Department of Transport
Scottish Development Department
Welsh Office
Department of the Environment for
Northern Ireland

BRIDGE INSPECTION GUIDE

Her Majesty's Stationery Office 1983
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County Surveyors Society
British Railways Board

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Introduction

In the United Kingdom there are approximately 150,000 highway bridges with a replacement value at 1981 prices of about £15,000,000,000. Bridges are key elements of the road network by virtue of their strategic location, and because of the unfavourable and costly consequences when they fail or when their capacity is impaired. Inspection is an essential part of their maintenance which must be done systematically and not just confined to those occasions when there is breakdown or failure. Inspection also has a valuable part to play in providing data for assessing the load carrying capacity of a structure and in providing a feedback of information into design and construction practices.

This guide is concerned with the inspection of bridges during their service lives after their construction and the associated contract maintenance periods. It attempts to set out in a logical way the essential information which will assist the bridge inspector in doing his job and thereby tries to fill a gap in the available technical literature.

CHAPTER 1:

Inspection and Reporting

In 1976 a Research Group of the Organisation for Economic Co-operation and Development (OECD) published a report on Bridge Inspection which, among other things, reviewed bridge inspection procedures in member countries and gave recommendations and guidelines for the future.

Following publication of this report and its recommendations, Technical Memorandum BE4/77 'The Inspection of Highway Structures' was issued by the Department of Transport. This sets out procedures for inspecting and reporting on trunk road (all purpose) and motorway bridges in England and Wales. Its use was recommended for other bridges. Four categories of inspection are defined in the memorandum, the definitions being those used in the OECD report: Superficial Inspection, General Inspection, Principal Inspection and Special Inspection. This Memorandum is being revised and it is hoped to issue a new Departmental Standard by the end of 1983.

The Guide is concerned mainly with the General and Principal Inspections which are described collectively as routine inspections. General Inspections are made at intervals not exceeding 2 years by observation from ground and deck level, and from any fixed walkways or travelling platform built into the structure. Principal Inspections require close examination of all parts of the structure at intervals not exceeding 6 years and suitable access is needed to enable this to be done. Special Inspections are made when some particular problem needs investigation and the Guide makes brief reference to situations where such inspections may be required. Special Inspections are also needed after flooding, after severe accidental damage and sometimes after the passage of an exceptional load. In movable bridges, the inspection of mechanical, electrical and hydraulic equipment will usually be done by specialists. Superficial Inspections are a quick check for damage or obvious faults and are made during the course of other duties; visits are not usually made solely for this purpose.

1.1 Routine Inspection

1.1.1 Bridge inspection is an important task, and though much of the work is of a repetitive nature, an alertness for spotting the unusual is needed. Cracking or spalling of concrete, movement, distortion, water or rust staining, breakdown of paint, corrosion of steel, cracking at or near welds, loose bolts or unusual noise can be the first indications of more serious trouble. The value of regular inspections depends largely on detecting defects at an early stage. This reduces the risk to users and often enables repairs to be made at lower cost.

1.1.2 The essential tasks of a bridge inspector are to observe and record the condition of a bridge and to transmit the appropriate information to the bridge engineer. This enables the engineer to assess the condition of the bridge in terms of load carrying capacity, in terms of durability of the structure and its components, and in terms of the maintenance and remedial work required to keep the bridge in a satisfactory condition. A broad understanding of the way in which bridges are designed and constructed to carry their loads will help in the effective inspection of bridges. An appendix to this Guide is intended to assist in this understanding.

1.1.3 The equipment needed by the bridge inspector is fairly simple and may include the following:

Personal equipment:
- protective clothing (see 3.5.2(c) and (d))
- clipboard with waterproof covering (for inspection forms) and writing materials (pen, pencil and chalk)
- pen-knife
- steel tape (2 m or 4 m)
- electric torch
- haversack or shoulder bag for equipment (to leave both hands free)
- mirror
- first aid materials

Technical equipment (as required)
- binoculars
- spirit level
- plumb line
- straight-edge with feeler gauges or a tapered wedge
- visual crack-width gauge
- illuminated magnifying glass and scale
- light tapping hammer
- underwater probing rods
- indelible marker
- scraper and emery paper
- plastic jars and heavy duty plastic bags for samples
- camera with flash equipment, colour film and clearly marked scale
- sectional ladder

Other more specialised equipment such as a fillet weld gauge, a paint thickness gauge, a depth of cover meter for reinforcement and tell-tales (with adhesive) may be needed on occasions.

1.1.4 Routine inspection consists mainly of a visual examination of the structure and this should be made in good light. The examination should be thorough and systematic; a casual approach can result in evidence of incipient defects being missed. It is expected that attention will be concentrated on faults and defects, but it should be appreciated that a certain number of them will occur as part of the process of normal wear and weathering and that some othes arise from causes that are difficult to foresee. The observations made may be influenced by the weather, for example, narrow cracks in most materials can be found more easily when the surface is dry, and in concrete even more easily when nearly dry, but the full extent of water leakage shows only after rain.

1.1.5 It may sometimes be desirable to supplement the visual inspection by measurements and observations such as:

measurement of the surface gap width of any wide cracks (eg in concrete, cracks which are wider than 0.3 mm)

fixing of tell-tales where the continued opening of cracks in concrete or masonry structures is suspected

tapping of concrete surfaces with a light hammer to detect, by the 'ring', whether lamination has occurred

measurement of out-of-flatness or out-of-straightness deformations in steel structures by means of a straight-edge and either feeler gauge or tapered wedge

measurement of the size of any defective fillet welds by means of a fillet weld gauge

examination of welds and adjacent areas for hairline cracks using an illuminated magnifying glass

use of paint thickness gauge when examining the protective system

local removal of paint by scraper or emery paper when examining the effectiveness of the protective system. This should be done only when the stripped area can be made good after the examination

use of tapping hammer for checking the tightness of riveted and bolted connections

removal of samples such as broken concrete, corrosion products, paint flakes, deposits and contaminants for further examination.

1.1.6 The condition of any maintenance or repair work previously done on the structure should be carefully examined and reported. Special attention should be given to this aspect of inspection since it will provide guidance on the most effective materials and techniques for dealing with defects in the future. Any maintenance work recommended at the previous inspection but not yet carried out should be noted.

1.2 Preliminaries

1.2.1 Before going to the site, reference should be made to relevant information already available in the central bridge office, on bridge record cards, on bridge registers and computerised data banks, and on as-built drawings. The inspector should familiaries himself with the details of the structure and how it is intended to function and he should note any particular features to be observed. A copy of the last inspection should be studied so that the condition of defects previously noted may be checked. Basic information on the structure, as listed below, should be inserted in the inspection form as required:

The bridge number

The bridge name

The location of the bridge, that is, either the gride reference, a small scale map showing the position, or an accurate description of the position giving road numbers and distances to the nearest junction etc.

The function of the bridge, eg 'carrying the M1 over the railway'

The type of bridge, eg masonry arch, reinforced concrete or M-beam deck on reinforced concrete piers, steel box girder, plate girder etc (see appendix A)

General dimensions, including overall length, overall width, width of carriageway, number and length of spans, whether spans are square or skew, skew angle, depth and width of beams or girders

Type of foundation

Materials of construction

Components, noting the make and type of expansion joints, bearings, waterproofing, parapets, guard rails etc

Services carried across the bridge

Date built

Examination of this data will provide the background to the inspection and will show whether there are any special problems which need to be discussed beforehand with the engineer responsible for the structure.

1.2.2 The programme of bridge inspection should be planned and the optimum sequence of operations determined to ensure thoroughness and to minimise time and cost. Advantage should be taken of any circumstances which will facilitate the work such as the erection of scaffolding for repair work on the bridge, the closure of traffic lanes or carriageways for road works, periods of drought (or spring tides in estuarial waters) which will reveal foundations or scour, and painting of steelwork which gives opportunity for examining the condition of the steel. Where possession of a motorway traffic lane is needed, it will usually be necessary to co-ordinate this with other work and to avoid daily or seasonal peak traffic flows.

1.2.3 Where mobile equipment for under-deck inspection is to be used, the hourly cost of hire is high and the inspection should be carefully planned beforehand so as to minimise the time needed. A preliminary visit should be made to the bridge to determine the best positions for the inspection vehicle, to give reference numbers to the various components and to foresee as far as possible any problems that may arise. The engineer should be consulted about the ability of the deck to carry the vehicle particularly near the edge. During the inspection a camera, with flash equipment, should be used as a 'notebook' and this could be supplemented by use of a tape recorder. In some circumstances it may be economical for the inspector to have an assistant. A communication link between inspectors above and below the deck may assist in examinations for cracks, water leakage and other faults.

1.2.4 The land beneath some structures may be leased by the highway authority and used for agricultural or commercial purposes. It will then be necessary for the inspector to check the arrangements for access and, where necessary, give notice to the user of the land that an inspection is to be made. During the inspection a check should be made that usage of the underbridge area does not interfere with the drainage system, is not detrimental to the functioning or durability of the structure, does not create a fire hazard and does not produce an unfavourable appearance.

1.3 Making the Inspection

1.3.1 A careful check on the identity of the structure to make sure it is the correct one should be made. Mistakes can easily occur and records can be misleading. Unless the structure is already known, a quick look round will be needed to make sure that movement joints, bearings etc are correctly identified and that the orientation is correct for subsequent descriptive notes.

1.3.2 The effectiveness of an inspection depends entirely on conveying clear and accurate information to the engineer who has the responsibility of deciding on any action needed. Every point should be noted as soon as the observation is made, never trusting to memory. After noting details of the defect, the notes should be checked to make sure that the engineer will gain the correct impression from them. In addition to recording defects or damage, their absence should also be recorded or the fact that previously noted defects have been made good.

1.3.3 The weather at the time of the inspection and during the previous few days should always be noted. Rain, wet surfaces or poor light can affect the observations and the width of a crack or joint may be dependent on the temperature. Apparent changes in condition between one inspection and the next can sometimes be due to different weather conditions at the times inspections were made.

1.3.4 A routine for inspection should be established. For example, it may start with the foundations, noting any evidence of movement, settlement or undermining. The abutments and wing walls would be dealt with next, then the piers, columns and the bearings on the top of the abutments and piers. This would be followed by the soffit of the deck including all longitudinal beams and girders, the fascia beams at the edges, and expansion details underneath the deck. The bridge deck would be examined next dealing with the condition of the surfacing, kerbs, drainage, expansion joints and parapets not forgetting the approaches to the bridge. Finally, any superstructure above deck level, including the girders, suspension towers and cables etc would be examined.

1.4 Underwater Inspections

1.4.1 Structure located in water, particularly where strong currents are present should always be regarded as susceptible to scour which, by removing material from river beds and banks, may undermine foundations. If probing indicates a likelihood of scour or if the water is too deep (even when at low level due to tide or drought) to permit probing inspection, a detailed inspection should be carried out by a diver but this is possible only if there is slack water or slow current.

1.4.2 It is essential that underwater inspection is only entrusted to competent people, experienced in this kind of work, who are fully briefed on the components to be inspected and the nature of defects to be expected. Any cavities should be examined with caution because of possible instability and because small cavities may harbour conger eels.

1.4.3 The inspection should include a detailed survey of the river bed in the vicinity of the structure to determine the locations, profiles and extent of any bed degradation. A detailed examination should be made of the condition of abutments or piers and their foundations.

1.4.4 Close circuit television may be used where the water is sufficiently clear. The systems consist of a self-propelled camera unit which is moved underwater to the area to be inspected and the picture is transmitted to the surface. Where visibility is poor, or conditions are difficult, portable echo sounding equipment can be used to provide a reasonably accurate profile. The diver requires no special skill to operate the camera; he simply places the frame over the target and pulls the trigger. The surface monitor and use of 2-way transmitters facilitates communication with the diver. Without close circuit television the diver must rely on simple notes and crude sketches made under water, as an aid to remembering exactly what has been seen. Remote controlled video systems with recording facilities may be used but are expensive.

1.4.5 If despite the fullest underwater inspection there is still concern for the safety of the structure, it will be necessary to lower the water level by pumping in conjunction with bagging or a cofferdam.

1.5 Assessment of defects and reporting of results

1.5.1 It is recommended that defects should be assessed according to their severity and extent. Both aspects are relevant to decisions about maintenance and their use avoids any blurring of the distinction between, for example, a single but severe defect and extensive but superficial deterioration. The following scales are suggested:

Extent —
- A. No significant defect.
- B. Slight, not more than 5 per cent affected (of area, length etc).
- C. Moderate, 5 per cent to 20 per cent affected.
- D. Extensive, over 20 per cent affected.

Severity —
1. No significant defects.
2. Minor defects of non-urgent nature.
3. Defects of an unacceptable nature which should be included for attention within the next two annual maintenance programmes.
4. Severe defects where action is needed (these should be reported immediately to the engineer) within the next financial year.

1.5.2 The results of the inspection should be reported in the manner required by the owner or the maintaining authority probably using standard forms. One version, used for motorway and trunk road bridges in England and Wales, is the Department of Transport's Inspection Report form BE10 (DB) a copy of which is reproduced in Appendix C.

1.5.3 Where the report form requires only a single marking for the condition of each part of the structure, it is still useful to consider severity and extent separately as an aid to making the correct assessment. The severity scale usually prevails when marking the form and, in the DTp Inspection Report form, the good, fair and poor markings correspond to categories 1, 2 and 3 respectively in the severity scale given in para 1.5.1. A special note should be made of defects requiring urgent action. The extent of the defect and any relevant circumstances such as restraint to movement should be noted.

1.5.4 Great care should be taken in filling in forms, as an accurate and consistent record of defects found is essential for comparison with previous forms and in the future with subsequent forms to show if the bridge condition is changing. This is a further reason for noting the extent of each defect at all inspections.

1.5.5. Sketches or photographs should be used to illustrate defects. Sketches should be made at the site and will normally be freehand, approximately to scale but with dimensions to show the size and location of the defect. For greater clarity it may sometimes be necessary to redraw the sketches later in the office. Photographs should preferably be in colour and should always include a clearly marked scale, the reference number of the bridge and location of the defect. The latter information may be written on the structure in chalk before taking the photograph but the bridge should not be left looking as if covered in graffiti.

1.5.6 The reports of the General and Principal Inspections taken together should provide a continuous record of any changes in the condition of the bridge and the assessment markings for both types of inspection should be made to the same standards. For the General Inspections, the location and orientation of all defects not previously reported should be described or sketched with sufficient accuracy to enable them to be identified as defects already in existence at the next inspection. It should always be kept in mind that personnel will change from time to time and the records must be clear to the newcomer. For the Principal Inspections the reporting will be more comprehensive. Full use should be made of sketches and photographs to record the condition of the whole structure.

