BS 1881 : Part 205 : 1986
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British Standard

Testing concrete

Part 205. Recommendations for radiography of concrete

Essais du béton
Partie 205. Recommandations relatives à la radiographie du béton

Prüfverfahren für Beton
Teil 205. Empfehlungen zur Untersuchung von Beton mittels Röntgenstrahlen

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 It supersedes BS 4408 : Part 3 : 1970, which is withdrawn.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. BS 1881 : Part 201 gives general guidance on the choice of non-destructive test methods and should be consulted for advice on methods which can be used to complement radiographic examination.

The use of gamma rays and high energy X-rays for the location and identification of steel and voids in structural concrete makes it desirable to give guidance on the procedures to be used. It is hoped that a more unified practice will result amongst experienced radiographers working in this field. The recommendations are based upon current good practice and are designed to provide methods applicable to the investigation of concrete where radiography is suitable.

It is emphasized that the radiography of concrete falls within the scope of the Factories Acts and is controlled by the Ionising Radiations Regulations 1985. Detailed guidance on the application of these regulations and on general safety procedures is given in the 'Approved Code of Practice. The protection of persons against ionising radiation arising from any work activity' published under the authority of the Health and Safety Commission in 1985.

The recommendations do not lay down standards of radiographic image quality, which need to be agreed between the parties for each investigation. The examples of imperfections given in appendix B are to enable interpretation of radiographs to be understood and are not intended as criteria of severity of imperfections.

Where applicable, these recommendations follow those given in BS 2600 and BS 2910.

The photographs forming figure 7 are reproduced by kind permission of the United Kingdom Atomic Energy Authority.

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Contents

Recommendations

1 Scope

This Part of BS 1881 gives recommendations for the radiographic inspection of concrete. Up to approximately 500 mm thick, gamma ray sources are usually employed; above this thickness the use of high-energy X-rays is more appropriate. Recommendations are given on the factors which govern the quality of the radiographic image, namely the source characteristic, the arrangement of source, object and film in space, the film speed, the use of screens, the exposure time and the film development technique.

This standard is for the guidance of radiographers and the information of others involved.

NOTE 1. By law, radiography has to be carried out under the supervision of qualified personnel.

NOTE 2. Explanatory notes on the radiographic technique are given in appendix A, and radiographic examples are given in appendix B.

NOTE 3. 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 3683 : Part 3 apply.

3 Applications

Radiography is used to determine the presence of reinforcement and its approximate location and size, to observe the general condition of concrete, e.g. lack of compaction, and to locate voids in specific cases, such as grouting ducts.

4 Image quality

The required image quality in terms of the definition and contrast of the image depends upon the purpose of the investigation and should be the subject of mutual agreement between the contracting parties. The assessment can be based either on the use of trial exposures to provide an acceptable image quality or on the use of image quality indicators of a mutually acceptable type.

5 Equipment

5.1 Radiation sources

Suitable sources for the examination of concrete are listed in table 1; the source appropriate to the thickness of concrete to be investigated should be chosen.

Table 1. Suitable sources of radiation

Source	Approximate thickness of concrete	
	Minimum	Maximum
	mm	mm
60 Cobalt	125	500
192 Iridium	25	250
Linac, 8 MeV X-rays	500	1600

The thicknesses are those which in practice can be radiographed in a reasonable amount of time with sources currently available.

NOTE. The physical sizes of gamma ray sources are specified in BS 5288.

5.2 Type of film

The film should generally be of the medium speed or fast direct-type X-ray for use with lead screens or without screens. The manufacturers provide data sheets that relate film speed, exposure and radiation source to the material under investigation.

5.3 Lead intensifying screens

The thicknesses of lead foil screens used should be in accordance with table 2 (see also **A.2**).

Table 2. Thicknesses of lead intensifying screens

Source	Thickness of front screen	Thickness of back screen
	mm	mm
Gamma rays	0.10 to 0.25	0.12 to 1.20
Linac (8 MeV)	0.5 to 1.0	0.5 to 1.0

5.4 Cassettes

The film and intensifying screens should be enclosed in a flat, rigid, metal or plastics light-tight cassette having sufficient compression to ensure adequate film-screen contact.

6 Procedure

6.1 Marking out

In general, permanent markings on the test piece should provide reference points for the accurate relocation of the position of each radiograph.

