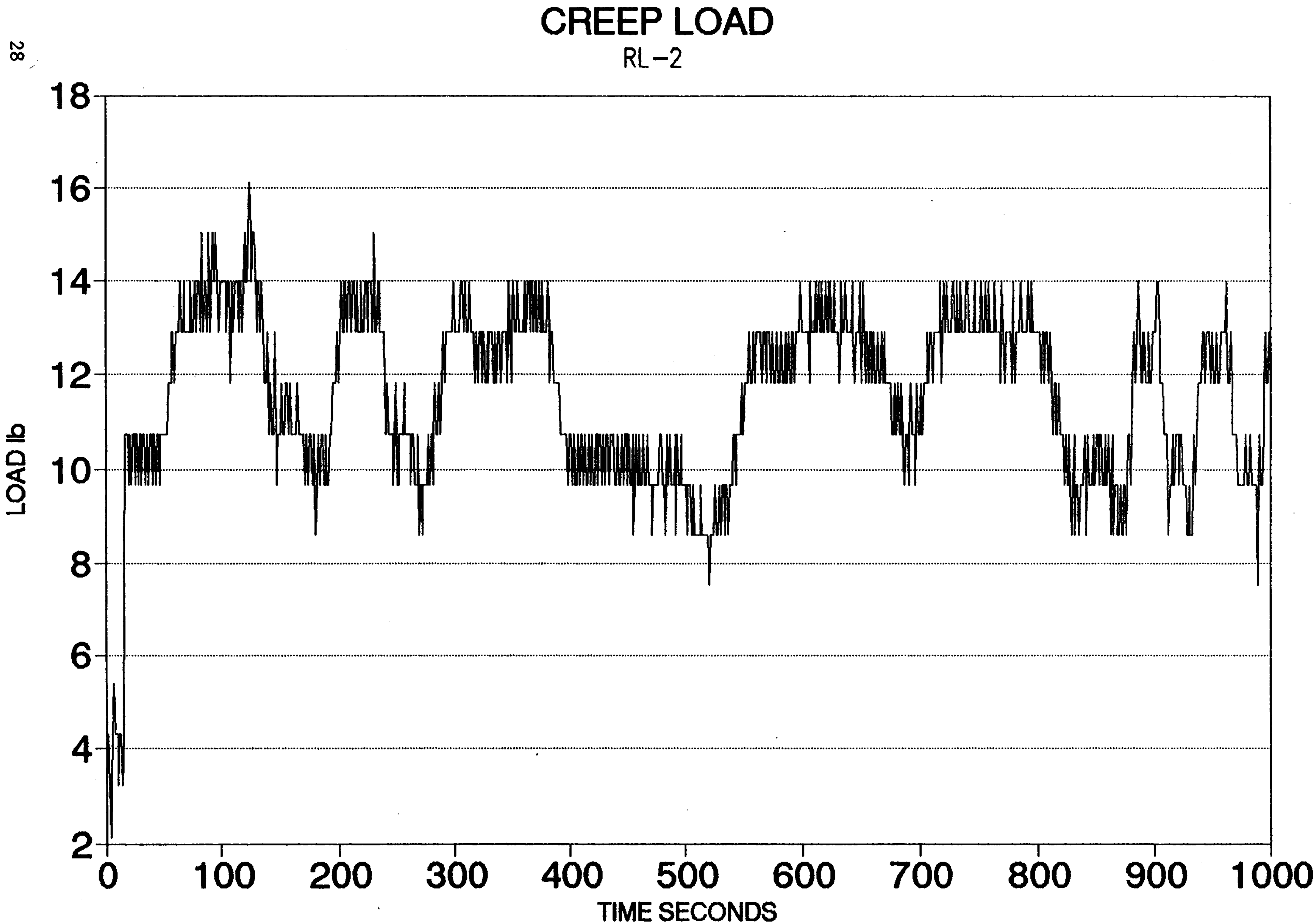


Figure 9.


CREEP LOAD
RL-2
LOAD lb
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16
14
12
10
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6
4
2
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100
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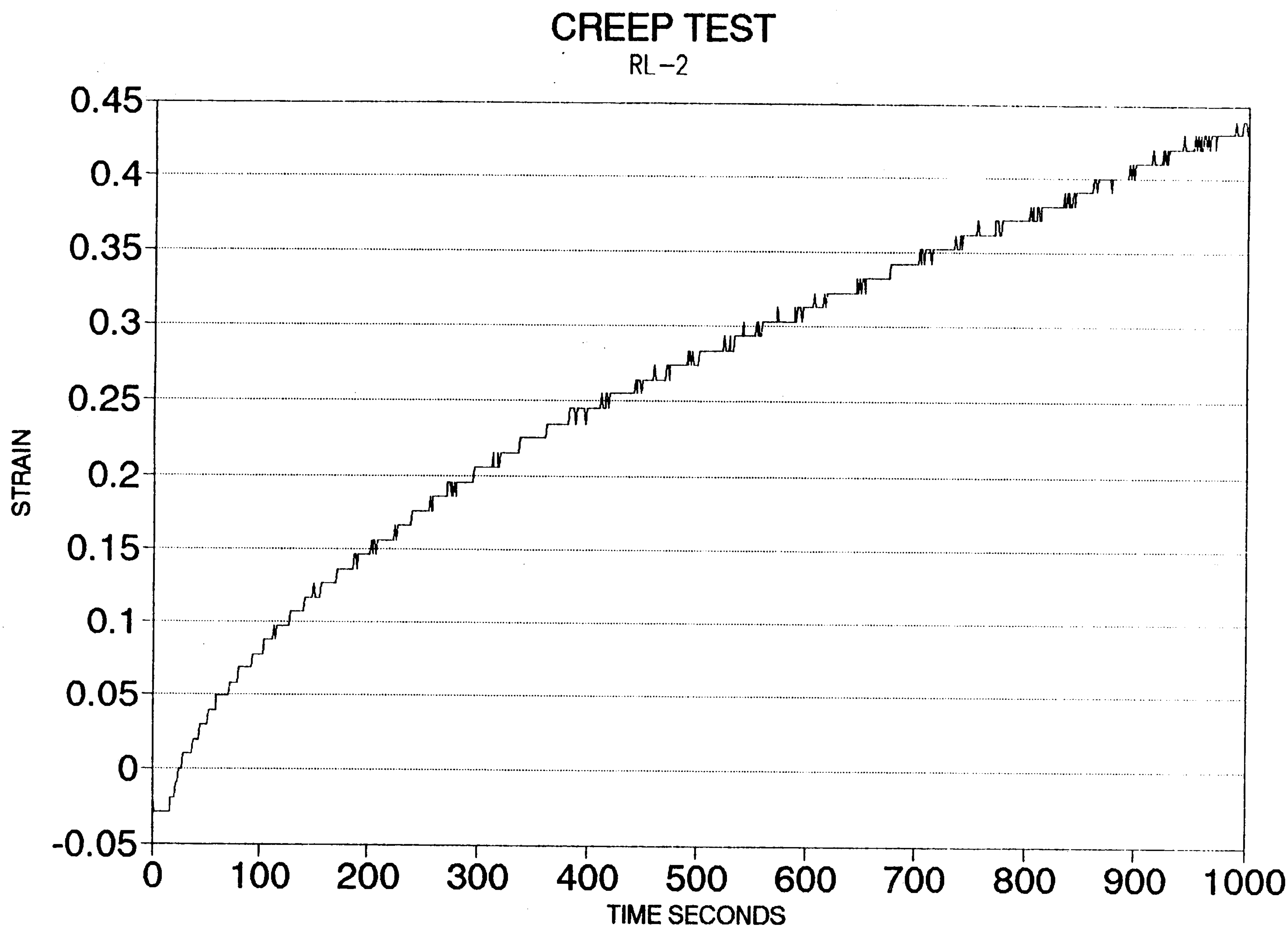
700
800
900
1000
TIME SECONDS