1.5.7 Defects in bridges are discussed in Chapter 2. Some of the features, in the various types of structure, which should receive particular attention during the inspection are listed in the Annex to Chapter 2. This list is given to assist in the inspection but should not be regarded as a comprehensive check list, since unusual or unexpected defects occur from time to time.

1.6 Training of staff

Staff involved in bridge inspection should receive training if the high standards required are to be achieved. Periodic cross checking is desirable to ensure that all involved in inspection and maintenance are working to consistent standards.

DEPARTMENT OF TRANSPORT

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Corrections:

Page 13. Para 2. 3. 7. C, 2nd word.
Insert 'should' *in place of* 'can'

Page 18. Heading 2nd line, 3rd word
Insert 'GUIDE' *in place of* 'MANUAL'

Page 41. Para B2.8, line 14 to 16
Replace the sentence
"The colour of . . . . . . purple"
by "The colour of any carbonated concrete is unchanged, but the uncarbonated material turns purple.

Page 41. Para B2.11 Heading
Insert "Measurement" *in place of* "Management"

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CHAPTER 2:

Faults and Deterioration

Defects are grouped under the four main headings of Foundations, Substructures, Superstructures and Components.

2.1 Foundations

The foundations of a bridge are basically the piles, pile caps, spread footings or any other means by which the loading from the substructure is transmitted into the ground.

a. Deterioration of foundations
It is not normally possible to inspect the foundations, but where they are exposed, for example in tidal waters, their condition should be checked. Concrete parts of the foundation may show cracking, erosion, disintegration or corrosion of the reinforcement (see para 2.3.1). Steel piles should be checked for corrosion and an attempt should be made to gauge the loss of thickness. It may be necessary to chip out corroded material in order to do this.

Timber piles are not often used nowadays, but they may be found in old structures. They suffer from attack by insects and by fungus and from other forms of deterioration (see para 2.3.4). If old timber piles are uncovered during the inspection, they should not be left exposed to the air longer than is absolutely necessary.

b. Scouring of river beds and banks
The removal of material from the beds and banks of rivers and from around the base of piers and protective works such as approach pitching may lead to subsequent undermining especially during floods. It is important therefore to look out for any changes in the river bed adjacent to and at a bridge, particularly after flooding.

c. Structural faults due to settlement of the foundations
In a few structures the movements may be sufficiently large to cause tilting, cracking or excessive movement at joints. These faults are usually due to causes such as the unpredicted settlement or failure of underlying foundation material, sometimes associated with the compression of weak layers of ground, underground workings, development of cavities in rocks, scour, frost action and changes in the water table.

The inspector should be on the lookout for any indication that the structure is in any way different from the 'as-built' condition, eg change of profile of an arch or outward movement of wingwalls in relation to abutments.

d. Differential settlement
Problems arise from the differential settlement of embankments and substructures. These appear as depressions in the road surface adjacent to the bridge deck. Settlement may introduce a risk of impact damage to the bridge from vehicles and cause discomfort and risk of accidents to the vehicles and their occupants. Sometimes transition slabs are used to reduce the effect of differential settlement between abutments and the approaches. Unfortunately these slabs, and their supports are often inaccessible for inspection.

2.2 Substructure

The substructure includes the abutments, wing walls, retaining walls, piers, columns and bank-seats. Construction materials are usually concrete, stone or brickwork, sometimes concrete with brick or stone facings and occasionally steel or cast iron (in old structures)

a. Faults in concrete
These include cracking, deterioration of the

concrete and corrosion of reinforcement. Corrosion may be a cause of cracking in some members, particularly vertical cracks in columns. In abutments, vertical cracks may accommodate some of the movement due to temperature changes. For further information see para 2.3.1.

b. Faults in masonry and brickwork
These include cracking, loss of mortar from pointing, loose or missing stones or bricks, weathering, spalling or splitting and growth of vegetation. For further information see para 2.3.6.

c. Drainage and water leakage
Surface water, often containing de-icing salt, may leak through the bridge deck and joints; ground water may leak through cracks, construction joints etc in the abutments. Water leakage may cause staining, corrosion of reinforcement, weathering and leaching of concrete and masonry (with associated formation of carbonated deposits and stalactites). Leakage is often due to blocked weep-holes, gutters or drains.

d. Movement of the substructure
This may be caused by movement of the foundations and may result in inadequate or abnormal clearance at the joint between the back wall or upstand of the abutment and the end beams or diaphragms of the deck.

e. Accidental damage
Vehicle impact may cause distortion, buckling or the removal of structural material. The condition of fenders or safety fences is important.

2.3 Superstructures

The superstructure is the main element of the bridge and many different forms are used, depending upon length of span, topography and other conditions. The following paragraphs discuss faults and deterioration of reinforced and prestressed concrete, steel beams, girders and trusses, timber, cast and wrought iron, masonry and brick arches, cable-supported structures and movable bridges.

2.3.1 Reinforced Concrete

a. Cracking of concrete
Fine cracks may be apparent in most sound concrete surfaces, but those which normally concern the inspector are the ones which are visible to the naked eye on the surface of concrete, ie 0.1mm and wider, and which have some continuity and sometimes a pattern.

It is quite common to see a multitude of minor cracks when a wet concrete surface is drying but usually, unless they are visible in the dry surface, they are not significant. Ideally, a map of crack patterns should be prepared and information recorded of the size, distribution and penetration of the cracks.

The width of some cracks may vary with change of temperature while others may be tending to open progressively. Tell-tales may be used to find out whether movement is continuing. The type and pattern of cracking will provide the Engineer with some guidance as to its cause and the records should clearly distinguish between cracks transverse to the main reinforcement, cracks along and over reinforcing bars, diagonal cracks in webs of beams, closely spaced parallel cracks and cracks forming a network pattern.

A photographic record is useful particularly if significant cracks have been outlined in a distinctive material, such as chalk or paint. Spalling and staining of the concrete along cracks should also be recorded as well as the incidence of leakage.

b. Scaling of concrete elements
This is the gradual and continuous loss of surface mortar and of aggregate often as flakes. In some cases it may be aggravated by wearing of the surfaces. It is most commonly an indication of frost damage.

c. Spalling of concrete
This occurs when pieces of concrete become detached from the parent mass as a result of, for example, local overstressing or of corrosion of the reinforcement. It may also occur as a result of fire damage.

d. Corrosion of reinforcement
This is difficult to detect in the early stages, but it gradually leads to staining of the concrete surface and sometimes cracking will be produced along the line of reinforcement by the pressure of the increased volume of rusted steel. Such cracking eventually leads to spalling of the concrete and to exposure of reinforcement leading to even more extensive corrosion and serious loss of structural material. In some cases rust stains may arise from the residue of tie bars securing the shuttering which have been left in the concrete and this may in fact have no significant structural effect. They can also be caused by particles of iron pyrites in the concrete.

Some new bridges also have rusty lines on the soffit due to form work being marked by rust staining from the reinforcement prior to the placing of the deck concrete.

e. Leakage of water
This can take place at expansion joints and through concrete decks where waterproofing is absent or has failed. It will penetrate most readily at construction joints and areas of porosity particularly where the sections are thin. The leakage or seepage of water may dissolve out constituent chemicals from the hardened concrete. Its effects are evident by staining, efflorescence, encrustation at cracks and in the formation of stalactites. Apart from its adverse effect on appearance, it can in time present a corrosion threat to reinforcement, because of the gradual loss of alkalinity of the concrete.

f. Porous concrete
This is usually the result of poor workmanship during construction, for example where good compaction of the concrete is difficult, as is the case in densely reinforced beams and slabs in the corners of form work. The dangers here are from the ingress of air and water. Air will cause the concrete to carbonate and when this reaches the reinforcement, moisture will then cause corrosion. If the water is chemically aggressive, the reinforcement may corrode even before the concrete has carbonated. The water may also cause leaching (see para 2.2(c)) and frost damage to the concrete.

g. Wear of deck surface
In the rare cases where the deck concrete forms the running surface for traffic, it will be subject to wear and polishing. The extent of wear and the resistance to skidding should be checked periodically, but this may best be done as part of the inspection and maintenance procedure on the highway as a whole rather than as an inspection of the bridge.

h. Applied finishes
An applied rendering may become detached and decorative slabs may disintegrate or become insecure due to corrosion of fixing lugs. The removal of rendering reduces the cover to reinforcement.

j. Accidental damage
This can take a variety of forms, from extensive damage to overbridges by high vehicles, to local damage to expansion joints and kerbs by snow ploughs.

k. Chemical attack
In certain aggressive environments concrete may be subject to chemical attack which causes surface crumbling of material. Similar forms of deterioration can occur in less aggressive environments due to defective materials or workmanship.

2.3.2 Prestressed Concrete

Bridges in prestressed concrete may suffer from the defects described under reinforced concrete (para 2.3.1), but special attention should be paid to the following items:

a. Cracking and spalling of concrete
Prestressed bridges are normally designed to avoid cracks in the concrete and, accordingly, the development of cracks can have serious structural implications. Spalling of the concrete may sometimes occur with or without associated cracking. Again, the structural implications can be serious.

b. Condition of prestressing cables
It is usually impossible to make a visual check on the condition of the prestressing cables because they are embedded either directly in the concrete or in grouted ducts inside a reinforced concrete element. In the rare cases where cables with a protective covering are exposed, usually inside box girders, the condition of the protected cable should be inspected. Bulges in the covering may indicate a fractured wire and damage to the covering may cause corrosion. The inspection should be done with caution, particularly if fractures of wires have occurred or seem likely, and the Engineer should be consulted beforehand.

2.3.3 Steel Beams, Girders and Trusses

a. Condition of the protective system
Paint systems suffer from various forms of deterioration such as cracking, flaking, chalking and peeling and it is beneficial to detect the early stages of breakdown because of the substantially reduced amount of maintenance that is then involved in correcting defects. The accumulation of debris, bird droppings, etc is detrimental to paintwork. Paint films may mask small cracks in the steel which will become apparent only when preparing for repainting.

b. Corrosion
This is usually associated with the breakdown or inadequacy of the protective system. It is important to assess the magnitude, location and form of corrosion and to identify its cause. Corrosion conditions will be changed by water leakage on to the steel surface. Any loss of effective structural section should be assessed. Corrosion of steel encased in concrete may occur and any evidence of this should be looked for. Junctions of steelwork with masonry, concrete and other structural materials need to be given particular attention. Mating and rubbing surfaces require special attention because of the adverse conditions to which they are sometimes subject and because some of the critical areas are out of sight. Weathering steel gets its protection from build-up of a coherent rust film and any tendency for this film to flake off will undermine the protection.

c. Fracture
Fracture of any member, bolt, rivet or weld is obviously serious and can have important structural implications.

d. Cracking
Cracks are potential causes of complete fracture and usually occur at connections, at changes of sections and at flaws in the metal. In welded members cracks may start at welds and extend into the metal alongside. Initial welding cracks can escape detection at the time of welding but may be extended by loading in service. In riveted or bolted structures cracks usually start from the holes. Places where additional members have been added after initial construction are potential problem areas. If cracks are found in any part of the structure, there will be important implications for any other similar parts.

e. Deformation and distortion
Distortions may be present in members or plates for a number of reasons. They could be due to initial distortions and residual stresses, or to initial out-of-flatness or out-of-straightness of the component concerned before fabrication or to external impact damage or to buckling deformations

