

The laboratory use of bonded-wire electrical-resistance strain gauges on concrete at the Building Research Station *

by R. W. Cooke, B.Sc.(Eng.) and A. E. Seddon, M.Sc., A.M.I.Struct.E.

**Contribution by Professor R. H. Evans, D.Sc.,
D. ès Sc., Ph.D., M.I.C.E., M.I.Mech.E., M.I.Struct.E.
(University of Leeds)**

A considerable number of research workers are now using electrical-resistance strain gauges on concrete test specimens as well as on steel members. It is generally agreed that e.r.s. gauges can be used with confidence on steel provided the usual instructions are faithfully carried out, but in the case of concrete, as Messrs Cooke and Seddon have stated, there does exist some doubt at all times about the accuracy and consistency of the e.r.s. gauges. So the appearance of this paper is most timely and the authors are to be congratulated for undertaking such a comprehensive and searching investigation.

All new research workers experience some difficulty at first in obtaining reliable results with e.r.s. gauges. They soon realize that the reliability depends very largely on acquiring the proper technique and skill in fixing the gauges to the specimens. A disadvantage of e.r.s. gauges is that there is no simple method of telling whether a gauge is recording the whole or only a part of the strain. The general practice is to assume that the observed reading is correct if it is of the right order and to ignore it completely if it is obviously wrong. Nevertheless, as the authors rightly point out, excellent results can be obtained with e.r.s. gauges provided the experimenters take great care and have obtained the necessary experience under different conditions.

Similar comments may be made concerning the method using a brass foil as a moisture barrier between the concrete and the gauge. The experiments conducted in our laboratories with brass foil barriers show that even greater care, time and skill are required than when the gauges are applied direct to the concrete. It has been found that the film of nitro-cellulose adhesive between the brass foil and the concrete must be uniform and as thin as possible, otherwise the recorded strain readings are too low.

It is noted that the authors have not attempted to give details of the advantages and disadvantages of different types of e.r.s. gauge and equipment. Continental engineers already have preferences for certain types of gauge, as is obvious to visitors to their laboratories. A type of gauge that has proved to be very suitable for concrete surfaces at Leeds is the Saunders-Roe foil e.r.s. gauge.

Experience and tests show that the foil gauges are not unduly susceptible to zero-drift and are more easily soldered to the panel leads.

No reference has been made in the paper to the possible use of dental cements for bonding gauges to both steel and concrete surfaces. In our laboratories the use of F.88 dental cement has been extremely successful. It is particularly suitable for all outside tests in which the gauges are fully exposed to the elements. The setting time is certainly less than one minute and the cement is very hard and tough in 10 minutes. Judging from our experience at Leeds there is no doubt that much greater use will be made of dental cements in future work.

The information contained in Figure 4 will be most valuable to all experimenters on concrete and it is of interest to note that a gauge length of at least four times the maximum aggregate size gives sufficient accuracy, namely $\pm 5\%$.

**Contribution by Professor I. M. Viest
(University of Illinois)**

The experiences at the Building Research Station with the use of bonded-wire electrical-resistance strain gauges on concrete surfaces agree to a large extent with those of the research teams at the University of Illinois. In our laboratory, the surface strains on reinforced concrete structural members subjected to *short-time* tests are measured almost exclusively by SR-4 electric strain gauges applied direct to concrete. Hundreds of gauges used in numerous investigations during the past ten years have given satisfactory performance; failures have been infrequent and have often been traced to improper application of the gauges.

The techniques used at Illinois have been given in an earlier paper⁽¹⁾. They are similar to those described by Messrs Cooke and Seddon. The major differences between the two techniques are in the final preparation of the concrete surface and in the length of time of curing the cement. After the surface has been smoothed and cleaned, nitrocellulose cement (Du Pont Cement No. 5458) thinned with acetone is worked into the pores of concrete and allowed to dry for 24 hr. The gauge is then attached with a coat of the nitrocellulose cement. The minimum drying period for this second coat is approximately 24 hr.

The most suitable gauges available commercially in the United States are either six inches or one inch long. Since in most of our studies concrete is made with

*Pages 31-38.

Discussion

aggregate of 1 in. maximum size the 6 in. gauge length is used whenever possible. Recourse is made to the 1 in. gauges only if the conditions of tests, such as strain gradient or inaccessibility, do not permit the use of the longer gauge.

