

# Testing concrete —

## Part 204: Recommendations on the use of electromagnetic covermeters

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# Committees responsible for this British Standard

The preparation of this British Standard was entrusted by the Cement, Gypsum, Aggregates and Quarry Products Standards Committee (CAB/-) to Technical Committee CAB/4, upon which the following bodies were represented:

Association of Lightweight Aggregate Manufacturers  
 Association of Metropolitan Authorities  
 British Aggregate Construction Materials Industries  
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The following bodies were also represented in the drafting of the standard, through subcommittees and panels:

British Nuclear Fuels Limited  
 United Kingdom Atomic Energy Authority

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## 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 It supersedes BS 4408-1:1969, which is withdrawn.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 and should be consulted for advice on methods which complement the measurement of cover to reinforcement or are useful as alternatives.

Electromagnetic covermeters have now been in use long enough for experience to have accumulated of applications for a variety of types of structure and under different conditions. Development of other forms of covermeter is in progress but no significant field experience is yet available.

A range of suitable devices is commercially available. Since the capabilities of these vary, the choice of instrument may be governed by the particular test conditions and information required.

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### Summary of pages

This document comprises a front cover, an inside front cover, pages i and ii, pages 1 to 8, an inside back cover and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

## 1 Scope

This Part of BS 1881 gives recommendations on and describes the principles of operation of electromagnetic devices that may be used for estimating the position, depth and size of reinforcement buried in concrete. It also describes their methods of use and applications, the accuracy to be expected and the factors which may influence the results.

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 6100-6 apply, together with the following.

### 2.1 actual cover

least distance,  $c_1$ , between the face of the concrete and the surface of the reinforcement as shown in Figure 1

### 2.2 indicated cover

distance,  $c_m$ , between the face of the concrete and a notional surface of the reinforcing bar under investigation as shown in Figure 1

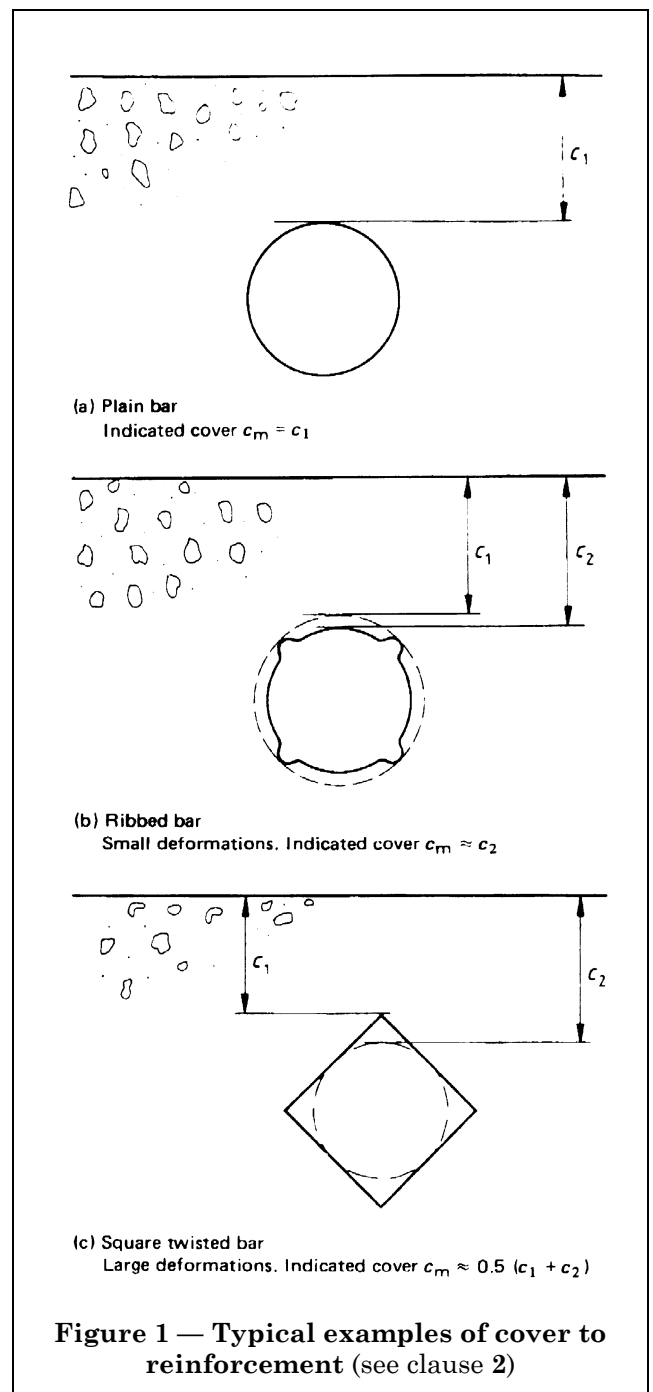
NOTE Where values of cover are required for compliance with specified cover to a bar of known cross section, the indicated cover has to be converted to actual cover by a method such as that described in 7.2 a).