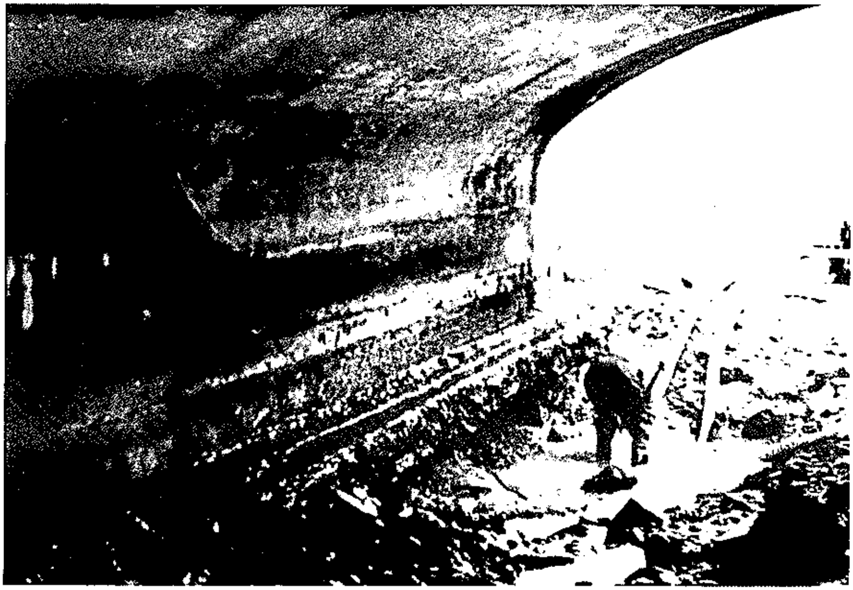

Plate 1. Scour of river bed

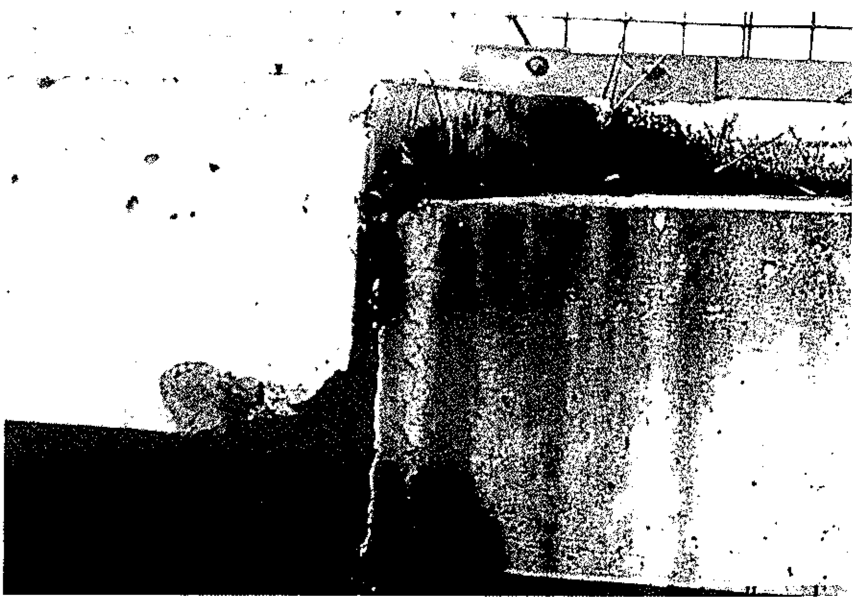

Plate 2. Differential settlement

Plate 3. Crack in column due to corrosion

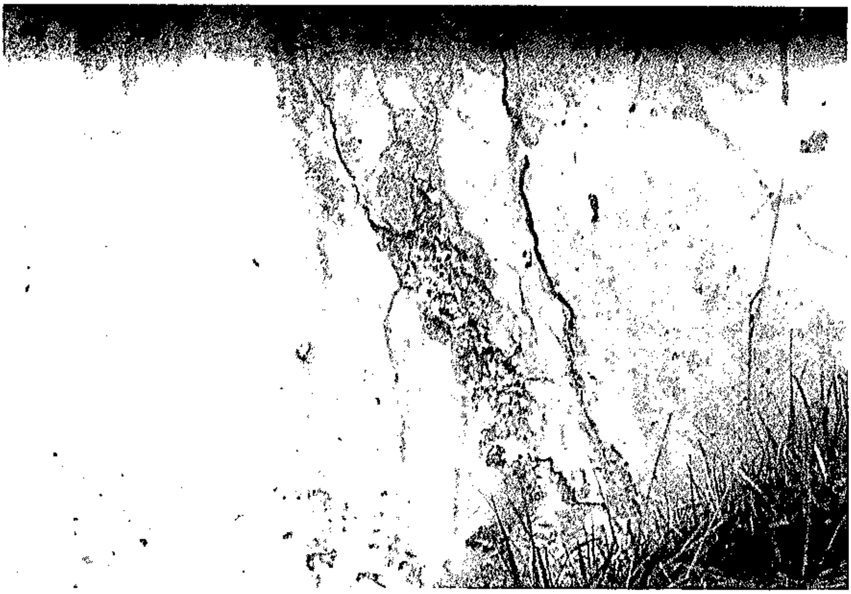

Plate 4. Water leakage through crack showing rust staining

Plate 5. Vehicle impact damage to concrete column

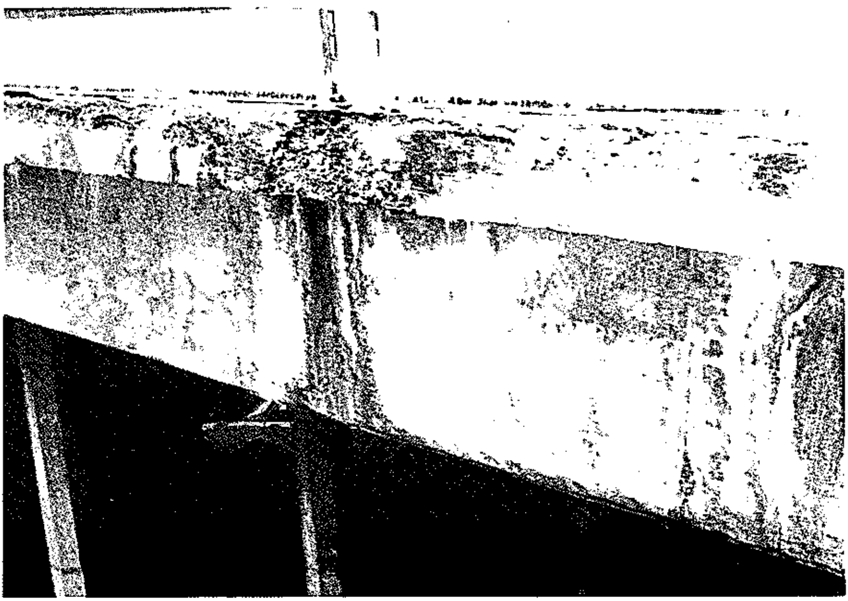

Plate 6. Scaling of edge beam

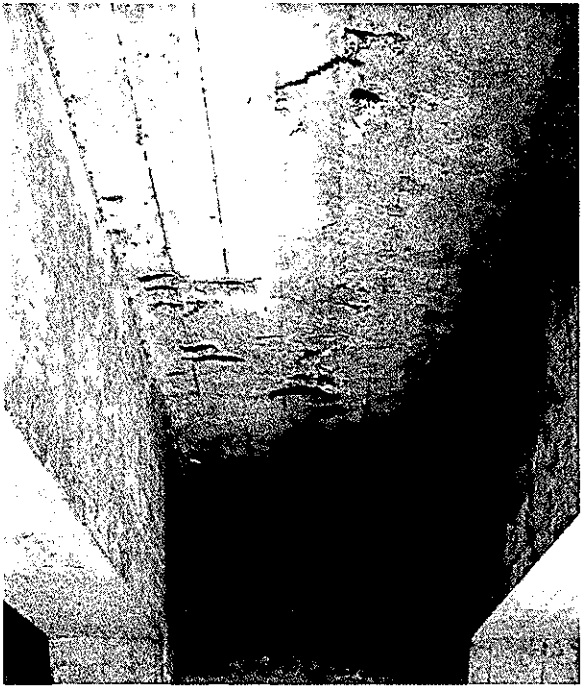

Plate 7. Spalling of concrete soffit

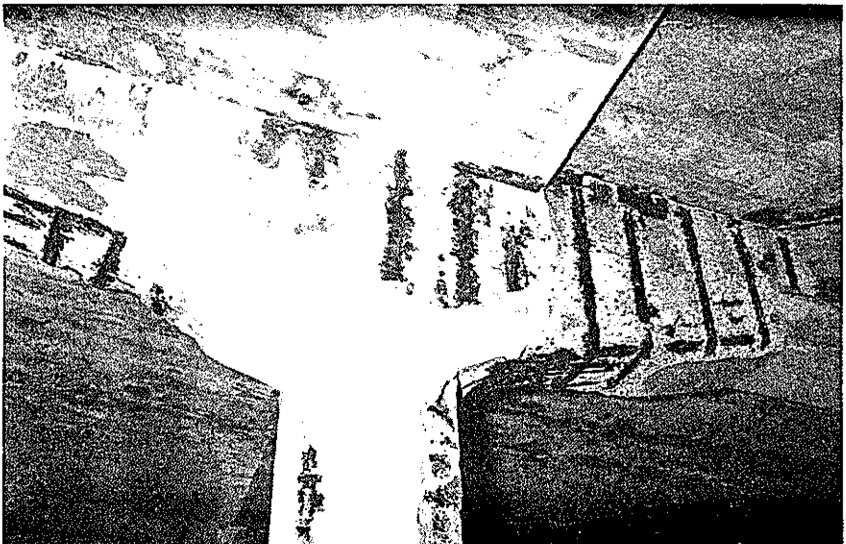

Plate 8. Corrosion of reinforcement

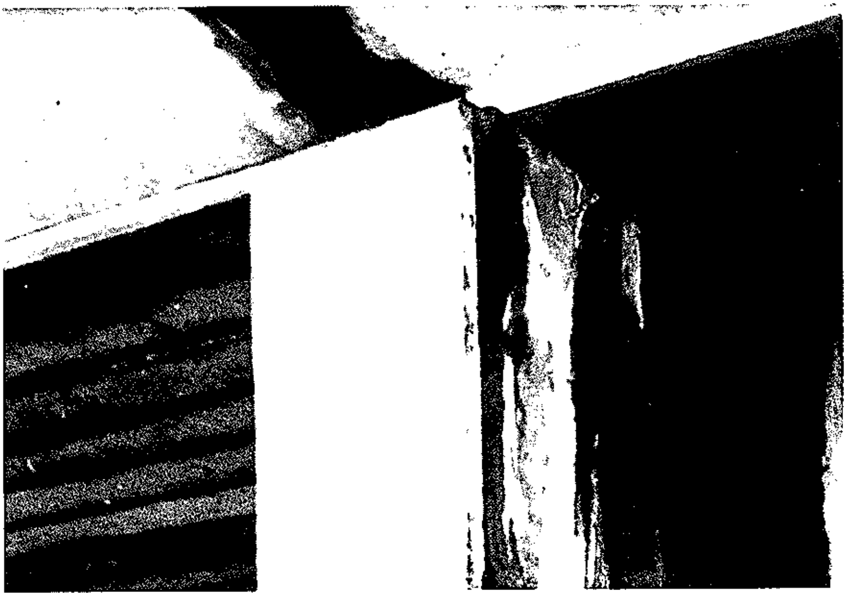

Plate 9. Leakage of water

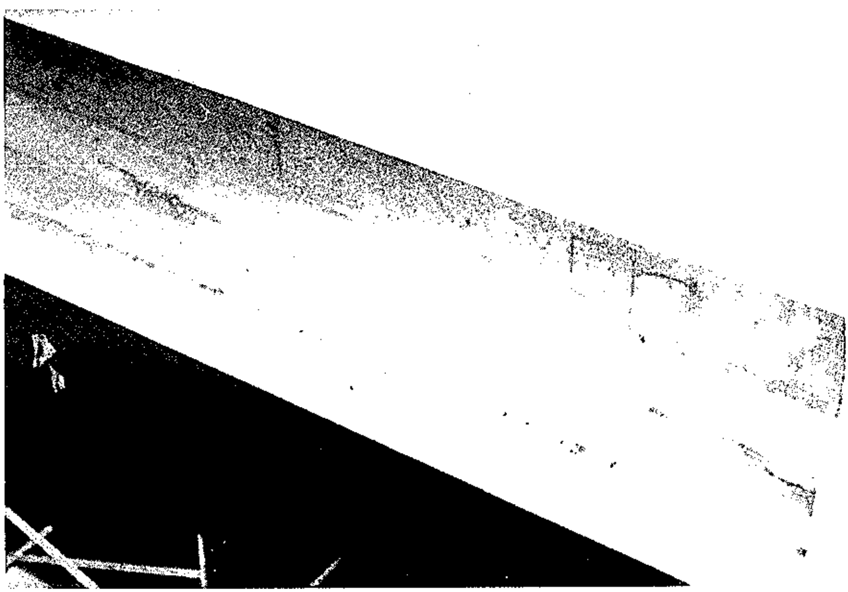

Plate 10. Cracking along line of duct in a post-tensioned concrete beam

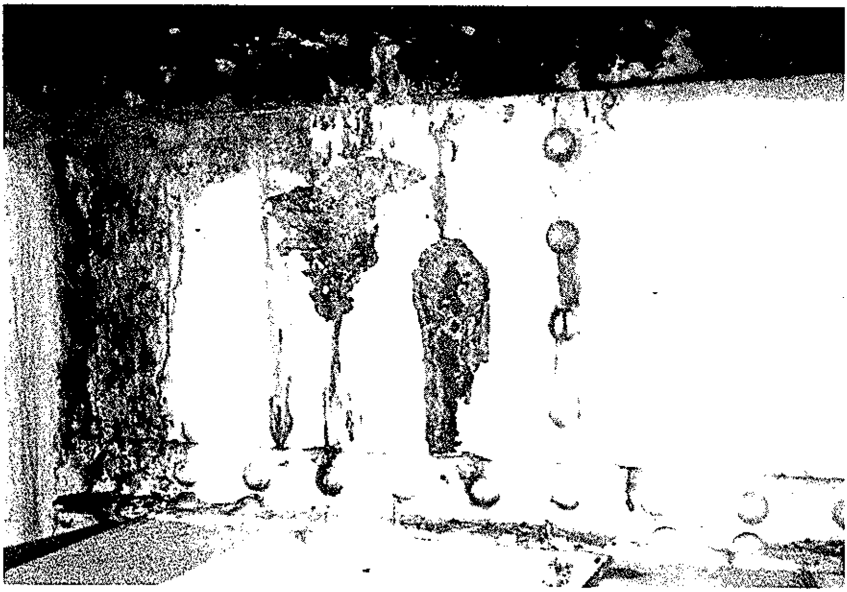

Plate 11. Corrosion of cross box girder

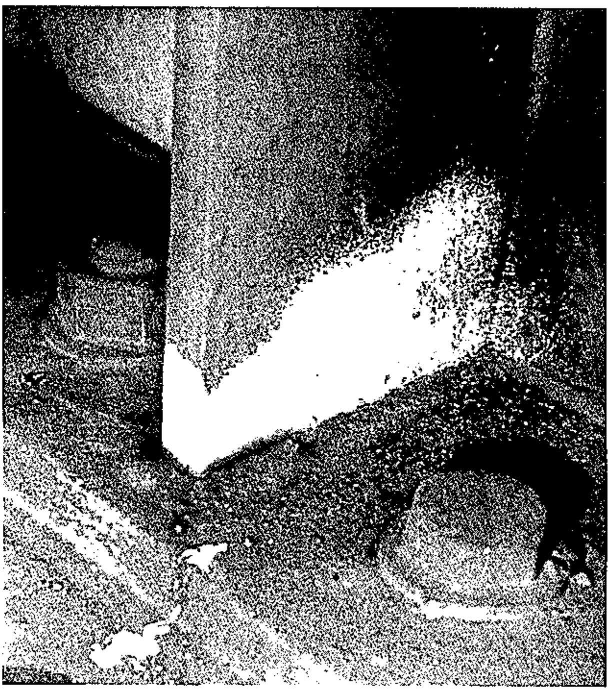

Plate 12. Crack at welded joint

IRRD 275200

Bridge inspection guide

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This guide is concerned with the inspection of bridges during their service lives after their construction and the associated contract maintenance periods. It attempts to set out the essential information to assist the bridge inspector in doing his job. The information relates to: inspection and reporting, faults and deterioration, access and safety, bridge design and construction, non destructive testing, and DTp Bridge Inspection Form BE10 (DB).

