CREEP TESTS ON ALUMINUM AND ALUMINUM ALLOY CONDUCTORS

by

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OF

ALUMINUM AND ALUMINUM ALLOY CONDUCTORS

INTRODUCTION

Formerly copper was used for electrical transmission purposes. In modern transmission lines aluminum has replaced copper. Aluminum posseses good electrical conductivity, good resistance to corrosion, has light weight, and relatively good strength. To justify the use of aluminum conductors, various important characteristics must be examined. One of these is creep resistance. In service, a conductor of a transmission line is subjected to a tensile stress which it must withstand for a long time, up to and sometimes exceeding 50 years. The combination of stress and time produces an elongation of the conductor which increases the amount of sag. Even an extremely small rate of creep will, after a long time produce an appreciable sagging. Therefore if a conductor has poor resistance to creep, it will be uneconomical due to the fact that it may require resagging, or shorter spans will have to be provided. Both of these increase the cost.

The Kaiser Aluminum and Chemical Corporation has been producing solution treated, cold worked all aluminum alloy (AAAC) conductors, aluminum conductors with a central steel reinforcement (ACSR), and all aluminum conductors (EC). It was deemed necessary to investigate creep properties of the various aluminum conductors to obtain engineering data for use in design and construction of transmission lines. The project is being carried out with the cooperation of Oregon State College. In the first four series of tests conducted, only AAAC conductors were investigated at different stress levels, 75%, 50%, and 25% of ultimate tensile strength. In the present series of tests ACSR and EC were also included, and the stress level reduced to 15% of the ultimate tensile strength. It was believed that AAAC might have a poorer creep resistance as compared to ACSR, due to the fact that all common aluminum alloys show poor resistance to creep at temperatures only a little higher than the service temperatures for transmission lines. Secondly ACSR has a central strand made of highly creep resistant steel.

OBJECTIVES

The tests reported here are actually a part of a much larger program. The ultimate objectives of this larger program are

a. to provide necessary engineering data on creep in a broad size range of AAAC conductors,

b. and to compare the characteristics of selected AAAC conductors with EC and ACSR conductors.

The objectives of the present series are:

1. To determine whether the difference in the creep properties of the two AAAC lots is due primarily to stranding,
2. To compare the creep properties of AAAC conductors with ACSR conductors,
3. To determine the creep characteristics of selected specimens at 15% ultimate tensile strength,
4. To check the accuracy of the loading system.

THEORY AND MECHANISM OF CREEP

Creep is defined as plastic deformation of a material over a long period of time during which the stress and temperature remain constant.

Fig. 1 shows a typical creep curve. The curve is based on the assumption that,throughout the test period, a constant load and temperature is being maintained. For the purposes of discussion creep is generally thought to proceed in three stages. The first stage which includes the instantaneous deformation during application of the load, is known as initial, primary, transient or diminishing rate state. This stage of creep dies out with time, and terminates the deformation at low temperature and low stress. The strain rate slows down due either to work hardening or may be due to lack of plastic elements. Eventually the creep rate becomes constant. This stage of the curve is approximately parabolic.

The second stage of creep, known as steady state creep, is characterized by a relatively constant creep rate especially pronounced at high temperatures, as shown in Fig. 1. This could be explained by the fact that the strain hardening is just balanced by the reduction in cross sectional area, but a better explanation claimed by various authorities is that the effect of strain hardening is just balanced by recovery phenomena, resulting in a steady state creep. Most probably the cause of the steady state creep is the joint effect of the two theories explained above. Some modern investigators deny the fact that a second state creep rate is constant; they claim it is a transition stage between initial and final stages.

The final or last stage of creep is known as "tertiary" creep, where flow accelerates thereby finally causing fracture. Early investigators claimed that the increasing rate of creep was due to reduction in cross-sectional area of the test piece. Later investigations showed that the reduction in cross-sectional area plays a minor part, and the real cause is due to other factors. Andrade (1) suggests that this could be due to recrystalization.

The creep rate may be varied appreciably by variation in the temperature and/or the applied stress. Various other factors, such as composition, impurities, presence of residual stresses within the material, also affect creep rate of material.

During any creep test, the temperature of the specimen must be controlled as accurately as possible. It has been observed that some materials under certain loads exhibit a creep rate which is double that of similar specimens tested at the same load but at ten degrees lower temperature (2).

Mechanism of Plastic Deformation

Modern concepts of plastic deformation are based on the theory of dislocations. Dislocations in a crystal are special types of defects which move readily upon application of stress. The dislocations thus cause a lowering of the stress required to cause plastic deformation. The theory attempts to explain, quantitatively, this lowering of elastic strength, the stress necessary to cause plastic deformation, as well as other phenomena such as the strengthening of metals due to cold work and heat treatment. Since creep is a form of plastic deformation the mechanism should be capable of elucidation by the theory of dislocations.

Calculations of theoretical strength indicate that crystals should develop 10^3 to 10^4 times the strength actually measured (3). Such strengths have been developed experimentally in perfect crystals, free of dislocations. It is therefore quite justified to assume that an actual crystal is full of dislocations. A single crystal of metal generally contains one plane that is weaker than the others due to the presence of dislocations. Initial deformation may start due to gliding of a dislocation along an atomic plane. During the initial stage of creep, the externally applied stress is sufficient to move dislocations and, unless there are some obstacles to this movement, the resulting deformation will be never-ending. In crystals such a movement is impeded by various obstacles like grain boundaries, precipitate particles, the forest of other dislocations and the far-reaching stress field of other dislocations in parallel glide planes (4). If the applied stress is not sufficient to push the moving dislocations through the obstacles, the rate of deformation will slow down. The piled up groups of dislocations exert a back pressure or stress which is greater than the stress exerted by the source of production of dislocations, resulting in a decreasing rate of creep. During initial deformation the crystal becomes work hardened due to these impediments to movements. The decelerating rate of creep continues till the process of recovery takes place. For plastic deformation to continue, the applied stress must be increased, or some recovery take place. During the creep process, the stress remains constant, hence the continuity in deformation must be due to recovery phenomena. This recovery could be due to a rearrangement of dislocations, resulting in a decrease in internal stress, or by combination of two opposite sign dislocations. The first is possible only if the dislocations leave their glide plane, which could be accomplished by the climb process. The movement of an edge dislocation perpendicular to its glide plane is called climbing. At low temperatures the dislocations trapped within the lattice tend to remain stationary, but at high temperature, dislocations are able to move in a perpendicular direction to another plane.

The analysis of creep based on climbing of dislocations made by Weertman (5) is as follows. He assumed that there are dislocations piled up in groups stopped by obstacles at a distance 2L apart in their glide planes, where L is the final radius to which a dislocation loop expands. The local shear stress in the glide plane at the place of dislocations is zero, with a possible normal stress of , which exerts a force on the dislocations normal to its glide plane. Due to this stress the dislocations start climbing, some giving off vacancies, others absorbing them. Within a grain if the atomic arrangement is not orderly, and if a position which should have been occupied by an atom is vacant, then such a vacant position is called a 'vacancy'. From the above discussion it is concluded that the creep rate is controlled by the rate and amount of recovery taking place.

Creep Correlations

As has been discussed in the foregoing pages, the creep phenomenon may occur in three different stages. This has been observed in many tests conducted on various types of materials. It is believed by present day investigators that actually there may not be anything like second stage creep. Second stage creep may be treated as a sort of lengthy transition period during which the decelerating deformation of the first stage creep is gradually transformed into the accelerating deformation of third stage.

In practice it is not possible to conduct creep tests for periods of time comparable with usually expected service life. It is, therefore, usual practice to extrapolate the data obtained from a relatively short time test to predict the creep strain at the desired time. Andrade (1) conducted numerous tests and on the basis of the results obtained arrived at the following equation for creep. This law is commonly known as the $t^{1/3}$ law.

$$l = l_o \, (1 - Bt^{1/3}) \exp KT \quad \text{---------------------------- } 1$$

where; l_o = initial length

l = final length

t = time

B = a constant

T = absolute temperature

K = a constant expressing an extension per unit length creeping, which proceeds at a constant rate.

This law has been later verified by Feltham (6) in his work on iron and plain carbon steels under constant stress.

Cotrell (7) reviewed different time laws of creep, and found that the creep rate can be represented by the equation.

$$\epsilon = Bt^n \quad \text{----} \quad 2$$

where

ϵ = the creep strain

t = the time

B and n are constants, which could be determined experimentally. The constant n appears to be dependent of the material, the mechanism of creep, the temperature, and the stress.

TEST EQUIPMENT

The creep tests were conducted in testing machines especially designed for the purpose. In order to assure sufficient provision of strain measurement, to simulate, to some degree, field conditions but taking cognigance of limitations of laboratory space specimens 25 feet long were selected for test. A gage length of 200 inches was set within this 25 feet so as to avoid end conditions. Six loading columns 30 feet long and housed in a temperature controlled chamber were used. An external view of the enclosure is shown in Fig. 2. Loading was accomplished by means of levers. This equipment had been constructed previously; the design and construction are not part of this thesis, but will be described for completeness.

To ensure sufficient rigidity the columns were designed for a capacity of 20,000 pounds. The corners of the column were made of four lengths of 2 x 2 x 3/16 inch angle iron. Cross bracings made out of 1/3 by 1 inch steel bar stock were welded to the four angles. To permit multiple testing of six specimen simultaneously, six separate columns were constructed; numbered from 1 to 6 looking from left to right as seen in Fig. 3. The advantage of such a construction is that one specimen could be taken out or inserted without causing disturbance to the remainder of the specimens in other columns.
Each column was bolted down rigidly at both ends and at two places in the middle in order to have minimum possible distortion and deflection.

The loading system consists of levers having a 20 to 1 ratio. The lever was cut from one inch thick plate. To minimize friction and to maintain a constant load on the specimen, needle bearings were provided both at the pivot of the lever and at the connecting linkage. The lever was mounted on a vertical column independent of the lattice column by means of a bracket. To insure that the force induced by the lever was applied axially to the column, the vertical column rested on against a pin welded to the end plate of the horizontal column.

Specimens were loaded by means of a box containing lead shot being supported by the outer end of the lever on a knife edge. The knife edges were machined from high carbon steel and hardened to minimize wear. Fig. 4 gives a schematic diagram of the loading and takeup ends of the equipment.

The amount by which lever falls down during the test due to elongation of the specimen, was measured by a pointer cemented to the top of the free end of the lever and vertical scale mounted separately as shown in Fig. 4.

Two means of takeup were provided. The grips were coupled to a 12 inch turnbuckle which adjusted for variation in overall conductor length, and was useful for the installation of specimens. The second takeup device consisted of a large nut, as shown on the extreme left end of the enclosure in Fig. 5. The nut was turned by a spanner wrench. Friction was minimized by using a ball thrust bearing provided between the adjusting nut and the column end. The one inch diameter takeup screw was prevented from turning by means of a loose-fitting key. The takeup nut in the shape of a wheel was graduated to indicate the amount of the takeup for a given fraction of a revolution.

The grips used were Cooline clamps in which the specimen was bent on a gentle radius making approximately an angle of 60° with the loading column. The back of the clamps were provided with holes for connecting one end of the specimen to the takeup screw linkage and the other end to the lever connecting linkage in such a fashion that the center line of the specimen coincided with the center line of the loading column.

The foregoing description applies to Columns 1 through 5. Column 6 was used for testing the single strand specimen. Since the load to be used was less than the minimum which could be applied by the lever, arrangements were made to load the single strands by dead weight.

A 4 inch diameter pulley was substituted for the lever mechanism. A steel cable was used to link the dead weight and the grip holding the single strand. A swivel was provided to minimize twisting of the specimen. The grips for the single strand specimen consisted of tapered chucks with matching tapered jaws tightened by means of a nut. The surfaces of the jaws which gripped the specimen were serrated to prevent slipping.

For measuring extension of the specimen during testing, a strainometer consisting of a dial gage and extension rod was used. The threaded portion of the sliding bar of the dial gage was screwed to one end of an aluminum tube, the other end of which was firmly clamped to the specimen making a gage length of 200 inches. The aluminum tube was supported by the specimen by clips at a spacing of approximately 15 inches. The least count of the dial gage being 0.001 inch, and using a gage length of 200 inches, strains of 5×10^{-7} inch per inch could be determined with accuracy. The use of an aluminum extension tube minimized variation in strain readings due to thermal expansion. The light weight of the aluminum tube minimized sagging of the specimen and extension tube especially in the single strand test.

Although the clamp nuts were tightened with a torgue of 60 lb ft, and therefore the possibility of clamp slipping was negligible, it was nevertheless worthwhile to have some means of checking for slippage during the test period. Moreover it was necessary to investigate the effect of clamping of the conductor on the creep rate. To obtain a measurement of these two effects the overall extension of the conductor was measured by means of the pointer as mentioned previously. The least count of the scale was 0.01 inch. The unit extension of the specimen is given by

$$e = \frac{\text{deflection on vertical scale}}{\text{lever ratio x overall length of the specimen}}$$

The lever ratio was obtained by calibration.

The above formula shows that unit elongation could be measured correctly to 3×10^{-4} inch per inch. The unit extension so obtained could then be compared with the unit elongation for the 200 inch gage, and thus the effect of the gripping device could be determined.

Temperature Control

The effect of temperature on creep rate has already been discussed, and was noted that temperature fluctuation has a significant effect on the creep rate. It was therefore essential to have a strict control of the test temperature. The loading columns were enclosed in a temperature controlled enclosure. The inside temperature of 75 ± 3 degrees F was maintained with the help of an air conditioning system. Fig. 5 shows the entire enclosure along with the temperature control system.

Fig. 6 gives a schematic diagram of the air conditioning system employed. The air was drawn out of the enclosure by a blower fan through an exhaust duct provided near the ceiling near one end of the enclosure. The exhaust air passed over electrically heated coil or chilled water cooling coils. The conditioned air was then distributed to the enclosure by a plenum chamber and two supply ducts running almost the full length of the chamber. The air then passed back over the specimens to be recirculated.

The temperature within the enclosure was automatically controlled. A two way bulb type thermostat was placed near the outlet end of one of the two supply ducts. This thermostat actuated relays which in turn actuated the heating coils or cooling system upon demand. A four point temperature recorder was used to verify temperatures within the test chamber as well as the ambient temperature.

CALIBRATION

The test columns were calibrated by using Baldwin SR-4 Calibration Kit. The Calibration Kit consists of a Calibration Indicator, a Standardizer, and a Load Cell. When the Load Cell is subjected to some load, it produces an output voltage proportional to the applied load which in turn is measured by the indicator.

The Load Cell functions in the following manner: Four resistance wire strain gages are cemented to a load element, forming a wheatstone bridge. On the application of load, the surface strains of the load element are transmitted to strain gages, thereby resulting in change of electrical resistance, which in turn unbalances the bridge. When power is applied to one pair of opposite bridge terminals, an output voltage proportional to load appears across the other pair of terminals. The Load Cell is compensated for the effects of "steady-state" temperature changes on both zero and calibration settings of the indicator.

