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British Standard

Testing concrete

Part 206. Recommendations for determination of strain in concrete

Essais du béton
Partie 206. Recommandations relatives à la détermination des contraintes dans le béton

Prüfverfahren für Beton
Teil 206. Empfehlungen zur Bestimmung der Spannung im Beton

Foreword

This Part of BS 1881 has been prepared under the direction of the Cement, Gypsum, Aggregates and Quarry Products Standards Committee. It supersedes BS 4408 : Part 2 : 1969, which is withdrawn. All aspects of testing concrete are being included as Parts of BS 1881, from sampling fresh concrete to assessing concrete in structures. Part 201 gives general guidance on the choice of non-destructive test methods.

This Part describes several well-tried and accepted methods of measuring strain in concrete. There are other methods of measuring strain, some of which were described in BS 4408 : Part 2. These include: semiconductor element electrical resistance; piezoresistance semiconductor; photoelastic gauges, fibre optics; micrometers, etc. While these methods may have special applications, they are not suitable for general use with concrete and so are not discussed in this standard.

There is a tendency for results obtained from a strain gauge to be accepted without question. The warning applies generally that it is often necessary to measure stress induced strains of the same order as those produced by changes in ambient temperature. Consideration should be given to the characteristics and limitations of the various devices and systems to ensure valid results.

Compliance with a British Standard does not of itself confer immunity from legal obligations.

Contents

Recommendations

1 Scope

This Part of BS 1881 gives recommendations on methods and devices which can be used to determine strain in concrete. Some devices measure a property directly related to strain in the gauge (e.g. electrical resistance gauges) whereas others actually measure displacement, which can be used to determine strain using a known base length (e.g. displacement transducers). References to strain gauges in this Part include both types of device.

The use of the following devices is described:

(a) mechanical (including mechanical/optical);

(b) electrical resistance (metal and alloy elements);

(c) vibrating wire (acoustic);

(d) electrical displacement transducers.

NOTE. The titles of the publications referred to in this standard are listed on the inside back cover.

2 Definitions

For the purposes of this Part of BS 1881 the definitions given in BS 6100 : Part 6 apply, together with the following.

2.1 strain. Change in length per unit length in a specified direction, i.e. $\Delta L/L$, where L is the initial length in the specified direction and ΔL is the length change in that direction.

NOTE. In metric units strain is normally expressed in micrometres per metre, but in this standard the well-known colloquial equivalent 'microstrain' has been adopted.

2.2 gauge length. Length of the concrete over which the initial measurement is made.

NOTE. This length is usually only part of the whole length of the concrete unit, and only part of the length of the device.

2.3 dummy gauge. Nominally identical gauge, not subjected to strain, installed in the same environmental conditions as the gauges used to measure strain. Properly connected in the measuring circuit it will cancel out environmental effects on the measurement gauges.

2.4 discrimination. Smallest change in strain which can be indicated or estimated from the scale of a device.

2.5 gauge factor. Constant by which the reading from the gauge has to be multiplied to derive the strain.

3 General guidance

There are several aspects which are common to all gauges. The most important consideration for any type of gauge is that the operator should be experienced in its use. Characteristics and limitations of various devices and systems should always be carefully studied before choosing the most appropriate. Careful note should be taken of the manufacturer's instructions.

Owing to the different methods of application of these devices, there is no universal method of checking their accuracy. It is essential that the operator both be aware of the factors which will affect the accuracy and calibration of the device and, where possible, check that the device is correctly calibrated by a method traceable to the length standards maintained by the National Physical Laboratory. Electrical displacement transducers, for example, can be calibrated using a micrometer complying with BS 870.

It should always be borne in mind that a strain gauge measures the strain in the gauge length only. The necessity for care in locating the gauges onto (or into) the concrete cannot be over-emphasized, whether they be located on lugs, stuck to or clamped onto the surface, or cast into the concrete. The effects of local strain concentrations and gradients should be borne in mind.

For general purpose strain measurement of a concrete structure, a gauge length less than about four times the size of the largest aggregate particle is likely to be affected by local variations in the mix.