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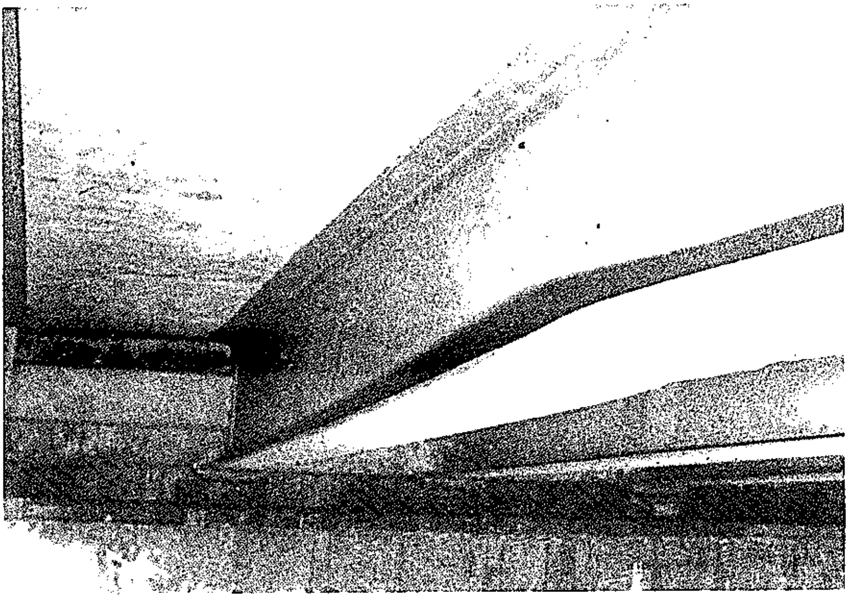

Plate 13. Deformation of steel beam due to impact

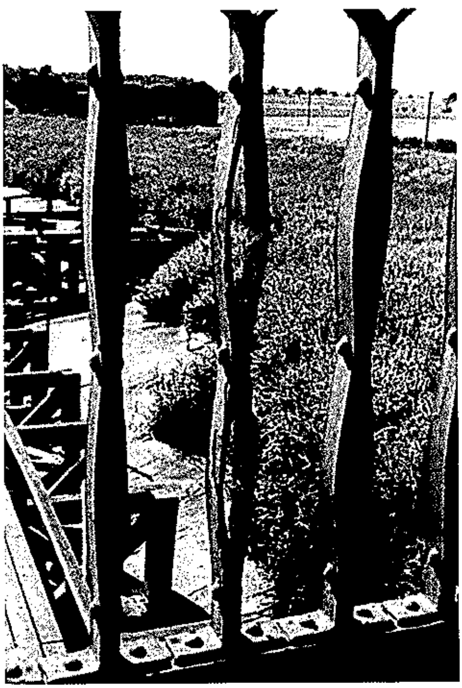

Plate 14. Expansion of wrought iron due to corrosion

Plate 15. Bulging of spandrel walls

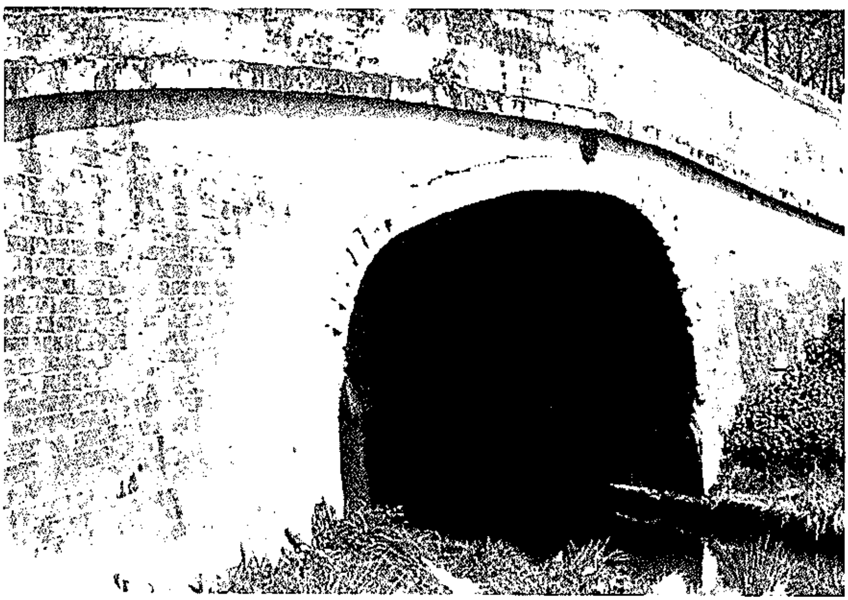

Plate 16. Distortion of arch profile

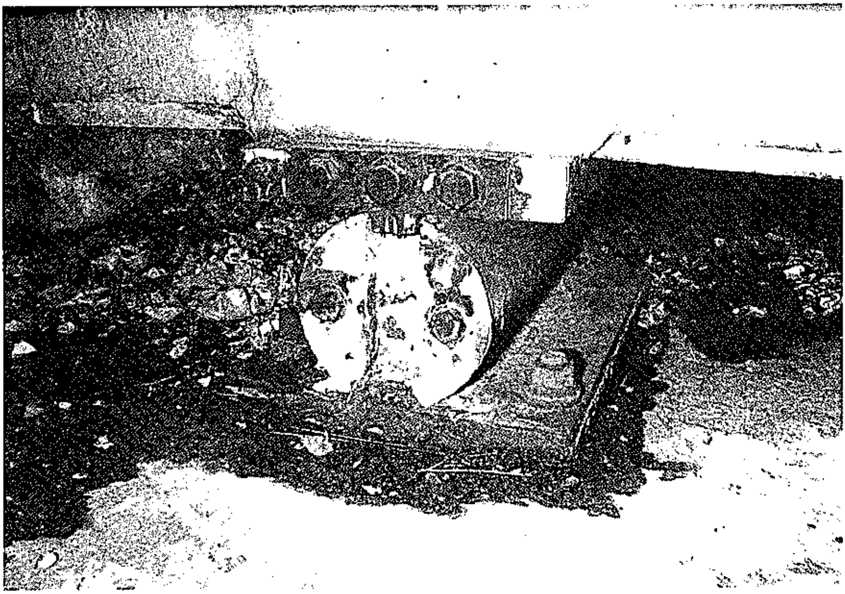

Plate 17. Dampness & debris at bearing

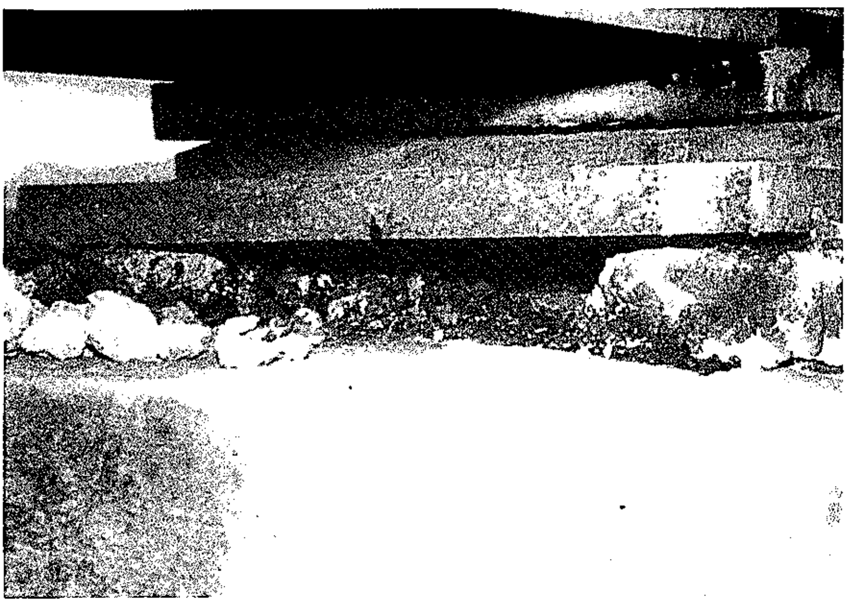

Plate 18. Void in bearing seating

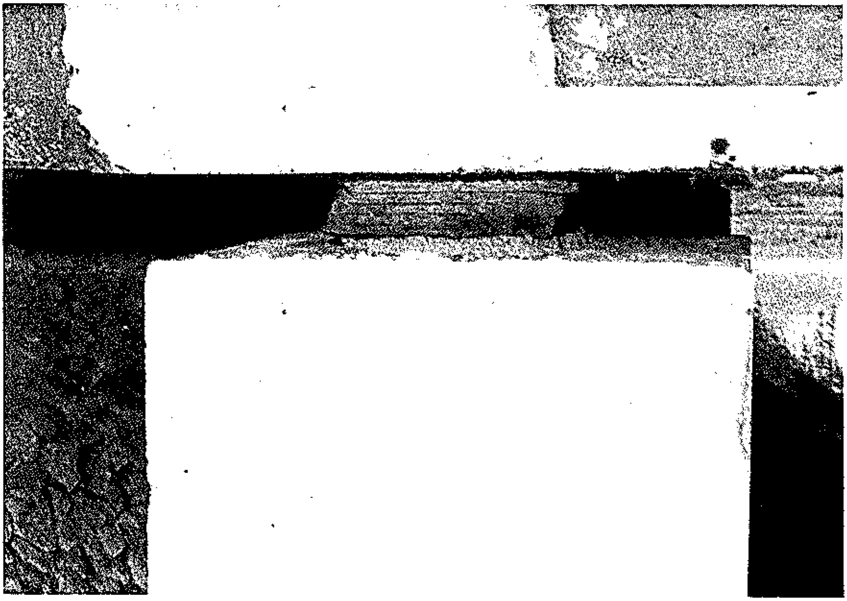

Plate 19. Horizontal shear failure of an elastomeric bearing

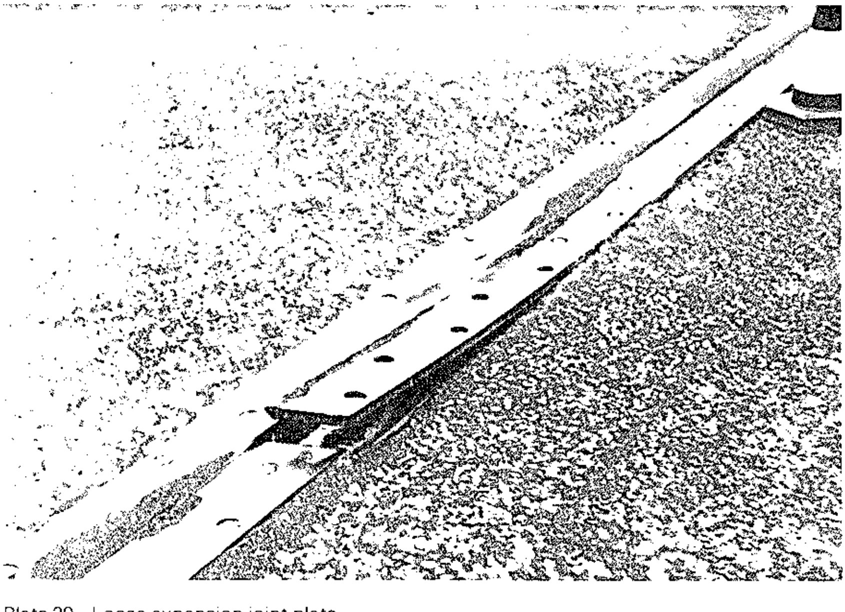

Plate 20. Loose expansion joint plate

Plate 21. Accumulation of debris at comb joint

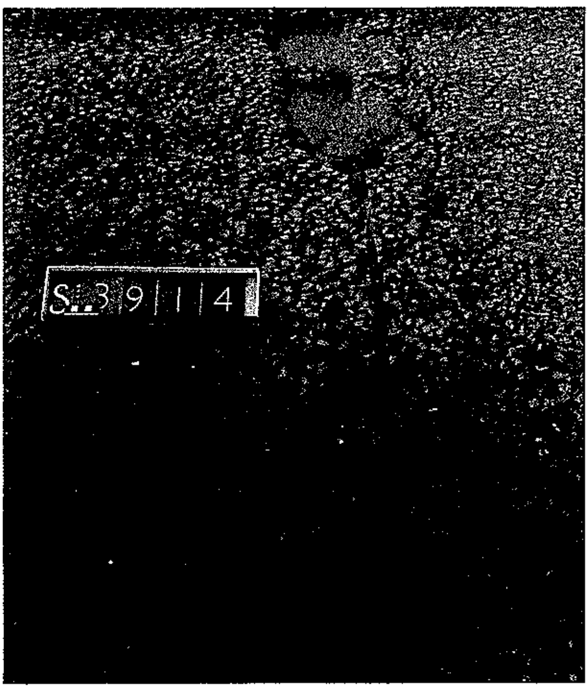

Plate 22. Cracking of surfacing at buried joint

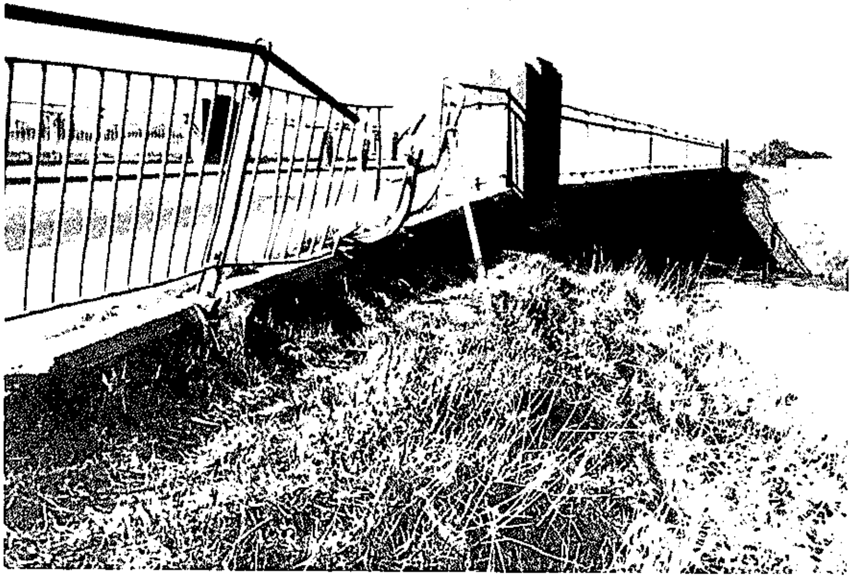

Plate 23. Damaged parapet due to impact

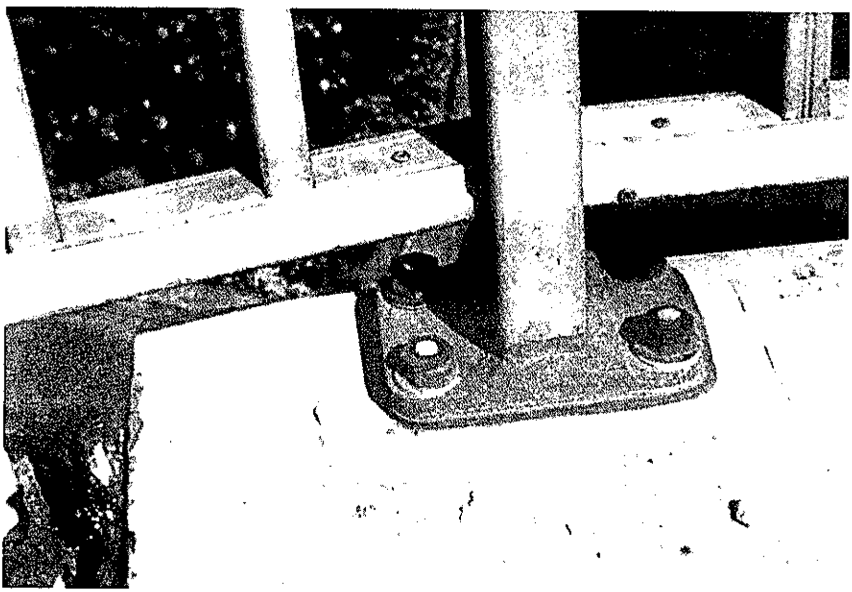

Plate 24. Corrosion of parapet holding down bolts

under compression loading. Distortions out of plane in the forms of waves, kinks or warping can considerably reduce the resistance to compressive forces. Any increase in distortion is significant and may reduce the load-carrying capacity of the structure.

f. Bolts and rivets

Faults include missing of loose bolts or rivets, slippage of the connection and corrosion. A close visual examination should be made to find out whether there is any evidence of slip or movement at cover plates, nuts, washers or bolt heads. This can sometimes be seen by the development of cracks in the paint film. Slippage is particularly important in the case of high strength friction grip bolts where it may indicate a defective joint even though the bolts appear to be tight. A 'Special Inspection' may then be necessary for the purpose of checking the tension in the bolts. A close visual examination should also reveal any evidence of corrosion, particularly at the interfaces where any bulging or separation of the plates may indicate fairly serious corrosion. Tapping the bolt or rivet heads with a light hammer can indicate to an experienced inspector whether the fastening is still tight.

g. Excessive wear

This will occur in the case of members accommodating movement, such as pins in joints, or trusses.

h. Condition of closed members

Closed members may be sealed or ventilated.