Figure 10.


CREEP TEST
RL-2
STRAIN
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
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0
100
200
300
400
500
600
700
800
900
1000
TIME SECONDS

Figure 11.

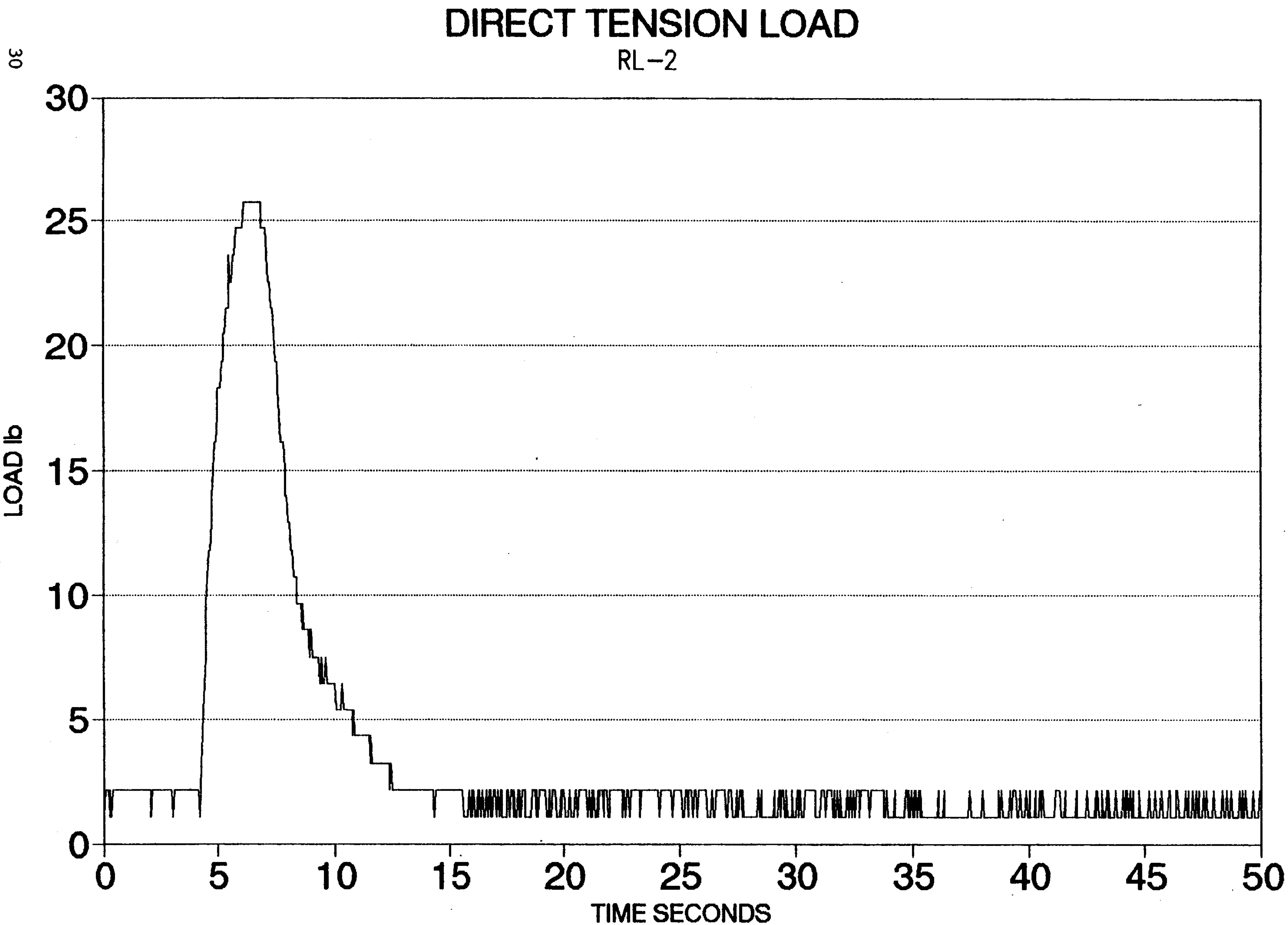
DIRECT TENSION LOAD
RL-2
LOAD lb
TIME SECONDS
0
5
10
15
20
25
30
35
40
45
50

Figure 12.

