Apparatus and Instrumentation for Creep and Shrinkage Studies

BERNARD L. MEYERS and ADRIAN PAUW, University of Missouri

With the rapid development of concrete technology during the past two decades, longer concrete bridge spans have become feasible as a result of increased permissible working stresses, by developing structural continuity through composite construction and by prestressing. As a result of these technological changes, new problems have arisen which previously were of only minor consequence. Among the more important are the volume changes resulting from creep and shrinkage of concrete.

In September 1959, the University of Missouri Engineering Experiment Station initiated a cooperative research project with the Missouri State Highway Commission and the Bureau of Public Roads to investigate the basic nature of creep and shrinkage and the effects of these volume changes on deflection and strength of reinforced concrete bridges. Eventually, it is hoped that from analysis and test results, design criteria can be developed which will enable the engineer to predict such deflections and thereby control them within reasonable limits.

SELECTION OF SPECIMENS

• THE initial stage of the experimental program was designed to obtain information concerning the effect of variation of the concrete constituents, the intensity and duration of load, the environment, and the geometry of the specimens. The variables selected for consideration were (a) size, (b) shape, (c) length, (d) stress intensity, (e) curing conditions, (f) water-cement ratio, (g) type of aggregate, (h) mix proportions (gradation, consistency, admixtures), (i) time of load application, (j) environmental conditions (temperature, humidity), and (k) reinforcement (normal, prestressed).

To study all these variables in a reasonable period of time, specimens which could be cast quickly and would be adaptable to instrumentation were needed. Other important considerations were concerned with the placement of reinforcement. It was felt that the effect of reinforcing should be studied using the same specimen as that used for the other variables. Rectangular prisms were selected because they seemed to fit these requirements better than standard 6- × 12-in. cylinders[1]. Such prisms can be conveniently cast in large quantities on specially constructed casting beds. Other advantages of the prismatic specimen are: instrumentation can be readily affixed to the flat surfaces, specimens need not be capped, and they can be easily stored.

Figure 1 shows a 40-specimen casting bed. The forms consist of slotted steel plate sides into which the desired number of spacer plates are placed. The concrete is cast and finished using a vibrating screed. The bed can make reinforced specimens by using different forms (Fig. 2).

Paper sponsored by Committee on Bridges.

[1] Cylinder-Prism Strength and Elastic Modulus Correlation Study, letter report submitted to the Missouri State Highway Commission and the Bureau of Public Roads.

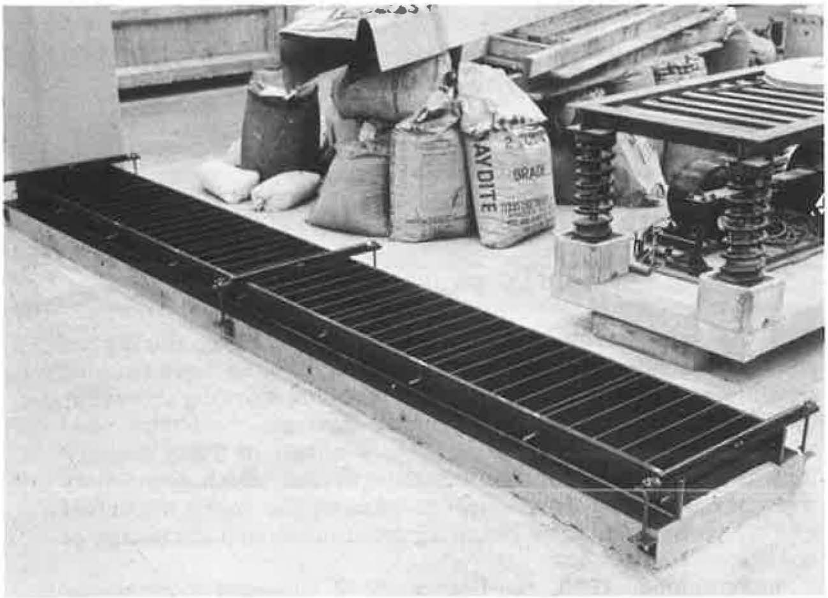


Figure 1. Casting bed.

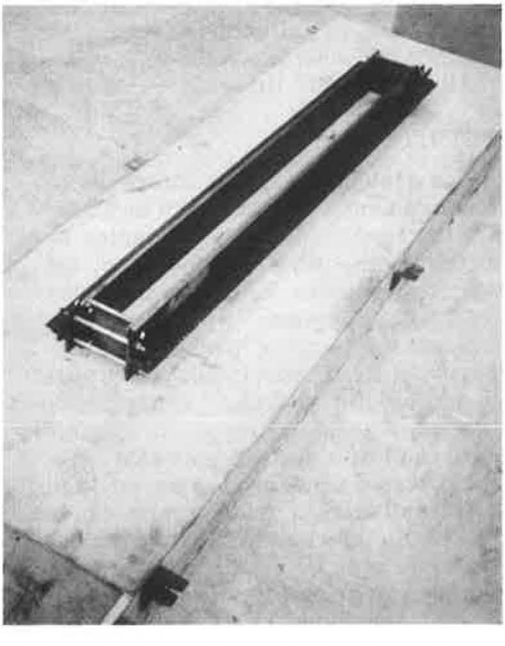


Figure 2. Form for reinforced specimen.

To determine the statistical reliability of the prism specimen, modulus of elasticity and strength tests were carried out using nine sets of prisms and standard 6- × 12-in. companion cylinders. The decision to use the prism for all experimental work on this project was based on an analysis of the data obtained in these tests.

LOADING REQUIREMENTS

Because creep and shrinkage of concrete are time-dependent variables, it was necessary to develop loading systems that would apply and maintain a constant load over a long period of time. These systems must be similar to a testing machine during the application of load, because data must be obtained to determine the elastic properties of the specimen while it is being placed under load. The loading systems should also permit the application of a concentric load, because volume changes are measured in terms of strain in both the longitudinal and the lateral directions.

In addition to the above requirements, the system should permit loading or unloading of any number of individual specimen groups without disturbing the other specimens under load. Finally, because it is desirable to perform the tests in a controlled temperature and humidity environment, the loading system should be as compact as possible.

LOADING SYSTEMS

A hydraulic loading system and a spring loading system were developed to accomplish these objectives. In the hydraulic system, the load is applied by oil pressure, and in the spring system, the load is applied by large nested springs. Each system will be considered separately and described in detail.

The Hydraulic Loading System

The hydraulic system permits a large number of specimens to be loaded quickly. The basic system consists of a motor, an oil-injection pump, an accumulator, a pressure-control system, pressure cells and associated plumbing, and loading frames. A schematic diagram of the system is shown in Figure 3.

A loading rack can accommodate a stack of three 16-in. long specimens or a single specimen up to 60 in. in length. The load is applied at the lower end of the rack by the floating circular plate of the pressure cell. A fully loaded frame consisting of six racks is shown in Figure 4. Castings machined to finished dimensions are used for the body of the pressure cells as shown in Figure 5. Oil is pumped under pressure through flexible hosing to each pressure cell and the loading pressure is transmitted to the floating plate through a rubber piston cup. The reaction is provided by high-strength steel tension rods and cold-rolled flat steel plates.