At times difficulty has been encountered with moisture. In some instances moisture loosened the gauge and thus rendered it inoperative after a few days in place; in other cases it decreased the resistance to earth. Both difficulties indicate that the nitrocellulose cement slowly absorbs moisture from the concrete. It appears to this writer that the brass foil barrier suggested by the authors might prevent the first difficulty and certainly would prevent the second. The use of a waterproof, non-absorbent cement however, might be a simpler solution.

REFERENCE

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Contribution by K. R. Peattie, B.Sc., Ph.D.,
A.R.T.C., A.M.I.C.E.

The authors' suggestions are interesting. I do not recollect having seen such long curing periods suggested for nitrocellulose adhesives used with strain gauges but if the curing is to take place entirely at room temperatures they are very likely necessary. This period of waiting would cause difficulties and I think that a certain amount of local heat, judiciously applied after an initial curing period at room temperature, is preferable. If curing takes place entirely at room temperature it will be difficult to ensure that a paper-backed gauge is free from moisture before wax is applied.

If either foil strain gauges or wire gauges with epoxy-resin backs are used with some form of Araldite cement, satisfactory results are obtained on concrete. The non-porous film back has a similar effect to that obtained by the authors with brass foil but it is much more convenient to apply. Some local application of heat is necessary to cure the cement but I have found the result to be more satisfactory than that obtained with paper-backed gauges.

Contribution by J. M. Prentis, M.Sc., Ph.D.
(University of Aberdeen)

The main cause of past reluctance to use electrical-resistance strain gauges on concrete has, I think, been their unreliability due to excessive zero-drift. In overcoming this problem Mr Cooke and Mr Seddon have done valuable work. I am sure that as a result there will be increased use of these gauges, which have many attractive features.

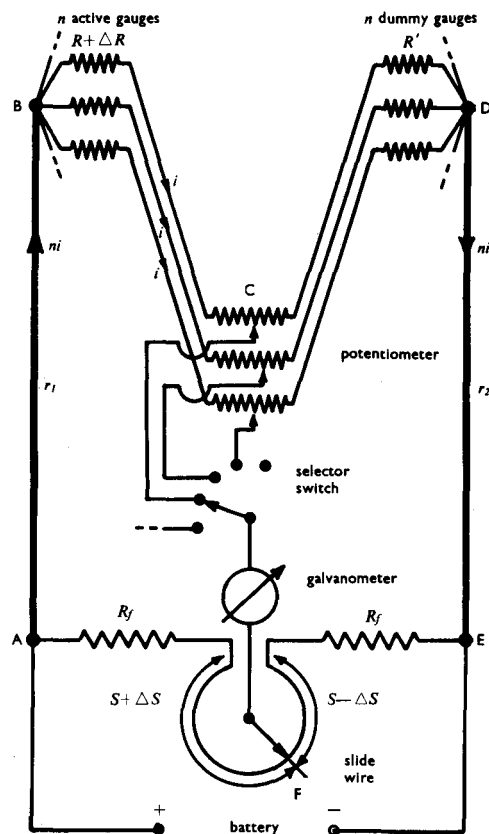


Figure A

The time required for proper drying of the adhesive (10 days) could be a drawback. It would be of interest to know whether the authors have considered using other adhesives, such as Araldite, which set by chemical action rather than by evaporation of a solvent. If Araldite or something similar were used, however, it might not prove possible to salvage gauges for further use.

On reading the paragraph on test procedure, I was particularly interested in the observation that disconnection of an unserviceable gauge may upset the balance of other gauges. In setting up an experiment in the Engineering Department at Aberdeen University a little while ago we observed the same sort of thing due, I think, to the use of bus-bars having different resistances.

The circuit used was as in Figure A, which is basically the same as Figure 3 in the paper. The common connexions for the gauges at B and D were not quite as shown. We ran a common lead to one leg of each gauge, but as all the active gauges were very close together the approximation to a single point connexion, as at B, is valid; similarly for the dummy gauges.

The diagram shows only three gauge pairs but we will assume that there are in fact n . Consider the circuit ABCDE. Resistances of the leads and potentiometers are added to the gauge resistances to give totals of $(R + \Delta R)$ from point B to point C, and R' from C to D. Approximately the same current i flows through each pair of gauges; the current in the leads AB and DE is thus ni .