The Load Indicator is operated by batteries, and contains following circuit elements: a 1,000 cycle per second oscillator, an amplifier, a phase-sensitive rectifier, a meter, and a measuring bridge. A transformer is provided in the oscillator circuit windings supplying power to the Load Cell bridge and to the measuring bridge. The difference between the load unbalance voltage and the measuring-bridge unbalance voltage is fed to the amplifier. The amplifier output passes through the phase-sensitive rectifier producing a voltage across the meter. The polarity of the voltage produced will depend upon the direction of load, and its magnitude is proportional to the difference between the two voltages.

The magnitude of the measuring bridge unbalance voltage is determined by the position of the slidewire and the setting of a "step" potentiometer. This potentiometer is controlled by a switch and serves to suppress the indicator zero by various fixed amounts. A direct-reading dial is attached to the slidewire, and the potentiometer setting is marked in thousands of units.

When the Load Cell output voltage is exactly equalled by the measuring bridge unbalance voltage, the meter reading is reduced to zero. The load then equals the sum of the dial and switch setting, multiplied by a constant, plus correction factor.

A "Tension-Compression" switch allows the indicator to measure either tensile or compressive loads on the Load Cell.

A standardizer is supplied for calibrating the Load Indicator, in case the indicator calibration changes by a small but significant amount (30 units or more.)

In the past load calibration of the various columns was done with the aid of a strain gage ring dynamometer designed especially for the purpose. The units were calibrated for a range of loads from 1000 to 8200 pounds. Results indicated that the ring sensitivity was 2.2 pounds per division on the strain indicator, and results were reproducible to about 10 pounds. An examination of the creep curves showed waviness. One of the reasons of this waviness could be friction. It was then decided to recalibrate using a more precise instrument, and then to make a study of the effect of friction.

Using the SR-4 Indicator, the load could be measured to a minimum count of 0.105 lb., for the range of 0 to 1200 pounds, and 1.05 lb. for the range up to 12,000 lb. By interpolation a load variation of as low as 0.5 lb. can be estimated for the range of 0 to 12,000 lb.

Procedure For Calibration

One end of a wire rope was connected to the takeup end of the unit, and to the other was connected the Load Cell, through an eye bolt. The other end of the Load Cell, was connected to the lever through another eye bolt. The loading levers were calibrated first for increasing load, then for decreasing load. The first observation was taken with the load of lever only, then the lever plus weight box, then for every addition of 50 lb lead shot in the weight box to a maximum of 400 lb lead shot. After reaching the maximum load, readings for decreasing load were noted. The meter was zeroed prior each set of load measurements. The load was then applied by bringing the lever to a horizontal position after placing a measured amount of lead shot in the weight box. This was done by rotating the takeup end wheel.

The applied load was then computed from the following expression:

$L = \text{Conversion Factor } (R \pm C) \pm \text{Temperature Correction.}$

To check the sensitivity of the loading system additional load varying from 0.5 to 2 lb were added to the weight box and removed. It was observed that the reading was never quite reproduced. It is believed that the sensivity of the lever system and the instrument is about 1 lb.

As described before two sets of observations were obtained for each load in the weight box, one for increasing load and the other for decreasing load. From Tables 12-14, appendix it can be seen that no two readings are the same. Had there been no frictional effect, the two sets of readings should have been the same.

Calibration data for the various columns were then analysed statistically, and the relation between the actual load on the cable and the load in the weight box was computed. The details of the statistical analysis are shown in the appendix. Plots of the results are shown in Fig. 10-12 appendix. The statistical analysis shows that the relation between the load in the weight box and load on the cable is linear. The relation can be expressed as

$$y_x = a + bx \quad \text{-----------------------} \quad 3$$

where y_x = actual load on cable, lb

x = load in weight box, lb.

<u>Discussion</u>

The standard deviation s_b of the slopes 'b' was computed. The details of computations are shown in the appendix. The error in the estimated values of the constant 'b' for various columns are as follows

Column 1	3.94%
Column 2	0.79%

TABLE 1

RESULTS OF ANALYTICAL TREATMENT OF CALIBRATION DATA

Column No	Const a	Const b	std Error s_b in b	95% Conf Lim	Estimated Actual Load in lb for 25 lb in Box	Estimated Actual Load in lb for 400 lb in Box	Diff in Estim and Upper & Lower Values for 25 lb in Box	Diff in Estim and Upper & Lower Values for 400 lb in Box
				Lower	1147.0	8352.0		
1	675.2	19.60	0.387	Estimated	1165.2	8514.9	1.61%	1.92%
				Upper	1183.0	8677.8		
				Lower	1148.1	8500.7		
2	665.0	19.68	0.0778	Estimated	1157.0	8537.0	0.77%	0.425%
				Upper	1165.9	8573.0		
				Lower	1194.8	8679.8		
5	699.86	20.056	0.0946	Estimated	1201.3	8723.8	0.55%	0.504%
				Upper	1207.9	8767.9		

Column 5 0.94%

The estimated values for the constants 'a' and 'b' are given in Table 1. The estimated, upper, and lower values of the actual load on cable for 25 lb and 400 lb load in weight box are also shown in Table 1.

The results shown in Table 1 indicate that the load calibration for Column 1 is less reliable as compared to Columns 2 and 5. This is no doubt due to greater friction in the loading lever system of this column.

Recommendation

The above conclusions were arrived at by treating only one set of observations, i.e., for each value of load in weight box, only two observations were taken, one for x increasing, and the other for x decreasing. In order to have more reliability the number of observations should be increased.

Several readings should be taken at zero load in the weight box to test the reliability of the reading. The average of these observations will be a more reliable value of the constant 'a' in the equation $y_x = a+bx$.

The lever mechanism of Column 1 should be checked and adjusted to reduce friction.

TEST MATERIAL

The material tested was aluminum alloy conductors manufactured by Kaiser Aluminum and Chemical Corporation. Tests were conducted on AAAC, EC and ACSR Conductors, and AAAC Lot 1 single strands. Specimen of AAAC were taken from two different manufacturing lots in which there were possible differences in processing. These were designated as Lot 1 and Lot 2; Lot 1 was shipped in a coil of relatively large diameter, wheras Lot 2 was shipped in a much tighter coil.

The single strand test was conducted on the central strand taken out of AAAC Conductor Lot 1

The diameter of a single strand of conductor wire was 0.188 inch. When stranded into cable form, a pitch of 7 inches per revolution of each of the six outside stranded was employed; the center strand remained relatively straight, being deformed slightly by the stranding operation. It was found that the central strand of Lot 2 was slightly twisted as compared to the central strand of Lot 1.

The nominal composition of the alloy is as follows:

Nominal Composition of the Alloy

Constituents	Percent by Weight
Magnesium	0.70%
Silicon	0.60%
Iron	0.25%
Copper	0.02%
Aluminum	98.43%

TABLE 2a

GENERAL INFORMATION ON TEST CONDUCTORS

Conductor	AAAC Lot 1	AAAC Lot 2	ACSR	EC
Code Name	4/0-Alliance	4/0-Alliance	4/0 Penguin	4/0-Oxlip
Strand Diameter, In.	0.1884	0.1884	0.1878	0.1739
Stranding	AAA (7 Strands)	AAA (7 Strands)	Aluminum (6 Strands) Steel (1 Strand)	AA-A (7 Strands)
Total Cross-Sectional Area Sq. In.	0.195	0.195	0.1939	0.1662
Nominal Breaking Load, lb	8427	8427	8420	3590

TABLE 2b

TESTING CONDITIONS

Code	Lot No.	Pre Load	Test Load lb	Test Load % UTS	Stress	Test Time hr
C-1-0-15	AAAC Lot 1	0	1264	15%	7000	1777
C-2-0-15	AAAC Lot 2	0	1264	15%	7000	2066
C-3-0-15	ACSR Lot 3	0	1263	15%	7000	2064
C-4-0-15	EC Lot 4	0	538.5	15% #	3240	a
S-1-0-15	AAAC Lot 1	0	204	15%	7000	a

Unless otherwise noted 100% UTS = 8427 lbs.
\# 100% UTS = 3590 lbs.
a Tests in Progress

The principal alloying elements are Magnesium and Silicon. The exact composition of the two Lots is not known. Small variations in alloying elements can cause significant changes not only in the creep properties but also in electrical conductivity and mechanical properties. It is therefore fair to assume that the manufacturer maintains a strict control on the alloying elements to avoid unacceptable properties of the products.

The manufacturing process of the conductor consists of rolling the billet into a 0.375 diameter rod; this is followed by a drawing process in which the diameter is reduced to 0.334 inches. After this the alloy is given a solution heat treatment. Thereafter, it is subjected to cold drawing process in which the wire is reduced to its final diameter of 0.188 inches. This is followed by an artificial aging at 350 F for 5½ hours. Fabrication is completed by coiling or stranding followed by coiling.

To identify test specimens and testing conditions on each specimen the following code symbols have been used: First, the letter C or the letter S identifies the specimen as a conductor or single strand respectively; this is followed by a number which identifies the lot of material from which the material was made. Lot 1 and Lot 2 refer to AAAC, Lot 3 and Lot 4 refer to ACSR and EC respectively. The lot identification number is followed by a number to indicate the preload conditions. Finally the last two digits give the test load. Thus the code symbol C-3-0-15 refers to a specimen taken from ACSR conductor tested without preload at 15 per cent of the ultimate tensile strength. Testing conditions are given in Table 2b.

EXPERIMENTAL PROCEDURE

The specimens in this series of tests were tested at a stress of 15 percent of ultimate tensils strength. The load to be applied was determined before starting the tests. This was calculated from the graphs plotted for calibration of different columns. Applied loads so determined were later checked with the values obtained after statistical analysis of the load calibration observations. It was found that the difference in two values was less than 1%. No calibration was done for the column used for testing single strand specimen since only a dead load was applied.

As mentioned before, conductors were received from the company in the form of a coil. Conductor coils were spread on a flat surface and the ends were bound with wires to some fixed supports. The conductors were handled carefully to avoid scratching them. It was observed that the specimens tend to take a helical shape when free and therefore inserting the specimen as it is into the column framework would have damaged the specimen. To avoid such damaging due to rubbing, and to make them straight while inserting in column framework, the specimens were bound in an angle iron. Ohio Brass, Cooline, 0.30 - 0.70-inch dead ends (Cat. No. 86541) were attached to the ends of the specimen to act as grips. These dead ends bend the specimen through a gentle curvature to an angle of about 60 degrees; and U bolt clamps, bearing against keeper pieces, hold the ends of the specimen firmly. The nuts of the U-bolts were tightened with a torque of 60 to 65 lb ft. One grip was attached to the loading lever link, and the other was attached to the turn-buckle. The specimen was then straightened by tightening the turn-buckle. The only load on the conductor at this time was that of the lever weight.

The tension due to lever load only on different specimen was as follows:

Conductor	Load lb
C-1-0-15	470
C-2-0-15	448
C-3-0-15	427
C-4-0-15	427
S-1-0-15	Unknown
S-1-0-15	75

The overall length of the specimen between the two grips was then measured by a steel tape, and a gage length of 200 inch was marked midway between the two grips while the specimens were subjected to the above mentioned tension. At one end of the gage length the dial gage was fixed on to the specimen. The aluminum actuating tube was placed on the specimen, one end of which was screwed to the stem of the dial gage, and the other end was firmly fastened to the specimen. The supporting clips were adjusted so that the actuating tube was parallel with the conductor. The dial of the strainometer was set to zero, and the weight box along with the required quantity of lead shot was hung on knife edges of the loading lever. The specimen was then placed under the test load by tightening the takeup nut until the lever floated slightly above the horizontal position. When the specimen was finally under the test load, the strainometer reading was recorded, and also the vertical scale reading on the free end of the loading lever. The schedule of recording the strainometer and vertical scale readings was as follows:

First 12 hours ---- every hour

Next 84 hours ---- every 12 hours

Next 400 hours ---- every 24 hours

Remainder of the test period --- every 96 hours.

Single Strand Specimen

The specimen was placed in the column framework, adopting the same procedure as used for conductors. To the ends of the specimen were attached grips consisting of tappered chucks with matching tappered jaws tightened by means of a nut. One grip was then attached to the inner end of the takeup bolt and the other was attached to the loading rope linkage. A load of 100 lb was applied on the specimen to straighten the specimen. The overall length of the specimen between the two grips was then measured, and a gage length of 200 inch was marked midway between the grips. The strainometer, the aluminum actuating tube, actuating tube supporting clips, and end clamps were then mounted on to the top of the specimen in a manner similar to that described for conductors. The dial reading of the strainometer was then brought to zero position. The test load was then applied by putting lead shot in the bucket attached to the rope. The schedule of taking strainometer readings was the same as the conductor test schedule.

DISCUSSION

Equipment and Experimental Procedure

An examination of the curves of test results reveals some variations in strain measurements. Since one objective of creep tests is to determine creep behavior for periods beyond the test time such variation decreases the confidence with which such extrapolations can be made.

There are evidently several causes of such variation. Some appear to be inherent in the equipment and some due to the mode of operation. Friction in the bearings of the levers and in the strainometer is probably the major factor inherent in the equipment contributing to the variation.

During calibration of the loading levers an attempt was made to evaluate the effect of friction of load variation. These results, together with a statistical analysis, are presented in Tables 11-13. Examination of these data reveals a greater variation at the lower loads and the variation is greater in Column 1 than in Columns 2 or 5. Error in the estimated value of the slope b for the three columns are Column 1 - 3.94%, Column 2 -0.79% and Column 5 - 0.94%.

Similar effects on strainometer readings were observed when setting up for the current series of tests. At this time the conductor was subjected to the lever load only, the dial gage set at zero, the lever raised to a slightly higher position then lowered carefully to the lever load position. This action resulted in a dial gage variation of 0.8 to 1.5 divisions.

There appears to be some frictional effects in the strainometer due to friction in the dial gage and between the actuating tube and its supports. To alleviate this friction it is standard practice to tap the dial gage with a pencil until no further movement of the pointer is observed. When this is done a movement of the pointer of from 0.5 to 2 divisions is observed. Evidently the amount of movement depends on the degree and intensity of tapping. During the current series of tests an attempt was made to standardize the reading procedure by tapping the dial gage case only five times with the rubber eraser of a pencil.

Other sources of variation were accidental touching of the levers during installation of conductors in adjacent test columns, to accidental sticking of the lever pointer on its scale and to the possibility of increased friction between the actuating tube of the extensometer and its supports due to deviations in straightness and the actuating tube.

Creep Data Analysis

If the creep data are plotted on log-log coordinates, a straight line results for data after a variable initial period. This feature is illustrated in Fig. 8-9. This fact would indicate that the creep data, for times beyond the initial period, can be expressed by the equation

$$\epsilon = Bt^n \text{ ------------------------ } 4$$

where ϵ = creep strain

t = time

B and n are constants

If the above equation is rewritten in the logarithmic form, the linearity becomes apparent

$$\log \epsilon = \log B + n \log t \text{ ----------- } 5$$

Now n becomes the slope of the straight line on log-log coordinates and B becomes the intercept at t = 1 hr.