## 3 Applications

Electromagnetic covermeters can be used for:

- quality control, to ensure correct location and cover to reinforcing bars after concrete placement;
- investigation of concrete members for which records are not available or need to be checked;
- location of reinforcement as a preliminary to some other form of testing in which reinforcement should be avoided or its nature taken into account, e.g. extraction of cores, ultrasonic pulse velocity measurement or "near-to-surface" methods;
- location of buried ferromagnetic objects other than reinforcement, e.g. water pipes, steel joists, lighting conduits.

NOTE Some devices may also detect non-ferromagnetic metal objects. Such use is outside the scope of this Part and reference should be made to manufacturers' publications.



## 4 Basic principles of the method

An electromagnetic field is generated by the search head (see clause 5). When a reinforcing bar or other metal object lies within this field, the lines of force become distorted. The disturbance caused by the presence of the metal in turn produces a local change in field strength as detected by the search head and indicated by the meter (see clause 5).

Both the orientation and the proximity of the metal to the search head affect the meter reading. It is therefore possible to locate reinforcing bars and determine their orientation. Cover to a bar may also be determined if a suitable calibration can be obtained for the particular size of bar and the materials under investigation.

With some devices it is possible, under ideal conditions, to estimate both bar size and cover when neither is known. (See appendix A.)

## 5 Apparatus

A number of suitable battery or mains operated covermeters exist. They comprise a search head, meter and interconnecting cable. The concrete surface is scanned with the search head kept in contact with it while the meter indicates by analogue or digital means the proximity of reinforcement.

The search head may consist of a single or multiple coil system. The physical principle involved can either be one utilizing eddy current effects or magnetic induction effects.

With covermeters based on the first principle, alternating. Instruments working on this principle operate at frequencies above 1 kHz and are thus sensitive to the presence of any conducting metal in the vicinity of the search head. Location of non-magnetic but conducting material is outside the scope of this Part of BS 1881. However, such instruments, being very dependent upon the conductivity of the material, may be very susceptible to changes in steel type (see 9.2.1) and special calibration may be needed.

With covermeters using magnetic induction, a multicoil search head is used with a lower operating frequency than the eddy current type of device (typically below 90 Hz). The principle used is similar to that of a transformer, in that one or two coils carry the driving current while one or two further coils pick up the voltage transferred via the magnetic circuit formed by the search head and embedded reinforcing bar. Such instruments are less sensitive to non-magnetic materials than those using the eddy current principle.

The meter should incorporate scales or digital display ranges (in this Part called scales), calibrated in accordance with clause 6, so that the indicated cover to the reinforcement can be read directly. The manufacturer's instructions should state clearly the conditions under which such scales are applicable. A reference scale, preferably linear, should also be provided for calibration by the user to suit particular conditions of use (see clauses 3 and 8).

The indicated cover to steel reinforcement, when the device is calibrated in the laboratory in the manner described in clause 6, should be accurate to within  $\pm 5\%$  or  $\pm 2$  mm, whichever is the greater, over the working range given by the manufacturer.

## 6 Basic calibration of the covermeter

### 6.1 General

Regular laboratory checks on the covermeter should be carried out to establish the accuracy of calibrated scale readings. The frequency of such checks will depend on the manufacturer's instructions and the condition of use of the covermeter, but it is recommended that they be carried out at least every 6 months. The dates of calibration should be recorded and kept with the covermeter.

The calibration should show that all meter measurements taken lie within the accuracy stated in clause 5. Instruments that do not comply should be returned to the manufacturer for adjustment.

Most covermeters in use are battery operated but, if mains operation is also available as an option, calibration accuracy should be checked under each type of power supply.

If different search heads are to be used with the same meter, calibration checks should be carried out for each head.