For zero current through the galvanometer the potential difference from A to C equals that from A to F and it is found that

$$\frac{\Delta R + \{(r_1 - r_2)n + R - R'\}}{(r_1 + r_2)n + (R + \Delta R + R')} = \frac{\Delta S}{R_f + S} \dots (1)$$

Adjustment of the potentiometers gives $\Delta S = 0$ for $\Delta R = 0$ so that $\{(r_1 - r_2)n + R - R'\} = 0$. If only the dominant terms are left in the denominators we have,

$$\Delta R/R = 2\Delta S/R_f \dots (2)$$

which is the standard Wheatstone bridge equation.

If we now disconnect a gauge and its dummy, equation (1) must be modified to

$$\frac{\Delta R + \{(r_1 - r_2)(n - 1) + R - R'\}}{R} = \frac{2\Delta S}{R_f} \dots (3)$$

Since the bridge was balanced for n gauge pairs we still have $\{(r_1 - r_2)n + R - R'\} = 0$ so that equation (3) becomes

$$\frac{\Delta R - (r_1 - r_2)}{R} = \frac{2\Delta S}{R_f} \dots (4)$$

which gives $2\Delta S/R_f = (r_2 - r_1)/R$ for $\Delta R = 0$.

If m gauges are removed,

$$2\Delta S/R_f = m(r_2 - r_1)/R \text{ for } \Delta R = 0 \dots (5)$$

Equation (5) was verified by balancing the bridge and then disconnecting the gauges, one pair at a time. As each pair was removed the slide-wire was adjusted to balance the remaining gauges. Only one adjustment was necessary each time and each removal required the same additional movement of the slide.

A further check involved methodical variation in the length of one of the bus-bars. This showed the alteration of the zero every time a gauge was removed to be directly proportional to the difference in resistance in the leads.

It will be appreciated that quite small values of $(r_1 - r_2)$ can lead to serious variations in the zero balance for, as equation (4) shows, $(r_1 - r_2)$ or in the general case $m(r_1 - r_2)$ must be compared directly with ΔR . In verifying the above theory the wire of the bus-bars had 14 strands 0.0076 in. in diameter. The resistance of this is about 0.013 Ω per foot. The gauge resistance was 200 Ω . Thus $(r_1 - r_2)$ for a difference of one foot in equivalent length of bus-bars corresponds to a 0.006% change in resistance, or a mechanical strain of 30×10^{-6} . This increases directly as more gauges are disconnected.

The authors avoid upsetting the initial balance by leaving unserviceable gauges in circuit. This is possible

only if breakdown is due to failure of the adhesive; if the gauge filament is broken the circuit is interrupted anyway. This can easily happen in testing concrete if a tension crack forms under a gauge. The use of foil appears to give extra protection against this type of failure.

A preliminary test on the lines of that described above will show the extent to which bus-bar resistances are unmatched. Adjustment by altering the length of one lead is quite simple. It appears desirable to do this whenever there is the possibility of fracture of one or more gauges during a test.

The above analysis does not account for the loss of balance of some gauges due to potentiometer adjustments of others. I have not observed this in my tests and can offer no explanation.

**Contribution by J. C. Lucas, B.Sc.
and R. Newsham, G.I.Mech.E.**

(British Railways Research Department, Derby)

We should like to make a few comments regarding the use of strain gauges on concrete structures in the field. It has usually been our misfortune to have to attach gauges during inclement weather conditions in the winter months. We have used exclusively for the last few years the foil strain gauge of 4 in. gauge length, using "Strain Gauge Cement" supplied by Aero Research as the adhesive. R. Newsham and myself have described earlier work⁽¹⁾ using foil gauges prior to the introduction of the 4 in. gauge. The technique has been changed a little but basically it is the same.

We usually find it necessary to rub the surface of the concrete with a carborundum block or sanding disc to remove the top dusty layer; we then brush it lightly with a wire brush. All traces of mould oil are removed by swabbing with carbon tetrachloride and a liberal coating of "Strain Gauge Cement" is applied to the surface and the gauge attached, using the thumb to give a rolling action to squeeze out excess adhesive and air bubbles. If the gauges are to be used under laboratory conditions, a layer of "Strain Gauge Cement" is applied over the gauge, and if they are to be used in the field, a liberal coating of Di-Jell is also applied.