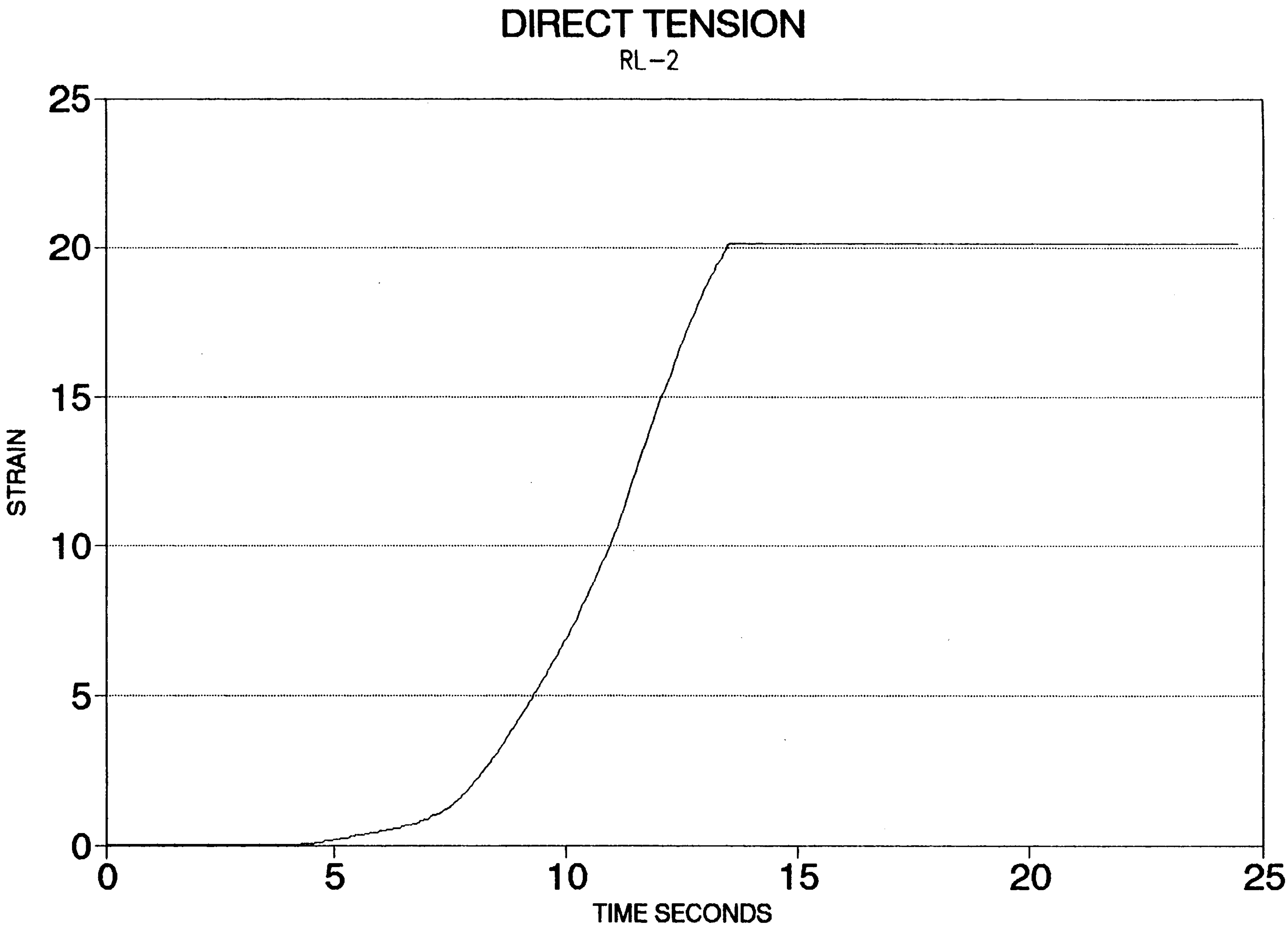

Figure 13.

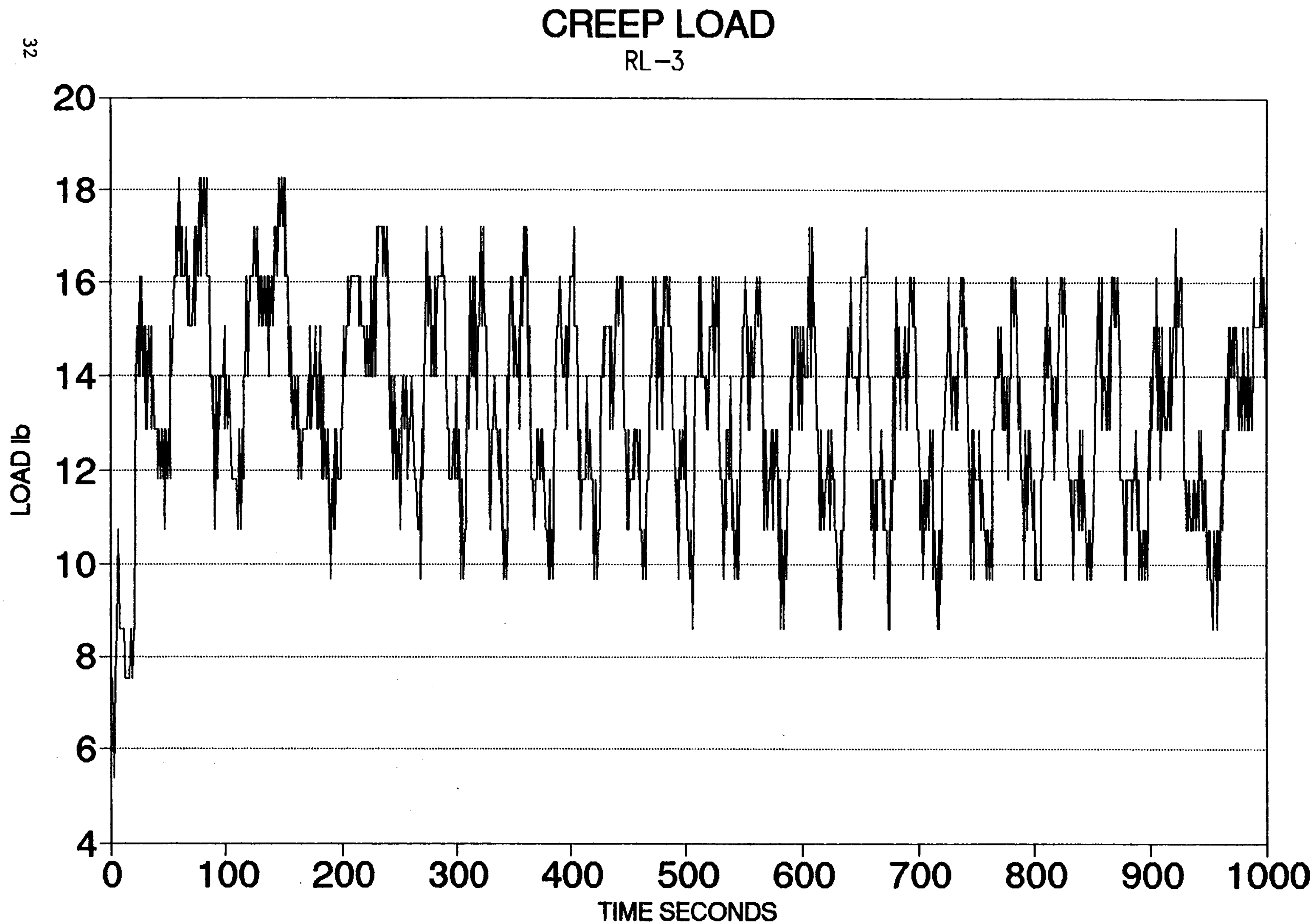
CREEP LOAD
RL-3
LOAD lb
20
18
16
14
12
10
8
6
4
0
100
200
300
400
500
600
700
800
900
1000
TIME SECONDS

Figure 14.

