AN ABSTRACT OF THE THESIS OF

YUAN-SHOU SHEN for the M.S. in Mechanical Engineering
(Name) (Degree) (Major)

Date thesis is presented OCTOBER 11 1963

Title CREEP STUDIES ON "EXPANDED," "CHUKAR," AND "DRAKE" ALUMINUM CONDUCTORS.

Abstract approved Redacted for privacy
(Major Professor)

This thesis presents the creep properties and the relations between stress and strain of "Expanded 460KV", "Chukar", and "Drake" conductors. The basic theories of the effect of load, material, and temperature on the conductor are also briefly discussed.

The long time creep curve of a conductor appears as a straight line in log-log plot. The stable period of this curve after prestressing is directly affected by the prestress load and time. The conductor's initial strain is increased if the conductor is reeled or severely bent.

The slope of the stress-strain curve of a conductor is only slightly affected by the long time creep. It is also slightly influenced by the initial condition of the conductor. However, the complete stress strain curve will move to the right of where it should be if

the conductor is severely reeled or bent.

Repeated temporary load (wind and ice) will increase the non-elastic elongation of a conductor.

The configuration of stress-strain curve of a conductor is different from that of a homogeneous metal. A hysteresis loop always exists between stress-strain curve of loading and the curve of unloading.

# CREEP STUDIES ON "EXPANDED," "CHUKAR," AND "DRAKE" ALUMINUM CONDUCTORS

by

YUAN-SHOU SHEN

A THESIS

submitted to

OREGON STATE UNIVERSITY

in partial fulfillment of
the requirements for the
degree of

MASTER OF SCIENCE

June 1964

APPROVED:

Redacted for privacy

Professor of Mechanical Engineering

In Charge of Major

Redacted for privacy

Head of Department of Mechanical Engineering

Redacted for privacy

Dean of Graduate School

Date thesis is presented OCTOBER 11, 1963

Typed by Nancy Kerley

ACKNOWLEDGEMENTS

The author is grateful to Professor O. G. Paasche of the Oregon State University Department of Mechanical Engineering for his kind guidance and valuable suggestions and criticisms of this thesis. He is further indebted to Mr. Paul F. Winkelman of Bonneville Power Administration for his suggestions. He is also grateful to Bonneville Power Administration for sponsoring this project.

Finally, the author wishes to express his thanks to Miss JessieMarie Manning for her assistance in typing the graphs.

TABLE OF CONTENTS


| Chapter | | Page |
|---|---|---|
| I | INTRODUCTION | 1 |
| | The Creep of Transmission Lines | 1 |
| | The Aluminum Conductor | 3 |
| II | SCOPE OF THIS THESIS | 5 |
| III | BASIC CONSIDERATIONS OF CONDUCTOR CREEP | 9 |
| | Load on the Conductor | 9 |
| | Creep and Conductor Materials | 10 |
| | Fundamentals of Creep Theory | 11 |
| | The Effect of Temperature on Conductor Creep | 15 |
| | Other Factors Affecting Conductor Creep | 16 |
| | The Effect of Load Change in Creep Strain | 17 |
| IV | EXPERIMENTAL WORK | 19 |
| | The Equipment | 19 |
| | The Specimen and Its Installation | 28 |
| | Loading Procedure | 34 |
| V | RESULTS | |
| | Discussion of Graphs | 37 |
| | The Equations Representing Observed Data | 59 |
| | Discussion of Data | 61 |
| VI | CONCLUSIONS | 68 |
| VII | RECOMMENDATIONS | 70 |
| | BIBLIOGRAPHY | 71 |
| | APPENDIX | 73 |

## LIST OF FIGURES


| Figure | | Page |
|---|---|---|
| 1 | Stress Strain Relationship in Creep Test. | 12 |
| 2 | Creep Recovery. | 12 |
| 3 | Schematic Diagram of Conductor Creep Testing Equipment. | 20 |
| 4 | Exterior of Conductor Creep Testing Equipment. | 21 |
| 5 | Schematic Diagram of Loading System. | 22 |
| 6 | Loading End of Conductor Creep Testing Equipment. | 23 |
| 7 | Take-Up End of Conductor Creep Testing Equipment. | 24 |
| 8 | Interior of Conductor Creep Testing Equipment. | 25 |
| 9 | Dial Gage. | 26 |
| 10 | Closeup of Dial Gage Showing Tension Spring and Mounting Clamp. | 27 |
| 11 | Closeup of Plastic End Fitting. | 30 |
| 12 | Cutaway of Plastic End Fitting. | 31 |
| 13 | Position of Levelling Chains and Levelling Device. | 33 |
| 14-25 | Long Time Creep Curve. | 103-114 |
| 26-31 | Stress Strain Curve. | 115-120 |
| 32-43 | Stress Strain and Creep Curve. | 121-132 |
| 44-49 | The Superimposed Curves. | 133-138 |

## LIST OF TABLES


| Table | | Page |
|---|---|---|
| I | Properties of Test Specimens. | 6 |
| II | Test Condition | 7 |
| III | Lever Load and Lever Ratio. | 29 |
| IV | Test Results. | 66 |
| V | Stress Distribution. | 67 |
| VI-XXIII | Creep and Final Stress Strain Data. | 73-102 |

# CREEP STUDIES ON "EXPANDED," "CHUKAR," AND "DRAKE" ALUMINUM CONDUCTORS

## I. INTRODUCTION

### 1. The Creep of Transmission Lines

Transmission lines are the most important links in electric power supply systems. These lines transmit power from the source, a dam or steam power plant, to the point of use, an urban or industrial area. Because distances over which the power is transmitted are relatively great, energy losses must be minimized by using high voltages and low currents. Also three-phase alternating power is usually transmitted. A transmission line, therefore, consists of three conductors - one for each phase.

The conductors of a transmission line are strung on steel towers which provide support and elevate them at safe distances above the ground. These safe distances, or clearances, are specified by a safety code and should be maintained throughout the life of the transmission line. However, experience has indicated that the conductors tend to increase in length and sag during service. Such an increase in length is known as "creep" and decreases the clearance. Excessive amounts of creep would lead to excessive sags and a dangerous loss of clearance.

With the continual increase in use of electric power comes

the necessity to transmit greater quantities over the same transmission lines and over additional lines. At the same time crowded conditions in urban areas mean fewer rights of way available for construction of transmission lines. Thus the power transmission engineer is forced to develop newer methods of power transmission such as the use of higher voltages and direct current transmission. At the same time there is greater emphasis on economy, both in transmission line construction and operation. For greater economy in construction designs utilizing fewer towers (thus longer spans), lower towers (thus less safety in clearance), and minimum conductor size necessary to carry the electrical loads are being developed. Longer spans increase the tension on the conductor (as does a smaller conductor) and this increases the rate of creep which, in turn, further reduces clearance. Lower towers, of course, have the same effect.

Thus the problem of creep in electrical conductors is becoming an important factor in transmission line design. The transmission line design engineer is concerned with two phases of the creep problem. The first is creep which occurs during construction of the line. This is a short time effect but involves relatively large changes of length. The second is creep which occurs during the life of the line. It is thus a long time effect. This thesis will be

concerned with both phases of the creep problem.

## 2. The Aluminum Conductor

Owing to its low electrical resistance to weight ratio, and high strength to weight ratio, aluminum conductor has almost entirely replaced copper conductor in construction of high voltage transmission lines. The first overhead high voltage transmission line made of 98 percent aluminum was installed in 1898. At present, over 90 percent of the transmission line in the United States employs aluminum cable. The aluminum may be alloyed to increase its strength or the conductor may employ steel reinforcement for the same purpose.

Steel reinforced aluminum conductor (Aluminum Conductor Steel Reinforced, or ACSR) was first introduced in 1908. ACSR is a composite, concentrically stranded conductor consisting of one or more layers of concentric-lay stranded Electrical Conductor (EC) grade hard drawn aluminum wires helically stranded around an inner core of high strength galvanized alloy steel. This steel core itself may be a single wire or it may be concentric lay stranded of one or more layers of zinc coated steel wire depending on the size of the conductor and its design.

In high voltage transmission ACSR is larger in diameter and

much stronger than an all aluminum conductor of the same electrical rating. The steel core usually contributes 55 to 60 percent of the total strength (1, p. 885), but has a higher electrical resistance. The strength to weight ratio is usually about twice that of copper of equivalent direct current resistance. Hence, ACSR permits longer spans and fewer towers or poles (1, p. 884, 885).

Aluminum alloys have been developed in which higher strength can be obtained than in the EC grade but with a small loss in electrical conductivity. Such aluminum alloys have been used to manufacture conductors either to replace the steel core or part, or all, of the EC grade aluminum.

## II. SCOPE OF THIS THESIS

A contractual agreement was entered into between The Bonneville Power Administration (BPA) and Oregon State University (OSU) for studies of the creep characteristics of all aluminum, ACSR, and Expanded 460KV conductors (3, p. 4). The studies were to include the following:

I. Determination of the effects of various combinations of prestress tension and time on conductor stabilization and long time creep.

II. Determination of the effect of conductor creep on the initial ($E_i$) and final ($E_f$) modulus of elasticity.

III. Determination of the cumulative effect of the non-elastic elongation of a conductor from creep and from a temporary load increase involving the difference in $E_i$ and $E_f$.

In this thesis Expanded 460KV and ACSR conductors have been studied. The specifications of the conductors tested are listed in Table I.

The test conditions for each conductor are listed in Table II. Each conductor was assigned a code number. The code number used in this thesis consists of four groups of notations. The first group denotes the conductor type and manufacturer. The second group

Table I

Properties of Test Specimens

| Type Code | Expanded 460KV | Expanded 460KV (AWR) | Chukar ACSR | Drake ACSR |
|---|---|---|---|---|
| Manufacturer* | S. E. | ALCOA | Kaiser | S. E. |
| Code Symbol | X(SE) | X(AWR)* | C(K) | D(SE) |
| Rated Strength (lb) | 82,800 | 69,900 | 53,650 | 31,200 |
| Strength-Weight Ratio | 25,300 | 24,500 | 25,900 | 29,300 |
| Copper Equivalent (MCM) | 1,707 | 1,621 | 1,119 | 500 |
| Diameter (in) | 2.136 | 2.145 | 1.602 | 1.108 |

*S. E.: Southern Electric Company

ALCOA, AWR: Aluminum Company of America, Wire Rope Design

Kaiser: The Kaiser Aluminum and Chemical Company

Stranding:

X(AWR): 34 x .1727" EC Al Wires
18/12/6/1 (7 x .0859") 5005 Al Alloy Rope Lay

X(SE): 36/30/24 x .1643" EC Al Wires
Core: 12 x .1443" Steel and 12 Shaped EC Al Wires

K(C): 30/24/18/12 x .1456 EC Al Wires
12/6/1 x .0874 Steel Wires

D(SE): 16/10 x .1749 EC Al
6/1 x .136 Steel Wires

Table II

Test Condition

| Code | Pretension | | | Creep Tension | | | Remarks |
|---|---|---|---|---|---|---|---|
| | Percent of Creep Tension | Load Pounds | Time Hour | Percent of Rated Strength | Load Pounds | Time | |
| X(SE)-100/1-20 | - | - | - | 20 | 14,000 | 2674.6 | Creep tension is |
| X(SE)-125/1-20 | 125 | 17,500 | 1 | 20 | 14,000 | 2693.8 | based on rated |
| X(SE)-125/1-20-R | 125 | 17,500 | 1 | 20 | 14,000 | 2741.9 | strength of 70,000 |
| X(SE)-150/1-20 | 150 | 21,000 | 1 | 20 | 14,000 | 2741.2 | pounds. |
| X(AWR)-125/1-20 | 125 | 17,500 | 1 | 20 | 14,000 | 2674.4 | Ditto |
| X(AWR)-150/1-20 | 150 | 21,000 | 1 | 20 | 14,000 | 2674.2 | Ditto |
| C(K)-100/1-20 | - | - | - | 20 | 10,720 | 2455.3 | |
| C(K)-125/1-20-1 | 125 | 13,400 | 1 | 20 | 10,720 | 2456.0 | From Reel 7 |
| C(K)-125/1-20-2 | 125 | 13,400 | 1 | 20 | 10,720 | 2455.8 | From Reel 2 |
| C(K)-125/16-20 | 125 | 13,400 | 1 | 20 | 10,720 | 2456.8 | |
| C(K)-125/1/4-20 | 125 | 13,400 | 1/4 | 20 | 10,720 | 2456.5 | |
| C(K)-150/1-20 | 150 | 53,650 | 1 | 20 | 10,720 | 2455.5 | |

C(K) Three specimens for stress strain test
D(SE) Three specimens for stress strain test

denotes the prestressing load and time. The third group denotes the creep load. The fourth group, if any, denotes some different initial condition of the conductor. For instance, C(K)-125/1-20-2 represents a conductor of the Chukar type made by Kaiser Aluminum and Chemical Corporation. In this experiment the conductor was first prestressed to 125 percent of the creep load for one hour. Its long creep load was 20 percent of its rated strength. It was the second conductor of the same type to be tested under the same conditions.

# III. BASIC CONSIDERATIONS OF CONDUCTOR CREEP

## 1. Load on the Conductor

The constant load applied to a conductor in service is its own weight. In actual service, in addition to its own weight, the conductor is also subjected to ice and wind loads. The amount of this load depends on the climate of a particular area. For design purposes, the ice accumulation is usually considered as half inch maximum in thickness acting vertically. The wind load is generally assumed from eight to twelve pounds per square foot acting horizontally. The resultant load ($W_e$) on the conductor is

$$W_e = \sqrt{W_v^2 + W_h^2} \quad ,$$

where

$W_v$ = vertical weight of conductor and ice in pounds per linear foot;

$W_h$ = horizontal wind load in pounds per linear foot.

Take "Drake" conductor as an example. Its own weight is 1.098 pounds per linear foot. But its maximum design load (weight, ice, and wind loads combined) is assumed to be 2.523 pounds per linear foot, i.e. 229.0 percent of the dead weight. Although the load on a conductor in service is variable, due to icing and wind conditions, the average load which the conductor experiences is known as

"everyday stress" (EDS). For an average dead end span of 1000 feet the EDS is assumed to be approximately 20 percent of the rated strength (RS) of the conductor (12, p. 2).

The ratio of load plus bare weight to bare weight of conductor decreases as the diameter of the conductor increases. This means that a larger conductor's everyday stress is closer to its maximum tension. Because of this fact, for cables of the same type of stranding, creep increases as the conductor diameter increases and as the steel core area decreases with respect to the total conductor cross-section (13, p. 2).

## 2. Creep and Conductor Materials

Among the three common materials used in the manufacture of conductors, steel shows the lowest amount of creep, next is copper, and aluminum has the most for the same loading condition (9, p. 2). ACSR is a composite material of steel and aluminum. Hence, the creep of ACSR conductor depends on the amount of steel in the conductor. Past experimental data (13, Figure 2) show that the creep strength of ACSR is a linear function of the percentage steel in the conductor, i.e. conductors with less steel show more creep.

## 3. Fundamentals of Creep Theory

Experience indicates that creep in metals usually progresses in three stages. In the first stage, immediately after application of the creep load, the initial high rate of deformation rapidly decreases until it approaches a steady or constant rate. This constant rate characterizes the second stage of creep. In the last stage the creep rate increases, terminating in fracture of the material. Although the rate of creep in the second stage is generally considered to be constant it may not actually be that. This stage is most likely a long time transient stage between the decelerating first stage and the accelerating third stage. This thesis will be concerned with the first and second stages of creep only.

The stress-strain relations of a conductor in a creep test can be explained by means of Figure 1. For a certain applied load the deformation of a conductor may be explained by the formula:

$$T_t = D + P + C_t \quad ,$$

where

$T_t$ = total deformation at time t;

$D$ = initial elastic deformation;

$P$ = initial plastic deformation;

$C_t$ = creep at time t.

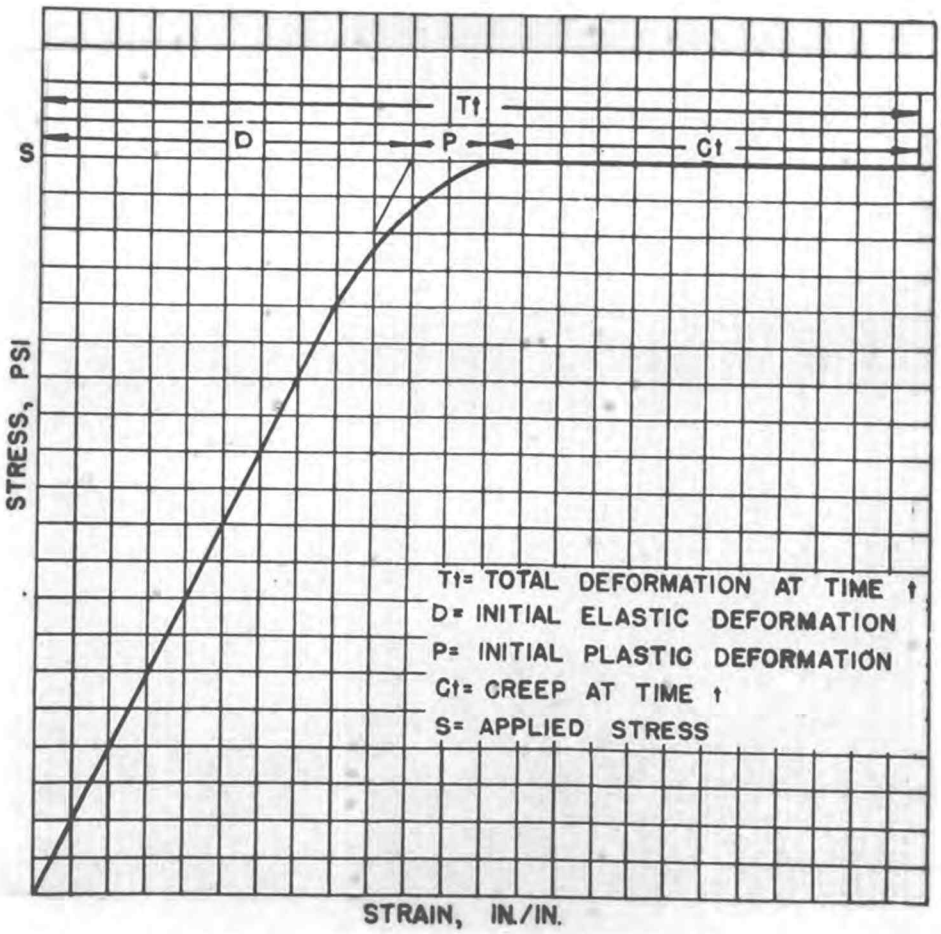



Figure 1. Stress Strain Relationship in Creep Test.

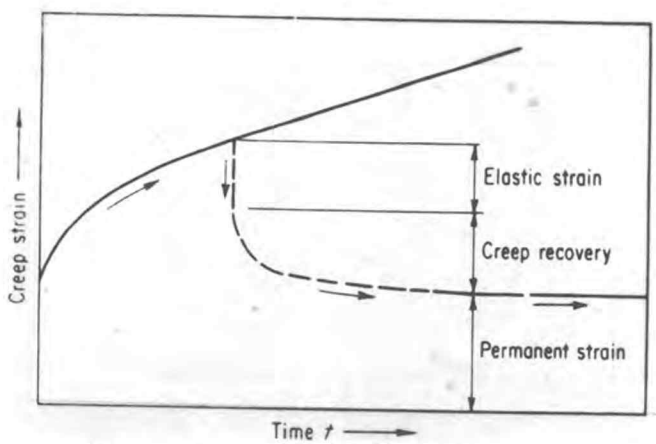



Figure 2. Creep Recovery.

When the load is released after time $t$ the conductor will not return to its original length but will retain an additional length $P + C_t$ (9, p. 3). This phenomenon is shown in Figure 2. If the conductor is unloaded during a creep test deformation will follow the dotted curve (5, p. 350).

Past experiments have shown that creep strain versus time data at normal tensions and at constant temperature for the first two stages of creep closely follow a straight line on a log-log scale. Thus the creep strain as a function of time can be represented by the following equation (6, p. 772):

$$\epsilon = B\,(t)^n,$$

where

$\epsilon$ = creep strain in inch/inch;

$B$ = a constant, it is the value of creep strain at unit time for a given slope curve;

$n$ = a constant, the slope of the creep curve;

$t$ = time.

Hence, prediction of long time creep behavior from short time tests can be made by extrapolating this straight line. The American Society for Testing and Materials (ASTM) recommends that test data cover ten percent of the period for which creep is to be determined (2, E-139). In the case of conductor the Aluminum Company of

America (ALCOA) has found that the elongation due to creep during the first ten years under tension is roughly equal to the creep which occurs during the next 90 years (9, p. 3).

Various experiments also show that increasing creep tensions shift the creep strain versus time curves vertically upward without appreciable change in slope. Hence, in the equation above "B" increases with the increase of tensile load and "n" is independent of load.

The above discussion is based upon curves which are plotted with log-log scale. The creep strain rate ($\dot{\epsilon}_c$), which is the slope of creep strain versus time curve in rectangular coordinates, depends on the stress and temperature. One of the most useful empirical generalizations is that the minimum creep rates can be represented as

$$(\dot{\epsilon}_c)_{min} = (\frac{d\epsilon_c}{dt})_{min} = K\sigma^c$$

Here $\sigma$ is stress, and k and c are constants; both depend upon temperature (4, p. 11). From this equation we can see that the slope ($\epsilon_c$) of the creep strain versus time curve increases with the increase of stress.

A more generalized formula is given as

$$\dot{\epsilon} = A \exp [\Delta H + f(\sigma)]/_{RT}$$

where $\Delta H$ approximates the energy of self-diffusion of matrix metal

as long as precipitation and aging reactions are not prominent, R is the gas constant, T is the absolute temperature, and $f(\sigma)$ is a stress dependent function.

## 4. The Effect of Temperature on Conductor Creep

Temperature is one of the important factors affecting the creep properties of conductor. From limited data it is observed that the slopes of the creep strain versus time curves for a conductor under low load (20 percent of rated strength) in log-log scale reveal little significant change with the change of testing temperature. When the loads are high (40 percent and 60 percent of rated strength) the slopes of the curves tend to increase with temperature (8, p. 3). These facts indicate that an increase of temperature increases the creep rate. Modern developments in power transmission design require the conductor to be operated at temperatures higher than experienced in the past. In the case of ACSR, as the temperatures increases, the mechanical stress shifts from the aluminum strands to the steel core due to the higher thermal expansion coefficient in the aluminum. In the case of all aluminum conductor creep may become serious as the temperature increases (8, p. 5). A test on 19-strand all-aluminum conductor at room temperature and $200^{\circ}$ F for several tensions revealed that creep at $200^{\circ}$ F was about five times

that at room temperature (8, p. 5).

In case of an installed transmission line the conductor tension decreases as the sag increases. Thus, the increased creep rate because of higher temperature is compensated to some extent by the reduced tension (14, p. 1547, H. H. Rodee's discussion).

### 5. Other Factors Affecting Conductor Creep

Conductors studied in this thesis were manufactured from a combination of wire sizes, or wires with tubes, and of two different materials. The variations in design, manufacture, and shipment also affect the creep characteristics of conductor. These are discussed below.

(a) The conductor design: Except in standardized designs each manufacturer has his own design pattern. Conductors from different manufacturers may all meet the specified physical and mechanical properties but their creep properties may be different. In addition, the stranding (type and length of lays) of each conductor will influence the amount of energy required for stretching, thus influencing the configuration of the stress-strain curve.

(b) The manufacturing method: The degree of the strand tightening, during and after the manufacturing, influences the creep characteristics of the conductor greatly. Loose stranding will

produce extra non-elastic elongation.

(c) The shipping method: In order to ship and store conductors in a practical way they are wound around a reel after manufacturing. Conductors near the center of the reel have a smaller radius of curvature and keep this helical form after unwinding. During test, or under actual load, extra non-elastic elongation will occur due to the straightening of this curvature.

### 6. The Effect of Load Change in Creep Strain

If a conductor is stressed at a high load for a period of time, then the load is reduced, the creep strain will cease for a time. The delay period will last until the creep strain of the higher load corresponds to the strain of the lower load. This delay period, which appears as a flat portion in the creep strain time curve, is called "stable period." After the stable period normal creep continues. The stable period can be controlled by means of a prestressing treatment such as a high load for a short time or a low load for a longer time.

This stable period is of interest during the installing of conductors in transmission lines. Since the conductor starts to creep at the instant of being installed it is difficult to maintain equal sags between two conductors. This problem becomes more serious in

bundle construction, or in matching new to old conductor, because small variations of a few inches between the sags of the conductors of one bundle can lead to undesirable power loss. This difficulty is overcome by means of prestressing. Having been prestressed the conductors will cease to creep for a certain period. Thus the conductors can be slacked off, sagged to required clearance, and be clipped in during this period.

# IV. EXPERIMENTAL WORK

## 1. The Equipment

The complete equipment had been designed, built and calibrated, before the experiments conducted for this thesis and have been completely described previously (7, p. 2-18). Hence, only a brief description will be given here. The complete setup is shown in Figures 3, 4, 5, 6, 7 and 8.

(1) The temperature control: Variations in ambient temperature cause the specimens and strain measuring instruments to expand and contract. These changes of dimension affect the test readings greatly. Therefore, the loading columns, specimens, and extensometers were housed in an air conditioned room. The temperature of this room was maintained within the range of $75 \pm 3^{\circ}$ F.

(2) The deformation measuring equipment, The Extensometer: The gage length, over which strain measurements for each conductor were made, was 200 inches. Two clamp blocks were placed at the ends of the gage length. The extensometer rod was held tightly at one end and its dial indicator was held at the other end (Figures 9 and 10). These two clamp blocks were firmly clamped on the conductor. A slight tension was applied to the extensometer rod so that the dial indicator would indicate the value of either the extension or

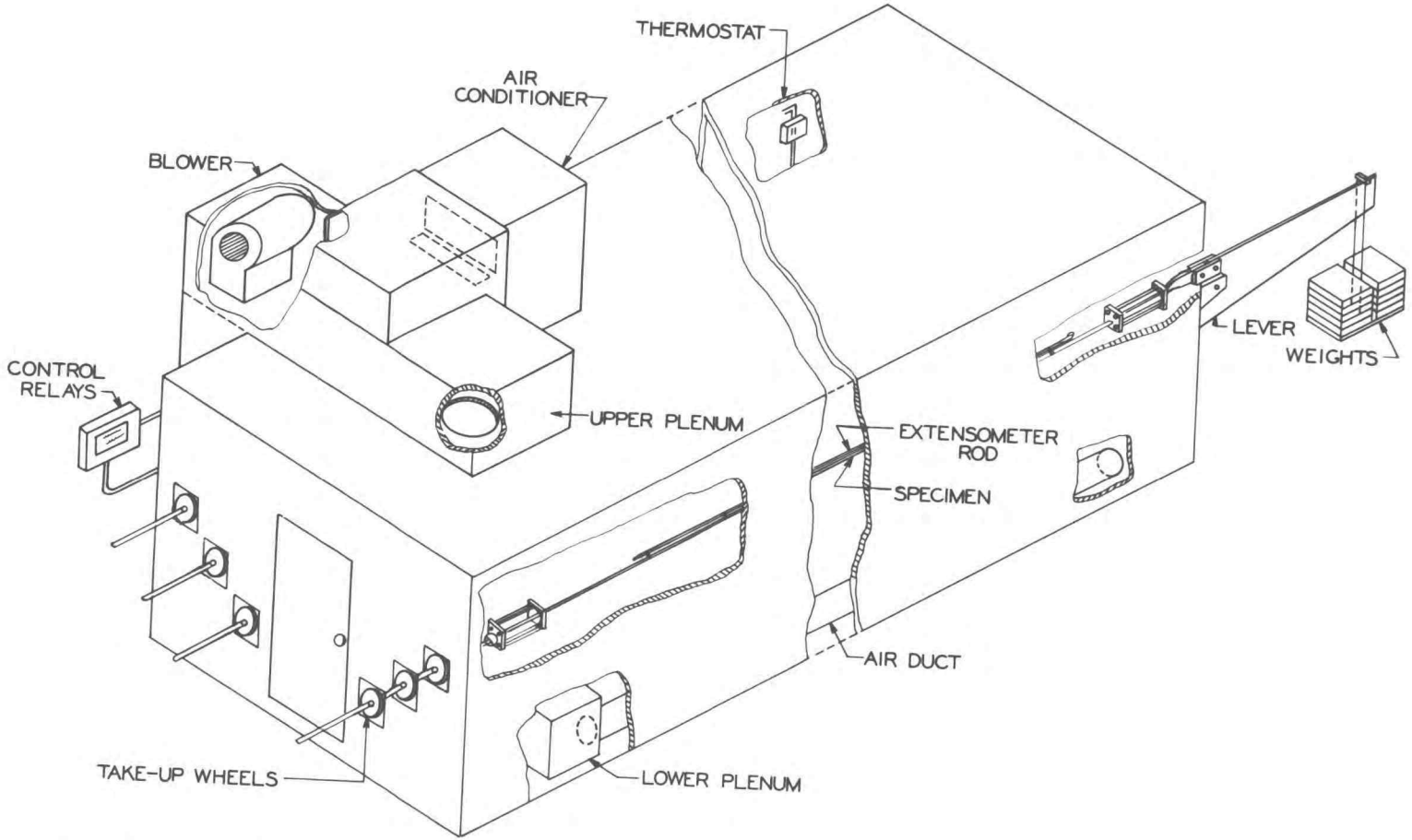



Figure 3. Schematic Diagram of Conductor Creep Testing Equipment.

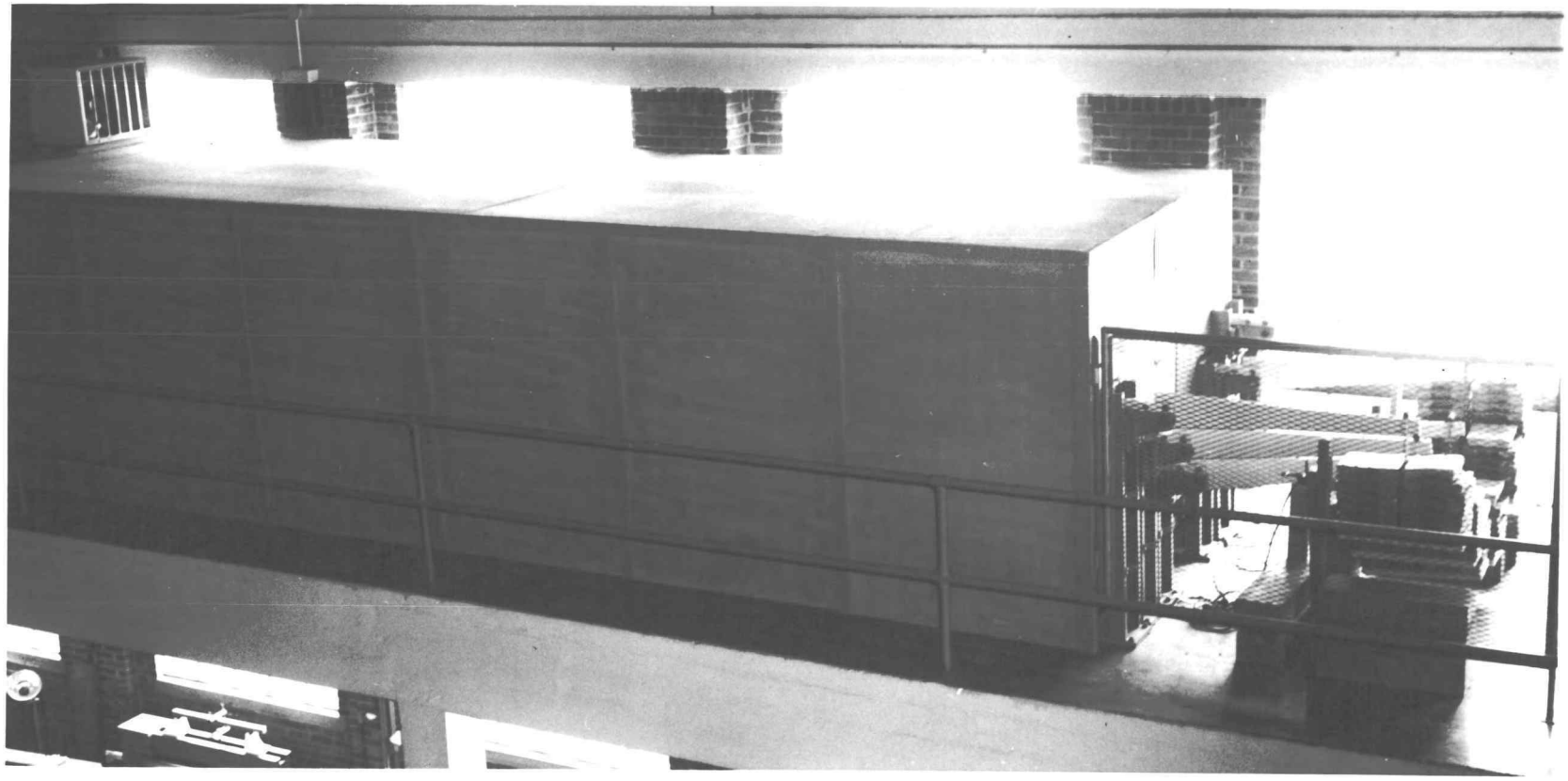


Figure 4. Exterior of Conductor Creep Testing Equipment.

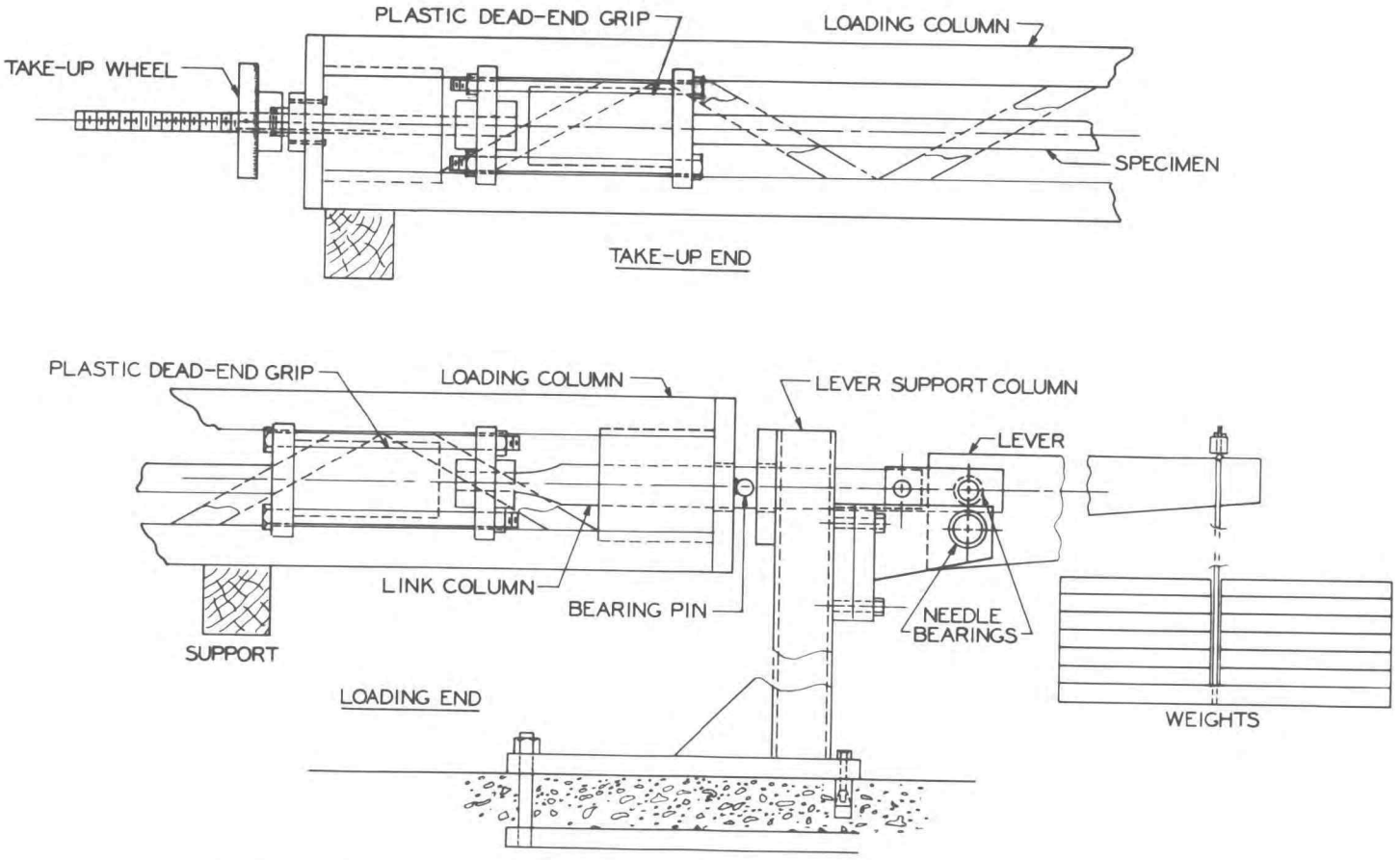



Figure 5. Schematic Diagram of Loading System.

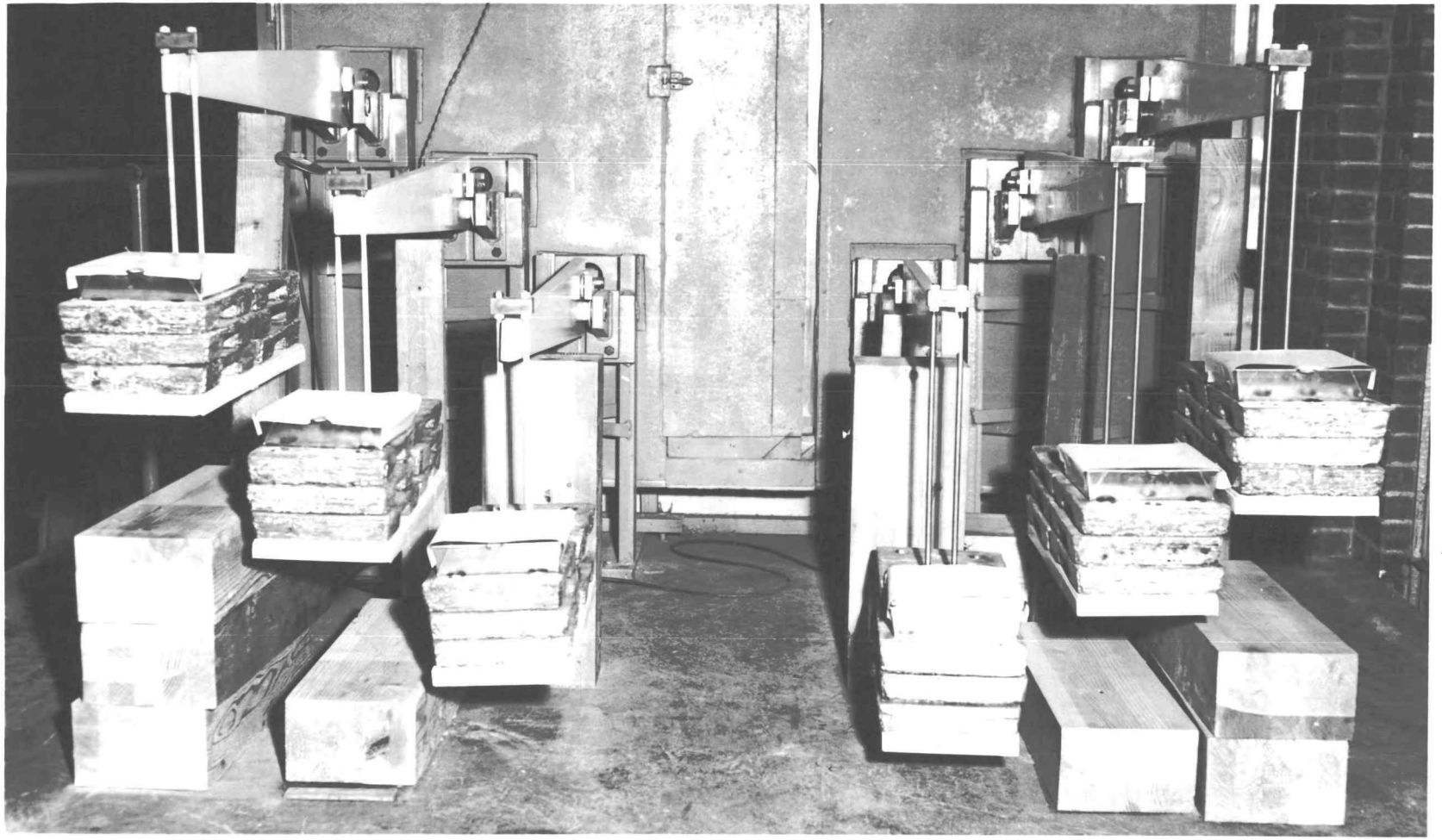


Figure 6. Loading End of Conductor Creep Testing Equipment.