This is the same form as equation 2 found by Cottrell as mentioned previously. Rodee (9) has shown that the creep data for ACSR conductors can be represented by equation 4. Paasche and Olleman (7) have also used the same equation to express the creep data on AAAC conductors.

The deviation from the straight line in initial period may be due to some mechanism, other than metallurgical phenomena, which later on dies out or becomes negligible. During the initial period, the specimen seems to be undergoing strand settling and straightening as well as metallurgical creep. The first two can be expected to die out with time. It is seen from Fig. 8-9, that the deviation is more apparent before about 500 hours; thereafter the data follow a straight line. Experiments conducted in the past (8) indicate that a constant slope results before the first 500 hours of test. Therefore the constants n and B have been evaluated using the data after the first 500 hours. It appears that the slopes for AAAC Lot 1 and

Lot 2, and ACSR are approximately the same.

The test data on AAAC Lot 1, single strand is highly unreliable due to malfunctioning of the equipment, and therefore it has not been shown in Fig. 8. As the load on AAAC Lot 1 specimen was disturbed by someone, the test was, therefore stopped after about 1700 hours.

Since the data obtained show some variability, it was necessary to statistically analyze the data to ascertain the reliability of the test results. Moreover it was necessary to determine the constants n and B, so as to extrapolate the results to longer time period.

Determination of the Slope 'n'

The constant 'n' which is the rate of change in creep strain per unit time based on logrithmic scale, has been computed using two experimental points, one at or near 500 hours, and the other at the end of the experiment. The data points in between the above-mentioned points are used to check the reliability of the slope and also the log B intercept.

Determination of Log B

The line of slope n is made to pass through the center of gravity of the selected data points. The intercept of this line on the log ordinate at 1 hour is the required value of log B. The center of gravity of the selected data points is the arithmetic mean of the log ϵ's and log t's.

<u>Reliability</u>

The estimated values of n, its standard deviation, which is a measure of reliability of estimates, and the value of B are given in Table 3. It is seen that if the estimated values of n are pooled together, the pooled n = 0.265 and pooled standard deviation equals 0.0754. For the test conducted, it appears that on the average, slope n may be in error by approximately 57 percent.

TABLE 3

RESULTS

OF

ANALYTICAL TREATMENT OF CREEP DATA

Specimen No	n	Std. Dev. s in n	B	90% Conf Lim (a)	Estimated Unit Creep Micro in/in 5 yr	10 yr	50 yr
				Lower	110	120	150
C-1-0-15	0.242	0.0674	15.10	Estimate	200	240	350
				Upper	360	470	850
				Lower	220	240	300
C-2-0-15	0.266	0.0997	23.03	Estimate	400	480	730
				Upper	710	930	1770
				Lower	210	230	300
C-3-0-15	0.288	0.0591	17.04	Estimate	370	450	720
				Upper	660	890	1740

(a)

Confidence Limits are limits which may be placed on the extrapolated values to indicate their reliability. The 90 percent confidence limits are limits such that for a large number of tests, nine times out of ten the true value of unit creep strain for each test would be expected to be between limits calculated for each test.

TABLE 3a

RESULTS OF ANALYTICAL TREATMENT OF CREEP DATA

FOR THE TEST IN PROGRESS

Specimen No.	n	B	Estimated 50 yr Unit Creep Micro In/In
S-1-0-15	0.315	8.40	504
C-1-0-15	0.334	7.53	580
C-2-0-15	0.354	13.70	1340
C-4-0-15	0.542	1.50	1710

Note: The above results are tentative as they are based on the data obtained during the first 500 hours. Therefore, they are liable to change when the complete data are analyzed.

The constants n and B were calculated by using two experimental points; namely, the point at about 300 hours, and the point at about 500 hours.

CONCLUSIONS

1. It appears that AAAC conductor Lot 1 creeps less than AAAC conductor Lot 2.
2. The creep rate of AAAC, conductor Lot 1 and the single strand are approximately the same.
3. The difference in creep rate of AAAC Lot 2 and AAAC Lot 1 is due to fabricating procedure.
4. AAAC Conductor Lot 2 and ACSR seem to have no difference in their creep rates whereas AAAC Lot 1 has a considerably lower creep rate.
5. The estimated values of creep strain after 50 years are approximately the same for AAAC Lot 2 and ACSR, whereas AAAC Lot 1 has a considerably lower creep strain.
6. The cause of large standard deviation seems to be due to
    a. friction in the actuating rod and supports,
    b. friction in the loading lever mechanism, and
    c. variations in technique of reading the strainometers.
7. The loading lever mechanism of Column 1 has higher friction than the mechanisms of Column 2 and 5.

RECOMMENDATIONS

1. All columns should be recalibrated for zero load in the weight box. Several observations should be taken at this load. The average value of these observations would then give a more reliable estimate of the constant 'a' in the load calibration equation $y_x = a + bx$. It is not necessary to repeat the entire calibration, as the statistical analysis has shown that the error in the estimated slope 'b' is within reasonable limits, except for Column 1.

2. The lever mechanism of Column 1 should be adjusted, or modified to reduce friction.

3. An enclosure should be provided around the loading levers to prevent accidental loading or unloading. Example: The theft of lead shot such as occurred on Column 5.

4. Movable partitions should be provided between the loading levers to facilitate individual adjustments without disturbing the adjacent levers.

5. The column framework should be enclosed individually, for the same reason as 4.

6. The strain measuring device should be modified to eliminate or reduce, as much as possible, the friction between the actuating rod and supporting clips.

7. The technique of reading the strainometers should be standardized by setting up routine procedures for tapping the dial gages and for actuating rods.

8. Tests on ACSR conductor should be repeated.

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8. Paasche and Olleman, Creep in AAAC, 4/0, Seven Strand, "Alliance" Conductor at 75 F. Without Prestressing Treatment, 1958.
9. H. H. Rodee, discussion, Trans. AIEE, 74, 1955, p. 199.

APPENDIX

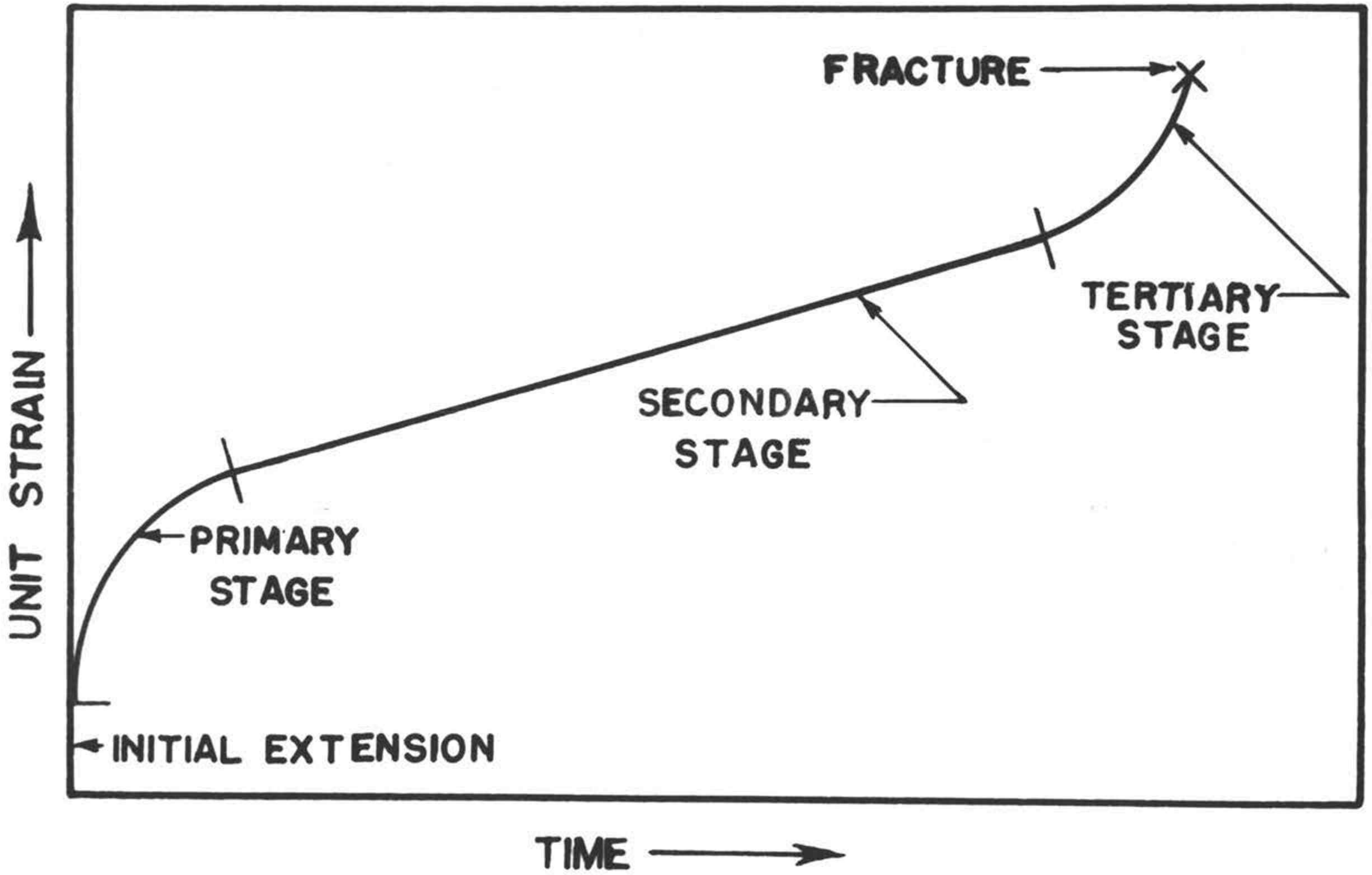

Figure 1. Typical Creep Curve Showing the Three Stages of Creep

Figure 2. Test Chambers and Loading Levers.

