A Standardizing Strain Gage for Measurements Requiring Long-Time Stability

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A new type of unbonded elastic wire strain gage is described. Strains are determined by measuring the changes in electrical resistance of the elastic wire with conventional strain bridges, but long-time stability is achieved in a novel manner by referring all strain measurements to a built-in Invar length standard. The performance of one standardizing strain gage was evaluated by comparison with a 10-in. Whittemore gage. The standardizing gage can be surface-mounted or embedded in concrete.

● DEVELOPMENT OF THE bonded wire strain gage shortly before 1940 increased the accuracy and convenience of many strain analyses. A large number and variety of mechanical and structural members have since been studied with the aid of this new tool. As is the case with most instruments, however, the bonded wire gage is better suited for some fields of study than others. The measurements of strains over periods longer than several days have not always been reliable.

During long periods of time there may be changes in the response of the gage which are not a direct result of changes in strain in the material being investigated. These long-time effects are commonly called "drift." The resistance of the wire in the bonded gage is measured at the start of a test, and subsequent changes in the gage resistance are interpreted as dimensional changes in the material. Should there be drift changes also, the separation of these drift changes from the real dimensional changes may be impossible, even though unstressed dummy gages are used to achieve a degree of compensation. Drift in bonded wire gages may be due to causes which cannot be accurately compensated by unstressed "dummies" including relaxation effects in the crystalline structure of the wire, dimensional changes in the bonding cement, changes in adhesion between the bonding cement and the surface under study, changes in electrical resistance between the gage wire and ground, changes in lead wires, or changes in the elements of the measuring circuits.

A well-known method of achieving long-time stability in length measurements is that of comparing the unknown with a standard. Such a method is commonly used with dial gages; the Whittemore strain gage is one example. The thought occurred to the author, when employed in the Denver Laboratories of the United States Bureau of Reclamation, that the incorporation of a length standard in an elastic wire strain gage would eliminate drift effects. The resultant gage should have long-time stability plus the accuracy and convenience associated with a resistance-type gage. The immediate problem was the measurement of creep in foundation rock, a property of considerable importance in the design of large concrete dams. The idea was developed to the point where one basic model was built and tested. The results indicated that a standardizing electrical resistance strain gage was feasible.

The project was renewed in the research laboratories of the Portland Cement Association with the objective of developing a gage suitable for measuring long-time dimensional changes which may occur in various concrete products and structures. The present report describes a standardizing strain gage which was designed for use either on the surface or embedded in concrete. Evaluation tests to which the gage was subjected are also discussed.

A patent application covering the standardizing strain gage has been filed with the U. S. Patent Office by the Solicitor of the Department of the Interior, and, in accordance with usual Federal procedure, all rights to any patent which may be issued thereon are assigned to the Federal Government.

OPERATION OF GAGE

The operation of the gage is best described by means of Figure 1, which shows the gage mounted on the surface of a solid. The essential parts of the gage are a tube, a piston fitted into one end of the tube, and a small-diameter elastic wire stretched inside the tube from the piston to the other end of the tube.

The wire is adjusted so that it is under slight tension when the piston is in the normal position (that is, when the piston shoulders are in contact with the end of the tube). A spring (not shown in Fig. 1) assures a positive contact between the piston shoulders and the end of the tube. The tube and piston assembly is attached to the solid by means of insert 1. Insert 2, located a distance L from insert 1, serves as a stop for the outward movement of the piston, which is accomplished by applying air pressure within the tube.

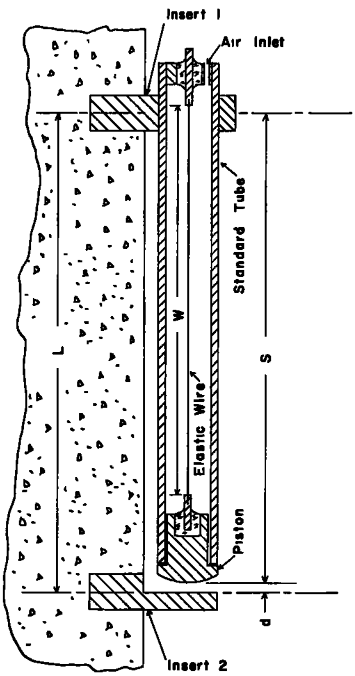

Figure 1. Standardizing strain gage.