A fuel-injection pump, driven intermittently by a small ¼-hp gear-head motor (Fig. 6), is used to pump oil under pressure to the pressure cells. A 2½- gal hydraulic accumulator is used to maintain constant pressure between pumping cycles. The pumping system is regulated to increase the pressure when leakage causes a 10-psi drop in the load. The regulator is shown in Figure 7.

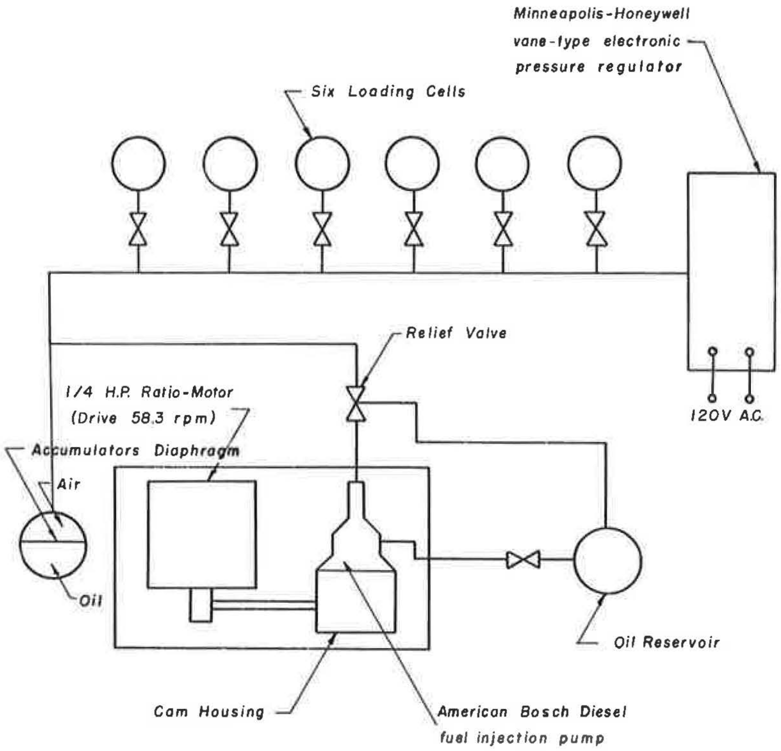


Figure 3. Hydraulic loading system.

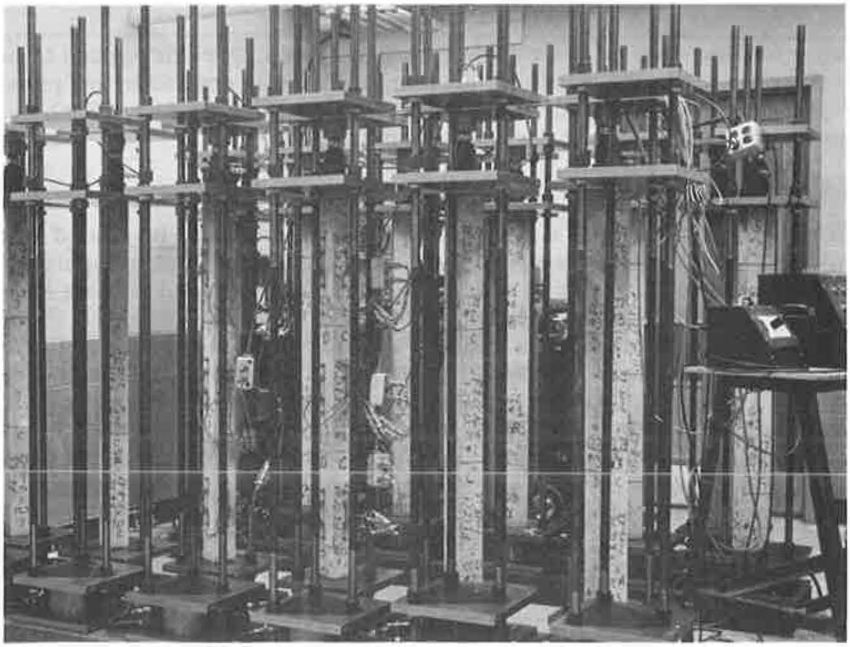


Figure 4. Loading frame.

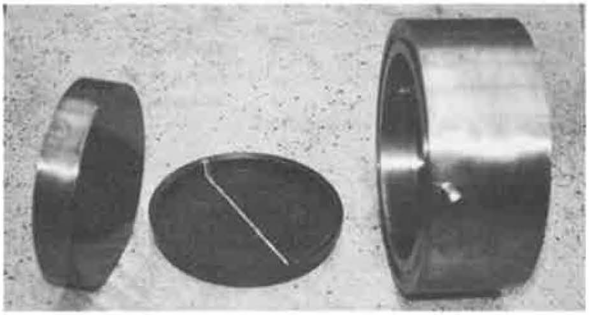


Figure 5. Pressure cell.

It is usually impractical to load a complete frame in a single operation. Therefore, a series of shut-off valves have been provided to permit cutting individual racks off the main pressure line while loading or unloading the other racks.

The system is equipped with a number of safety features designed to prevent overloads or pressure losses in case of specimen failure. A safety plate is provided above the floating plate of the pressure cell and immediately below the lower specimen. Three high-strength nuts, set with enough clearance above the safety plate, allow for normal volume changes. In case of a specimen failure, the load is transferred to these nuts. Thus, other loaded specimens are unaffected by the failure. A second safety feature is a pressure-relief valve to shut off the system should the control mechanism break down and the pressure become dangerously high. In over a year of continuous operation, neither of the safety devices was needed.

In loading, the specimens are centered in the rack using scribe lines on the upper and lower plates. The load-measuring device, which is placed on a floating plate

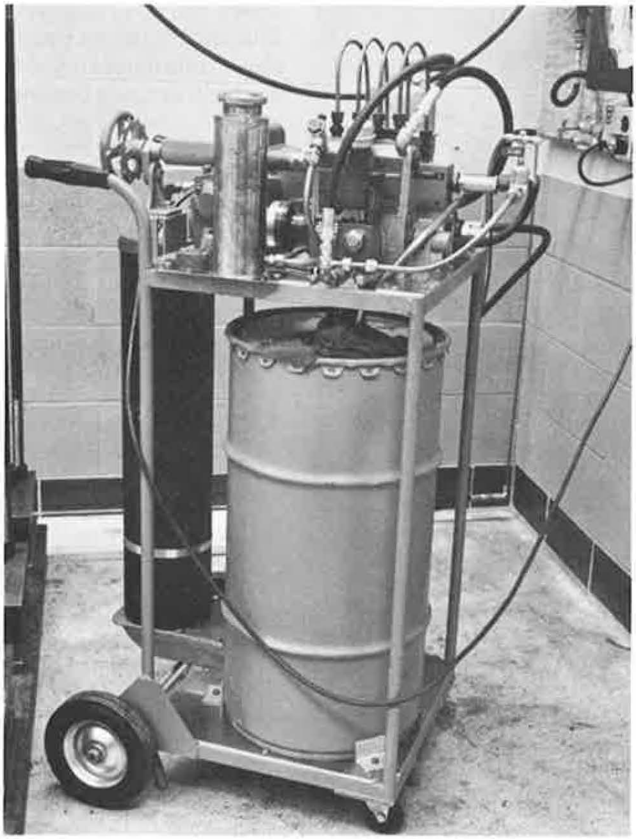


Figure 6. Pumping system.