Seals are provided at access covers in some structures with the intention of restricting the ingress of air and water. Even if the seals are not fully air-tight, sealing will restrict the entry of pollutants. An accumulation of water in closed members is not uncommon and can lead to corrosion and to frost damage. Mould and fungus growth can develop to the detriment of the protective system.

2.3.4 Timber

a. Condition of the timber

Timber may deteriorate through weathering and chemical or fungus attack such as wet or dry rot. Such deterioration ranges from staining of the surface to extensive decay of the member as a result of which the timber may become soft, spongy, fibrous or crumbly. Particular attention has to be paid to connections, bolt holes, splices and support points. A common failure is splitting along the grain.

b. Vermin attack

A variety of termites, beetles, ants and borers can attack timber in various environments. Most of the damage is internal and to assess its extent core samples may have to be drilled.

c. Mechanical wear

Timber is usually protected against mechanical wear due to traffic. Various surfacing materials are used and these should be intact and properly bonded to the timber deck.

d. Accidental damage

Structural damage to the timber cause by collision or fire may sometimes be evident.

e. Absorption of moisture

Apart from accelerating the decay of timber, this can cause a substantial increase in its dead weight without any visual indication that this is happening. This can present problems with the operation of movable bridges where timber has been used as a lightweight material both for structural and infilling purposes.

f. Bolts and connectors

Rusty or loose bolts and connectors, together with unplugged holes can lead to gradual deterioration of the structure.

2.3.5 Cast Iron and Wrought Iron

These materials are found in older bridges and many of the defects which they exhibit have been described in the paragraphs on steel structures (para 2.3.3). It should be recognised that the homogeneity and purity of cast and wrought iron is inferior to that of present day steels. Cast iron is a brittle material and its failure is sudden.

a. Cracking
Blow holes and cracking are common defects, the cracking often being associated with the cooling of the metal after casting. Water may accumulate in hollow members and cause cracking when it freezes.

b. Corrosion
Although corrosion of these materials is relatively slow, it may reach significant proportions because of the age of the structures. Corrosion of cast iron may occur by a process known as graphitisation. In this form of corrosion the iron is replaced by graphite with no significant change in volume but with a considerable loss of strength. When this occurs at the surface it can be detected by scraping with a hard sharp instrument as the graphite is soft and can be excavated from pockets. In wrought iron, corrosion may extend between the layers causing separation and the deterioration may be greater than is apparent at the surface. In general the corrosion products of wrought iron and steel cause expansion and can be readily detected. Tapping with a hammer by an experienced inspector can provide useful qualitative information.

2.3.6 Masonry and Brick Arches

a. Splitting of the arch into several separate rings.

b. Bulging and outward movement of spandrel walls
This may be associated with traffic damage to parapets.

c. Diagonal cracking originating at the springing
This defect is particularly serious.

d. Distortion of arch profile.

e. Weathering.
Stone blocks, bricks and mortar, especially lime mortar, may spall and crumble due to weathering or percolation of water. In the more severe cases splitting and disintegration of stones and bricks may occur.

f. Opening of joints and movements of supports
Such movements will cause the loss of bedding mortar between components of an arch and in severe cases to displacement or loss of brick and stone blocks.

g. Inadequate drainage of infilling between spandrel walls
Some materials have a potential for storing a substantial volume of water, increasing undesirably the load on the arch and causing deterioration of the materials particularly under frost action.

h. Accumulation of debris and vegetation
Because of the accumulation of soil in various parts of the structure, a good deal of vegetable life can be supported on the bridge. The root systems can cause damage.

2.3.7 Cable Supported Structures

Many of the faults in cable-stayed and suspension bridges are similar to those described for steel structures. In addition the following factors may require special attention:

a. Displacement or slippage of strand shoes, strand sockets, saddles and cable bands
Such movements may result in maldistribution of loads between members and are an indication of some degree of failure of connection between the cable and the particular element which is being displaced.

b. Broken wires
In large cables, which may be fully wrapped and protected on the outside, the breakage of wires will be difficult to detect until there is some visual evidence in the outer casing. However, in the anchorage zone continuity of unwrapped strand between strand shoes and splay saddles can be tested and this will reveal the presence of broken wires for some distance past the splay saddle under the wrappings.

c. Condition of protective systems
There can be no loose wrapping wires and no cracks in caulking, where water can enter and cause corrosion of the main cables. That water has entered usually becomes apparent by the flow of water from the cable near the anchorage or near the lowest point. Cable bands, saddles, anchorages, sockets and splay castings need to be inspected for water seepage.

d. Loose or broken hangers
The tension in hangers can be measured but this should be done only as part of the 'Special Inspection' procedure.

e. Wear and cracks in eye-bars and links
Eye-bars and links are critical elements and the junction between the bar and pin may be highly stressed. It is important to look for any evidence of defects.

2.3.8 Movable Bridges

The structural defects and deterioration which are found in fixed bridges may also occur in movable bridges (ie bridges with opening, lifting or swivelling spans) but the mechanical, electrical and hydraulic equipment should be inspected by specialists. Inspection of the structure should be co-ordinated with operational needs.

2.4 Components

2.4.1 Bearings and Bearing Seatings

The condition of a bearing and its seating is an important indicator, not only of the condition of the bearing itself but sometimes of some other defect in the structure. Bearings are located where movement is intended to take place so that if they do not function adequately the structure may suffer excessive stress.

a. Effect of debris and water
Debris may accumulate around the bearings and water from the road surface may leak through the joint above. Some bearings will deteriorate under these conditions and metal parts will corrode. This may lead to excessive restraint against movement. Where provision is made for lubrication, this should be adequately maintained.

b. Position and alignment
Faulty positioning or alignment may prevent the bearing from functioning correctly. For example, there may be incomplete contact at bearing surfaces on thrust plates, and keyways and gearing may bind or not engage properly. In skew and curved bridges, bearings and lateral shear keys may bind or suffer damage.

c. Setting of bearing relative to temperature
Movement will be restricted if the bearing is set so that it reaches its limit of travel before the maximum or minimum temperature is attained.

d. Loose fixings
Anchor bolts and other fittings may become loose allowing movement or vibration of the bearing. This is sometimes due to free movement of the bearing being restrained by its deterioration and, in extreme cases, all the movement may take place between the bearing and its seatings.

e. Seatings
This applies to the seating of superstructure on bearings and of bearings on substructure. The seating materials may crack or disintegrate and gaps may occur between the bearing and seating. These are

potentially serious defects since they can reduce the support given to the superstructure.

f. Elastomeric bearings

Faults include splitting, tearing or cracking of the outer casing and uneven bulging and distortion. The first signs of distress usually show as non-uniform rippling of the vertical surfaces followed by horizontal cracks near the junction of the rubber pad and steel laminate. Differences in thickness between the front and back of the bearing show the amount of rotation; this should not be excessive. In other bearings where there is no outer casing corrosion and delamination of the steel plates may occur.

g. Sliding bearings

Excessive wear, dirt or corrosion of the sliding surfaces will increase the resistance to movement. Where a low friction sliding material such as ptfe (polytetraflouroethylene) sliding on stainless steel is used, it is particularly important that no faults develop which could increase frictional resistance since this would transmit undesirable forces to the substructure. Debonding or flow of the ptfe are faults additional to those listed above. Any suspected malfunctioning of a ptfe bearing may require 'Special Inspection' investigations.

h. Concrete hinges

Bearings of the concrete of Freyssinet hinge type can be subject to splitting of the concrete in the neck of the hinge.

j. Simple sliding bearings

These were used in many of the older bridges and have tended to become more resistant to movement with age. Bearings using lead or bitumen may have ceased to function as sliding bearings.

k. Faults caused by bearings

The failure of a bearing to function correctly may cause cracking or deformation in the structure.

l. Skew and curved bridges

Bearings and lateral shear keys may bind or suffer damage from unforeseen movements.

2.4.2 Expansion Joints

Expansion joints are generally troublesome features in bridge construction because of the onerous conditions to which they are subject. The main defects are:

a. Loosening or movement of the joint

This is a common form of failure and may be accompanied by rattling and breaking of bolts, joint components and seating. The onset of some form of loosening can usually be detected by a crack developing between the joint material and the adjoining surfacings. Eventually a series of cracks will develop in the surfacing itself or in the material forming the joint. Adhesion or tie down of the joint to the deck can sometimes be checked by tapping wth a hammer. Joints may be damaged by snow ploughs.

b. Freedom of movement, clearance and alignment

There should be adequate space for the joint to function under the prevailing temperatures. For example, lateral displacement of a comb joint may lead to restraint of movement and damage to the joint.

c. Irregularity of vertical profile

One part of a joint may become displaced relative to the other and, if this displacement is excessive, it will cause additional impact forces under traffic loading and may represent a hazard to the safety of small and two-wheeled vehicles.

d. Leakage of water through joints

Some joints are designed with open gaps through which water and debris can fall. In such cases there should be an adequate drainage system beneath but this may be blocked by an accumulation of debris and water may then flow over the bearings and substructure. Some joints using seals and sealants are designed to exclude water and dirt. The quality of sealing does not always ensure water tightness over a long period of time. The quantity of water which may leak through a joint can be substantial and this can go on over a long period. Water stored in the surfacing system may continue leaking out of joints for several weeks after rain has ceased.

e. Cracking of surfacing and buried joints
On short span bridges the road surfacing is often carried over the joint, so as to make the laying of the surfacing easier and to provide a better standard of riding quality. Cracks may eventually appear over the buried expansion joint thus formed and this cracking may require local repair.

2.4.3 Surfacing and waterproofing systems

a. Cracking
Cracking can take many forms depending on the nature of the failure and the characteristics of the particular surfacing materials. In some cases, the cracking is an indication of failure of the surfacing material, while in others it indicates excessive movement or deterioration of the underlying deck. With time, crumbling of the surfacing material along the edges of the cracks takes place and the ingress of water may lead to loss of adhesion between surfacing and deck. Joints in the surfacing and at kerbs are especially vulnerable even when a sealing compound has been used. Where surfacing is laid on steel bridge decks the ingress of water between the surfacing and the deck may lead to serious and rapid pitting corrosion of the steel.

b. Excessive deformation of surfacing
Deformation, as it progresses, will lead to increasingly severe impact loading under traffic particularly at joints. It will usually take place due to the combined effects of traffic and warm weather. Blisters may form in the surfacing or waterproofing system in warm weather. Traffic normally prevents them rising, but footpaths may be badly affected.

c. Sliding of the surfacing material
This can take place because of a weakness in shear or loss of adhesion at the interface with the waterproofing layer or between the waterproofing layer and deck. Sliding may be caused by traffic forces or gravity and may lead to humps or depressions in the surfacing at kerbs and expansion joints.

d. Loss of skid resistance
Because of polishing under traffic, the surfacing may become slippery with time and usually the check on resistance to skidding will be done as part of the assessment of the road as a whole.

e. Defects in waterproofing
Punctures in waterproofing system sometimes result from damage during construction, from the installation of cats eyes or from resurfacing. Subsequently such damage can seldom be identified except when a substantial leakage of water has occurred through the structure. Water may travel along or across various parts of the structures and patches of dampness do not always coincide with the position of defects in the waterproofing membrane.

f. Clearance under bridges
Resurfacing of a road below a bridge may reduce the headroom.

2.4.4 Drainage

Defective drainage can result in serious damage to the structure and, if water leaks on to the road surface, it may represent a hazard to traffic, particularly in cold weather.

a. Removal of surface water
Surface water should flow freely to outlets from all parts of the bridge deck without overflowing, ponding or leaking through the deck.

b. Water stains
Water stains on beams, slabs, piers, columns and abutments may indicate leaky pipes, blocked gutters, inadequate drainage systems, leakage through decks or joints, or clogging of drainage gulleys and pipes.

c. The drainage systems
All drainage pipes, channels and gullies should be free from damage and all joints or connections should be properly sealed. Adequate falls must be maintained. Plugs and covers to traps and rodding points should be correctly in place. Pipes are often concealed and it may be necessary to trace and complete run of the drainage system.

d. Accumulation of debris
A substantial amount of debris can find its way into the drainage system and there may be traps for it at various strategic points. Traps should not be full and their outlets should be clear.

e. Defective outlets
Outlets should not discharge water where it may be detrimental to components of the structure, cause erosion of fill and embankment material or spill on to the road or railway below.

f. Inflammable and toxic materials
Such materials may sometimes enter the drainage system and they then create a considerable hazard. If contamination is suspected, it should be promptly reported to the engineer.

g. Blowing of water on to the structure
In addition to the blowing and spillage of water from drainage outlets that are inappropriately located, substantial amounts of water can be blown on to the soffit of beams and slabs by the wind aided by the funnelling effect of the abutments. Projections or grooves along the edge of the deck soffit should prevent the spread of water in this way.

h. Drains in box girder bridges
In box girder bridges drains should be provided to remove water from the lowest point of the boxes, except for some steel box girders which are deliberately sealed to prevent the ingress of air and water.

j. Drainage and waterproofing of service ducts
The drains and waterproofing of such ducts should function satisfactorily and not be impaired or damaged by work on the services.

k. Water tightness of fastenings to bridge deck
Fastenings may be associated with lighting equipment, gantries, parapet posts, safety fences and inspection manholes.