The purpose of the gage is to measure changes in length L; that is, changes in the gage length. From Figure 1,

$$L = S + d \tag{1}$$

in which S is the length of the standard, which in the present gage was made of Invar. For small temperature changes length S will be essentially constant; for larger temperature changes a small correction may be applied. If S is assumed to be constant, changes in L may be measured by measuring the equal changes in d. The elastic wire is used as a convenient and accurate method of measuring d. The change in the electrical resistance of the wire as the piston is moved outward from the standardizing position until it contacts insert 2 provides the data necessary for determining d.

The change in resistance per unit resistance of small diameter Advance wire, which was used in the standardizing strain gage, has been found experimentally by many investigators to be proportional to the strain of the wire; that is,

$$\Delta R/R = K \Delta W/W = Kd/W \qquad (2)$$

in which ΔR is the change in resistance and ΔW (= d) is the change in length of a wire of initial resistance R and length W. K is a proportionality constant and is a property of the wire; it is logically called the strain coefficient of resistance. A similar proportionality constant between resistance change and strain in the material under study is called gage factor. Gage factor and strain coefficient are equal when W = L. If K and W are known, d may be determined from resistance measurements. At the beginning of a test d is measured by the change in resistance caused by moving the piston from the standardizing position to the gaging position. At any later time d is measured in the same manner by a resistance change from the standardizing to the gaging position. Thus a "zero" reading is taken for each measurement, and drift effects are thereby eliminated.

The strain in the material under test is equal to $\Delta d/L$, and may be read directly from bridges calibrated in strain units.

The maximum value which d may have is fixed by the elastic properties of the wire; the wire strain d/W must not exceed the elastic limit. For hard-tempered Advance wire, used in the present gage, this limit is about 0.005 in. per in. If W = L, the maximum strain which can be measured in the material under study is likewise 0.005 in. per in. millionths. However, W and L do not necessarily have to be equal, as the gage insert 1 (Fig. 1) may be fixed anywhere along the tube. For example, if W = 2L, strains up to 0.01 in. per in. may be measured.

The purpose of the present paper is primarily to explain the principle of the standardizing strain gage, rather than to discuss details of construction. Several additional gages are being built and modifications will certainly be made in some details. In fact, one gage has been built in which the piston is mechanically rather than pneumatically actuated. Anyone interested in fabrication details may correspond with the author.

EVALUATION TESTS

The length standard of the gage used in the tests to be described was made entirely of Invar. The gage was $\frac{1}{4}$ in. in diameter and the hard-tempered Advance wire was 0.001 in. in diameter and 4 in. long. The gage length was also 4 in. The gage was calibrated by applying known movements to the gage by means of a Gaertner micrometer slide and measuring gage response with a Baldwin type L strain indicator. Values obtained for the gage factor from calibrations made during the 15 weeks of tests were 2.17, 2.17, 2.16, and 2.17.

In all of the tests the response of the standardizing strain gage was compared to that of a 10-in. Whittemore gage. The Whittemore gage was chosen because it is also a standardizing gage and hence is inherently stable. An Invar bar was used as the standard for the Whittemore gage.

In the first comparison, strains along the same gage line on the surface of a 6- by 18-in. lightweight aggregate concrete cylinder were measured with the two different gages. Four inserts were cast in the cylinder. The standardizing gage was fastened to the two inner inserts, and adapters for the Whittemore gage were screwed into the two outer inserts. Figure 2 shows the Whittemore adapters and the standardizing strain gage in place on the cylinder. The lead wires from the standardizing gage were contained in the plastic tube fastened to one end of the gage. This tube served also