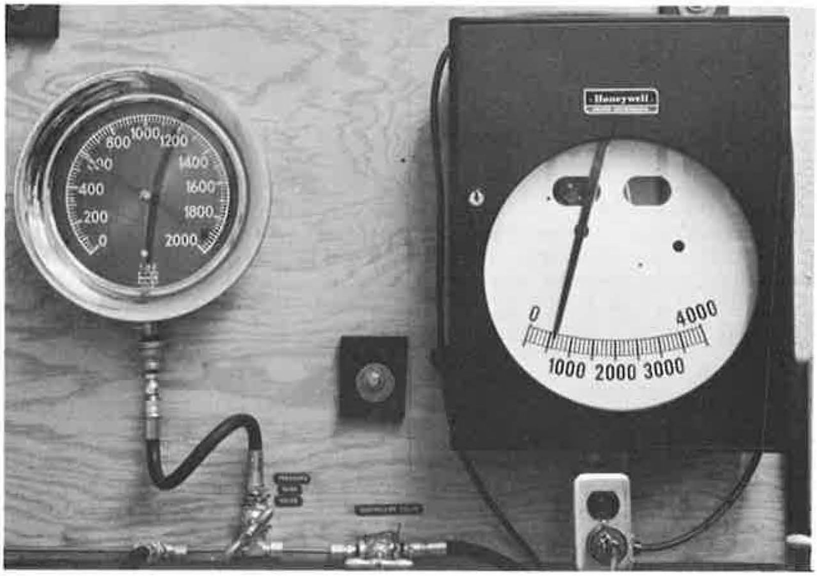


Figure 7. Control system.

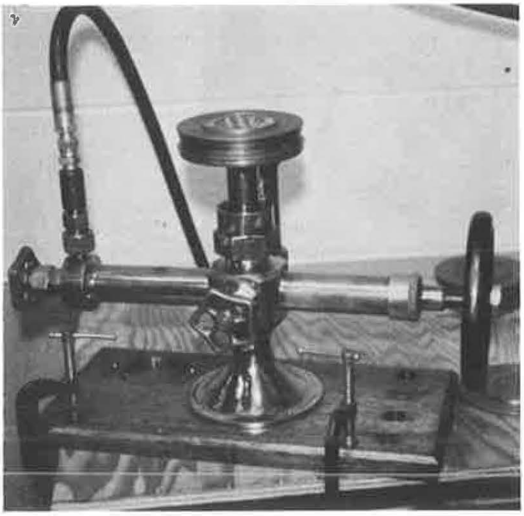


Figure 8. Dead-weight gage tester.

above the specimens, contains a ball seat. Therefore, when properly centered, the upper plate applies a uniform load to the surface of the specimen. As the load is applied, a number of strain readings are taken. If the strain-reading increments are unequal, indicating eccentricity, the specimens are re-centered and the procedure is repeated. The final load is applied in 50-psi increments using a dead-weight gage tester (Fig. 8). Because the specimens have been preloaded at least twice, the stress-strain curve is almost a straight line.

The Spring Loading System

The spring system was designed to load specimens in the field. The nested springs used were tested and calibrated. In calibrating the springs, load was applied with a mechanical testing machine and deflection of the springs was recorded using a 4-in. dial gage.

The load is applied to the specimen by placing a hydraulic jack between the two steel plates at the upper end of the rack (Fig. 9). The load is measured with a load cell placed between the floating plate above the specimen and the plate below the jack. The preloading procedure is also used in this system. When the final load has been applied, high-strength nuts are tightened down on the plate above the load cell and the hydraulic jack is removed (Fig. 10). A safety plate similar to the one used with the pressure cells is used above the springs.

The loading systems described are similar to the one recommended in an ASTM publication (4). A comparison of the two systems is shown in Figure 11.

INSTRUMENTATION REQUIREMENTS

The volume changes caused by creep and shrinkage are measured in terms of lateral and longitudinal strain. The requirements suggested by ASTM for measuring such strains are summarized.

> Suitable apparatus shall be provided for measurement of longitudinal strain in the specimen to the nearest 10 micro-in. The apparatus may be embedded, attached, or portable.... The gages may be instrumented so that the average strain on all gage lines may be read directly.... The prime requirement of the strain measuring device is that it shall be capable of measuring strains for at least one year without change in calibration. Systems in which the varying strains are compared with a constant-length standard bar are considered most reliable, but unbonded electrical strain gages are satisfactory.

In addition to measuring the strains, it is also desirable to monitor the load, especially for specimens in the spring-loaded frames. A special load-measuring device, employing strain gages mounted on a prestressed sleeve, was developed for this purpose.

THE CLIP-ON STRAIN METERS

The clip-on strain meter (Fig. 12) is essentially a two-link mechanism joined by thin flexure elements which simulate hinges. Thus, the action of the instrument may be considered to be that of a three-hinged arch. The center hinge (the reduced section) is the strain-sensing element. The effective gage length is determined by the center-to-center distance of the gage points on which the instrument is mounted. The relative movement of these points rotates the center hinge by an amount proportional to the strain in the specimen. The bending strains induced by the rotation are measured by SR-4 strain gages attached to the upper and lower faces of the center hinge.

Because most of the measured strains are compressive and might cause buckling of the strain-sensing element, a pretensioning screw was incorporated into the instrument. After the meter is attached to the specimen, a screw is tightened to pretension the instrument and subject it to a tensile force throughout the test.