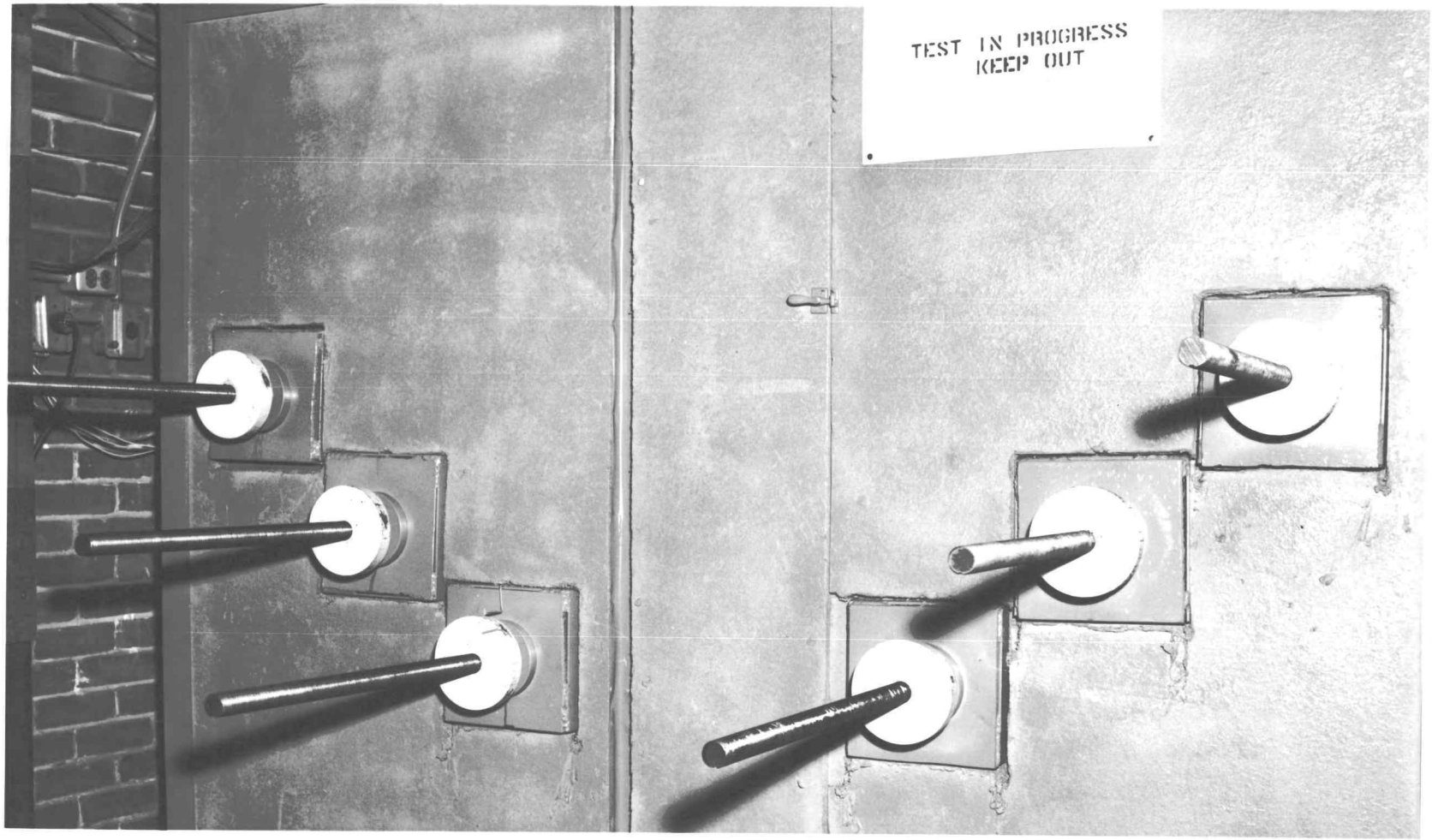



Figure 7. Take-Up End of Conductor Creep Testing Equipment.

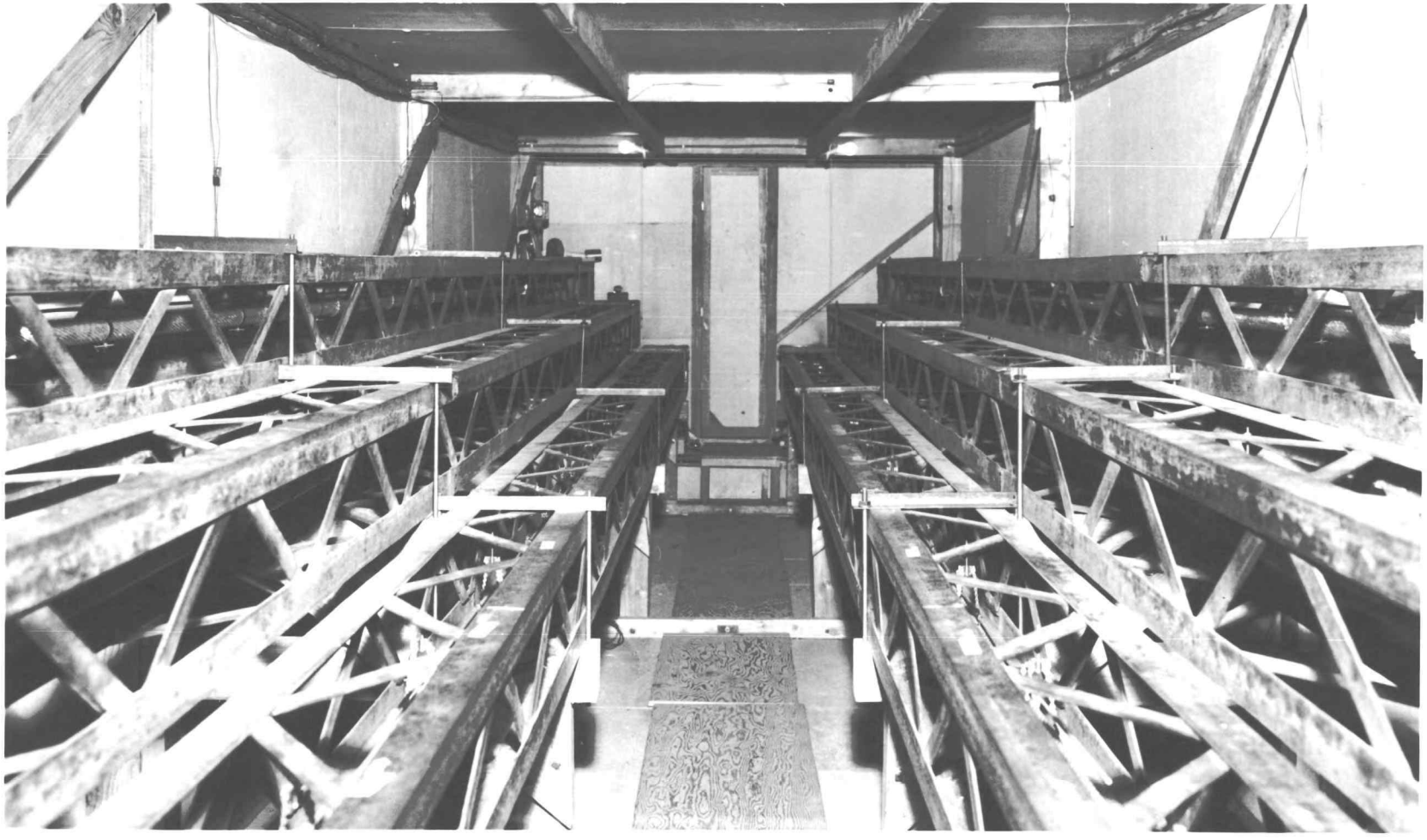


Figure 8. Interior of Conductor Creep Testing Equipment.

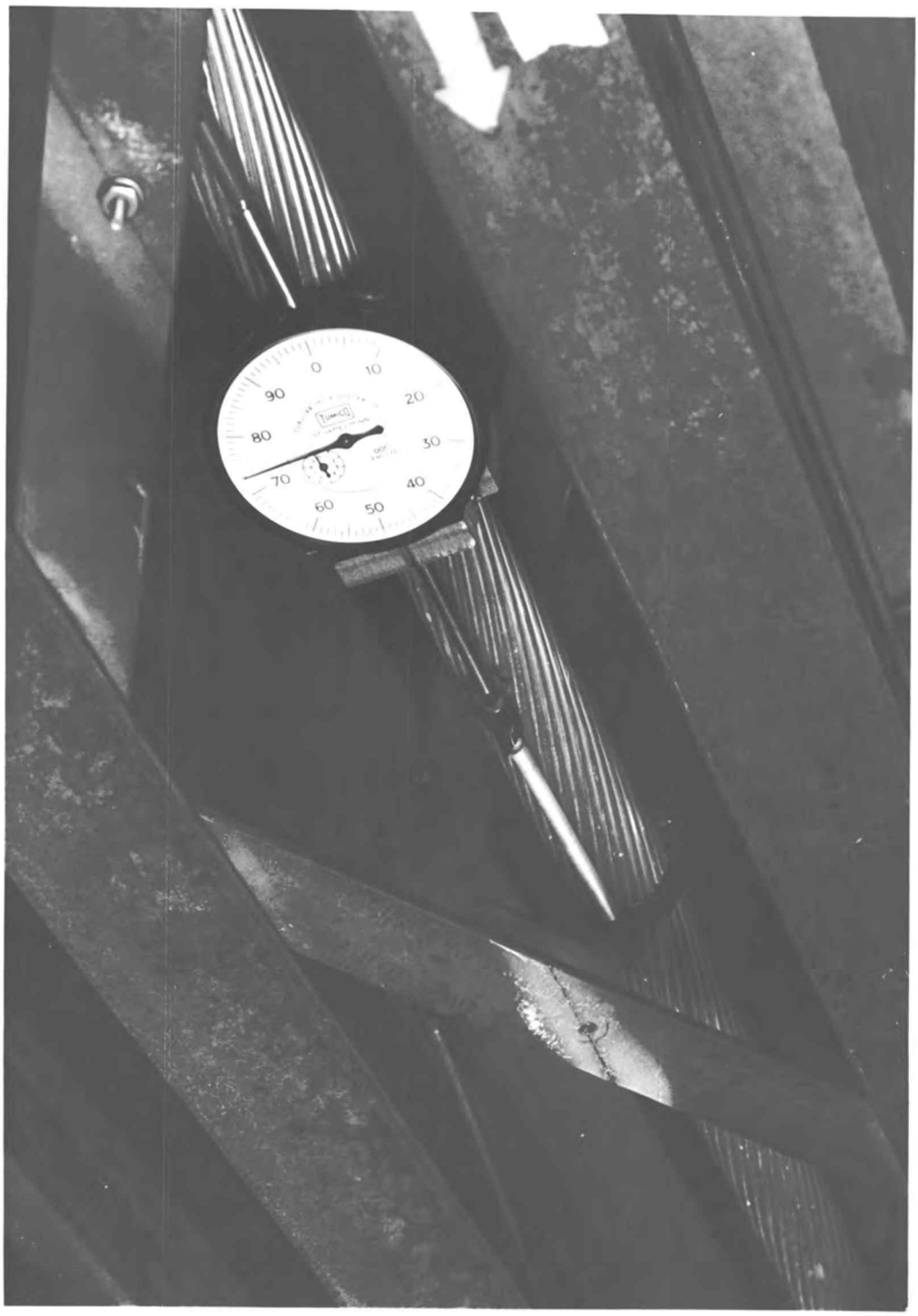



Figure 9. Dial Gage.

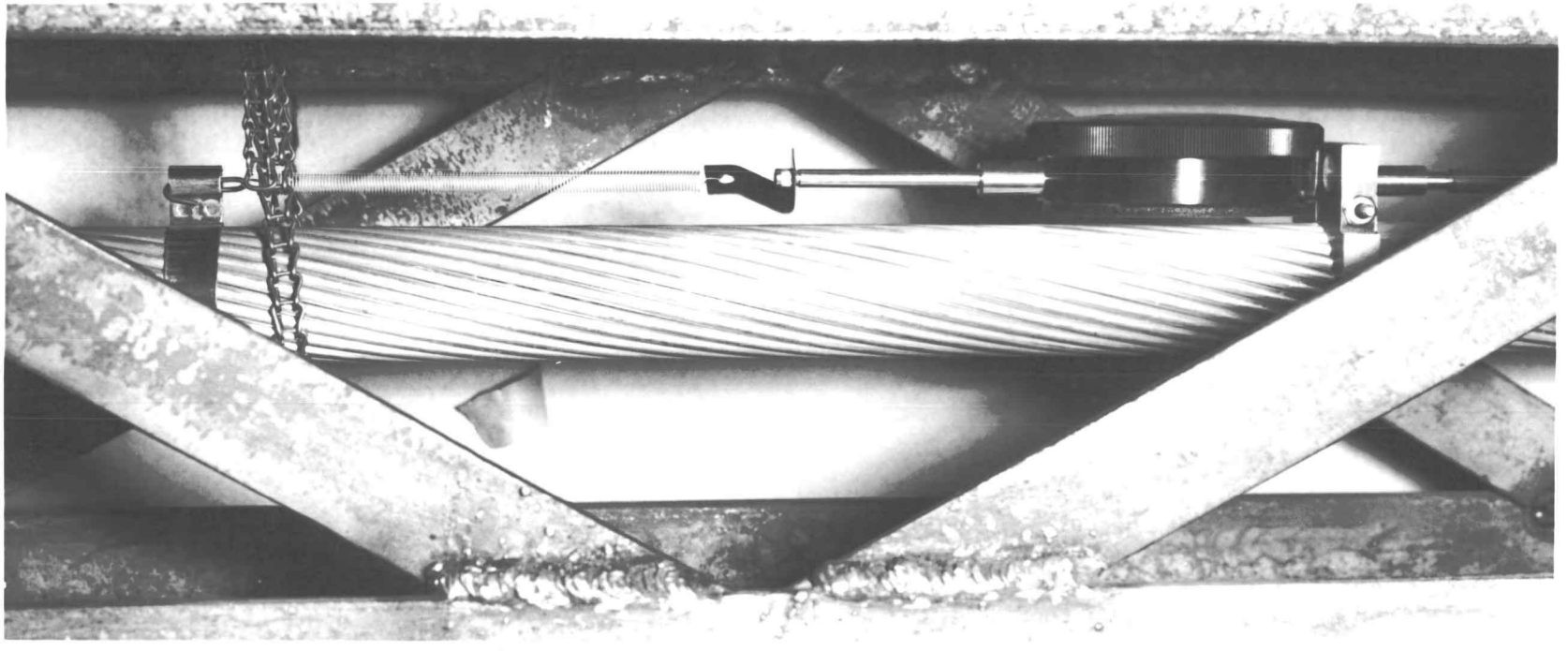


Figure 10. Closeup of Dial Gage Showing Tension Spring and Mounting Clamp.

the contraction of the conductor. The extensometer rod was supported with nine supports clamped to the conductor in order to keep the rod in level position. The precision of measurement of the creep strain was $10^{-3}$ inches.

(3) The loading method: Dead weight was applied to the specimen through a lever and linkage system. The exact lever load and lever ratio for each column are shown in Table III. These values were previously determined by calibration.

## 2. The Specimen and Its Installation

All specimens were cut to 28 feet in length. Both ends were frayed and plastic fittings cast on in such a manner that all the individual strands were all gripped equally (Figures 11 and 12). This work was done by the Bonneville Power Administration.

During shipping all specimens were covered and kept as straight as possible, Specimens, if reeled, would give variable results. This will be discussed in the latter part of this thesis.

In order to keep the specimens level without sag during the entire test, the specimens were supported with a series of chains. These chains were levelled as follows: The screw was removed from the take-up wheel. A transit was placed at the take-up end in such a manner that one could look from the eye-piece of the transit

Table III

Lever Load and Lever Ratio

| Column No. | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| Lever Load: $a_1$ | 769 | 745 | 788 | 752 | 741 | 725 |
| Lever Ratio: $a_2$ | 20.17 | 19.47 | 20.62 | 19.73 | 19.91 | 19.98 |

The actual load to be applied to a specimen was calculated from the following formula:

$$X = \frac{L - a_1}{a_2} ,$$

where:

$X$ = actual load applied to the conductor in pounds;

$L$ = load applied to the lever in pounds;

$a_1$ = lever weight in pounds;

$a_2$ = lever ratio.

Lead slabs were used as dead weight. Each slab weighed 50 pounds with an accuracy of $\pm 0.1$ pound. Tare weights, made of lead shot, were also measured with an accuracy of $\pm 0.1$ pound.

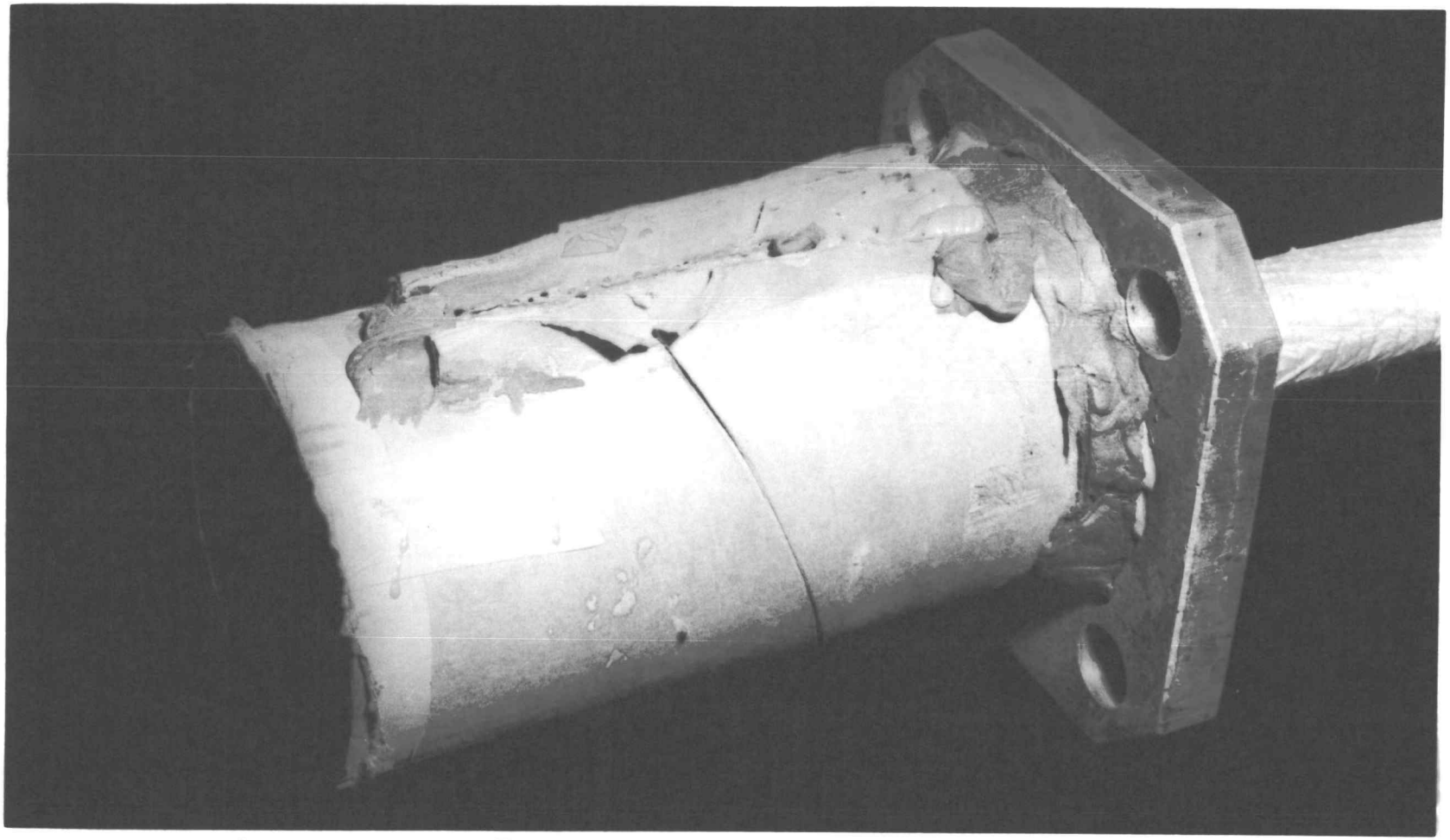


Figure 11. Closeup of Plastic End Fitting.

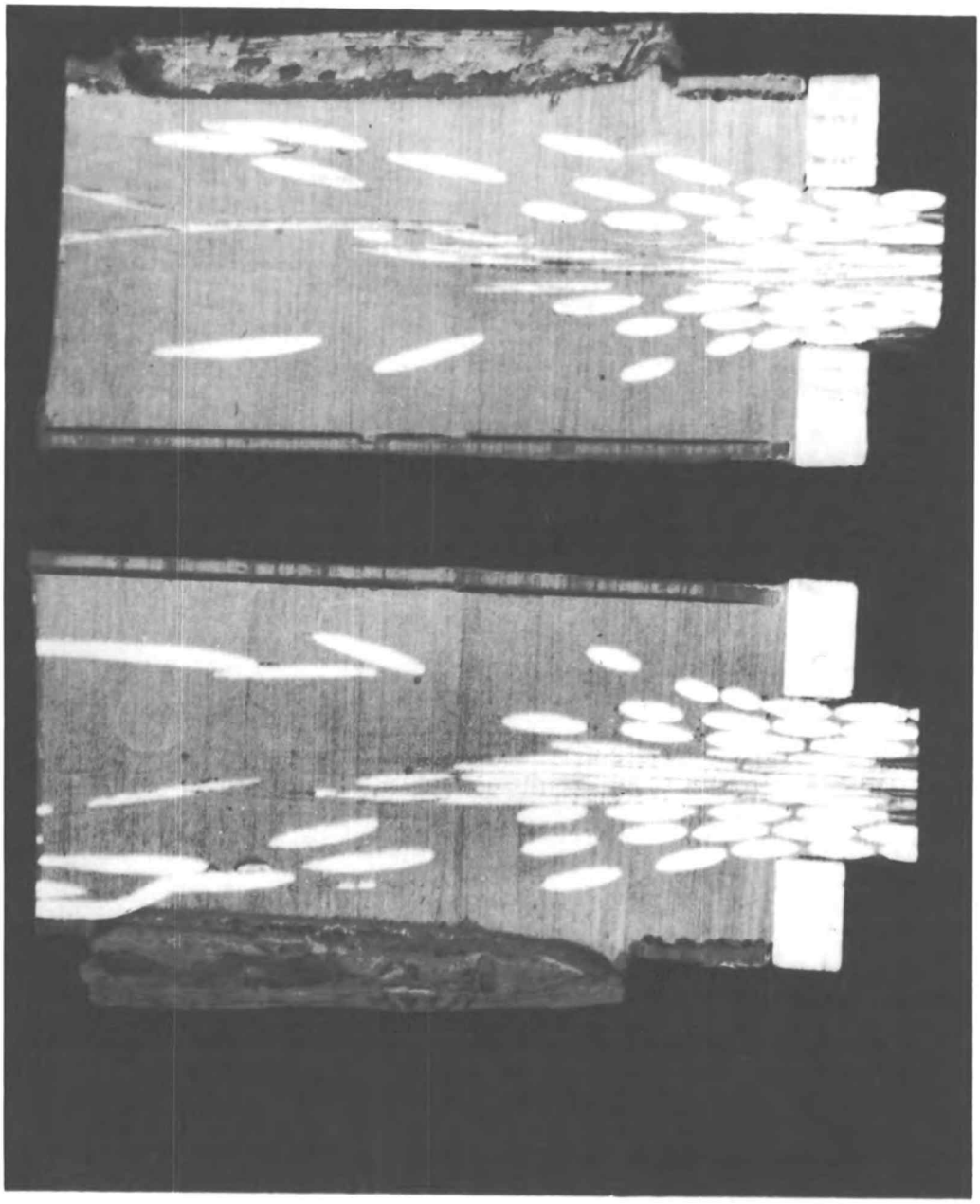


Figure 12. Cutaway of Plastic End Fitting.

through the hole in the plate to the hole of the lever end cover plate. A short metal cylinder, with the same diameter as the conductor and with the center marked, was hung on a chain. While looking through the transit,the cylinder was brought to the center of the column by adjusting the length of the chain and the height of the screw. The latter was measured with a levelling device shown in Figure 13. The length of the chain and height of the screw were recorded for each chain. In a similar manner all other chains were adjusted to positions where the conductors should be located.

The specimen, with its protecting cover on, was inserted to the column from the take-up end after which the protective cover was removed. The specimen was connected to the take-up mechanism and load mechanism by bolts. All four bolts at each end were adjusted to the same length so that every bolt took the same load and the specimen remained straight.

The conductor was then raised to level position by means of levelling chains. The chains were hooked around the specimen with the same length as the levelling cylinder, and the screws were adjusted to the same height as recorded.

The gage length, nearly centered at midlength, was marked and the extensometer installed as outlined previously.

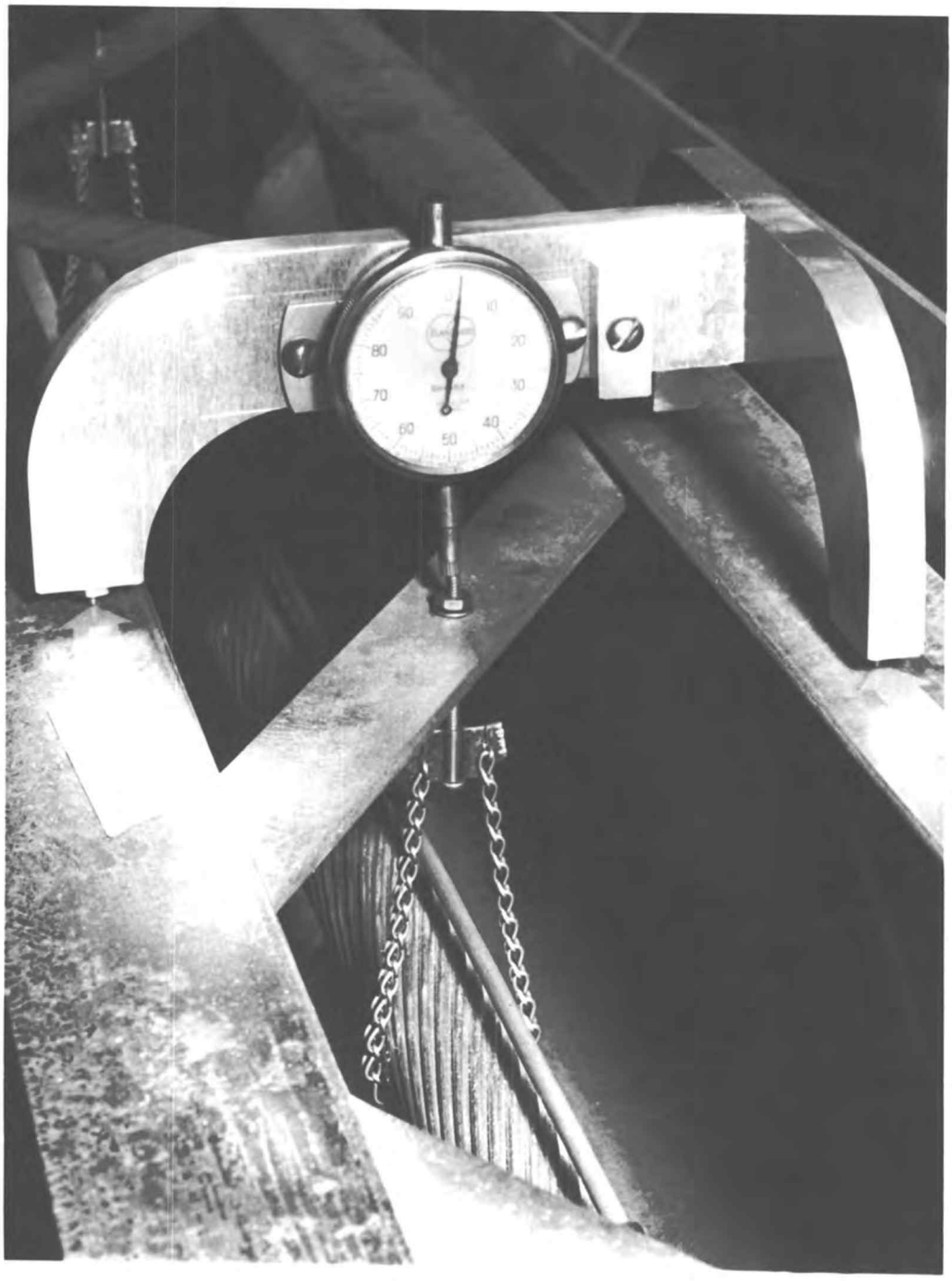


Figure 13. Position of Levelling Chains and Levelling Device.

## 3. Loading Procedure

### A. The Stress-Strain Test

The stress-strain tests were conducted on samples which had never undergone stressing in order to establish the initial modulus of elasticity. Similar tests were conducted after completion of a creep test to establish the final modulus.

Although the specimens were leveled by means of the levelling chains as described previously, the specimens were seldom actually straight. In order to straighten them so an accurate gage length could be measured, a small load, corresponding to the lever load (about 750 pounds), was applied. The initial load was different in each column because of variations in the testing machine mechanism. The gage length was measured with the specimen loaded to the initial load.

The load was increased in approximately 2000-pound increments at three-minute intervals up to about 22,000 pounds for Chukar, and 18,000 pounds for Drake conductor. These values are 40 percent of the rated strength of each conductor. It took about 33 minutes for Chukar and 27 minutes for Drake to attain to the peak load. The specimen was then unloaded in 4000-pound increments at three-minute intervals down to lever load. The load was increased again

at 2000-pound increments at the same time interval to creep tension. It took 69 minutes and 55 minutes, respectively, to complete the tests of Chukar and Drake. All readings were taken 30 seconds prior to load changes.

B. The Long Time Creep

Three different stages of loading were conducted during this test. They are (1) prestress loading, (2) unloading to creep load, and (3) the stress-strain loading after long time creep.

Having installed the specimen, the lever load (about 750 pounds) was applied to the conductor. The dial indicator was set to zero reading. Then half of the total prestressing load was applied on the lever within one minute. The full prestress load was applied and a strain reading taken at three minutes loading time. The take-up wheel was adjusted so that the lever was in a level position which indicated that the proper load had been applied.

As soon as the prestressing period was over the conductor was unloaded to the creep tension load within one minute.

During the entire prestressing and long time creep period (this period lasted more than 2000 hours), the readings of the dial indicator were taken according to a time schedule. The readings were taken at 0.013 (1 minute), 0.04 (3 minutes), 0.067 (5 minutes),

0.13 (10 minutes), 0.25 (15 minutes), 0.50 (30 minutes), 0.75 (45 minutes), 1, 1.5, 2, 3, 4, 6, 8, 12, 16, 24, and 36 hours, and then every 96 hours until the end of the test. This time schedule was established to make readings at approximately equal increments on a log time scale.

The last stage of loading was for stress-strain curve after the long time creep. The loading method was the same as that for the "Stress-Strain Test" except the starting load was creep load. It took 51 minutes to complete the last stage of test for each Expanded 460KV conductor and 63 minutes for Chukar conductor.

# V. RESULTS

## 1. Discussion of the Graphs

### A. The Long Time Creep Curve

Figures 14 to 25 show the long time creep curves. They present the relations between log time (hours) and log creep strain (in microinch per inch).

This set of curves shows the amount of nonelastic elongation from creep, the nonelastic elongation due to pretension, and the nonelastic elongation due to creep tension. The specimen started to creep as soon as the prestress load was applied. After the specimen was unloaded to creep load the unit strain of the specimen decreased. However, the nonelastic elongation due to prestressing remained in the specimen. Hence, the creep strain due to creep tension (C. T.) was plotted in such a way that the last value of the prestressing was treated as the starting point of the creep strain.

All curves except the no-prestressing curves show three different stages of creep caused by prestressing. The first stage is from 0.1 hour to the end of the prestressing period. The creep rate is high at first, then drops gradually. The high initial creep rate is due to strand settling and conductor straightening. The creep curve of

a solid conductor of the same material would be a straight line on the log-log scale.

The second stage of the curve is the flattened portion immediately after the prestressed period. For a certain length of time, which is called stable period, the conductor ceases to creep after the conductor load is decreased from prestressing load to creep load. After this period the conductor continued to creep under the creep load. The stable period for each curve was determined by the following method: The straight line of the third stage was extended until it intersected the creep strain horizontal corresponding to the strain at the load change. The length of the horizontal line from the load change to the point of intersection was taken as the stable period. It is assumed that the conductor undergoes no change of dimension during this period.

The third stage follows the stable period. Theoretically, the progress of the creep should follow a straight line with constant slope on a log-log scale. In an actual experiment, each reading scatters at the neighborhood of this straight line. The slope of this straight line was established by the least squares method.

The curves of the experiments without prestressing show only two stages of creep, the initial creep and the final creep. However, the point of demarcation between these stages is not readily

determined and is probably quite variable depending on conductor conditions such as tightness of stranding, reeling, and conductor design.

The data obtained from the experiment were treated in the following manner. From the test two different readings were obtained: the time and the deformation of the conductor at that particular time. The value of deformation, obtained from the extensometer, was expressed in thousandths of an inch. This value included both elastic and nonelastic deformation. The "Unit Strain" was calculated by the following formula:

$$\text{Unit Strain} = (\text{G. R.}) \quad (1000)/200$$

where G. R. is the gage reading in thousandths of an inch, and 200 inches is the gage length. The result (Unit Strain) of this equation will be in the unit of microinch/inch.

"Creep Strain" is the term which represents the nonelastic deformation of the conductor. The reading of "three minutes," while the full creep load or full prestress load was applied, was considered as zero "creep strain." In other words, nonelastic elongation was measured from this "three minutes" point.

At the end of the prestressing period the prestressing load was removed but the nonelastic elongation still remained in the conductor. In the following discussion "Total Creep Strain" is the value

of the nonelastic elongation caused by creep load plus the nonelastic elongation caused by the prestress load at the end of the test. "Total Unit Strain" is the total strain accumulated throughout the test. It includes all the elastic and plastic deformations which occurred during both the prestressing and creep stages.

(1) Expanded 460KV Conductor: Manufacturer - Southern Electric Company.

(a) Figure 14: X(SE)-100/1-20

Prestress: None

Total Creep Strain: 200 microinch/inch.

Total Unit Strain: 1415.5 microinch/inch.

This curve is the basic creep curve. The creep tension (C.T.) of this series of test (about 20 percent of the rated strength, R.S. = 82,800 pounds) was 14,000 pounds. The creep rate was high at the beginning of the test because of effects of strand settling and conductor straightening. Then it decreased rapidly as these effects were removed. The final creep curve exhibits a straight line in this figure.

(b) Figure 15: X(SE)-125/1-20

Prestress: 125 percent C.T. (17,500 pounds) for one hour.

Creep Strain after Prestressing: 39 microinch/inch.

Unit Strain after Prestressing: 1661.0 microinch/inch.

Total Creep Strain: 175.0 microinch/inch.

Total Unit Strain: 1652.0 microinch/inch.

Stable Period: 6.0 hours.

This curve is a typical creep curve with prestressing. It shows clearly the creep strains in three different stages: The prestressing stage, the stable stage, and the long-time creep stage. The creep curve without prestress is also plotted in this figure. The curve X(SE)-125/1-20 tends to converge on the no-prestressing curve.

(c) Figure 16: X(SE)-125/1-20-R

Prestress: 125 percent C.T. (17,500 pounds) for one hour.

Creep Strain after Prestressing: 50.5 microinch/inch.

Unit Strain after Prestressing: 2680.0 microinch/inch.

Total Creep Strain: 197.0 microinch/inch.

Total Unit Strain: 2671.0 microinch/inch.

Stable Period: 9.0 hours.

The test conditions for this specimen were the same as the one

in Figure 15, but this specimen was reeled before testing. This curve shows the significant difference in creep characteristics from the last curve. At the end of prestressing the unit strain of this specimen is 2680 microinch/inch which is about 161 percent of the not reeled one (1661 microinch/inch). The creep strain at the end of 2000 hours is also greater. This curve converged on the no-prestressing curve at about 1000 hours.

(d) Figure 17: X(SE)-150/1-20

Prestress: 150 percent C. T. (21,000 pounds) for one hour.

Creep Strain after Prestressing: 56.0 microinch/inch.

Unit Strain after Prestressing: 1886.0 microinch/inch.

Total Creep Strain: 181.5 microinch/inch.

Total Unit Strain: 1705.0 microinch/inch.

Stable Period: 20 hours.

This curve shows that a larger prestress load produces a higher creep strain and unit strain after prestressing. The high prestressing load also results in a long stable period (20 hours). This curve tends to converge on the no-prestress curve.

(2) Expanded 460KV Conductor: Manufacturer - Aluminum Company of America (Wire Rope Design).

(a) Figure 18: X(AWR)-125/1-20

Prestress: 125 percent C. T. (17, 500 pounds) per one hour.

Creep Strain after Prestressing: 30. 5 microinch/inch.

Unit Strain after Prestressing: 1806. 5 microinch/inch.

Total Creep Strain: 129. 0 microinch/inch.

Total Unit Strain: 1722. 5 microinch/inch.

Stable Period: 8. 3 hours.

The creep rate of this specimen dropped after 1000 hours evidently because the lever became stuck causing the load on the conductor to drop off. The lever was raised and lowered slightly to free it after which the creep strain increased again and assumed its previous log-log rate. The dotted line indicates a normal creep curve. Data obtained after 500 hours were not used for least square calculation.

(b) Figure 19: X(AWR)-150/1-20

Prestress: 150 percent C. T. (21, 000 pounds) for one hour.

Creep Strain after Prestressing: 39.5 microinch/inch.

Unit Strain after Prestressing: 1976.5 microinch/inch.

Total Creep Strain: 164.0 microinch/inch.

Total Unit Strain: 1705.5 microinch/inch.

Stable Period: 7.0 hours.

The creep strain dropped from 140 microinch/inch to 124 microinch/inch during the period between 849 and 937.9 hours. After this drop the creep rate remained as it was before. The reason for this drop is not known but is probably due to some malfunction of the lever. The broken line shows the adjusted curve which is almost parallel to the original one.

(3) Chukar Conductor: Manufacturer - Kaiser Aluminum and Chemical Company.

(a) Figure 20: C(K)-100/1-20

Prestress: None

Total Creep Strain: 338.5 microinch/inch.

Total Unit Strain: 1225.0 microinch/inch.

This is the basic creep curve for Chukar conductor. The creep tension of this series of tests (20 percent of the rated strength, R.S. = 53,600 pounds) was 10,720 pounds. As compared with the

creep curves of the previous experiments, this curve appears normal.

(b) Figure 21: C(K)-125/1-20-1

Prestress: 125 percent C. T. (13,400 pounds) for one hour.

Creep Strain after Prestressing: 53.5 microinch/inch.

Unit Strain after Prestressing: 1120.0 microinch/inch.

Total Creep Strain: 292.0 microinch/inch.

Total Unit Strain: 1194.0 microinch/inch.

Stable Period: 5 hours.

This curve shows a significant effect of the prestressing. The conductor ceased to creep for five hours after the change from the prestressing to the creep load. At the end of the stable period, the amount of creep strain was about 14 microinch/inch lower than the no-prestressing curve. After this point the creep rate increased and the curve tends to converge on the no-prestressing curve.

(c) Figure 22: C(K)-125/1-20-2

Prestress: 125 percent C. T. (13,400 pounds) for one hour.

Creep Strain after Prestressing: 53.5 microinch/inch.

Unit Strain after Prestressing: 1131.0 microinch/inch.

Total Creep Strain: 282.5 microinch/inch.

Total Unit Strain: 1207.5 microinch/inch.

Stable Period: 6 hours.

The test conditions of this specimen were the same as the specimen C(K)-125/1-20-1. However, this specimen is from a different reel. The creep strain of these two specimens after prestressing was almost the same. This specimen's stable period was longer, and the slope of the log-log curves was greater. This curve converges on the no-prestressing curve.

(d) Figure 23: C(K)-125/16-20

Prestress: 125 percent C.T. (13,400 pounds) for 16 hours.

Creep Strain after Prestressing: 140.0 microinch/inch.

Unit Strain after Prestressing: 1235.0 microinch/inch.

Total Creep Strain: 340.0 microinch/inch.

Total Unit Strain: 1270.0 microinch/inch.

Stable Period: 28 hours.

Owing to the long prestressing period, the creep strain increased to 130 microinch/inch after the 16 hour prestressing period. The stable period (28 hours) was also longer. This curve converged on the no-prestressing curve at about 1000 hours.

(e) Figure 24: C(K)-125/$\frac{1}{4}$-20

Prestress: 125 percent C. T. (16,080 pounds) for 15 minutes.

Creep Strain after Prestressing: 23.0 microinch/inch.

Unit Strain after Prestressing: 1084.0 microinch/inch.

Total Creep Strain: 229 microinch/inch.

Total Unit Strain: 1102.5 microinch/inch.

Stable Period: 0.36 hours.

The results of this test do not agree with the results obtained from the previous experiments with the same percentage of prestressing load and prestressing period. The creep rate is exceedingly low after the prestressing period before the 100 hours. No explanation for this abnormality is offered. It might be due to the sticking of the linkage. The slope of the curve increased and became constant after 100 hours on this log-log plot.

(f) Figure 25: C(K)-150/1-20

Prestress: 150 percent C. T. (16,080 pounds) for one hour.

Several experimental difficulties were encountered during the early portion of this test. During the prestressing treatment the lever position indicator failed to operate and the lever was raised beyond its trough so that the specimen was inadvertantly overloaded. The value of this overload is unknown. However, it did result in a high strain after prestressing. At 12 hours of testing, it was discovered that the clamp block of the extensometer had become loose. Thus, all the readings before this point should be considered erroneous. From this curve we can learn only that creep rate becomes constant after a certain amount of time. The results of the least square calculation are indicated by a dotted line on the curve.

## B. The Stress-Strain Curve

In a perfectly elastic specimen Hooke's Law applies. It is commonly known that transmission line conductors do not act in a perfectly elastic manner. Also, because the wires are not loaded perfectly axially, and their response to loading can only be conjectured, the actual stress developed in any part of the conductor cannot be determined. Nevertheless, it is useful to describe the action of a

conductor under test in the usual engineering terms. For example, over a certain portion of the loading cycle the relationship between load and strain may be linear. For this portion the relationship may be expressed as

$$E = \frac{P}{A\epsilon} ,$$

where

P = the load on the conductor in pounds;

$\epsilon$ = the measured strain at load P;

A = the cross section of the conductor which is a summation of the cross sections of the individual wires making up the conductor;

E = the modulus of elasticity of the conductor.

The value of the modulus is not usually very constant from one specimen to another even of the same type. This is because the measured strain is influenced by such things as the lay of the wires and how tightly the wires are bound together. In conductors of different types the modulus also depends on the design, manufacture, and percentage of steel in the conductor.

As stated in the loading procedure, the stress-strain test was carried on in three different stages, i. e. the conductor was loaded from lever load to about 40 percent of its rated strength, then unloaded to the lever load, and then reloaded to its creep tension.

Hence, the stress-strain curve of each conductor also shows three different sections which describe the three different loading stages.

From the graphs, we can see that there are two significant dissimilarities between the stress-strain curve of conductor and the stress-curve of homogeneous metal. First, in the stress-strain curve of conductor, the slope of the unloading section is different from the slope of the loading curve. Second, the stress-strain curves of unloading and reloading at low stress are non-linear, while in the case of homogeneous metal, its stress-strain curve remains linear despite load change.

These phenomena are due to the fact that the conductor itself can be considered as a composite material. It is considered so not only because it is made of two different metals, but also its construction is different from the construction of one single piece of homogeneous metal. The conductor is made of many layers of stranded wires (steel and aluminum) helically laid together. The wires of each layer are of different length and curvature than the wires of other layers. The coil pitch and direction of lay of each wire in any one layer are also different from the wires in other layers. Hence, the stress-strain relations of conductor can be expected to be different from that of single piece homogeneous metal.