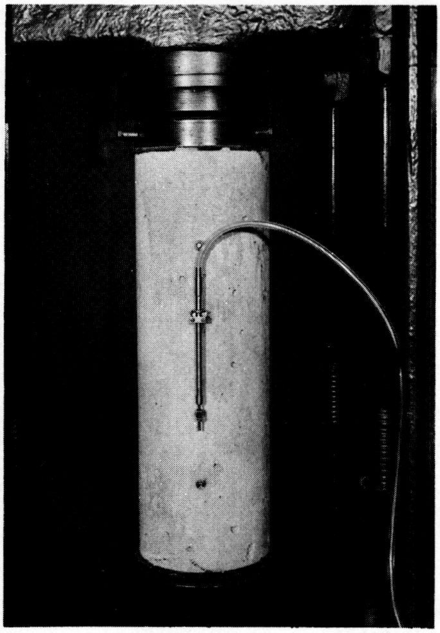

Figure 2. Gage attached to surface of 6- by 18-in. cylinder.

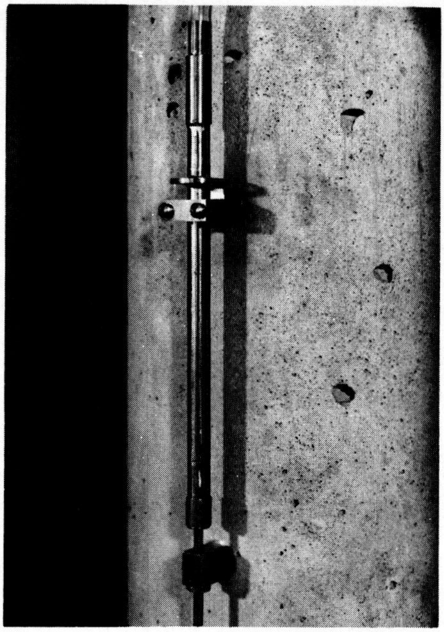

Figure 3. Details of surface mounting.

as the air line for operating the gage piston. A close-up of the standardizing gage is shown in Figure 3.

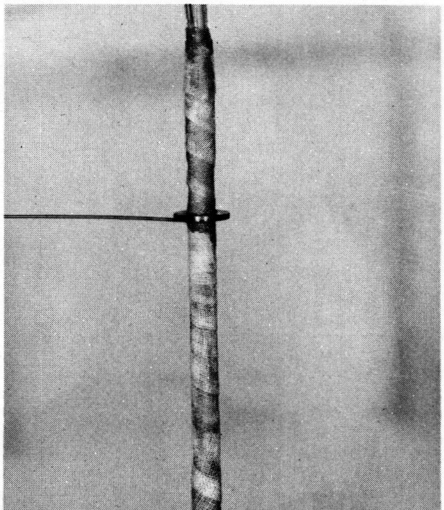

Figure 4. Gage with flanges for embedment.

In the second series of tests, the standardizing gage was embedded on the axis of a 6- by 18-in. lightweight aggregate concrete cylinder and was compared to Whittemore readings taken on two sets of gage points located 180 deg apart. For this test the standardizing gage was fitted with 5/8- by 1/16-in. flanges, as shown in Figure 4. One flange was fastened to the standard tube and the other served as the stop for the piston. The body of the gage was wrapped with gauze so that the only bond between gage and concrete would be at the flanges. The steel wires extending from the flanges were used to fix the gage in the mold while the concrete was being cast. The cylinder was cast on its side in a special mold to insure good contact between the flanges and concrete.

The stress-strain relations of the cylinders were determined first;

the cylinders were then subjected to constant stress for about three weeks; and finally the stress-strain relations were determined again. The results of the stress-strain tests served as a comparison of the calibrations of the standardizing and Whittemore gages. The results of the sustained load tests compared the stability of the standardizing gage to that of the Whittemore gage.