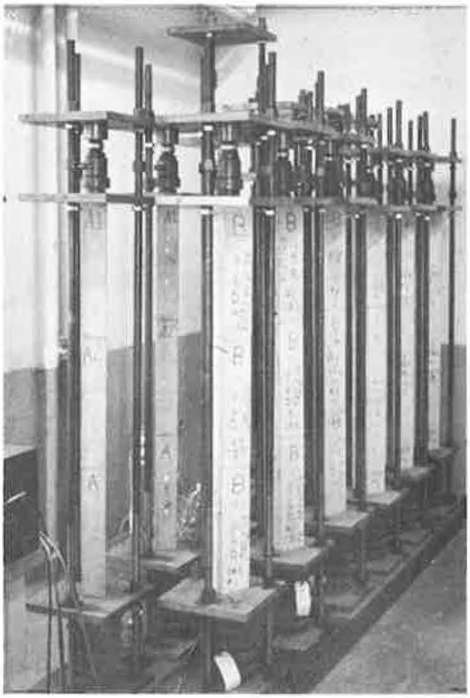


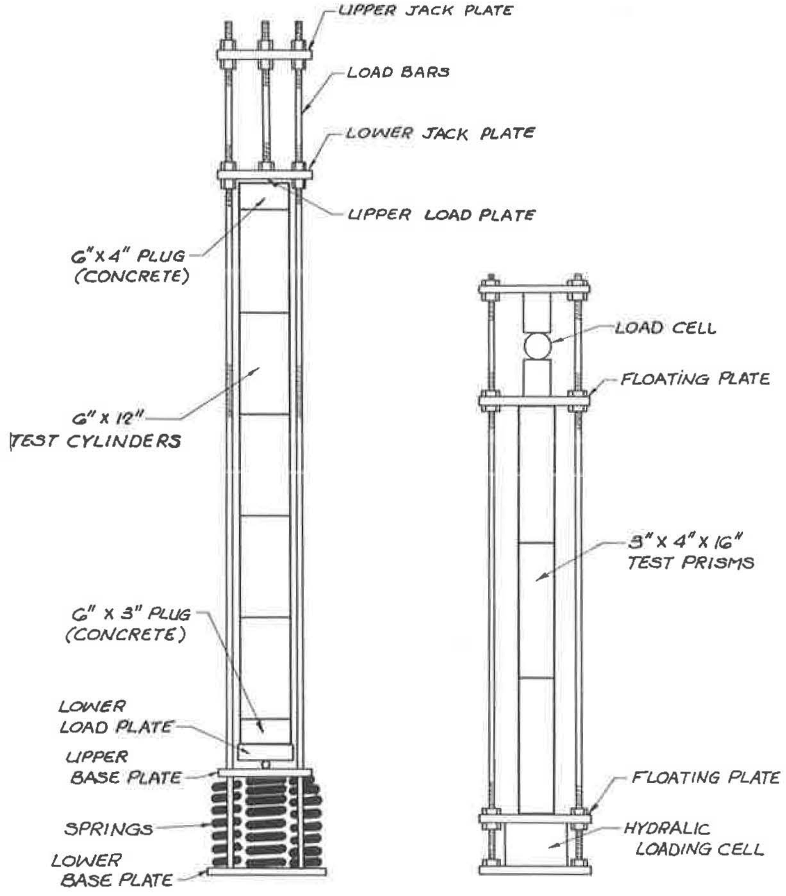
Figure 10. Spring-loaded frame.

Figure 9. Hydraulic jack used in spring-loading system.

The meter is constructed of 24S-T aluminum and requires the use of only two machines — a milling machine and a drill press. The SR-4 gages are cemented to the strain-sensing element and a laminated fiberglass terminal board with three copper eyelets is provided to make electrical connection between the strain gage lead wires and the main lead wires.

The strain meter is attached to the specimen by means of steel connecting posts which serve as the gage points (Fig. 13). The posts are cemented to the specimen using a strong adhesive and are positioned with a special mounting jig. The meter is pushed down firmly on the connecting posts after the adhesive has hardened. Clamp nuts are then threaded onto the posts and run down against the ends of the strain meter. The clamp nuts are tapered slightly to fit into beveled holes in the meter thereby preventing rotation of the ends of the strain meter.

Some of the major advantages of the instrument are derived from the fact that the SR-4 gages are attached to both faces of the strain-sensing element. Rotation of this element produces tension on one face and compression on the other. This design feature automatically compensates for changes in gage resistance due to tem-



ASTM LOADING FRAME MISSOURI LOADING FRAME

Figure 11. ASTM loading frame and Missouri loading frame.

perature variations, and because both gages are active, the sensitivity of the instrument is doubled.

An additional advantage is obtained by wiring the two clip-on strain meters in a bridge circuit on opposite faces of the specimen. In this way, the readings of the two meters are automatically averaged, eliminating the bending strain component.

The strain meter is calibrated with the instrument shown in Figure 14. The motion of the tapered floating gage block relative to the fixed block is measured by means of a dial gage. The calibration is performed by recording 20 strain-meter readings at 100 micro-in. displacement increments as measured by the dial gage. The strain-meter output is linear to an accuracy of ±2% within a range of 200 micro-in. per in.

THE LONGITUDINAL EXTENSOMETER

Because of the large number of variables studied in this program, it became necessary to develop a strain-measuring device to supplement the clip-on strain meter. It was felt that the reliability of the clip-on meter should be incorporated into a portable instrument.

In the instrument shown in Figure 15, one end of a clip-on strain meter is attached to a fixed-end block and the other to a floating-end block. The gage points attached to the specimen consist of small ball bearings swedged into small aluminum discs. Dur-

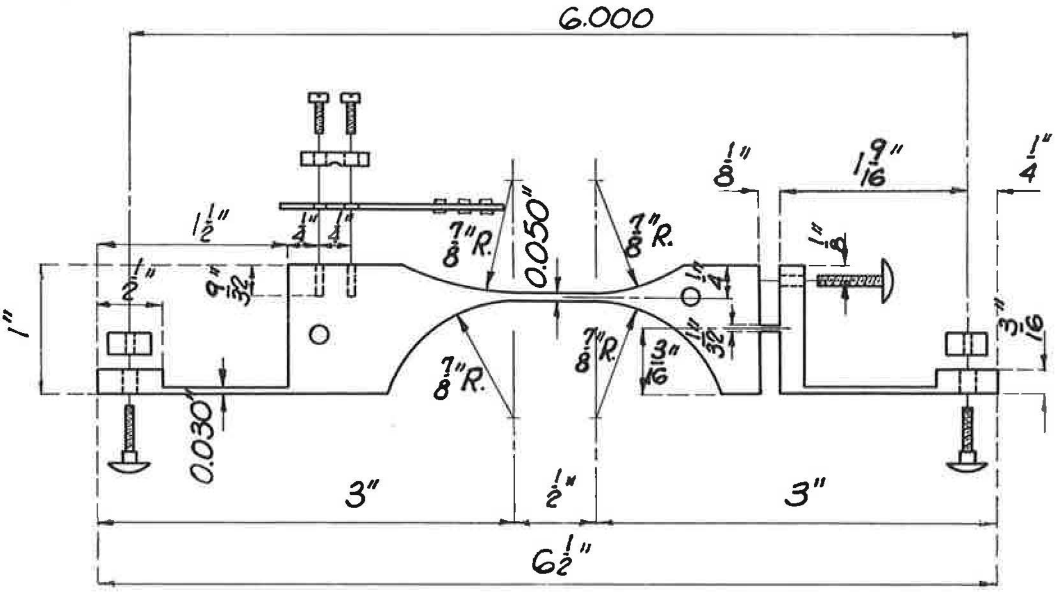


Figure 12. Clip-on strain meter.

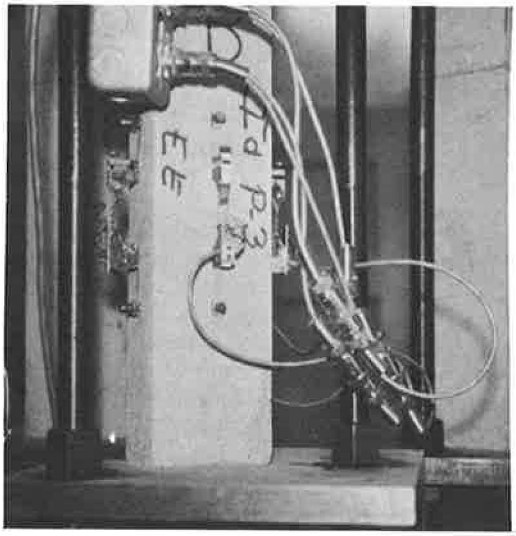


Figure 13. Clip-on strain meter attached to specimen.

ing the use of the instrument, these balls fit into holes drilled into tapered studs threaded into the end blocks. The apparatus used to swedge the steel balls into the aluminum discs is shown in Figure 16. The swedging action creates excellent anchorage by causing the aluminum in the discs to flow around the steel ball.