6.2 Specimen-to-film distance

The distance between the film and the adjacent concrete should be as small as possible.

Where a gap between the concrete and film exists, the minimum source-to-film distances derived in accordance with **6.5** should be increased in the ratio $a + b$: a, where a is the thickness of the concrete and b is the width of the gap.

6.3 Alignment of the beam

The beam of radiation should be directed to the middle of the section under examination and should be normal to the material surface at that point, except in a special examination for certain imperfections which it is known would be best revealed by a different alignment of the beam, e.g. examination of multiple grouting ducts, whose images would otherwise overlap.

6.4 Overlap of film

Where it is necessary to overlap film, the overlap should not be less than 10 % of the film length or width, and film marking should demonstrate continuity of examination on both front and rear faces of the concrete.

6.5 Source-to-film distance

The geometric unsharpness (see **A.6**) should not be greater than 0.75 mm. The minimum source-to-film distance, f, in millimetres, is calculated from the following equation.

$$f = \frac{(d + 0.75)t}{0.75}$$

where

d is the source diameter (in mm);

t is the object-to-film distance (in mm).

Where the object-to-film distance is unknown, then t can be taken as half the concrete thickness, T, from which f can be calculated using the following equation.

$$f = \left(\frac{d + 0.75}{1.5}\right) T$$

Table 3 gives source-to-film distances for various sizes of source.

Table 3. Source-to-film distances

Source diameter	Distance
mm	mm
2	$3.67 \times t$
3	$5.00 \times t$
4	$6.33 \times t$
6	$9.00 \times t$

The source-to-film distance can be reduced by mutual agreement between the contracting parties if a greater geometrical unsharpness can be tolerated, bearing in mind the related factors of exposure time and size of film irradiated.

6.6 Processing

The film should be processed in accordance with recognized good practice. A recognized type of X-ray film developer should be used and the processing solutions should be maintained in good working condition. Either the film or the processing solution or both should be agitated during development. The development time and temperature should be in accordance with the film manufacturer's recommendations.

The radiographs should be free from imperfections due to processing, pressure marks or other artefacts which would interfere with interpretation. Any such marks should be indicated by the radiographer in the report.

6.7 Density of radiograph

In the image of the concrete examined, the film density corresponding to the sound material should not be less than 1.5 nor greater than 3.0. These values are inclusive of a fog density, which should not be greater than 0.3. (See also **A.5**.)

6.8 Viewing

A viewer designed for the purpose should be used. The radiograph should be examined by diffused light in a darkened room and the illuminated area should be masked to the minimum required for viewing the radiographic image.

The luminance (or brightness) of the radiograph of mutually agreed density should be such that it can be satisfactorily interpreted; it should not be less than 10 candelas per square metre (10 cd/m^2) and should preferably be greater than 100 cd/m^2. (See also **A.4**.)

Guidance on spurious effects, such as processing imperfections, that could be misinterpreted may be found in the appropriate film manufacturers data sheets.

6.9 Identification of the radiograph

Each concrete element examined should have symbols affixed to identify:

(a) the part being radiographed;

(b) the position of the radiographic film.

The symbols, consisting of lead letters, numerals or geometric shapes, should in general be placed on the film side of the concrete, care being taken to reverse numbers and letters to ensure that the film reproduces the symbols the right way round.

An accurate record of exposure geometry should be kept, with the time and date of exposure.

6.10 Identification and location of reinforcement and defects

When neither the size nor position of reinforcement or defect is known, stereoscopic radiographs should be taken. A photogrammetric technique* should then be used to obtain this information from the radiograph.

*A suitable technique is described by W. Watson in Wiltshire, W.J., ed, 'A further handbook of industrial radiology', Arnold, 1957.

7 Precautions

7.1 Protection

As exposure of any part of the human body to ionizing radiation can be highly injurious, it is essential that wherever radioactive sources are in use, adequate precautions should be taken to protect the radiographer and others in the vicinity. Such precautions should involve the careful regulation and supervision of operating conditions and procedures, including, for example, the provision of adequate shielding and the use of barriers, warning notices and sufficiently large areas of restricted access.

NOTE. Further information on the risks associated with the use of sealed radioactive sources in industry are dealt with in 'Ionizing Radiations: Precautions for Industrial Users', New Series No. 13, HMSO. By law, dosemeters, suitably calibrated, have to be used to measure the amount of radiation and establish the area dangerous to personnel (see figure 1).