Figure 3. Arrangement of Testing Columns

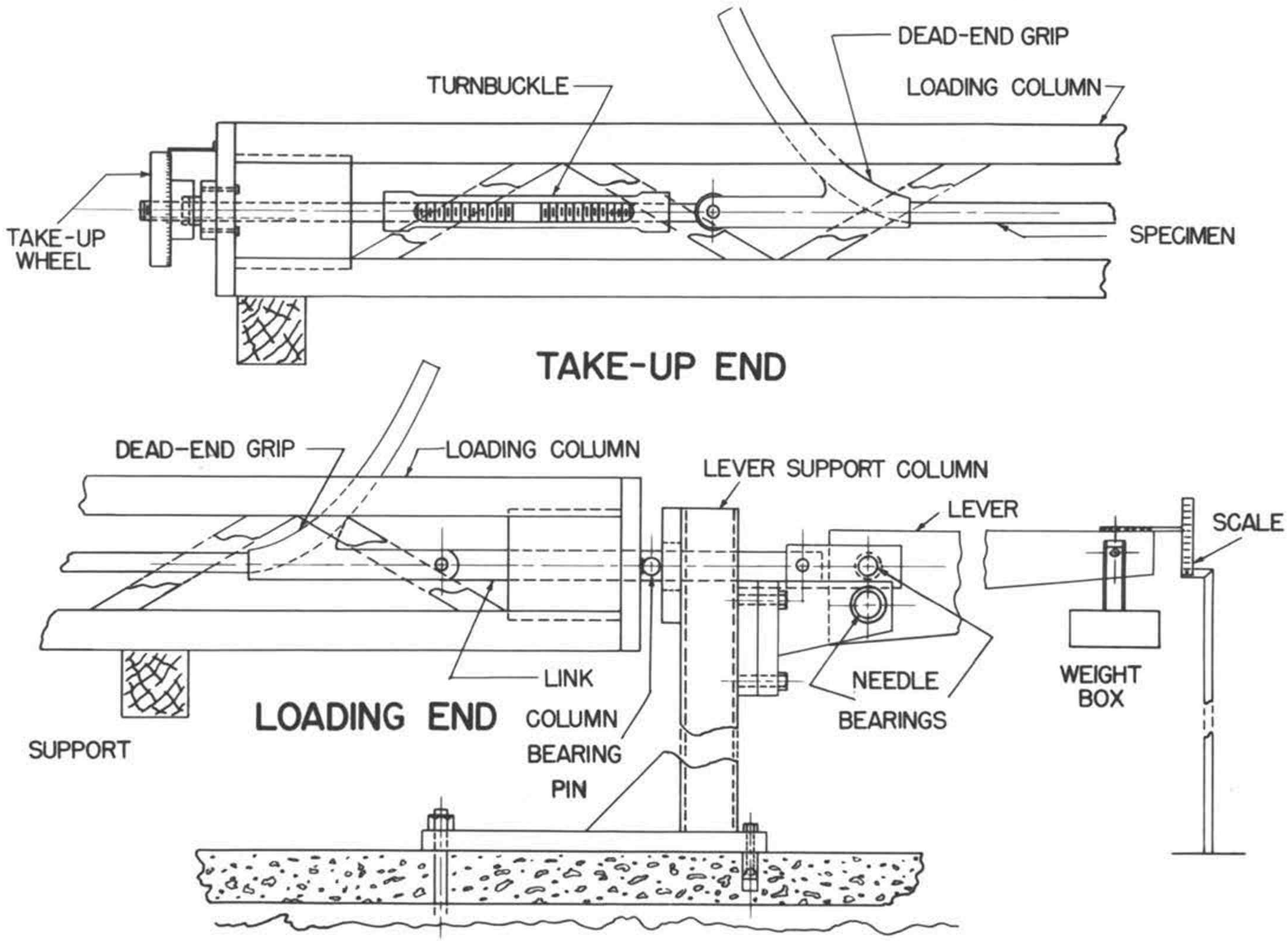

Figure 4. Details of Loading System

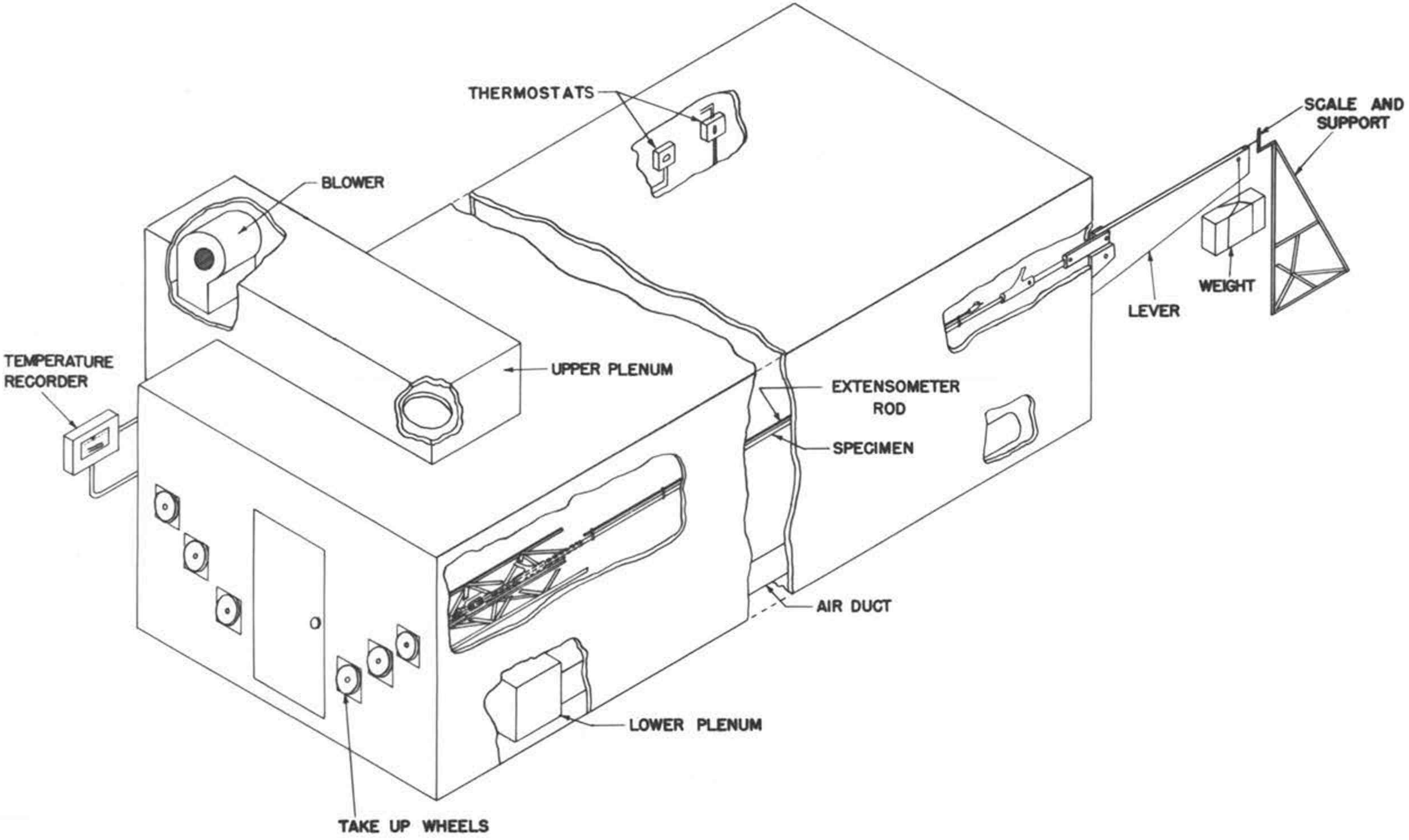

Figure 5. Schematic Diagram of Conductor Creep Testing Apparatus

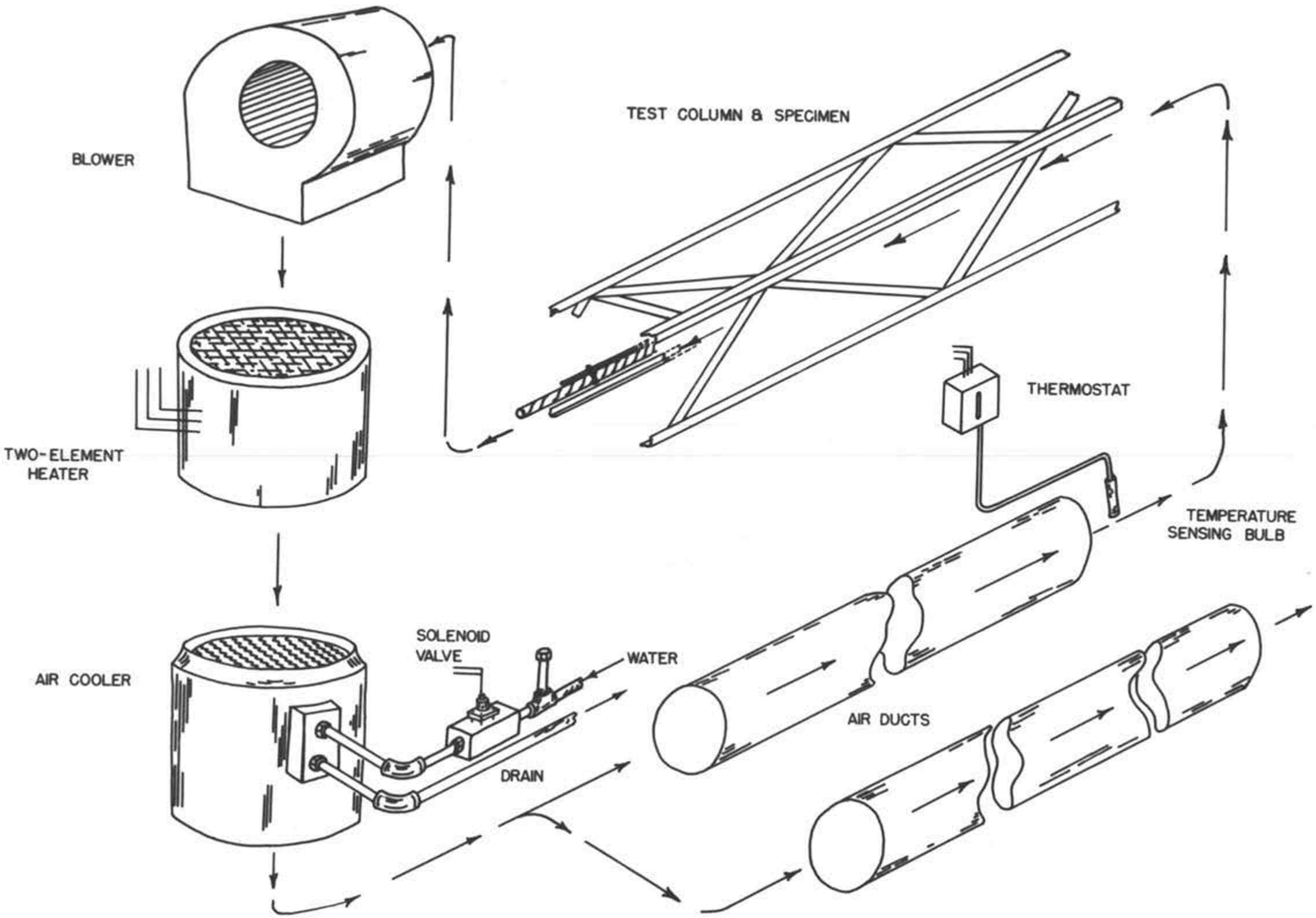

Figure 6. Schematic of the Air Conditioning System

TABLE 4. CREEP TEST DATA

SUBJECT CREEP TEST: Conductor Lot 1 Specimen 4C Position 4

BY: O. G. Paasche - Prem Prasad DATE: December 26, 1958 1037 Hours

GENERAL DATA 4/0 AAAC CABLE C-1-0-15 GAGE LENGTH: 200 In. (Set at Lever Load)

LEVER MULTIPLICATION: 22.0 to 1 KAISER ALUMINUM AND CHEMICAL CORPORATION

TEST LOAD: 1264 lb. 15% (3427 lb.) 28.75 Lead Shot

COLUMN 5 Length Between Grips 24 ft.- 10 in.

	Strain Gage Readings			Overall Elongation		
Elapsed Time Hours	Strain Gage Readings Thousandths In.	Change In Strain Gage Readings Thousandths In.	Unit Elongation Micro-Inches/In.	Scale Readings Inches	Change Of Scale Readings Inches	Overall Elongation Thousandths In.
		Lever load only (470 lb.)				
0	112.8	Test load		1.10		
1.0	113.8	1.0	5.0	1.18	0.08	3.64
2.0	114.2	1.4	7.0	1.25	0.15	6.82
3.0	114.4	1.6	8.0	1.28	0.18	8.18
4.0	114.9	2.1	11.5	1.30	0.20	9.09
5.0	115.0	2.2	12.0	1.32	0.22	10.0
6.0	115.3	2.5	12.5	1.34	0.24	10.9
7.0	115.5	2.7	13.5	1.43	0.33	15.0
8.0	116.0	3.2	16.0	1.50	0.40	18.2

TABLE 4. (cont.)

Elapsed Time Hours	Strain Gage Readings: Strain Gage Readings Thousandths In.	Strain Gage Readings: Change In Strain Gage Readings Thousandths In.	Strain Gage Readings: Unit Elongation Micro-Inches/In.	Overall Elongation: Scale Readings Inches	Overall Elongation: Change Of Scale Readings Inches	Overall Elongation: Overall Elongation Thousandths In.
9.0	116.3	3.5	17.5	1.52	0.42	19.1
10.0	116.9	4.1	20.5	1.53	0.43	19.55
11.0	117.0	4.2	21.0	1.53	0.43	19.55
12.0	117.0	4.2	21.0	1.54	0.44	20.0
13.0	117.1	4.3	21.5	1.54	0.44	20.0
24.0	117.8	5.0	25.0	1.58	0.48	21.8
36.0	118.7	5.9	29.5	1.60	0.50	22.75
48.0	119.0	6.2	31.0	1.60	0.50	22.75
60.0	119.2	6.4	32.0	1.61	0.51	23.2
72.0	119.2	6.4	32.0	1.68	0.58	26.4
84.0	119.4	6.6	33.0	1.69	0.59	26.8
96.0	120.0	7.2	36.0	1.73	0.63	28.65
121.1	121.6	8.8	44.0	2.00	0.90	40.9
145.1	122.0	9.2	46.0	2.02	0.93	41.8
169.1	122.2	9.4	47.0	2.03	0.93	42.3
193.1	122.7	9.9	49.5	2.06	0.96	43.7
217.1	123.2	10.4	52.0	1.86	0.76	34.6
241.1	123.0	10.2	51.0	2.00	0.90	40.8
266.9	123.2	10.4	52.0	2.05	0.95	43.2
291.2	123.8	11.0	55.0	2.10	1.00	45.4
313.2	124.0	11.2	56.0	2.12	1.02	46.4
337.2	124.5	11.7	58.5	2.14	1.04	47.3

TABLE 4. (cont.)

Elapsed Time Hours	Strain Gage Readings: Strain Gage Readings Thousandths In.	Strain Gage Readings: Change In Strain Gage Readings Thousandths In.	Strain Gage Readings: Unit Elongation Micro-Inches/In.	Overall Elongation: Scale Readings Inches	Overall Elongation: Change Of Scale Readings Inches	Overall Elongation: Overall Elongation Thousandths In.
386.2	125.0	12.2	61.0	2.13	1.03	46.8
411.2	125.0	12.2	61.0	2.16	1.06	48.2
433.2	125.1	12.3	61.5	2.18	1.08	49.1
529.2	126.6	13.8	69.0	2.22	1.12	50.8
625.2	127.0	14.2	71.0	2.32	1.22	55.5
721.2	128.2	15.4	77.0	2.43	1.33	60.5
817.2	127.9	15.1	75.5	2.48	1.38	62.7
913.2	128.8	16.0	80.0	2.47	1.37	62.3
1009.2	129.0	16.2	81.0	2.50	1.40	63.7
1105.2	129.3	16.5	82.5	2.56	1.46	66.4
1201.2	129.9	17.1	85.5	2.56	1.46	66.4
1297.2	129.9	17.1	85.5	2.58	1.48	67.3
1393.2	130.6	17.8	89.0	2.55	1.45	65.9
1489.2	130.6	17.8	89.0	2.60	1.50	68.2
1585.2	130.8	18.0	90.0	2.62	1.52	69.1
1681.2	131.0	18.2	91.0	2.63	1.53	69.6
1777.2	131.3	18.5	92.5	2.64		

Loading disturbed by someone, test discontinued at 1200 hours on March 14, 1959.

TABLE 5. CREEP TEST DATA

SUBJECT CREEP TEST: Single Strand Lot 1 Specimen 35 Position 3

BY: Prem Prasad - O. G. Paasche DATE: December 26, 1958, 1100 hrs

GENERAL DATA 4/0 ALUMINUM CONDUCTOR CABLE S-1-0-15 AAAC

GAGE LENGTH: 200 In. (Set at 54 lb.) KAISER ALUMINUM AND CHEMICAL CO

TEST LOAD: 204 lb. - (15% of 1360 lb.)

COLUMN 6 Length Between Grips 24 ft. 3 in.

Elapsed Time Hours	Strain Gage Readings: Strain Gage Readings Thousandths In.	Strain Gage Readings: Change In Strain Gage Readings Thousandths In.	Strain Gage Readings: Unit Elongation Micro-Inches/In.
		Load 54 lb.	
Grips slipped during loading -		Load not reset to 54 lb. Load unknown	
0	62.7	Specimen twisted, gauge reset to horizontal position	
0	54.5	New reading after setting gauge	
1	55.3	0.8	4.0
2	55.7	1.2	6.0
3	56.2	1.7	8.5
4	56.4	1.9	9.5
5	56.7	2.2	11.0
6	57.2	2.7	13.5
7	57.3	2.8	14.0
8	57.4	2.9	14.5
9	57.7	3.2	16.0
10	57.9	3.4	17.0
11	58.0	3.5	17.5
12	58.0	3.5	17.5
23	58.8	4.3	21.5
35	59.6	5.1	25.5
47	60.1	5.6	28.0
59	60.2	5.7	28.5
71	60.2	5.7	28.5
83	60.2	5.7	28.5

TABLE 5. (cont.)

Elapsed Time Hours	Strain Gage Readings Strain Gage Readings Thousandths In.	Change In Strain Gage Readings Thousandths In.	Unit Elongation Micro-Inches/In.
95.0	60.2	5.7	28.5
120.1	60.2	5.7	28.5
144.1	60.6	6.1	30.5
168.1	60.6	6.1	30.5
192.1	60.6	6.1	30.5
216.1	60.8	6.3	31.5
240.1	60.8	6.3	31.5
265.9	60.2	5.7	28.5
290.2	60.2	5.7	28.5
Strainometer was noticed slipping - necessary adjustments made and dial set at 60.2			
312.2	59.2	4.7	23.5
336.2	60.2	5.7	28.5
360.2	60.4	5.9	29.5
385.2	60.7	6.2	31.0
410.2	60.9	6.4	32.0
432.2	61.0	6.5	32.5
528.2	61.8	7.3	36.5
624.2	62.6	8.1	40.5
720.2	63.2	8.7	43.5
816.2	63.4	8.9	44.5
912.2	63.8	9.3	46.5
1008.2	63.3	8.8	44.0
1104.2	64.7	10.2	51.0
1200.2	65.1	10.6	53.0
1296.2	65.2	10.7	53.5
1392.2	65.7	11.2	56.0
1488.2	65.9	11.4	57.0
1584.2	66.1	11.6	58.0
1680.2	66.4	11.9	59.5
1776.0	66.7	12.2	61.0
1872.0	67.1	12.6	63.0
1968.0	67.1	12.6	63.0
2064.0	67.2	12.7	63.5

Test completed at 1200 hours on March 22, 1959

TABLE 6. CREEP TEST DATA

SUBJECT CREEP TEST: Conductor Lot 2 Specimen 3C Position 3 AAAC

BY: O. G. Paasche - Prem Prasad DATE: December 26, 1958, 0950 Hours

GENERAL DATA 4/0 ALUMINUM CONDUCTOR CABLE C-2-0-15 GAGE LENGTH: 200 In. (Set at Lever Load)

LEVER MULTIPLICATION 20.8 to 1 KAISER ALUMINUM AND CHEMICAL CORPORATION

TEST LOAD 1264 lb. - 15% (8427lb) 30.25 lb. shot

COLUMN 1 Length of Conductor Between Grips 23 ft.- 11 in.