The end blocks and base of the extensometer are made of the same material as the clip-on strain meter and the entire instrument is enclosed in a plastic case to provide a protective covering and thermal insulation.

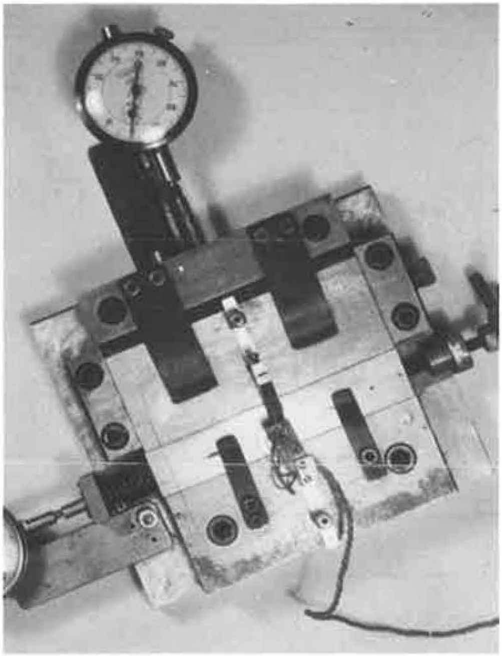


Figure 14. Calibration device for clip-on strain meter.

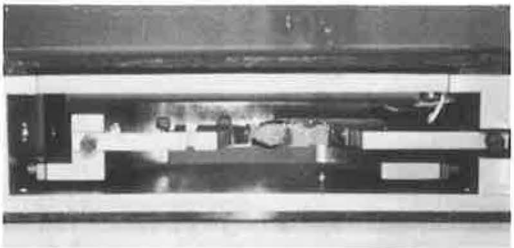


Figure 15. Longitudinal extensometer.

The advantages of the instrument are its economy, its flexibility, and its ease of calibration. The only calibration required is that of the clip-on strain meter encased in the instrument. Before and after each set of measurements, the zero stability of the instrument is checked on a standardized gage bar. In this way, any change in zero can be recorded and incorporated into the reduced data.

With the longitudinal extensometer, the strain measurements on opposite faces of the specimen cannot be automatically averaged. Therefore, the strains measured on each face of the specimen must be recorded and labeled so that average strains can be calculated.

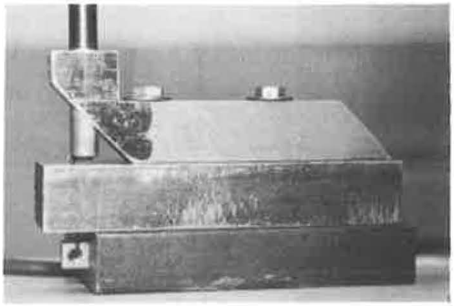


Figure 16. Swedging jig used to make gage joints.

THE LATERAL EXTENSOMETER

To determine the volume changes due to creep and shrinkage, it is necessary to measure both the longitudinal and the lateral strains. The lateral extensometer shown in Figure 17 was designed to measure lateral strains using the tapered studs shown at the left of the instrument. These studs are similar to those used on the longitudinal extensometer. The instrument is attached to the specimen by applying pressure to the hand grip to increase the distance between the studs, permitting them to slide over the spherical gage points on the specimen. The strain-sensing element consists of two SR-4 strain gages cemented on each side of a flexural element at the center of the instrument. The strain gages are connected in a full bridge circuit.

Aluminum is also used for the lateral extensometer to reduce its weight. Advantages of the instrument are that it is removable and the same gage points used for the longitudinal extensometer can be used.

A special jig was devised to insure uniform longitudinal and lateral gage point spacing. This jig (Fig. 18) has two fixed points, an adjustable point and a grinding tool with a fixed stop at the desired lateral gage length. The gage points are applied in the following manner: points are cemented on two adjacent sides of the specimen; the mounting jig is placed on the specimen with the fixed points over the gage points already in place; the adjustable point is tightened down; and the specimen is ground to the desired depth. The grinding tool is then replaced by a special centering tool to hold the

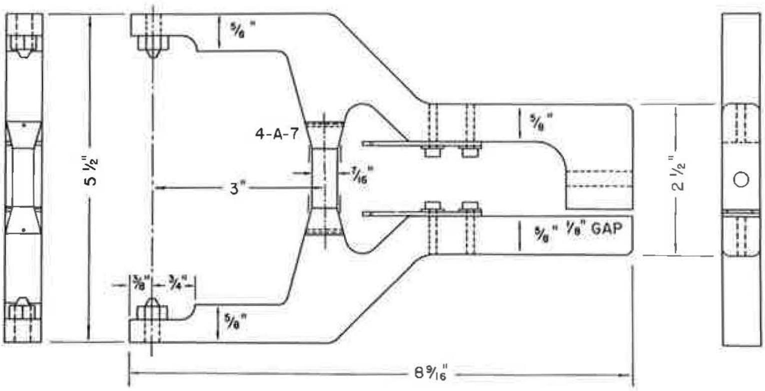


Figure 17. Lateral extensometer.

disc at the exact gage length until the cement has hardened. The procedure is repeated at the lower end, thereby creating the gage length required for the longitudinal extensometer.

Figure 19 shows the calibration device for the lateral extensometer. The extensometer is placed over the two gage points at the right end of the calibration device. The distance between these points is varied by means of a thumb screw at the left end of the device. These variations are indicated by a 0.0001-in. dial gage. Dial gage readings must be divided by the lever ratio of the calibration device. The extensometer has an accuracy equivalent to that of the read-out equipment.

THE MECHANICAL COMPRESSOMETER

In the early stages of the project, the instruments described were used in the following manner. In a test series consisting of three specimens, clip-on strain meters were mounted on one, and spherical gage points were mounted on the other two. Using this type of instrumentation, the elastic properties of the concrete were obtained using the clip-on strain meters. Early in the load period, an independent check of the creep and shrinkage strain rate was also obtained by using the clip-on strain meters as well as the longitudinal extensometer. When the data indicated a satisfactory check, the clip-on meters were removed for use on other specimens.

It seemed desirable also to obtain an independent check of the elastic properties measured by the clip-on strain meters

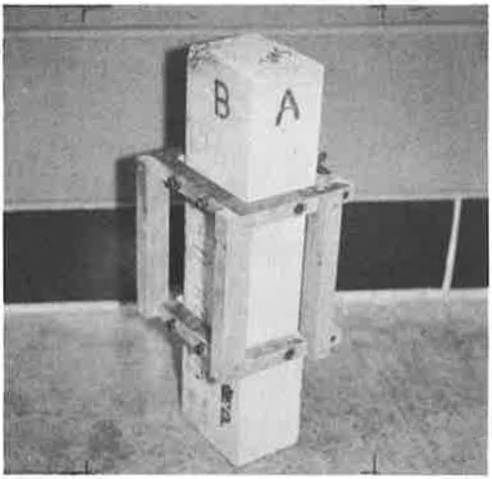


Figure 18. Apparatus used to mount gage points.