In the first case, it is observed that the unloading section

shows a larger slope than that of the loading curve. Since the area between the stress-strain curve and the strain axis represents the work required to cause the deformation, it is obvious that the work released from the conductor during the unloading is less than the work stored during loading. The energy difference is denoted by the area between two curves which is called the hysteresis loop. The existence of this energy difference is due to two different causes: (a) the friction loss--when the conductor is stretched, relative motion occurs between the wires and energy is consumed to overcome the friction between wires; and (b) the plastic deformation--during stretching, some of the wires deform plastically as a result of strand settling and the strand tightening. The wires tend to move in an axial direction. In doing so, they become tightened around the underlying layers. This fact is denoted by the shrinkage of the conductor diameter. These events require energy, and energy thus consumed cannot be recovered during the unloading process.

In the second case, the stress-strain curves of unloading and reloading flattens at very low load. This is due to the fact that the helical coils of each wire are straightened to a certain extent before any plastic deformation occurs when the conductor is first stretched. This straightening phenomenon is very much similar to the stretching of a helical spring or a group of concentric springs.

Less load is required to straighten the coil than the load required to deform the conductor material in tension. Thus, the slope of the low stress portion of the stress-strain curve becomes smaller. As load increases, the elasticity of each metal element prevails. Then the deformation of the conductor follows the Hooke's law, and the stress-strain curve becomes a straight line.

Six specimens (three Chukar and three Drake) were used for conducting stress-strain test.

(1) The Chukar Conductor: Manufacturer - Kaiser Aluminum and Chemical Company.

The curves (Figures 26, 27 and 28) obtained from the three Chukar experiments give approximately the same result. The configurations of all curves are identical.

Figure 26 shows the curve of a conductor which was loaded twice at the first stage during the test. The broken line denotes the first loading. The first loading was stopped 15 minutes after the beginning of the test because it was noticed that the linkage did not have full bearing. The specimen was then unloaded to the lever load. The test was started again after adjusting the bearing. It is clearly shown in Figure 26 that the curve shifts upward, which indicates that higher strength is required to obtain the same strain of the first loading. This deviation indicates that a conductor, being stretched

and being partly strand set, requires more energy to deform.

(2) The Drake Conductor: Manufacturer - The Southern Electric Company.

Figures 29, 30 and 31 show the stress-strain curves of three Drake conductors. They reveal the similar configuration of the other type conductors, except the second loading part of Figure 29. The diameter, hence the cross section, of Drake is smaller than the diameter of the other type conductors. Thus the slopes of these curves are smaller than the slopes of the other type conductors, since the load-strain ratio in our case is a function of the cross section area. (Note: These three curves were drawn in different scale from Chukar conductor.)

Figure 31 shows the curve of conductors from different reel The smaller slope of the curve indicates that the specimen was unwound from the inner part of the reel. The radius of curvature was small which caused the specimen to retain some of its reeled helical shape. Thus this specimen produced larger elongation when under tensile load.

## C. The Stress Strain and Creep Curve

Figures 32 to 43 show the stress-strain and creep curves. Each curve expresses the test history of the respective specimen.

The first part of the curve denotes the stress-strain relation between the lever load and the prestress load. The "one minute" point shows that the stress-strain relations of most specimens between the lever load and the prestress load are non-linear.

The second part of the curve denotes the total non-elastic elongation due to pre-stressing load and creep load. The last part of this curve demonstrates the result of the stress strain relation after the long time creep. The maximum loads for the stress-strain test were 40 percent of the rated strength.

(1) The X(SE) Group:

Figures 32 to 35 show the stress-strain curves of Expnaded 460KV conductors manufactured by Southern Electric Company. These four curves demonstrate that they have almost the same configurations.

Figure 34 shows the results obtained from a reeled conductor. The specimen was subjected to the same testing condition as the specimen in Figure 33. It demonstrates clearly the significant effect of straightening during testing. The strain data obtained from the reeled conductor reveal much higher strain than those from not reeled conductor. Nevertheless, the values of nonelastic elongation due to prestressing load and creep load are about the same.

(2) The X(AWR) Group:

These two curves (Figures 36 and 37) demonstrate that they are normal stress-strain and creep curves.

(3) The Chukar Group:

Figures 38 to 42 demonstrate normal testing results.

Figure 43 shows the stress-strain and creep curve of the specimen which was overloaded during prestressing, and on which the clamp block of the extensometer became loose at 12 hours of test. The specimen crept under the overload prestressing condition from 3 to 15 minutes. When the load was released by means of cranking back to the levelling position, the cable contracted during the interval between 15 and 30 minutes. It started to creep again at 30 minutes. The value of the percent strain at the end of the prestressing period (60 minutes) was even lower than the value at 15 minutes. Hence, the data obtained for the complete prestressing period are not reliable. The loosened extensometer clamp block apparently slid along the specimen which gave a lower reading than it should have.

The configuration of the stress-strain curve after creep of this test is similar to the other curves. Because the clamp block slid back for a certain unknown distance the reading of the strain went negative at the lever load.

A hypothetical adjustment has been made to this curve. Assume the unit strain of the stress-strain curve at the lever-load is approximately the value of the total non-elastic strain. And assume the non-elastic strain of the prestressing period is about the same as the value of 125 percent C. T. prestress. In this case, 00.00535 percent was assumed for the prestress creep. The total non-elastic elongation was assumed to be 0.00535 + 0.01765 = 0.0230 percent. A distance of 0.0230 percent was measured to the left of the unit strain of the lever load. This point (which now is -0.36 percent) is the hypothetical zero of the adjusted coordinate. Measuring from this zero coordinate, we plot the "one minute" point of the prestressing curve in a new position. Connecting this adjusted "one minute" point with the adjusted "three minutes" point, it is seen that this line is almost in parallel with the line between the "60 minutes" and "61 minutes" points. Hence,the assumption might be considered close to the actual case.

All adjusted curves are plotted in broken lines.

## D. The Superimposed Curves

Figures 44 to 49 show the superimposed curves of X(SE) and X(AWR) conductors. There are two different curves in these figures. The full line curve in each figure denotes the stress-strain curve for

the conductor tested at Oregon State University (OSU). The limited capacity (23,000 pounds) of the OSU equipment made it impossible to stress the conductors to the desired 40 percent of the rated strength (28,000 pounds). Therefore, the conductors were shipped to the laboratory of the Aluminum Company of America (ALCOA) for further stress-strain testing. The results obtained from the ALCOA test are shown as a broken line in these figures.

(1) Figure 44: This figure shows the two stress-strain curves (by OSU and ALCOA) of ALCOA Wire Rope 460KV Expanded conductor. These two sets of curves have almost the same slope at high load, but the ALCOA curve is shifted to the left. Possible causes for this difference between the ALCOA and OSU tests are: (a) A part of the strands of ALCOA specimen had been set during the OSU test in which the maximum load was 22,000 pounds. (b) The ALCOA loading time-intervals were different from OSU. The time-intervals for the first part of loadings were one minute between each 2,000 pound increment of load. After eight minutes (16,000 pounds) the time intervals were changed to three minutes. This interval was maintained until the peak load (28,000 pounds) was reached. The unloading intervals were three minutes for every 4,000 pounds until 12,000 pounds. Then the unloading intervals were changed to one minute for every 4,000 pounds down to the lever load.

Then the specimen was loaded at one minute intervals for every 2,000 pounds until 14,000 pounds. The comparatively shorter loading and unloading intervals at lower load (OSU interval was three minutes through the complete test) stretched the cable less. Consequently, the entire ALCOA curve lies at the left of the OSU curve.

(2) Figure 45: This figure shows the two stress-strain curves (by OSU and ALCOA) of Southern Electric 460KV Expanded conductor. The slopes of the two curves are alike. But the slope of the ALCOA curve at low load of the first loading is much lower. Therefore, this curve was shifted to the right of OSU curve. This fact is hard to explain. It is possible that this specimen may have been bent during shipment from OSU to ALCOA.

(3) Figures 46 and 47: These two figures show the relative positions of the following three curves: (a) the OSU stress-strain and creep curve, (b) the ALCOA stress-strain curve of the specimen after OSU stress-strain, and (c) the ALCOA stress-strain curve of the specimen after OSU creep test. Curves (b) and (c) lie at the left of curve (a). The explanation of this event is the same as paragraph D, (1).

(4) Figures 48 and 49: These figures show the same curves as in Figures 46 and 47 respectively. But the two ALCOA curves are

shifted purposely to the required position. Curve (b) is shifted so that the loading section matches the loading section of the prestressing curve, and curve (c) matches the loading curve of the after-creep-stress-strain curve.

The significance of this figure is that they show the relationship between the non-elastic stretch from creep and from other extra loads such as ice and wind loads. In the particular case of Figure 48, having taken the maximum wind and ice load, the conductor will creep 0.0185 percent more in addition to the long time creep.

The area between the loading and unloading curves, as mentioned before, denotes the energy consumed. A part of the energy goes to the strand setting. Therefore, the energy consumption will become less and less for each subsequent loading and unloading cycle. In a climate where frequent icing is experienced each icing and melting cycle will increase the deformation.

## 2. The Equations Representing Observed Data

It has been shown in the early part of this thesis that the creep-strain-time curve appears as a straight line in log-log scale. It can be represented by the formula:

$$e = B(t)^n$$

where

e = strain;

t = time;

B and n = constants.

This equation can be written in log form:

$$\log e = \log B + n \log t.$$

Elementarily, this formula is a straight line equation represented by

$$y = a + bx.$$

In this equation, "x" and "y" are determined from experiment, and "a" and "b" evaluated by means of least-square equations. It is safe to assume the readings of all "x" values (which represent time) were accurate, and "y" values (the creep strain) might be subject to error. Then, "a" and "b" can be calculated from the equations:

$$a = \frac{\Sigma x^2 \Sigma y - \Sigma x \Sigma xy}{N \Sigma x^2 - (\Sigma x)^2}$$

$$b = \frac{N \Sigma xy - \Sigma x \Sigma y}{N \Sigma x^2 - (\Sigma x)^2}$$

where

N is the number of points selected (15, p. 240).

In this thesis, all points were selected in the following manner: (1) they were selected from the portion which appears to be straight line in the graph, and (2) every other point in the curve was

selected for this analysis.

These formulae were used to find strain beyond the testing period by means of extrapolation. As discussed in the earlier part of this thesis, extrapolations beyond ten times of the testing period are not recommended. The values of 10,000 hour creep strain has been calculated from these equations.

### 3. Discussion of Data

All results are presented in tabular form as shown in Table IV.

The values of creep strain after prestressing were determined by methods described in paragraph VII-1. The data of creep strain after long time creep were the amounts of non-elastic elongations between the end of prestressing periods and the end of tests. The total creep strains were the summations of these two readings. These data reveal that conductors subjected to one-hour prestressing treatments (the prestressing tension was either 150 percent of creep tension or 125 percent) will result in less total creep strain than conductors without prestressing. Only 125 percent creep tension for 16 hours resulted in a larger total creep strain.

The two specimens of X(SE) conductors under the same testing conditions produced different creep strains after the prestressing

period because of different initial specimen conditions. The amount of creep strain after prestressing of the reeled specimen was about 128 percent of that of the not reeled specimen. However, the difference between their creep strain after long time creep was very small.

The initial specimen conditions also affected the total unit strain. At the end of creep test the unit strain of the reeled or heavily bent specimen was 162.5 percent of that of the not reeled specimen.

The larger the prestress load, or the longer the prestressing time, or both, will result in a longer stable period.

The no-prestressing creep curves exhibit the smallest slope (as expressed by the value "n") as compared with the prestressing creep curves. This result does not agree with previous experiments (11, p. 15). Among the test data from prestressed specimens, the higher the prestressing load or the longer the prestressing time, the smaller the creep curve slope.

The data for creep strain after 10,000 hours, as calculated from the least square equations, demonstrate that the Expanded 460KV conductors creep much less than the ACSR Chukar conductors.

Although the creep tensions for different types of conductor were all of the same percentage (20 percent) of the rated strength,

the average stress on the material was different. For a conductor made of wires of the same material, such as X(AWR), stress on each wire is calculated by dividing the load by the summation of the areas of the individual wires. For a conductor made of aluminum wires and steel wires, such as X(SE) and ACSR, the stress on each wire is the function of its cross section area and its Young's modulus. ACSR is designed in such a way that the steel wires take a higher load than the aluminum wires, hence, higher stress is produced in steel wire. The stress on each different material can be calculated from the following derivation.

Let:

$P$ = total load on a conductor;

$A$ = total cross section of a conductor;

$P_s$ = percentage of load taken by all steel wires;

$P_a$ = percentage of load taken by all aluminum wires;

$A_s$ = total cross section area of all steel wires;

$A_a$ = total cross section area of all aluminum wires;

$E_s$ = Young's modulus of steel;

$E_a$ = Young's modulus of aluminum;

$S_s$ = unit stress of steel wires;

$S_a$ = unit stress of aluminum wires;

$L$ = length of conductor.

In our case,

$$P_s + P_a = 1 \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; (1)$$

Since the aluminum wires deform the same amount as the steel wires under load, therefore

$$\frac{P_s L}{A_s E_s} = \frac{P_a L}{A_a E_a} \quad . \; . \; . \; . \; . \; . \; . \; . \; (2).$$

Equations (1) and (2) can be solved simultaneously. The results will be

$$P_s = \frac{1}{\frac{A_a E_a}{A_s E_s} + 1} = \frac{1}{\frac{A_a}{3A_s} + 1}$$

and

$$P_a = \frac{1}{\frac{A_s E_s}{A_a E_a} + 1} = \frac{1}{\frac{3A_s}{A_a} + 1}$$

The stresses in steel and aluminum are

$$S_s = P_s / A_s \quad ,$$

and

$$S_a = P_a / A_a \quad .$$

Results of calculations based on the above equations are shown in No. 5 and No. 6 of Table V. It is apparent that the unit stresses in both the steel and the aluminum wires of Chukar are higher than that of X(SE). The higher stress may be a reason which causes higher creep strain after 10,000 hours, since the creep rate is a function of

stress (see paragraph III-3). The stresses in the wires of Drake are greater than the stresses in the wires of Chukar. This also explains why the slope of the load-strain curve of Drake is smaller than that of Chukar (see paragraph V-1-B). If we consider that the load is distributed uniformly throughout the entire cross section of conductor (including both the steel and aluminum), we can see that the differences of the average stresses (P/A) among these conductors are even more significant (see No. 7 and No. 8 of Table V).

Table IV

Test Results

| Specimens | Creep Strain (Microin/in) After Prestressing | Creep Strain (Microin/in) After Long Time Creep | Creep Strain (Microin/in) Total | Total Unit Strain (Microin/in) | Stable Period (Hour) | Constants for $\varepsilon = Bt^n$ B | Constants for $\varepsilon = Bt^n$ n | 10,000 Hours Creep Strain (Microin/in) |
|---|---|---|---|---|---|---|---|---|
| X(SE)-100/1-20 | - | 200.0 | 200.0 | 1415.5 | - | 34.341 | 0.222 | 264.82 |
| X(SE)-125/1-20 | 39.0 | 136.0 | 175.0 | 1652.0 | 6.0 | 25.016 | 0.215 | 239.54 |
| X(SE)-125/1-20-R | 50.5 | 136.5 | 197.0 | 2671.0 | 9.0 | 29.401 | 0.242 | 273.35 |
| X(SE)-150/1-20 | 56.0 | 125.5 | 181.5 | 1705.0 | 20.0 | 27.585 | 0.234 | 238.42 |
| X(AWR)-125/1-20 | 30.5 | 98.5 | 129.0 | 1722.5 | 8.3 | 14.154 | 0.310 | 244.59 |
| X(AWR)-150/1-20 | 39.5 | 125.5 | 164.5 | 1705.5 | 7.0 | 21.587 | 0.278 | 280.14 |
| C(K)-100/1-20 | - | 338.5 | 338.5 | 1225.0 | - | 46.061 | 0.260 | 502.13 |
| C(K)-125/1-20-1 | 53.5 | 238.5 | 292.0 | 1194.0 | 5.0 | 31.861 | 0.284 | 437.30 |
| C(K)-125/1-20-2 | 53.5 | 229.0 | 282.5 | 1207.0 | 6.0 | 29.983 | 0.297 | 447.65 |
| C(K)-125/16-20 | 140.0 | 200.0 | 340.0 | 1270.0 | 28.0 | 61.641 | 0.233 | 526.38 |
| C(K)-125/1/4-20* | 23.0 | 206.0 | 229.0 | 1102.5 | 0.36 | 6.988 | 0.458 | 471.85 |
| C(K)-150/1-20* | - | - | 176.5 | 792.0 | - | 9.764 | 0.301 | 326.27 |

* The data of these two specimen are not reliable.

Table V

Stress Distribution

| No. | | Unit | X(AWR) | X(SE) | | | CHUKAR | | | DRAKE | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Al | Steel | Al | Total | Steel | Al | Total | Steel | Al | Total |
| 1. | Cross Section Area | in.$^2$ | 2.291 | 0.196 | 2.106 | 2.232 | 0.1138 | 1.398 | 1.5118 | 0.1017 | 0.6244 | 0.7261 |
| | | % | 100 | 0.085 | 0.915 | 1.000 | 0.075 | 0.925 | 1.000 | 0.141 | 0.859 | 1.000 |
| 2. | Load Distribution | % | | 0.218 | 0.782 | 1.000 | 0.196 | 0.804 | 1.000 | 0.328 | 0.672 | 1.000 |
| 3. | Load Distribution at 40% R. S. | lbs. | 28,000 | 6,100 | 21,900 | 28,000 | 4,210 | 17,230 | 21,440 | 4,090 | 8,390 | 12,480 |
| 4. | Load Distribution at 20% R. S. | lbs. | 14,000 | 3,050 | 10,950 | 14,000 | 2,105 | 8,615 | 10,720 | 2,045 | 4,195 | 6,240 |
| 5. | Stress at 40% R. S. | psi | 12,320 | 31,100 | 10,400 | - | 36,200 | 12,350 | - | 40,200 | 13,450 | - |
| 6. | Stress at 20% R. S. | psi | 6,160 | 15,000 | 5,200 | - | 18,100 | 6,175 | - | 20,100 | 6,725 | - |
| 7. | Average Stress at 40% R. S. | psi | 12,320 | - | - | 12,150 | - | - | 14,150 | - | - | 17,150 |
| 8. | Average Stress at 20% R. S. | psi | 6,160 | - | - | 6,075 | - | - | 7,075 | - | - | 8,575 |

# VIII. CONCLUSIONS

1. The stable period is directly affected by the prestressing load and time. It increases with the increase of the prestress load, with an increase of time, or both.
2. The long time conductor creep has little or no influence on the slope (E) of the conductor stress-strain curve.
3. The repeated temporary load (wind and ice) will increase the non-elastic elongation of a conductor.
4. The creep curve of the prestressed conductor tends to converge to the creep curve of no-prestressed conductor after the stable period.
5. The initial creep strain will increase if the conductor is reeled.
6. The total unit strain of a conductor will increase when a specimen is reeled or severely bent.
7. Strand settling and specimen straightening will cause the stress-strain curve to shift to the right of a stress-strain curve of a homogeneous material. The configuration and the slope of the stress-strain curve are only slightly influenced by these effects.
8. A hysteresis loop which exists between the stress-strain curve of loading and the curve of unloading indicates the energy loss during loading and unloading the material.

9. Under the same test condition, the Expanded 460 KV conductor creeps less than the ACSR Chukar conductor.

# IX. RECOMMENDATIONS

1. There should be at least one sixteenth of an inch distance between the two pieces of each extensometer clamp block. Otherwise, the shrinkage of the conductor diameter will cause the clamp block to slide along the conductor and introduce errors in strain readings.
2. More cycles of loading and unloading are desired in order to find the effect of the repeated wind and ice load on the conductor.
3. Whenever the specimen is sent to another laboratory for further study, a similar loading procedure should be adopted so that the results can be compared.

# BIBLIOGRAPHY


1. American Society for Metals. Metals handbook. 8th ed., Cleveland, Ohio, 1961. 1300 p.

2. American Society for Testing and Materials. Tentative recommended practice for conducting creep and time-for-rupture tension tests of materials. ASTM designation: E139-58T. In: ASTM Standards, part 3. Metals test methods. 1961. p. 274-285.

3. Bonneville Power Administration and Oregon State University. Special Study Authorization No. SST-73. Portland, 1961. 4 p. (Mimeographed)

4. Heller, Finnie. Creep of engineering materials, New York, McGraw-Hill Book Company, Inc., 1959. 341 p.

5. Marin, Joseph. Mechanical behavior of engineering materials. Englewood Cliffs, N. J., Prentice-Hall, Inc., 1962. 502 p.

6. _____. Mechanics of creep for structural analysis. American Society of Civil Engineers. Proceedings 68:719-735. 1942.

7. Paasche, O. G. and L. E. Johnson. Laboratory creep studies on "Pheasant" conductor. Corvallis, Oregon State University. Engineering Experiment Station, 1961. 28 p. (Mimeographed)

8. Phillips, George H. Effect of creep on sags and tensions of overhead conductors. Pittsburgh, Pa., Electrical Conductor Division, Aluminum Company of America. April 21, 1958. 5 p. (not released for publication)

9. Sandell, Donald H. Recent developments affecting sags and tensions of overhead conductors. Rome Cable Division, Aluminum Company of America, presented to Missouri Valley Electric Association Meeting, April 20-22, 1960. 13 p. (Mimeographed)

10. Strum, R. G. A method of analyzing creep data. American Society of Mechanical Engineers. Transactions 58:A62-A66. 1936.

11. Wilson, Laurance M. Laboratory creep studies on "Pheasant" and "Expanded" aluminum conductors. Master's thesis. Corvallis, Oregon State University, 1963. 81 numb. leaves.

12. Winkelman, Paul F. Conductor creep and transmission line construction. Bonneville Power Administration. Presented to Conference Internationale des Grands Reseaux Electriques, International Study Committee No. 6, Montreal, Quebec, Canada. Sept. 13 and 14, 1961. (Mimeographed)

13. _____. Report on creep of overhead conductors. Bonneville Power Administration, presented to Conference Internationale des Grands Reseaux Electriques, International Study Committee No. 6, Paris, France, May 18, 1962. (Mimeographed)

14. _____. Sag-tension computation and field measurement of Bonneville Power Administration. American Institute of Electric Engineers Transactions 71-III: 1532-1547. 1952.

15. Worthing, A. G. and J. Gefner. Treatment of experimental data. New York, Wiley, 1943. 342 p.

# APPENDIX

Table VI

Creep and Final Stress Strain Test Data

SUBJECT: Creep Test of 460KV Conductor X(SE)-100/1-20
BY: O. G. Paasche, P. F. Winkelmen, L. M. Wilson and Y. S. Shen
DATE: June 13, 1962 to October 3, 1962 PRETENSION: None
CREEP TENSION: 20% R. S. (14,000 pounds) TOTAL TESTING TIME: 2674.6 Hours
GAGE LENGTH: 200 inches TEMPERATURE: 75 ± 2° F

| Elapsed Time Hours | Gage Reading 0.001 in. | Creep Strain Microin/in. | Unit Strain Microin/in. |
|---|---|---|---|
| 0 | 0 | | 0 |
| 1 min | 206.2 | | 1031.0 |
| 3 min | 243.1 | 0 | 1215.5* |
| 5 min | 244.0 | 4.5 | 1220.0 |
| 10 min | 245.3 | 11.0 | 1226.5 |
| 15 min | 245.6 | 12.5 | 1228.0 |
| 30 min | 247.0 | 19.5 | 1235.0 |
| 45 min | 247.9 | 24.0 | 1239.5 |
| 1 | 249.6 | 32.5 | 1248.0 |
| 1.5 | 249.7 | 33.0 | 1248.5 |
| 2 | 250.1 | 35.0 | 1250.5 |
| 3 | 250.9 | 39.0 | 1254.5 |
| 4 | 252.1 | 45.0 | 1260.5 |
| 6 | 253.8 | 53.5 | 1269.0 |
| 8 | 254.2 | 55.5 | 1271.0 |
| 12 | 255.2 | 60.5 | 1276.0 |
| 16 | 256.1 | 65.0 | 1280.5 |
| 24 | 257.3 | 71.0 | 1286.5 |
| 38 | 258.8 | 78.5 | 1294.0 |
| 49.5 | 258.9 | 79.0 | 1294.5 |
| 73.5 | 260.9 | 89.0 | 1304.5 |
| 97.5 | 262.0 | 94.5 | 1310.0 |
| 121.5 | 262.1 | 95.0 | 1310.5 |
| 145.5 | 263.2 | 100.5 | 1316.0 |
| 169.5 | 264.6 | 107.5 | 1323.0 |
| 265.7 | 266.8 | 118.5 | 1334.0 |
| 360.9 | 268.2 | 125.5 | 1341.0 |
| 469.6 | 270.0 | 134.5 | 1350.0 |
| 563.1 | 271.2 | 140.5 | 1356.0 |
| 659.9 | 271.7 | 143.0 | 1358.5 |
| 747.5 | 273.0 | 149.5 | 1365.0 |
| 849.5 | 273.9 | 154.0 | 1369.5 |
| 938.4 | 274.1 | 155.0 | 1370.5 |
| 1043.5 | 274.8 | 158.5 | 1374.0 |
| 1139.5 | 275.4 | 161.5 | 1377.0 |
| 1248.8 | 276.9 | 169.0 | 1384.5 |
| 1331.0 | 277.2 | 170.5 | 1386.0 |

Table VI (continued)

| Elapsed Time Hours | Gage Reading 0.001 in. | Creep Strain Microin/in. | Unit Strain Microin/in. |
|---|---|---|---|
| 1416.6 | 277.9 | 174.0 | 1389.5 |
| 1523.7 | 277.9 | 174.0 | 1389.5 |
| 1622.9 | 278.1 | 175.0 | 1390.5 |
| 1716.2 | 279.0 | 179.5 | 1395.0 |
| 1813.9 | 279.3 | 181.0 | 1396.5 |
| 1992.3 | 280.3 | 186.0 | 1401.5 |
| 2122.7 | 280.5 | 187.0 | 1402.5 |
| 2212.6 | 281.5 | 192.0 | 1407.5 |
| 2454.4 | 282.6 | 197.5 | 1413.0 |
| 2553.4 | 282.7 | 198.0 | 1413.5 |
| 2674.6 | 283.1 | 200.0 | 1415.5 |

*Half Load: 10,854 pounds.

Final Stress Strain
(October 3, 1962)

| Elapsed Time Minutes | Conductor Tension Pounds | Gage Reading 0.001 in. | Unit Strain Microin/in. |
|---|---|---|---|
| 0* | 14,000 | 283.1 | 1415.5 |
| 3 | 16,892 | 311.0 | 1555.0 |
| 6 | 18,941 | 329.8 | 1649.0 |
| 9 | 20,933 | 349.3 | 1746.5 |
| 12 | 22,929 | 368.6 | 1843.0 |
| 15 | 20,933 | 351.8 | 1759.0 |
| 18 | 16,892 | 316.8 | 1584.0 |
| 21 | 12,856 | 280.2 | 1401.0 |
| 24 | 8,808 | 242.8 | 1214.0 |
| 27 | 4,772 | 204.4 | 1022.0 |
| 30 | 769 | 129.8 | 649.0 |
| 33 | 2,768 | 171.9 | 859.5 |
| 36 | 4,772 | 198.7 | 993.5 |
| 39 | 6,793 | 219.6 | 1088.0 |
| 42 | 8,808 | 239.2 | 1196.0 |
| 45 | 10,821 | 258.8 | 1294.0 |
| 48 | 12,856 | 277.1 | 1385.5 |
| 51 | 14,000 | 288.2 | 1441.0 |

* 2674.6 hours = 0 minutes.

Table VII

Creep and Final Stress Strain Test Data

SUBJECT: Creep Test of 460KV Conductor X(SE)-125/1-20
BY: O. G. Paasche, P. F. Winkelmen, L. M. Wilson, and Y. S. Shen
DATE: June 13, 1962 to October 4, 1962
PRETENSION TIME: 1 hour
TOTAL TESTING TIME: 2693.8 hours
TEMPERATURE: 75 ± 2° F.
PRETENSION: 125% C. T. - 17,500 pounds
CREEP TENSION: 20% R. S. - 14,000 pounds
GAGE LENGTH: 200 inches

| Elapsed Time Hours | Gage Reading 0.001 in. | Creep Strain Microin/in. | Unit Strain Microin/in. |
|---|---|---|---|
| 0 | 0 | | 0 |
| 1 min | 242.6 | | 1213.0* |
| 3 min | 324.4 | 0 | 1622.0 |
| 5 min | 325.6 | 6.0 | 1628.0 |
| 10 min | 328.9 | 22.5 | 1644.5 |
| 15 min | 329.5 | 25.5 | 1647.5 |
| 30 min | 331.2 | 34.0 | 1656.0 |
| 45 min | 331.5 | 35.5 | 1657.5 |
| 1 | 332.2 | 39.0 | 1661.0 |
| 1 | 303.1 | 39.0 | 1515.5 |
| 1.5 | 303.2 | 39.5 | 1516.0 |
| 2 | 303.9 | 43.0 | 1519.5 |
| 3 | 304.2 | 44.5 | 1521.0 |
| 4 | 304.0 | 43.5 | 1520.0 |
| 6 | 304.0 | 43.5 | 1520.0 |
| 8 | 304.8 | 47.5 | 1524.0 |
| 12 | 305.9 | 53.0 | 1529.5 |
| 16 | 306.2 | 54.5 | 1531.0 |
| 24 | 307.0 | 58.5 | 1535.5 |
| 35.7 | 307.9 | 63.0 | 1539.5 |
| 47.2 | 308.0 | 67.5 | 1540.5 |
| 71.2 | 309.8 | 72.5 | 1549.0 |
| 95.2 | 310.4 | 75.5 | 1552.0 |
| 119.2 | 311.2 | 79.5 | 1556.0 |
| 143.2 | 312.2 | 84.5 | 1561.0 |
| 167.2 | 313.1 | 89.0 | 1565.5 |
| 263.5 | 314.8 | 97.5 | 1574.0 |
| 358.7 | 316.6 | 106.5 | 1583.0 |
| 467.4 | 317.4 | 111.0 | 1587.5 |
| 560.9 | 319.0 | 118.5 | 1595.0 |
| 657.7 | 318.8 | 117.5 | 1594.0 |
| 745.3 | 320.7 | 126.5 | 1603.5 |
| 847.3 | 321.1 | 128.5 | 1605.5 |
| 936.2 | 322.0 | 134.0 | 1610.0 |
| 1041.3 | 322.4 | 136.0 | 1612.0 |
| 1137.3 | 322.9 | 138.5 | 1614.5 |
| 1246.6 | 324.5 | 146.5 | 1622.5 |

Table VII (continued)

| Elapsed Time Hours | Gage Reading 0.001 in. | Creep Strain Microin/in. | Unit Strain Microin/in. |
|---|---|---|---|
| 1328.8 | 324.8 | 148.0 | 1624.0 |
| 1414.4 | 325.2 | 150.0 | 1626.0 |
| 1521.5 | 324.9 | 148.0 | 1624.5 |
| 1620.7 | 325.2 | 150.0 | 1626.0 |
| 1714.0 | 326.8 | 157.5 | 1634.0 |
| 1810.7 | 326.8 | 157.5 | 1634.0 |
| 1990.1 | 327.9 | 158.0 | 1634.5 |
| 2120.4 | 328.0 | 163.5 | 1640.0 |
| 2210.3 | 328.8 | 167.5 | 1644.0 |
| 2452.1 | 330.0 | 173.5 | 1650.0 |
| 2551.2 | 330.1 | 174.0 | 1650.5 |
| 2672.4 | 330.2 | 174.5 | 1651.0 |
| 2693.8 | 330.4 | 175.0 | 1652.0 |

*Half Load = 10,617 pounds.

Final Stress Strain
(October 4, 1962)

| Elapsed Time Minutes | Conductor Tension Pounds | Gage Reading 0.001 in. | Unit Strain Microin/in. |
|---|---|---|---|
| 0* | 14,000 | 330.4 | 1652.0 |
| 3 | 16,540 | 352.3 | 1761.5 |
| 6 | 18,510 | 370.8 | 1854.0 |
| 9 | 20,480 | 389.4 | 1947.0 |
| 12 | 22,460 | 407.3 | 2036.5 |
| 15 | 20,480 | 391.2 | 1956.0 |
| 18 | 16,540 | 358.7 | 1793.5 |
| 21 | 12,560 | 324.7 | 1623.5 |
| 24 | 8,644 | 289.8 | 1449.0 |
| 27 | 4,600 | 240.3 | 1201.5 |
| 30 | 752 | 164.1 | 820.5 |
| 33 | 2,725 | 204.3 | 1021.5 |
| 36 | 4,600 | 232.0 | 1160.0 |
| 39 | 6,670 | 257.6 | 1288.0 |
| 42 | 8,644 | 281.4 | 1407.0 |
| 45 | 10,620 | 300.9 | 1504.5 |
| 48 | 12,560 | 318.7 | 1593.5 |
| 51 | 14,000 | 332.7 | 1663.5 |

*0 minutes = 2693.8 hours.

Table VIII

Creep and Final Stress Strain Test Data

SUBJECT: Creep Test of 460KV Conductor X(SE)-125/1-20-R
BY: O. G. Paasche, P. F. Winkelmen, L. M. Wilson and Y. S. Shen
DATE: June 13, 1962 to October 6, 1962
PRETENSION TIME: 1 hour
TOTAL TESTING TIME: 2741.9 hours
TEMPERATURE: 75 ± 2° F.
PRETENSION: 125% C. T. - 17,500 pounds
CREEP TENSION: 20% R. S. - 14,000 pounds
GAGE LENGTH: 200 inches

| Elapsed Time Hours | Gage Reading 0.001 in. | Creep Strain Microin/in. | Unit Strain Microin/in. |
|---|---|---|---|
| 0 | 0 | | 0 |
| 1 min | 429.3 | | 2146.5 |
| 3 min | 525.9 | 0 | 2629.5* |
| 5 min | 527.9 | 10.0 | 2639.5 |
| 10 min | 529.7 | 19.0 | 2648.5 |
| 15 min | 531.3 | 27.0 | 2656.5 |
| 30 min | 533.1 | 36.0 | 2665.5 |
| 45 min | 535.0 | 45.5 | 2675.0 |
| 1 | 536.0 | 50.5 | 2680.0 |
| 1 | 504.9 | 50.5 | 2524.5 |
| 1.5 | 504.0 | 46.0 | 2520.0 |
| 2 | 504.9 | 50.5 | 2524.5 |
| 3 | 505.4 | 53.0 | 2527.0 |
| 4 | 505.8 | 55.0 | 2529.0 |
| 6 | 505.8 | 55.0 | 2529.0 |
| 8 | 506.1 | 56.5 | 2530.5 |
| 12 | 507.0 | 61.0 | 2535.0 |
| 16 | 507.8 | 65.0 | 2539.0 |
| 24 | 508.9 | 70.5 | 2544.5 |
| 36.2 | 509.9 | 75.5 | 2549.5 |
| 47.7 | 509.9 | 75.5 | 2549.5 |
| 71.7 | 511.8 | 85.0 | 2559.0 |
| 95.7 | 512.9 | 90.5 | 2564.5 |
| 119.7 | 513.7 | 94.5 | 2568.5 |
| 143.7 | 514.1 | 96.5 | 2570.5 |
| 167.7 | 515.2 | 102.0 | 2576.0 |
| 264.1 | 517.7 | 114.0 | 2588.0 |
| 359.3 | 519.0 | 121.0 | 2595.0 |
| 468.0 | 520.6 | 129.0 | 2603.0 |
| 561.5 | 522.0 | 136.0 | 2610.0 |
| 658.3 | 522.0 | 136.0 | 2610.0 |
| 745.9 | 523.9 | 145.5 | 2619.5 |
| 847.9 | 524.4 | 148.0 | 2622.0 |
| 936.8 | 525.3 | 152.5 | 2626.5 |
| 1041.9 | 525.8 | 155.0 | 2629.0 |
| 1137.9 | 526.3 | 157.5 | 2631.5 |
| 1247.2 | 528.1 | 166.5 | 2640.5 |

Table VIII (continued)

| Elapsed Time Hours | Gage Reading 0.001 in. | Creep Strain Microin/in. | Unit Strain Microin/in. |
|---|---|---|---|
| 1329.4 | 528.3 | 167.5 | 2641.5 |
| 1415.0 | 528.8 | 170.0 | 2644.0 |
| 1522.1 | 528.6 | 169.0 | 2643.0 |
| 1621.3 | 529.5 | 173.5 | 2647.5 |
| 1714.6 | 530.1 | 176.5 | 2650.5 |
| 1811.3 | 530.2 | 177.0 | 2651.0 |
| 1990.7 | 531.4 | 183.0 | 2657.0 |
| 2121.1 | 531.5 | 183.5 | 2657.5 |
| 2211.0 | 531.8 | 185.0 | 2659.0 |
| 2452.2 | 533.8 | 195.0 | 2669.0 |
| 2551.9 | 533.9 | 195.5 | 2669.5 |
| 2673.1 | 534.0 | 196.0 | 2670.0 |
| 2741.9 | 534.2 | 197.0 | 2671.0 |

*Half Load = 10, 415 pounds.

Final Stress Strain
(October 6, 1962)

| Elapsed Time Minutes | Conductor Tension Pounds | Gage Reading 0.001 in. | Unit Strain Microin/in. |
|---|---|---|---|
| 0* | 14,000 | 535.0 | 2675.0 |
| 3 | 16,230 | 556.0 | 2780.0 |
| 6 | 18,170 | 576.0 | 2880.0 |
| 9 | 20,100 | 595.3 | 2976.5 |
| 12 | 22,040 | 614.9 | 3074.5 |
| 15 | 20,100 | 598.8 | 2994.0 |
| 18 | 16,230 | 565.2 | 2826.0 |
| 21 | 12,350 | 528.3 | 2641.0 |
| 24 | 8,480 | 483.9 | 2419.5 |
| 27 | 4,600 | 438.8 | 2194.0 |
| 30 | 725 | 275.5 | 1377.5 |
| 33 | 2,633 | 387.9 | 1939.5 |
| 36 | 4,600 | 426.0 | 2130.0 |
| 39 | 6,450 | 451.0 | 2250.0 |
| 42 | 8,480 | 473.6 | 2368.0 |
| 45 | 10,420 | 497.2 | 2486.0 |
| 48 | 12,350 | 519.5 | 2597.0 |
| 51 | 14,000 | 536.4 | 2684.0 |

*0 minutes = 2579.0 hours.

Table IX

Creep and Final Stress Strain Test Data

SUBJECT: Creep Test of 460KV Conductor X(SE)-150/1-20
BY: O. G. Paasche, P. F. Winkelmen, L. M. Wilson and Y. S. Shen
DATE: June 13, 1962 to October 6, 1962
PRETENSION TIME: 1 hour
TOTAL TESTING TIME: 2741.2 hours
TEMPERATURE: 75 ± 2° F.
PRETENSION: 150% C. T. - 21,000 pounds
CREEP TENSION: 20% R. S. - 14,000 pounds
GAGE LENGTH: 200 inches

| Elapsed Time Hours | Gage Reading 0.001 in. | Creep Strain Microin/in. | Unit Strain Microin/in. |
|---|---|---|---|
| 0 | 0 | | 0 |
| 1 min | 246.0 | | 1230.0* |
| 3 min | 366.0 | 0 | 1830.0 |
| 5 min | 368.7 | 13.5 | 1843.5 |
| 10 min | 370.9 | 24.5 | 1854.5 |
| 15 min | 372.8 | 34.0 | 1864.0 |
| 30 min | 375.8 | 49.0 | 1879.0 |
| 45 min | 377.1 | 55.5 | 1885.5 |
| 1 | 377.2 | 56.0 | 1886.0 |
| 1 | 315.9 | 56.0 | 1579.5 |
| 1.5 | 315.9 | 56.0 | 1579.5 |
| 2 | 315.9 | 56.0 | 1579.5 |
| 3 | 316.7 | 60.0 | 1583.5 |
| 4 | 316.7 | 60.0 | 1583.5 |
| 6 | 317.4 | 63.5 | 1587.0 |
| 8 | 316.7 | 60.0 | 1583.5 |
| 12 | 317.5 | 64.0 | 1587.5 |
| 16 | 318.2 | 67.5 | 1591.0 |
| 24 | 318.8 | 70.5 | 1594.0 |
| 36 | 319.5 | 74.0 | 1597.5 |
| 47.5 | 319.5 | 74.0 | 1597.5 |
| 71.5 | 320.9 | 81.0 | 1604.5 |
| 95.5 | 321.9 | 86.0 | 1609.5 |
| 119.5 | 322.2 | 87.5 | 1611.0 |
| 143.5 | 323.0 | 91.5 | 1615.0 |
| 167.5 | 323.8 | 95.5 | 1619.0 |
| 263.6 | 325.3 | 103.0 | 1626.5 |
| 358.8 | 327.0 | 111.5 | 1635.0 |
| 467.5 | 327.9 | 116.0 | 1639.5 |
| 561.0 | 329.2 | 122.5 | 1646.0 |
| 657.8 | 329.1 | 122.0 | 1645.5 |
| 745.4 | 330.9 | 131.0 | 1654.5 |
| 847.4 | 331.3 | 133.0 | 1656.5 |
| 936.3 | 332.2 | 137.5 | 1661.0 |
| 1041.4 | 332.7 | 140.0 | 1663.5 |
| 1137.4 | 333.1 | 142.0 | 1665.5 |
| 1246.7 | 334.5 | 149.0 | 1672.5 |

Table IX (continued)

| Elapsed Time Hours | Gage Reading 0.001 in. | Creep Strain Microin/in. | Unit Strain Microin/in. |
|---|---|---|---|
| 1328.9 | 334.8 | 150.5 | 1674.0 |
| 1414.5 | 335.1 | 152.0 | 1675.5 |
| 1521.6 | 335.0 | 151.5 | 1675.0 |
| 1620.8 | 335.8 | 155.5 | 1679.0 |
| 1714.1 | 336.8 | 160.5 | 1684.0 |
| 1810.8 | 336.8 | 160.5 | 1684.0 |
| 1990.2 | 337.9 | 166.0 | 1689.5 |
| 2120.6 | 338.0 | 166.5 | 1609.0 |
| 2210.5 | 338.3 | 168.0 | 1691.5 |
| 2452.1 | 339.9 | 176.0 | 1699.5 |
| 2672.6 | 340.2 | 177.5 | 1701.0 |
| 2741.2 | 341.0 | 181.5 | 1705.0 |

*Half Load = 10,696 pounds.