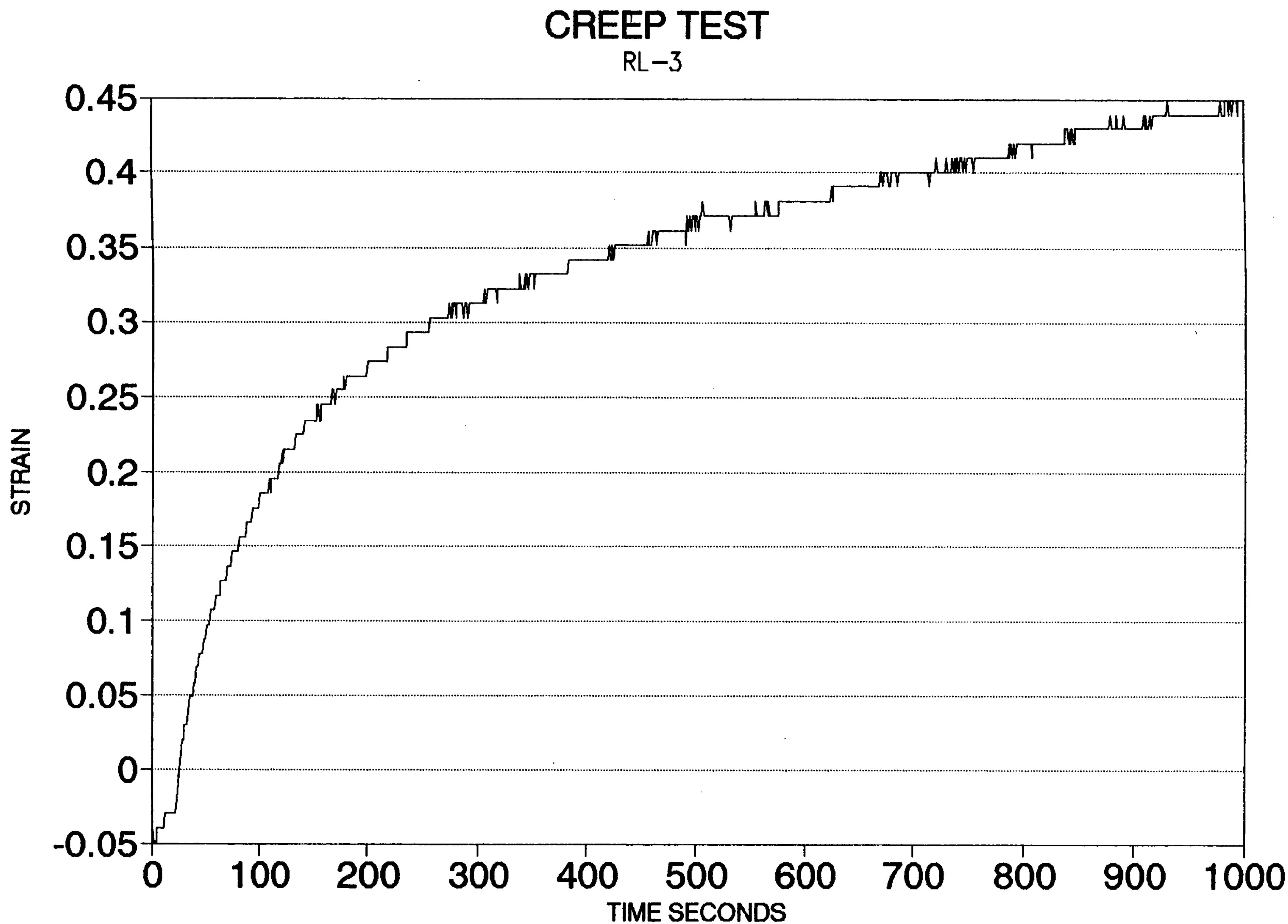
CREEP TEST
RL-3
STRAIN
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
-0.05
0
100
200
300
400
500
600
700
800
900
1000
TIME SECONDS

Figure 15.