We should like to ask the authors if they have had any trouble with the strain gauges after waterproofing, especially those mounted directly on the concrete. It has been our experience that with paper gauges, waterproofing prevents the escape of moisture from the concrete surface and it collects underneath the waterproofing, moistening the paper base and after a day or two causing a decrease in the gauge insulation to earth.

REFERENCE

- (1) LUCAS, J. C. and NEWSHAM, R. The use of electrical resistance strain gauges on concrete structures. *Engineering*. Vol. 176, No. 4577. 16th October 1953. pp. 487-488.

Contribution by J. J. Trott, B.Sc., A.Inst.P.

(Road Research Laboratory, D.S.I.R.)

The technique described in the paper for cementing resistance strain gauges to concrete is of great interest to workers on problems of stresses in concrete structures, particularly to those who can carry out loading tests under controlled laboratory conditions.

At the Road Research Laboratory we have not been successful in attaching gauges with nitro-cellulose cement to concrete road slabs. In such severe conditions of exposure the cement is attacked by moisture; its electrical insulation falls to a low value and it may even peel off the slab. We have found that strain gauges may be cemented to concrete road slabs in the open air using Araldite "D", even under unfavourable weather conditions. The technique used is as follows: the concrete surface is first ground smooth, and dried out with a heater lamp; the surface is then wiped clean and degreased with trichloroethylene; a layer of Araldite "D" is applied and cured at about 100°C with the heater lamp; when this has hardened, the gauge is cemented to the hardened layer, and covered with a further coating of Araldite after attaching the leads; a protective layer is built up over the soldered joints by using Araldite stiffened with Distrene powder.

The curing time for each application of Araldite is 20–30 minutes, and the gauges are ready for use as soon as the concrete has cooled to the ambient temperature.

In general, foil-type strain gauges have been used in the past in this way, but recent experiments suggest that wire-type gauges are equally satisfactory, provided the paper backing is entirely encased in Araldite. Gauges installed on road surfaces by this technique can be made completely waterproof, are also extremely robust mechanically and have withstood the passage of vehicle wheels over them without damage.

As to methods of measurement, it is not clear from the paper what strain sensitivity is required by the authors for their work. In work on concrete, if large compressive strains are to be measured, a range of about $1,000 \times 10^{-6}$ is required and a strain sensitivity of about $\pm 10 \times 10^{-6}$ would probably be adequate. If, on the other hand, the main interest is in measuring tensile strains, as in our work on concrete road slabs, a much higher sensitivity is required since the tensile strain in concrete at failure is only about 100×10^{-6} . It is, therefore, desirable to measure tensile strains to about $\pm 1 \times 10^{-6}$.

At the Laboratory we have found it convenient for static tests to use a bridge consisting of the "live" and "dummy" gauges and two matched fixed resistors. A known voltage is applied to the bridge and the out-of-balance voltage is measured with a precision vernier potentiometer, using a sensitive galvanometer to indicate the null point. The strain is determined in the following way.

For one "active" gauge, if the resistance is R , and the change of resistance due to a strain s is dR then, for

small resistance changes, with a bridge voltage V , and a resultant out-of-balance voltage change of dV :

$$dV = \frac{V}{4} \frac{dR}{R}$$

If the gauge sensitivity factor is K ,

$$\frac{dR}{R} = Ks$$

thus

$$dV = \frac{V}{4} Ks$$

and

$$s = \frac{4}{VK} dV$$

The vernier potentiometer in use measures dV to the nearest micro-volt; thus, if V is made 4 volts, and with gauges having a value of K of about 2, a strain of 1×10^{-6} gives a change of reading of about 2 micro-volts. The advantages of this method are:

- (1) the possibility of error through accidental alteration of a "balancing" potentiometer during a long test is eliminated;
- (2) the use of a precision potentiometer combines high strain sensitivity with a very large range of possible measurement.

Its main disadvantage is the necessity for accurate measurement of the bridge voltage V , but this can be measured on the same potentiometer as is used for the measurement of dV .

Reply by the authors

The authors thank the contributors for commenting on the paper and including useful remarks on their own experiences with e.r.s. gauges on concrete. The paper is restricted to the use in the laboratory of bonded-wire gauges and nitrocellulose adhesive, but the contributors' remarks on other types of gauge and adhesive and on field testing are very useful.