Final Stress Strain
(October 6, 1962)

| Elapsed Time Minutes | Conductor Tension Pounds | Gage Reading 0.001 in. | Unit Strain Microin/in. |
|---|---|---|---|
| 0* | 14,000 | 340.1 | 1700.5 |
| 3 | 16,670 | 367.0 | 1835.0 |
| 6 | 18,661 | 386.1 | 1939.5 |
| 9 | 19,650 | 405.0 | 2025.0 |
| 12 | 22,640 | 423.9 | 2114.5 |
| 15 | 19,650 | 407.2 | 2046.0 |
| 18 | 16,670 | 373.2 | 1866.0 |
| 21 | 12,688 | 336.0 | 1680.0 |
| 24 | 8,706 | 298.9 | 1494.5 |
| 27 | 4,724 | 250.9 | 1254.5 |
| 30 | 741 | 177.1 | 885.1 |
| 33 | 2,733 | 213.3 | 1066.5 |
| 36 | 4,724 | 241.7 | 1208.5 |
| 39 | 6,717 | 269.4 | 1347.0 |
| 42 | 8,706 | 292.2 | 1461.0 |
| 45 | 10,687 | 311.6 | 1558.0 |
| 48 | 12,688 | 330.3 | 1651.5 |
| 51 | 14,000 | 343.0 | 1715.0 |

*0 minutes = 2741.3 hours.

Table X

Creep and Final Stress Strain Test Data

SUBJECT: Creep Test of 460KV Conductor X(AWR)-125/1-20
BY: O. G. Paasche. P. F. Winkelmen. L. M. Wilson. Y. S. Shen
DATE: June 13, 1962
PRETENSION TIME: 1 hour
TOTAL TESTING TIME: 2674.4 hours
TEMPERATURE: 75 ± 2° F.
PRETENSION: 125% C. T. - 17,500 pounds
CREEP TENSION: 20% R. S. = 14,000 pounds
GAGE LENGTH: 200 inches

| Elapsed Time Hours | Gage Reading 0.001 in. | Creep Strain Microin/in. | Unit Strain Microin/in. |
|---|---|---|---|
| 0 min | 0 | | 0 |
| 1 min | 242.8 | | 1214.0* |
| 3 min | 355.2 | 0 | 1776.0 |
| 5 min | 356.9 | 8.5 | 1784.5 |
| 10 min | 357.9 | 13.5 | 1789.5 |
| 15 min | 358.1 | 14.5 | 1790.5 |
| 30 min | 359.3 | 20.5 | 1796.5 |
| 45 min | 360.9 | 28.5 | 1804.5 |
| 1 | 361.3 | 30.5 | 1806.5 |
| 1 | 324.8 | 30.5 | 1624.0 |
| 1.5 | 325.5 | 34.0 | 1627.5 |
| 2 | 325.2 | 32.5 | 1626.0 |
| 3 | 325.3 | 33.0 | 1626.5 |
| 4 | 326.0 | 36.5 | 1630.0 |
| 6 | 326.1 | 37.0 | 1630.5 |
| 8 | 326.1 | 37.0 | 1630.5 |
| 12 | 326.8 | 40.5 | 1634.0 |
| 16 | 327.1 | 42.0 | 1635.5 |
| 24 | 327.2 | 42.5 | 1636.0 |
| 37.7 | 328.3 | 48.0 | 1641.5 |
| 49.2 | 328.0 | 46.5 | 1640.0 |
| 73.2 | 329.5 | 54.0 | 1647.5 |
| 97.2 | 330.1 | 57.0 | 1650.5 |
| 121.2 | 330.4 | 63.5 | 1657.0 |
| 145.2 | 331.6 | 64.5 | 1658.0 |
| 169.2 | 332.9 | 71.0 | 1664.5 |
| 265.4 | 334.7 | 80.0 | 1673.5 |
| 360.6 | 336.1 | 87.0 | 1680.5 |
| 469.3 | 337.2 | 94.5 | 1686.0 |
| 562.8 | 338.4 | 98.5 | 1692.0 |
| 659.6 | 338.5 | 99.0 | 1692.5 |
| 747.2 | 338.9 | 101.0 | 1694.5 |
| 849.2 | 338.1 | 97.0 | 1690.5 |
| 938.1 | 338.2 | 97.5 | 1691.0 |
| 1043.2 | 337.7 | 95.0 | 1688.5 |
| 1139.2 | 337.5 | 94.0 | 1687.5 |
| 1139.2 | 338.7 | 100.0 | 1693.5 |

Table X (continued)

| Elapsed Time Hours | Gage Reading 0.001 in. | Creep Strain Microin/in. | Unit Strain Microin/in. |
|---|---|---|---|
| 1248.5 | 339.9 | 106.0 | 1699.5 |
| 1330.7 | 339.9 | 106.0 | 1699.5 |
| 1416.3 | 339.8 | 105.5 | 1699.0 |
| 1523.4 | 339.3 | 103.0 | 1696.5 |
| 1622.6 | 340.0 | 106.5 | 1700.0 |
| 1715.9 | 340.8 | 110.5 | 1704.0 |
| 1812.8 | 340.9 | 110.0 | 1704.5 |
| 1992.8 | 341.9 | 116.0 | 1709.5 |
| 2122.4 | 342.2 | 117.5 | 1711.0 |
| 2211.5 | 342.9 | 121.0 | 1714.5 |
| 2454.1 | 244.0 | 126.5 | 1720.0 |
| 2553.2 | 344.2 | 127.5 | 1721.0 |
| 2674.4 | 344.5 | 129.0 | 1722.5 |

*Half Load = 10, 480 pounds.

Final Stress Strain
(October 3, 1962)

| Elapsed Time Minutes | Conductor Tension Pounds | Gage Reading 0.001 in. | Unit Strain Microin/in. |
|---|---|---|---|
| 0* | 14, 000 | 345.1 | 1725.5 |
| 3 | 16, 301 | 373.1 | 1865.5 |
| 6 | 18, 248 | 395.6 | 1978.0 |
| 9 | 20, 195 | 420.2 | 2101.0 |
| 12 | 22, 142 | 444.4 | 2222.0 |
| 15 | 20, 195 | 422.8 | 2114.0 |
| 18 | 16, 301 | 380.2 | 1901.0 |
| 21 | 12, 377 | 335.9 | 1679.5 |
| 24 | 8, 488 | 287.9 | 1439.5 |
| 27 | 4, 608 | 229.1 | 1145.5 |
| 30 | 745 | 122.9 | 614.5 |
| 33 | 2, 682 | 175.4 | 877.0 |
| 36 | 4, 608 | 215.8 | 1074.0 |
| 39 | 6, 595 | 248.6 | 1243.0 |
| 42 | 8, 488 | 277.5 | 1387.0 |
| 45 | 10, 435 | 302.4 | 1512.0 |
| 48 | 12, 377 | 327.7 | 1638.5 |
| 51 | 14, 000 | 347.6 | 1738.0 |

*0 minutes = 2512.4 hours.

Table XI

Creep and Final Stress Strain Test Data

SUBJECT: Creep Test of 460 KV Conductor X(AWR)-150/1-20
BY: O. G. Paasche, P. F. Winkelmen, L. M. Wilson and Y. S. Shen
DATE: June 13, 1962 to October 3, 1962 PRETENSION: 150% C. T. - 21,000 pounds
PRETENSION TIME: 1 hour CREEP TENSION: 20% R. S. - 14,000 pounds
TOTAL TESTING TIME: 2764.2 hours GAGE LENGTH: 200 inches

| Elapsed Time Hours | Gage Reading 0.001 in. | Creep Strain Microin/in. | Unit Strain Microin/in. |
|---|---|---|---|
| 0 min | 0 | | 0 |
| 1 min | 239.2 | | 1196.0* |
| 3 min | 387.4 | 0 | 1937.0 |
| 5 min | 388.9 | 7.5 | 1944.5 |
| 10 min | 391.1 | 18.5 | 1955.5 |
| 15 min | 391.4 | 20.0 | 1957.0 |
| 30 min | 394.1 | 33.5 | 1970.5 |
| 45 min | 394.9 | 37.5 | 1974.5 |
| 1 | 395.3 | 39.5 | 1976.5 |
| 1 | 316.1 | 39.5 | 1580.5 |
| 1.5 | 316.8 | 43.0 | 1584.0 |
| 2 | 317.2 | 45.0 | 1586.0 |
| 3 | 317.1 | 44.5 | 1585.5 |
| 4 | 317.1 | 44.5 | 1585.5 |
| 6 | 318.1 | 49.5 | 1590.5 |
| 8 | 318.1 | 49.5 | 1590.5 |
| 12 | 318.4 | 51.0 | 1592.0 |
| 16 | 318.8 | 53.0 | 1594.0 |
| 24 | 319.8 | 58.0 | 1599.0 |
| 37.5 | 321.0 | 64.0 | 1605.0 |
| 49.0 | 320.9 | 63.5 | 1604.5 |
| 73.0 | 322.8 | 73.0 | 1614.0 |
| 97.0 | 323.8 | 78.0 | 1619.0 |
| 121.0 | 323.9 | 78.5 | 1619.5 |
| 145.0 | 324.6 | 82.0 | 1623.0 |
| 169.0 | 326.8 | 93.0 | 1634.0 |
| 265.2 | 328.8 | 103.0 | 1644.0 |
| 360.4 | 330.8 | 113.0 | 1654.0 |
| 469.1 | 331.9 | 118.5 | 1659.5 |
| 562.6 | 333.9 | 128.5 | 1669.5 |
| 659.4 | 334.0 | 129.0 | 1670.0 |
| 747.0 | 335.4 | 136.0 | 1677.0 |
| 849.0 | 336.4 | 141.0 | 1682.0 |
| 937.9 | 333.3 | 124.5 | 1666.5 |
| 1043.0 | 333.8 | 128.0 | 1669.0 |
| 1139.0 | 333.7 | 127.5 | 1668.5 |
| 1248.3 | 334.8 | 133.0 | 1674.0 |
| 1330.5 | 335.0 | 134.5 | 1677.5 |

Table XI (continued)

| Elapsed Time Hour | Gage Reading 0.001 in. | Creep Strain Microin/in. | Unit Strain Microin/in. |
|---|---|---|---|
| 1416.1 | 335.0 | 136.5 | 1677.5 |
| 1523.2 | 335.9 | 138.5 | 1679.5 |
| 1622.4 | 336.1 | 139.5 | 1680.5 |
| 1715.7 | 337.7 | 147.5 | 1688.5 |
| 1812.4 | 337.7 | 147.5 | 1688.5 |
| 1991.8 | 338.8 | 153.0 | 1694.0 |
| 2122.2 | 339.1 | 154.5 | 1695.5 |
| 2212.1 | 339.4 | 156.0 | 1697.0 |
| 2453.9 | 341.0 | 164.0 | 1705.0 |
| 2553.0 | 341.1 | 164.5 | 1705.5 |
| 2674.2 | 341.5 | 164.5 | 1705.5 |

*Half Load = 11,098 pounds

Final Stress Strain
(October 3, 1962)

| Elapsed Time Minutes | Conductor Tension Pounds | Gage Reading 0.001 in. | Unit Strain Microin/in. |
|---|---|---|---|
| 0* | 14,000 | 341.2 | 1706.0 |
| 3 | 17,376 | 377.4 | 1887.0 |
| 6 | 19,321 | 400.8 | 2004.0 |
| 9 | 21,383 | 424.8 | 2124.0 |
| 12 | 23,445 | 449.6 | 2248.0 |
| 15 | 21,383 | 428.1 | 2140.5 |
| 18 | 17,276 | 383.5 | 1917.5 |
| 21 | 13,134 | 337.1 | 1685.5 |
| 24 | 9,019 | 288.4 | 1442.0 |
| 27 | 4,889 | 228.6 | 1143.0 |
| 30 | 788 | 122.8 | 614.0 |
| 33 | 2,842 | 176.7 | 883.5 |
| 36 | 4,889 | 217.9 | 1089.5 |
| 39 | 6,958 | 249.8 | 1249.0 |
| 42 | 9,010 | 278.6 | 1393.0 |
| 45 | 11,079 | 303.7 | 1518.5 |
| 48 | 13,134 | 328.7 | 1643.5 |
| 51 | 14,000 | 338.7 | 1693.5 |

*0 minutes = 2674.2 hours.

Table XII

Creep and Final Stress Strain Test Data

SUBJECT: Creep Test of Chukar Conductor C(K)-100/1-20
BY: O. G. Paasche and Y. S. Shen
DATE: December 27, 1962 to April 10, 1963
PRETENSION: None
CREEP TENSION: 20% R. S. - 10,720 pounds
TOTAL TESTING TIME: 2456 hours
GAGE LENGTH: 200 inches
TEMPERATURE: 75 ± 2° F

| Elapsed Time Hours | Gage Reading 0.001 in. | Creep Strain Microin/in. | Unit Strain Microin/in. |
|---|---|---|---|
| 0 min | 0 | | 0 |
| 1 min | 97.0 | | 485.0 |
| 3 min | 177.2 | 0 | 886.5* |
| 5 min | 180.0 | 14.0 | 900.5 |
| 13 min | 180.5 | 16.0 | 902.5 |
| 15 min | 181.3 | 20.0 | 906.5 |
| 30 min | 182.5 | 26.0 | 912.5 |
| 45 min | 184.6 | 36.5 | 923.0 |
| 1 | 185.0 | 38.5 | 925.0 |
| 1.5 | 186.1 | 44.0 | 930.5 |
| 2 | 187.0 | 48.5 | 935.0 |
| 3 | 188.6 | 56.5 | 943.0 |
| 4 | 189.9 | 63.0 | 949.0 |
| 6 | 191.7 | 72.0 | 958.5 |
| 8 | 192.7 | 77.0 | 963.5 |
| 12 | 194.9 | 88.6 | 974.5 |
| 16 | 196.1 | 94.0 | 980.5 |
| 24 | 198.0 | 103.5 | 990.0 |
| 36 | 200.5 | 116.0 | 1002.5 |
| 48 | 202.3 | 130.0 | 1016.5 |
| 72 | 205.9 | 143.0 | 1029.5 |
| 96 | 208.3 | 155.0 | 1041.5 |
| 120 | 209.9 | 163.3 | 1049.5 |
| 144 | 211.0 | 163.5 | 1050.0 |
| 192 | 214.0 | 183.5 | 1070.0 |
| 248 | 216.4 | 195.5 | 1082.0 |
| 344 | 220.1 | 214.0 | 1100.5 |
| 440 | 221.9 | 223.0 | 1109.5 |
| 536 | 225.0 | 239.0 | 1125.5 |
| 632 | 226.4 | 245.5 | 1132.0 |
| 728 | 229.0 | 258.5 | 1145.0 |
| 823 | 230.2 | 264.5 | 1151.0 |
| 920 | 231.7 | 272.0 | 1158.5 |
| 1016 | 233.0 | 279.0 | 1165.5 |
| 1112 | 234.2 | 284.5 | 1171.0 |
| 1208 | 235.1 | 289.0 | 1175.5 |
| 1304 | 236.5 | 296.0 | 1182.5 |

Table XII (continued)

| Elapsed Time Hours | Gage Reading 0.001 in. | Creep Strain Microin/in. | Unit Strain Microin/in. |
|---|---|---|---|
| 1400 | 237.6 | 301.5 | 1188.0 |
| 1496 | 238.5 | 306.0 | 1192.5 |
| 1592 | 239.4 | 310.5 | 1197.0 |
| 1688 | 240.2 | 314.5 | 1201.0 |
| 1784 | 241.4 | 320.5 | 1207.0 |
| 1880 | 242.1 | 324.0 | 1210.5 |
| 1976 | 242.4 | 325.5 | 1212.0 |
| 2064 | 243.8 | 332.5 | 1219.0 |
| 2090 | 244.0 | 333.5 | 1220.0 |
| 2168 | 244.8 | 337.5 | 1224.0 |
| 2264 | 245.0 | 338.5 | 1225.0 |
| 2360 | 244.5 | 336.0 | 1222.5 |
| 2456 | 245.0 | 338.5 | 1225.0 |

*Half Load = 5721 pounds.

Final Stress Strain
(April 10, 1963)

| Elapsed Time Minutes | Conductor Tension Pounds | Gage Reading 0.001 in. | Unit Strain Microin/in. |
|---|---|---|---|
| 0* | 10,720 | 244.8 | 1224.0 |
| 3 | 12,688 | 270.1 | 1350.5 |
| 6 | 14,678 | 295.2 | 1476.0 |
| 9 | 16,670 | 320.8 | 1604.0 |
| 12 | 18,661 | 348.9 | 1744.5 |
| 15 | 19,650 | 380.8 | 1904.0 |
| 18 | 22,640 | 412.7 | 2063.5 |
| 21 | 19,650 | 387.2 | 1936.0 |
| 24 | 16,670 | 335.7 | 1678.5 |
| 27 | 12,688 | 283.1 | 1415.5 |
| 30 | 8,706 | 229.0 | 1145.0 |
| 33 | 4,724 | 173.9 | 869.5 |
| 36 | 741 | 51.9 | 258.5 |
| 39 | 2,733 | 140.2 | 701.0 |
| 42 | 4,724 | 170.0 | 850.5 |
| 45 | 6,717 | 197.3 | 986.5 |
| 48 | 8,706 | 224.7 | 1123.5 |
| 51 | 10,720 | 252.0 | 1270.5 |

*0 minutes = 2477.1 hours.

Table XIII

Creep and Final Stress Strain Test Data

SUBJECT: Creep Test of Chukar Conductor C(K)-125/1-20-1
BY: O. G. Paasche and Y. S. Shen
DATE: December 27, 1962 to April 9, 1963
PRETENSION TIME: 1 hour
TOTAL TENSION TIME: 2456 hours
TEMPERATURE: 75 ± 2° F

PRETENSION: 125% C. T. - 13, 400 pounds
CREEP TENSION: 20% R. S. - 10, 720 pounds
GAGE LENGTH: 200 inches

| Elapsed Time Hour | Gage Reading 0.001 in. | Creep Strain Microin/in. | Unit Strain Microin/in. |
|---|---|---|---|
| 0 min | 0 | | 0 |
| 1 min | 106.9 | | 534.5 |
| 3 min | 213.3 | 0 | 1066.5 |
| 5 min | 216.1 | 14.0 | 1080.5 |
| 10 min | 218.2 | 24.5 | 1091.0 |
| 15 min | 220.0 | 33.5 | 1100.0 |
| 30 min | 220.4 | 33.5 | 1102.0 |
| 45 min | 224.2 | 54.5 | 1121.0 |
| 1 | 224.0 | 53.5 | 1120.0 |
| 1 | 191.1 | 53.5 | 955.5 |
| 1.5 | 191.1 | 53.5 | 955.5 |
| 3 | 191.3 | 54.5 | 956.5 |
| 4 | 191.7 | 56.5 | 958.5 |
| 6 | 192.2 | 59.0 | 961.0 |
| 8 | 192.9 | 62.0 | 964.5 |
| 12 | 193.9 | 66.5 | 968.5 |
| 16 | 194.8 | 77.0 | 979.0 |
| 24 | 196.1 | 79.0 | 980.5 |
| 36 | 197.9 | 87.5 | 989.5 |
| 48 | 199.2 | 94.0 | 996.0 |
| 72 | 202.5 | 110.5 | 1012.5 |
| 96 | 204.4 | 120.0 | 1022.0 |
| 120 | 205.8 | 127.5 | 1029.5 |
| 144 | 206.8 | 132.0 | 1034.0 |
| 192 | 209.3 | 144.5 | 1046.5 |
| 248 | 211.5 | 155.5 | 1057.5 |
| 344 | 214.4 | 170.0 | 1072.0 |
| 440 | 216.5 | 180.5 | 1082.5 |
| 536 | 218.9 | 192.5 | 1094.5 |
| 632 | 220.4 | 200.0 | 1102.0 |
| 728 | 222.7 | 211.5 | 1113.5 |
| 823 | 223.3 | 214.5 | 1116.5 |
| 920 | 224.8 | 222.0 | 1124.0 |
| 1016 | 226.2 | 229.0 | 1131.0 |
| 1112 | 227.4 | 235.0 | 1137.0 |
| 1208 | 228.9 | 242.5 | 1144.5 |
| 1304 | 229.5 | 245.5 | 1147.5 |

Table XIII (continued)

| Elapsed Time Hour | Gage Reading 0.001 in. | Creep Strain Microin/in. | Unit Strain Microin/in. |
|---|---|---|---|
| 1400 | 230.2 | 249.0 | 1151.0 |
| 1496 | 231.0 | 253.0 | 1155.0 |
| 1592 | 232.0 | 258.0 | 1160.0 |
| 1688 | 232.9 | 262.5 | 1164.5 |
| 1784 | 234.4 | 270.0 | 1172.0 |
| 1880 | 235.0 | 273.0 | 1175.0 |
| 1976 | 235.0 | 273.0 | 1175.0 |
| 2064 | 235.9 | 277.5 | 1179.5 |
| 2090 | 236.2 | 279.0 | 1181.0 |
| 2168 | 236.9 | 282.5 | 1184.5 |
| 2264 | 237.3 | 284.5 | 1186.5 |
| 2360 | 238.0 | 288.0 | 1190.0 |
| 2456 | 238.8 | 292.0 | 1194.0 |

*Half Load = 6569 pounds

Final Stress Strain
(April 9, 1963)

| Elapsed Time Minutes | Conductor Tension Pounds | Gage Reading 0.001 in. | Unit Strain Microin/in. |
|---|---|---|---|
| 0* | 10,720 | 238.1 | 1190.5 |
| 3 | 12,377 | 263.2 | 1316.0 |
| 6 | 14,374 | 288.6 | 1443.0 |
| 9 | 16,301 | 314.9 | 1574.5 |
| 12 | 18,248 | 344.5 | 1722.5 |
| 15 | 20,195 | 375.6 | 1878.0 |
| 18 | 22,142 | 404.1 | 2020.5 |
| 21 | 20,195 | 384.4 | 1922.0 |
| 24 | 16,301 | 333.2 | 1666.0 |
| 27 | 12,377 | 282.6 | 1413.0 |
| 30 | 8,488 | 231.2 | 1156.0 |
| 33 | 4,608 | 178.2 | 891.0 |
| 36 | 745 | 60.3 | 301.5 |
| 39 | 2,682 | 147.3 | 736.5 |
| 42 | 4,608 | 174.7 | 873.5 |
| 45 | 6,569 | 200.8 | 1004.0 |
| 48 | 8,488 | 226.7 | 1133.0 |
| 51 | 10,720 | 254.3 | 1271.5 |

*0 minutes = 2477.3.

Table XIV

Creep and Final Stress Strain Test Data

SUBJECT: Creep Test of Chukar Conductor C(K)-125/1-20-2
BY: O. G. Paasche and Y. S. Shen
DATE: December 27, 1962 to April 9, 1963
PRETENSION TIME: 1 hour
TOTAL TENSION TIME: 2456 hours
TEMPERATURE: $75 \pm 2^{\circ}$ F

PRETENSION: 125% C. T. - 13,400 pounds
CREEP TENSION: 20% R.S. - 10,720 pounds
GAGE LENGTH: 200 inches

| Elapsed Time Hour | Gage Reading 0.001 in. | Creep Strain Microin/in. | Unit Strain Microin/in. |
|---|---|---|---|
| 0 | 0 | | 0 |
| 1 min | 113.2 | | 566.0 |
| 3 min | 215.5 | 0 | 1077.5 |
| 5 min | 217.9 | 12.0 | 1089.5 |
| 10 min | 220.7 | 26.0 | 1103.5 |
| 15 min | 221.8 | 31.5 | 1109.0 |
| 30 min | 224.3 | 44.0 | 1121.5 |
| 45 min | 226.0 | 52.5 | 1130.0 |
| 1 | 226.2 | 53.5 | 1131.0 |
| 1 | 195.6 | 53.5 | 978.5 |
| 1.5 | 195.2 | 51.0 | 976.0 |
| 2 | 195.1 | 50.5 | 975.5 |
| 3 | 195.4 | 52.0 | 977.0 |
| 4 | 195.4 | 52.0 | 977.0 |
| 6 | 195.8 | 54.0 | 979.0 |
| 8 | 196.3 | 56.5 | 981.5 |
| 12 | 197.2 | 60.0 | 986.0 |
| 16 | 198.2 | 66.0 | 991.0 |
| 24 | 199.7 | 73.5 | 998.5 |
| 36 | 201.1 | 80.5 | 1005.5 |
| 48 | 202.8 | 89.0 | 1014.0 |
| 72 | 205.8 | 104.0 | 1029.0 |
| 96 | 207.8 | 114.0 | 1039.0 |
| 120 | 209.1 | 120.5 | 1045.5 |
| 144 | 210.5 | 127.5 | 1052.5 |
| 192 | 213.0 | 140.0 | 1065.0 |
| 248 | 215.3 | 151.5 | 1076.5 |
| 344 | 218.9 | 169.5 | 1094.5 |
| 440 | 220.8 | 179.0 | 1104.0 |
| 536 | 223.8 | 194.0 | 1119.0 |
| 632 | 224.8 | 199.0 | 1124.0 |
| 728 | 227.2 | 211.0 | 1136.0 |
| 823 | 228.0 | 215.0 | 1140.0 |
| 920 | 229.2 | 221.0 | 1146.0 |
| 1016 | 230.8 | 229.0 | 1154.0 |
| 1112 | 231.9 | 234.5 | 1159.5 |
| 1208 | 233.0 | 240.0 | 1165.0 |

Table XIV (continued)

| Elapsed Time Hours | Gage Reading 0.001 in. | Creep Strain Microin/in. | Unit Strain Microin/in. |
|---|---|---|---|
| 1304 | 234.0 | 245.0 | 1170.0 |
| 1400 | 234.8 | 249.0 | 1174.0 |
| 1496 | 235.5 | 253.0 | 1177.5 |
| 1592 | 236.3 | 256.5 | 1181.5 |
| 1688 | 236.8 | 259.0 | 1184.0 |
| 1784 | 237.5 | 262.5 | 1187.5 |
| 1880 | 238.3 | 266.5 | 1191.5 |
| 1976 | 238.9 | 269.5 | 1194.5 |
| 2064 | 239.4 | 272.5 | 1197.5 |
| 2090 | 239.8 | 274.0 | 1199.0 |
| 2168 | 240.1 | 275.5 | 1200.5 |
| 2264 | 240.5 | 277.5 | 1202.5 |
| 2360 | 240.5 | 277.5 | 1202.5 |
| 2456 | 241.5 | 282.5 | 1207.5 |

*Half Load = 6958 pounds

Final Stress Strain
(April 9, 1963)

| Elapsed Time Minutes | Conductor Tension Pounds | Gage Reading 0.001 in. | Unit Strain Microin/in. |
|---|---|---|---|
| 0* | 10,720 | 240.8 | 1204.0 |
| 3 | 13,134 | 273.9 | 1369.0 |
| 6 | 15,222 | 301.2 | 1506.0 |
| 9 | 17,276 | 329.2 | 1646.0 |
| 12 | 19,321 | 361.2 | 1806.0 |
| 15 | 21,383 | 396.5 | 1982.5 |
| 18 | 23,445 | 436.2 | 2181.0 |
| 21 | 21,383 | 410.9 | 2054.5 |
| 24 | 17,276 | 356.1 | 1780.5 |
| 27 | 13,134 | 300.8 | 1504.5 |
| 30 | 9,019 | 244.8 | 1224.0 |
| 33 | 4,889 | 187.3 | 936.5 |
| 36 | 788 | 63.8 | 319.0 |
| 39 | 2,842 | 150.0 | 750.5 |
| 42 | 4,889 | 181.3 | 906.5 |
| 45 | 6,958 | 210.2 | 1051.0 |
| 48 | 9,019 | 238.2 | 1191.0 |
| 51 | 10,720 | 260.7 | 1303.5 |

*0 minutes = 2477.3 hours.

Table XV

Creep and Final Stress Strain Test Data

SUBJECT: Creep Test of Chukar Conductor C(K)-125/16-20
BY: O. G. Paasche and Y. S. Shen
DATE: December 27, 1962 to April 9, 1963
PRETENSION TIME: 16 hours
TOTAL TENSION TIME: 2456 hours
TEMPERATURE: 75 ± 2° F

PRETENSION: 125% C. T. - 13,400 pounds
CREEP TENSION: 20% R. S. - 10,720 pounds
GAGE LENGTH: 200 inches

| Elapsed Time Hours | Gage Reading 0.001 in. | Creep Strain Microin/in. | Unit Strain Microin/in. |
|---|---|---|---|
| 0 | 0 | | 0 |
| 1 min | 113.0 | | 506.0 |
| 3 min | 219.0 | 0 | 1095.0* |
| 5 min | 221.7 | 13.5 | 1108.5 |
| 10 min | 225.1 | 30.5 | 1125.5 |
| 15 min | 226.8 | 39.0 | 1134.0 |
| 30 min | 230.5 | 57.5 | 1152.5 |
| 45 min | 231.0 | 60.0 | 1155.0 |
| 1 | 232.0 | 65.0 | 1160.0 |
| 1.5 | 234.0 | 75.0 | 1170.0 |
| 2 | 234.1 | 75.5 | 1170.5 |
| 2.5 | 235.9 | 84.5 | 1179.5 |
| 3 | 236.5 | 87.5 | 1182.5 |
| 4 | 238.2 | 96.0 | 1191.0 |
| 6 | 240.8 | 109.0 | 1204.0 |
| 8 | 242.4 | 117.0 | 1212.0 |
| 12 | 245.0 | 130.0 | 1225.0 |
| 16 | 247.0 | 140.0 | 1235.0 |
| 16.1 | 214.1 | 140.0 | 1070.5 |
| 24 | 214.5 | 142.5 | 1072.5 |
| 36 | 215.5 | 142.5 | 1072.5 |
| 48 | 216.4 | 152.0 | 1082.5 |
| 72 | 218.5 | 162.0 | 1092.5 |
| 96 | 220.1 | 190.0 | 1100.5 |
| 120 | 221.4 | 196.5 | 1107.0 |
| 144 | 222.4 | 181.5 | 1112.0 |
| 192 | 224.8 | 193.5 | 1124.0 |
| 248 | 226.9 | 204.0 | 1134.5 |
| 344 | 229.8 | 219.5 | 1149.5 |
| 440 | 231.1 | 225.0 | 1155.5 |
| 536 | 233.1 | 235.0 | 1165.5 |
| 632 | 233.3 | 236.0 | 1166.5 |
| 728 | 237.1 | 255.0 | 1185.5 |
| 823 | 240.0 | 269.0 | 1200.0 |
| 920 | 240.4 | 271.5 | 1202.0 |
| 1016 | 241.8 | 278.5 | 1209.0 |
| 1112 | 242.6 | 282.5 | 1213.0 |

Table XV (continued)

| Elapsed Time Hour | Gage Reading 0.001 in. | Creep Strain Microin/in. | Unit Strain Microin/in. |
|---|---|---|---|
| 1208 | 243.5 | 287.5 | 1217.5 |
| 1304 | 244.0 | 289.5 | 1220.0 |
| 1400 | 246.0 | 299.5 | 1230.0 |
| 1496 | 246.9 | 304.0 | 1243.5 |
| 1592 | 247.8 | 308.5 | 1239.0 |
| 1688 | 248.5 | 312.0 | 1242.5 |
| 1784 | 249.5 | 317.0 | 1247.5 |
| 1880 | 250.3 | 321.0 | 1251.5 |
| 1976 | 251.0 | 324.5 | 1255.0 |
| 2064 | 251.9 | 329.0 | 1259.5 |
| 2168 | 252.9 | 334.0 | 1264.5 |
| 2264 | 253.4 | 336.5 | 1267.0 |
| 2360 | 253.4 | 336.5 | 1267.0 |
| 2456 | 254.1 | 340.0 | 1270.5 |

*Half Load = 6670 pounds.

Final Stress Strain
(April 9, 1963)

| Elapsed Time Minutes | Conductor Tension Pounds | Gage Reading 0.001 in. | Unit Strain Microin/in. |
|---|---|---|---|
| 0* | 10,720 | 254.2 | 1271.0 |
| 3 | 12,560 | 278.9 | 1394.5 |
| 6 | 14,563 | 304.1 | 1520.5 |
| 9 | 16,540 | 331.8 | 1659.0 |
| 12 | 18,510 | 360.3 | 1801.5 |
| 15 | 20,480 | 390.7 | 1953.5 |
| 18 | 22,460 | 426.3 | 2131.5 |
| 21 | 20,480 | 401.4 | 2007.0 |
| 24 | 16,540 | 349.7 | 1748.5 |
| 27 | 12,560 | 297.5 | 1487.5 |
| 30 | 8,644 | 244.8 | 1224.0 |
| 33 | 4,600 | 190.6 | 953.0 |
| 36 | 752 | 58.9 | 294.5 |
| 39 | 2,725 | 157.3 | 786.5 |
| 42 | 4,600 | 189.1 | 845.5 |
| 45 | 6,670 | 216.2 | 1081.0 |
| 48 | 8,644 | 242.7 | 1213.5 |
| 51 | 10,720 | 270.7 | 1353.5 |

*0 minutes = 2477.3 hours.

Table XVI

Creep and Final Stress Strain Test Data

SUBJECT: Creep Test of Chukar Conductor C(K)-125/1/4-20
BY: O. G. Paasche and Y. S. Shen
DATE: December 27, 1962 to April 9, 1963
PRETENSION TIME: 1/4 hour
TOTAL TENSION TIME: 2456 hours
TEMPERATURE: 75 ± 2° F

PRETENSION: 125 % C. T. - 13,400 pounds
CREEP TENSION: 20% R. S. - 10,720 pounds
GAGE LENGTH: 200 inches

| Elapsed Time Hours | Gage Reading 0.001 in. | Creep Strain Microin/in. | Unit Strain Microin/in. |
|---|---|---|---|
| 0 min | 0 | | 0 |
| 1 min | 117.0 | | 585.0* |
| 3 min | 212.2 | 0 | 1061.0 |
| 5 min | 214.0 | 9.0 | 1070.0 |
| 10 min | 215.1 | 14.5 | 1075.5 |
| 15 min | 216.8 | 23.0 | 1084.0 |
| 16 min | 179.3 | 23.0 | 896.5 |
| 18 min | 179.4 | 23.5 | 897.0 |
| 20 min | 179.4 | 23.5 | 897.0 |
| 25 min | 179.4 | 23.5 | 897.0 |
| 30 min | 179.5 | 24.0 | 897.5 |
| 45 min | 179.5 | 24.0 | 897.5 |
| 1 | 179.7 | 25.0 | 898.5 |
| 1.5 | 181.0 | 31.5 | 905.0 |
| 2 | 180.2 | 27.5 | 901.0 |
| 3 | 180.5 | 29.0 | 902.5 |
| 4 | 180.8 | 30.5 | 904.0 |
| 6 | 181.0 | 31.5 | 905.0 |
| 8 | 181.2 | 32.5 | 906.0 |
| 12 | 181.6 | 34.5 | 908.0 |
| 16 | 181.8 | 35.5 | 909.0 |
| 24 | 181.8 | 35.5 | 909.0 |
| 36 | 182.0 | 36.5 | 910.0 |
| 48 | 182.2 | 37.5 | 911.0 |
| 72 | 183.0 | 41.5 | 915.0 |
| 96 | 185.5 | 54.0 | 927.5 |
| 120 | 186.9 | 61.0 | 934.5 |
| 144 | 188.0 | 66.5 | 940.0 |
| 192 | 190.5 | 79.0 | 952.5 |
| 248 | 192.9 | 91.0 | 964.5 |
| 344 | 195.8 | 105.5 | 979.0 |
| 440 | 197.8 | 115.5 | 989.0 |
| 536 | 200.8 | 130.5 | 1004.0 |
| 632 | 202.4 | 138.5 | 1012.0 |
| 728 | 204.6 | 149.5 | 1023.0 |
| 823 | 205.2 | 152.5 | 1026.0 |
| 920 | 207.3 | 163.0 | 1036.5 |

Table XVI (continued)

| Elapsed Time Hours | Gage Reading 0.001 in. | Creep Strain Microin/in. | Unit Strain Microin/in. |
|---|---|---|---|
| 1016 | 208.3 | 168.0 | 1041.5 |
| 1112 | 209.5 | 174.0 | 1047.5 |
| 1208 | 210.8 | 180.5 | 1054.0 |
| 1304 | 211.8 | 185.5 | 1059.0 |
| 1400 | 212.7 | 190.0 | 1063.5 |
| 1496 | 213.5 | 194.0 | 1067.5 |
| 1592 | 214.8 | 200.5 | 1074.0 |
| 1688 | 215.2 | 202.5 | 1076.0 |
| 1784 | 216.3 | 208.0 | 1081.5 |
| 1880 | 217.0 | 212.0 | 1085.5 |
| 1976 | 217.4 | 213.5 | 1087.0 |
| 2064 | 218.0 | 216.5 | 1090.0 |
| 2096 | 218.2 | 217.5 | 1091.0 |
| 2168 | 218.6 | 219.5 | 1093.0 |
| 2264 | 219.2 | 222.5 | 1096.0 |
| 2360 | 219.5 | 224.0 | 1097.5 |
| 2456 | 220.5 | 229.0 | 1102.5 |

*Half Load = 6793 pounds.

Final Stress Strain
(April 9, 1963)

| Elapsed Time Minutes | Conductor Tension Pounds | Gage Reading 0.001 in. | Unit Strain Microin/in. |
|---|---|---|---|
| 0* | 10,720 | 219.3 | 1096.5 |
| 3 | 12,856 | 248.6 | 1243.0 |
| 6 | 14,888 | 274.8 | 1374.0 |
| 9 | 16,892 | 302.2 | 1511.0 |
| 12 | 18,941 | 332.3 | 1661.5 |
| 15 | 20,933 | 364.7 | 1823.5 |
| 18 | 22,929 | 401.0 | 2005.0 |
| 21 | 20,933 | 375.1 | 1875.5 |
| 24 | 16,892 | 322.8 | 1614.0 |
| 27 | 12,856 | 269.9 | 1349.5 |
| 30 | 8,808 | 217.1 | 1085.5 |
| 33 | 4,772 | 160.2 | 801.0 |
| 36 | 769 | 29.9 | 149.5 |
| 39 | 2,768 | 125.5 | 627.5 |
| 42 | 4,722 | 156.2 | 781.0 |
| 45 | 6,793 | 184.8 | 924.0 |
| 48 | 8,808 | 213.3 | 1066.5 |
| 51 | 10,720 | 238.3 | 1191.5 |

*0 = 2477.3 hours.

Table XVII

Creep and Final Stress Strain Test Data

SUBJECT: Creep Test of Chukar Conductor C(K)-150/1-20
BY: O. G. Paasche and Y. S. Shen
DATE: December 27, 1962 to April 12, 1963
PRETENSION TIME: 1 hour
TOTAL TENSION TIME: 2456 hours
TEMPERATURE: 75 ± 2° F

PRETENSION: 150% C. T. - 16,080 pounds
CREEP TENSION: 20% R. S. - 10,720 pounds
GAGE LENGTH: 200 inches

| Elapsed Time Hours | Gage Reading 0.001 in. | Creep Strain Microin/in. | Unit Strain Microin/in. |
|---|---|---|---|
| 0 min | 0 | | 0 |
| 1 min | 116.0 | | 580.0* |
| 3 min | 194.2 | 0 | 971.0 |
| 5 min | 195.1 | 4.5 | 975.5 (note 1) |
| 10 min | 196.1 | 9.5 | 980.5 |
| 15 min | 198.0 | 19.5 | 990.0 |
| 30 min | 193.1 | -6.5 | 965.5 |
| 45 min | 194.3 | 0.5 | 971.5 |
| 1 | 194.9 | 3.5 | 974.5 |
| 1 | 123.8 | 3.5 | 619.5 |
| 1.5 | 122.8 | -2.0 | 614.9 |
| 2 | 122.9 | -1.5 | 614.5 |
| 3 | 122.9 | -1.5 | 614.5 |
| 4 | 122.6 | -1.7 | 614.3 |
| 6 | 121.9 | -7.0 | 609.5 |
| 8 | 119.1 | -20.5 | 595.5 |
| 12 | 124.5 | 3.0 | 622.5 (note 2) |
| 16 | 125.8 | 13.0 | 629.0 |
| 24 | 129.0 | 29.0 | 645.0 |
| 36 | 129.6 | 32.0 | 648.0 |
| 48 | 130.2 | 35.0 | 651.0 |
| 72 | 132.4 | 46.0 | 662.0 |
| 96 | 134.1 | 54.5 | 670.5 |
| 120 | 134.9 | 58.5 | 674.5 |
| 144 | 135.9 | 63.5 | 679.5 |
| 192 | 137.8 | 73.0 | 689.0 |
| 248 | 139.4 | 81.0 | 697.0 |
| 344 | 142.2 | 95.0 | 711.0 |
| 440 | 143.1 | 99.5 | 715.5 |
| 536 | 145.6 | 112.0 | 728.0 |
| 632 | 146.1 | 114.5 | 730.5 |
| 728 | 148.4 | 126.0 | 742.0 |
| 823 | 149.2 | 130.0 | 746.0 |
| 920 | 150.5 | 136.5 | 752.5 |
| 1016 | 150.8 | 143.0 | 759.0 |
| 1112 | 152.0 | 144.0 | 760.0 |
| 1208 | 152.7 | 147.5 | 763.5 |
| 1304 | 154.0 | 154.0 | 770.0 |

Table XVII (continued)

| Elapsed Time Hour | Gage Reading 0.001 in. | Creep Strain Microin/in. | Unit Strain Microin/in. |
|---|---|---|---|
| 1400 | 154.4 | 156.0 | 772.0 |
| 1496 | 155.0 | 159.0 | 775.0 |
| 1592 | 155.1 | 159.5 | 775.5 |
| 1688 | 155.5 | 161.5 | 777.5 |
| 1784 | 156.5 | 166.5 | 782.5 |
| 1880 | 156.6 | 167.0 | 783.0 |
| 1976 | 156.4 | 166.0 | 782.0 |
| 2064 | 157.2 | 170.0 | 786.0 |
| 2168 | 158.2 | 175.0 | 791.0 |
| 2264 | 158.4 | 176.0 | 792.0 |
| 2360 | 159.0 | 170.0 | 785.0 |
| 2456 | 158.5 | 176.5 | 792.5 |

*Half Load = 8480 pounds

Note 1: The conductor was overloaded due to over cranking at takeup end.