7.2 Interception of scattered radiation

Scattered radiation can arise from structures adjacent to or behind the concrete being examined. It is essential that sufficient lead screening, whose position can be determined experimentally, be provided to offset this.

8 Report

8.1 General

The report should affirm that the radiographic inspection was carried out in accordance with this Part of BS 1881.

8.2 Information to be included in the test report

The following information should be included in the test report:

(a) date, time and place of investigation;

(b) identification of work piece and the position of the radiograph on the structure;

(c) technique used;

(d) symbols used to identify radiographs;

(e) object-to-film distance or concrete thickness;

(f) type and diameter of source used;

(g) source-to-film distance;

(h) name of film;

(i) exposure in becquerel hours for gamma sources or in grays at 1 m for high voltage sources;

(j) sketch of exposure geometry, indicating position of source with reference to film and object;

(k) indication of any processing or pressure marks, etc.

Appendices

Appendix A. Explanatory notes on the radiographic technique

A.1 General

The techniques represent a balance between many factors.

While some latitude may be permissible in the techniques recommended, it will be found that an alteration in any one factor will, in general, involve changes in other factors such that the overall result may be worse than before.

A.2 Lead intensifying screens

NOTE. See **5.3**.

Although X-ray films are sensitive to gamma rays, and can, therefore, be used alone to record the image, it is usual to expose them between intensifying screens, as these usually reduce the exposure required.

Metal-foil intensifying screens consist of thin sheets of metal, usually lead, and usually mounted on thin card. They are used in pairs, one being in contact with each side of the X-ray film. The closeness of contact between screen and emulsion, and the cleanliness of the screen and freedom from scratches and other surface marks, are important points to which attention should be paid.

Metal screens emit electrons under irradiation and the action of these electrons on the film contributes to producing a chosen density of radiograph with a shorter exposure time than if no screens were used. The front screen also helps to reduce the amount of scattered radiation generated in the material and reaching the film.

In general, the thickness of lead intensifying screens to be employed is not critical. A thicker front screen tends to absorb more scattered radiation but gives a smaller intensifying factor. This additional filtration is sometimes employed with advantage on material of irregular section.

The thickness of the back screen, also, is not critical, provided it exceeds 0.12 mm.

A.3 Continuous examination

For continuous examination the source may have to be moved to cover adjacent areas. Attention should be paid to the geometry to ensure that no section is left unexamined. In this case, complete coverage can be shown by placing markers on the source side of the concrete.

A.4 Viewing

NOTE. See **6.8**.

To achieve a value of 10 cd/m^2 in viewing a radiograph of density 3.0, the luminance (or brightness) of the illuminator needs to be 10 000 cd/m^2. For critical viewing, complete darkening of the viewing room is essential.

A.5 Density of radiograph

NOTE. See **6.7**.

Optical density is expressed as $\log_{10}$ of the ratio of the intensity of the incident light to the intensity of the emergent light (see BS 1384). With films of density 1.0 or 2.0 the transmitted light has an intensity of 1/10 or 1/100 of its original value respectively. Densitometers are available commercially for density measurement; alternatively, a visual comparison can be made using a calibrated density step-wedge.

The fog density of the film should not be greater than 0.3. With direct-type film the contrast increases with film density up to the highest densities.

A density of 3.0 represents the usual limit of most film viewing equipment, but higher densities can be used with advantage where the viewing light is sufficiently bright to permit adequate interpretation.

A.6 Source-to-film distance

NOTE. See **6.5**.

To obtain the best definition, the geometric unsharpness should be as small as possible, but in any case it is desirable that it should not exceed the inherent unsharpness of the film-screen combination.

An improvement in sharpness may result from the use of larger source-to-film distances than those calculated in accordance with **6.5**.

The geometric unsharpness should be calculated using the following equation.

$$\text{Geometric unsharpness} = d\left(\frac{t}{f-t}\right)$$

where

d is the source diameter (in mm);

t is the maximum object-to-film distance (in mm);

f is the source-to-film distance (in mm).

The use of a greater source-to-film distance than the recommended minimum may often be more convenient, as a larger area can thereby be examined in one exposure. On the other hand, the total time of examination can often be appreciably reduced by examining shorter lengths of concrete at each exposure, and using a correspondingly shorter source-to-film distance, bearing in mind the variation in film density.