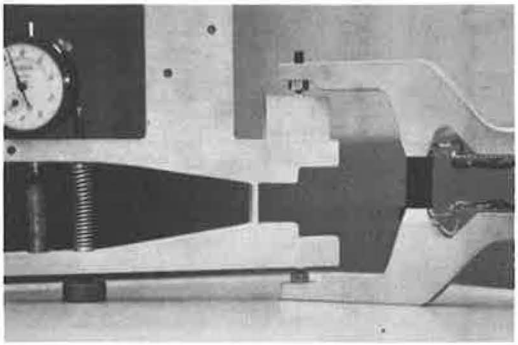


Figure 19. Calibration device for lateral extensometer.

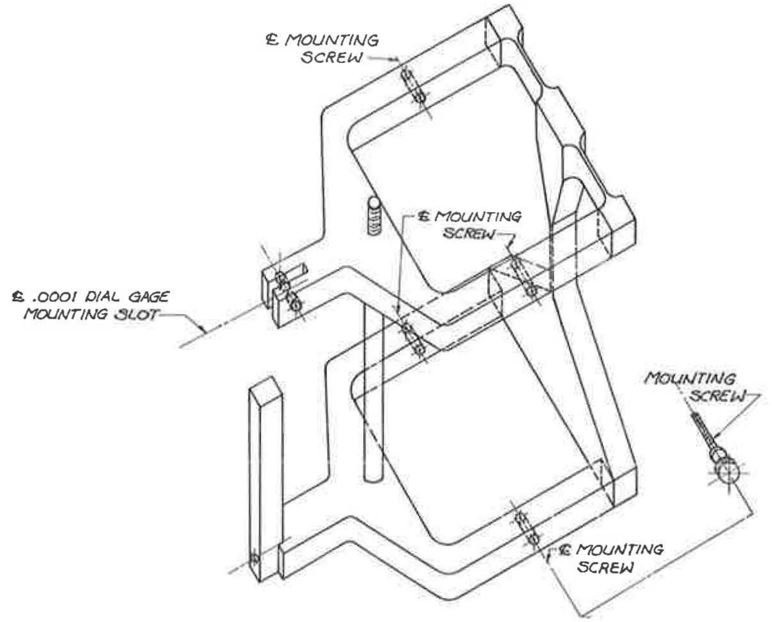


Figure 20. Mechanical compressometer.

during the initial loading. A mechanical compressometer (Fig. 20) for direct mounting on the spherical gage points was developed for this purpose. The instrument is designed so it can be removed after the initial loading period.

The compressometer is constructed with a pivot on one side of the specimen to increase the mechanical advantage. By simulating the pivot with a bi-axial flexure hinge, it was possible to construct an automatically-averaging instrument with no moving parts.

The longitudinal extensometer, the lateral extensometer, and the mechanical compressometer all use the same gage points. The system provides a check of all longitudinal strain measurements, both elastic and creep, through duplication of specimen and the use of clip-on strain meters, the longitudinal extensometer, and the mechanical compressometer. The system is flexible, complete and easy to operate.

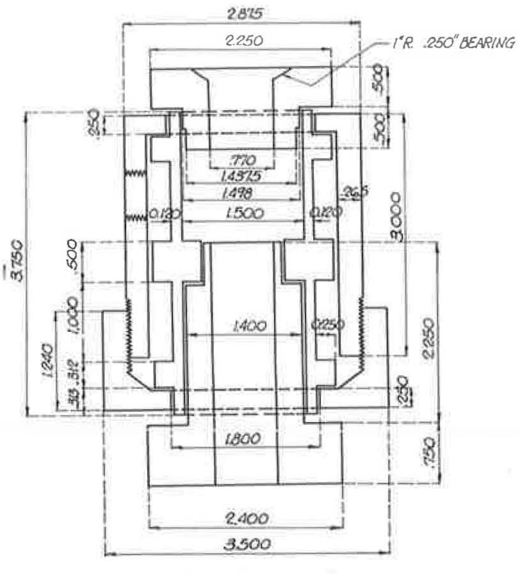


Figure 21. Load cell.

THE LOAD CELL

Figure 21 shows the special load-measuring instrument developed for use on this project. This device performs two important functions: the ball seat at the top insures a uniform load distribution to the specimen, and the instrument can be used to monitor the load transmitted to the specimen.

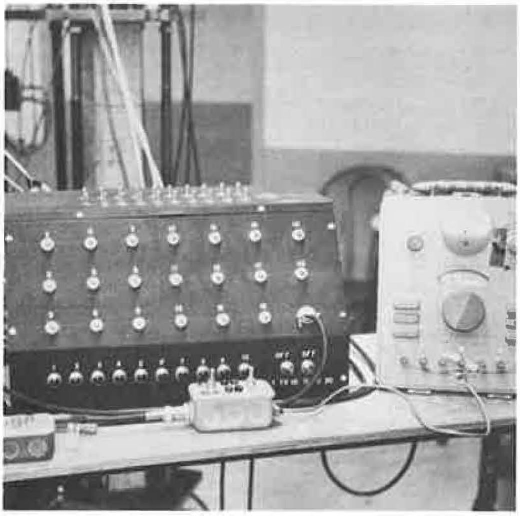


Figure 22. Read-out equipment.

The transducer consists of four SR-4 strain gages attached to a strain-sensing sleeve. The gages are connected in a bridge circuit with two gages mounted above and two mounted below the center of the sleeve. The sleeve is prestressed so that it is subjected to a tensile force throughout the test. The load is applied to the center of the sleeve by a plunger located directly below the ball and is transmitted to the case which serves as the reaction. Thus, the external load increases the strain in the top half of the sleeve and decreases the strain in the bottom half. Hence, all four of the gages are subjected to a change in strain. By mounting the gage pairs in opposite quadrants of the sleeve, the average axial-strain component is measured.

The load cells are calibrated in a hydraulic testing machine. Before used, all load cells are placed under a sustained load until all measurable creep has been eliminated. The load cells used in this test series have a capacity of 35,000 lb with an accuracy of ±100 lb.

THE READ-OUT EQUIPMENT

All of the electrical instruments described in this paper have one important common feature: the strain-sensing elements are bridge circuits using SR-4 strain gages. This makes it possible to read all the instruments with a single strain indicator. The strain indicator is connected to a 20-channel switch-and-balance unit (Fig. 22). The switch-and-balance unit is provided with 20 plug-type receptacles to connect the various instruments required for measuring the load and strain for a given series of specimens. With the four switch-and-balance units presently available connected in series, the output from 80 channels can be read with a single strain indicator.

INSTRUMENT RELIABILITY

Each instrument was calibrated and tested before it was used in the tests. Calibration data for the lateral extensometer, and for a typical clip-on strain meter and load cell are given in Table 1. Calibration curves, plotted using these data, are shown in Figures 23, 24, and 25. The mechanical compressometer does not require calibration, because the multiplication ratio for the dial readings can be determined by measuring the lever arms. Each instrument is re-calibrated every few months as a check on instrument stability. In most cases, there has been no appreciable change in the calibration.

Figure 26 shows a comparison of typical load-deflection curves using data obtained with the mechanical compressometer and the clip-on strain meters. The calculated moduli of elasticity seem to be in excellent agreement.

Figure 27 shows the average creep and shrinkage measured by four clip-on strain meters during the first 14 days under load and the average creep and shrinkage measured on a specimen in the same series using the longitudinal extensometer. The curves indicate sufficient agreement to warrant removal of the clip-on strain meters at the end of 14 days.