For measuring strains in different directions at the same location, electrical resistance gauges are available in the form of rosettes and can be used as single 2-way devices or single 3-way devices, depending upon whether or not the principal strain axes are known. Similar arrangements can be contrived with other gauges.

4 Common types of strain gauge and their use

4.1 Mechanical gauges

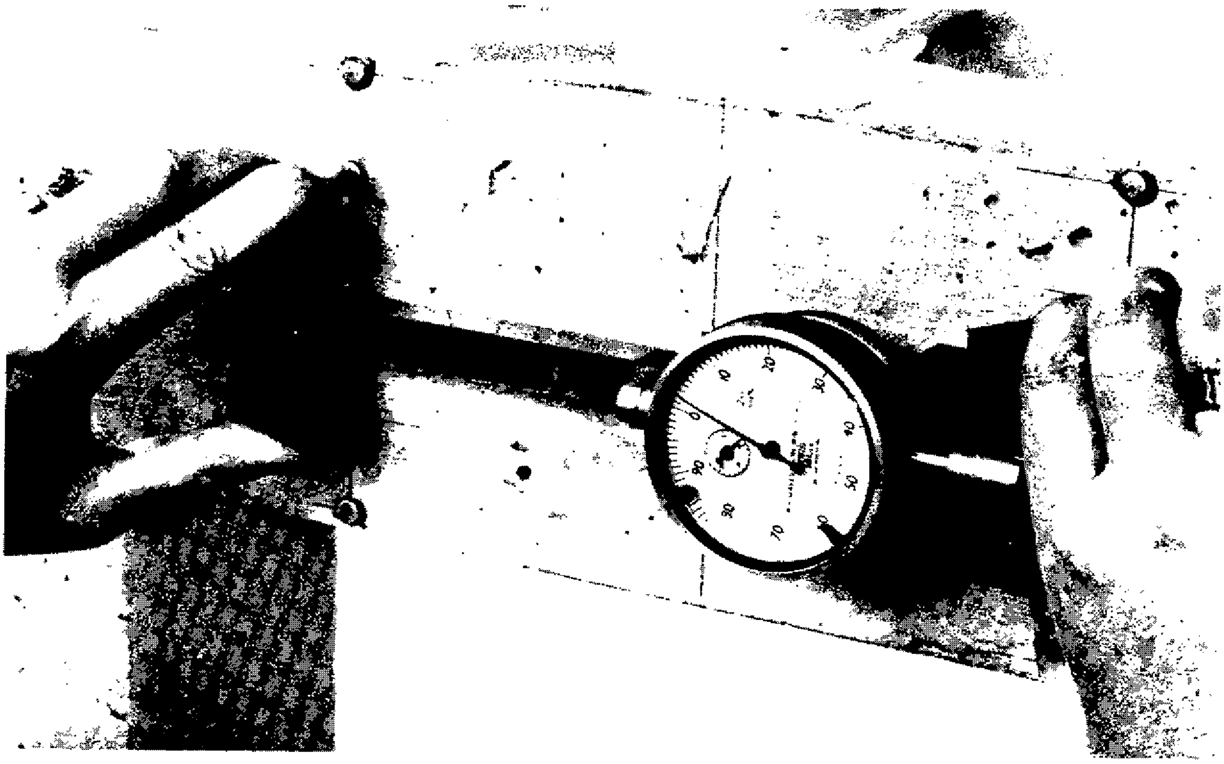
4.1.1 *Principle.* The movement at the surface of the concrete specimen is magnified by a lever or roller linkage and the magnified movement measured by means of a sensitive dial gauge (the most sensitive gauge complying with BS 907), an optical lever, a linear displacement transducer or other device. The gauge can be on a fixed plate or can be of the demountable type and held by hand against locating lugs, studs, balls or recesses stuck to or cast into the specimen (see figure 1(a)).

The strain is recorded as either a direct difference between two readings or the difference between the readings and those on a standard bar (usually invar) divided by the gauge length.