The application of the recommended minimum distance depends on the knowledge of the effective size of the source of radiation, which should be taken as the greatest projection dimension.

A.7 Exposure time

The exposure time is proportional to a function of the concrete thickness. It is also proportional to the film speed, the square of the source-to-film distance, and the inverse of the source strength. Exposure time may extend over a period of hours.

Appendix B. Radiographic examples

B.1 Grouting flaws

In post-tensioned prestressed concrete the prestressing wires are contained in ducts which are usually preformed by a duct lining. The duct is subsequently grouted and the grout should completely fill the duct. Imperfections in this duct can take the form of settlement, which leaves a gap at the top of the duct (which may be filled with air or water) as shown in figure 2, or an air or water pocket entrapped in the grout, as shown in figure 3, or a void near the anchorage of prestressing wire as shown in figure 4.

B.2 Compaction

Incomplete compaction or honeycombing is shown in figure 5.

B.3 Joints between concrete units

Figure 6(a) shows radiographically the defects in the joint illustrated photographically in figure 6(b).

B.4 Heavy section concrete

The photograph in figure 7(a) shows the general layout for the investigation of a road bridge using high energy X-rays from a Linac. The bridge was especially closed for the occasion and the work consequently undertaken at night to minimize dislocation of traffic. Figure 7(b) shows the placing in position of a recording film underneath the bridge.