	Strain Gage Readings			Overall Elongation		
Elapsed Time Hours	Strain Gage Readings Thousandths In.	Change In Strain Gage Readings Thousandths In.	Unit Elongation Micro-Inches/In.	Scale Readings Inches	Change Of Scale Readings Inches	Overall Elongation Thousandths In.
0.0	0.0	Lever load only (443 lb.)				
10 min.	98.9	Test load (1264 lb.)		4.93		
1.6	100.4	1.5	7.5	4.82	0.11	5.28
2.6	101.2	2.3	11.5	4.75	0.18	8.64
3.7	101.5	2.6	13.0	4.74	0.19	9.12
4.7	102.8	3.9	19.5	4.72	0.21	10.08
5.7	103.0	4.1	20.5	4.71	0.22	10.57
6.7	103.1	4.2	21.0	4.70	0.23	11.04
7.7	103.3	4.4	22.0	4.67	0.26	12.48
8.7	103.4	4.5	22.5	4.66	0.27	12.97

TABLE 6. (cont.)

Elapsed Time Hours	Strain Gage Readings: Strain Gage Readings Thousandths In.	Strain Gage Readings: Change In Strain Gage Readings Thousandths In.	Strain Gage Readings: Unit Elongation Micro-Inches/In.	Overall Elongation: Scale Readings Inches	Overall Elongation: Change Of Scale Readings Inches	Overall Elongation: Overall Elongation Thousandths In.
9.8	103.5	4.6	23.0	4.66	0.27	12.97
10.8	103.9	5.0	25.0	4.65	0.28	13.45
11.8	104.4	5.5	27.5	4.65	0.28	13.45
12.8	104.5	5.6	28.0	4.64	0.29	13.93
13.8	104.6	5.7	28.5	4.63	0.30	14.4
24.8	105.9	6.0	30.0	4.56	0.37	17.78
36.8	107.6	8.7	43.5	4.54	0.39	18.73
48.8	108.7	9.8	49.0	4.53	0.40	19.21
60.8	109.3	10.4	52.0	4.48	0.45	21.6
72.8	110.2	11.3	56.5	4.40	0.53	25.45
84.8	111.2	12.3	61.5	4.36	0.57	27.4
96.8	111.5	12.6	63.0	4.34	0.59	28.35
121.9	113.5	14.6	73.0	4.30	0.63	30.25
145.9	114.3	15.4	77.0	4.26	0.67	32.2
169.9	114.7	15.0	79.0	4.23	0.70	33.6
193.9	116.1	17.2	86.0	4.28	0.65	31.2
217.9	116.9	18.0	90.0	4.34	0.59	38.35
214.9	117.1	18.2	91.0	4.26	0.72	34.6
267.7	117.5	18.6	93.0	4.16	0.77	37.0
292.0	119.3	20.4	102.0	4.11	0.82	39.4
314.0	119.4	20.5	102.5	4.10	0.83	39.85
338.0	120.1	21.2	106.0	4.07	0.86	41.3

TABLE 6. (cont.)

Elapsed Time Hours	Strain Gage Readings: Strain Gage Readings Thousandths In.	Strain Gage Readings: Change In Strain Gage Readings Thousandths In.	Strain Gage Readings: Unit Elongation Micro-Inches/In.	Overall Elongation: Scale Readings Inches	Overall Elongation: Change Of Scale Readings Inches	Overall Elongation: Overall Elongation Thousandths In.
362.0	120.6	21.7	108.5	4.05	0.88	42.25
387.0	120.6	21.7	108.5	4.05	0.88	42.25
412.0	121.1	22.2	111.0	4.02	0.91	43.7
434.0	121.3	22.4	112.0	4.00	0.93	44.7
530.0	123.4	24.5	122.5	3.94	0.99	47.6
626.0	124.3	25.4	127.0	3.89	1.04	49.99
722.0	126.5	27.6	138.0	3.85	1.10	52.8
818.0	126.2	27.3	136.4	3.78	1.15	55.25
914.0	128.1	29.2	146.0	3.72	1.21	58.1
1010.0	129.2	30.3	151.5	3.70	1.23	59.6
1106.0	129.4	30.5	152.5	3.63	1.30	62.4
1202.0	130.3	31.4	157.0	3.60	1.33	63.8
1298.0	130.6	31.7	158.5	3.57	1.36	63.3
1394.0	131.2	32.3	161.5	3.56	1.35	64.8
1490.0	131.5	32.6	163.0	3.53	1.38	66.25
1586.0	132.2	33.3	166.5	3.52	1.39	66.75
1682.0	132.7	33.8	169.0	3.50	1.41	67.7
1778.0	133.3	34.4	172.0	3.48	1.43	68.7
1874.0	133.7	34.8	174.0	3.46	1.45	69.6
1970.0	134.0	35.1	175.5	3.46	1.45	69.6
2066.0	134.1	35.2	176.0	3.45	1.46	70.1

Test completed at 1200 hours on March 22, 1959

TABLE 7. CREEP TEST DATA

SUBJECT CREEP TEST: Conductor Lot 3 ACSR Specimen XI

BY: O. G. Paasche - Prem Prasad DATE: December 26, 1958, 1010 Hours

GENERAL DATA 4/0 ALUMINUM CONDUCTOR CABLE C-3-0-15 GAGE LENGTH 200 in. (Set at Lever Load)

LEVER MULTIPLICATION 20.6 to 1 KAISER ALUMINUM AND CHEMICAL CORPORATION

TEST LOAD : 1263 lb. - 15% (8420 lb.) 30.25 lb. Shot

COLUMN 2 Length Between Grips 24 ft. - 3 in.

	Strain Gage Readings			Overall Elongation		
Elapsed Time Hours	Strain Gage Readings Thousandths In.	Change In Strain Gage Readings Thousandths In.	Unit Elongation Micro-Inches/In.	Scale Readings Inches	Change Of Scale Readings Inches	Overall Elongation Thousandths In.
		Lever load only (427 lb.)				
0.0	91.4	Test load (1263 lb.)		5.27		
1.3	92.8	1.4	7.5	5.20	0.07	3.4
2.4	93.5	2.1	11.5	5.15	0.12	5.82
3.4	94.0	2.6	13.0	5.14	0.13	6.31
4.4	95.1	3.7	18.5	5.10	0.17	8.25
5.4	95.8	4.4	22.0	5.08	0.19	9.25
6.4	96.0	4.6	23.0	5.06	0.21	10.2
7.4	96.2	4.8	24.0	5.05	0.22	10.7
8.4	96.2	4.8	24.0	5.04	0.23	11.17

TABLE 7. (cont.)

Elapsed Time Hours	Strain Gage Readings: Strain Gage Readings Thousandths In.	Strain Gage Readings: Change In Strain Gage Readings Thousandths In.	Strain Gage Readings: Unit Elongation Micro-Inches/In.	Overall Elongation: Scale Readings Inches	Overall Elongation: Change Of Scale Readings Inches	Overall Elongation: Overall Elongation Thousandths In.
9.4	96.3	4.9	24.5	5.04	0.23	11.17
10.4	97.0	5.6	28.0	5.03	0.24	11.65
11.4	97.2	5.8	29.0	5.03	0.24	11.65
12.4	97.3	5.9	29.5	5.02	0.25	12.13
13.4	97.3	5.9	29.5	5.01	0.26	12.63
24.4	98.6	7.2	36.0	4.94	0.33	16.05
36.4	100.1	8.7	43.5	4.90	0.37	17.98
48.4	100.7	9.3	46.5	4.89	0.38	18.45
60.4	101.2	9.8	49.0	4.87	0.40	19.43
72.4	101.7	10.3	51.5	4.80	0.47	22.83
84.4	102.4	11.0	55.5	4.78	0.49	23.81
96.4	102.8	11.4	57.0	4.75	0.52	25.25
121.5	104.8	13.4	67.0	4.70	0.57	27.70
145.5	105.3	13.9	69.5	4.68	0.59	28.65
169.5	106.8	15.4	77.0	4.66	0.61	29.63
193.5	108.2	16.6	83.0	4.67	0.60	29.15
217.5	108.2	17.6	88.0	4.69	0.58	28.20
241.5	100.5	16.9	84.5	4.61	0.66	32.05
267.3	108.1	16.5	82.5	4.59	0.68	33.05
291.6	108.7	17.1	85.5	4.56	0.71	34.50
Pointer got stuck up with scale, clearance made at 1500 hours.						
313.6	109.2	17.6	88.0	4.53	0.74	35.95
337.6	109.6	18.0	90.0	4.51	0.76	36.90

TABLE 7. (cont.)

Elapsed Time Hours	Strain Gage Readings: Strain Gage Readings Thousandths In.	Strain Gage Readings: Change In Strain Gage Readings Thousandths In.	Strain Gage Readings: Unit Elongation Micro-Inches/In.	Overall Elongation: Scale Readings Inches	Overall Elongation: Changed Of Scale Readings Inches	Overall Elongation: Overall Elongation Thousandths In.
361.6	109.8	18.2	91.0	4.50	0.77	37.40
386.6	110.2	18.6	93.0	4.50	0.77	37.40
411.6	110.7	19.1	95.5	4.47	0.80	38.85
433.6	110.7	19.1	95.5	4.45	0.82	39.85
529.6	112.4	20.8	104.0	4.39	0.86	41.75
625.6	114.0	22.4	112.0	4.27	0.98	47.6
721.6	116.3	24.7	123.5	4.17	1.08	52.5
817.6	115.8	24.2	121.0	4.13	1.12	54.4
913.6	117.0	25.4	127.0	4.08	1.17	56.8
1009.6	118.5	25.9	129.5	4.03	1.22	59.25
1105.6	119.3	26.7	133.5	3.90	1.35	65.6
1201.6	120.0	27.4	137.0	3.88	1.37	66.5
1297.6	120.0	27.4	137.0	3.87	1.38	67.0
1393.6	121.0	28.4	142.0	3.86	1.39	67.5
1489.6	121.2	28.6	143.0	3.88	1.45	70.4
1585.6	121.7	29.1	145.5	3.78	1.47	71.4
1681.6	122.0	29.4	147.0	3.77	1.48	71.8
1777.6	122.3	29.7	148.5	3.76	1.49	72.3
1873.6	122.8	30.2	151.0	3.73	1.52	73.8
1969.6	122.9	30.3	151.5	3.73	1.52	73.8
2065.6	123.4	30.8	154.0	3.73	1.52	73.8

Test completed at 1200 hours on March 22, 1959.

TABLE 8. CREEP TEST DATA

SUBJECT CREEP TEST: Conductor Lot 1 C-1-0-15

BY: O. G. Paasche - Prem Prasad DATE: March 30, 1959 1035 hours

GENERAL DATA 4/0 AAAC Cable GAGE LENGTH: 200 inch (Set at Lever Load)

LEVER MULTIPLICATION : 22.0 to 1 KAISER ALUMINUM CORPORATION

TEST LOAD: 1264 lb. - 15% (8427 lb.) 28.74 lb. Lead Shot

COLUMN 5 Length of Conductor Between Grips 24 ft. 10 in.

	Strain Gage Readings			Overall Elongation		
Elapsed Time Hours	Strain Gage Readings Thousandths In.	Change In Strain Gage Readings Thousandths In.	Unit Elongation Micro-Inches/In.	Scale Readings Inches	Change Of Scale Readings Inches	Overall Elongation Thousandths In.
0	0	Lever Load Only				
0	106.0	106.0	Test Load Applied	1.47		
1	106.9	0.9	4.5	1.50	0.03	1.36
2	107.0	1.0	5.0	1.51	0.04	1.82
3	107.3	1.3	6.5	1.53	0.06	2.73
4	107.8	1.8	9.0	1.55	0.08	3.64
5	108.1	2.1	10.5	1.56	0.09	4.09
6	108.4	2.4	12.0	1.57	0.10	4.55
7	108.5	2.5	12.5	1.59	0.12	5.46
8	108.9	2.9	14.5	1.59	0.12	5.46
9	109.0	3.0	15.0	1.59	0.12	5.46
10	109.0	3.0	15.0	1.59	0.12	5.46

TABLE 8. (cont.)

	Strain Gage Readings			Overall Elongation		
Elapsed Time Hours	Strain Gage Readings Thousandths In.	Change In Strain Gage Readings Thousandths In.	Unit Elongation Micro-Inches/In.	Scale Readings Inches	Change Of Scale Readings Inches	Overall Elongation Thousandths In.
11.0	109.1	3.1	15.5	1.60	0.13	5.91
12.0	109.2	3.2	16.0	1.60	0.13	5.91
12.5	109.2	3.2	16.0	1.61	0.14	6.37
24.5	109.9	3.9	19.5	1.65	0.18	8.19
36.5	110.8	4.8	24.0	1.68	0.21	9.52
48.5	111.5	5.5	27.5	1.72	0.25	11.37
60.5	112.0	6.0	30.0	1.75	0.28	12.74
72.5	112.3	6.3	31.5	1.77	0.30	13.60
84.5	112.6	6.6	33.0	1.78	0.31	14.07
96.5	112.8	6.8	34.0	1.79	0.32	14.56
108.5	113.3	7.3	36.5	1.79	0.32	14.56
120.5	113.6	7.6	38.0	1.80	0.33	14.96
132.5	113.7	7.7	38.5	1.81	0.34	15.42
144.5	113.9	7.9	39.5	1.82	0.35	15.92
168.5	114.1	8.1	40.5	1.85	0.38	17.28
192.5	114.6	8.6	43.0	1.85	0.38	17.28
216.5	114.8	8.8	44.0	1.89	0.42	19.10
240.5	115.3	9.3	46.5	1.91	0.44	20.00
264.5	115.5	9.5	47.5	1.92	0.45	20.40
288.5	116.2	10.2	51.0	1.93	0.46	20.87
312.5	116.4	10.4	52.0	1.93	0.46	20.87
336.5	116.5	10.5	52.5	1.94	0.47	21.40

TABLE 8. (cont.)