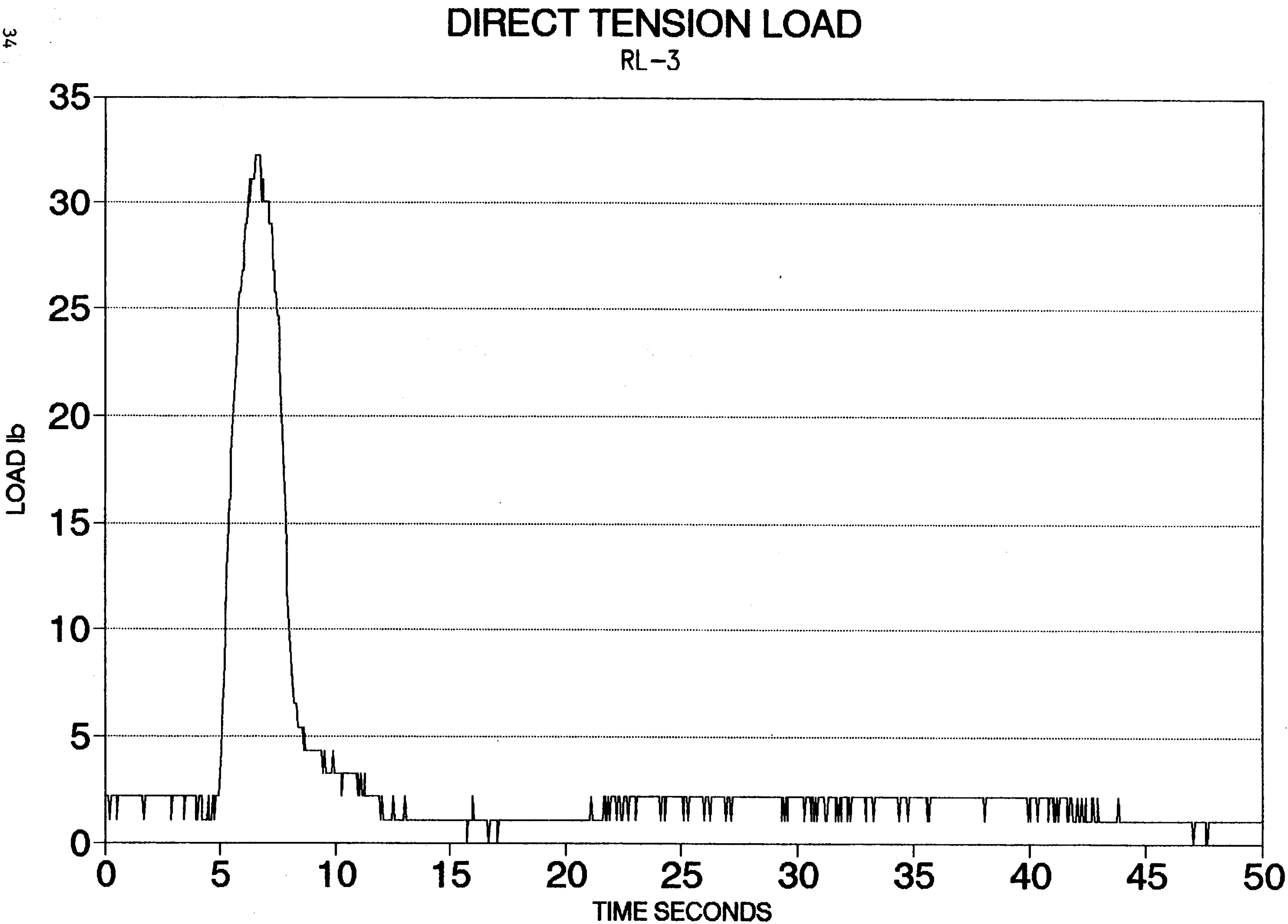
DIRECT TENSION LOAD
RL-3
LOAD lb
0
5
10
15
20
25
30
35
TIME SECONDS
0
5
10
15
20
25
30
35
40
45
50

Figure 16.

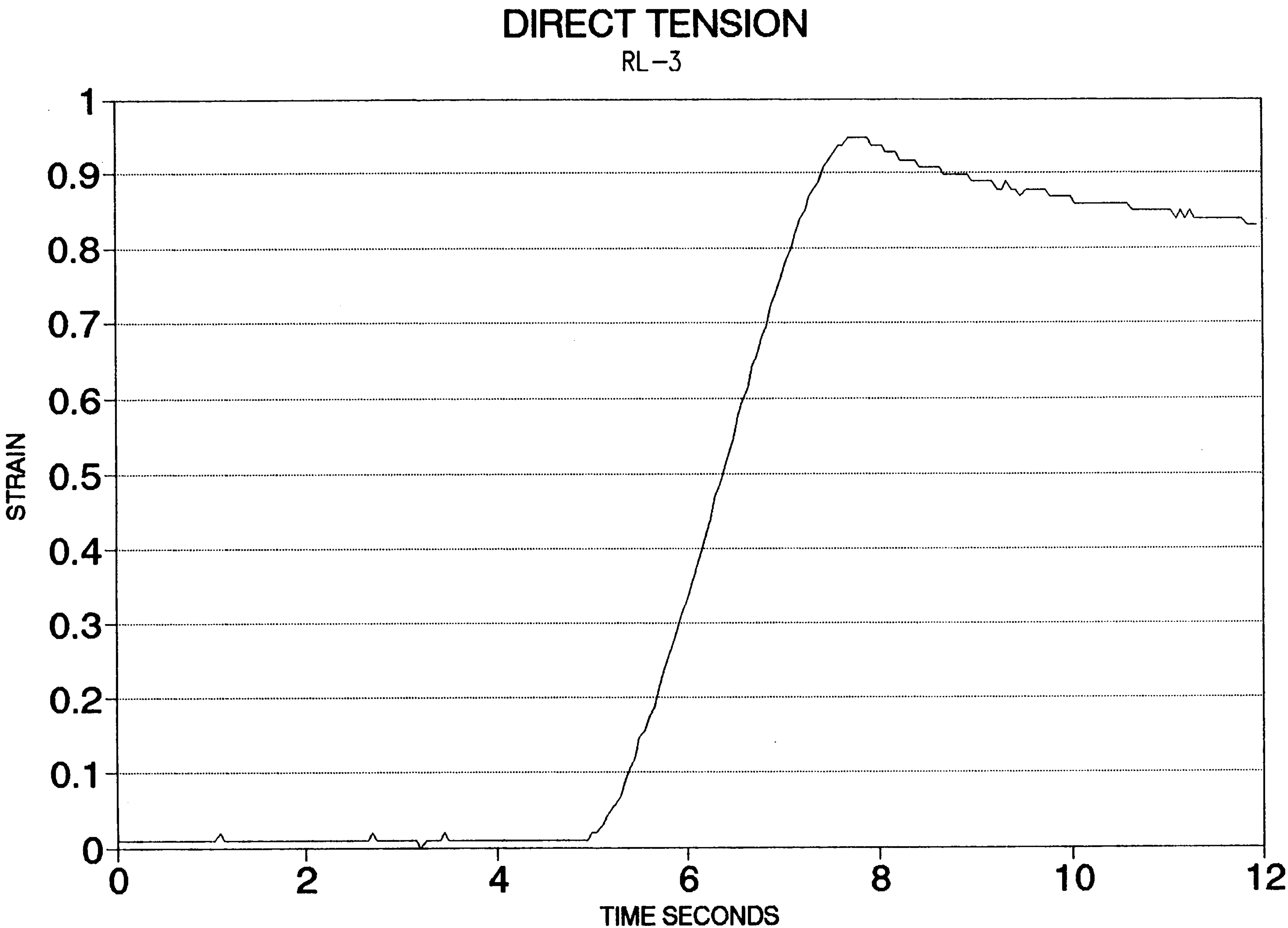
DIRECT TENSION
RL-3
STRAIN
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
2
4
6
8
10
12
TIME SECONDS

Figure 17.