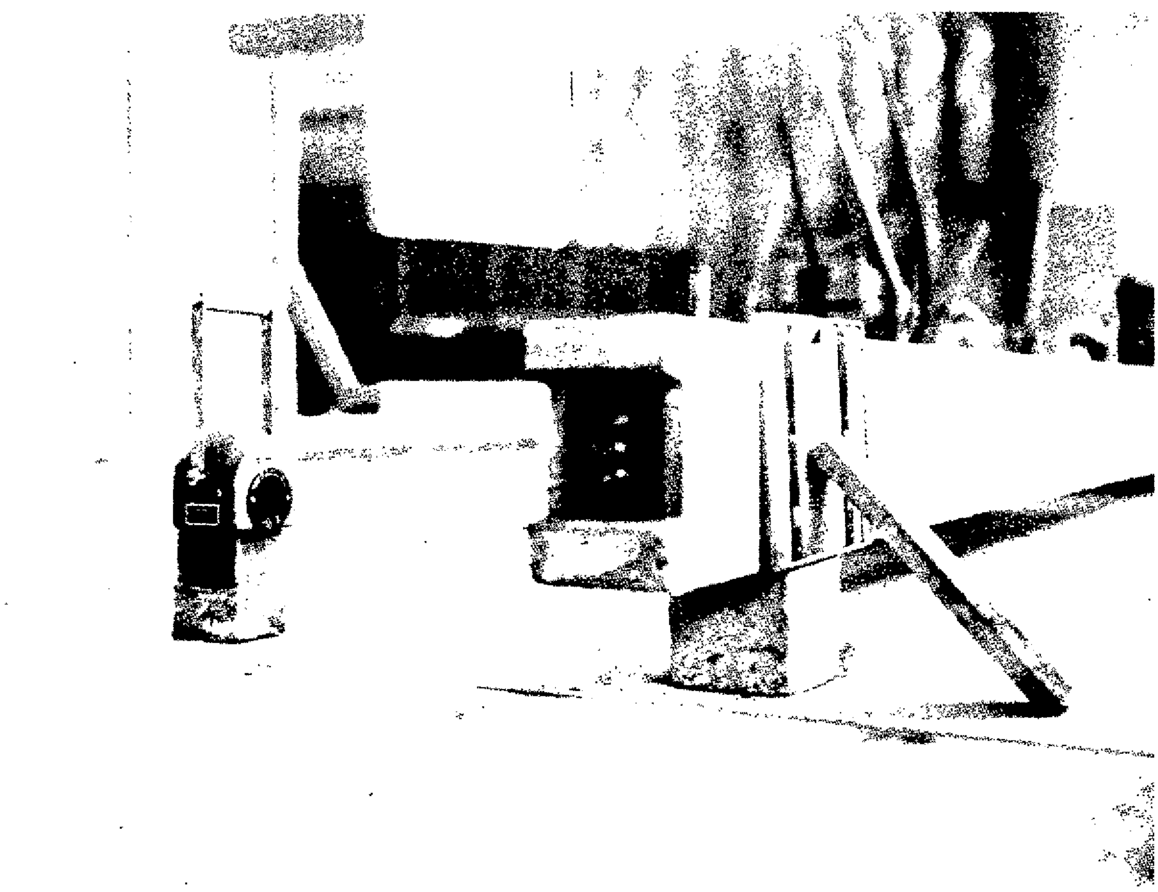


Figure 1. Typical arrangement for gamma radiography