Note 2: The extensometer clamp block became loose.

Final Stress Strain
(April 12, 1963)

| Elapsed Time Minutes | Conductor Tension Pounds | Gage Reading 0.001 in. | Unit Strain Microin/in. |
|---|---|---|---|
| 0* | 10,720 | 158.7 | 793.5 |
| 3 | 12,350 | 179.3 | 896.5 |
| 6 | 14,291 | 204.0 | 1020.0 |
| 9 | 16,230 | 229.9 | 1149.5 |
| 12 | 18,170 | 255.7 | 1278.5 |
| 15 | 20,100 | 283.1 | 1415.5 |
| 18 | 22,040 | 314.4 | 1572.0 |
| 21 | 20,100 | 290.0 | 1450.0 |
| 24 | 16,230 | 240.0 | 1200.0 |
| 27 | 12,350 | 187.9 | 939.5 |
| 30 | 8,480 | 136.7 | 638.5 |
| 33 | 4,600 | 84.1 | 420.5 |
| 36 | 725 | -25.9 | -129.0 |
| 39 | 2,663 | 56.9 | 280.0 |
| 42 | 4,600 | 82.7 | 413.5 |
| 45 | 6,540 | 108.0 | 540.5 |
| 48 | 8,480 | 134.0 | 670.0 |
| 51 | 10,720 | 163.5 | 817.5 |

*0 minutes= 2543.7 hours.

Table XVIII
Initial Stress Strain Test Data

SUBJECT: Initial Stress-Strain of Chukar Conductor C(K)-1
BY: O. G. Paasche and Y. S. Shen DATE: December 21, 1962
GAGE LENGTH: 200 inches TEMPERATURE: $75 \pm 2^{\circ}$ F
TIME: Time is time of load change, gage reading taken 2-1/2 minutes later than indicated.

| Elapsed Time Minutes | Conductor Tension Pounds | Gage Reading 0.001 in. | Unit Strain Microin/in. |
|---|---|---|---|
| 0 | 725 | 0 | 0 |
| 3 | 2,663 | 39.0 | 185.0 |
| 6 | 4,601 | 71.3 | 356.5 |
| 9 | 6,539 | 101.1 | 505.5 |
| 12 | 8,477 | 130.8 | 654.0 |
| 15 | 10,415 | 162.0 | 810.0 |
| 18 | 12,353 | 193.5 | 967.5 |
| 21 | 14,291 | 226.2 | 1131.0 |
| 24 | 16,229 | 260.0 | 1300.0 |
| 27 | 18,167 | 296.3 | 1481.5 |
| 30 | 20,105 | 334.2 | 1671.0 |
| 33 | 22,043 | 374.5 | 1872.5 |
| 36 | 20,105 | 349.7 | 1748.5 |
| 39 | 16,229 | 298.2 | 1491.0 |
| 42 | 12,353 | 245.4 | 1227.0 |
| 45 | 8,477 | 191.2 | 956.6 |
| 48 | 4,001 | 135.2 | 676.0 |
| 51 | 725 | 44.3 | 221.5 |
| 54 | 2,663 | 103.2 | 516.0 |
| 57 | 4,601 | 131.9 | 659.5 |
| 60 | 6,539 | 159.4 | 797.0 |
| 63 | 8,477 | 186.6 | 933.0 |
| 66 | 10,415 | 213.9 | 1089.5 |
| 69 | 10,714 | 218.0 | 1090.0 |

Table XIX

Initial Stress Strain Test Data

SUBJECT: Initial Stress-Strain of Chukar Conductor C(K)-2
BY: O. G. Paasche and Y. S. Shen DATE: December 21, 1962
GAGE LENGTH: 200 inches TEMPERATURE: 75 ± 2° F
TIME: Time is time of load charge, gage reading taken 2-1/2 minutes later than indicated.

| Elapsed Time Minutes | Conductor Tension Pounds | Gage Reading 0.001 in. | Unit Strain Microin/in. |
|---|---|---|---|
| | FIRST LOADING | | |
| 0 | 752 | 0 | 0 |
| 3 | 2,725 | 39.7 | 198.5 |
| 6 | 4,698 | 71.0 | 355.0 |
| 9 | 6,671 | 101.3 | 506.5 |
| 12 | 8,644 | 131.3 | 656.5 |
| 15 | 10,617 | 162.2 | 816.0 |
| | SECOND LOADING | | |
| 0 | 752 | 0 | 0 |
| 3 | 2,725 | 37.2 | 186.0 |
| 6 | 4,698 | 65.9 | 329.5 |
| 9 | 6,671 | 93.0 | 465.0 |
| 12 | 8,644 | 120.7 | 603.5 |
| 15 | 10,617 | 148.9 | 744.5 |
| 18 | 12,590 | 179.5 | 897.5 |
| 21 | 14,563 | 212.7 | 1013.5 |
| 24 | 16,536 | 247.1 | 1235.5 |
| 27 | 18,509 | 283.7 | 1416.5 |
| 30 | 20,482 | 321.8 | 1609.0 |
| 33 | 22,455 | 360.5 | 1802.5 |
| 36 | 20,482 | 335.8 | 1679.0 |
| 39 | 16,536 | 282.2 | 1411.0 |
| 42 | 12,590 | 230.6 | 1158.0 |
| 45 | 8,644 | 176.2 | 881.0 |
| 48 | 4,698 | 120.1 | 600.5 |
| 51 | 752 | 29.8 | 149.0 |
| 54 | 2,725 | 87.5 | 437.5 |
| 57 | 4,698 | 116.3 | 586.5 |
| 60 | 6,671 | 143.3 | 716.5 |
| 63 | 8,644 | 171.0 | 855.0 |
| 66 | 10,617 | 197.8 | 989.0 |
| 69 | 10,700 | 200.0 | 1000.0 |

Table XX

Initial Stress Strain Test Data

SUBJECT: Initial Stress-Strain of Chukar Conductor C(K)-3
BY: O. G. Paasche and Y. S. Shen DATE: December 21, 1962
GAGE LENGTH: 200 inches TEMPERATURE: 75 ± 2° F
TIME: Time is time of load charge, gage reading taken 2-1/2 minutes later than indicated.

| Elapsed Time Minutes | Conductor Tension Pounds | Gage Reading 0.001 in. | Unit Strain Microin/in. |
|---|---|---|---|
| 0 | 741 | 0 | 0 |
| 3 | 2,732 | 40.2 | 201.0 |
| 6 | 4,723 | 73.2 | 366.0 |
| 9 | 6,714 | 104.1 | 520.5 |
| 12 | 8,705 | 135.0 | 675.0 |
| 15 | 10,696 | 165.0 | 825.0 |
| 18 | 12,687 | 194.7 | 973.5 |
| 21 | 14,687 | 225.2 | 1126.0 |
| 24 | 16,669 | 257.5 | 1287.5 |
| 27 | 18,660 | 291.7 | 1458.5 |
| 30 | 20,651 | 327.3 | 1636.5 |
| 33 | 22,642 | 366.3 | 1831.5 |
| 36 | 20,651 | 341.5 | 1707.5 |
| 39 | 16,669 | 290.2 | 1456.0 |
| 42 | 12,687 | 237.0 | 1185.0 |
| 45 | 8,705 | 182.6 | 913.0 |
| 48 | 4,723 | 126.0 | 630.0 |
| 51 | 741 | 43.3 | 216.5 |
| 54 | 2,732 | 96.2 | 481.0 |
| 57 | 4,723 | 124.9 | 624.5 |
| 60 | 6,714 | 152.2 | 761.0 |
| 63 | 8,705 | 179.1 | 895.5 |
| 66 | 10,696 | 205.8 | 1029.0 |
| 69 | 10,700 | 206.9 | 1034.5 |

Table XXI

Initial Stress Strain Test Data

SUBJECT: Initial Stress-Strain of Drake Conductor D(SE)-1
BY: O. G. Paasche and Y. S. Shen DATE: May 5, 1963
GAGE LENGTH: 200 inches TEMPERATURE: 75 ± 2° F
TIME: Time is time of load change, gage reading taken 2-1/2 minutes later than indicated.

| Elapsed Time Minutes | Conductor Tension Pounds | Gage Reading 0.001 in. | Unit Strain Microin/in. |
|---|---|---|---|
| 0 | 725 | 0 | 0 |
| 3 | 2,663 | 67.2 | 336.0 |
| 6 | 4,601 | 117.7 | 588.5 |
| 9 | 6,539 | 170.8 | 854.0 |
| 12 | 8,477 | 226.3 | 1131.5 |
| 15 | 10,415 | 284.8 | 1424.0 |
| 18 | 12,353 | 349.8 | 1749.0 |
| 21 | 14,291 | 422.6 | 2113.0 |
| 24 | 16,229 | 502.9 | 2514.5 |
| 27 | 18,167 | 594.5 | 2972.5 |
| 30 | 16,299 | 550.0 | 2750.0 |
| 33 | 12,353 | 455.2 | 2276.0 |
| 36 | 8,477 | 359.5 | 1797.5 |
| 39 | 4,601 | 260.0 | 1300.0 |
| 42 | 725 | 81.0 | 405.0 |
| 45 | 2,663 | 196.8 | 984.0 |
| 48 | 4,601 | 272.3 | 1361.5 |
| 51 | 6,240 | 293.9 | 1469.5 |

Table XXII

Initial Stress Strain Test Data

SUBJECT: Initial Stress-Strain of Drake Conductor D(SE)-2
BY: O. G. Paasche and Y. S. Shen DATE: May 4, 1963
GAGE LENGTH: 200 inches TEMPERATURE: 75 ± 2° F
TIME: Time is time of load change, gage reading taken 2-1/2 minutes later than indicated.

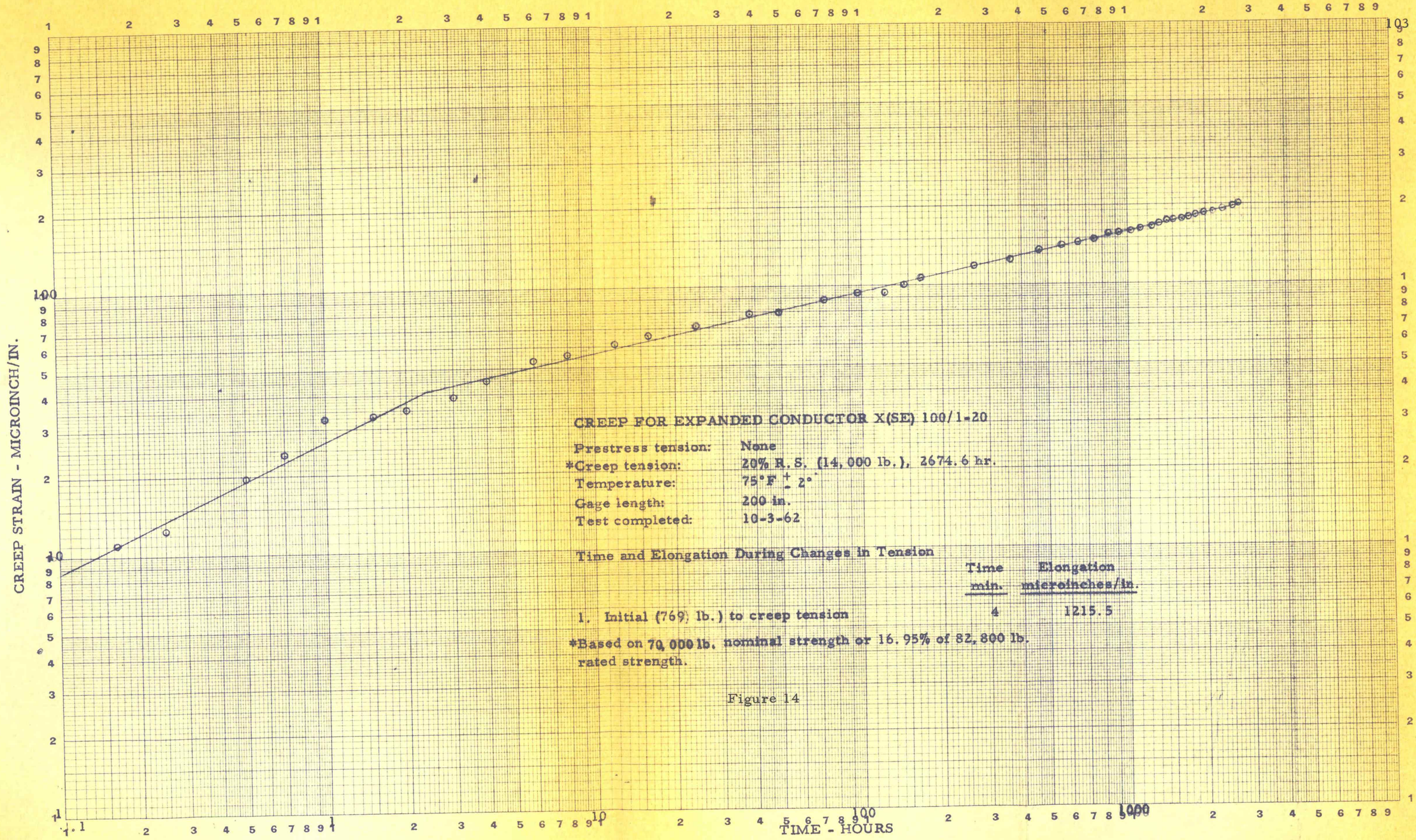
| Elapsed Time Minutes | Conductor Tension Pounds | Gage Reading 0.001 in. | Unit Strain Microin/in. |
|---|---|---|---|
| 0 | 752 | 0 | 0 |
| 3 | 2,725 | 59.0 | 295.0 |
| 6 | 4,698 | 111.5 | 557.5 |
| 9 | 6,671 | 165.0 | 825.0 |
| 12 | 8,644 | 220.5 | 1102.0 |
| 15 | 10,617 | 280.6 | 1403.0 |
| 18 | 12,590 | 328.6 | 1643.0 |
| 22 | 14,593 | 400.8 | 2004.0 |
| 25 | 16,536 | 487.0 | 2435.0 |
| 28 | 18,509 | 538.7 | 2918.0 |
| 30 | 16,536 | 538.2 | 2691.0 |
| 33 | 12,590 | 442.8 | 2214.0 |
| 36 | 8,644 | 344.0 | 1720.0 |
| 39 | 4,698 | 243.7 | 1218.0 |
| 42 | 752 | 56.1 | 280.5 |
| 45 | 2,725 | 178.0 | 890.5 |
| 48 | 4,698 | 235.0 | 1175.0 |
| 51 | 6,240 | 273.8 | 1369.0 |

Table XXIII

Initial Stress Strain Test Data

SUBJECT: Initial Stress-Strain of Drake Conductor D(SE)-3
BY: O. G. Paasche and Y. S. Shen DATE: May 5, 1963
GAGE LENGTH: 200 inches TEMPERATURE: 75 ± 2° F
TIME: Time is time of load change, gage reading taken 2-1/2 minutes later than indicated.

| Elapsed Time Minutes | Conductor Tension Pounds | Gage Reading 0.001 in. | Unit Strain Microin/in. |
|---|---|---|---|
| 0 | 741 | 0 | 0 |
| 3 | 2,732 | 75.0 | 375.0 |
| 6 | 4,723 | 139.0 | 695.0 |
| 9 | 6,714 | 199.1 | 995.5 |
| 12 | 8,705 | 260.2 | 1301.0 |
| 15 | 10,696 | 324.2 | 1621.0 |
| 18 | 12,687 | 392.8 | 1964.0 |
| 21 | 14,678 | 467.2 | 2336.0 |
| 24 | 16,669 | 549.2 | 2746.0 |
| 27 | 18,660 | 640.8 | 3204.0 |
| 30 | 16,669 | 595.1 | 2975.0 |
| 33 | 12,687 | 496.7 | 2483.5 |
| 36 | 8,705 | 396.3 | 1981.5 |
| 39 | 4,723 | 289.9 | 1449.5 |
| 42 | 741 | 82.0 | 410.0 |
| 45 | 2,732 | 208.8 | 1044.0 |
| 48 | 4,723 | 278.3 | 1391.5 |
| 51 | 6,240 | 319.8 | 1599.0 |




CREEP FOR EXPANDED CONDUCTOR X(SE) 100/1-20

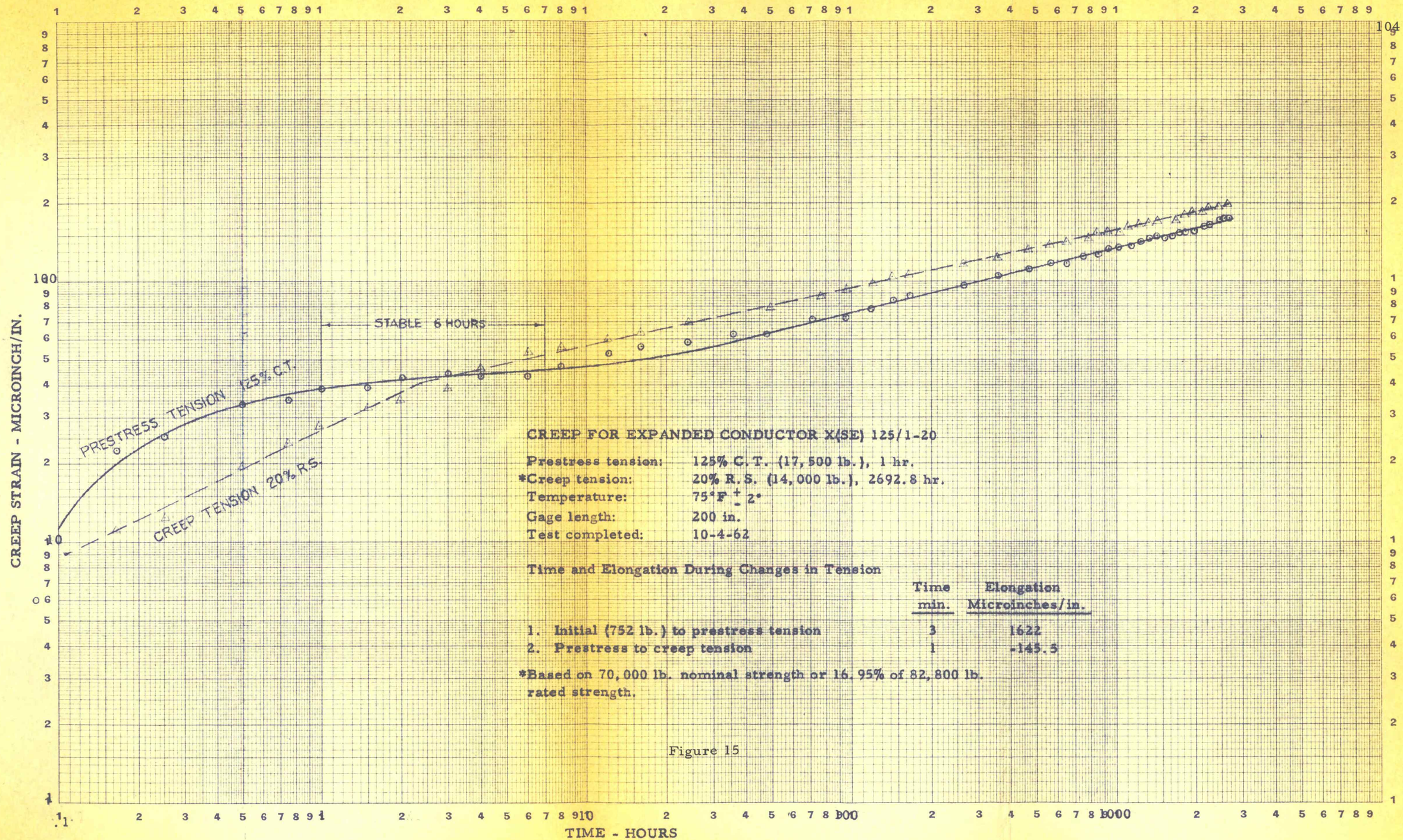
| | |
|---|---|
| Prestress tension: | None |
| *Creep tension: | 20% R.S. (14,000 lb.), 2674.6 hr. |
| Temperature: | 75°F ± 2° |
| Gage length: | 200 in. |
| Test completed: | 10-3-62 |

Time and Elongation During Changes in Tension

| | Time min. | Elongation microinches/in. |
|---|---|---|
| 1. Initial (769 lb.) to creep tension | 4 | 1215.5 |

*Based on 70,000 lb. nominal strength or 16.95% of 82,800 lb. rated strength.

Figure 14




**CREEP FOR EXPANDED CONDUCTOR X(SE) 125/1-20**

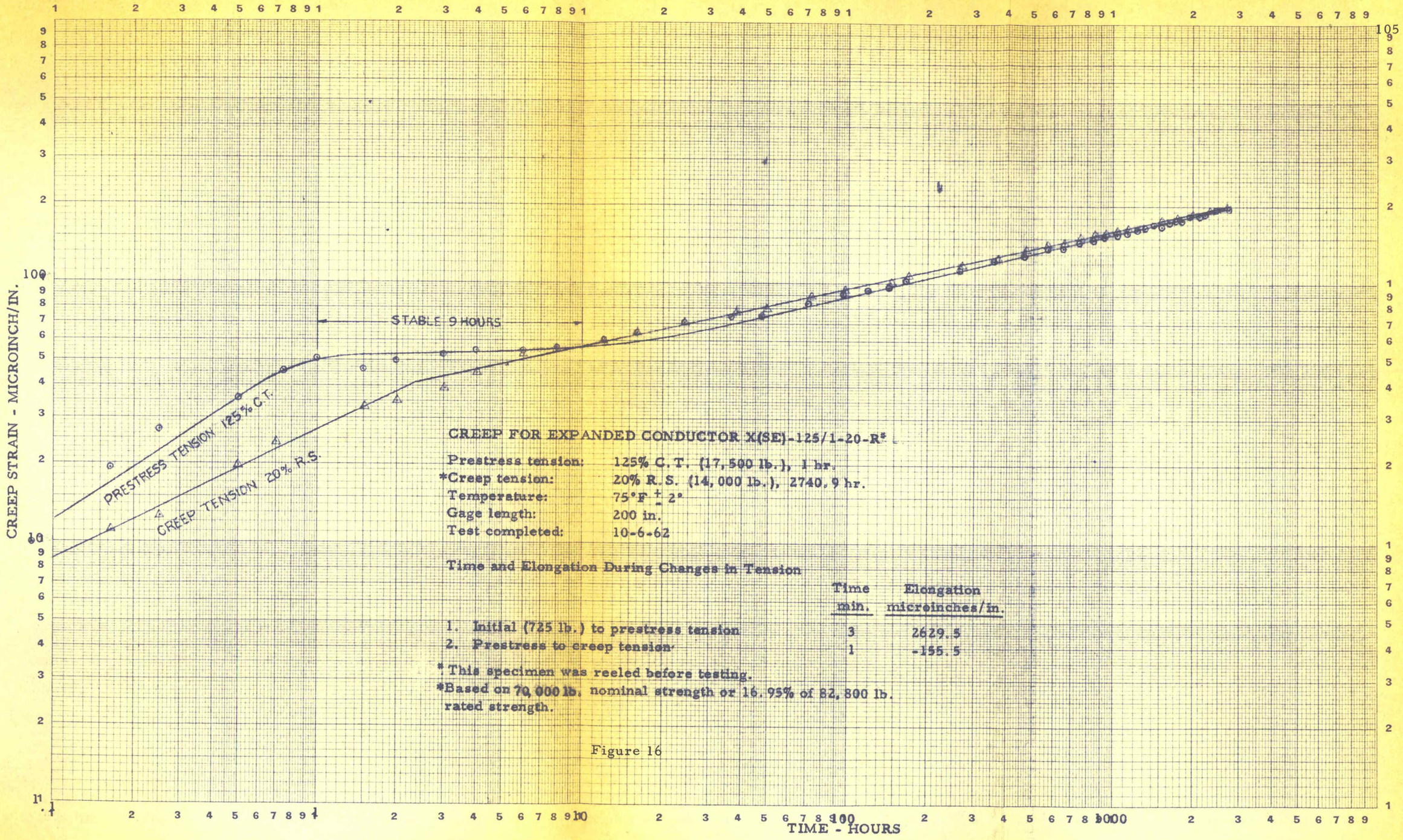
| | |
|---|---|
| Prestress tension: | 125% C.T. (17,500 lb.), 1 hr. |
| *Creep tension: | 20% R.S. (14,000 lb.), 2692.8 hr. |
| Temperature: | 75°F ± 2° |
| Gage length: | 200 in. |
| Test completed: | 10-4-62 |

**Time and Elongation During Changes in Tension**

| | Time min. | Elongation Microinches/in. |
|---|---|---|
| 1. Initial (752 lb.) to prestress tension | 3 | 1622 |
| 2. Prestress to creep tension | 1 | -145.5 |

*Based on 70,000 lb. nominal strength or 16.95% of 82,800 lb. rated strength.

Figure 15




CREEP FOR EXPANDED CONDUCTOR X(SE)-125/1-20-R*

| | |
|---|---|
| Prestress tension: | 125% C.T. (17,500 lb.), 1 hr. |
| *Creep tension: | 20% R.S. (14,000 lb.), 2740.9 hr. |
| Temperature: | 75°F ± 2° |
| Gage length: | 200 in. |
| Test completed: | 10-6-62 |

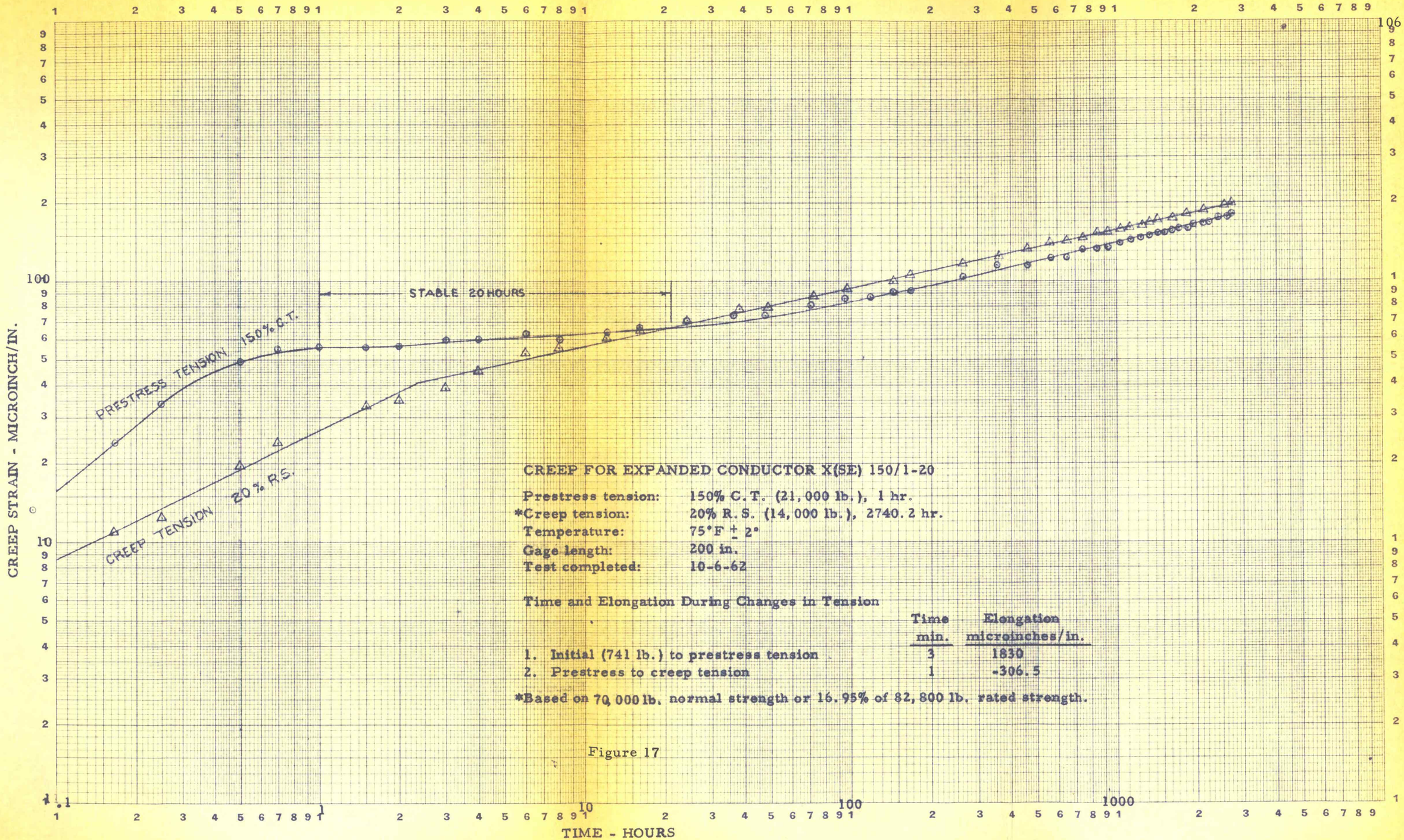
Time and Elongation During Changes in Tension

| | Time min. | Elongation microinches/in. |
|---|---|---|
| 1. Initial (725 lb.) to prestress tension | 3 | 2629.5 |
| 2. Prestress to creep tension | 1 | -155.5 |

* This specimen was reeled before testing.

*Based on 70,000 lb. nominal strength or 16.95% of 82,800 lb. rated strength.

Figure 16




CREEP FOR EXPANDED CONDUCTOR X(SE) 150/1-20

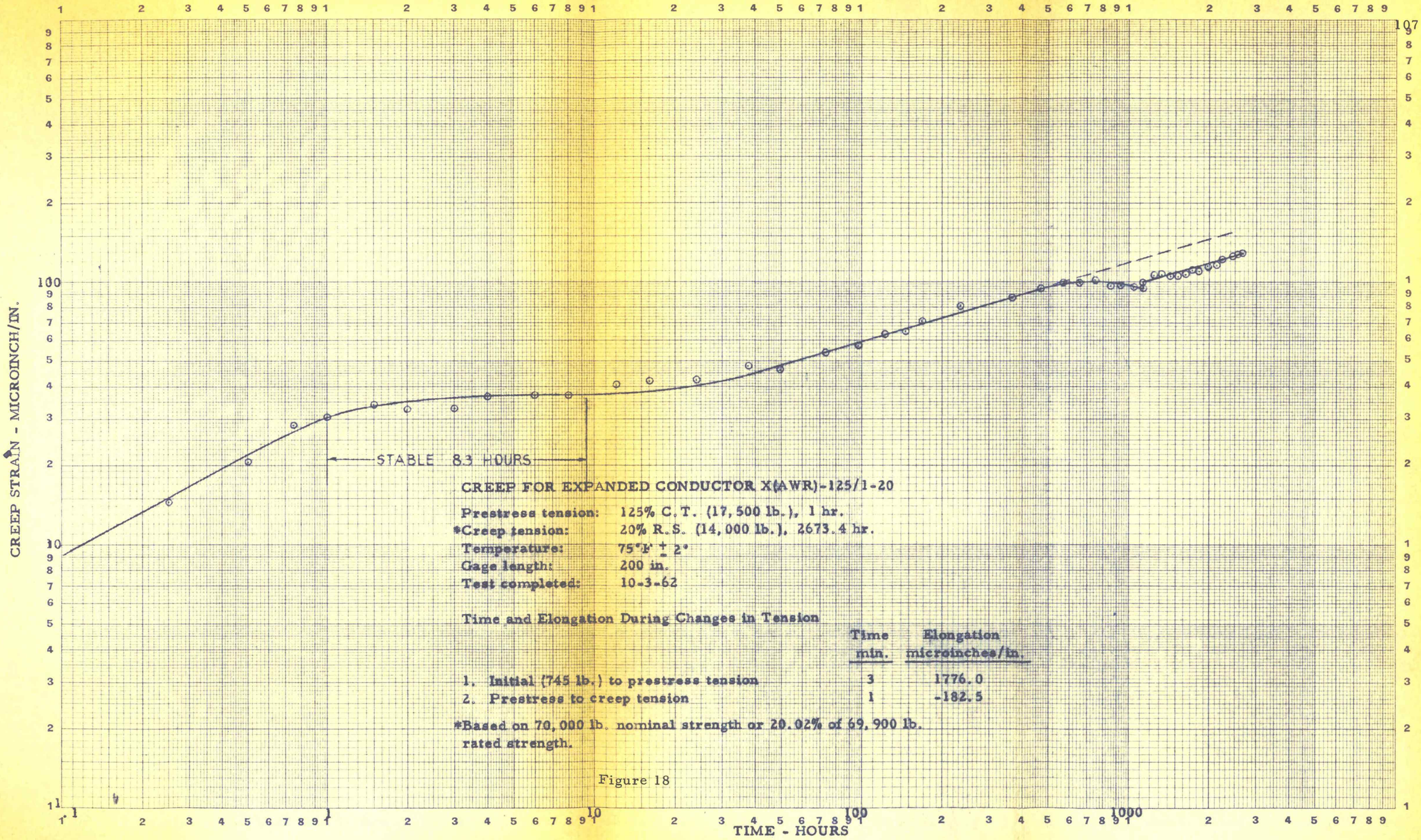
| | |
|---|---|
| Prestress tension: | 150% C.T. (21,000 lb.), 1 hr. |
| *Creep tension: | 20% R.S. (14,000 lb.), 2740.2 hr. |
| Temperature: | 75°F ± 2° |
| Gage length: | 200 in. |
| Test completed: | 10-6-62 |

Time and Elongation During Changes in Tension

| | Time min. | Elongation microinches/in. |
|---|---|---|
| 1. Initial (741 lb.) to prestress tension | 3 | 1830 |
| 2. Prestress to creep tension | 1 | -306.5 |

*Based on 70,000 lb. normal strength or 16.95% of 82,800 lb. rated strength.

Figure 17




CREEP FOR EXPANDED CONDUCTOR X(AWR)-125/1-20

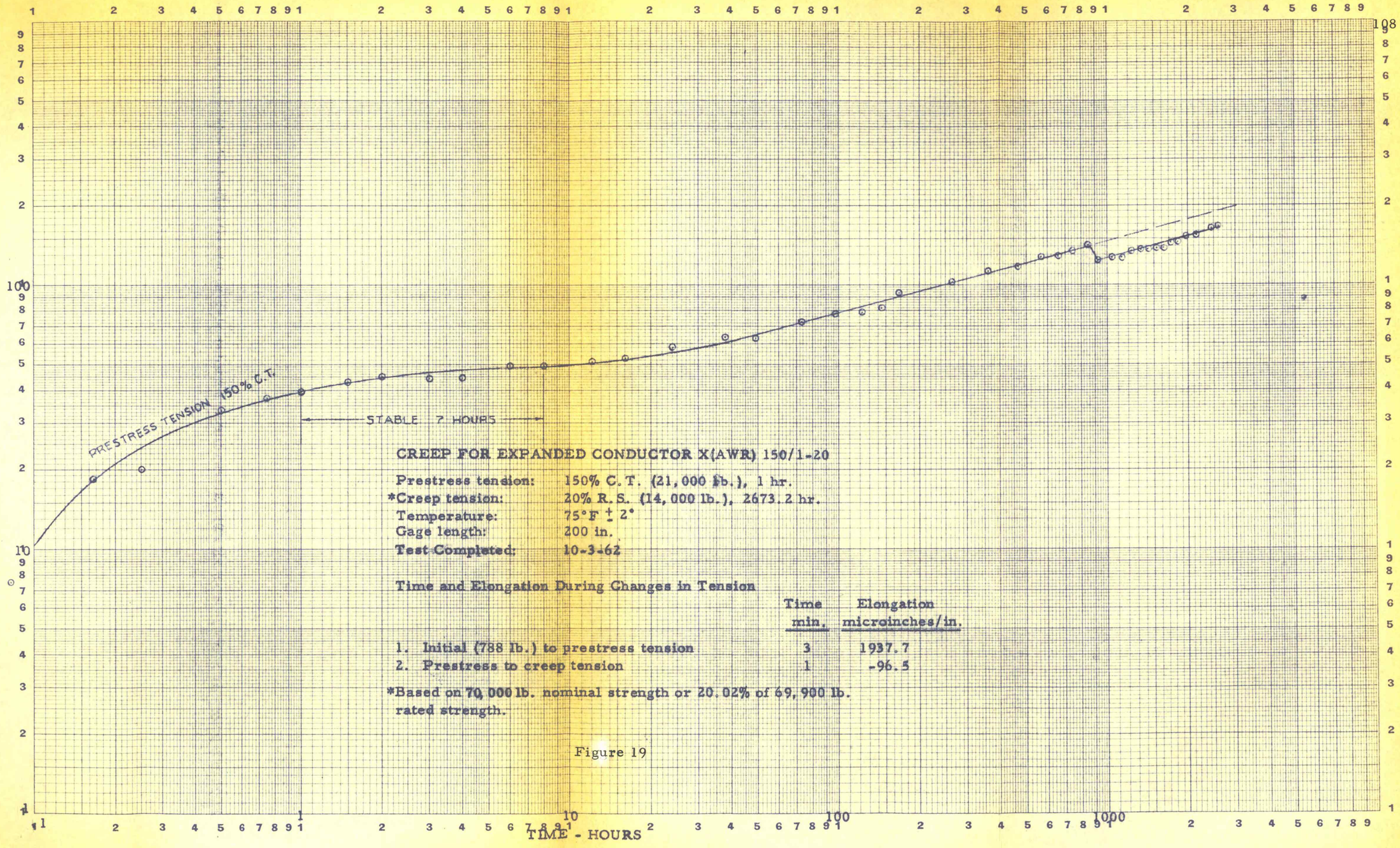
Prestress tension: 125% C.T. (17,500 lb.), 1 hr.
*Creep tension: 20% R.S. (14,000 lb.), 2673.4 hr.
Temperature: 75°F ± 2°
Gage length: 200 in.
Test completed: 10-3-62

Time and Elongation During Changes in Tension

| | Time min. | Elongation microinches/in. |
|---|---|---|
| 1. Initial (745 lb.) to prestress tension | 3 | 1776.0 |
| 2. Prestress to creep tension | 1 | -182.5 |

*Based on 70,000 lb. nominal strength or 20.02% of 69,900 lb. rated strength.

Figure 18




CREEP FOR EXPANDED CONDUCTOR X(AWR) 150/1-20

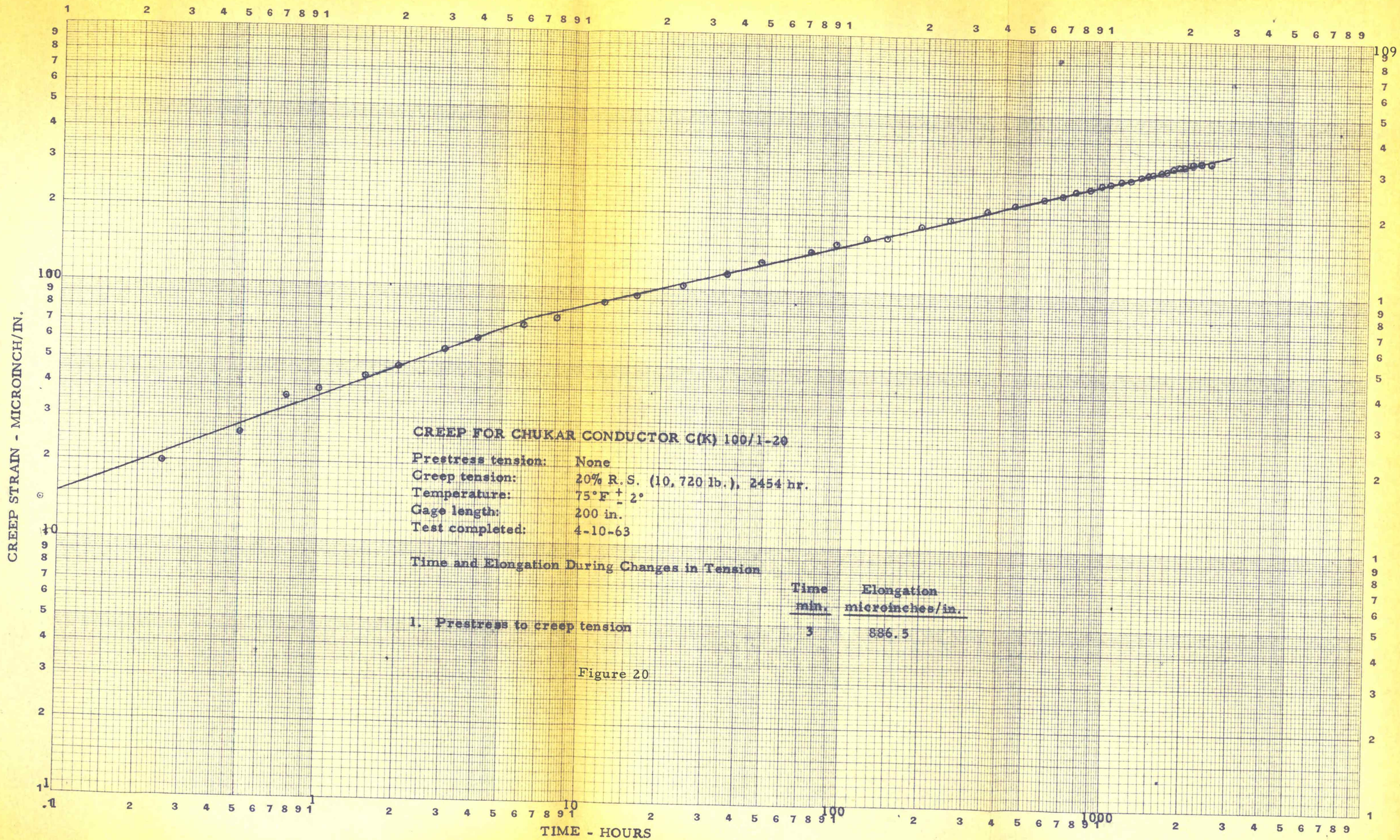
| | |
|---|---|
| Prestress tension: | 150% C.T. (21,000 lb.), 1 hr. |
| *Creep tension: | 20% R.S. (14,000 lb.), 2673.2 hr. |
| Temperature: | 75°F ± 2° |
| Gage length: | 200 in. |
| Test Completed: | 10-3-62 |

Time and Elongation During Changes in Tension

| | Time min. | Elongation microinches/in. |
|---|---|---|
| 1. Initial (788 lb.) to prestress tension | 3 | 1937.7 |
| 2. Prestress to creep tension | 1 | -96.5 |

*Based on 70,000 lb. nominal strength or 20.02% of 69,900 lb. rated strength.