For the tests in which the standardizing gage was mounted on the surface of the cylinder on the same gage line as the Whittemore gage, Figure 5 shows that the calibrations of the two gages were nearly the same. For the cylinder with the embedded gage, however, the Whittemore readings taken on one gage line differed considerably from those taken on the other

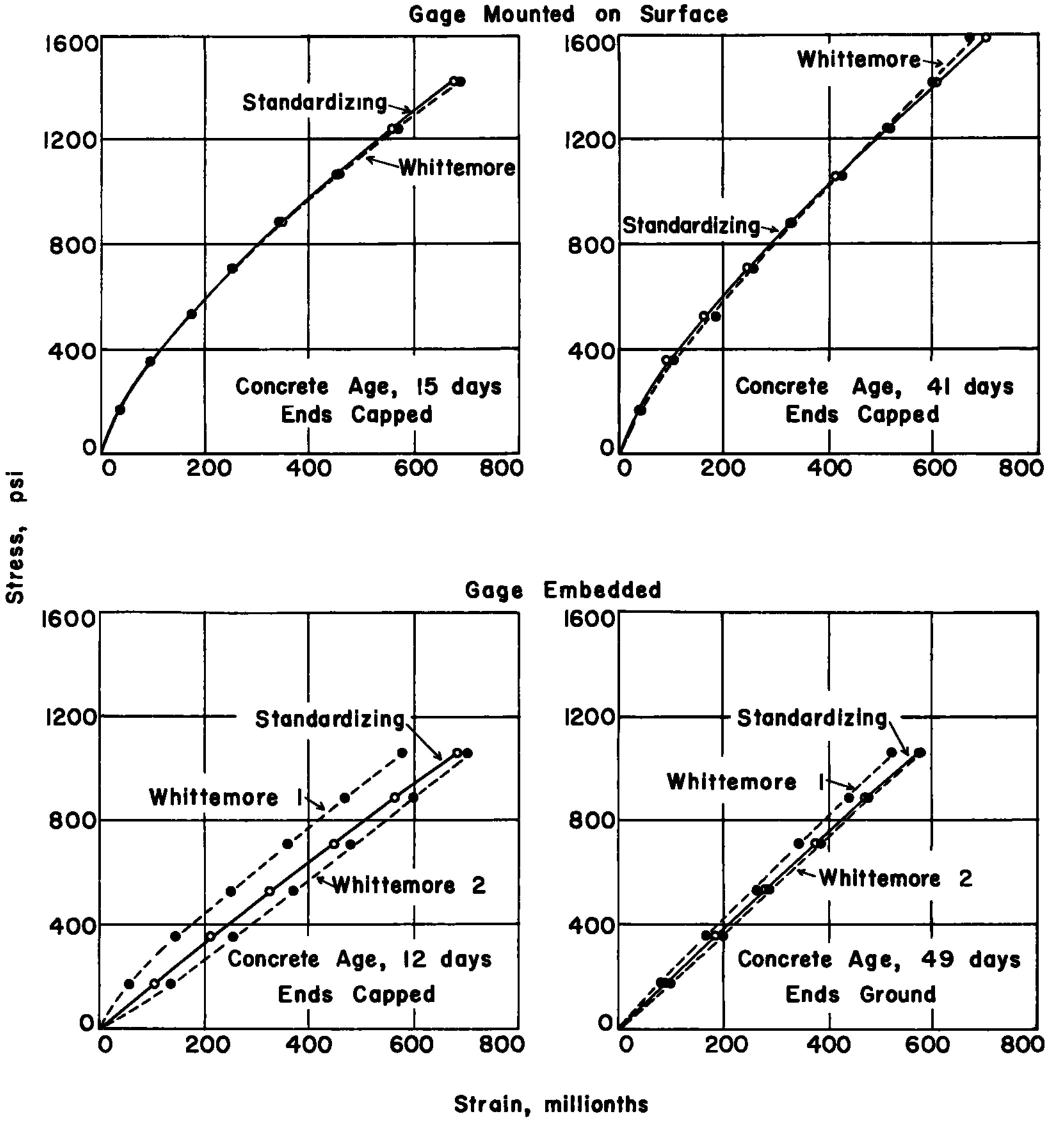

Figure 5. Stress-strain curves.

gage line. This difference may have been caused by non-uniform stress in the cylinder, somehow associated with end conditions. The cylinder ends were capped with sulfur and fire-clay when the first stress-strain tests were made. Before the second stress-strain test, which was made upon completion of the sustained loading, the caps were removed and the cylinder ends were ground flat. This second test (Fig. 5) showed a considerable improvement in the response of the Whittemore for the two gage lines.