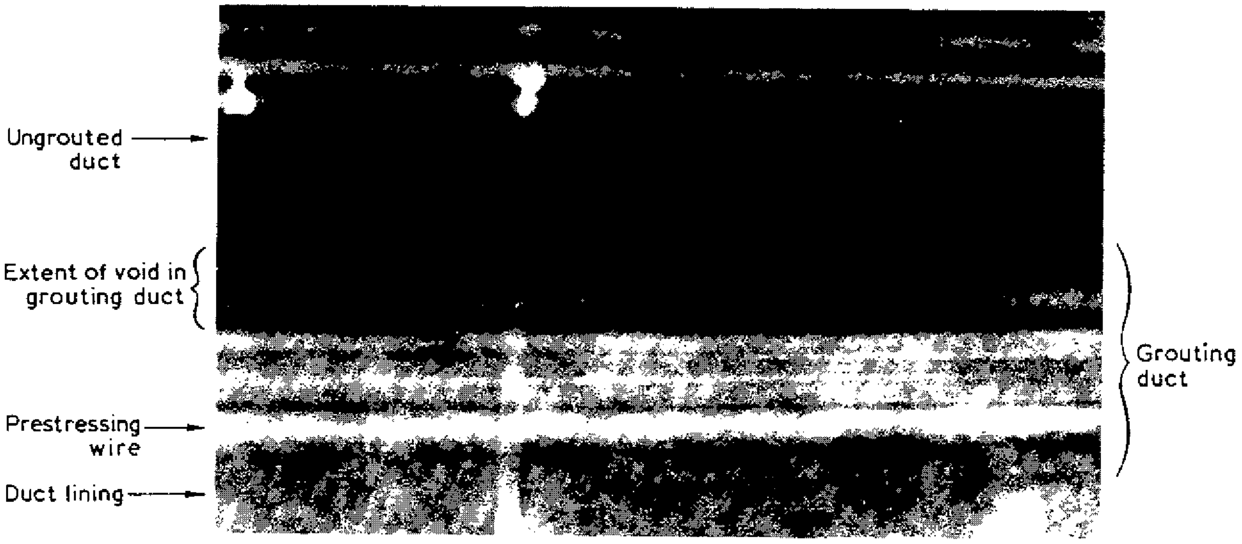
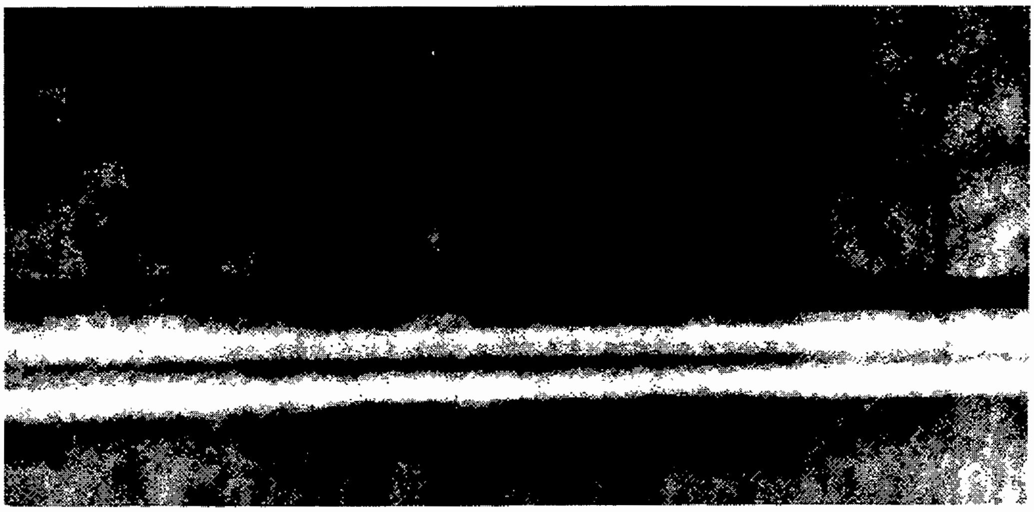
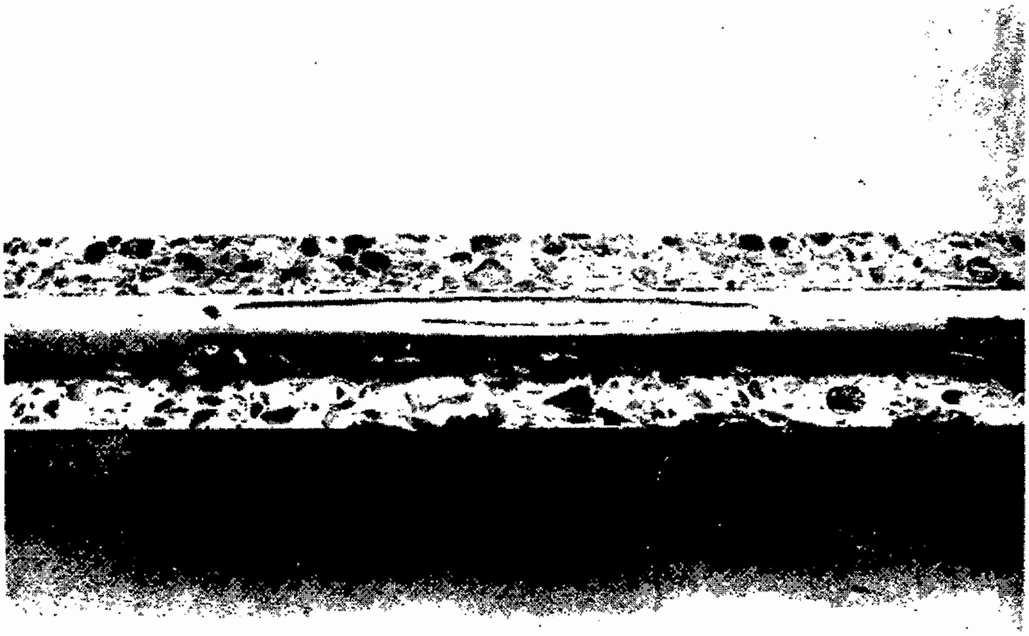