Data obtained with the lateral extensometer indicate that lateral creep and shrinkage strains are extremely small, the order of magnitude of the strains being about the same as the accuracy of the read-out equipment. This result may be due to the fact that lateral shrinkage and dilation due to creep tend to compensate each other.

TABLE 1

CALIBRATION DATA

Clip-on Electrical Strain Meter No. 601		Lateral Extensometer	
Δ, in. x 10^{-4}	K-Box Rdg.	Δ, in. x 10^{-4}	K-Box Rdg
0	0	0	0
4	50	117	350
8	100	235	700
12	150	353	1040
16	200	471	1390
20	250	588	1740
24	295		
26	320		

Load Cell No. 3504

Load, kips	K-Box Rdg.	Load, kips	K-Box Rdg.
0	0	16	1725
1	105	17	1825
2	215	18	1935
3	325	19	2040
4	430	20	2145
5	535	21	2250
6	645	22	2355
7	755	23	2465
8	865	24	2565
9	975	25	2665
10	1085	26	2775
11	1195	27	2875
12	1300	28	2980
13	1405	29	3085
14	1515	30	3185
15	1615		

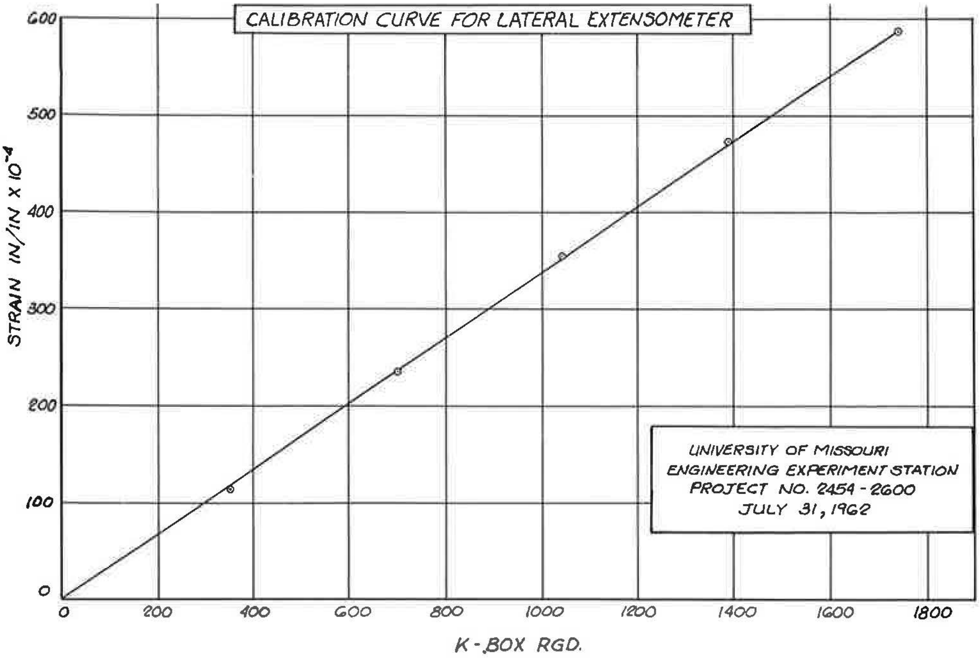


Figure 23. Calibration curve for lateral extensometer.

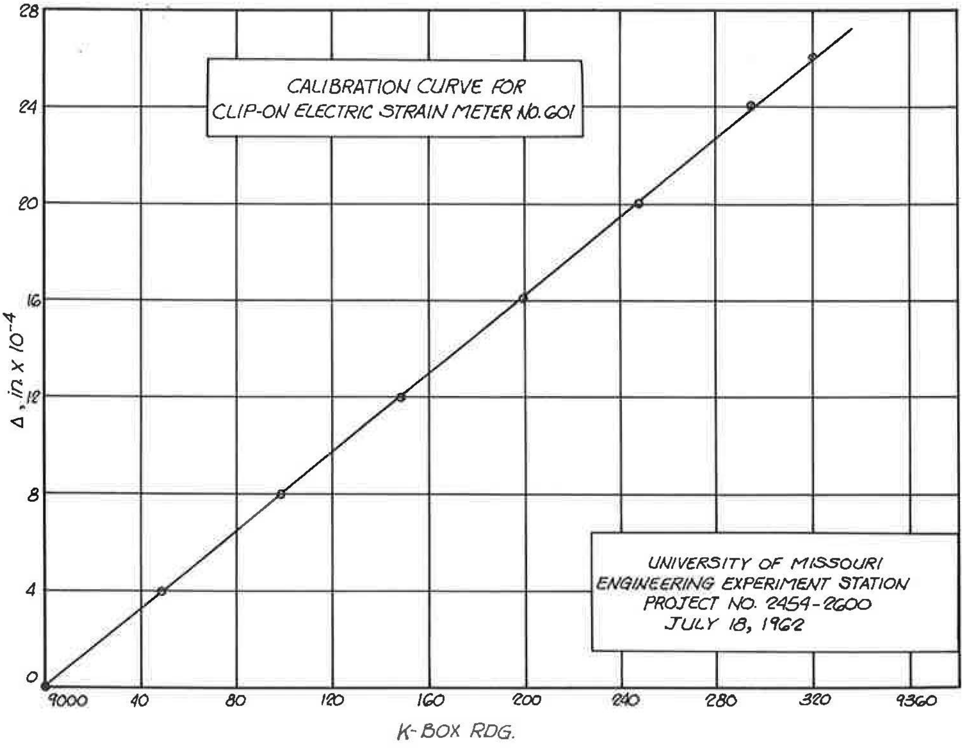


Figure 24. Calibration curve for clip-on electric strain meter.

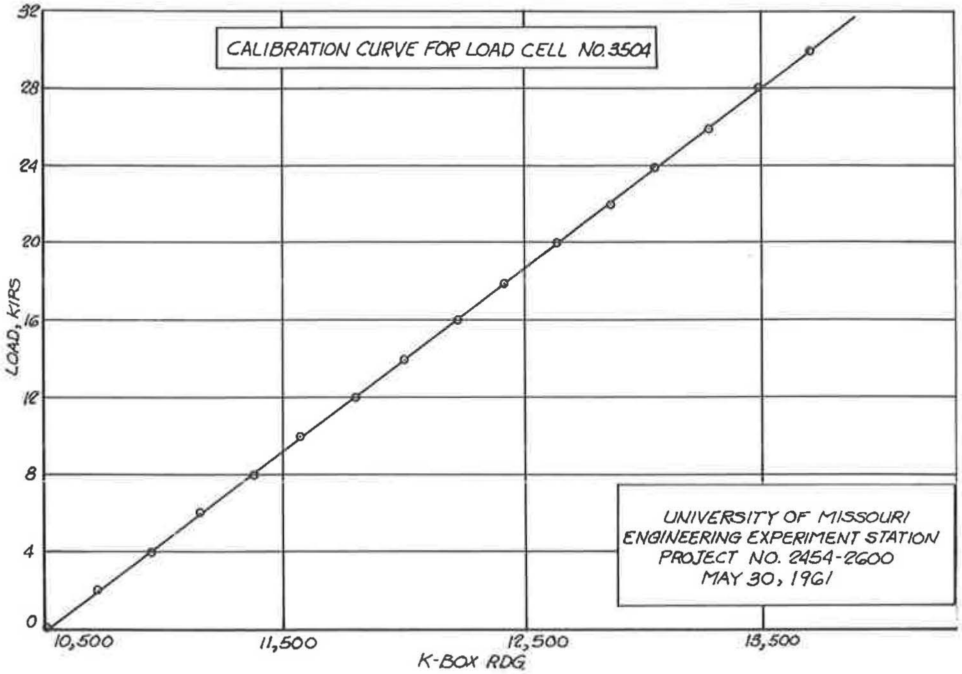


Figure 25. Calibration curve for load cell.