Professor Evans emphasized the need for ensuring that the layer of adhesive between the brass foil and the concrete is uniform and as thin as possible. This requirement also applies to the adhesive between the gauge and the foil, and to the gauge-to-concrete adhesive when the foil is dispensed with. While the authors agree that the need for care and skill cannot be too strongly emphasized, they feel that the only important disadvantage of using the foil with nitrocellulose adhesive is the time required for complete drying of the foil-to-concrete adhesive.

Statements in the paper as to the time required for thorough drying of nitrocellulose adhesive at room temperature have received comment, and Professor Viest has quoted a minimum drying time of 24 hours. This is a much shorter time than the authors have found necessary for reliable strain measurements. There is also some evidence to suggest that a much longer period than that usually recommended is necessary. Unpublished tests made by the Admiralty have shown that gauges attached

to mild steel with nitrocellulose adhesive require 10 to 14 days at room temperature to reach stability.*

Dr Peattie favours the use of heat to accelerate drying, but the authors consider that heating should be avoided if possible. There are circumstances where gentle heating can be used without fear of undesirable effects on the concrete, but the possible effects of heating are not always small. In particular, they can be important when gauges are attached to concrete at an early age, as is often done in laboratory tests. As mentioned in the paper, local heating can cause tensile splitting of the concrete, and the authors consider that heating should only be employed when the required insulation resistance cannot be achieved by storage at room temperature in the time available before testing.

Professor Viest's remarks on practice at the University of Illinois are very welcome. He mentions the use of 1 in. gauges on concrete of 1 in. maximum size aggregate when it is not possible to use longer gauges. It is doubtful, however, whether much importance should be attached to the strains measured in these circumstances; the work of Binns and Mygind suggests that errors as great as 40% can occur.

Dr Prentis's interesting explanation of the unbalancing effect of disconnecting an unserviceable gauge is sound for the simplified arrangement that he assumes for calculation but in practice the arrangement of the leads and bus-bars is generally far more complex. In particular, the resistances of the active gauges and their leads are generally unequal when many gauges are distributed over a large member. The point made by Dr Prentis in regard to the effect of a break in a gauge wire during a test emphasizes the need for separate circuits for gauges that are likely to fail in tension. In the authors' experience, it is very unusual for a gauge wire to break during a test, except when a tension crack occurs in the concrete beneath the gauge.

In reply to Mr Trott's query as to the accuracy of strain measurements, the authors normally measure strains to an accuracy of $\pm 5 \times 10^{-6}$ when using the circuit shown in Figure 3 of the paper. While agreeing with Mr Trott that the accuracy required for a particular purpose depends on the magnitude of the strains to be

measured, the authors regard the above-mentioned accuracy as adequate for most tests on concrete. Mr Trott has described how greater accuracy of measurement can be achieved using a vernier potentiometer. The authors question whether this method has any real advantages over using more accurate components in the circuit of Figure 3. As Mr Trott mentions, his equipment requires accurate measurement of the bridge voltage, which might vary during the course of a test, and the elimination of this requirement is one of the main features of the circuit used by the authors.

Some experience of using dental compound as a strain gauge adhesive has been obtained at the Building Research Station. The remarks of Mr Lucas and Mr Trott on their experience with nitrocellulose adhesive in exposed conditions are in agreement with the authors' view that this adhesive is unsuitable where moisture from the concrete has access to it. Dental compound has been used satisfactorily by the staff of the Station for short-term field tests⁽¹⁾ on masonry and has the advantages mentioned by Professor Evans. It has been used when gauges have had to be installed quickly and tests were required immediately after installation. The long-term stability of the compound has not been investigated at the Station.

When using Araldite it has been found necessary to take particular care in waterproofing. A thick layer of Araldite over the gauge, and particularly over the gauge connexions to the leads, appears to be necessary when a high standard of waterproofing is required. A difficulty experienced with "Strain Gauge Cement" is ensuring that the layer of adhesive beneath the gauge is thin and uniform, and in this respect Araldite is easier to apply.

Foil gauges have been used at the Station much less extensively than bonded-wire gauges. This is partly owing to shortage of supply, and the gauges have so far been used chiefly on steel. They have been found to be very satisfactory on steel encased in concrete when care is taken to ensure complete waterproofing by adequately covering the gauges with Araldite or "Strain Gauge Cement".

REFERENCE

- ⁽¹⁾ DAVEY, N. *Testing techniques used by the Building Research Station in the measurement of stresses.* RILEM Symposium on the Observation of Structures, Lisbon, October 1955. Paper No. 19.

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