Figure 2. Radiograph of ungrouted prestressed concrete duct and partially grouted prestressed concrete duct

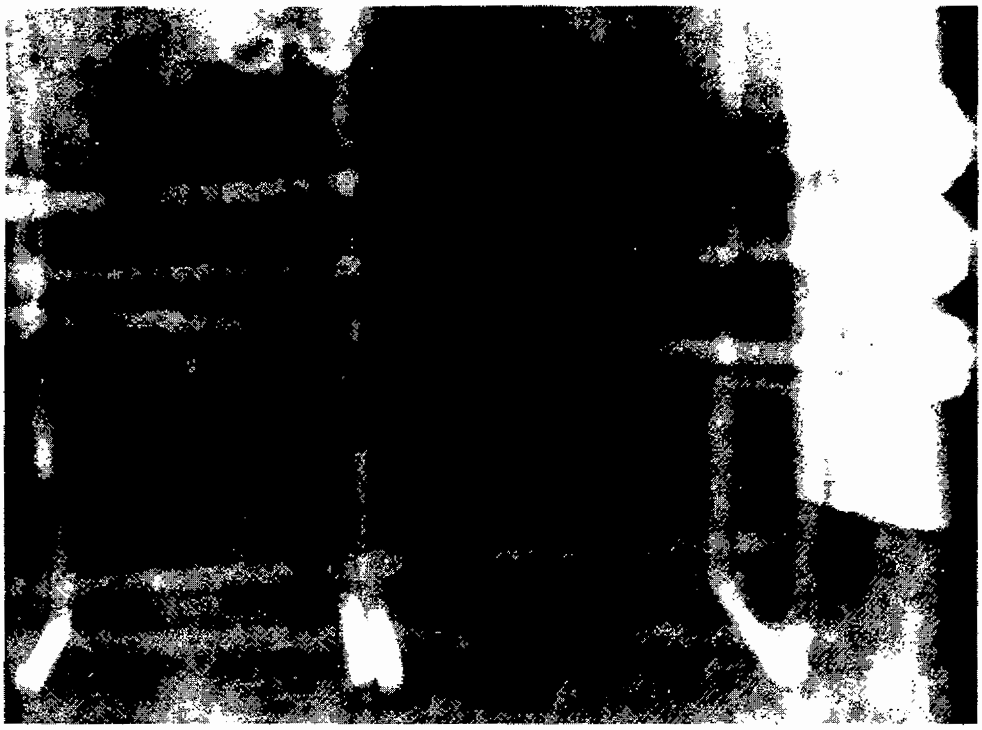


(a) Radiograph of part of the prestressed beam section shown in (b)

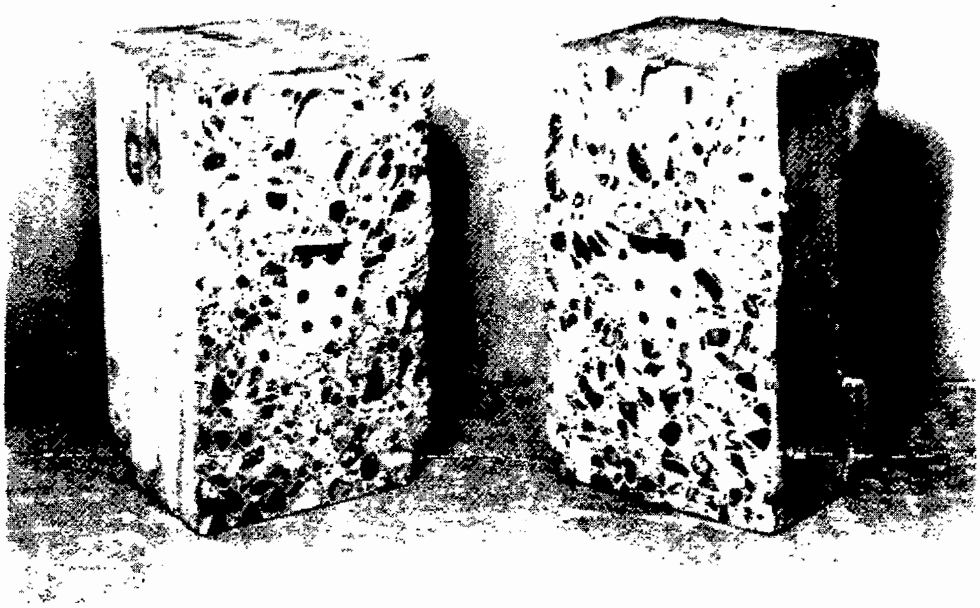


(b) Sectioned beams with grouting fault exposed

Figure 3. Grouting fault and its radiographic representation



(a) Radiograph of the anchorage of a prestressed concrete beam shown in (b)