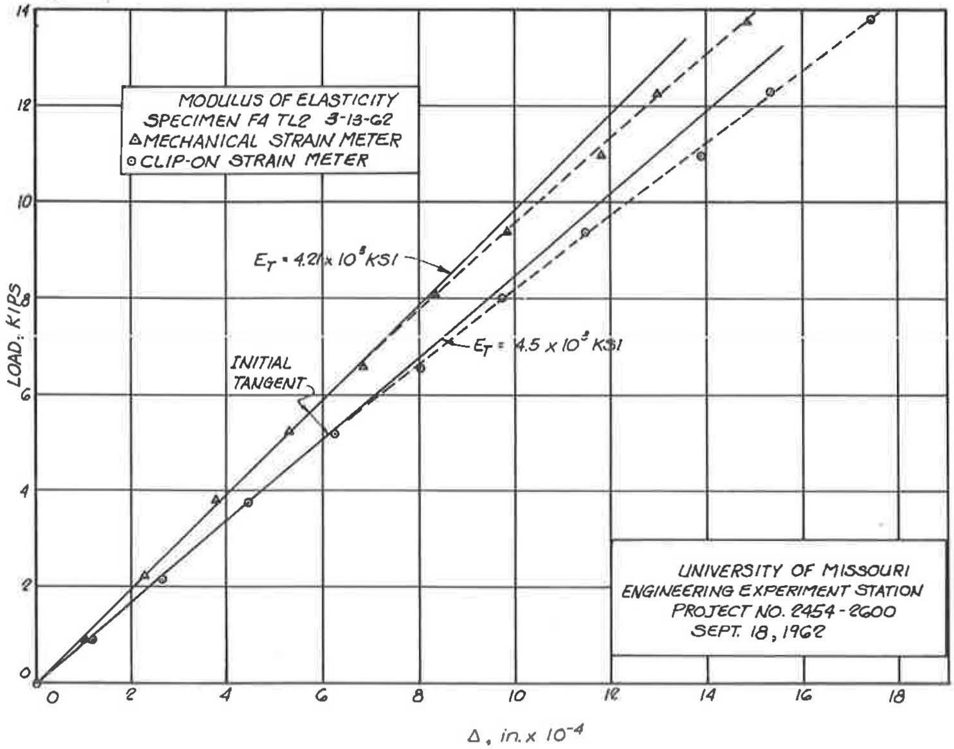


Figure 26. Modulus of elasticity.

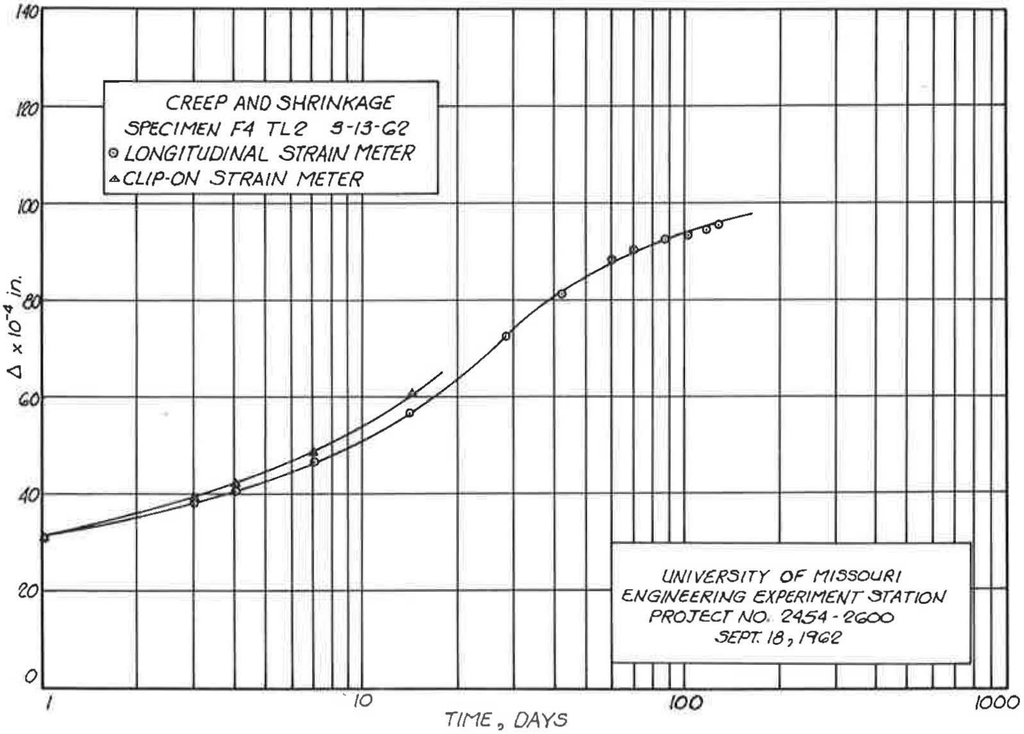


Figure 27. Creep and shrinkage.

CONCLUSIONS AND RECOMMENDATIONS

The loading frames used in this project are similar to the one recommended by ASTM and have performed satisfactorily during the past year's operation.

The design of the pumping-and-control system was based on apparatus originally developed at the University of California. Oil leakage past the piston cups has been much smaller than anticipated and seems to decrease with continued operation as reflected by the frequency of the pumping cycle. This cycle has decreased from several strokes every few minutes to several strokes every few hours. Therefore, it appears that the capacity of the oil-injection system may have been somewhat overdesigned.

The strain- and load-measuring instruments described have produced consistent data. The accuracy of all instruments meets the proposed ASTM requirements.

ACKNOWLEDGMENTS

The instrumentation described herein was developed as a part of the work of the Engineering Experiment Station of the University of Missouri. The program was sponsored jointly by the Missouri State Highway Commission and the Bureau of Public Roads.

Research assistants assigned to the project were James Monsees, Dean Froerer, and Jack Hill. The manuscript was typed by Jonette Rielle. The study was under the direction of Bernard L. Meyers, Project Engineer; Adrian Pauw, Professor of Civil Engineering; and H. D. Comins, Associate Professor of Civil Engineering.

REFERENCES

1. Pauw, A., and Breen, J. E., "Field Testing and Analysis of Two Prestressed Concrete Girders." HRB Bull. 307 (1961).

2. Technical Report No. 1, "Structural and Economic Study of Precast Bridge Units—Instrumentation." Univ. of Missouri, Eng. Experimentation (1957).
3. Pauw, A., and Meyers, B. L., "A Review of Literature Pertaining to Creep and Shrinkage of Concrete." Bull. 56, Univ. of Missouri, Eng. Exp. Sta. (1963).
4. "Tentative Method of Test for Creep of Concrete in Compression." ASTM (August 1, 1962).