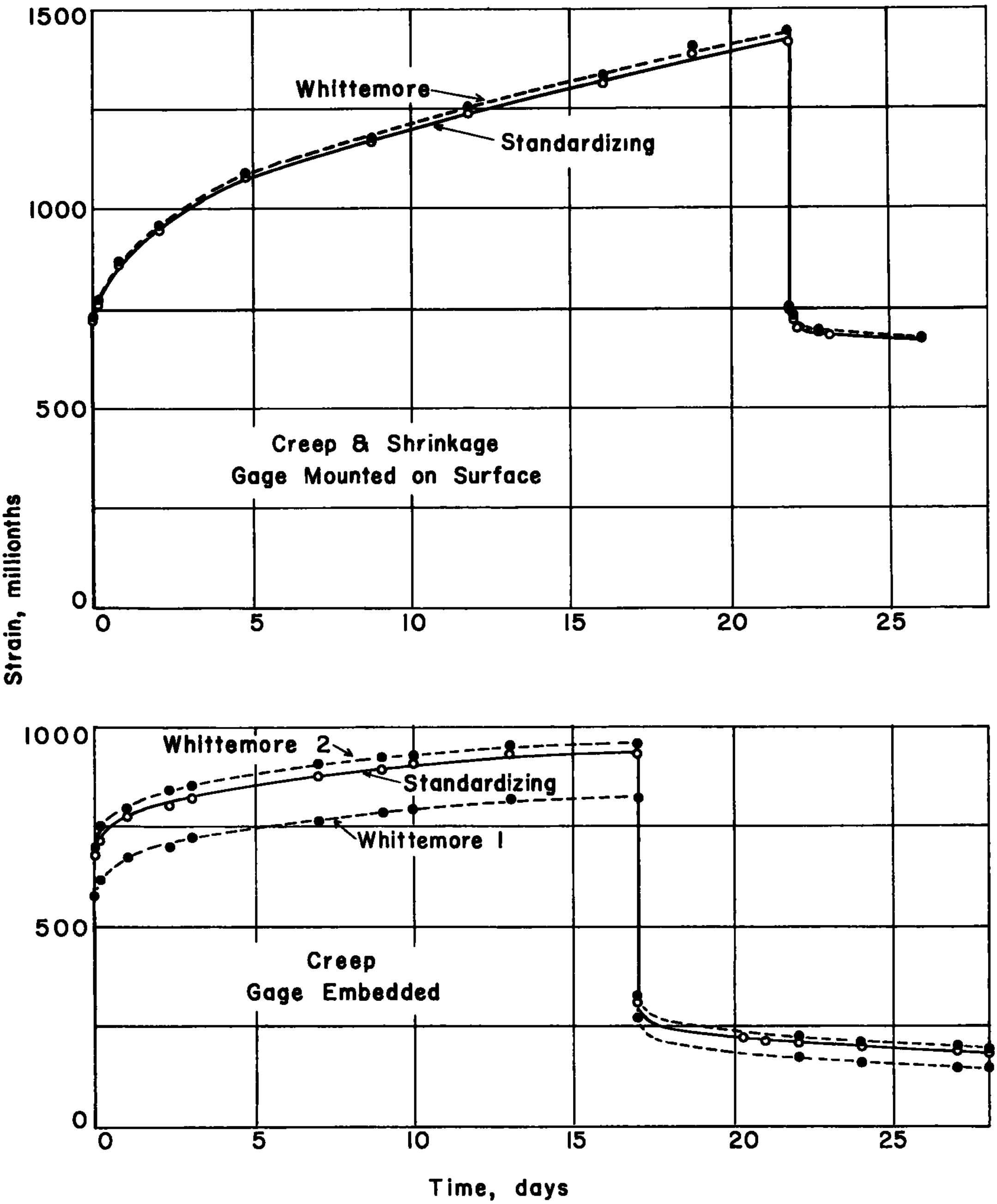

Figure 6. Strain-time curves.