Figure 19



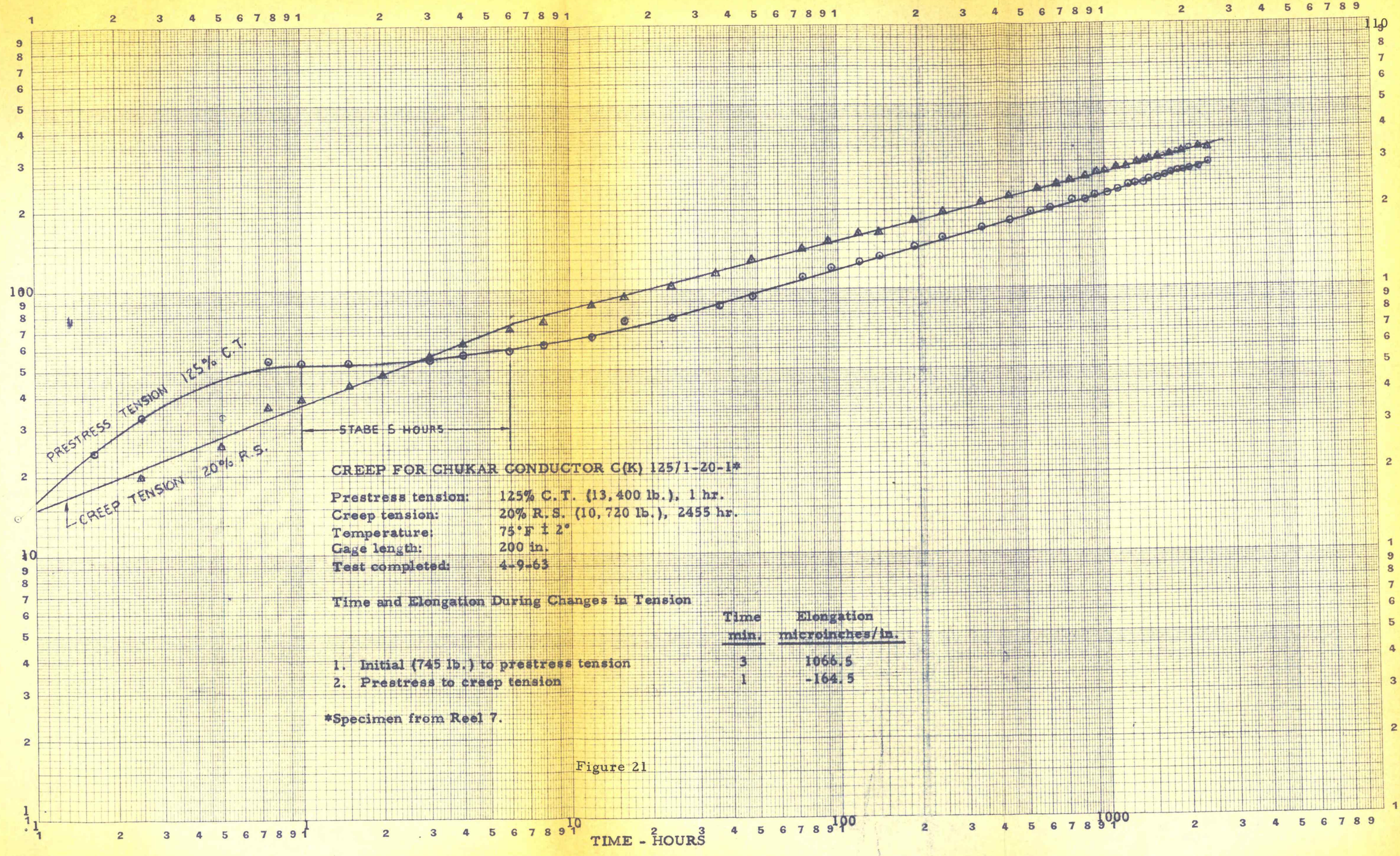

CREEP FOR CHUKAR CONDUCTOR C(K) 100/1-20

| | |
|---|---|
| Prestress tension: | None |
| Creep tension: | 20% R.S. (10,720 lb.), 2454 hr. |
| Temperature: | 75°F ± 2° |
| Gage length: | 200 in. |
| Test completed: | 4-10-63 |

Time and Elongation During Changes in Tension

| | Time min. | Elongation microinches/in. |
|---|---|---|
| 1. Prestress to creep tension | 3 | 886.5 |

Figure 20




CREEP FOR CHUKAR CONDUCTOR C(K) 125/1-20-1*

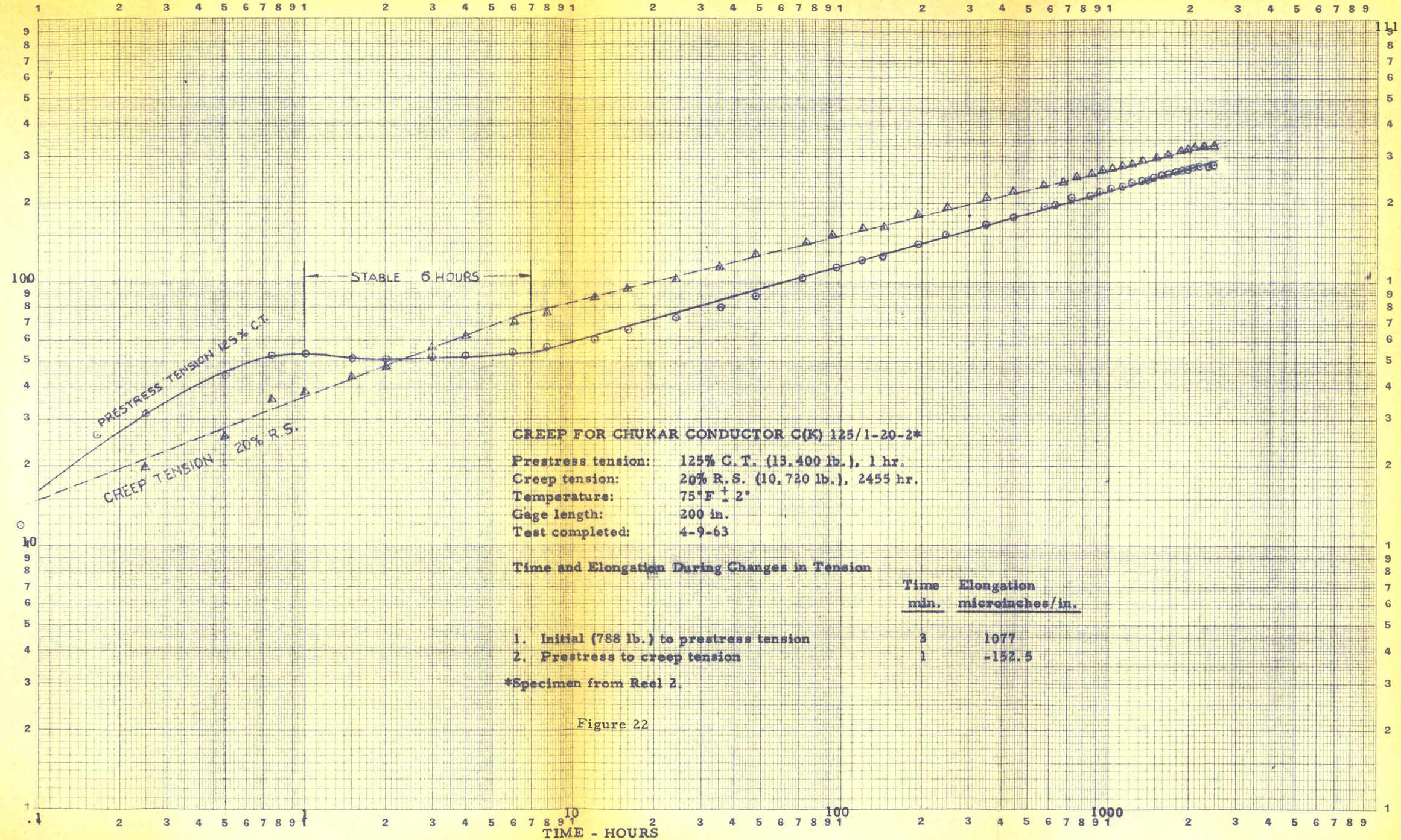
| | |
|---|---|
| Prestress tension: | 125% C.T. (13,400 lb.), 1 hr. |
| Creep tension: | 20% R.S. (10,720 lb.), 2455 hr. |
| Temperature: | 75°F ± 2° |
| Gage length: | 200 in. |
| Test completed: | 4-9-63 |

Time and Elongation During Changes in Tension

| | Time min. | Elongation microinches/in. |
|---|---|---|
| 1. Initial (745 lb.) to prestress tension | 3 | 1066.5 |
| 2. Prestress to creep tension | 1 | -164.5 |

*Specimen from Reel 7.

Figure 21




**CREEP FOR CHUKAR CONDUCTOR C(K) 125/1-20-2***

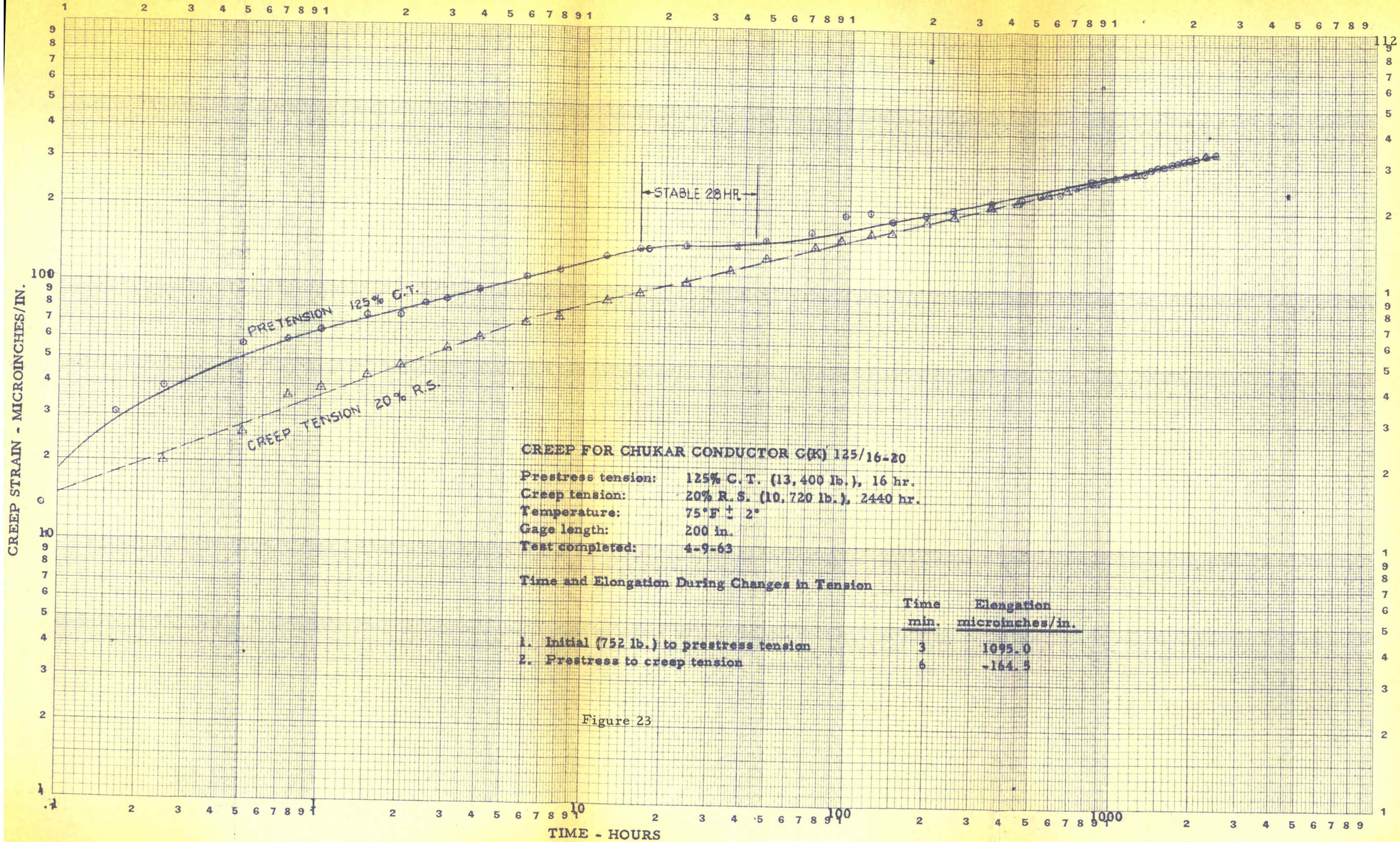
| | |
|---|---|
| Prestress tension: | 125% C.T. (13,400 lb.), 1 hr. |
| Creep tension: | 20% R.S. (10,720 lb.), 2455 hr. |
| Temperature: | 75°F ± 2° |
| Gage length: | 200 in. |
| Test completed: | 4-9-63 |

**Time and Elongation During Changes in Tension**

| | Time min. | Elongation microinches/in. |
|---|---|---|
| 1. Initial (788 lb.) to prestress tension | 3 | 1077 |
| 2. Prestress to creep tension | 1 | -152.5 |

*Specimen from Reel 2.

Figure 22



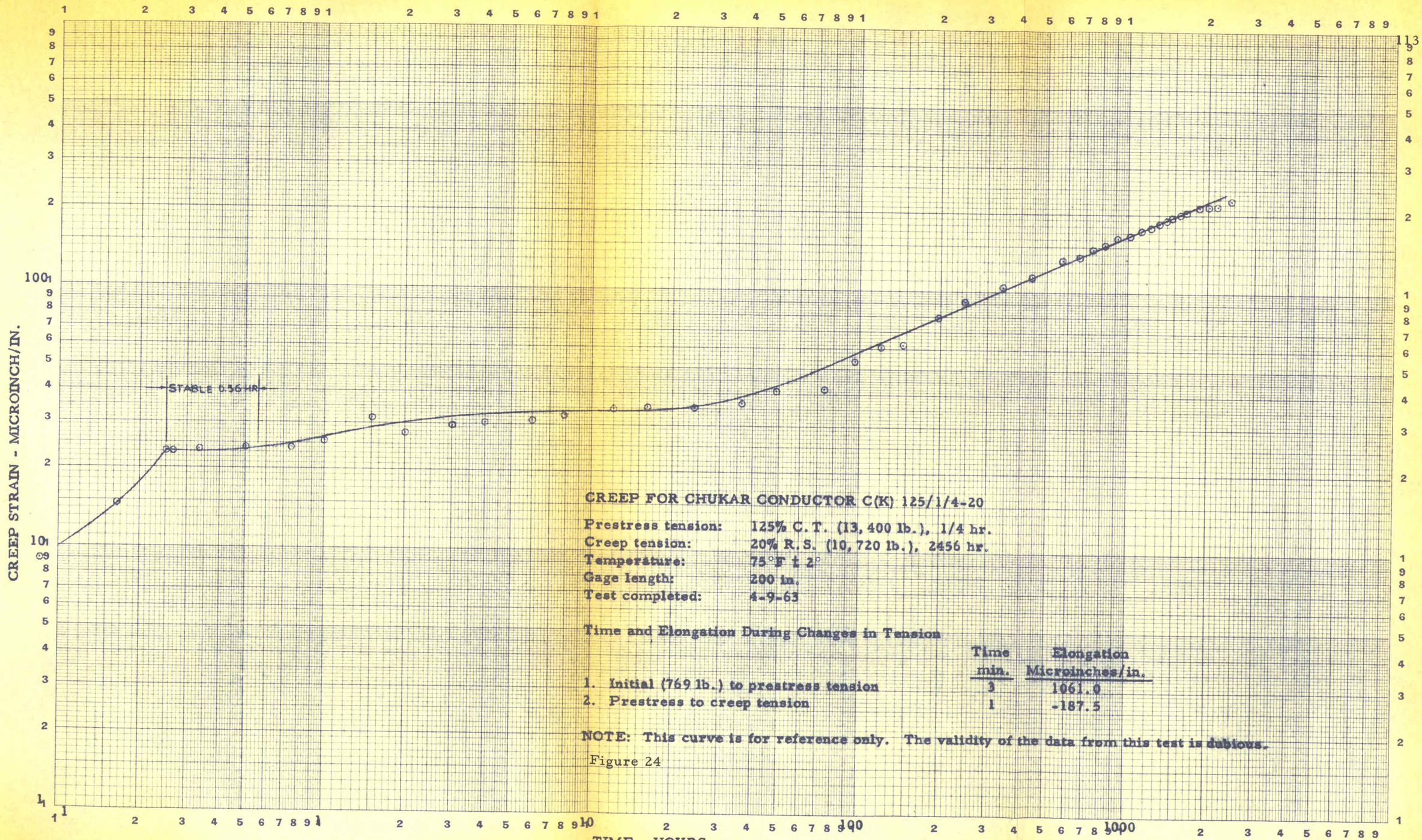

**CREEP FOR CHUKAR CONDUCTOR C(K) 125/16-20**

| | |
|---|---|
| Prestress tension: | 125% C.T. (13,400 lb.), 16 hr. |
| Creep tension: | 20% R.S. (10,720 lb.), 2440 hr. |
| Temperature: | 75°F ± 2° |
| Gage length: | 200 in. |
| Test completed: | 4-9-63 |

**Time and Elongation During Changes in Tension**

| | Time min. | Elongation microinches/in. |
|---|---|---|
| 1. Initial (752 lb.) to prestress tension | 3 | 1095.0 |
| 2. Prestress to creep tension | 6 | -164.5 |

Figure 23




**CREEP FOR CHUKAR CONDUCTOR C(K) 125/1/4-20**

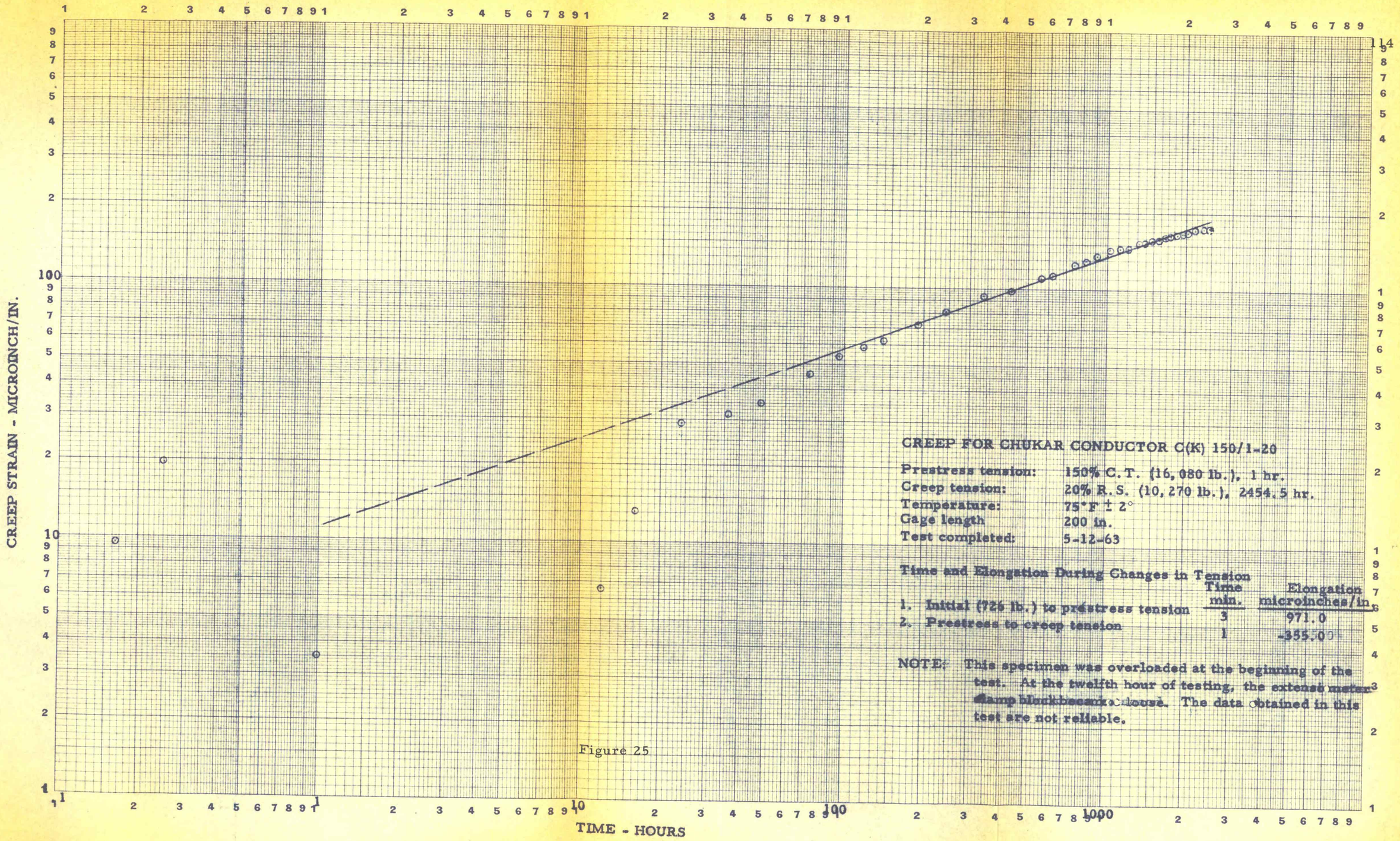
| | |
|---|---|
| Prestress tension: | 125% C.T. (13,400 lb.), 1/4 hr. |
| Creep tension: | 20% R.S. (10,720 lb.), 2456 hr. |
| Temperature: | 75°F ± 2° |
| Gage length: | 200 in. |
| Test completed: | 4-9-63 |

Time and Elongation During Changes in Tension

| | Time min. | Elongation Microinches/in. |
|---|---|---|
| 1. Initial (769 lb.) to prestress tension | 3 | 1061.0 |
| 2. Prestress to creep tension | 1 | -187.5 |

NOTE: This curve is for reference only. The validity of the data from this test is dubious.

Figure 24




**CREEP FOR CHUKAR CONDUCTOR C(K) 150/1-20**

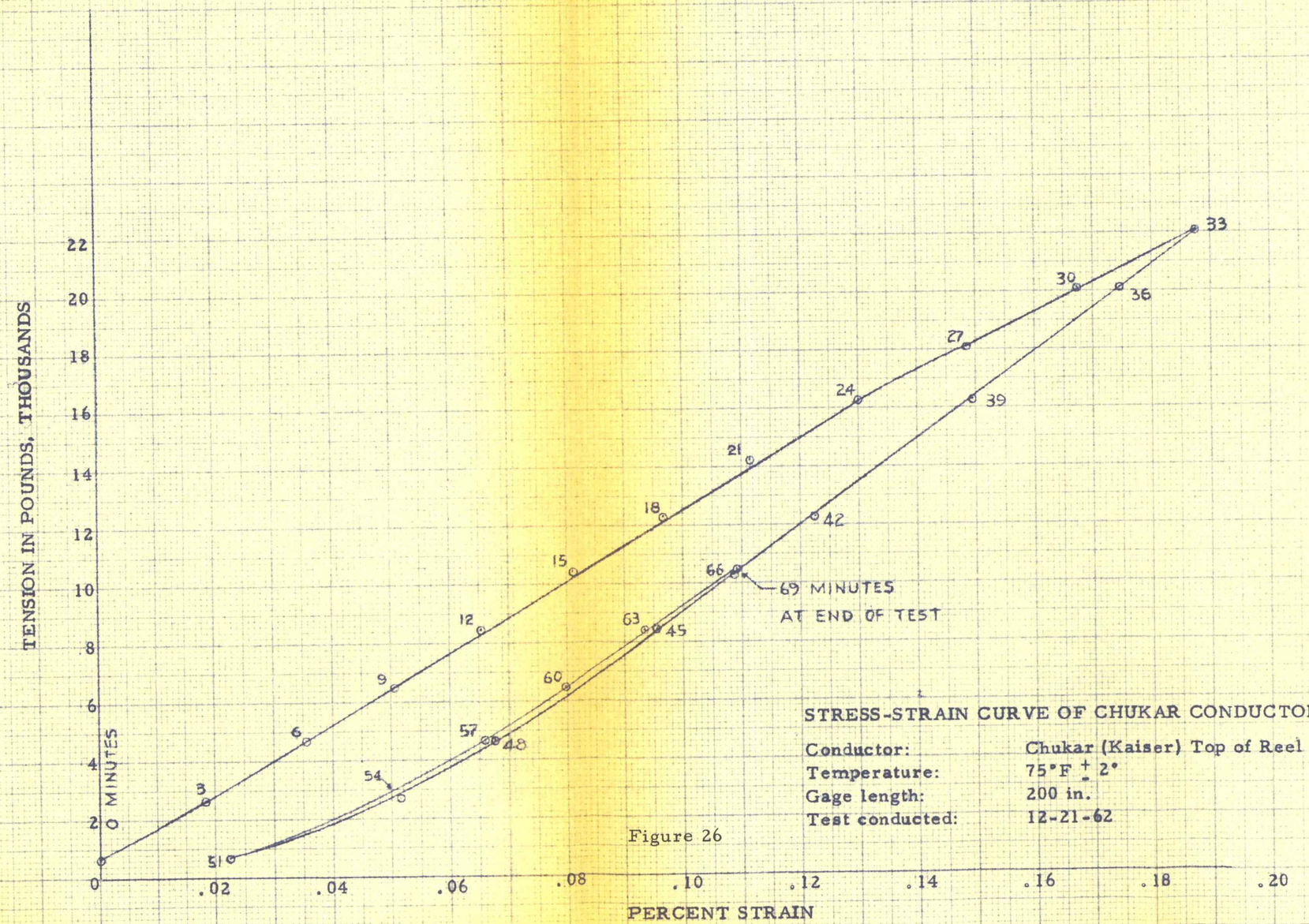
| | |
|---|---|
| Prestress tension: | 150% C.T. (16,080 lb.), 1 hr. |
| Creep tension: | 20% R.S. (10,270 lb.), 2454.5 hr. |
| Temperature: | 75°F ± 2° |
| Gage length | 200 in. |
| Test completed: | 5-12-63 |

**Time and Elongation During Changes in Tension**

| | Time min. | Elongation microinches/in. |
|---|---|---|
| 1. Initial (726 lb.) to prestress tension | 3 | 971.0 |
| 2. Prestress to creep tension | 1 | -355.0 |

NOTE: This specimen was overloaded at the beginning of the test. At the twelfth hour of testing, the extensometer clamp blocks became loose. The data obtained in this test are not reliable.

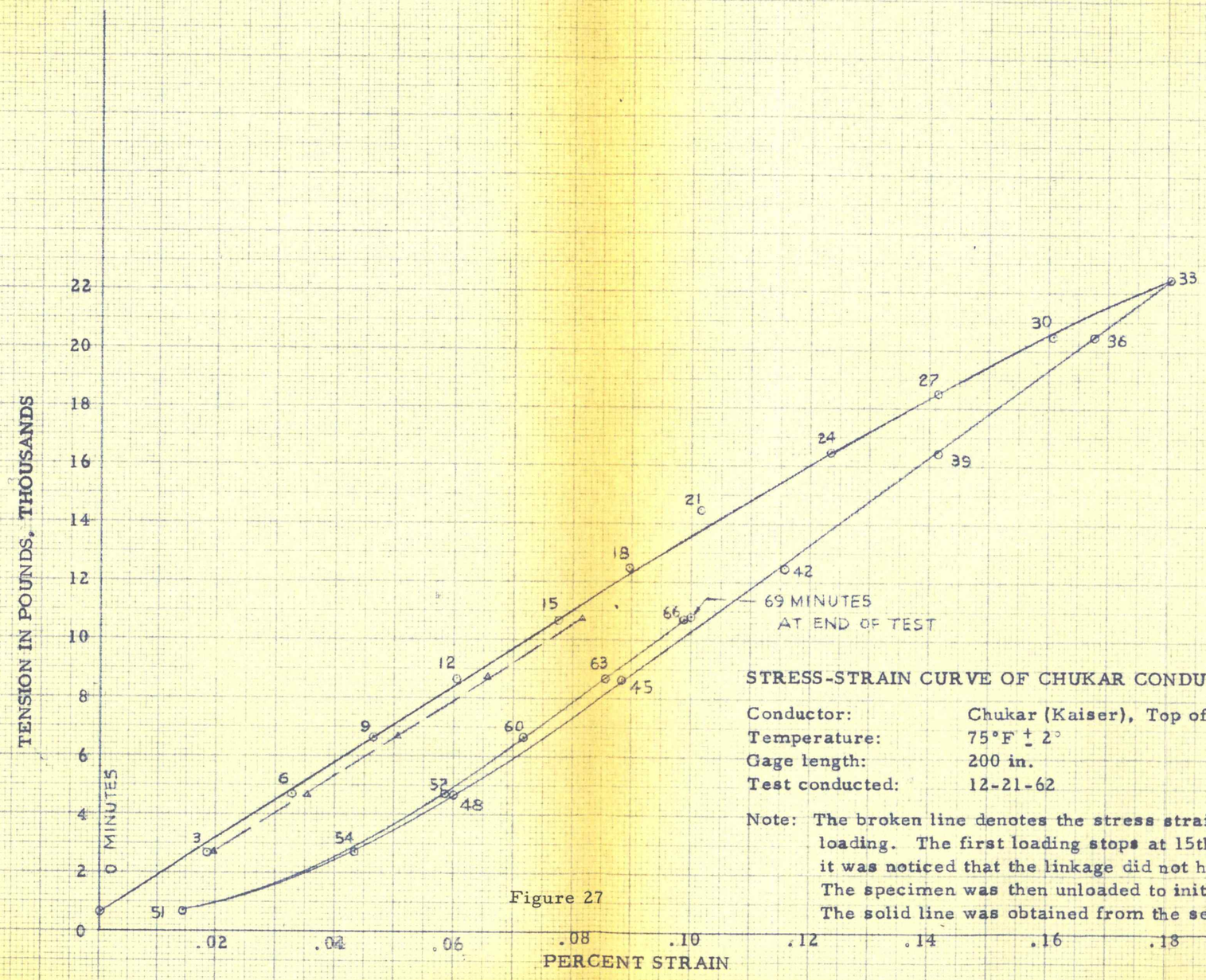
Figure 25




STRESS-STRAIN CURVE OF CHUKAR CONDUCTOR C(K)-1

| | |
|---|---|
| Conductor: | Chukar (Kaiser) Top of Reel 7 |
| Temperature: | 75°F ± 2° |
| Gage length: | 200 in. |
| Test conducted: | 12-21-62 |

Figure 26

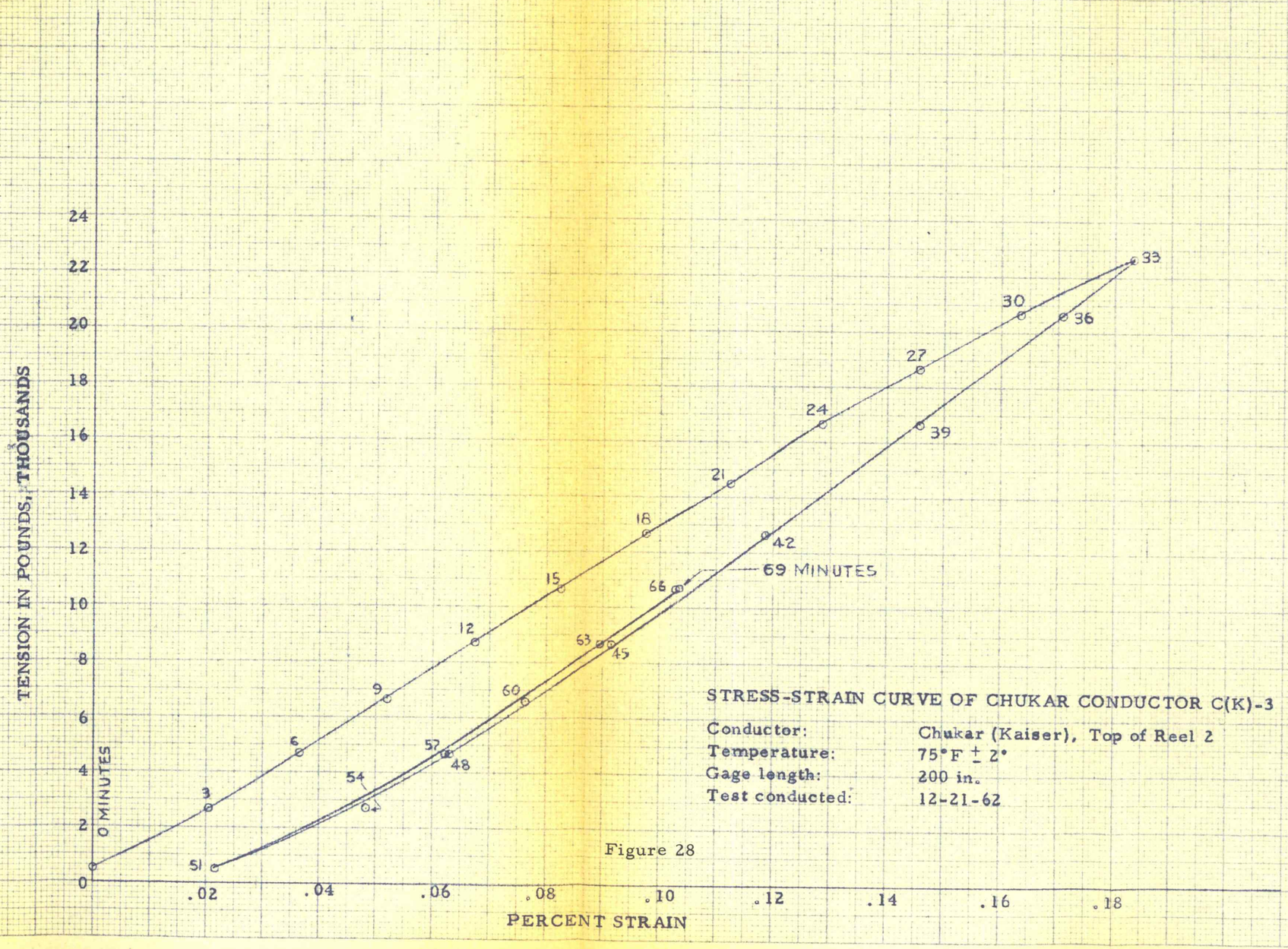



STRESS-STRAIN CURVE OF CHUKAR CONDUCTOR C(K)-2

| | |
|---|---|
| Conductor: | Chukar (Kaiser), Top of Reel 7 |
| Temperature: | 75°F ± 2° |
| Gage length: | 200 in. |
| Test conducted: | 12-21-62 |

Note: The broken line denotes the stress strain curve of the first loading. The first loading stops at 15th minutes, because it was noticed that the linkage did not have full bearing. The specimen was then unloaded to initial loading. The solid line was obtained from the second loading.

Figure 27




STRESS-STRAIN CURVE OF CHUKAR CONDUCTOR C(K)-3

| | |
|---|---|
| Conductor: | Chukar (Kaiser), Top of Reel 2 |
| Temperature: | 75°F ± 2° |
| Gage length: | 200 in. |
| Test conducted: | 12-21-62 |

Figure 28

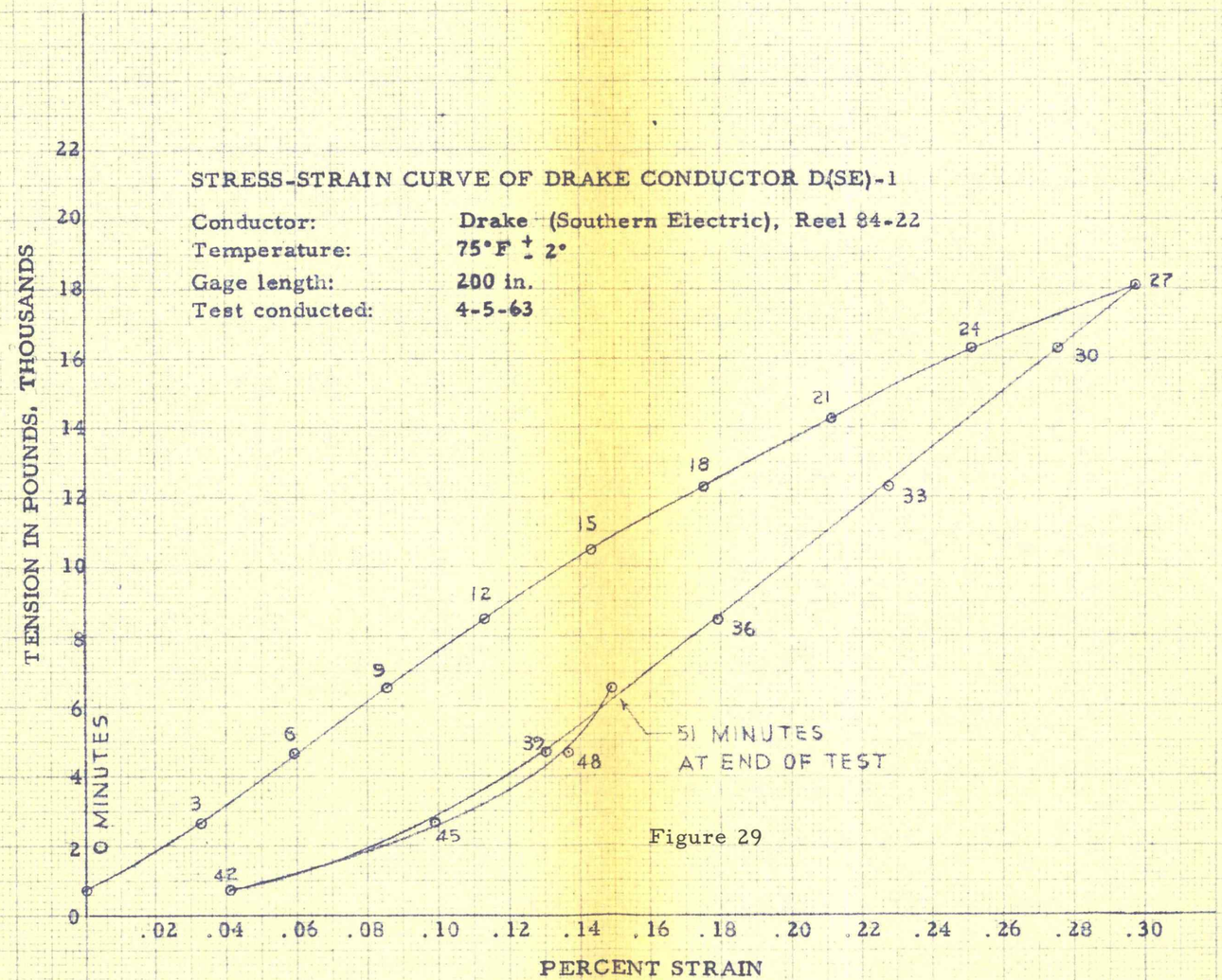

STRESS-STRAIN CURVE OF DRAKE CONDUCTOR D(SE)-1
Conductor: Drake (Southern Electric), Reel 84-22
Temperature: 75°F ± 2°
Gage length: 200 in.
Test conducted: 4-5-63
TENSION IN POUNDS, THOUSANDS
0 MINUTES
51 MINUTES AT END OF TEST
PERCENT STRAIN
0
2
4
6
8
10
12
14
16
18
20
22
.02
.04
.06
.08
.10
.12
.14
.16
.18
.20
.22
.24
.26
.28
.30
3
6
9
12
15
18
21
24
27
42
45
48
32
36
33
30

Figure 29

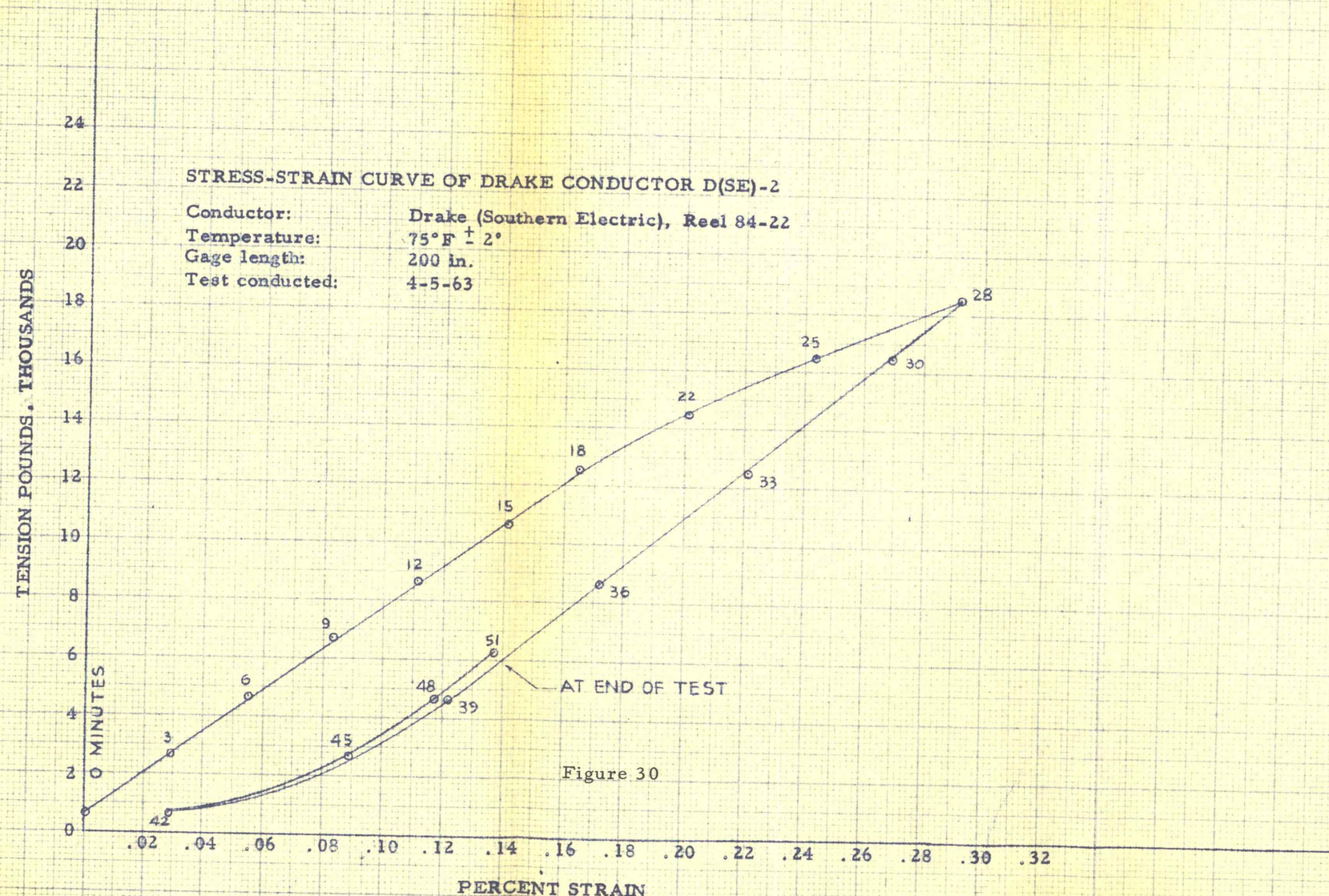

STRESS-STRAIN CURVE OF DRAKE CONDUCTOR D(SE)-2
Conductor: Drake (Southern Electric), Reel 84-22
Temperature: 75°F ± 2°
Gage length: 200 in.
Test conducted: 4-5-63
TENSION POUNDS, THOUSANDS
PERCENT STRAIN
0 MINUTES
AT END OF TEST
0
2
4
6
8
10
12
14
16
18
20
22
24
.02
.04
.06
.08
.10
.12
.14
.16
.18
.20
.22
.24
.26
.28
.30
.32
3
6
9
12
15
18
22
25
28
42
45
48
51
30
33
36
39