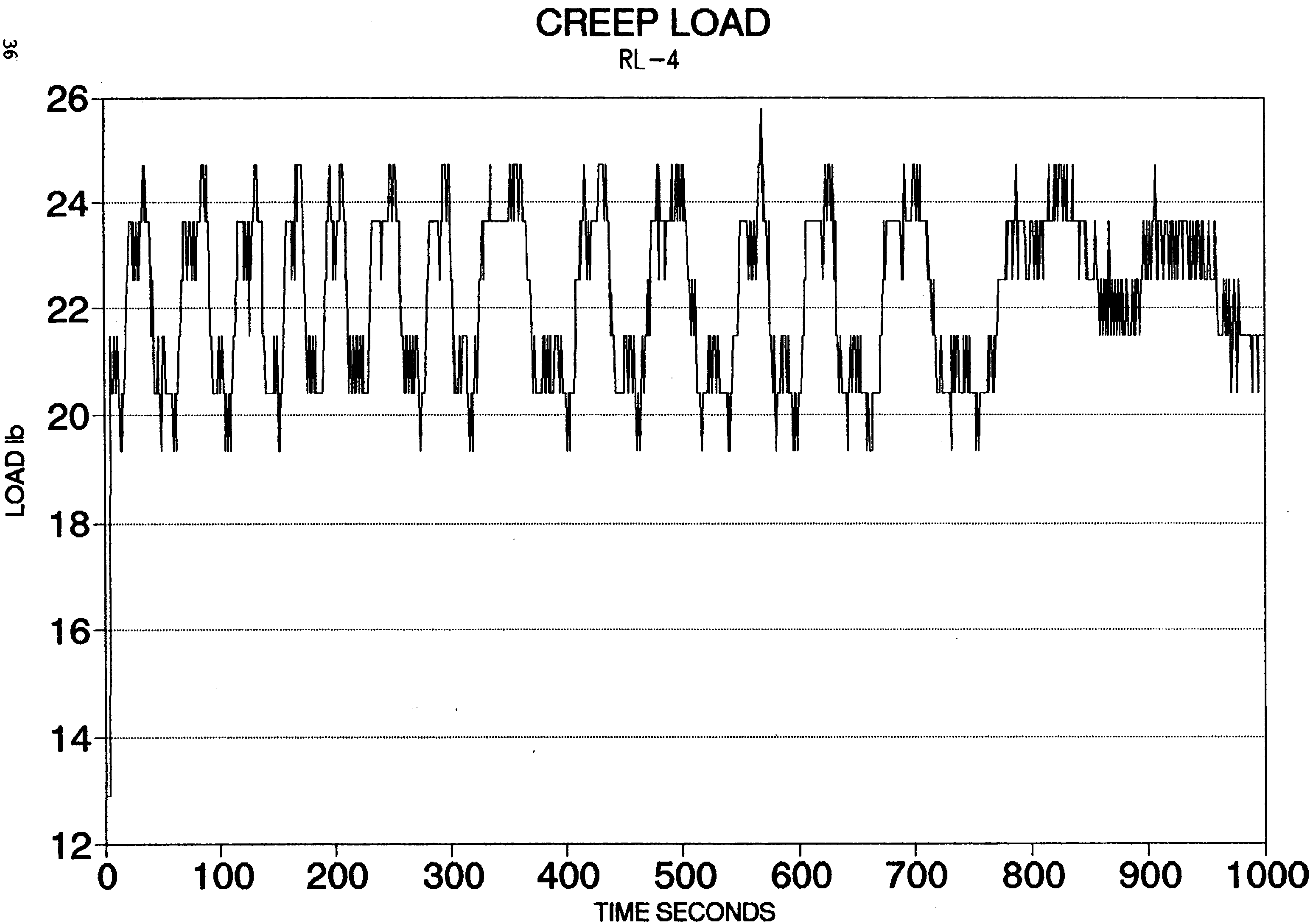
CREEP LOAD
RL-4
26
24
22
20
18
16
14
12
LOAD lb
0
100
200
300
400
500
600
700
800
900
1000
TIME SECONDS

Figure 18.

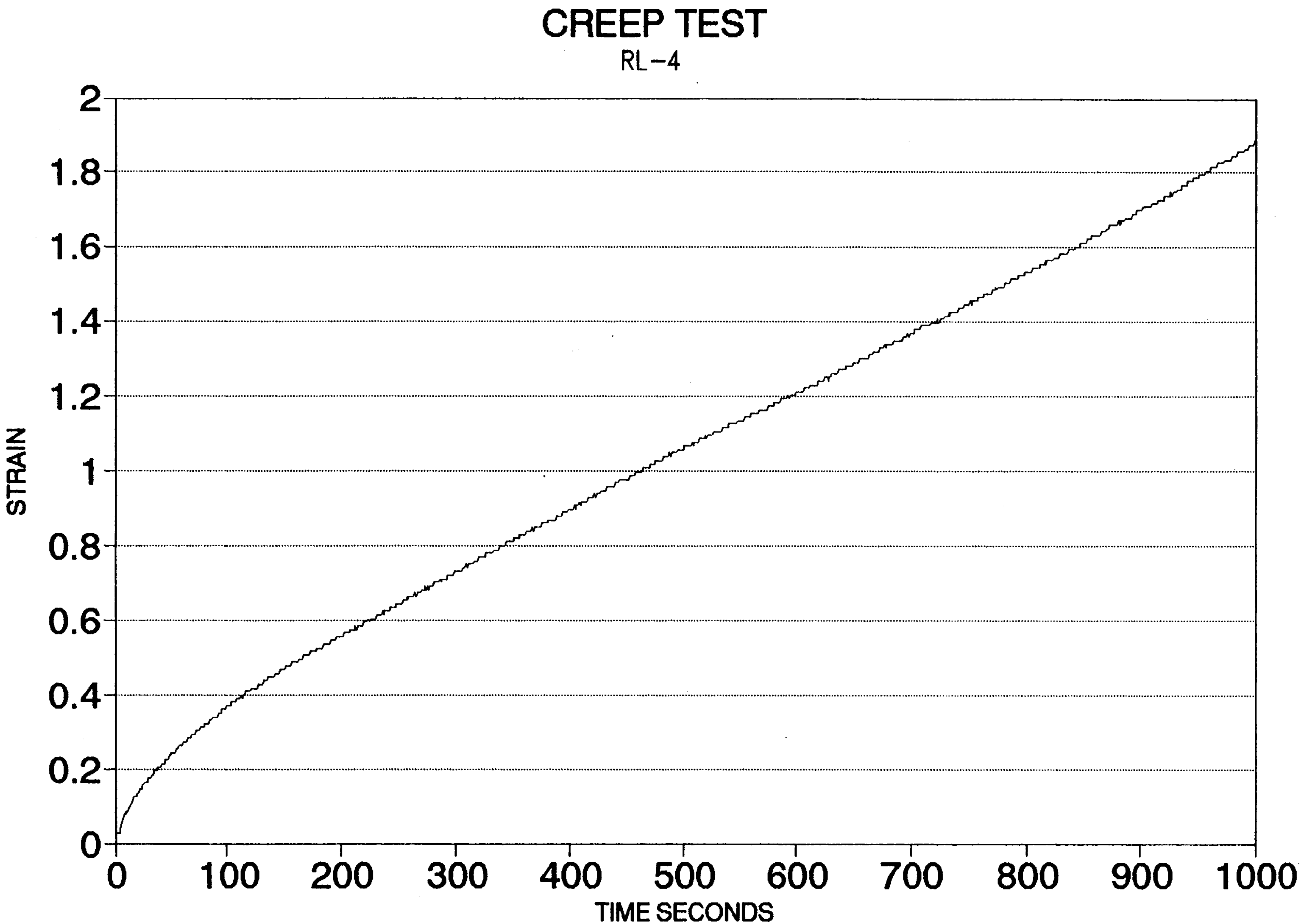
CREEP TEST
RL-4
STRAIN
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
100
200
300
400
500
600
700
800
900
1000
TIME SECONDS