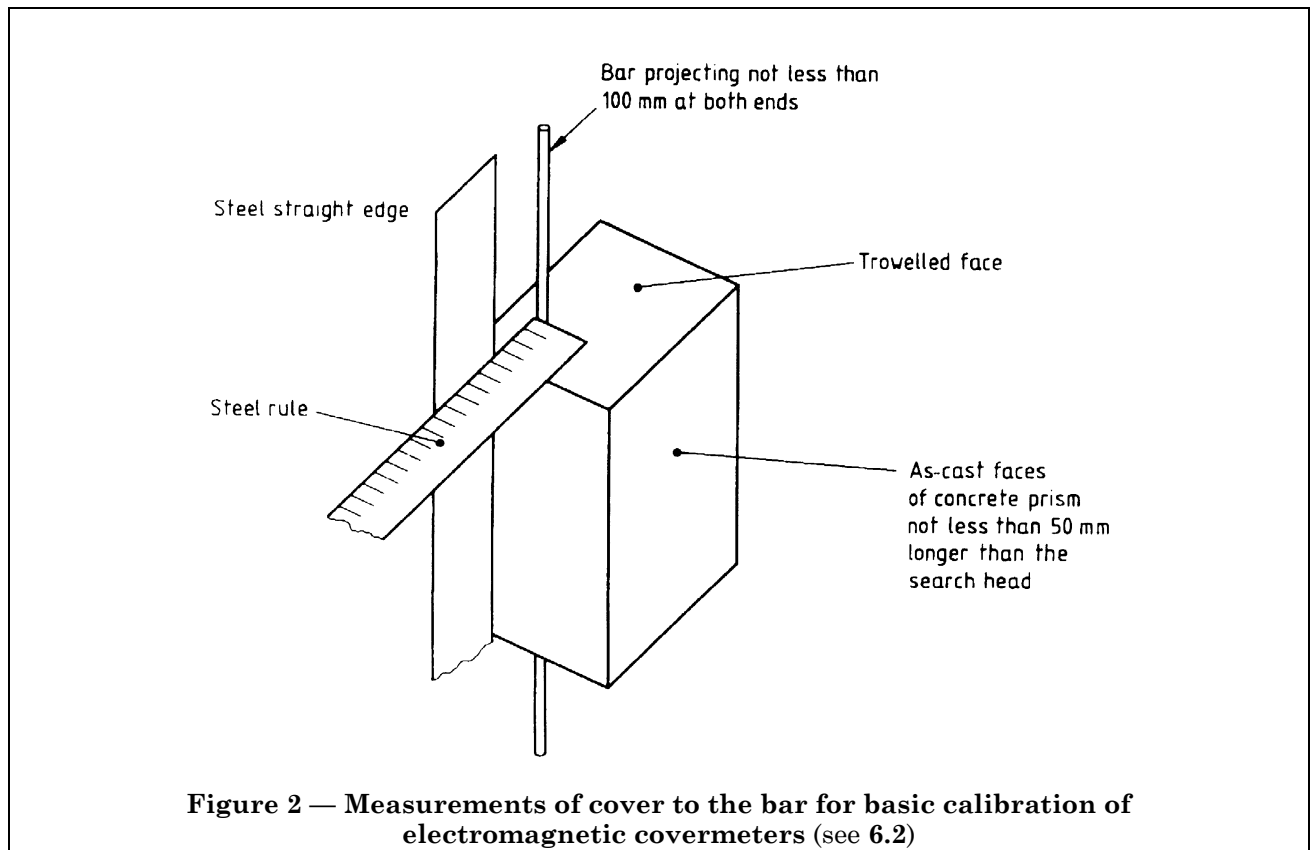
In some analogue instruments, a single calibrated scale is divided into sectors, each sector identifying a given indicated cover for a stated range of bar sizes. In such a case, a bar of the largest stated size at a given actual cover should produce a scale indication at the end of the relevant sector nearer to zero cover indication. Similarly, a bar of the smallest stated size will produce a scale indication at the end of the sector further from zero cover indication. Such sectors should not overlap.

The methods described in 6.2, 6.3 and 6.4 may be used in the laboratory. Suitable methods for routine site calibration checks are given in clause 7.

### 6.2 Method A

A straight, clean, smooth steel bar of the type designated by the manufacturer of the device is cast off-centre in a concrete prism, in such a position that the range of actual covers from the as-cast faces extends through the manufacturer's stated range of operation of the device. The minimum cover is 12 mm (see Figure 2). For checking smaller covers directly use method B or C.