Elapsed Time Hours	Strain Gage Readings: Strain Gage Readings Thousandths In.	Strain Gage Readings: Change In Strain Gage Readings Thousandths In.	Strain Gage Readings: Unit Elongation Micro-Inches/In.	Overall Elongation: Scale Readings Inches	Overall Elongation: Change Of Scale Readings Inches	Overall Elongation: Overall Elongation Thousandths In.
360.5	116.6	10.6	53.0	1.96	0.49	22.20
384.6	116.9	10.9	54.5	1.99	0.52	23.60
408.6	117.1	11.1	55.5	1.99	0.52	23.60
432.6	117.4	11.4	57.0	1.99	0.52	23.60
456.6	117.4	11.4	57.0	1.96	0.49	22.20
480.6	118.0	12.0	60.0	1.96	0.49	22.20
504.6	118.2	12.2	61.0	1.98	0.51	23.15

Test in Progress

TABLE 9. CREEP TEST DATA

SUBJECT CREEP TEST: Single Strand Lot 1 S-1-0-15

BY: O. G. Paasche - Prem Prasad DATE: March 30, 1959 1045 hours

GENERAL DATA 4/0 AAAC GAGE LENGTH 200 in. (Set at 75 lb. Load)

KAISER ALUMINUM AND CHEMICAL CORPORATION

TEST LOAD: 204 lb. - (15% of 1360 lb.)

COLUMN 6 Length of Conductor Between Grips 20 ft. - 11 3/4 In

	Strain Gage Readings		
Elapsed Time Hours	Strain Gage Readings Thousandths In.	Change In Strain Gage Readings Thousandths In.	Unit Elongation Micro-Inches/In.
0	0	75 lb. Load	
0	103.5	Test Load Applied	
0.7	103.9	0.4	2.0
1.7	104.0	0.5	2.5
2.7	104.4	0.9	4.5
3.7	104.8	1.3	6.5
4.7	105.2	1.7	8.5
5.7	105.6	2.1	10.5
6.7	106.0	2.5	12.5
7.7	106.4	2.9	14.5
8.7	106.8	3.3	16.5
9.7	106.9	3.4	17.0
10.7	107.3	3.8	19.0
11.7	107.6	4.1	20.5
12.2	107.8	4.3	21.5
24.2	108.1	4.6	23.0
36.2	108.8	5.3	26.5
48.2	109.1	5.6	28.0
60.2	109.6	6.1	30.5
72.2	110.0	6.5	32.5
84.2	110.2	6.7	33.5
96.2	110.4	6.9	34.5
108.2	110.6	7.1	35.5
120.2	110.8	7.3	36.5
132.2	111.0	7.5	37.5

TABLE 9. (cont.)

Elapsed Time Hours	Strain Gage Readings Thousandths In.	Change In Strain Gage Readings Thousandths In.	Unit Elongation Micro-Inches/In.
	Strain Gage Readings		
144.2	111.4	7.9	39.5
168.2	111.5	8.0	40.0
192.2	112.3	8.8	44.0
216.2	112.5	9.0	45.0
240.2	112.6	9.1	45.5
264.2	112.9	9.4	47.0
288.2	113.4	9.9	49.5
312.2	113.7	10.2	51.5
336.6	114.1	10.6	53.0
360.6	114.2	10.7	53.5
384.6	114.4	10.9	54.5
408.6	114.5	11.0	55.0
432.6	114.7	11.2	56.0
456.6	114.8	11.3	56.5
480.6	115.5	12.0	60.0
504.6	115.5	12.0	60.0

Test in Progress.

TABLE 10. CREEP TEST DATA

SUBJECT CREEP TEST: Conductor Lot 2 C-2-0-15 AAAC

BY: O. G. Paasche - Prem Prasad DATE: March 30, 1959, 1025 hours

GENERAL DATA 4/0 C-2-0-15 GAGE LENGTH: 200 in. (Set at Lever Load)

Lever Multiplication: 20.8 to 1 KAISER ALUMINUM AND CHEMICAL CORPORATION

TEST LOAD: 1264 lb. = 15% (8427 lb.) 30.25 lb. shot

COLUMN 1 Length of Conductor Between Grips 24 ft. 1 1/4 in.

Elapsed Time Hours	Strain Gage Readings: Strain Gage Readings Thousandths In.	Strain Gage Readings: Change In Strain Gage Readings Thousandths In.	Strain Gage Readings: Unit Elongation Micro-Inches/In.	Overall Elongation: Scale Readings Inches	Overall Elongation: Change Of scale Readings Inches	Overall Elongation: Overall Elongation Thousandths In.
0.0	0.0	Lever Load Only				
0.0	97.8					
0.0	97.8	97.8 Test Load Applied		4.25		
1.1	99.5	1.7	8.5	4.23	0.02	0.96
2.1	99.8	2.0	10.0	4.20	0.05	2.40
3.1	100.2	2.4	12.0	4.17	0.08	3.84
4.1	101.0	3.2	16.0	4.15	0.10	4.81
5.1	101.4	3.6	17.5	4.13	0.12	5.77
6.1	101.7	3.9	19.0	4.12	0.13	6.25
7.1	101.8	4.0	19.5	4.10	0.15	7.21
8.1	102.5	4.7	23.0	4.10	0.15	7.21

TABLE 10. (cont.)

Elapsed Time Hours	Strain Gage Readings: Strain Gage Readings Thousandths In.	Strain Gage Readings: Change In Strain Gage Readings Thousandths In.	Strain Gage Readings: Unit Elongation Micro-Inches/In.	Overall Elongation: Scale Readings Inches	Overall Elongation: Change Of Scale Readings Inches	Overall Elongation: Overall Elongation Thousandths In.
9.1	102.7	4.9	24.0	4.10	0.15	7.21
10.1	102.9	5.1	25.0	4.08	0.17	8.17
11.1	103.0	5.2	25.5	4.06	0.19	9.13
12.1	103.1	5.3	26.0	4.03	0.22	10.58
12.6	103.1	5.3	26.0	4.03	0.22	10.58
24.6	104.6	6.8	33.5	3.96	0.29	13.90
36.6	106.7	8.9	44.0	3.90	0.35	16.85
48.6	108.1	10.3	51.0	3.85	0.40	19.50
60.6	109.0	11.2	56.0	3.81	0.44	21.15
72.6	109.5	11.7	58.5	3.76	0.49	23.55
84.6	110.6	12.8	64.0	3.74	0.51	24.50
96.6	111.2	13.4	67.0	3.72	0.53	25.50
108.6	111.9	14.1	70.5	3.70	0.55	26.45
120.5	112.5	14.7	73.5	3.67	0.58	27.90
132.6	112.6	14.8	74.0	3.66	0.59	28.40
144.6	112.8	15.0	75.0	3.65	0.60	29.87
168.6	113.8	16.0	80.0	3.60	0.65	31.25
192.6	115.0	17.2	86.0	3.56	0.69	33.20
216.6	115.6	17.8	89.0	3.54	0.71	34.15
240.6	116.5	18.7	93.5	3.52	0.73	35.10
264.6	117.2	19.4	97.0	3.50	0.75	36.10
288.6	117.8	20.0	100.0	3.46	0.79	38.00
312.6	118.6	20.8	104.0	3.45	0.80	38.50

TABLE 10. (cont.)

Elapsed Time Hours	Strain Gage Readings: Strain Gage Readings Thousandths In.	Strain Gage Readings: Change In Strain Gage Readings Thousandths In.	Strain Gage Readings: Unit Elongation Micro-Inches/In.	Overall Elongation: Scale Readings Inches	Overall Elongation: Change Of Scale Readings Inches	Overall Elongation: Overall Elongation Thousandths In.
336.6	119.5	21.7	108.5	3.44	0.81	38.95
360.6	119.9	22.1	110.5	3.42	0.83	39.90
384.6	120.3	22.5	112.5	3.40	0.85	40.80
408.6	120.6	22.8	114.0	3.37	0.88	42.35
432.6	121.2	23.4	117.0	3.36	0.89	42.80
456.6	121.7	23.9	119.5	3.38	0.87	41.80
480.6	122.2	24.4	122.0	3.37	0.88	42.35
504.6	122.4	24.6	123.0	3.35	0.90	43.30

Test in Progress

TABLE 11. CREEP TEST DATA

SUBJECT CREEP TEST: Conductor Lot 4 C-4-0-15

BY: O. G. Paasche - Prem Prasad DATE: March 30, 1959 1105 hours

GENERAL DATA 4/0 E.C. (AAC) GAGE LENGTH: 200 in. (Set at Lever Load)

LEVER MULTIPLICATION: 20.6 to 1 KAISER ALUMINUM AND CHEMICAL CORPORATION

TEST LOAD: 538.5 lb. - 15% (3590 lb.) Lead shots & bucket - 5.81 lb.

COLUMN 2 Length of Conductor Between Grips 24 ft. 1¼ in.

	Strain Gage Readings			Overall Elongation		
Elapsed Time Hours	Strain Gage Readings Thousandths In.	Change In Strain Gage Readings Thousandths In.	Unit Elongation Micro-Inches/In.	Scale Readings Inches	Change Of Scale Readings Inches	Overall Elongation Thousandths In.
0.0	0.0	Lever Load Only				
0.0	9.7	9.7 Lever Load Applied		4.2		
0.4	9.9	0.2	1.0	4.18	0.02	0.97
1.4	10.0	0.3	1.5	4.17	0.03	1.45
2.4	10.1	0.4	2.0	4.16	0.04	1.94
3.4	10.4	0.7	3.5	4.16	0.04	1.94
4.4	10.7	1.0	5.0	4.15	0.05	2.43
5.4	10.8	1.1	5.5	4.13	0.07	3.40
6.4	10.8	1.1	5.5	4.13	0.07	3.40
7.4	11.0	1.3	6.5	4.12	0.08	3.88

TABLE 11. (cont.)

	Strain Gage Readings			Overall Elongation		
Elapsed Time Hours	Strain Gage Readings Thousandths In.	Change In Strain Gage Readings Thousandths In.	Unit Elongation Micro-Inches/In.	Scale Readings Inches	Change Of Scale Readings Inches	Overall Elongation Thousandths In.
8.4	11.1	1.4	7.0	4.12	0.08	3.88
9.4	11.1	1.4	7.0	4.11	0.09	4.37
10.4	11.2	1.5	7.5	4.11	0.09	4.37
11.4	11.2	1.5	7.5	4.11	0.09	4.37
12.0	11.2	1.5	7.5	4.10	0.10	4.85
24.0	11.4	1.7	8.5	4.07	0.13	
36.0	11.7	2.0	10.0	4.04	0.16	
48.0	12.3	2.6	13.0	4.01	0.19	
60.0	12.7	3.0	15.0	3.99	0.21	10.20
72.0	13.0	3.3	16.5	3.95	0.25	12.13
84.0	13.2	3.5	17.5	3.94	0.26	12.61
96.0	13.4	3.7	18.5	3.94	0.26	12.61
108.0	13.6	3.9	19.5	3.93	0.27	13.10
120.0	13.9	4.2	21.0	3.92	0.28	13.60
132.0	14.1	4.4	22.0	3.91	0.29	14.07
144.0	14.3	4.6	23.0	3.89	0.31	15.05
168.0	14.7	5.0	25.0	3.85	0.35	17.00
192.0	14.9	5.2	26.0	3.82	0.38	18.45
216.0	15.2	5.5	27.5	3.78	0.42	20.40
240.0	15.6	5.9	29.5	3.75	0.45	21.85
264.0	15.8	6.1	30.5	3.74	0.46	22.30
288.0	16.3	6.6	33.0	3.73	0.47	22.80

TABLE 11. (cont.)

Elapsed Time Hours	Strain Gage Readings: Strain Gage Readings Thousandths In.	Strain Gage Readings: Change In Strain Gage Readings Thousandths In.	Strain Gage Readings: Unit Elongation Micro-Inches/In	Overall Elongation: Scale Readings Inches	Overall Elongation: Change Of Scale Readings Inches	Overall Elongation: Overall Elongation Thousandths In.
312.0	16.4	6.7	33.5	3.73	0.47	22.80
336.0	16.7	7.0	35.0	3.70	0.50	24.25
360.0	16.9	7.2	36.0	3.68	0.52	25.23
384.0	17.1	7.4	37.0	3.66	0.54	26.20
408.0	17.3	7.6	38.0	3.65	0.55	26.70
432.9	17.5	7.8	39.0	3.62	0.58	27.50
456.0	17.5	7.8	39.0	3.66	0.54	26.20
480.0	18.0	8.3	41.5	3.65	0.55	26.70
504.0	18.4	8.7	43.5	3.64	0.56	27.18

Test in Progress.