2.4.5 Parapets, railings, safety fences and lighting columns

a. Damage due to traffic impacts.

b. Corrosion
These accessories are subject to splash from road vehicles and are therefore susceptible to corrosion, especially around the base of the supporting posts.

c. Tightness of bolts
Holding down bolts and connecting bolts should be tight, taking into account in the latter case the provision for expansion movement in the parapet or between the parapet and the guard rails on the approaches.

d. Condition of welds
Welds should be sound since much of the effectiveness of the parapet in containing vehicles depends on continuity of rails and on security of connections of posts to bases.

e. Alignment of parapets and guard rails
Connections and overlaps between guard rails on approaches and parapets on bridge

decks should be such as to prevent collision between the vehicles and the end post of a parapet.

f. Frost damage

Splitting of hollow sections in posts and rails may be due to freezing of accumulated water. Galvanizing holes should be sealed to prevent the ingress of water and drain holes in hollow sections should be clear.

ANNEX TO CHAPTER 2

BRIDGE INSPECTION MANUAL

Check List

FOUNDATIONS (2.1)
Cracking of concrete
Corrosion of reinforcement
Spalling of concrete
Signs of movement
Scour
Erosion
Debris
Decay of timber piles
Settlement
Tilting
Differential movement

SUBSTRUCTURES (2.2)
Excessive or abnormal movement
Cracking
Accident Damage
Fenders
Safety fences
Debris
Drains and weep-holes
Leakage, seepage and leaching
Spalling concrete
Exposed or corroded reinforcement
Cracks in masonry
Mortar joints
Vegetable growth

SUBSTRUCTURES (2.3)

REINFORCED CONCRETE (2.3.1)
Cracking
Scaling
Spalling
Corrosion of reinforcement
Staining
Leakage
Leaching
Deterioration of deck concrete
Porous concrete (seepage)
Concrete box girders – cracks in faces of flanges and webs, cracks at junctions of interior diaphragms and webs, debris or water ingress
Loose rendering and fixing of facing slabs
Accident damage
Excessive deformation or vibration
Chemical (Salt) attack

PRESTRESSED CONCRETE (2.3.2)
All as for reinforced concrete
Location and direction of cracks
Protective coating to exposed cables
Fracture of wires (exercise caution)

STEEL BEAMS, GIRDERS AND TRUSSES (2.3.3.)
Condition of protective system
Corrosion – magnitude, location, estimate loss of section
Identify cause, mating and rubbing surfaces, flaking and residual thickness of weathering steel and water leakage
Fracture
Cracking in steel and welds
Deformation and distortion including buckling and warping
Bolts and rivets
Excessive wear in pins etc
Closed members – as above and effectiveness of seal, water leakage, condensation, mould and fungus growth
Accident damage
Debris and vegetable growth

TIMBER (2.3.4)
Condition of protective treatment
Signs of wear, crushing or splitting
Decay or vermin attack
Fire damage
Excessive vibration or deflection
Bolts and connectors
Accident damage

CAST IRON AND WROUGHT IRON (2.3.5)
All as for steel beams etc
Blow holes and cracking
Water accumulation in hollow members

MASONRY AND BRICK ARCHES (2.3.6)
Spalling or erosion of masonry
Cracking or splitting of masonry
Opening of joints
Movements of supports

Bulging and outward movement of spandrel walls
Loss of arch shape
Longitudinal cracks in surfacing
Inadequate drainage
Loss of infill materials between spandrel walls
Condition of mortar joints
Leakage of water
Debris and vegetable growth
Adequacy of waterway
Condition of invert

CABLE SUPPORTED STRUCTURES (2.3.7)

All as for steel beams, etc in relation to cables, strand shoes and sockets, anchorages, saddles, cable bands, hanger rods, suspender ropes and wrapping wires
Displacement or slippage or strand shoes, sockets, saddles and cable bands
broken wires
Water seepage in cable bands saddles and splay castings
Tension of hangers and cables
Eye bars and links

MOVABLE BRIDGES (2.3.8)

Defects as listed for fixed bridges
Mechanical, electrical and hydraulic equipment
Cables pipes etc
Wear to bearings, trunnions, wedges, locking mechanism, racks and pinions, ropes, pulleys and sheaves
Operating procedures for opening and closing
Fatigue
Counter weights and attachments
Guiding mechanisms and chambers

COMPONENTS (2.4)

BEARINGS AND SEATINGS (2.4.1)

Bearing material eg corrosion, bulging, splitting
Position and alignment
Freedom of movement
Excessive movement
Fixings
Drainage
Cracked concrete seating
Gaps between bearing faces and/or seatings
Movement between bearings and seating
Adequacy of bedding
Splitting in neck of concrete hinge
Vegetable growth

EXPANSION JOINTS (2.4.2)

Loosening or movement of joint fixing
Movement clearance and alignment
Vertical profile
Water leakage
Surface cracking over buried joints
Accumulation of debris

SURFACING AND WATERPROOFING (2.4.3)

Cracking
Condition of seals
Deformation and tracking
Sliding of surfacing
Skid resistance
Defects in waterproofing
Clearance under bridges

DRAINAGE (2.4.4)

Water stains
Drain outlets
Damaged pipes
Accumulation of debris
Condition of drips or grooves
Surface falls
Open drains and gulleys
Drain in box girder bridges
Service ducts
Water tightness of fastenings

PARAPETS, SAFETY FENCES AND LIGHTING COLUMNS (2.4.5)

Traffic impact damage
Corrosion
Tightness of bolts
Soundness of welds
Alignment of rails and fences
Fatigue cracks
Frost damage to hollow members

CHAPTER 3:

Access and Safety

3.1 Access

Access to many structures can be obtained using simple equipment such as ladders, vertical portable platforms, planks or at most a scissor lift platform. Where access is more difficult, alternatives have to be considered taking into account the degree of thoroughness of the inspection, ie superficial, general, or principal, and the nature of different tasks to be carried out. All access equipment must be regularly inspected and maintained, including power units. Access to gantries must be carefully planned to avoid danger to the inspector and yet to be secure against unauthorised use. The safe working load should be indicated on all access equipment by means of permanent plating and this safe load must not be exceeded. All possible advantage should be taken of occupations arranged for other purposes (see para 1.2.2) and it is thus important for the inspector to liaise with other maintenance interests in the Highway Department.

3.1.1 Scaffolding

This has, to date, been the most common method and in many cases will continue to be so. It has the disadvantage of being fairly expensive, time-consuming to erect and dismantle and if erected from the ground, requires a firm accessible area. Structures over rivers and railways can be difficult in this respect. Scaffolding has the advantage that it can provide access for several tasks to be carried out concurrently, or successively, such as inspection, weld examination, painting and drainage maintenance, if these can be properly programmed. Scaffold stagings may also be suspended from the structure. Guidance on the correct method of erecting scaffolding is given in the British Standard Code of Practice CP 97: Part 1: 1967, Common scaffolds in steel; Part 2: 1970, Suspended scaffolds; and Part 3: 1972, Special scaffold structures in steel. Scaffolds must not infringe the minimum headroom, and should be protected from high loads.

3.1.2 Fixed Ladders and Walkways

Fixed ladders and walkways give access to bearings, drainage system and parts of the bridge soffit. Walkways can be supplemented by staging, cradles and scaffolding to give access to any part of the bridge. In view of the substantial cost and time of erecting scaffolding from the ground, permanent walkways may be a quicker and a cheaper long-term alternative in some situations, yet still preserving the flexibility of scaffolding in providing safe access for a variety of concurrent or successive tasks. They could also incorporate auxiliary services for inspection and maintenance work such as electricity supplies, water and compressed air.

3.1.3 Travelling gantries

Some long span structures have been equipped with Purpose-built travelling gantries suspended from the structure.

3.1.4 Mobile Equipment: Lifting Platforms

For comparatively low reaches from flat ground up to 11 metres, there are platforms which extend only in a vertical direction. These are not generally self-propelling and require access to firm reasonably level ground below a structure. They are relatively cheap, but of limited use.

3.1.5 Mobile Equipment: Hydraulic Hoists

For reaches which may exceed 50 metres, truck mounted, upward working hydraulic hoists are available. As they are heavy, up to 25 tonnes weight, they require a firm base to stand on but can cover a large area from one siting. Downward-working vehicle-mounted platforms available have a limited inward reach depending on construction depth of the bridge. For the latter, care must be taken that the bridge structure including its verges is capable of withstanding the wheel loads and outrigger reactions, which can be considerable. In no case should the load capacity of the structure be exceeded and it may be necessary to restrict other traffic. A sufficient area of road must be coned off to allow traffic to pass safely when the tail of the hoist protrudes across the carriageway during the inspection. It is advisable to park another vehicle in a position to protect the inspection vehicle. In some circumstances it may be necessary to effect a closure or partial closure of the road to permit the inspection vehicle to be used.

3.1.6 Confined Spaces

Certain types of structures such as steel and concrete box girder bridges, hollow abutments, piers and towers will require internal inspection. Access internally will generally be gained via manholes. Hinged covers should be securely propped to prevent closure during inspection and all openings guarded to prevent anyone falling in. Consideration needs to be given to the following:

a. Physical fitness of personnel and psychological aspects such as fear of heights or claustrophobia.
b. Rescue procedures in cases of illness or accident.
c. Provision of lighting to enable all elements to be inspected and to help avoid accidents due to tripping etc.
d. Adequate ventilation of all sealed structures prior to entry.
e. Biological hazards such as mould growth and dust from dried bird-droppings.

3.1.7 Underwater Access

Reference should be made to para 1.4.

3.2 The Health & Safety at Work Act 1974

The Act brings together, and expands on, earlier Acts and Regulations concerned with people at work and places of work and is principally directed towards:

a. Securing the health, safety and welfare of persons at works.
b. Protecting other people, including members of the public, against risks to health and safety arising out of the activities of persons at work.

Every employer is bound by the Act to issue a statement of his safety policy to every employee, and this has been done for directly employed Department of Transport staff. Other employers such as local authorities will also have issued statements.

3.2.1 Principal Provision of the Act

Section 2 – places a duty on the employer to provide and maintain workplaces, plant, systems of work, institutions and training adequate for the health, safety and welfare of his employees.

Section 3 – places a duty on the employer to ensure that persons other than his employees are not exposed to risks to their health and safety.

Section 4 – places a duty on persons who control premises to ensure that they are safe and without risks to health of persons working there although they are not their own employees.

Section 6 – places a duty on those who supply, erect, or install any article for use at work to ensure that it imposes no risk to safety or health, provided it is properly used.

Section 7 – places a duty on the employee to take care of his own health and safety and of other persons who may be affected by his acts or omission and to co-operate with his employer in enabling him to comply with his duties under the Act.

Section 8 – places a duty on the employee not to interfere with or misuse things provided for safety.

It should be noted that the Act is concerned with criminal, as opposed to civil liabilities.

3.2.2 Implications for Bridge Inspectors

For the present purpose, the main implications are as follows:

Sections 2, 3, 4 and 6 are not the direct responsibility of the inspector, but he should be aware that they exist, and not proceed into a situation where he can see a hazard. Examples are an inadequately coned-off or protected section of the motorway (as in 3.1.5 above), or an inadequately secured ladder or staging. Section 7 requires that he must not only look after his own health and safety but of other personnel under his control and of third parties (such as passing pedestrians or traffic). He must also co-operate with his employers to see that standing instructions in force for the site at the time of the inspection are observed. To sum up, the Act sets down in legal terms the responsibility of everyone at work to act in a common sense, safety conscious way using all the rules of "good practice" for themselves, their colleagues, and members of the public.

3.3 The Factories Act and Construction Regulations

The Health and Safety at Work Act does not supersede the Factories Act and its associated Construction Regulations, it reinforces them. Statutory instruments which are particularly applicable to bridge inspection are listed below, but the list is not exhaustive:

SI 94 The Construction (Working Places) Regulations 1966. This covers scaffolds, trestles, platforms, toe-boards, etc.

SI 95 The Construction (Health and Welfare) Regulations 1966. This covers first aid boxes, protective clothing, etc.

SI 808 Ionizing Radiation (Sealed Source) Regulations 1969.

SI 1580 The Construction (General Provision) Regulations 1961 This covers supervision, safe places to work, work adjacent to water, etc.

SI 1581 Reconstruction (Lifting Operation) Regulations 1961 This covers cranes, testing of cranes and ropes, safe working load, use of hoists, etc

The Abrasive Wheels Regulations 1970.

The Protection of Eyes Regulations 1974.

3.4 The Traffic Signs Manual — Chapter 8

The Traffic Signs Manual issued by the Department of Transport is mandatory for use on the Department's own trunk roads and motorways but at present only advisory for local authority and other works. There is a possibility that the Health and Safety Executive may make its use obligatory to all at some time in the future.

The Section of most concern of bridge inspection is Chapter 8 dealing with roadworks signing. This covers coning off, signs and their lighting, safe lengths of working space, etc, and is particularly relevant for example where road mounted inspection hoists and platforms extending down under a bridge are in use.

3.5 Safety Rules for Inspectors

3.5.1 Detailed rules to comply with the Health and Safety at Work Act are issued from time to time by the Department of Transport and other employers. There are particular standing instructions for working sites or areas. The inspector should ensure that he is familiar with, and complies with, all these current requirements.