Figure 19.

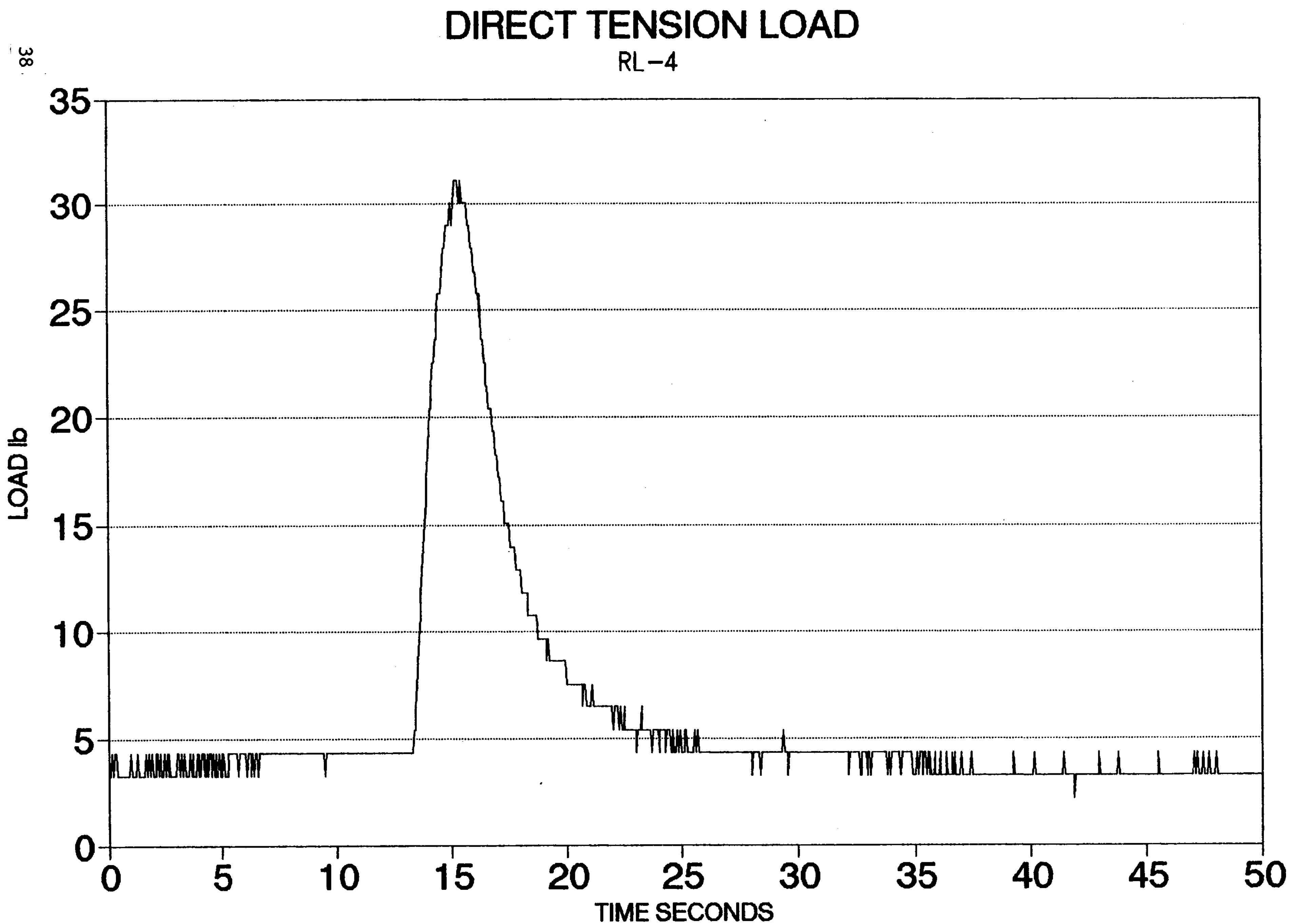
DIRECT TENSION LOAD
RL-4
LOAD lb
0
5
10
15
20
25
30
35
TIME SECONDS
0
5
10
15
20
25
30
35
40
45
50

Figure 20.