These results indicated that the differences between readings for the Whittemore gage line 1, Whittemore gage line 2, and the standardizing gage were not caused by differences in calibration, but were due to non-uniform stresses in the cylinder.

The cylinder with the standardizing gage mounted on the surface was loaded in a mechanical testing machine when the concrete was 15 days old. The stress in the cylinder was maintained constant at 1,400 psi for 22 days. As the cylinder was not shielded in any way, there was drying shrinkage as well as creep. This was of no consequence, however, because both gages were mounted on the same gage line and the purpose was not to determine the properties of the concrete but to evaluate the performance of the standardizing gage. The strains in the cylinder as a function of time are shown graphically in Figure 6. The readings from the standardizing gage agreed well with the readings from the Whittemore gage.

The cylinder in which the standardizing gage was embedded was loaded in the mechanical testing machine when the concrete was 12 days old. A constant stress of 1,060 psi was maintained for 17 days (Fig. 6). The elastic strains obtained upon application of the load were different for the two Whittemore gage lines, as previously discussed. However, the increases in strains with time were nearly the same for Whittemore gage line 1, Whittemore gage line 2, and the standardizing gage. Shrinkage during drying of a concrete cylinder being greater on the surface than at the center, drying was prevented in this test by enclosing the cylinder in an aluminum sheath.

The standardizing strain gage is independent of changes which may occur in the bridge circuit. This was illustrated during the creep and shrinkage test by substituting another bridge for the one usually used. The strain reading by the usual bridge was 0.001392 and that by the substitute was 0.001388 in. per in.

The effect of temperature was determined by placing the cylinder containing the embedded gage successively in rooms controlled at 40, 70, and 100 F and measuring the resultant strains. The standard bar for the Whittemore gage was subjected to the same temperature, so that the Whittemore readings would be comparable to the standardizing gage readings. The strains per degree measured by the gages should be equal to the difference between the coefficient of expansion of the concrete and the coefficient of expansion of Invar. From the measured strains, and assuming the coefficient of expansion of Invar to be 0.000006 in. per in. per degree F, the values calculated for the coefficient of expansion of the concrete were as follows:

Temp. Range, F	Coefficient of Expansion, 0.000001 in./in./deg F		
	Standardizing Gage	Whittemore Gage Line 1	Whittemore Gage Line 2
40 to 70	3.4	3.1	2.9
70 to 100	4.4	4.4	4.3

At the conclusion of the tests on the second cylinder, two axial slots were sawed in the cylinder about 180 deg apart, the cylinder was split open, and the standardizing strain gage was recovered undamaged. The calibration of the recovered gage was the same as the calibration made at the beginning of the tests.

APPLICATIONS

The standardizing strain gage was designed primarily for measurements which require remote readings and long-time stability. These measurements include various long-time dimensional changes, such as creep and shrinkage, which may occur in concrete. The gage is adapted to different measuring problems simply by changing the method of attaching it. For instance, in the first evaluation test the gage was attached to inserts at the surface of the concrete; in the second test flanges were fitted to the same gage so that strains could be measured at the interior of the concrete. Another type of clamp has been designed for attaching the gage to the steel wire used in prestressed concrete. Many other applications are possible by the use of suitable clamps.

In 1949 the author designed and built several small disc-shaped stress gages, which were later used successfully for measuring the stresses in the compression zone of a large reinforced concrete beam. These stress gages consisted essentially of two parts: the disc-shaped cases, which reacted elastically to the stress in the concrete, and electrical resistance strain gages for measuring the elastic deformations of the discs. Although the stress gages were satisfactory for short-time tests, they were not useful for long-time studies because of drift effects in the strain-measuring elements. The incorporation of the standardizing strain gage for measuring the elastic deformations of the disc should produce an instrument suitable for measuring stresses over long periods of time.