Figure 30

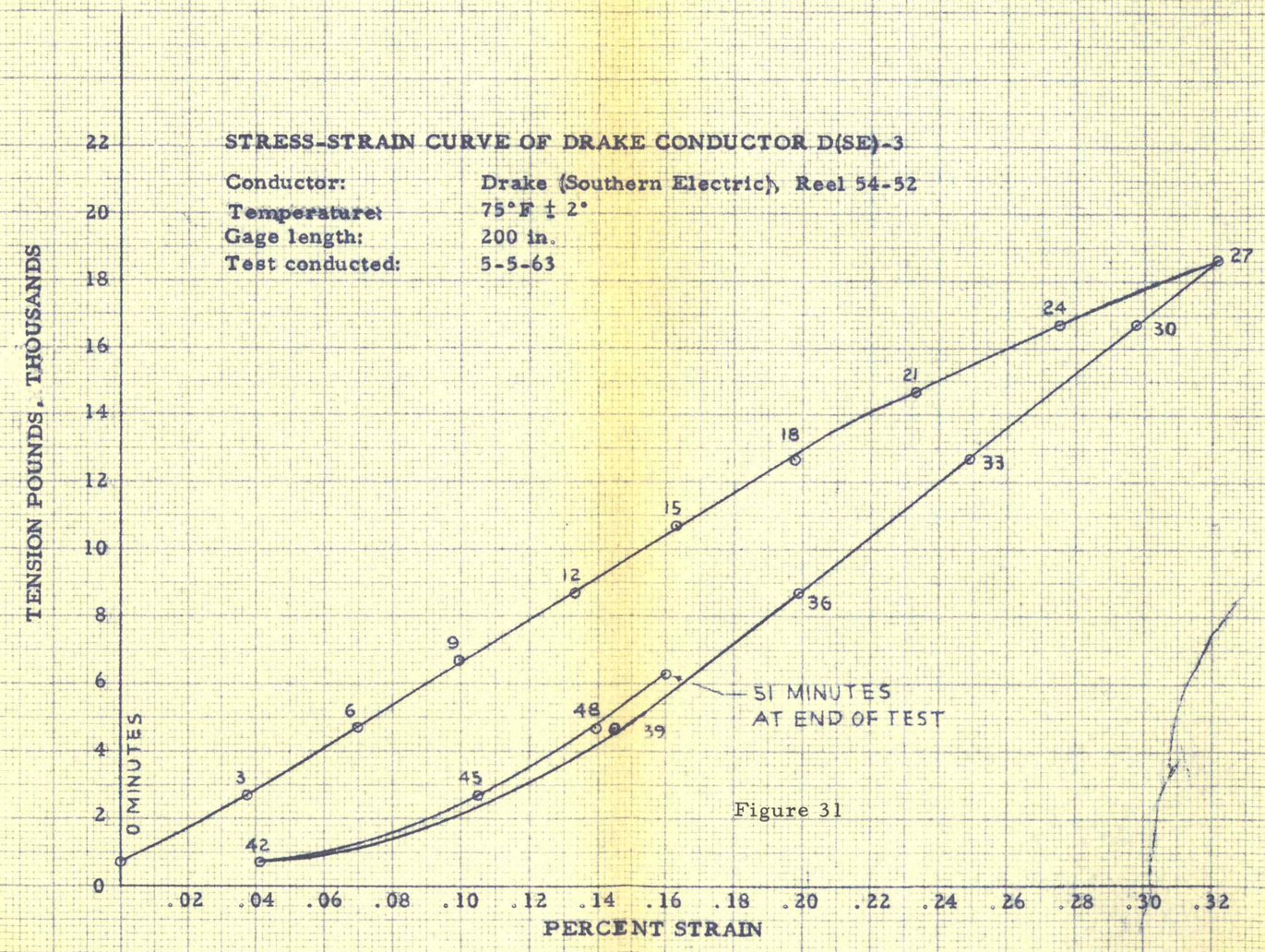

STRESS-STRAIN CURVE OF DRAKE CONDUCTOR D(SE)-3
Conductor: Drake (Southern Electric), Reel 54-52
Temperature: 75°F ± 2°
Gage length: 200 in.
Test conducted: 5-5-63
TENSION POUNDS, THOUSANDS
PERCENT STRAIN
0 MINUTES
51 MINUTES AT END OF TEST
0
2
4
6
8
10
12
14
16
18
20
22
.02
.04
.06
.08
.10
.12
.14
.16
.18
.20
.22
.24
.26
.28
.30
.32
3
6
9
12
15
18
21
24
27
42
45
48
39
36
30
33

Figure 31

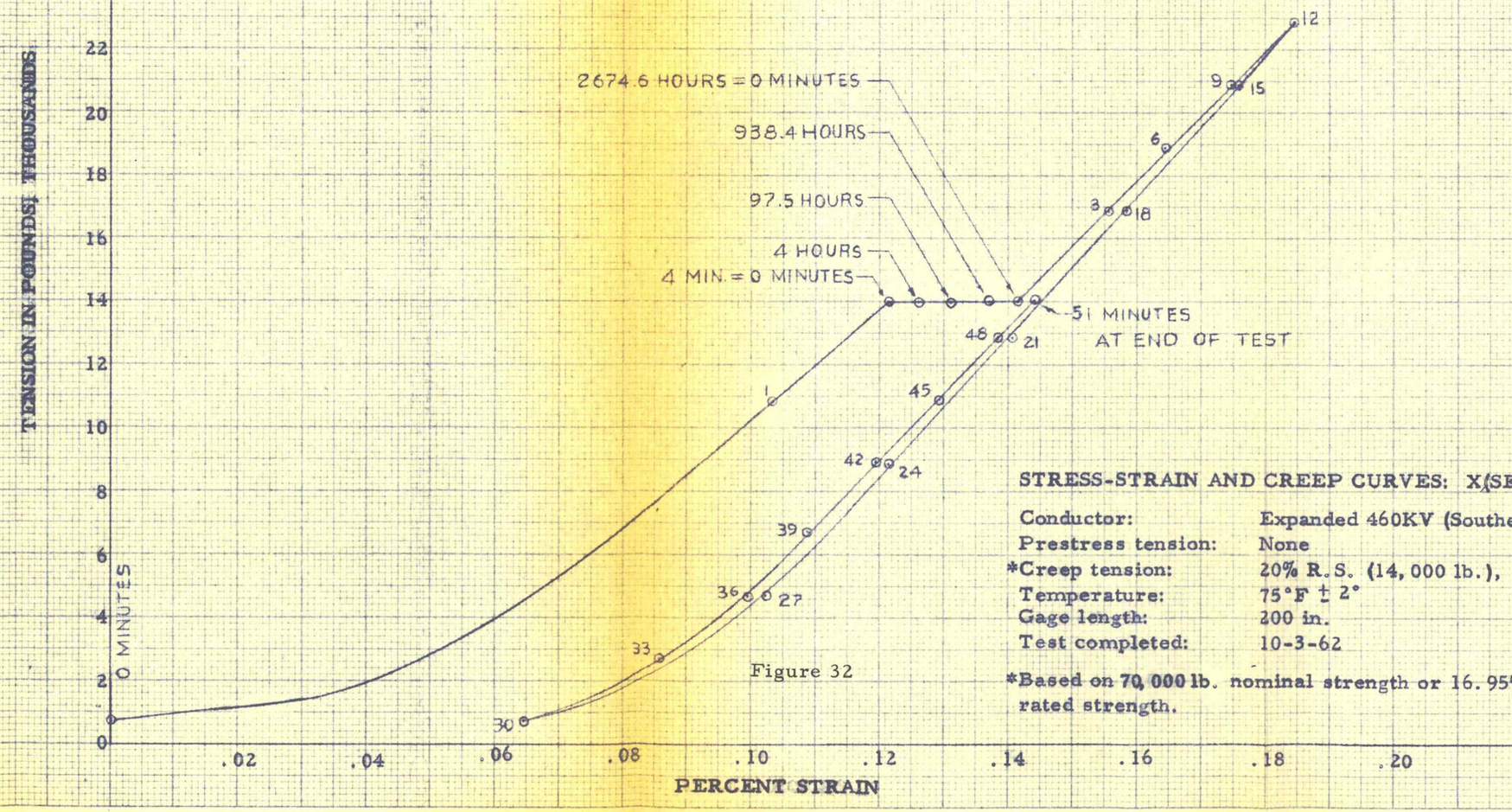



Figure 32

**STRESS-STRAIN AND CREEP CURVES: X(SE) 100/1-20**

| | |
|---|---|
| Conductor: | Expanded 460KV (Southern Electric) |
| Prestress tension: | None |
| *Creep tension: | 20% R.S. (14,000 lb.), 2674.6 hr. |
| Temperature: | 75°F ± 2° |
| Gage length: | 200 in. |
| Test completed: | 10-3-62 |

*Based on 70,000 lb. nominal strength or 16.95% of 82,800 lb. rated strength.

STRESS-STRAIN AND CREEP CURVES: X(SE)-125/1-20

| | |
|---|---|
| Conductor: | Expanded 460KV (Southern Electric) |
| Prestress tension: | 125% C.T. (17,500 lb.), 1 hr. |
| *Creep tension: | 20% R.S. (14,000 lb.), 2692.8 hr. |
| Temperature: | 75°F ± 2° |
| Gage length: | 200 in. |
| Test completed: | 10-4-62 |

*Based on 70,000 lb. nominal strength or 16.95% of 82,800 lb. rated strength.

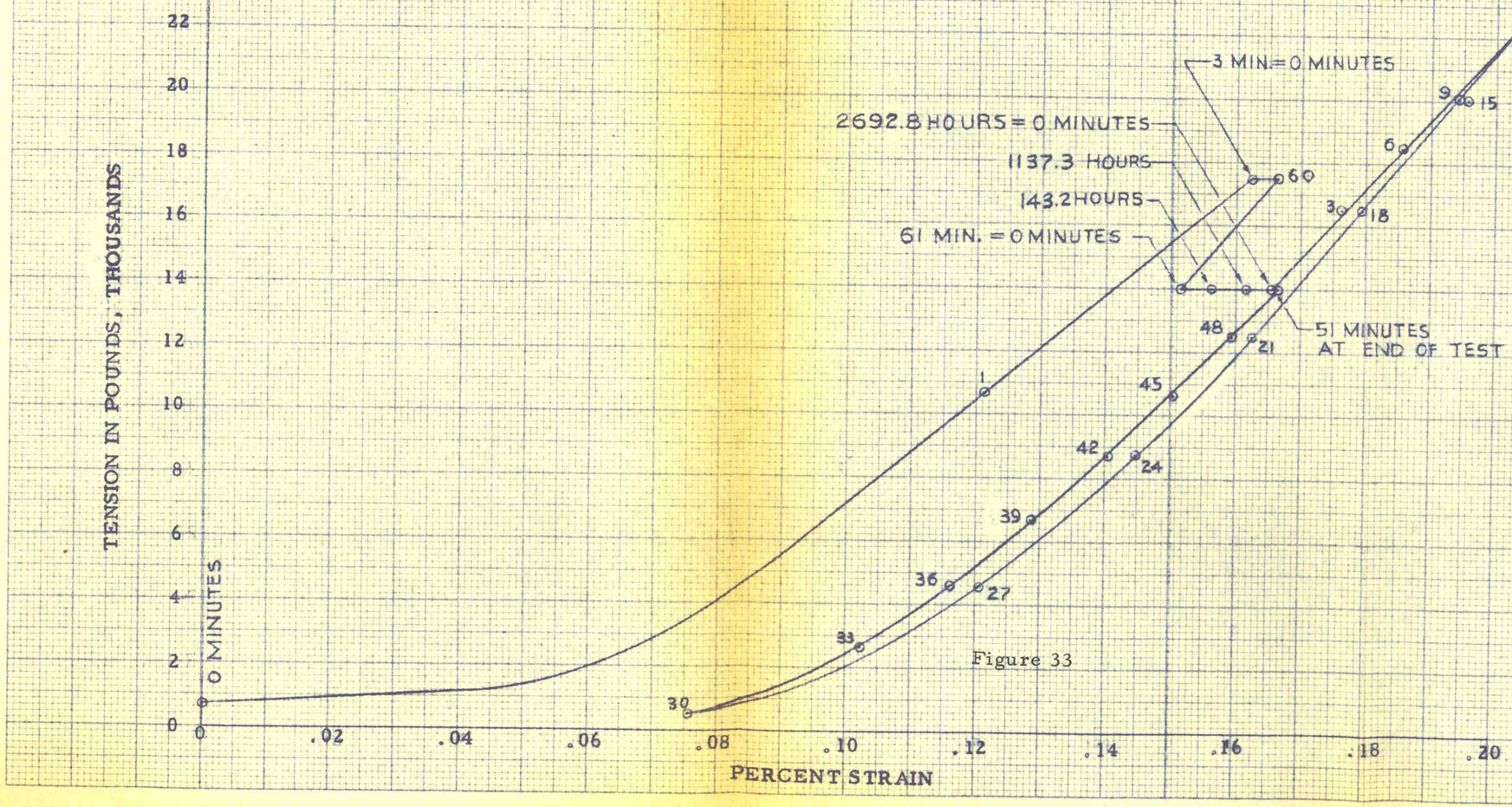



Figure 33

STRESS-STRAIN AND CREEP CURVES: X(SE)-125/1-20-R*

| | |
|---|---|
| Conductor: | Expanded 460KV (Southern Electric) |
| Prestress tension: | 125% R.S. (17,500 lb.), 1 hr. |
| *Creep tension: | 20% R.S. (14,000 lb), 2740.9 hr. |
| Temperature: | 75°F ± 2° |
| Gage length: | 200 in. |
| Test completed: | 10-6-62 |

*This specimen was reeled before testing.

*Based on 70,000 lb. nominal strength or 16.95% of 82,800 lb. rated strength.

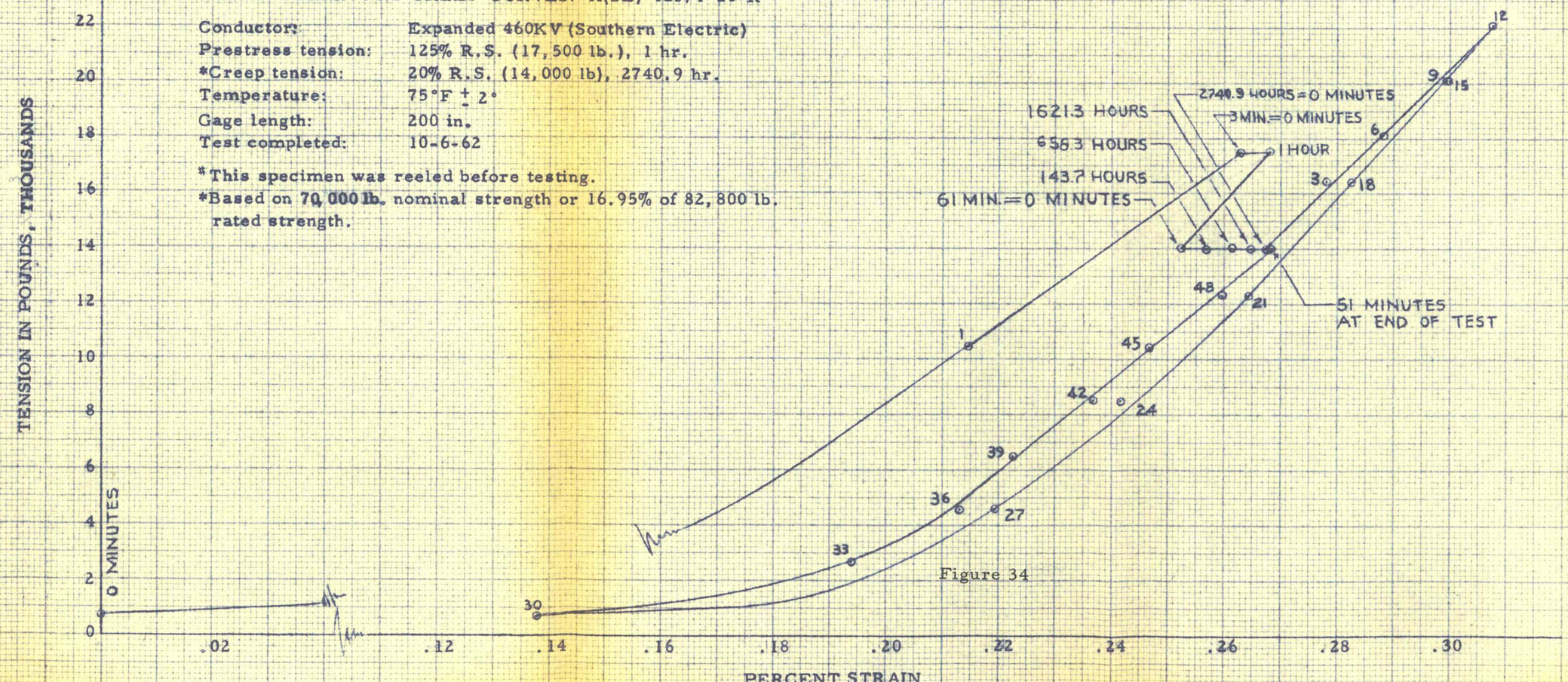



Figure 34

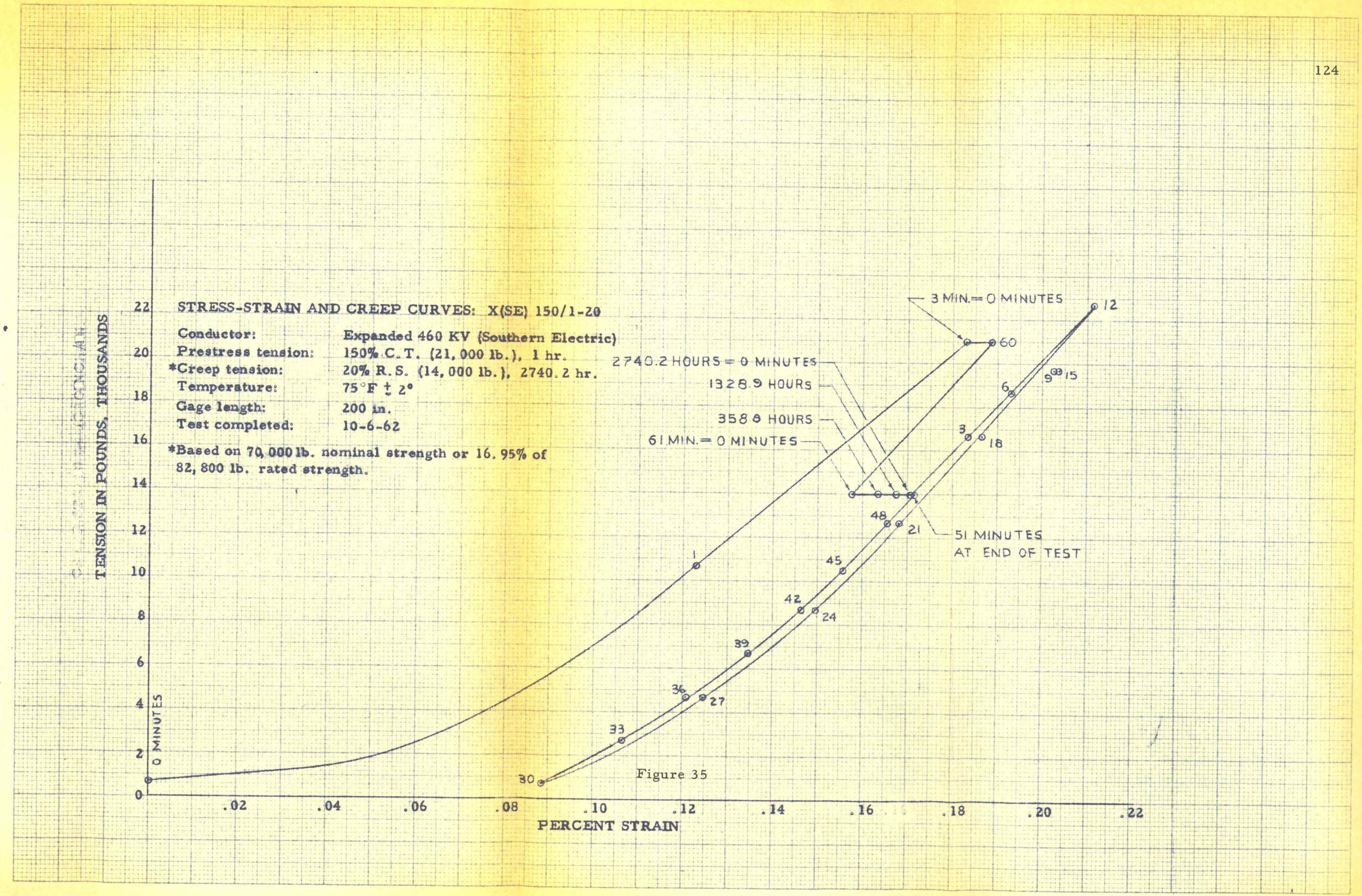

STRESS-STRAIN AND CREEP CURVES: X(SE) 150/1-20
Conductor: Expanded 460 KV (Southern Electric)
Prestress tension: 150% C.T. (21,000 lb.), 1 hr.
*Creep tension: 20% R.S. (14,000 lb.), 2740.2 hr.
Temperature: 75°F ± 2°
Gage length: 200 in.
Test completed: 10-6-62
*Based on 70,000 lb. nominal strength or 16.95% of 82,800 lb. rated strength.
TENSION IN POUNDS, THOUSANDS
PERCENT STRAIN
0 MINUTES
3 MIN. = 0 MINUTES
2740.2 HOURS = 0 MINUTES
1328.9 HOURS
358.8 HOURS
61 MIN. = 0 MINUTES
51 MINUTES AT END OF TEST

Figure 35

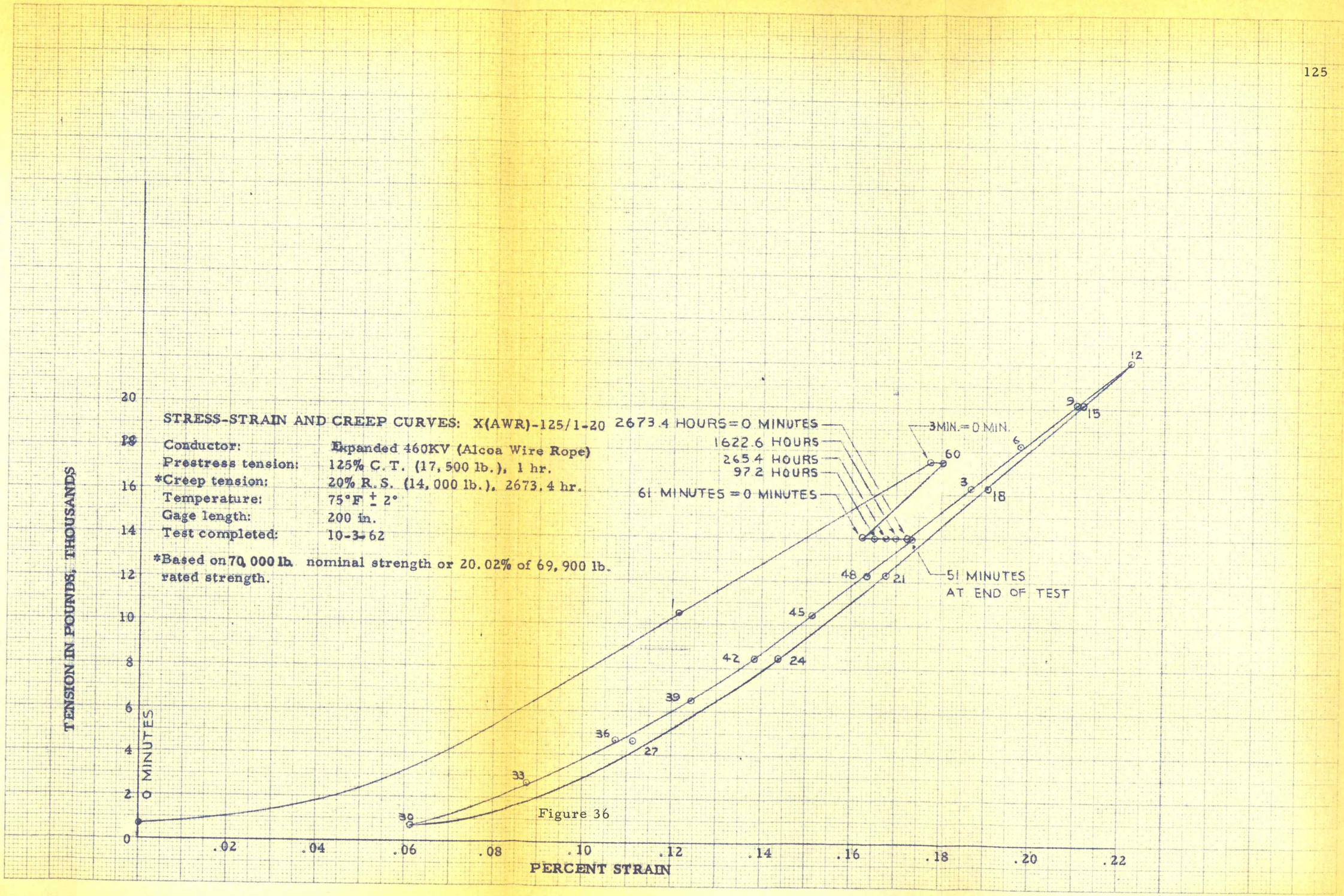
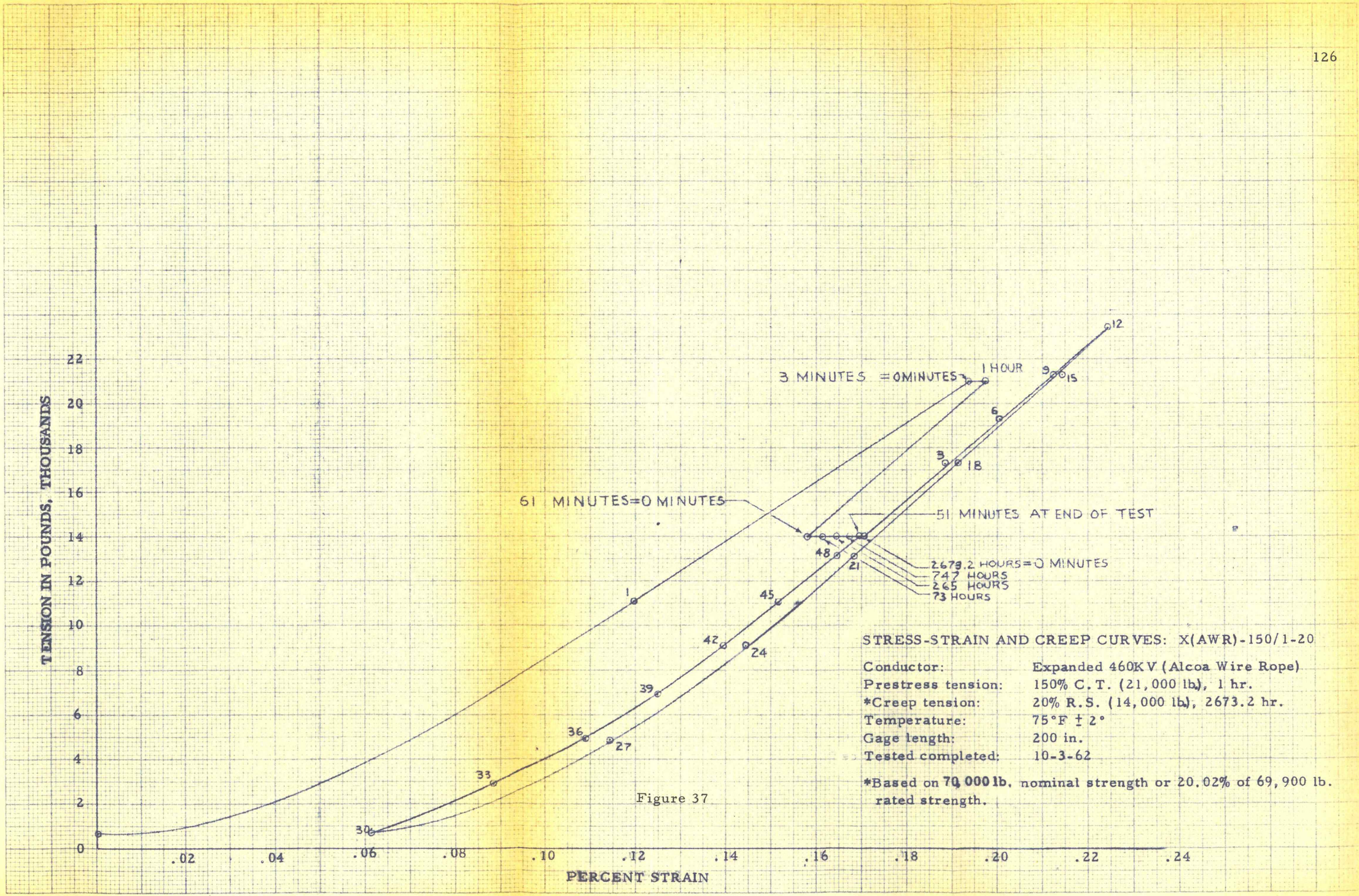

STRESS-STRAIN AND CREEP CURVES: X(AWR)-125/1-20
Conductor: Expanded 460KV (Alcoa Wire Rope)
Prestress tension: 125% C.T. (17,500 lb.), 1 hr.
*Creep tension: 20% R.S. (14,000 lb.), 2673.4 hr.
Temperature: 75°F ± 2°
Gage length: 200 in.
Test completed: 10-3-62
*Based on 70,000 lb. nominal strength or 20.02% of 69,900 lb. rated strength.
2673.4 HOURS = 0 MINUTES
1622.6 HOURS
265.4 HOURS
97.2 HOURS
61 MINUTES = 0 MINUTES
3MIN. = 0 MIN.
51 MINUTES AT END OF TEST
0 MINUTES
TENSION IN POUNDS, THOUSANDS
PERCENT STRAIN
0
2
4
6
8
10
12
14
16
18
20
.02
.04
.06
.08
.10
.12
.14
.16
.18
.20
.22

Figure 36




STRESS-STRAIN AND CREEP CURVES: X(AWR)-150/1-20

| | |
|---|---|
| Conductor: | Expanded 460KV (Alcoa Wire Rope) |
| Prestress tension: | 150% C.T. (21,000 lb.), 1 hr. |
| *Creep tension: | 20% R.S. (14,000 lb.), 2673.2 hr. |
| Temperature: | 75°F ± 2° |
| Gage length: | 200 in. |
| Tested completed: | 10-3-62 |

*Based on 70,000 lb. nominal strength or 20.02% of 69,900 lb. rated strength.

Figure 37

STRESS-STRAIN AND CREEP CURVES: C(K)-100/1-20

Conductor: Chukar (Kaiser)
Prestress tension: None.
Creep tension: 20% R.S. (10,720 lb.), 2454 hr.
Temperature: 75°F ± 2°
Gage length: 200 in.
Test completed: 4-10-63

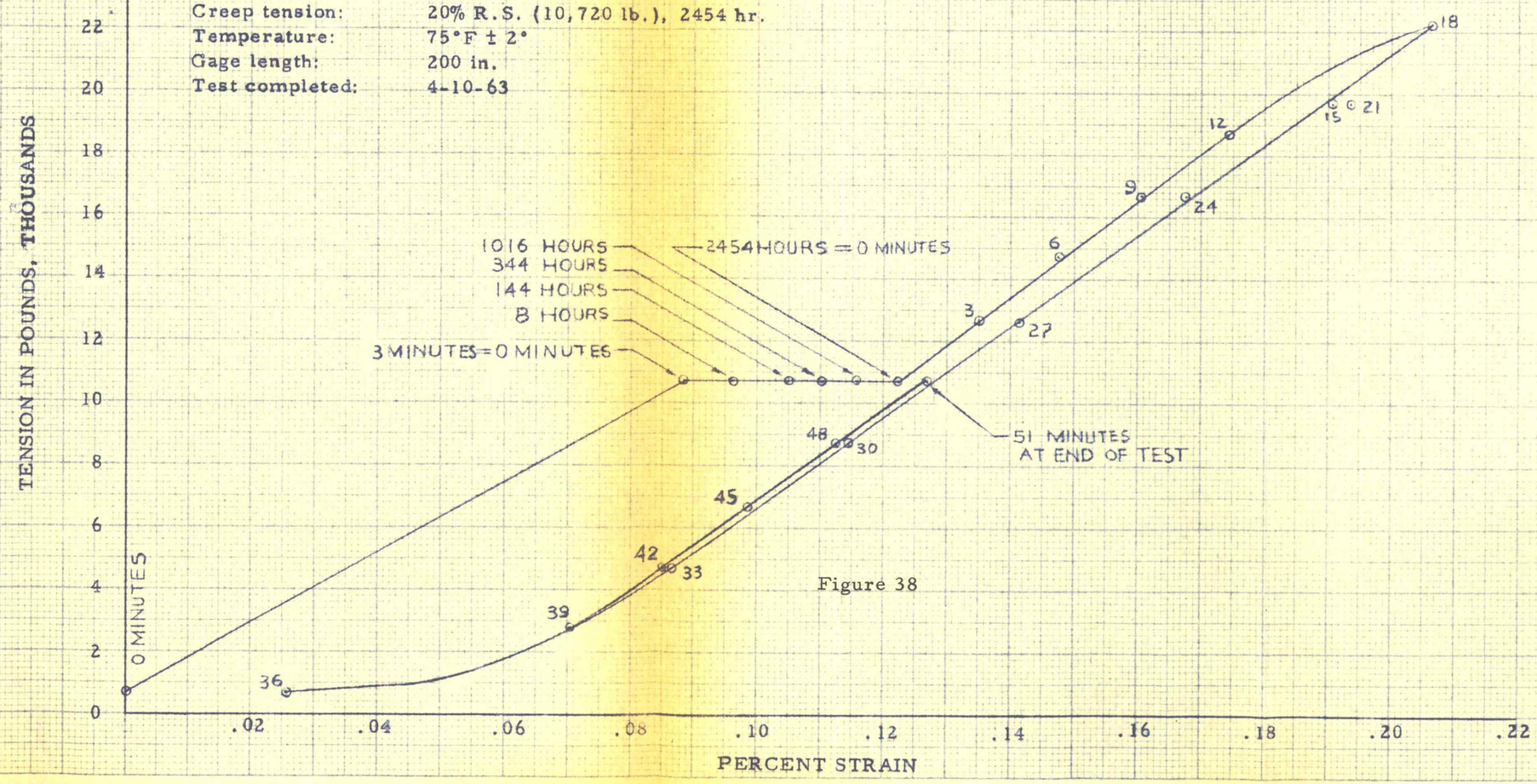



Figure 38

STRESS-STRAIN AND CREEP CURVES: C(K)-125/1-20-1*

Conductor: Chukar (Kaiser)
Prestress tension: 125% C.T. (13,400 lb.), 1 hr.
Creep tension: 20% R.T. (10,720 lb.), 2455 hr.
Temperature: 75°F ± 2°
Gage length: 200 in.
Test completed: 4-9-63

*Specimen from Reel 7.

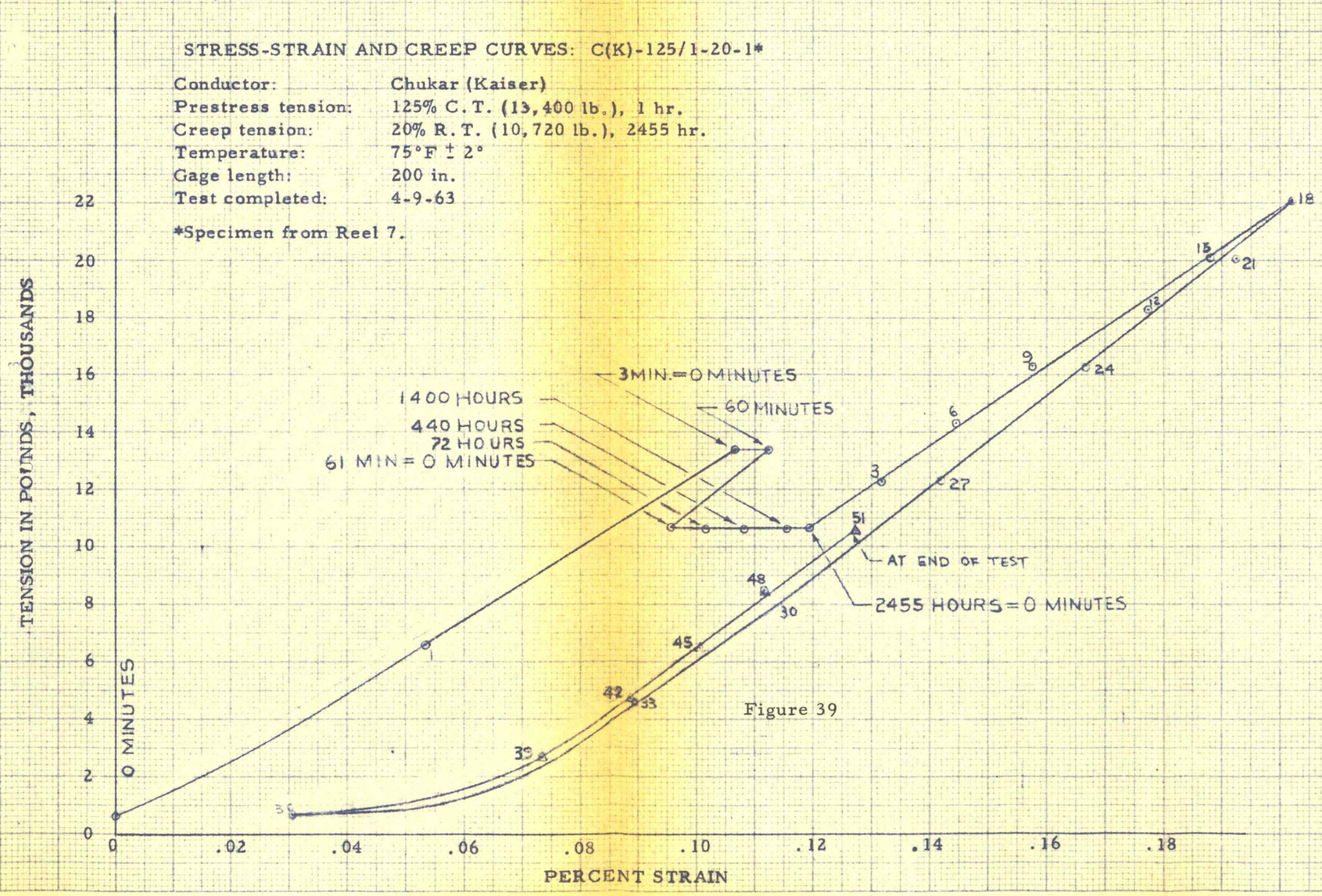



Figure 39

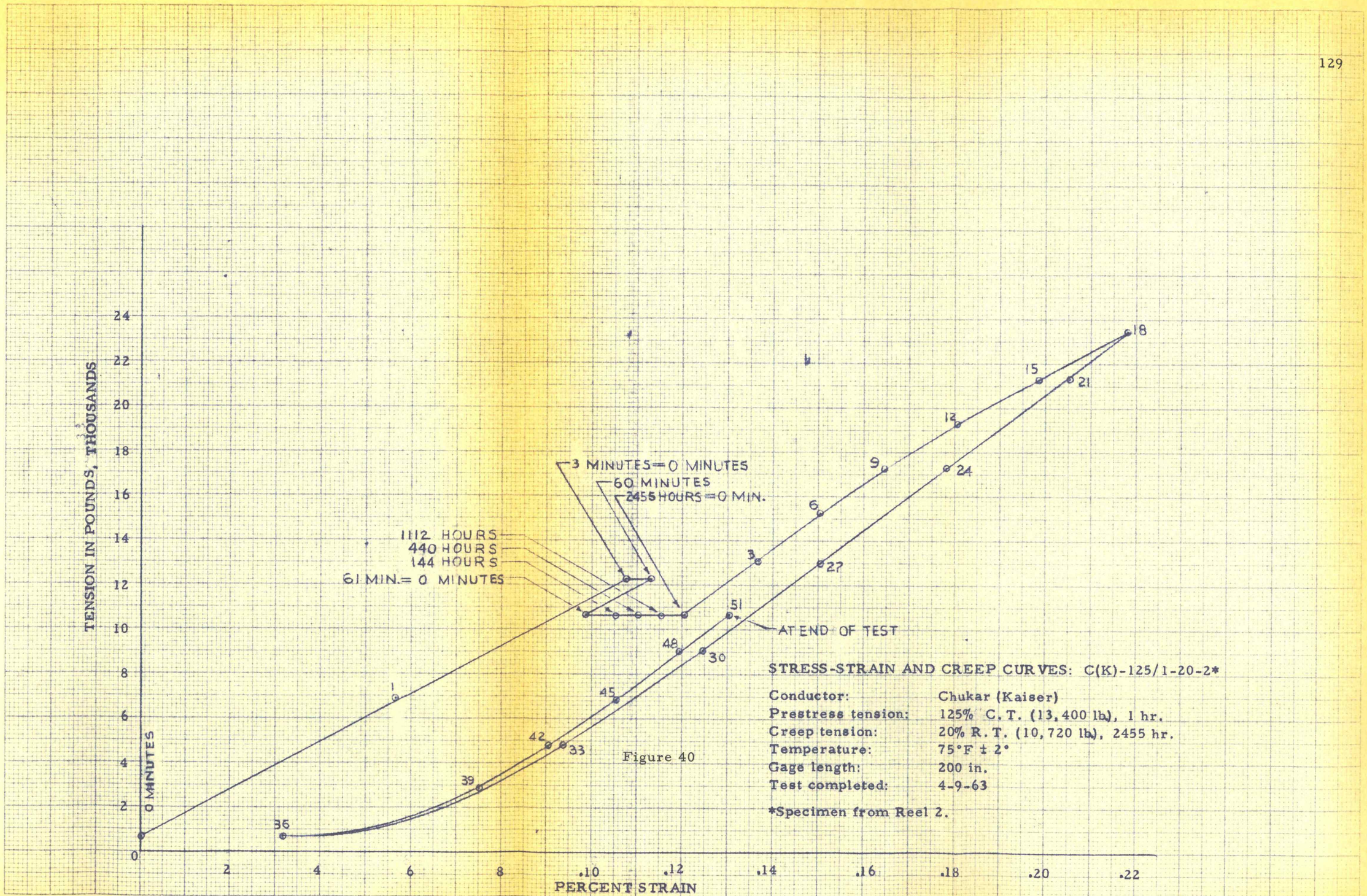

TENSION IN POUNDS, THOUSANDS
PERCENT STRAIN
0 MINUTES
3 MINUTES = 0 MINUTES
60 MINUTES
2455 HOURS = 0 MIN.
1112 HOURS
440 HOURS
144 HOURS
61 MIN. = 0 MINUTES
AT END OF TEST
STRESS-STRAIN AND CREEP CURVES: C(K)-125/1-20-2*
Conductor: Chukar (Kaiser)
Prestress tension: 125% C.T. (13,400 lb), 1 hr.
Creep tension: 20% R.T. (10,720 lb), 2455 hr.
Temperature: 75°F ± 2°
Gage length: 200 in.
Test completed: 4-9-63
*Specimen from Reel 2.