The flatness of the mould faces should be such that no part of any cast surface of the prism deviates by more than 0.5 mm from the mean surface.



The concrete should have an ordinary Portland cement content between  $300 \text{ kg/m}^3$  and  $400 \text{ kg/m}^3$  and the aggregate should not have significant magnetic properties. No additions should be used in the concrete. Care should be taken during casting not to bend the bar.

After curing and demoulding the specimen, the actual cover to the bar is measured to an accuracy of  $\pm 0.5 \text{ mm}$  from the working faces at both ends of the prism. If the two measurements from one face to the bar do not differ by more than  $1 \text{ mm}$ , their mean is taken as the actual cover. If the difference exceeds  $1 \text{ mm}$ , a new prism should be cast.

The covermeter is then used in accordance with the manufacturer's instructions to measure the indicated cover to the reinforcement on all moulded faces parallel to the bar, within the working range of the device and under conditions where extraneous effects on the magnetic field are at a minimum.

If separate scales are available for different bar sizes it is advisable to carry out the preceding calibration procedure using a range of calibration blocks incorporating bars of representative sizes. In each case the range of actual covers to the bar from the four faces should extend over the manufacturer's stated working range of the device, as indicated on the respective scale.

### 6.3 Method B

A bar as described in method A is moved across a table towards the search head and the actual cover compared with the reading on the appropriate calibrated meter scale.

It is essential that no metallic materials, e.g. nails or screws, are incorporated in the table top near the search coil. The search head should also be parallel to the bar and both search head and bar stationary when readings are made. The tolerances should not exceed those for method A.

### 6.4 Method C

A series of vertical holes is drilled in two opposite faces of a box such that a bar, as described in method A, can be placed horizontally at different distances from the top. The search head is placed over the line of holes and the actual covers compared with the readings on the appropriate calibrated meter scale.

It is essential that no metallic materials, e.g. nails or screws, are incorporated in the table top near the search coil or in the box. The search head should also be parallel to the bar and both search head and bar stationary when readings are made. The tolerances should not exceed those for method A.

## 7 Method of use

### 7.1 Preliminary procedures

The covermeter is switched on and the meter adjusted so that the needle on the indicator dial (analogue devices) corresponds to the appropriate calibration mark as indicated by the manufacturer ("zeroing" the instrument). In the case of digital indicating devices, the manufacturer's instructions on setting up the meter before the test should be followed.

In all cases this procedure should be carried out with the search head far removed from the reinforced concrete surface and in such a way that any other extraneous effects on the magnetic field are at a minimum. Rapid movement of the search head should be avoided as this can affect the "zeroing".

A warming up period may be specified by the manufacturer after which time a further adjustment should be made. In any case, measurements should not be taken before the "zero" reading is stable. During the period of operation, further frequent "zero" checks should be made.

For battery operated covermeters, an initial check on the state of charge of the battery should be made followed by further frequent checks during the period of operation.

The search head is then scanned over the surface of the concrete to be examined for the presence of reinforcement. If reinforcement exists below the surface and within the working range of the covermeter, this will be indicated by the meter.

### 7.2 Works or site calibration

It is strongly recommended that calibration checks be carried out on site using either of the methods described in 6.3 or 6.4 and the relevant calibrated scale(s). This is particularly important when the bar type is different from that used for the laboratory calibration.

Where this site calibration check is unsatisfactory or where bars are present of size outside the range of specific scales on the meter, or it is suspected that the concrete in the structure will significantly affect the results, calibration by either of the following methods will be necessary.

a) A series of test holes is drilled to the bars at positions relating to the full range of covers in the structure as indicated by the meter. Care should be taken not to damage the reinforcement. The distance between bar and concrete surface is then measured at each point. A measurement is also made with the covermeter at each position using the linear reference scale and a calibration curve constructed. In situ covers are then calculated using the reference scale readings and this calibration curve.

b) The calibration procedures described in clause 6 are adopted using bars of the known type and size and concrete of the same type as that under investigation. A calibration curve is then constructed using the linear reference scale.

Procedure a) may be more applicable to on site investigative work whilst procedure b) would be more likely to be suited to manufacturing processes such as those in precast concrete works.

It may be possible to take advantage of projecting reinforcement to check the performance of the covermeter.