(b) Sawn section of prestressed beam end

Figure 4. Grouting void and its radiographic representation

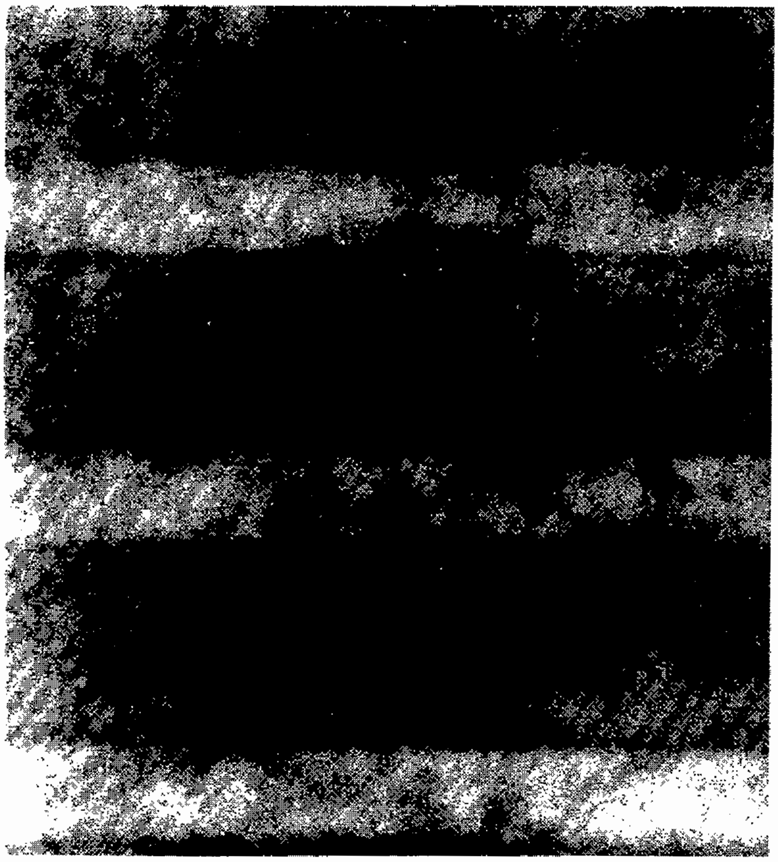
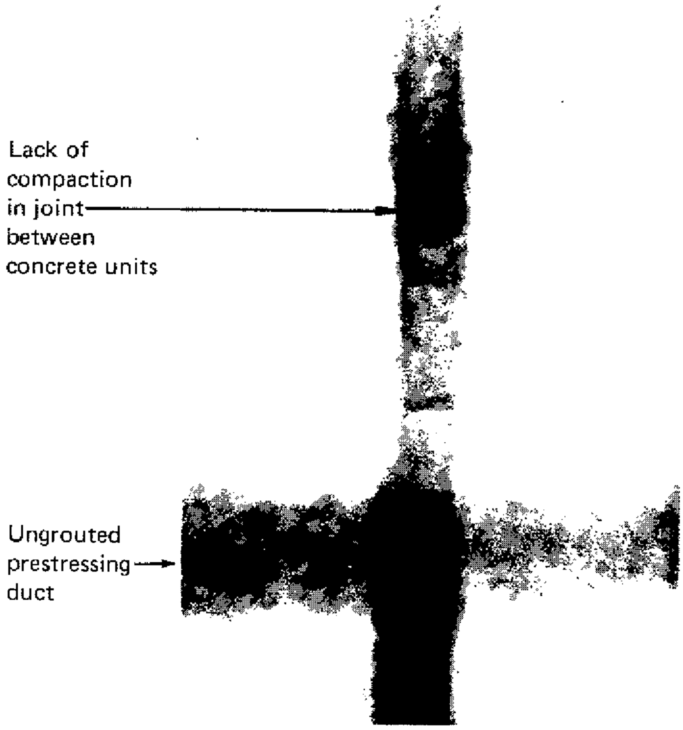


Figure 5. Radiograph of poorly compacted concrete



(a) Radiograph of the joint defects shown in (b)

(b) Joint defects

Figure 6. Joint defects and their radiographic representation

(a)

(b)

Figure 7. Typical layout for Linac radiography

Publications referred to

BS 1384 Photographic density measurements

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

BS 2600* Radiographic examination of fusion welded butt joints in steel

BS 2910* Methods for radiographic examination of fusion welded circumferential butt joints in steel pipes

BS 3683 Glossary of terms used in non-destructive testing
Part 3 Radiological flaw detection

BS 5288 Sealed radioactive sources

Wiltshire, W.J., ed, 'A further handbook of industrial radiology', Arnold, 1957

'Approved Code of Practice. The protection of persons against ionising radiation arising from any work activity' Health and Safety Commission†

'Ionizing Radiations: Precautions for Industrial Users', New Series No. 13, HMSO†

*Referred to in the foreword only.

†Available from HMSO, 49 High Holborn, London WC1.

This British Standard, having been prepared under the direction of the Cement, Gypsum, Aggregates and Quarry Products Standards Committee, was published under the authority of the Board of BSI and comes into effect on 28 November 1986.

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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
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
County Surveyors' Society
Department of the Environment (Building Research Establishment)
Department of the Environment (Property Services Agency)
Department of Transport (Highways)
Department of Transport (Transport and Road Research Laboratory)
Electricity Supply Industry in England and Wales
Federation of Civil Engineering Contractors
Greater London Council
Institute of Concrete Technology
Institution of Civil Engineers
Institution of Highways and Transportation
Institution of Structural Engineers
Institution of Water Engineers and Scientists
Royal Institution of Chartered Surveyors
Sand and Gravel Association
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