3.5.2 Some particular points which will normally be included in standing instructions and which should be observed when visiting or inspecting bridges, gantries, culverts, tunnels or other structures are set out below.

a. Approach to site

Wherever possible approach to a motorway bridge should not be from the motorway, but from the road which crosses over or under the motorway or from the ground below an underbridge. If it is necessary to approach the structure via a railway track this should be done only by arrangement with the railway authority, and even so the inspector must exercise extreme caution and be particularly alert. Whenever the inspector parks his vehicle it must be left so that it is not a danger to other road users. Care must be taken if the approach is by way of the slopes to an embankment or cutting. Not only is it possible to trip over bumps or hollows concealed by vegetation, but slopes can be slippery in very dry as well as in very wet or frosty weather. Paved slopes below motorway bridges can also be extremely slippery if proper steps or walkways are not provided.

b. Access

At the site, staff must satisfy themselves as far as possible that access facilities if provided by others are adequate and safe. For example, the tops of ladders should be lashed; scaffolds and stagings should be secure and have handrails; fixed guide wires for safety harnesses should be checked, and confined spaces should be adequately ventilated beforehand (see Sec 3.1.6). The inspectors must at all times have a top-man and a method of communication when entering confined spaces or areas away from the public such as box girders or culverts.

c. Precautions

Staff must take all necessary precautions in advance to safeguard their health. They should wear suitable protective clothing including helmet and non-slip boots. For an operational site, particularly a motorway, they must have a fluorescent jacket. After any possible exposure to infection such as in old culverts the inspector should wash with disinfectant. Staff who were spectacles, particularly bifocals, should take extra care on stages or scaffolding. Where very particular procedures are laid down ie in certain box girders, high or deep ladders, or compressed air working, staff must ensure that they are capable of meeting the physical requirements needed to observe such procedures. Staff who are not physically fit should not attempt strenuous procedures which could bring on a heart attack or similar, not only for their own sakes, but because they could endanger the safety of others attempting to resue them. Staff should remain alert and safety conscious at all times and not rely blindly on facilities provided by others.

d. Equipment

Staff must ensure that they are in possession of a first-aid box and of all necessary safety equipment before proceeding on site. Any equipment carried such as tools, cameras, testing gear etc should be properly slung from the shoulders in carrying cases so as to leave both hands free for negotiating ladders or scaffolding. Equipment should be handled and used in such a way that it does not endanger others, for example by dropping articles from an overbridge or using the photographic flash in circumstances dangerous to a driver. There are extreme risks in approaching too near to electrical conductors (eg on railways) and inspectors must be aware of these dangers.

e. Radiographic testing

Where radiographic testing is being carried out by authorised personnel the work and safety precautions must be approved by HM Factory Inspectorate. The radiation area surrounding the radio active source must be marked and secured by barriers to prevent entry into this area by unauthorised personnel. This boundary must be set where the level of radiation from the source has fallen to prescribed safety limits. Appropriate warnings must be sounded when a source is about to be exposed, and a different warning signal provided whilst the source remains exposed. These procedures

APPENDIX A

Bridge Design and Construction

This Appendix deals with some of the principles involved in the design of bridges and in the selection of materials of construction. The subject matter is specifically concerned with bridges but is relevant to other highway structures such as culverts, retaining walls, sign and signal gantries, etc.

A1 Bridge Design

A highway bridge is designed to carry vehicles, pedestrians and other transient loads such as those due to temperature effects and wind; all collectively referred to as "live loads". In addition the bridge has to carry its own weight and the weight of any permanent items such as parapets, surfacings and finishes; these constitute "dead load". In older bridges, such as arch bridges, the dead load greatly exceeded the live load with the result that the bridge was primarily required to sustain its own weight, the effects of traffic being small. With the improvements that have taken place in the strength to weight ratio of steel and concrete, modern bridges carry larger traffic loads in relation to their own weight and this is reflected in greater "liveliness" in their response to live loads. This liveliness has implications with regard to several forms of deterioration which are discussed in Chapter 2.

Vehicular loading used in the design of a bridge falls basically into two categories. One is the equivalent of a queue of heavy, but commonly occurring, commercial vehicles and the other is the equivalent of one special vehicle carrying an exceptionally heavy load. The bridge is required to carry such loads with adequate margins of safety against collapse. However, a bridge may show signs of distress, such as cracking, under a succession of much smaller loads, leading to a reduction in the durability and/or carrying capacity of the structure or its individual components. Such deterioration affects the "serviceability" of the structure and modern design codes require adequate safeguards to ensure serviceability of all components for specified loading and life.

Traffic loads change in their character and intensity during the life of the bridge. Bridges are part of a highway system which has been developed over a very long period of time; so that sometimes contraints have to be imposed on vehicle loads to avoid structural damage and an unacceptable increase in maintenance work. Very old bridges were built to carry horses, carts and pedestrians and their response to modern traffic may have to be carefully monitored. Fortunately, many arch bridges have a considerable reserve of strength.

The structural function of a bridge is to transfer the loads through several structural members to the ground, without causing undue movement. Fluctuations in temperature, shrinkage and creep of concrete will cause movements which if restrained can generate high forces and it is the purpose of bearings and joints to accommodate these movements. Temperature and other movements are particularly important in long bridges and can be the cause of many defects developing in service.

A2 Load Effects

The structural effects of loads and movements are assessed in terms of tension, compression, bending, shear and torsion, acting singly or in combination. A member is said to be in tension when forces applied to it tend to pull it apart, as for example in the cables or hangers of a suspension bridge. A member is in compression when the applied force tends to squash it, as in the columns supporting a bridge deck. Bending occurs when the forces produce curvature of a member.

Shear forces are forces applied transversely across a member producing a slicing or scissors action. Shear forces normally occur in conjunction with other systems of forces and may result in the development of tension cracks in concrete at 45 degrees to the axis of a member. A state of torsion is produced when a member is subject to a twisting motion as in the case of a shaft loaded by a force on a crank. Beams experience torsion when the load is located away from the longitudinal axis. As with shear, torsion is normally associated with other systems of forces giving rise to complex distributions of stress.

Stress is defined as the intensity of a force per unit area of the section of the member across which the force is applied.

When a force is applied to a structural member it changes its length and this change of length, expressed as a fraction of the original length, is called strain. When load is applied to a piece of rubber, strain is readily visible. Much smaller strains occur when structural materials such as steel, concrete or masonry are loaded; they are not usually visible and strain gauges are required to measure them. This difference arises because concrete or steel are less elastic than rubber. The extent to which they are elastic is determined by a characteristic of the material known as the elastic modulus.

A structural member which is subjected to frequent loading may fail by fatigue of the material. Fatigue is defined as the fracture of a material caused by many repetitions of stress within the normal working range.

A3 Forms of Construction for Bridge Decks

Simply supported construction:
A beam or slab is said to be simply supported when it is supported so that its ends are free to rotate (Fig 1). A viaduct may consist of several spans of simply supported beams, with expansion joints between them.

Continuous construction:
In any multi-span structure the main structural members may be designed to be continuous over supports (as distinct from a series of simply supported beams) (Fig 2). Movements are accommodated in a few widely spaced joints. A special case of a continuous structure is the portal frame bridge shown in Fig 3. In this the deck is made structurally continuous with the supporting columns or abutments.

Cantilever and suspended span:
This form of construction is shown diagrammatically in Fig 4. The cantilever is formed by continuing the side span over the support into the main span to provide a seating for the central simply supported beam or slab, which is referred to as the suspended span. A series of alternating fixed and suspended spans is sometimes used in multi-span structures.

A4 Materials of Construction

A4.1 *Concrete*

Concrete is an economical and convenient material which can easily be cast into any shape. Its main use and strength lies in resisting compressive forces. Its tensile strength is low and normally tensile stresses associated with concrete have to be resisted by steel reinforcement. The compressive strength of concrete can vary widely depending on the proportions of the mix and the amount of water which has been added. Concrete which has a large number of voids, due to inadequate compaction, is considerably weaker than dense concrete.

A4.2 *Steel*

Steel is at present the most economical structural material to provide tensile strength. Steel can also be used in compression, care being taken to ensure

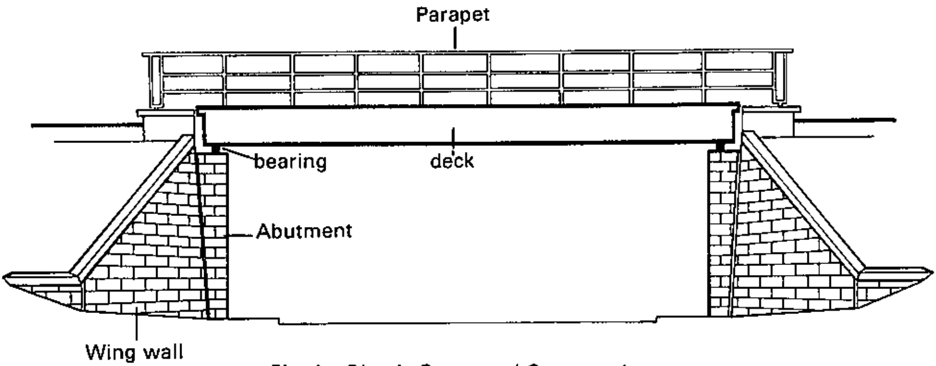

Fig. 1 Simply Supported Construction

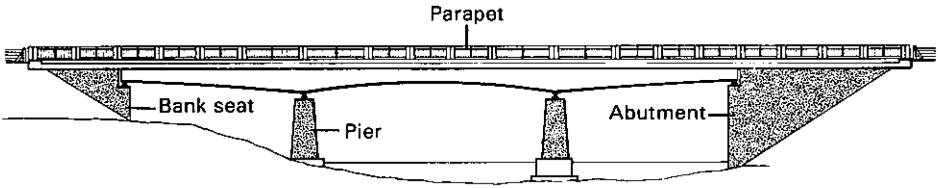

Fig. 2 Continuous Construction

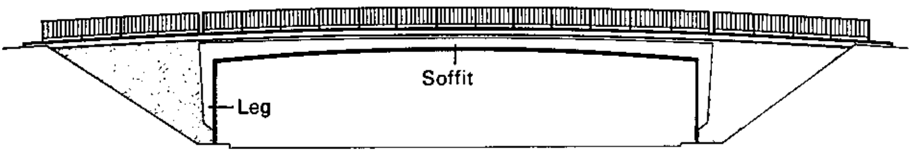

Fig. 3 Portal Frame

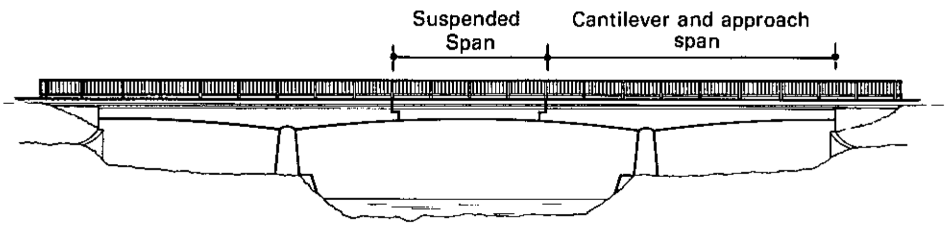

Fig. 4 Cantilever and Suspended Span

that relatively slender plates do not buckle. Steel is used for structural members, box beams, plate girders, rolled sections, tubes and plates and also as reinforcing bars and prestressing tendons in concrete. There are various grades of steel; mild steel is the most commonly used but high yield steels are used for structural members which have to carry higher stresses and for reinforcement and prestressing tendons.

Steel requires protection from the atmosphere if it is not to rust and sound paint systems are very important where steel is exposed. Early reporting of signs of breakdown of the paint system will assist the Engineer's planning of painting maintenance operations. See BS 16 - Assessment of Paintwork.

Recently a type of structural steel has been used on a few bridges which produces, under normal exposure to the atmosphere, a rust film which adheres strongly and provides a measure of protection to the steel as it develops. This steel is known as weathering steel and under certain conditions it may not require painting.

A4.3 *Wrought Iron and Cast Iron*

Wrought iron and cast iron are found in some of the older structures. Wrought iron, though its working stress is less than that of modern steels, is usually a durable material capable of yielding or distorting under excessive loads without fracturing. However, if inadequately protected against the weather its laminar nature is very susceptible to corrosion.

Cast iron is a brittle material but satisfactory for carrying compression loads. Tensile failure in this material happens very suddenly because there is little or no yield before fracture. Owing to the difficulties of casting there are likely to be considerable variations in quality and also high possibility of voids being undetected in large castings.

A4.4 *Reinforced Concrete*

Reinforced concrete is a composite material using concrete for compressive strength and steel reinforcing bars to carry the tensile forces. The concrete which is cast round the reinforcing bars shrinks slightly as it hardens thus gripping the reinforcement and ensuring composite action. The concrete provides good protection to the steel from corrosion, provided the cover is adequate and the concrete is dense.

A4.5 *Prestressed Concrete*

Prestressed concrete, after casting, is put into a state of compression by tension in steel tendons. In this way all the concrete in a beam can be made to act in resisting a bending moment because the concrete is in compression across the whole section. In pretensioned beams or slabs the steel tendons are stressed before the concrete is cast around them and the concrete is allowed to harden and grip the steel before the initial tensile loads are released and transferred to the concrete. In most post-tensioned beams on the other hand ducts are formed in the concrete during casting and the tendons are placed in these and tensioned after the concrete has hardened. The tendons are protected from corrosion by cement grout, injected into the duct to fill them completely, an objective which is not always achieved. In a few cases the tendons are external to the concrete and are protected by encasing in cementitious or other special materials.

A4.6 *Masonry and Brickwork*

Masonry and brickwork are not commonly used in modern bridges but will be frequently encountered when inspecting older structures. The blocks or bricks are bonded togther with relatively weak mortar and there is no question of the structure being designed to resist tensile forces apart from, a certain interlocking action due to careful arrangement of the courses and joints between blocks. The strength of these structures is affected by the quality of the materials used, the quality of the workmanship involved in the construction and the geometric proportions of the design.

A4.7 *Aluminium and its Alloys*

Aluminium and its alloys are used where the light weight and relative freedom from maintenance are of advantage. Aluminium alloys in contact with other metals such as steel or with concrete can give rise to localised corrosion problems. Various alloys of aluminium have been developed for particular purposes.

A4.8 *Timber*

Timber is not now used for the main members of vehicular bridges in the UK but is used in the form of laminates for footbridges and also for the decks of some movable bridges. The main problems in the use of timber are connected with fixings and preservation against rotting.

A5 Bridge Types

The faults which occur in foundations, substructures, superstructures and ancillaries are dealt with in Chapter 2; the following deals briefly with some of the design and construction, influences and defines the principal bridge types.

Foundations may be divided into two broad categories, namely spread footings and piled foundations; their construction, particularly piling, is very expensive. Failure of foundations can be catastrophic. The most common cause of failure of river piers is scouring particularly during floods, whereby pockets are eroded in the river bed to expose the foundation and perhaps undermine it. Stone pitching or training walls may be provided around the bases of piers and banks to stop the river from eroding the soft materials around the foundation and to encourage the deposition of sand and gravel on the protective system during natural flow. The saturation of ground under and around foundations can cause settlement, so that signs of flooding or non-functioning of drains, may be important. Foundations may suffer from chemical attack by ground water containing aggressive substances such as sulphates.