### 7.3 Examination of the concrete

The search head is traversed systematically across the concrete and, where reinforcement is located, rotated until a position of maximum disturbance of the electromagnetic field is indicated by the meter. In such a position, under ideal conditions, the indicated cover to the nearest piece of reinforcement may be read if the bar size is known (see clause 9 for factors affecting readings). Further, the axis of the reinforcement will then lie in the plane containing the centre line through the poles of the search head.

Where reinforcement is not too congested, it is possible to map out all bars within the area under examination which lie sufficiently close to the surface. It may also be possible to determine positions of laps. If the bar size is known, the cover can be measured. If the cover is known, the bar size can be estimated. It cannot be too strongly emphasized that, for maximum accuracy, interference from other reinforcement or magnetic material has to be avoided. The amount and accuracy of information obtained will depend on the influencing factors given in clause 9 and the experience of the operator.



## 7.4 Additional procedures

Where accurate measurement of concrete cover to reinforcement is required in the range 0 to 20 mm the following procedure is recommended.

A 20 mm thick spacer of material inert to the covermeter, such as wood or plastics, is placed between the search head and the concrete surface. An apparent cover for the particular bar size is read directly from the meter and the indicated cover obtained by subtracting 20 mm from this value. This method is only suitable where the concrete surface is flat and smooth (see clause 9).

Where special probes are available for investigating shallow or closely spaced bars with increased accuracy, the manufacturer's instructions should be followed.

Depending on the device used and the reinforcement configuration, other techniques may be applied to extract a greater amount of information, such as the direction of reinforcement or both size and cover when neither is known. One such technique is given in appendix A. Another, referred to as the orthogonal technique, has been described by Das Gupta and Tam, and Tam et al (see publications referred to, inside back cover). The instrument manufacturer's instructions may refer to further techniques. It should be stressed, however, that only an experienced operator should use any of these methods.

## 8 Accuracy

Under the most favourable site conditions, indicated cover can be measured to an accuracy approaching that obtainable in the laboratory when the bar size is known. When the bar size is not known and a procedure such as described in appendix A is adopted, this level of accuracy may be reduced. The experienced operator may be able to counter the effects of some of the sources of inaccuracy by selecting the most appropriate combination of procedures.

While the accuracy of the covermeter should be within the limits given in clause 5, the accuracy of measurement likely to be obtained on the average site is within  $\pm 15\%$  or  $\pm 5$  mm, whichever is the greater, for reinforcement at covers of less than 100 mm.

Where influences occur of the type described in clause 9, accuracy of measurements of cover and bar size may be significantly less although the accuracy with which reinforcement can be located may not be reduced. The level of accuracy in such cases may be improved by making calibration test drillings.

## 9 Influence of test conditions

### 9.1 General

Potential loss of accuracy (which may be minimized by the experienced operator) is due to many extraneous factors affecting the magnetic field within the range of the covermeter and to other physical influences.

### 9.2 Steel

**9.2.1 Type.** Calibrated meter scales are generally valid for a particular type of steel (see manufacturer's instructions). The effect of different types of steel on the readings obtained is generally small but in special cases, such as high tensile prestressing bars, it may include errors as high as  $\pm 5\%$  or more. Where such materials are present, the calibration procedures described in clause 7 should be adopted.

**9.2.2 Cross section.** Calibration curves or scales derived for smooth bars can generally be used for ribbed bars. It should be noted that the minimum thickness of concrete between the bar and the surface will be the indicated cover less the height of the rib. The indicated cover in this Part is as defined in 2.2 and illustrated in Figure 1.

Where twisted section bars are present, significant errors may arise unless one of the calibration procedures described in clause 7 is adopted [see Figure 1 c)].

**9.2.3 Shape and orientation.** For accurate measurement of cover and size, the bar has to be both straight and parallel to the concrete surface.

**9.2.4 Multiple bars.** Closely spaced bars may have a significant effect on the measurements made. The manufacturer's recommendations should be followed in the case of closely packed perpendicular or parallel bar assemblies.

It is essential that measurements under these conditions are carried out by experienced operators. In the case of parallel bars, the cover at which the reinforcement detail becomes significant depends on several factors including the sensitivity of the device and the search head dimensions. As a general rule the accuracy of indicated cover measurements will be influenced whenever there is more than one bar within the detection range of the search head.

As the distance between parallel bars decreases a point is reached at which it is impossible to locate individual bars. Special probes may be available to improve the accuracy of indicated cover measurements and differentiation between individual bars in such cases.

In the case of bundled or lapped bars, it is recommended that separate calibration is carried out as described in clause 7.