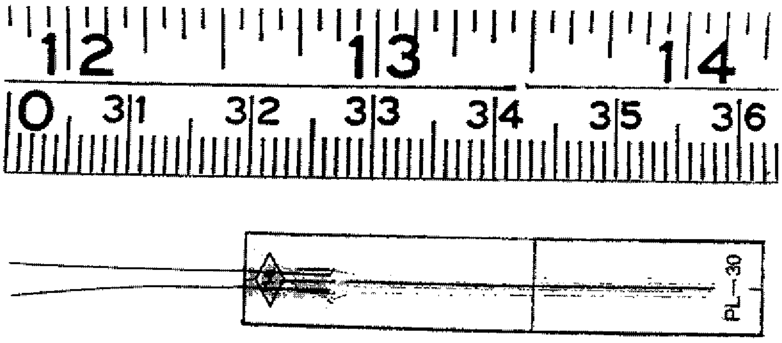
4.1.2 *Gauge length and discrimination.* Types of mechanical gauge are available in a wide range of gauge lengths, from 12 mm to 2000 mm. The discrimination of any type of gauge normally increases with gauge length and can vary from 50 microstrain to 2 microstrain per division of the scale.

4.1.3 *Mounting the gauge.* The studs, etc., should be so fixed that the gauge locates on the reference points symmetrically. Out-of-alignment can give misleading results. The adhesive chosen should be such, and applied in such a way, that the movement of the concrete is directly reflected in the movement of the reference points.

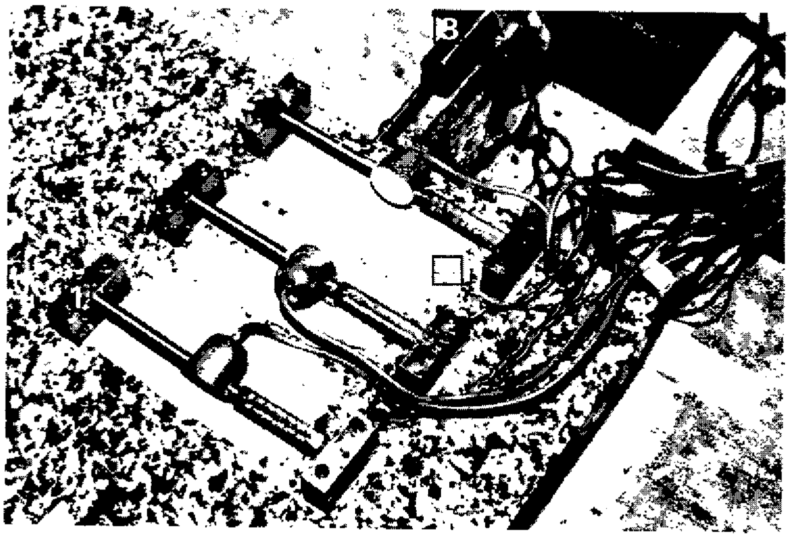
Sound parts of the surface should be chosen and prepared carefully by roughening and cleaning. To achieve reliable results, bubbles in the adhesive should be avoided. For long-term tests the reference points should be made of stainless



(a) Demountable mechanical gauge



(b) Typical electrical resistance gauge



(c) Vibrating wire gauges (1), electrical resistance gauges (2) and linear displacement transducer (3)

Figure 1. Types of device for measuring strain

steel and covered with a film of grease when not in actual use. Grease should be removed before taking readings. Under the conditions of exposure, neither the adhesive nor the reference points should be such as to creep, degrade or corrode. Cleanliness of the gauge and gauge reference points cannot be over-emphasized.

4.1.4 *Precautions.* For gauges which are clamped to the concrete, the pressure is critical. Most types of demountable gauges should be held with two hands, and with all types an even pressure should be maintained. It has been found that different operators can obtain different results and, therefore, if subsequent readings are to be taken at a later date, it is recommended that the same operator should, if possible, take the readings.

Temperature variations have to be taken into account, both in the concrete and in the instrument. Variation can be caused by handling, direct sunlight, etc. For this reason an invar steel bar is generally used either to form the main frame of the gauge and/or to check the gauge each time it is used.

To allow for the effect of possible wear in the instrument or the invar bar, the latter should be checked either after every 1000 readings or yearly, whichever represents the more frequent use, against a reference invar bar kept solely for this purpose.