Figure 40

STRESS-STRAIN AND CREEP CURVES: C(K)-125/16-20

| | |
|---|---|
| Conductor: | Chukar (Kaiser) |
| Prestress tension: | 125% C.T. (13,400 lb.), 16 hr. |
| Creep tension: | 20% R.T. (10,720 lb.), 2440 hr. |
| Temperature: | 75°F ± 2° |
| Gage length: | 200 in. |
| Test completed: | 4-9-63 |

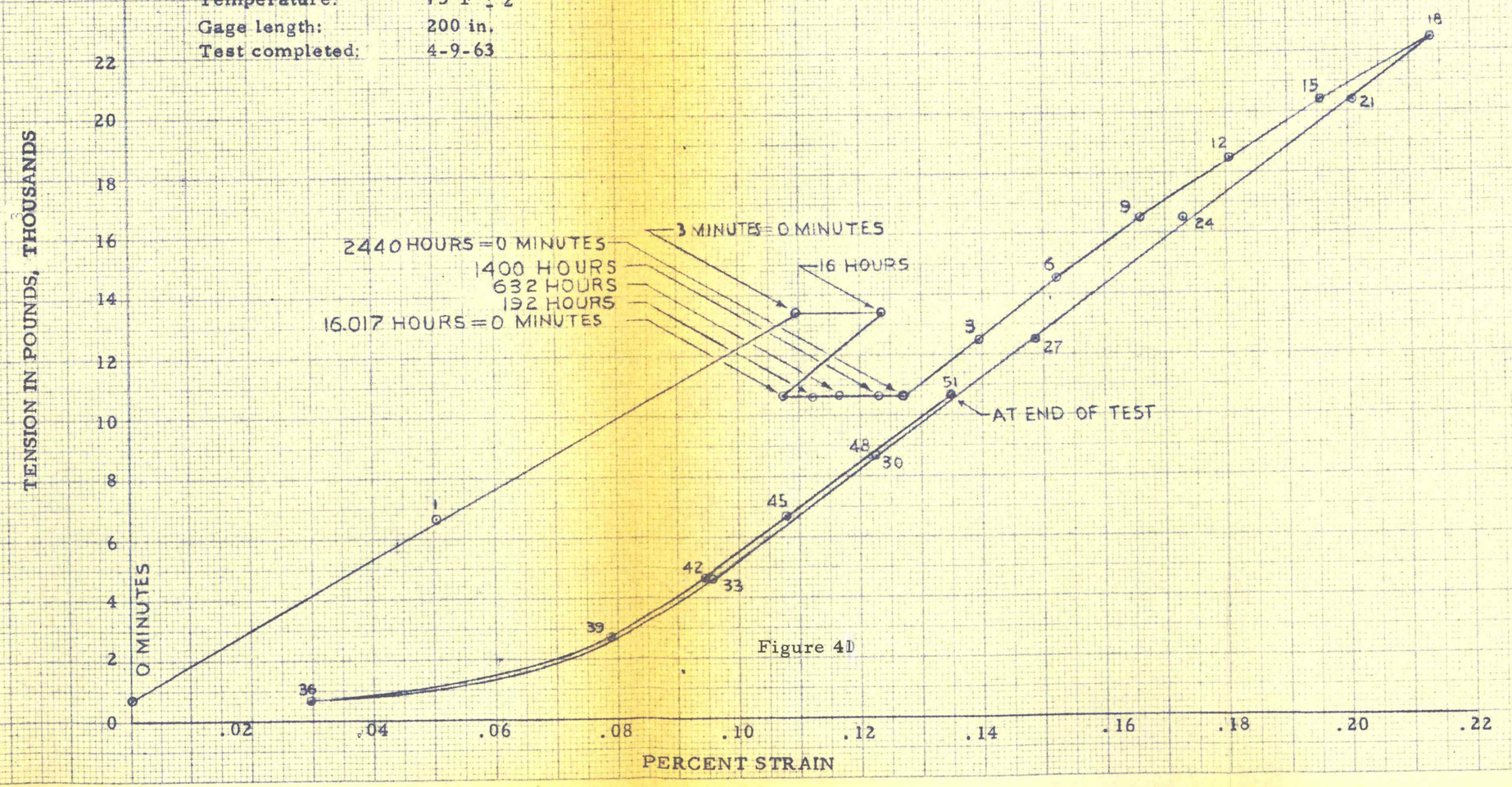



Figure 41

STRESS-STRAIN AND CREEP CURVES: C(K)-125/1/4-20

| | |
|---|---|
| Conductor: | Chukar (Kaiser) |
| Prestress tension: | 125% (13,400 lb.), 1/4 hr. |
| Creep tension: | 20% R.T. (10,720 lb.), 2456 hr. |
| Temperature: | 75°F ± 2° |
| Gage length: | 200 in. |
| Test completed: | 4-9-63 |

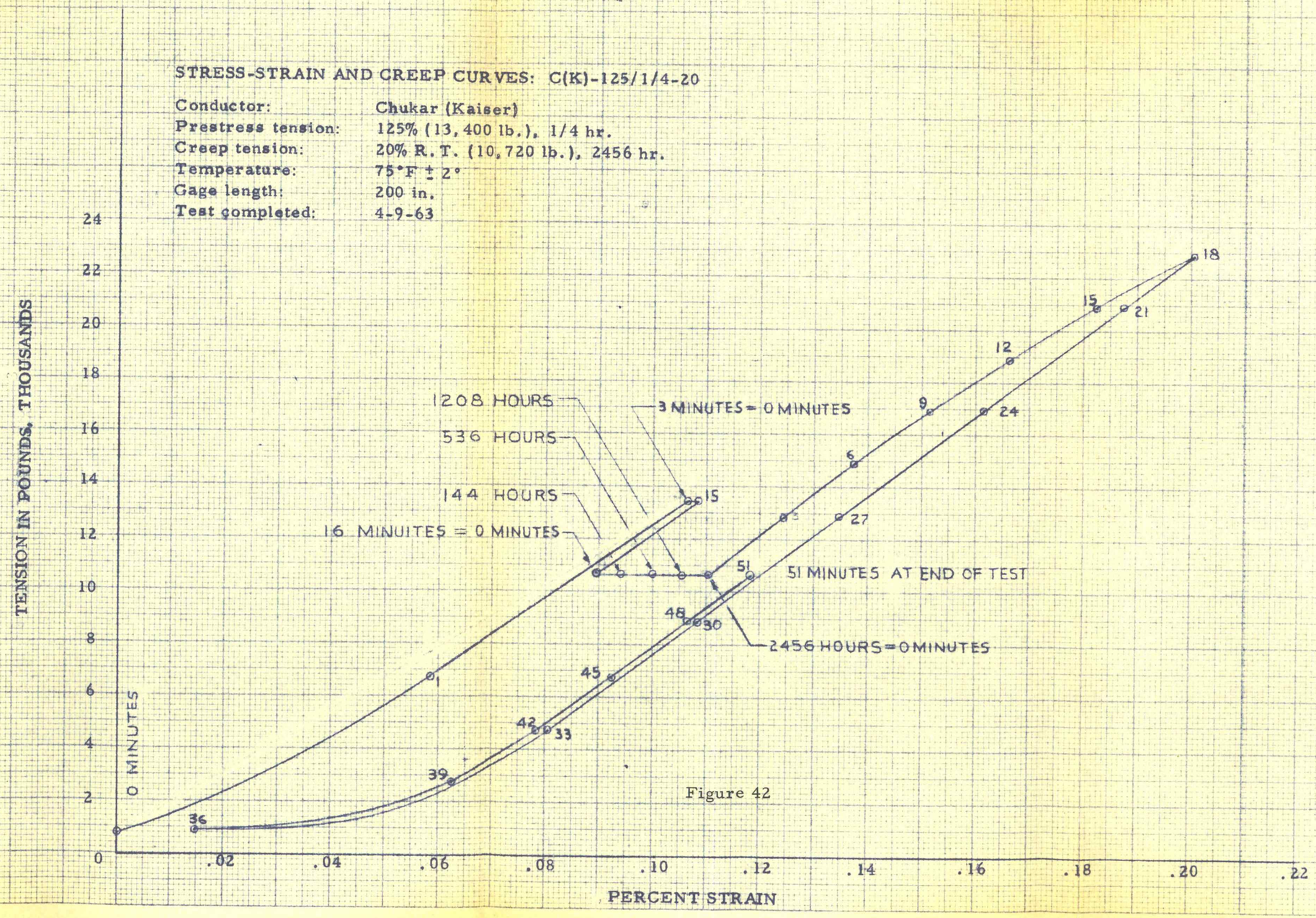



Figure 42

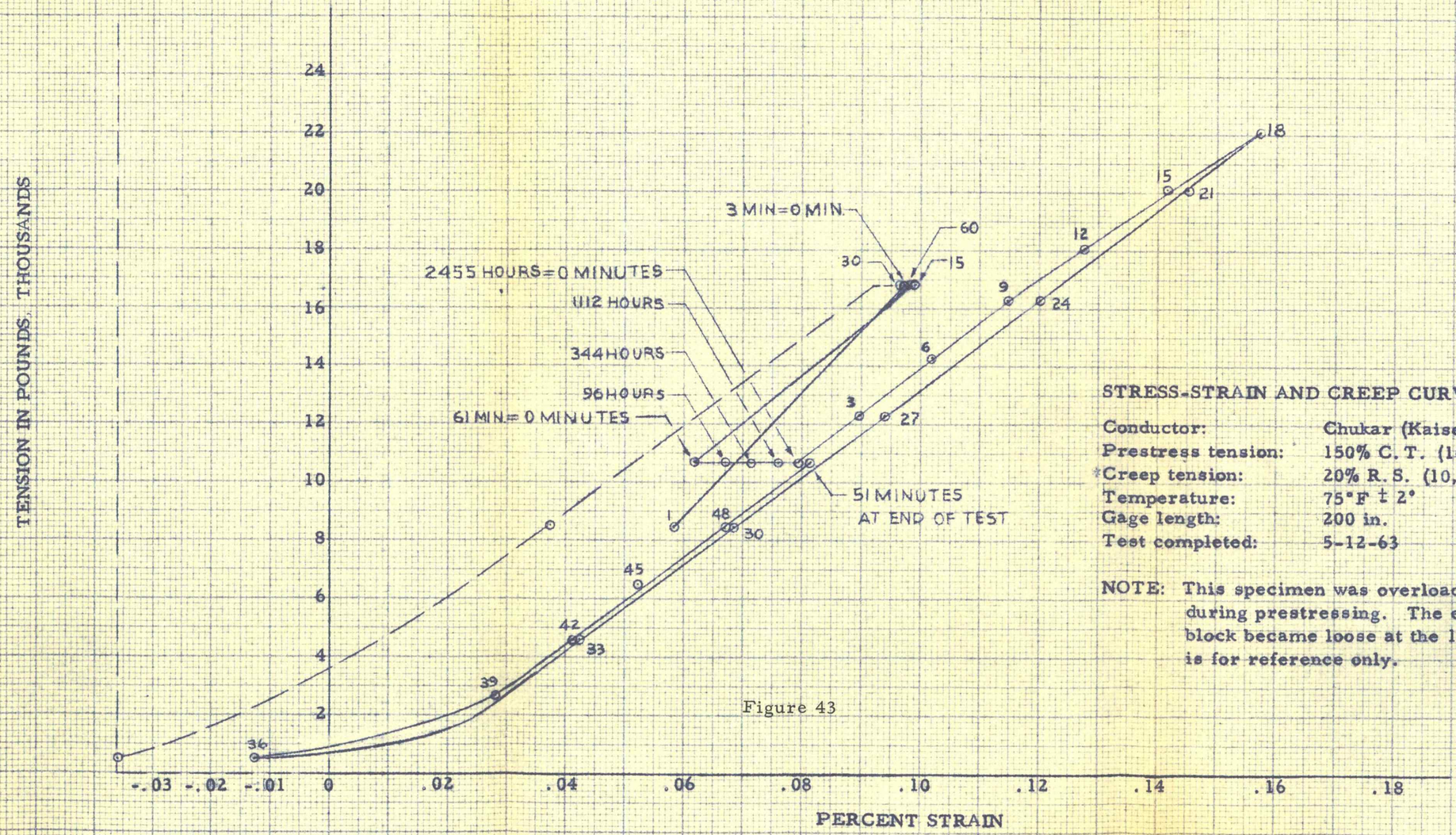



Figure 43

STRESS-STRAIN AND CREEP CURVES C(K)-150/1-20

| | |
|---|---|
| Conductor: | Chukar (Kaiser) |
| Prestress tension: | 150% C. T. (16,080 lb.), 1 hr. |
| *Creep tension: | 20% R. S. (10,720 lb.), 2455 hr. |
| Temperature: | 75°F ± 2° |
| Gage length: | 200 in. |
| Test completed: | 5-12-63 |

NOTE: This specimen was overloaded for a brief period during prestressing. The extensometer clamp block became loose at the 12th hour. This graph is for reference only.

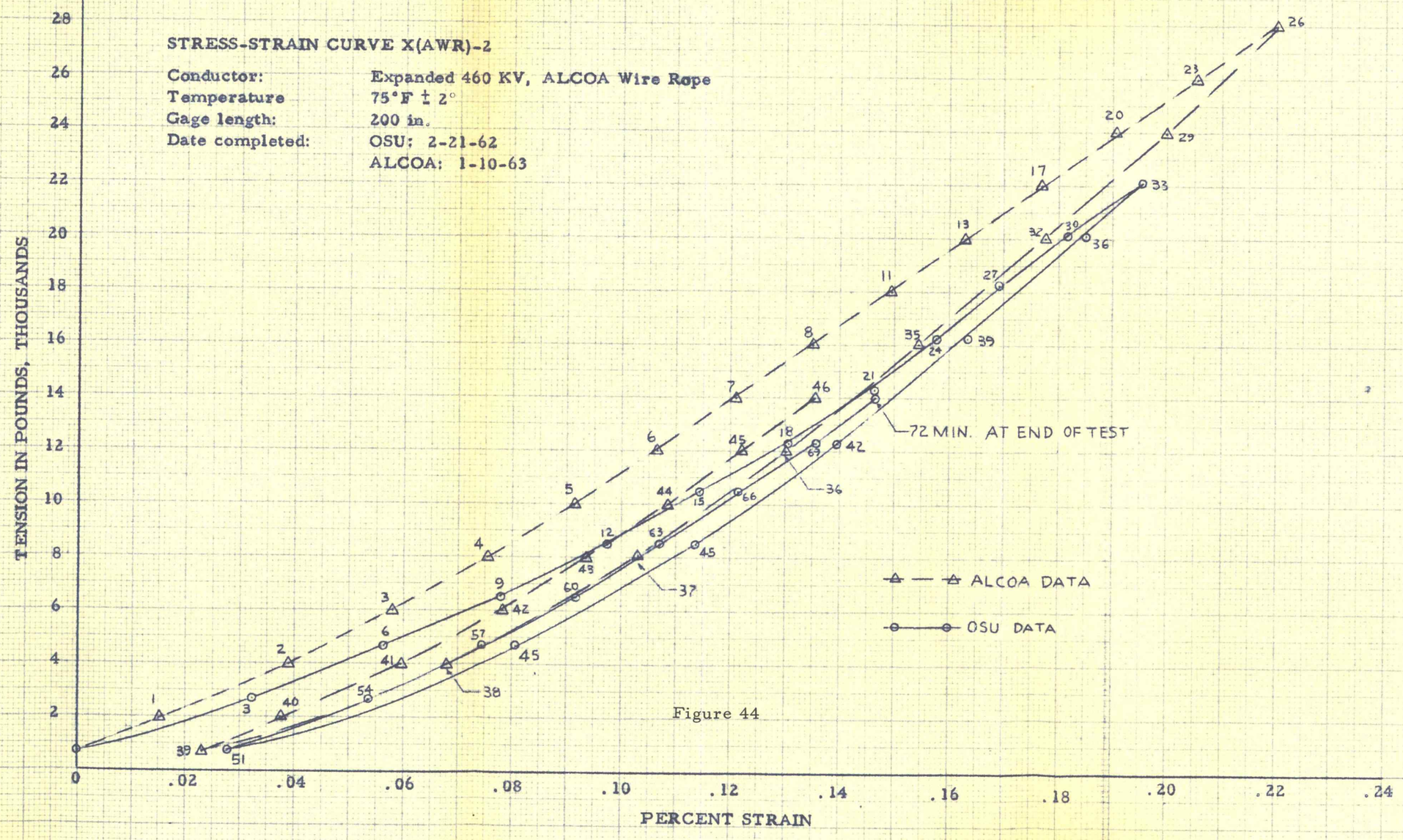

STRESS-STRAIN CURVE X(AWR)-2
Conductor: Expanded 460 KV, ALCOA Wire Rope
Temperature 75°F ± 2°
Gage length: 200 in.
Date completed: OSU: 2-21-62
ALCOA: 1-10-63
TENSION IN POUNDS, THOUSANDS
PERCENT STRAIN
72 MIN. AT END OF TEST
ALCOA DATA
OSU DATA

Figure 44

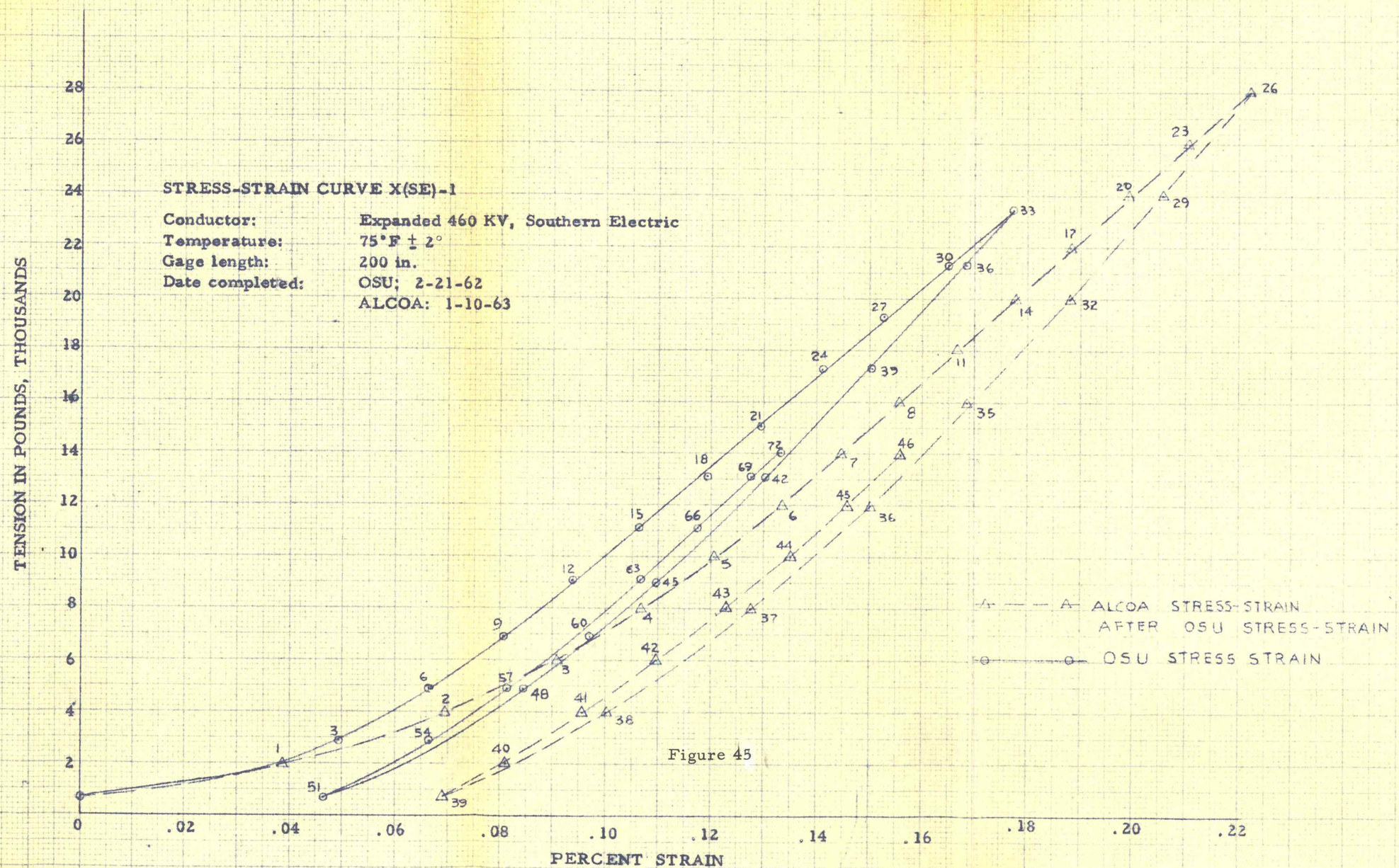

STRESS-STRAIN CURVE X(SE)-1
Conductor: Expanded 460 KV, Southern Electric
Temperature: 75°F ± 2°
Gage length: 200 in.
Date completed: OSU; 2-21-62
ALCOA: 1-10-63
TENSION IN POUNDS, THOUSANDS
PERCENT STRAIN
ALCOA STRESS-STRAIN AFTER OSU STRESS-STRAIN
OSU STRESS STRAIN

Figure 45

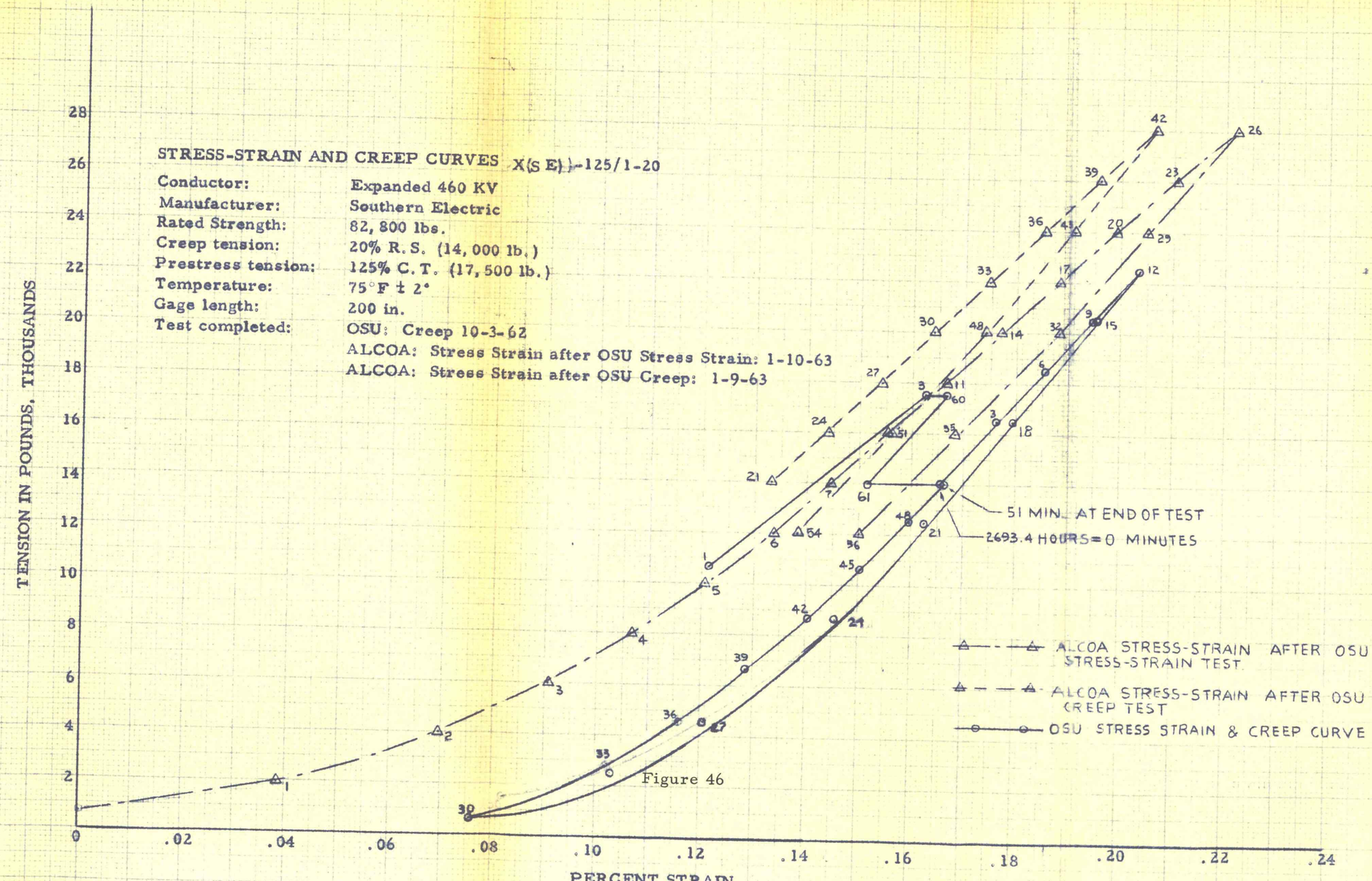

STRESS-STRAIN AND CREEP CURVES X(S E)-125/1-20
Conductor: Expanded 460 KV
Manufacturer: Southern Electric
Rated Strength: 82, 800 lbs.
Creep tension: 20% R.S. (14, 000 lb.)
Prestress tension: 125% C.T. (17, 500 lb.)
Temperature: 75°F ± 2°
Gage length: 200 in.
Test completed: OSU: Creep 10-3-62
ALCOA: Stress Strain after OSU Stress Strain: 1-10-63
ALCOA: Stress Strain after OSU Creep: 1-9-63
TENSION IN POUNDS, THOUSANDS
PERCENT STRAIN
51 MIN. AT END OF TEST
2693.4 HOURS = 0 MINUTES
ALCOA STRESS-STRAIN AFTER OSU STRESS-STRAIN TEST
ALCOA STRESS-STRAIN AFTER OSU CREEP TEST
OSU STRESS STRAIN & CREEP CURVE

Figure 46

STRESS-STRAIN AND CREEP CURVES X(AWR) 125/1-20

| | |
|---|---|
| Conductor: | Expanded 460 KV |
| Manufacturer: | ALCOA 652, Wire Rope |
| Rated Strength: | 69,900 lb. |
| Creep tension: | 20% R.S. (14,000 lb.) |
| Prestress tension: | 125% C.T. (17,500 lb.) |
| Temperature: | 75°F ± 2° |
| Gage length: | 200 in. |
| Test completed: | OSU: 10-3-62 |

ALCOA Stress-Strain after OSU Stress-Strain: 1-10-63
ALCOA Stress-Strain after OSU Creep: 1-9-63

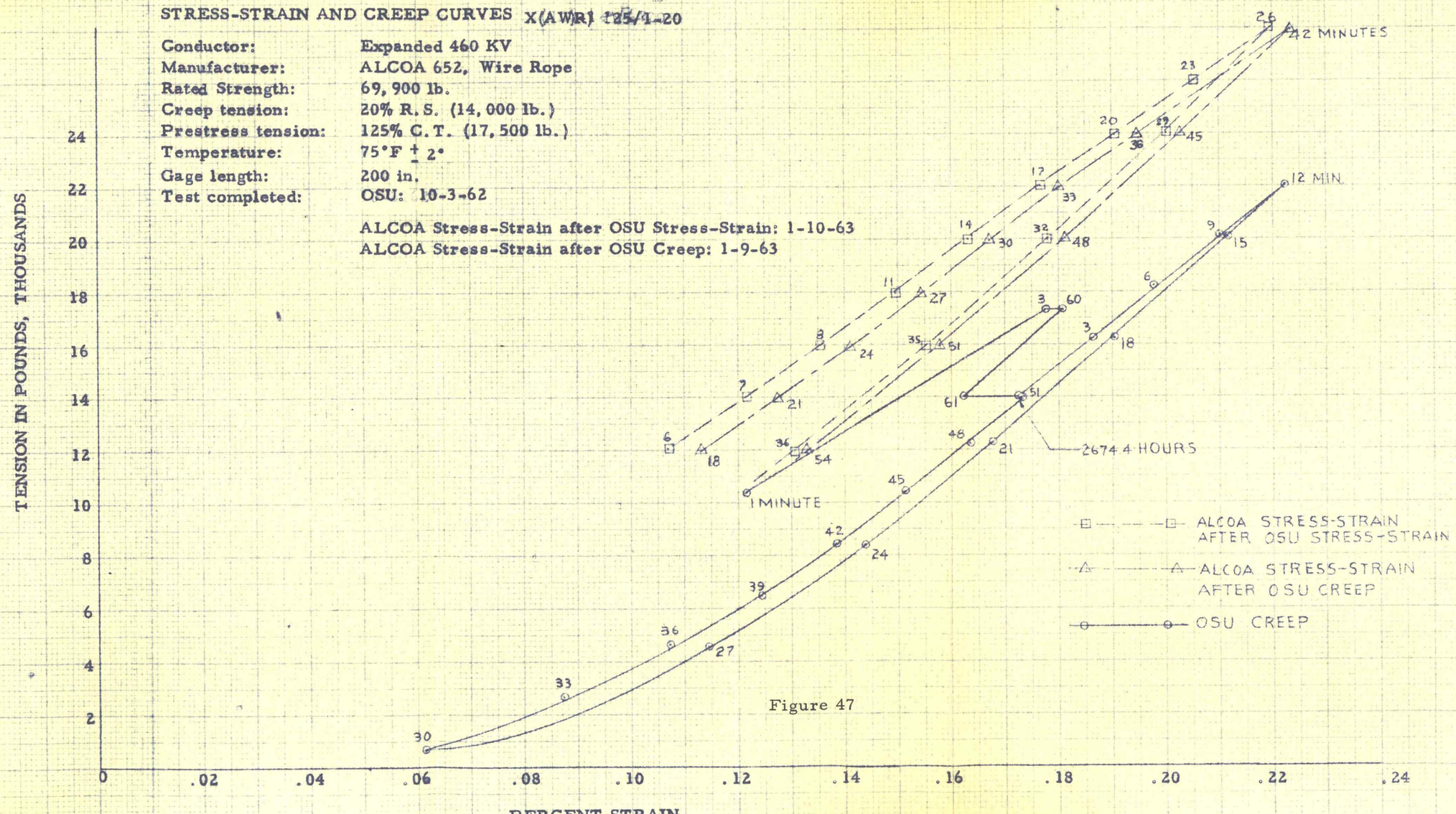



Figure 47

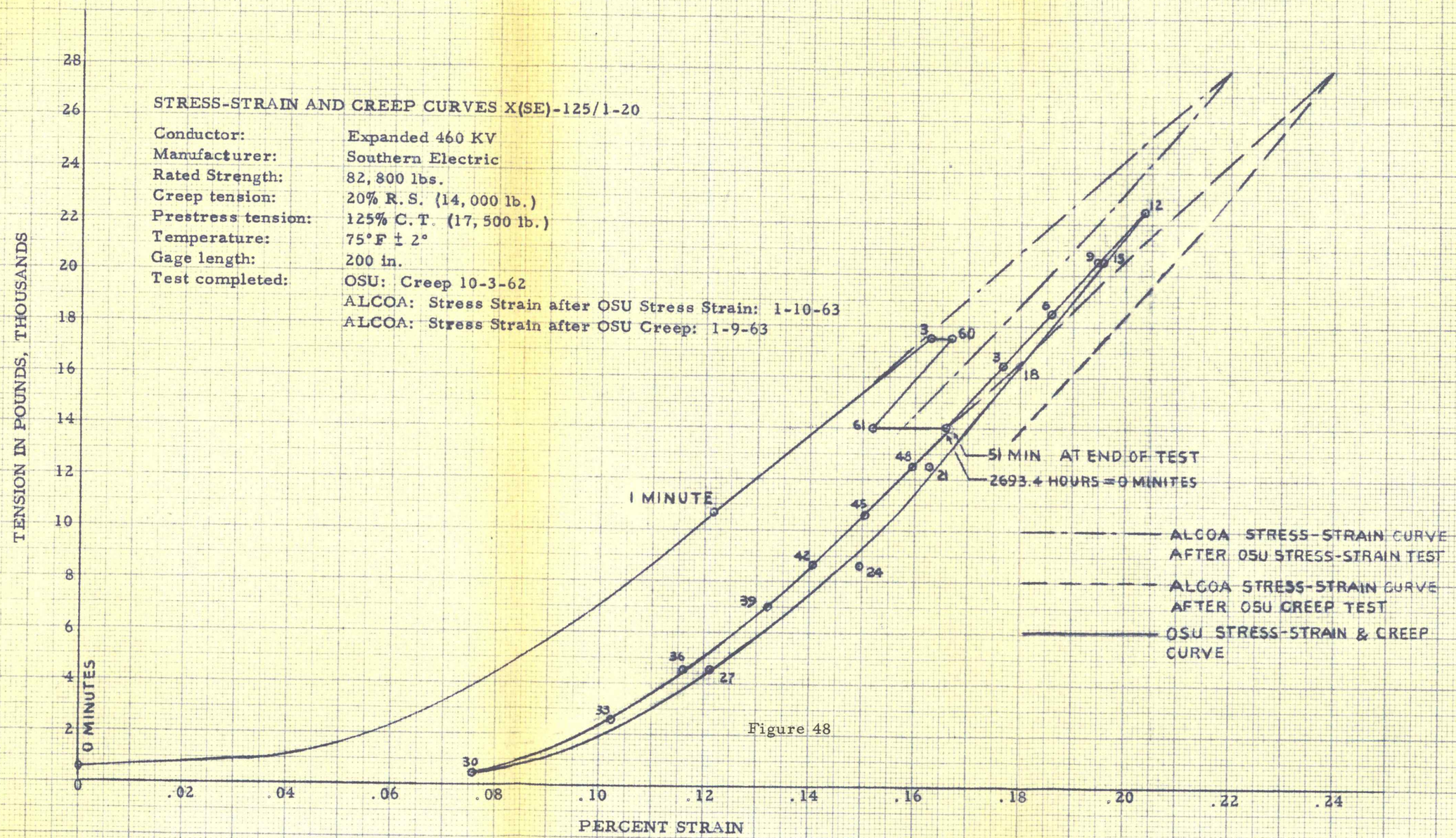

STRESS-STRAIN AND CREEP CURVES X(SE)-125/1-20
Conductor: Expanded 460 KV
Manufacturer: Southern Electric
Rated Strength: 82,800 lbs.
Creep tension: 20% R.S. (14,000 lb.)
Prestress tension: 125% C.T. (17,500 lb.)
Temperature: 75°F ± 2°
Gage length: 200 in.
Test completed: OSU: Creep 10-3-62
ALCOA: Stress Strain after OSU Stress Strain: 1-10-63
ALCOA: Stress Strain after OSU Creep: 1-9-63
TENSION IN POUNDS, THOUSANDS
PERCENT STRAIN
0 MINUTES
1 MINUTE
51 MIN AT END OF TEST
2693.4 HOURS = 0 MINUTES
ALCOA STRESS-STRAIN CURVE AFTER OSU STRESS-STRAIN TEST
ALCOA STRESS-STRAIN CURVE AFTER OSU CREEP TEST
OSU STRESS-STRAIN & CREEP CURVE

Figure 48

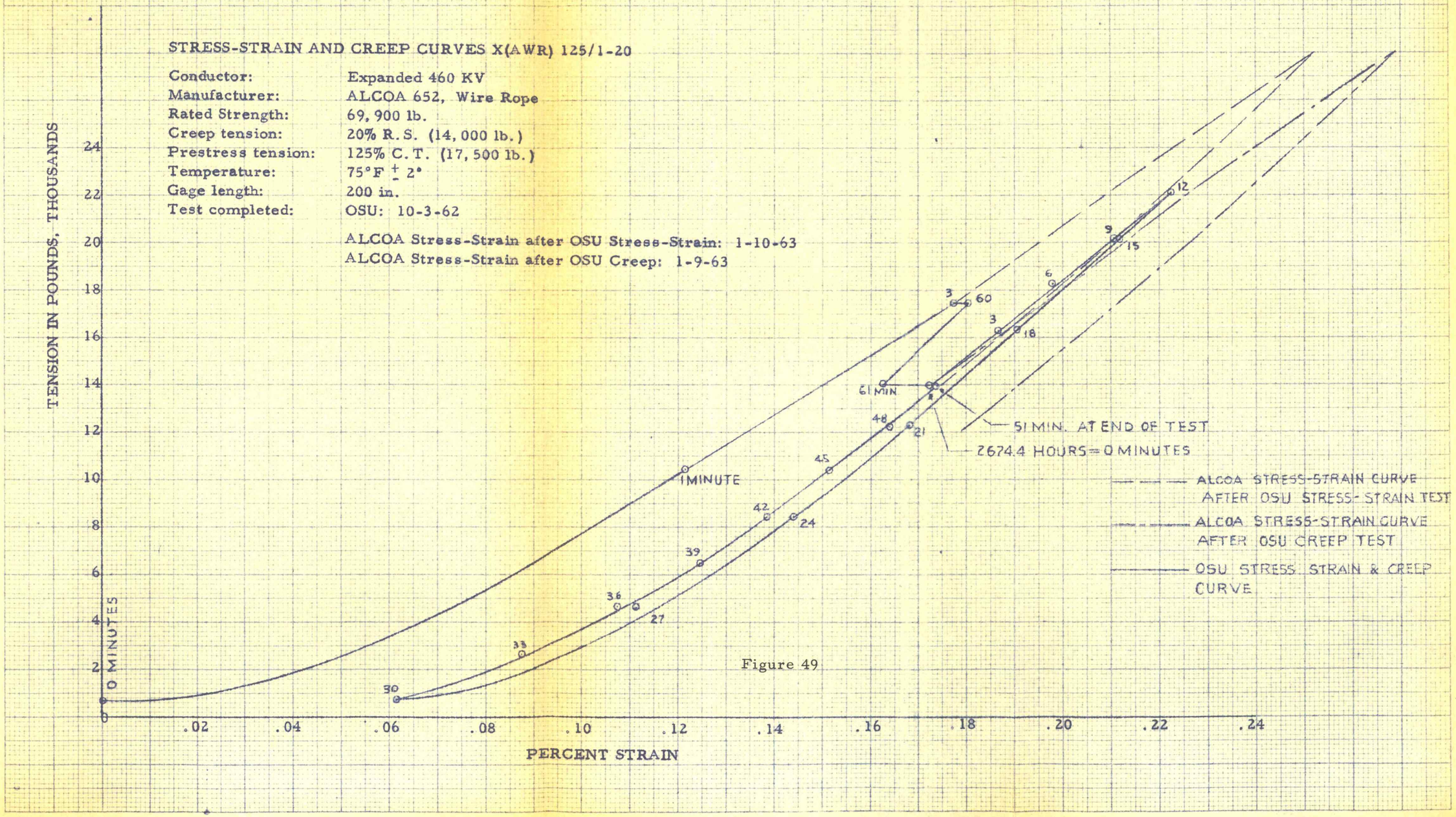

STRESS-STRAIN AND CREEP CURVES X(AWR) 125/1-20
Conductor: Expanded 460 KV
Manufacturer: ALCOA 652, Wire Rope
Rated Strength: 69,900 lb.
Creep tension: 20% R.S. (14,000 lb.)
Prestress tension: 125% C.T. (17,500 lb.)
Temperature: 75°F ± 2°
Gage length: 200 in.
Test completed: OSU: 10-3-62
ALCOA Stress-Strain after OSU Stress-Strain: 1-10-63
ALCOA Stress-Strain after OSU Creep: 1-9-63
TENSION IN POUNDS, THOUSANDS
PERCENT STRAIN
0 MINUTES
1 MINUTE
61 MIN
51 MIN. AT END OF TEST
2674.4 HOURS = 0 MINUTES
ALCOA STRESS-STRAIN CURVE AFTER OSU STRESS-STRAIN TEST
ALCOA STRESS-STRAIN CURVE AFTER OSU CREEP TEST
OSU STRESS STRAIN & CREEP CURVE

Figure 49