**9.2.5 Tie wire.** Tie wire, particularly where close to the surface, can lead to misleadingly low cover readings for the main reinforcement. However, an experienced operator will be able to distinguish between the localized effects of wire, nails, etc., superimposed on the major reinforcement effects.

### 9.3 Concrete

**9.3.1 Aggregate.** Significant inaccuracies in indicated cover may arise when aggregates with magnetic properties are incorporated in the mix. Similarly, certain specialized floor finishes can render measurements inaccurate though it may still be possible for individual bars to be located.

In some cases calibrations carried out as described in clause 7 may assist but results from such methods should be treated with caution.

The presence of magnetic materials may be detected by placing the search head on the concrete at such a position as to be out of the range of influence of the nearest reinforcing bar and noting a reading on the meter.

**9.3.2 Matrix.** Variations in the magnetic properties of the cement and of any additions are likely to affect measurements of cover.

The comments in 9.3.1 with regard to calibration similarly apply.

**9.3.3 Surface finish.** Where rough or undulating surfaces occur, e.g. exposed aggregate finishes, the effect on indicated cover will be similar in magnitude to the surface irregularities within the area of the search head.

### 9.4 Temperature

Some search heads are sensitive to changes in temperature that may be caused by the operator's hand. Frequent zero adjustments should be made and the manufacturer's recommendations should be followed in these cases.

### 9.5 Extraneous effects

Interference effects will occur in the neighbourhood of metallic structures of significant size such as window fixings, scaffolding and steel pipes, especially when they are immediately behind the search head. The degree of influence will depend on the particular covermeter used but all are affected by either stray magnetic fields or electric fields or both.

In such cases reliable use of the instrument may be severely restricted.

### 9.6 Corrosion of reinforcement

Where significant corrosion to reinforcement has occurred, in particular, scaling and migration of corrosion products, misleading indicated cover readings are likely to be obtained.

## 10 Report

### 10.1 General

The report should state that the methods used are in accordance with those described in this Part of BS 1881. Where other specialized techniques are adopted, these should be clearly described.

### 10.2 Information to be included in the test report

The test report should include the following information:

- a) date, time and place of test;
- b) description of the structure or component under investigation;
- c) locations of test areas;
- d) details of the concrete in the test areas, with reference to possible influencing factors (see clause 9);
- e) make and type of covermeter used and date of last laboratory calibration;
- f) details of any site calibration procedures;
- g) measured values of indicated cover and/or bar size. Where these values are derived by calculation, this should be stated;
- h) the estimated accuracy of quantitative measurements;
- i) configuration of steel reinforcement, if required, including individual bar spacings. Sketches may assist here.

## Appendix A Method for determining bar size and cover when neither is known

This method can be used with meters having separate calibrated scales for different bar sizes. The range of covers over which the method is applicable will depend on the equipment being used.

Measurement of apparent cover to the bar is made using the method described in clause 6, the measurements being recorded, however, assuming each of the calibrated scale bar sizes in turn,  $x_i$ .

This procedure is repeated after inserting a non-metallic spacer of known thickness,  $d$ , between the search head and concrete face,  $y_i$ .

The first reading is subtracted from the second for each scale ( $D_i = y_i - x_i$ ) and the true bar size taken to be that on the particular calibrated scale for which the condition  $D_i = d$  is approached. A graphical technique may be helpful in increasing the accuracy of this method.

Once the bar size has been established, the indicated cover can be read off from the respective scale.

Under ideal conditions, an accuracy of better than 20 % can be achieved for both bar size and indicated cover using this procedure. The experienced operator will, by use of different thickness spacers and repeated measurements, often be able to improve on this level of accuracy. However, the effects mentioned in clause 9 may be particularly important here.

The method is unsuitable in the case of closely packed bar assemblies.



## Publications referred to

BS 1881, *Testing concrete*.

BS 1881-201, *Guide to the use of non-destructive methods of test for hardened concrete*.

BS 6100, *Glossary of building and civil engineering terms*.

BS 6100-6, *Concrete and plaster*.

DAS GUPTA, N.C., TAM, C.T. Non destructive technique for simultaneous detection of size and cover of embedded reinforcement. In: *British Journal of Non-destructive testing*, November 1983.

TAM, C.T., LAI, L.N., LAM, P.W. Orthogonal detection technique for determination of size and cover of embedded reinforcement. In: *Journal Institute Engineers Malaysia*, 22, 6, 1977.

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