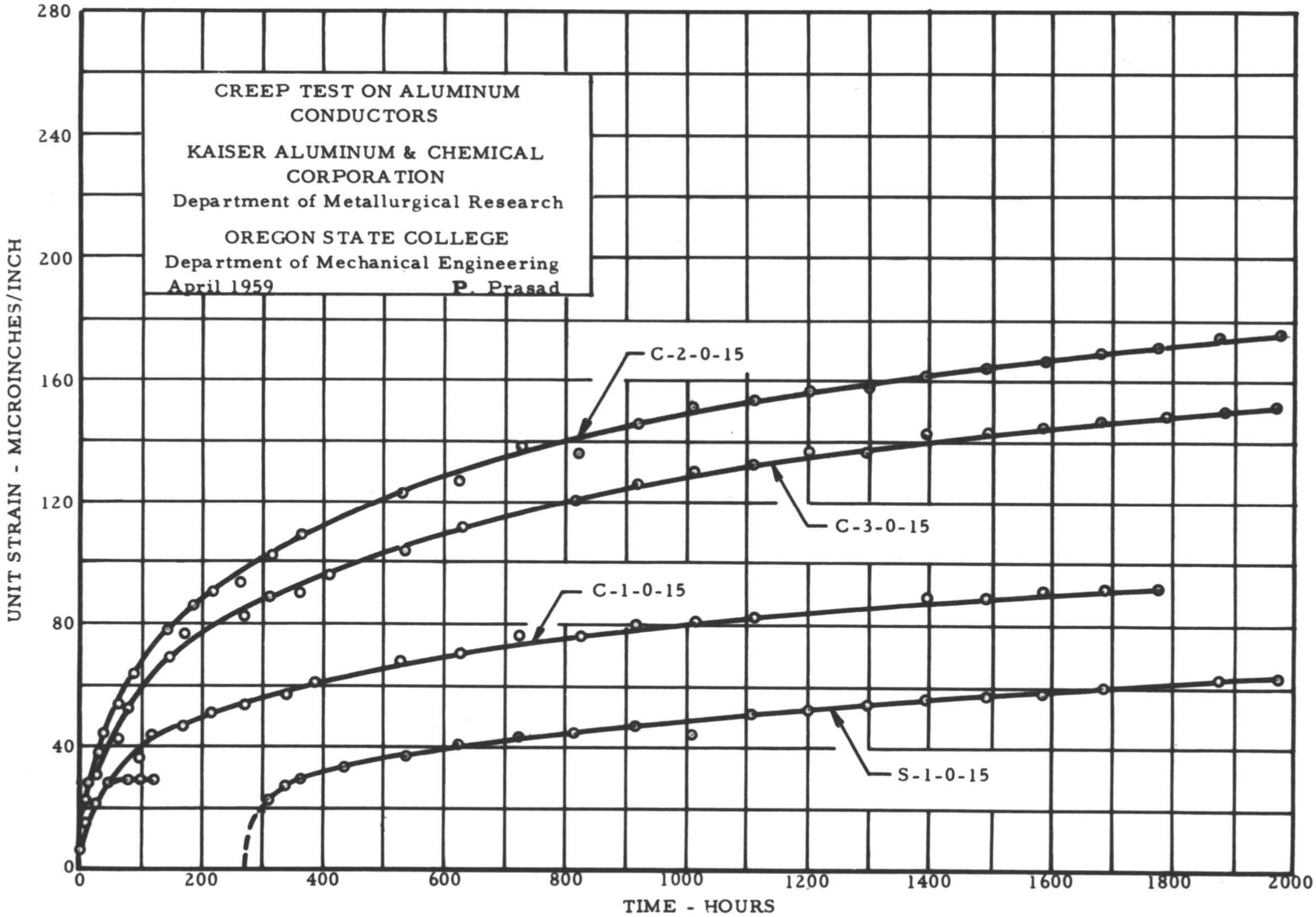

Figure 7. Creep Curves

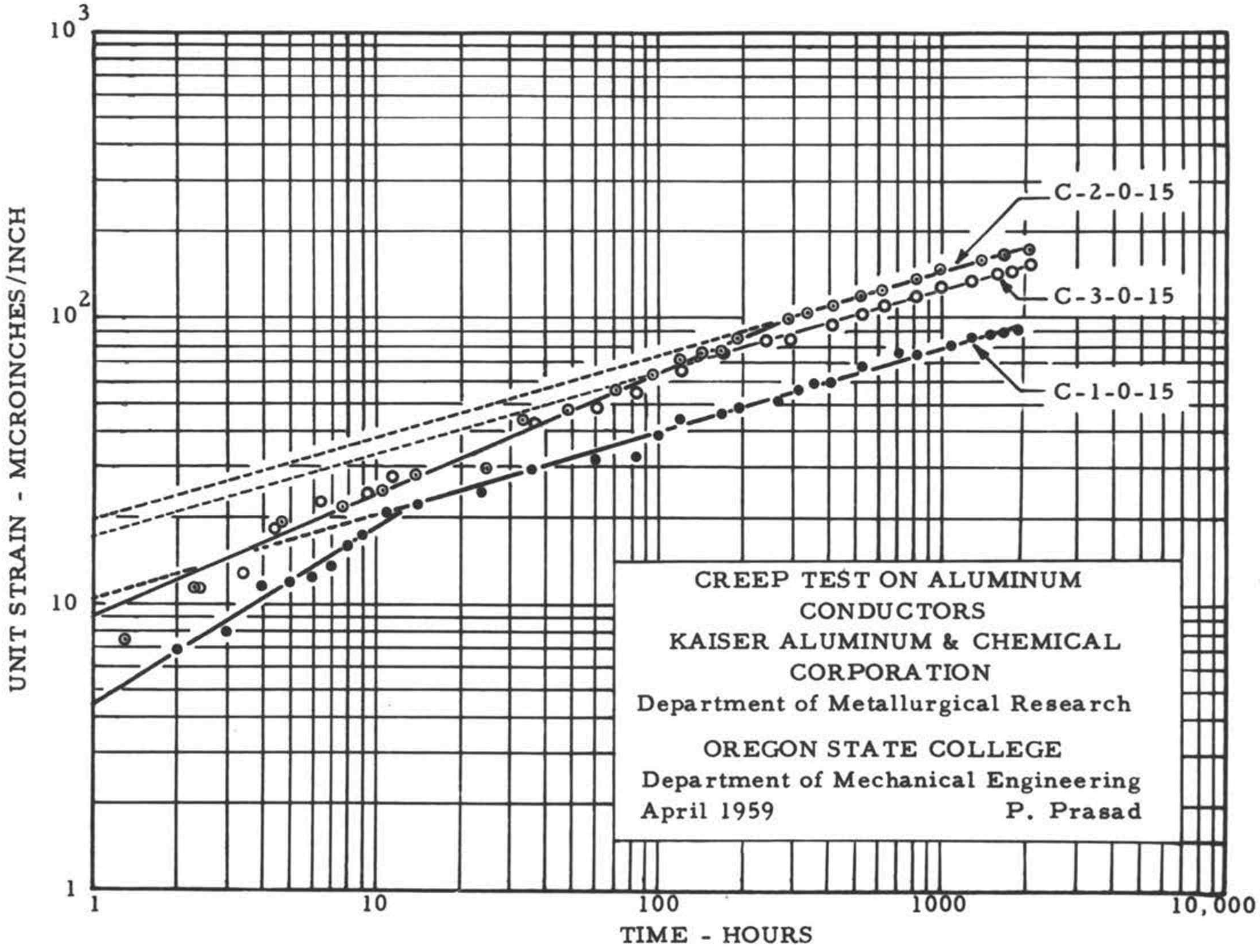

Figure 8. Creep Curves Plotted on Log Strain vs Log Time Coordinates

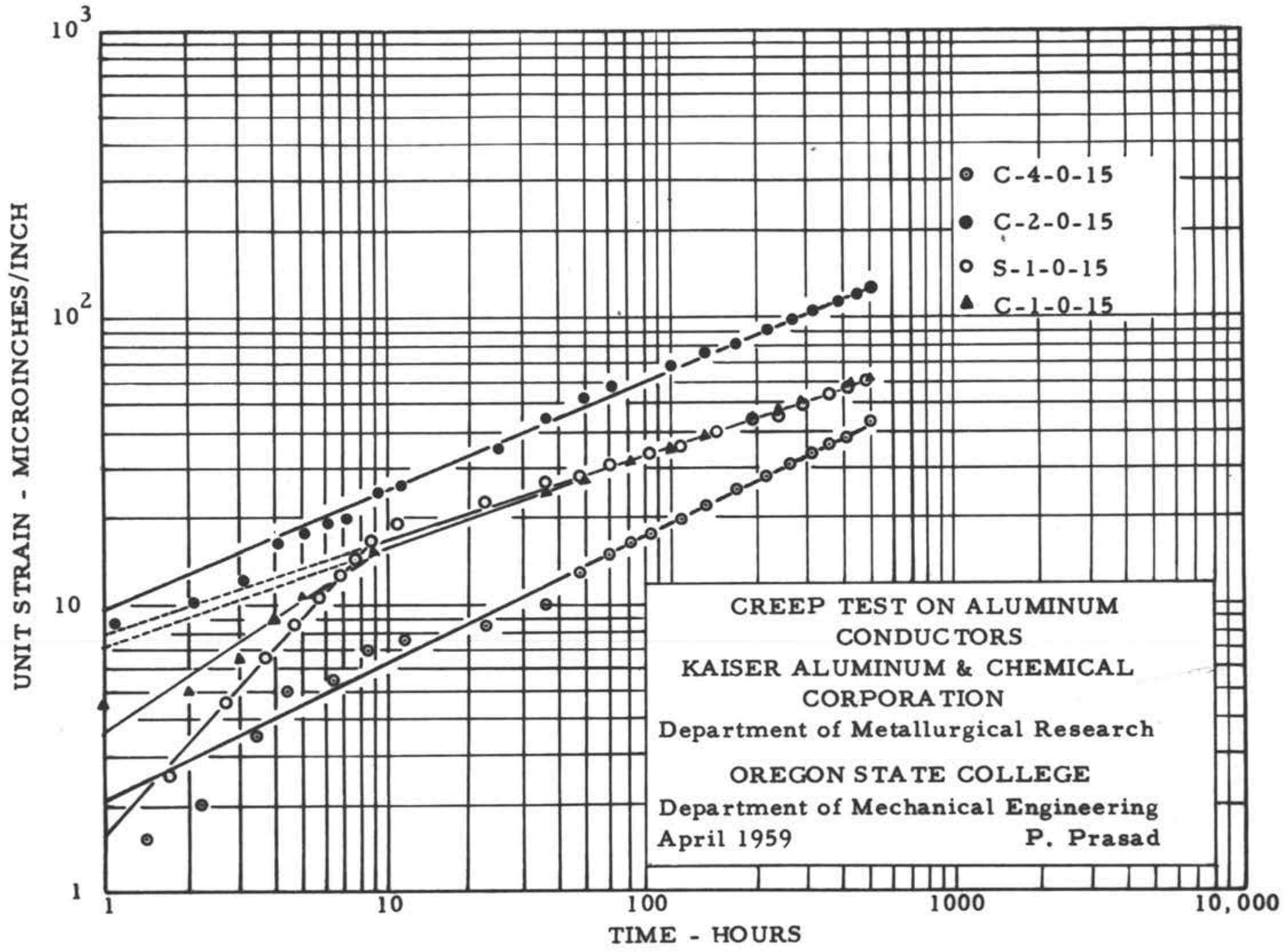

Figure 9. Creep Curves Plotted on Log Strain vs Log Time Coordinates

TABLE 12.

SUBJECT: Load Calibration COLUMN 1

BY: Prem Prasad DATE: November 23, 1958

GENERAL DATA: Standard - Baldwin SR 4 Load Cell - Type U-1C

1200 lb. Capacity and SR 4 Calibration Indicator

Tension Load in Pounds = 0.201 x (R + C)

Load On Weight Box End Of The Lever x lb.	Tension On Rope (x Increasing) y_1 lb.	Tension On Rope (x Decreasing) y_2 lb.	$(y_1 + y_2)$ T	$\frac{(y_1 + y_2)}{2}$ $\bar{y}$
Lever	443	442		
Lever+Box+0	683	677	1360	680
L+B+5	776	773		
L+B+10	866	866		
L+B+15	963	964		
L+B+20	1042	1044		
L+B+25	1158	1158		
L+B+50	1668	1656	3324	1662
L+B+100	2634	2630	5264	2632
L+B+150	3622	3600	7222	3611
L+B+200	4608	4578	9186	4593
L+B+250	5578	5546	11124	5562
L+B+300	6563	6531	13094	6547
L+B+350	7552	7520	15072	7536
L+B+400	8526	8526	17052	8526

Load Calibration equation by statistical analysis

Regression of y on x $y_x = 675.2 + 19.6\,x$

TABLE 13.

SUBJECT: Load Calibration COLUMN 2

BY: Prem Prasad DATE: November 25, 1958

GENERAL DATA: Standard - Baldwin SR 4 Load Cell - Type U-1C

1200 lb. Capacity and SR 4 Calibration Indicator

Tension Load in Pounds = 0.201 (R ≠ C)

Load On Weight Box End Of The Lever x lb.	Tension On Rope (x Increasing) y_1 lb.	Tension On Rope (x Decreasing) y_2 lb.	$(y_1 \neq y_2)$ T	$\frac{(y_1 \neq y_2)}{2}$ $\bar{y}$
Lever	428	426		
Lever ≠ Box ≠ 0	649	668	1317	658.5
L≠B≠5	764	764		
L≠B≠10	860	861		
L≠B≠15	957	958		
L≠B≠20	1053	1053		
L≠B≠25	1150	1150		
L≠B≠50	1651	1653	3304	1652.0
L≠B≠100	2628	2631	5259	2629.5
L≠B≠150	3630	3618	7248	3624.0
L≠B≠200	4602	4598	9200	4600.0
L≠B≠250	5588	5582	11170	5585.0
L≠B≠300	6574	6579	13153	6576.5
L≠B≠350	7555	7541	15096	7548.0
L≠B≠400	8530	8530	17060	8530.0

Load calibration equation by statistical analysis

Regression of y on x $y_x = 665 \neq 19.68\ x$

TABLE 14.

SUBJECT: Load Calibration COLUMN 5

BY: Prem Prasad DATE: December 5, 1958

GENERAL DATA: Standard - Baldwin SR 4 Load Cell - Type U-1C

12,000 lb. Capacity and SR 4 Calibration Indicator

Tension Load in Pounds = 0.201 (R + C)

Load on Weight Box End Of The Lever x lb.	Tension On Rope (x Increasing) y_1 lb.	Tension On Rope (x Decreasing) y_2 lb.	$(y_1 + y_2)$ T	$\frac{(y_1 + y_2)}{2}$ $\bar{y}$
Lever	470	470		
Lever+Box+0	695	694	1389	694.5
L+B+5	792	793		
L+B+10	893	896		
L+B+15	991	988		
L+B+25	1188	1188		
L+B+50	1688	1733	3421	1710.5
L+B+100	2701	2705	5406	2703.0
L+B+150	3710	3707	7417	3708.5
L+B+200	4712	4710	9422	4711.0
L+B+250	5716	5712	11428	5714.0
L+B+300	6719	6716	13435	6717.5
L+B+350	7721	7715	15436	7713.0
L+B+400	8722	8722	17444	8722.0

Load calibration equation by statistical analysis

Regression of y on x $y_x = 699.86 + 20.056\ x$

TABLE 15.

STATISTICAL ANALYSIS OF LOAD CALIBRATION DATA

Sample Calculations for Column 1

x	0	50	100	150	200	250	300	350	400
Obs. y	683 677	1668 1656	2634 2630	3622 3600	4608 4578	5578 5546	6763 6531	7552 7520	8526 8526
T	1360	3324	5264	7222	9186	11124	13094	15072	17052
$\bar{y}$	680	1662	2632	3611	4593	5562	6547	7536	8526
M	-4	-3	-2	-1	0	+1	+2	+3	+4

$$\Sigma y = 82698$$

$$\bar{\bar{y}} = \frac{\Sigma y}{n} = 4594.3333$$

$$(\Sigma y)^2 = 6838959204$$

$$\Sigma T^2 = 990280252$$

$$\Sigma y^2 = 495142452$$

TABLE 16a

Type of Total	Sum of Squares of Totals	No. of Totals Squared	No. of Observations per Total	Sum of Squares per Observations
Grand	6838959204	1	18	379942178
Load	990280252	9	2	495140126
Observation	495142452	18	1	495142452

TABLE 16b

Analysis of Variance

Test of Linearity of Regression of Actual Load

on Cable (y) on Load in Box (x)

Source of Variation	D.F.	Sum of Squares	Mean Square	F
Load	8	115197948		
Linear Regression	1	115197948		
Deviation from Linearity	7	902	129	0.49
Error	9	2326	258	

<u>Results:</u> Computations shown on the foregoing pages show that F with 7 and 9 degrees of freedom comes equal to 0.49, which is not significant.

Conclusion: The conclusion is that the regression of y on x is linear, ie the relation between the actual loads and load in the weight box is linear.

The constants 'a' and 'b' in the equation $y_x = b_x$ are determined as follows.

$$\bar{\bar{y}} = 4594.333$$

$$\Sigma MT = 117574$$

$$\Sigma M^2 = 6000$$

$$\bar{\bar{x}} = 200$$

$$\therefore \quad b = \frac{(50)^2 (\Sigma MT)^2}{2(\Sigma M^2)\ (50)^2}$$

$$= 19.595666$$

$$\therefore \quad a = 4594.333 - 200\ (19.595666)$$

$$= 675.200133$$

$$\therefore \quad y_x = 675.2 - 19.6\ x$$

Similarly, it can be shown for the rest of the columns.