When the concrete is heated by artificial means, the gauge should be thermally shielded and insulated.

4.2 Electrical resistance gauges (metal and alloy elements)

4.2.1 *Principle.* This type of gauge is in the form of a flat grid of wires, or etched copper-nickel foil mounted on thin plastics sheet, which is stuck to the test surface (see figure 1(b)). Strain is measured by means of changes in electrical resistance resulting from extension and compression of the gauge. The resistance changes can be measured by a single Wheatstone bridge, which can be connected to multichannel reading and recording devices. The relationship between strain and resistance for these gauges will be approximately linear and defined by the gauge factor.

Characteristics will vary according to the gauge construction, but foil gauges will generally be more sensitive than wire gauges and have a higher heat dissipation, which reduces the effects of self-heating.

4.2.2 *Gauge length and discrimination.* Commercial gauges are available in lengths from 0.2 mm to 150 mm, and their discrimination, depending on the measuring equipment, varies from 20 microstrain to 1 microstrain. These gauges are more often used than mechanical gauges over shorter gauge lengths.

4.2.3 *Mounting the gauge*

4.2.3.1 *Surface mounted gauges.* The location, mounting and protection of the gauge is critical. Care should be taken to ensure that:

(a) the surface is free of dirt, grease, laitance and loose material;

(b) the adhesive is carefully applied in a thin layer;

(c) the adhesive is free of air bubbles;

(d) the adhesive is fully cured, particularly in cold weather.

4.2.3.2 *Embedded gauges.* Suitably encapsulated gauges can be cast into the concrete. For guidance on the precautions to be taken see **4.2.4**.

4.2.4 *Precautions.* The relationship between strain and resistance will change with temperature, and gauges may be self-compensating or incorporate a thermocouple. Alternatively, a dummy gauge can be used. Gauges should be sited away from draughts and direct sunlight, although changes in ambient temperature will not normally affect readings over a small time-scale. Gauges should be waterproofed if they are subject to changes of humidity, or for long-term use.

Background electrical noise and interference will seriously affect the results. This may sometimes be reduced by suitable shielding, wiring systems and instrumentation. Constant calibration is needed to allow for drift.

Long-term instability of gauges and adhesives limits their suitability for long-term tests. The strain capacity will also generally be small unless special 'post yield' gauges having a high strain limit are used.

The use of these gauges requires considerable care, skill and experience if reliable results are to be obtained.

If the gauge is to be embedded, the elasticity of the encapsulated gauge should be made approximately equal to the elasticity of the concrete for the period over which the measurements are to be taken.

4.3 Vibrating wire (acoustic) gauges

4.3.1 *Principle.* A wire stretched between two points has a fundamental resonant frequency. Changes in strain will result in changes in the resonant frequency. This property is used to measure strain. The wire is excited by an electric pulse passed through an electromagnet situated close to the centre of the wire. The same magnet can then be used to detect and transmit the vibration to a frequency measuring device (see figure 1(c)).

4.3.2 *Gauge length and discrimination.* These gauges are commercially available in lengths from 12 mm up to 200 mm and have a discrimination of 1 microstrain to 10 microstrain.

4.3.3 *Mounting the gauge.* The gauge is either securely anchored onto supports fixed in the specimen, or cast into the concrete. In order to protect the wire against damage it is sealed in a tube of material, e.g. acrylic resin. If the gauge is to be cast into the concrete, then a careful and consistent procedure is important to ensure that the gauges are not displaced during concreting and that the concrete is fully compacted around them. It is often helpful to encapsulate the gauges before use in 'dog-bones' of matching concrete, which should have no sharp corners and an exposed aggregate finish.

4.3.4 *Precautions.* If the gauge is to be embedded, the elasticity of the gauge should be so selected that it approximates to the elasticity of the concrete for the period over which the measurements are to be taken. The assembly of a gauge and the materials and workmanship are all important: there is no substitute for experience when dealing with these gauges and the interpretation of the results obtained.

Avoidance of magnetic fields, magnetic particles, physical damage and corrosive influences, cannot be over-emphasized. Allowance should be made for the effect of temperature due to the slightly different coefficients of thermal expansion of the wire and the concrete.