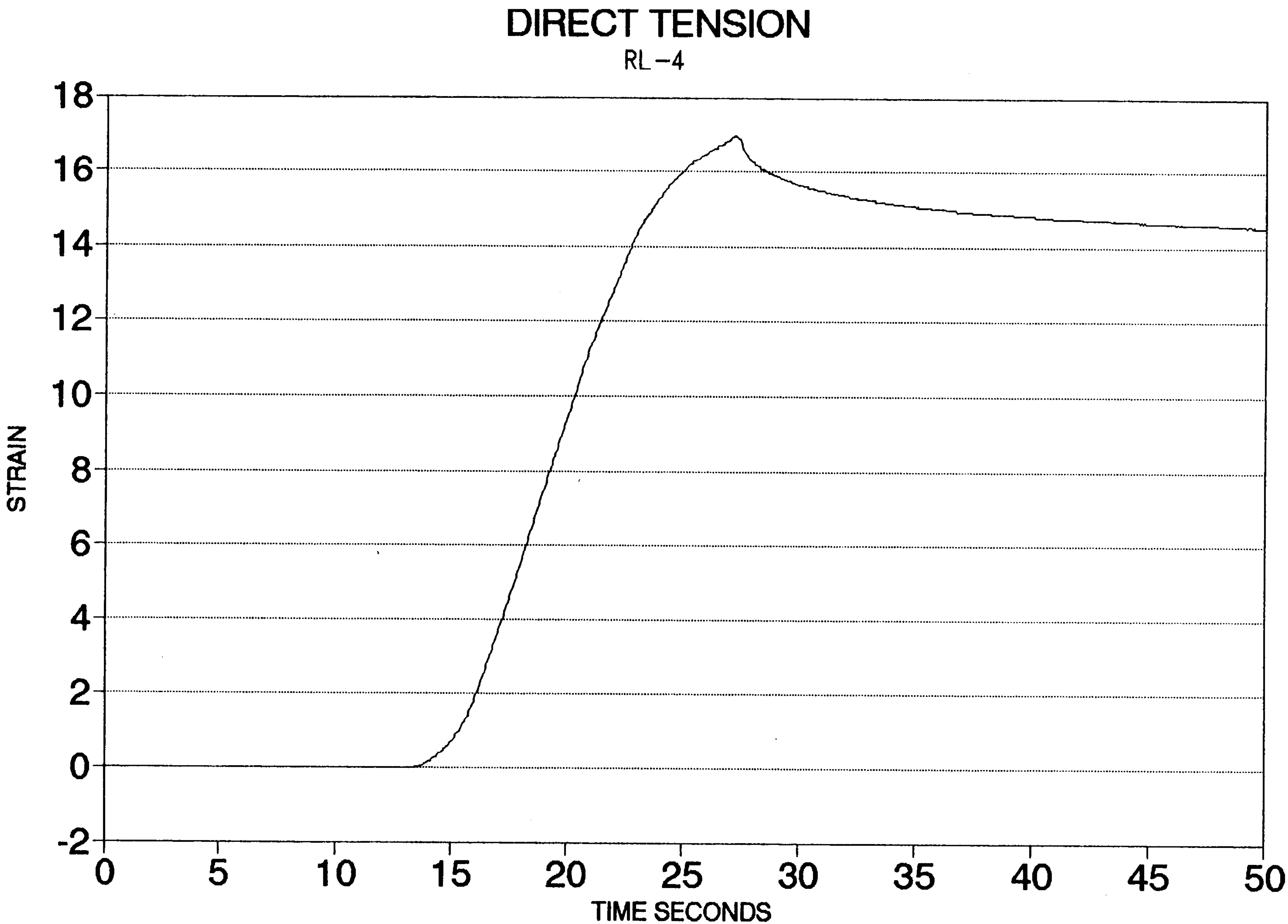
DIRECT TENSION
RL-4
STRAIN
18
16
14
12
10
8
6
4
2
0
-2
0
5
10
15
20
25
30
35
40
45
50
TIME SECONDS

Figure 21.

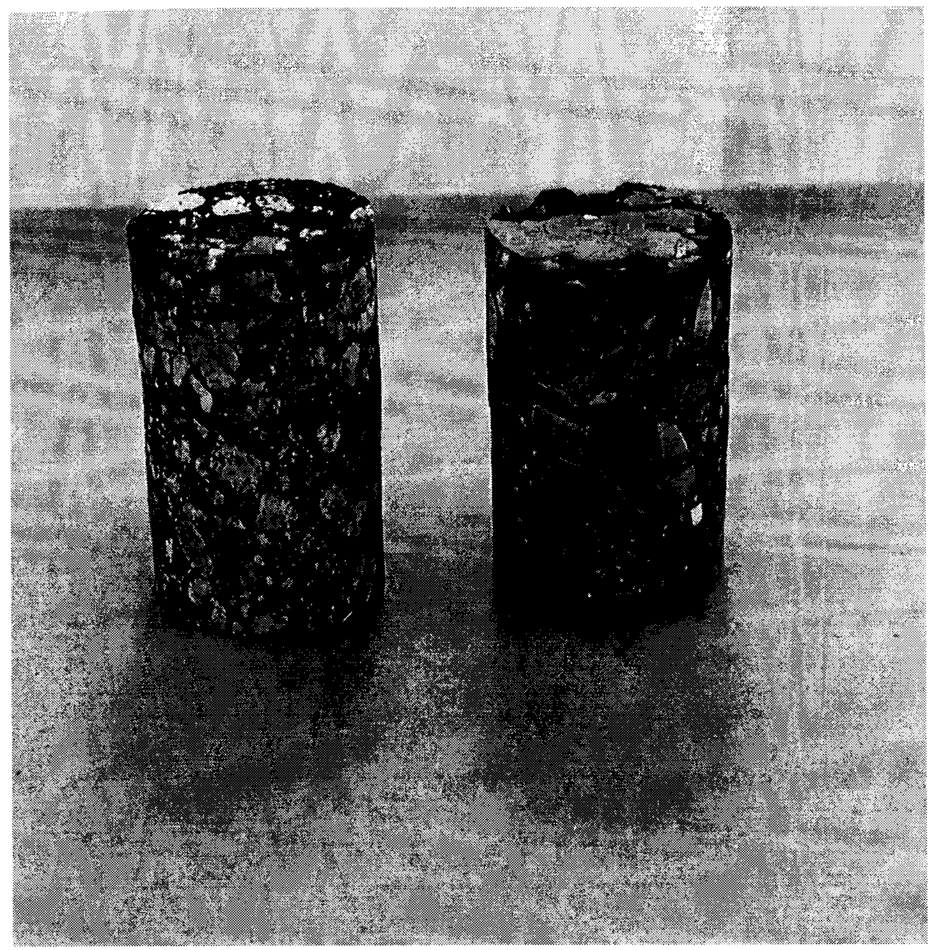

Figure 22. Asphalt Concrete Samples Manufactured with two Different Aggregates after Direct Tension Test.

Asphalt Advisory Committee