TABLE 17.

STATISTICAL ANALYSIS FOR CHECKING THE RELIABILITY OF LOAD CALIBRATION

Col. 1	x	0	50	100	150	200	250	300	350	400	350	300	250	200	150	100	50	0
	y	683	1668	2634	3622	4608	5578	6563	7552	8526	7520	6531	5546	4578	3600	2630	1656	677
	y	985	966	988	986	970	985	989	974	0	1006	989	985	968	978	960	974	979
Col. 2	x	0	50	100	150	200	250	300	350	400	350	300	250	200	150	100	50	0
	y	649	1651	2628	3630	4602	5588	6574	7555	8530	7541	6579	5582	4598	3618	2631	1653	668
	y	1002	977	1002	972	986	986	981	975	0	989	962	997	984	980	987	978	985
Col. 5	x	0	50	100	150	200	250	300	350	400	350	300	250	200	150	100	50	0
	y	695	1688	2701	3710	4712	5716	6719	7721	8722	7715	6716	5712	4710	3707	2705	1733	694
	y	993	1013	1009	1002	1004	1003	1002	1001	0	1007	999	1004	1002	1003	1002	972	1039

CALCULATIONS

COLUMN 1

$\Sigma(\Delta y)^2 = 15426250$

$$s_b^2 = \frac{1}{(x\ max. - x\ min.)}\ \frac{1}{2\ (n-1)} \left\{ \frac{\overset{16}{\Sigma}\ (\Delta y)^2}{x\ interval} - \frac{(y\ max. - y_\circ)^2}{x\ max. - x\ min.)} - \frac{(y\ max. - y_\circ)^2}{x\ max. - x\ min.} \right\}$$

Where s_b = standard deviation

2n = number of y values = 16

$$s_b^2 = \frac{1}{400} \times \frac{1}{14} \left\{ \frac{15426250}{50} - \frac{61502649}{400} - \frac{61566701}{400} \right\}$$

$= 0.152$

$s_b = 0.387$

$$b = \frac{y\ max. - y\ min.}{x\ max. - x\ min.} = \frac{7522 - 677}{400} = 19.625 \quad \text{slope of the regression equation.}$$

$$\therefore \frac{2s_b}{b} = \frac{0.774}{19.625} = 3.94\%$$

The error in the estimated value of the constant 'b' is 3.94%

COLUMN 2

$\overset{16}{}\ (\Delta y)^2 = 15491802$

$$s_b^2 = \frac{1}{400} \times \frac{1}{14} \left\{ \frac{15491802}{50} - \frac{123920805}{400} \right\}$$

CALCULATIONS (cont.)

COLUMN 2 (Cont.)

$s_b^2 = 0.00607$

$\therefore \quad s_b = 0.0778$

$\therefore \quad b = 19.679$

$\therefore \quad \frac{2s_b}{b} = \frac{0.1556}{19.679} = 0.79\%$

The error in the estimated value of the constant 'b' is 0.79%

COLUMN 5

$\sum^{16} (\Delta y)^2 = 16112721$

$\therefore \quad s_b^2 = \frac{1}{400} \times \frac{1}{14}\left\{\frac{16112721}{50} - \frac{12881543}{400}\right\}$

$= 0.00898$

$\therefore \quad s_b = 0.0946$

$b = 20.069$

$\therefore \quad \frac{2s_b}{b} = \frac{0.1892}{20.069} = 0.94\%$

The error in the estimated value of the constant 'b' is 0.94%

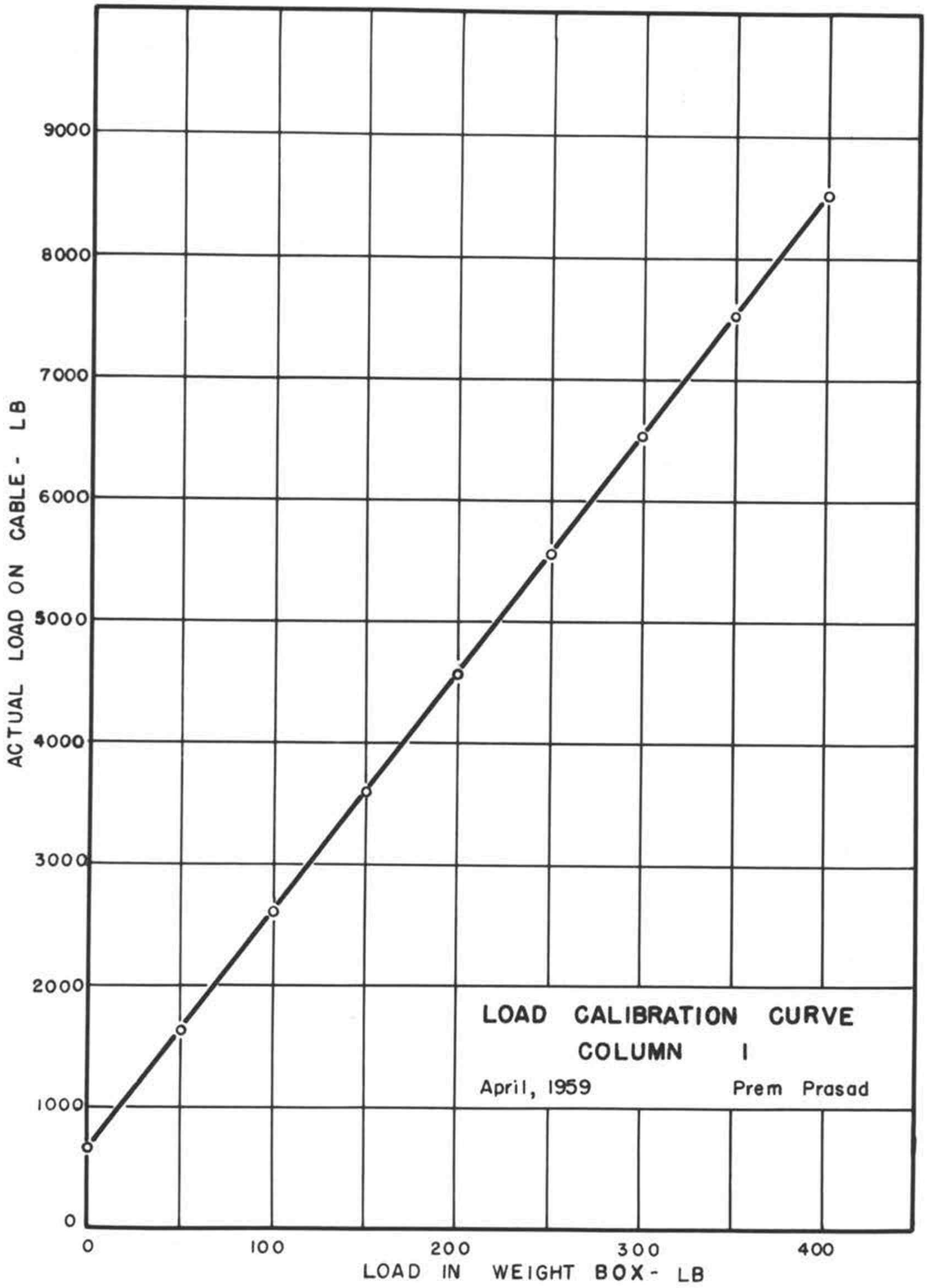

Figure 10. Load Calibration Curve

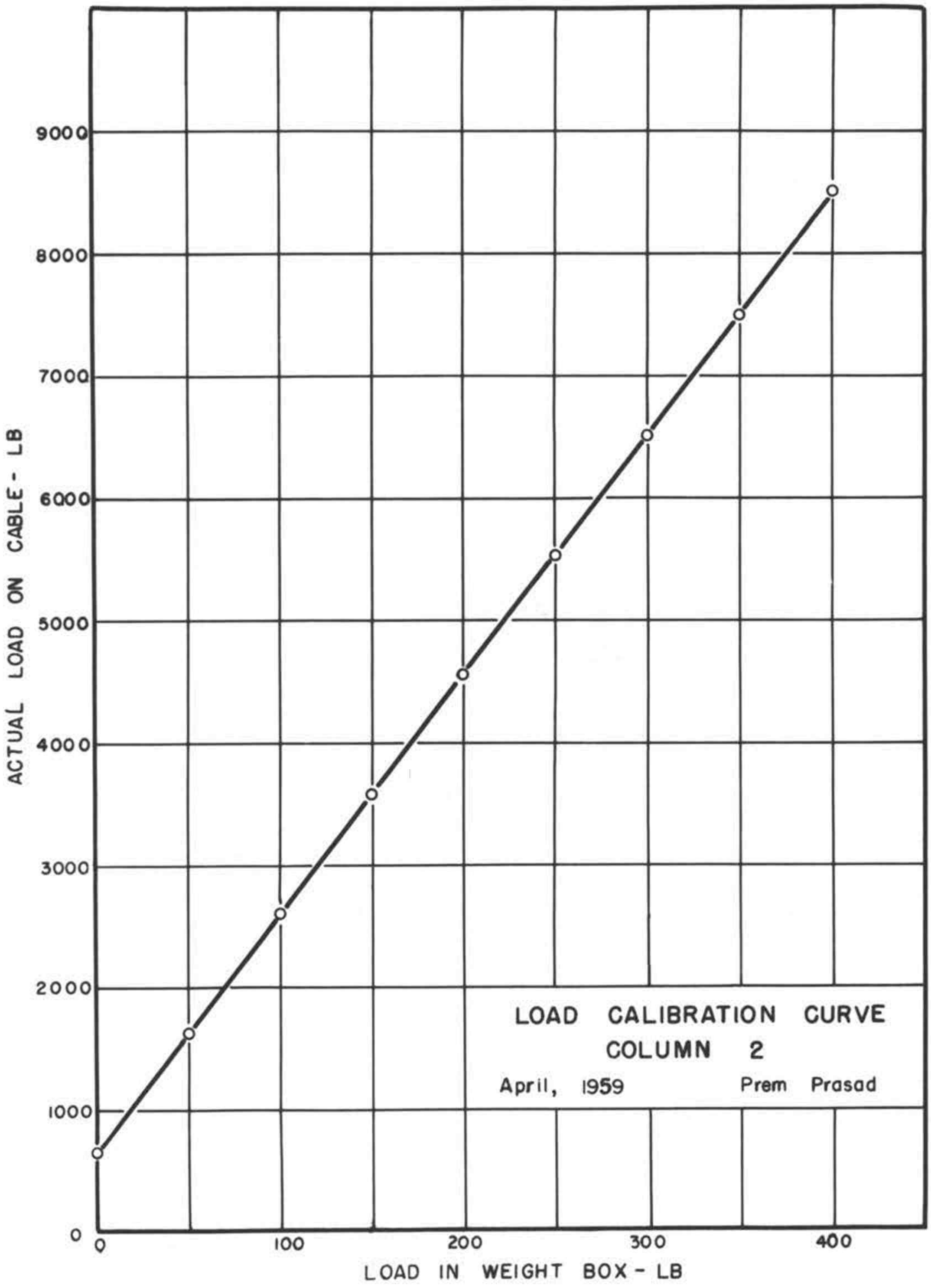

Figure 11. Load Calibration Curve

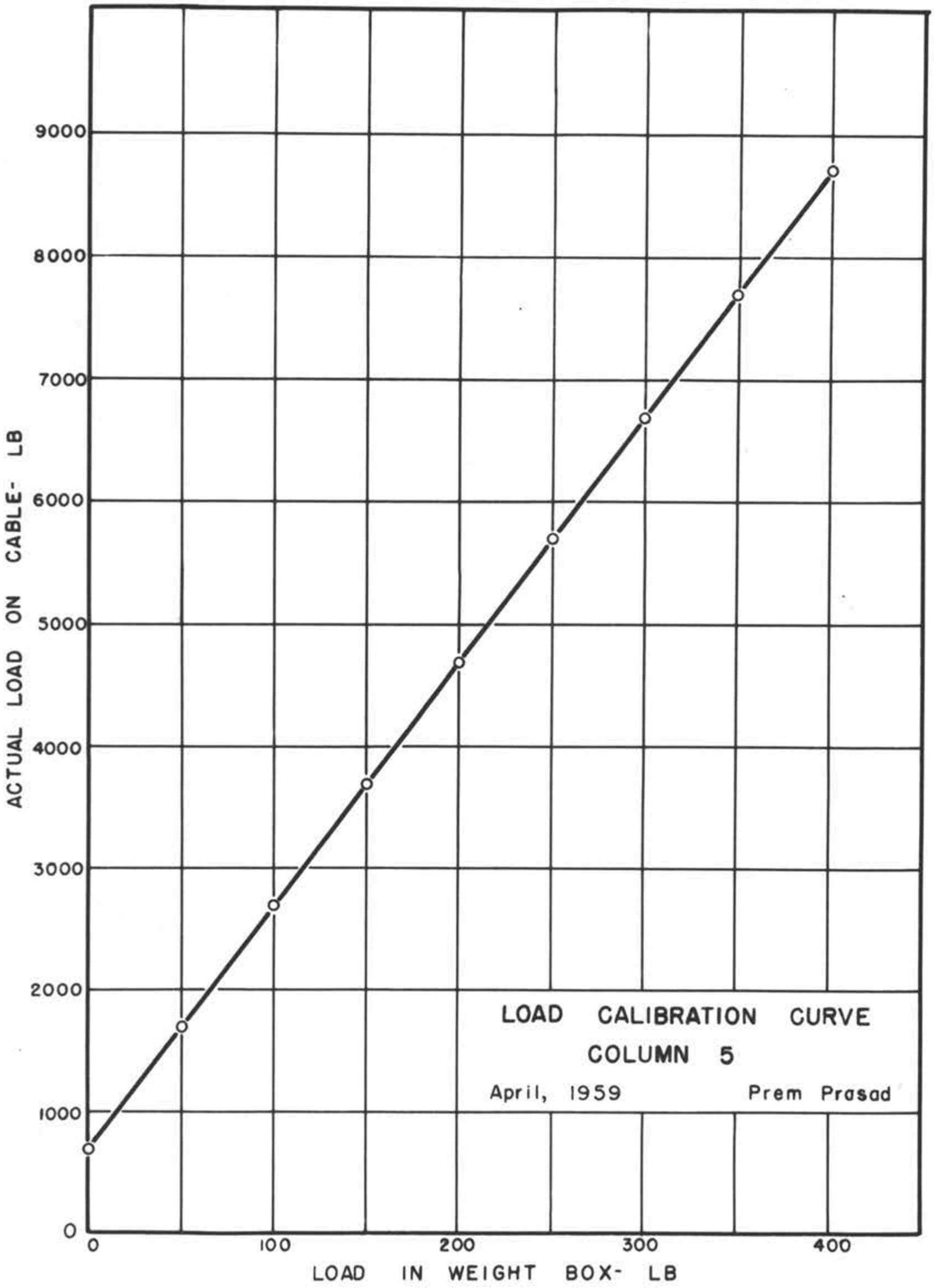

Figure 12. Load Calibration Curve