4.4 Electrical displacement transducers

4.4.1 *Principle.* The movement of an armature is measured by its effects on the properties of a circuit in the main body of the transducer. Different principles are involved using changes in resistance, capacitance, inductance and so on. Each type of transducer requires compatible electronic equipment to provide the necessary input and convert the output to a reading (see figure 1(c)).

4.4.2 *Gauge length and discrimination.* Commercial transducers are available in a wide range of lengths and strokes. High discrimination is usually obtained with short strokes so the length and stroke should be chosen to suit the particular application.

4.4.3 *Mounting the transducer.* The transducer is fixed between gauge points located on the surface of (or embedded in) the concrete. An adjusting mechanism is usually incorporated so that the transducer may be zeroed before commencing a test.

4.4.4 *Precautions.* A large amount of electrical equipment is necessary for supplying the input signal and monitoring, modifying, filtering and amplifying the output signal. The user needs a great deal of experience if strains of the order of 10 microstrain are to be measured. For example, with many linear variable differential transformers (lvdt) the input signal usually has a low voltage (e.g. 5 V) and a frequency of the order of 1 kHz to 5 kHz. The response time of this gauge is directly proportional to this frequency, the measured frequency being up to one-quarter of the energizing frequency.

When dynamic tests are being undertaken and the rate of change of strain requires measurements at intervals closer than 0.004 s, then an input signal of higher frequency than 1 kHz should be used. This response time of the measuring instrument should also be carefully noted. For example, many lvdt's now incorporate their own oscillators and demodulators requiring a stable d.c. input and giving a d.c. output.

Accurate location of the gauge and fitting is important. The plate or disc which touches the end of the armature should be friction-free and should be fixed firmly to the concrete or to a reference device.

Screened cable should be used between the gauge and the monitoring device to counteract the effects of stray electromagnetic fields. The usual precautions, well-known to the experienced engineer, which are necessary when dealing with complicated electronic equipment should be observed.

5 Choice of device

Careful consideration should be given to the type of test, whether it is a laboratory or field test, short- or long-term, static or cyclic, and how rapidly changing if cyclic.

Any gauge can be used under laboratory conditions provided that the relevant precautions are taken. Mechanical gauges are preferred for tests carried out under outside exposure because of their robust nature and cheapness. Mechanical gauges are not suitable for embedment or use under water, where vibrating wire gauges are appropriate.

When a long-term test is undertaken, the effects of ageing and temperature on the performance of the gauge have to be considered. Some adhesives used in mounting gauges are subject to creep and chemical deterioration, and the supplier should be consulted about the performance of the adhesive under the expected conditions of test. Mechanical and acoustic gauges, or transducers, are preferred for long-term tests, where fatigue life is important.

Any gauge can be used for static tests, but the mechanical and acoustic gauges are not recommended for tests where the rate of change of strain is faster than 1 microstrain per second. Electrical resistance gauges or transducers are better for cyclic tests.

6 Report

The following information should be included in the report of the investigation:

(a) date, time and place of each test;

(b) description of the structure and its load history;

(c) locations of gauges, including whether surface or embedded, with a dimensioned sketch;

(d) details of the concrete, including its condition at the time of the investigation;

(e) environmental conditions;

(f) type of gauge;

(g) method of attachment, including adhesive description if needed;

(h) gauge length, discrimination and details of calibration;

(i) readings obtained and mean values, with appropriate measure of variation.

Publications referred to

BS 870	External micrometers
BS 907	Dial gauges for linear measurement
BS 1881	Testing concrete
	Part 201 Guide to the use of non-destructive methods of test for hardened concrete
BS 6100	Glossary of building and civil engineering terms
	Part 6 Concrete and plaster

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Committees responsible for this British Standard

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British Civil Engineering Test Equipment Manufacturers' Association
British Precast Concrete Federation
British Ready Mixed Concrete Association
Building Employers' Confederation
Cement Admixtures Association
Cement and Concrete Association
Cement Makers' Federation
Concrete Society
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Institution of Highways and Transportation
Institution of Structural Engineers
Institution of Water Engineers and Scientists
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