The substructure must be capable of resisting all vertical and horizontal loads and to transfer them to the foundations. In addition, abutments and retaining walls must resist the earth pressure from the fill material behind them. A drainage layer is usually placed behind retaining walls and abutments with weep holes through the walls to prevent the build-up of water pressure.

The superstructure or deck readily identifies the bridge type. A general classification of the main types of highway bridges is as follows:

A5.1 *Arch*

The arch is an ancient form of construction in which the loads are carried by compressive forces developed between the elements of the arch (Fig 5). In masonry and brick arches solid filling to the spandrel provides good distribution of concentrated loading but adds dead weight. In some bridges, to relieve this weight, voids are formed in spandrels which are sometimes visible as holes in the spandrel walls. Reinforced concrete and metal arches can resist bending and are used for longer spans. It is important to reduce the dead load and provide open spandrels with columns or cross walls to carry the deck. These latter arches can be fixed or pinned.

All arches depend for stability on very firm foundations capable of resisting the thrusts at the springings. It may be that on some sites the ground is not adequate to take this thrust and it is then resisted by a tie. Fig 6 shows an example of an arch bridge with a tie at deck level. Ties to resist horizontal thrusts from arches and inclined supports can be located below ground level and in such cases care must be taken to identify and protect the tie before excavations are carried out near foundations.

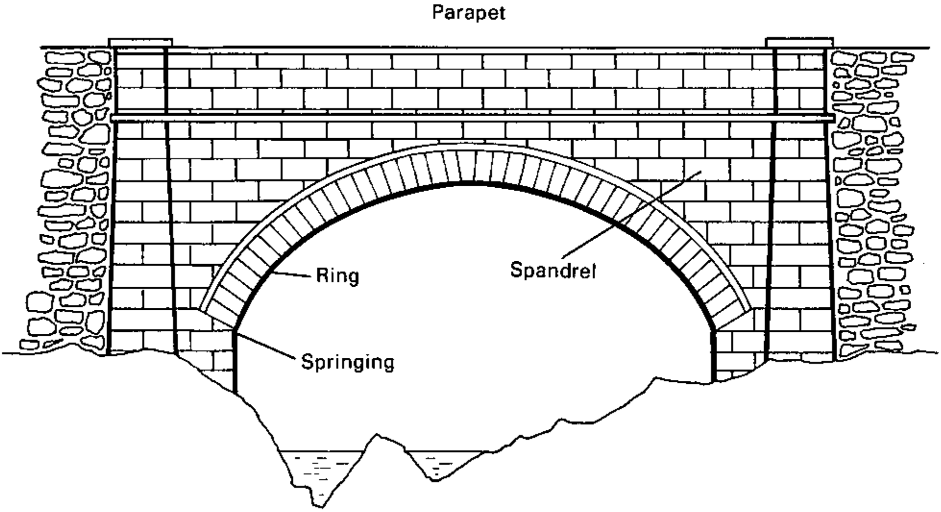

Fig. 5 Arch

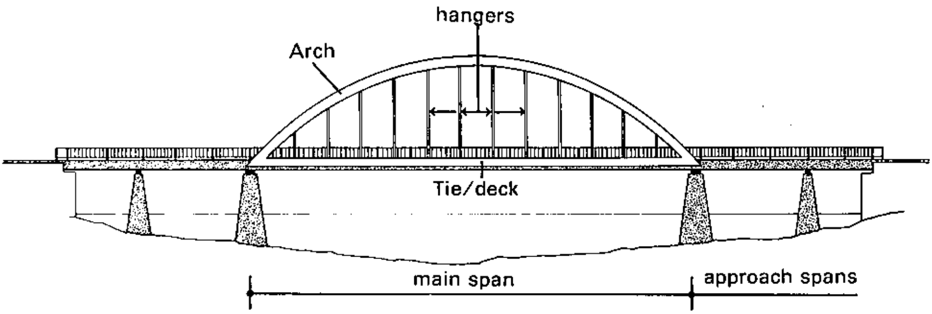

Fig. 6 Tied Arch

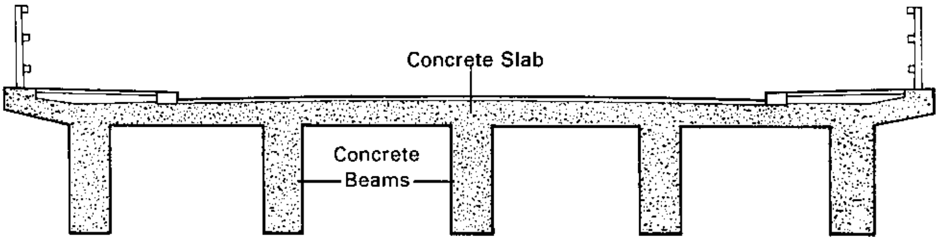

Fig. 7 Beam and Slab Construction

A5.2 *Slab, Beam and Slab, and Composite*

The simplest form of bridge superstructure for short and medium spans is the slab. It is a descendant of the prehistoric clapper bridge. Nowadays slab bridges are built in either reinforced or prestressed concrete and may be solid in section or have voids to reduce their weight.

For longer spans the superstructure consists of main longitudinal beams and a deck slab as shown in Fig 7.

In beam and slab construction the beams are either monolithic with the slab or are made separately from different materials and structurally connected together. The latter is known as composite construction. In its most common form the beams are of steel to span the gap and the concrete slab is placed over the top to form the road deck. The slab is made composite by shear connectors, such as headed studs. The beams may be of steel or concrete. In the latter case the structural connection is made through reinforcement extended from the beams into the slab. Typical cross sections are shown at Fig 8.

A5.3 *Plate Girders*

For spans beyond the range of standard rolled steel sections, girders are made up from plates by welding. Prior to the 1940s the plates were joined by riveting with angles and cover plates. Large steel plate elements have stiffeners welded to them to strengthen the plates to prevent local buckling. At the points of concentrated loading, as at supports, there may be transverse plate elements known as diaphragms to distribute load to web and flanges.

A5.4 *Box Girders*

Box girders are structurally more efficient in carrying the loads on longer spans, continuous spans and wider bridges. Those constructed in steel are almost invariably built up by welding, the larger sections being either bolted or welded together on site. Box girders constructed of reinforced and prestressed concrete may be monolithic with the deck slab forming the carriageway. The top and bottom horizontal members of the box are usually referred to as flanges and the vertical joining members as the webs. Box girders may have sloping or vertical fascias (outer webs) and the wider box sections may have multiple internal webs, with transverse diaphragms at the supports and elsewhere as necessary.

A5.5 *Spine Beam Construction*

This consists of a central solid or box section member which is the main structural load carrying element, and from which transverse cantilever projections make up the required width of the road. Fig 9 shows a section of such construction.

A5.6 *Trusses*

Trusses or trussed girders of the form shown in Fig 10 are usually built up from standard rolled sections to span longer gaps and make the best use of structural material. They may be of beam form as illustrated or of cantilever form, but they have not been so extensively used in recent years because their maintenance tends to be labour intensive. Occasionally reinforced concrete has been used.

A5.7 *Cable Stayed Girders*

The general form of the cable stayed bridge is shown in Fig 11. This type has become popular since about 1950 and enables girders of a given section to span larger gaps due to the support provided by the cables attached to a tower or a series of towers.

A5.8 *Suspension Bridge*

The form of the suspension bridge is illustrated in Fig 12. It is used either for very long spans or to provide a very light structure for shorter spans. Its primary structural element is the cable, anchored at each end to an abutment or into the ground and carried across the gap over high

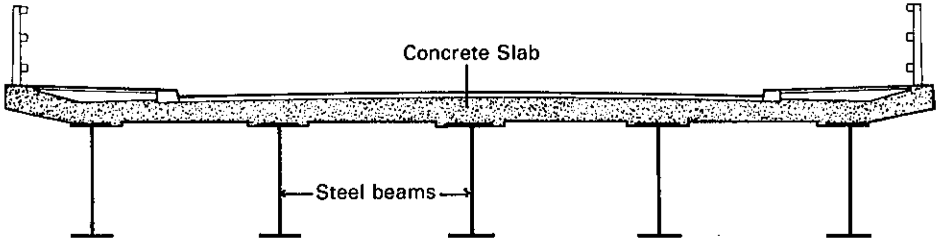

Fig. 8 Composite Construction

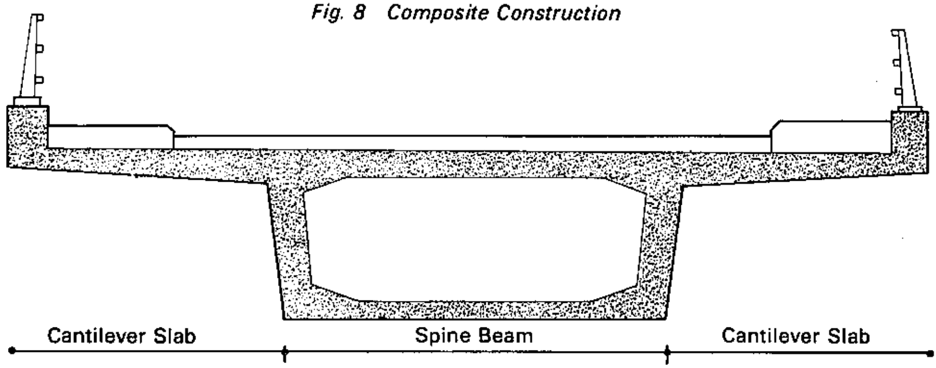

Fig. 9 Spine Beam Construction

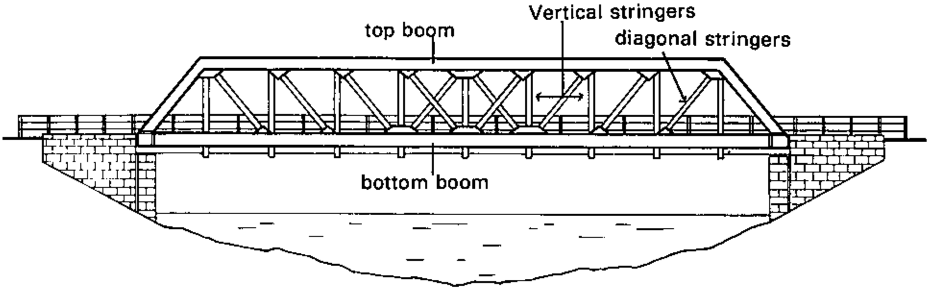

Fig. 10 Truss Bridge

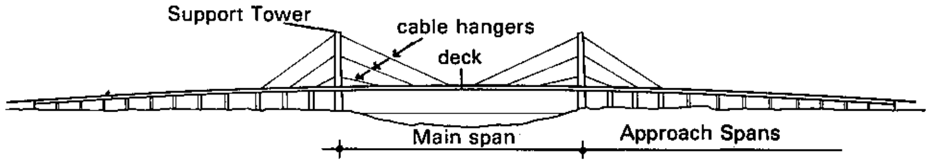

Fig. 11 Cable Stayed

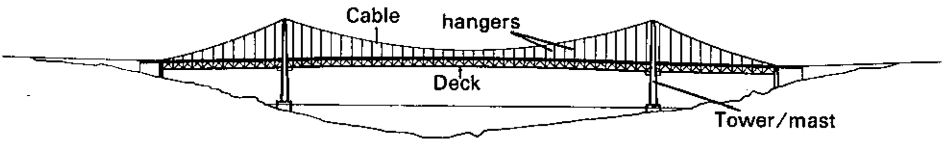

Fig. 12 Suspension Bridge

towers. The deck and stiffening girder are suspended from the cable by another set of vertical or inclined cables known as hangers. The stiffening girder may be of either plate or box girder form and may be integrated with the deck carrying the traffic.

A5.9 *Movable Bridge*

Bridges with opening, lifting or swivelling spans are classified as moveable bridges.

A6 Structural Connections

A6.1 *Definitions*

Bridges require the joining together of a number of component parts. Some joints may be internal and not visible for inspection after the structure is built, eg connections between precast and insitu concrete or between steel beams and concrete slabs in composite construction. Defects in such joints can only be inferred from associated surface cracks or from load tests with measurements of strains and deflections. Other joints are visible and can be inspected.

A6.2 *Rivets*

In older steel bridges rivets were used for joining plates together, but have been superseded by welding and friction-grip bolting since the 1950s. The simplest form of riveted joint is the lap joint (Fig 13) where the rivets are holding together two overlapping plates. The lines of force in adjoining plates are not coincident so that there is a tendency to cause the joint to rotate. A more satisfactory joint is one in which the plates butt against each other with cover plates placed across the joint on both sides of the plates (Fig 14). The strength of the riveted joint lies in the resistance of the rivets to shear on the contact surface between the plates.

A6.3 *Bolts*

Bolts with nuts may be used in the same way as rivets. In order to achieve the highest strength from a bolted joint the threaded part of the bolt shank should stop at the surface of the plate, as the weakest section of a bolt is at the root of the thread not engaged by the nut. Nuts should be sufficiently tight to ensure that bolts will not work loose but excessive tightening is detrimental.

High strength friction grip (HSFG) bolts do not rely on sher of bolts but rather on the friction which develops across the contact surfaces between the plates when they are clamped together by the bolts. The bolts used are specially made for this purpose from high strength steels. The bolts are tightened in a controlled manner, either to a given torque by means of a torque wrench or by monitoring the turns of the nut, or by a combination of the two techniques. Special load indicating washers or bolts have an initial gap which is closed down to a set range when the bolt is correctly tightened. Such devices do not indicate any relaxation after tightening. The surfaces of the plates in contact with each other are known as the faying surfaces which are usually grit blasted to ensure uniform and predictable friction. After tightening all the bolts it is necessary to maintain an effective seal at the edges of cover plates against the ingress of water.

A6.4 *Welding*

Welding is a method of joining metal parts together by locally melting the joining surfaces and allowing the metals to fuse together to form a fairly homogeneous joint on cooling. The main method of melting the metal in structural work for bridges is by various versions of the electric arc. Generally, welding electrodes provide additional metal together with a flux to protect the molten metal from the harmful effects of oxidation at high temperatures which would otherwise weaken the joint. In other versions, protection is provided by a shield or carbon dioxide or inert gas. The success of welding depends greatly on the skill of the operator and on the conditions in which the work is done. Many defects can

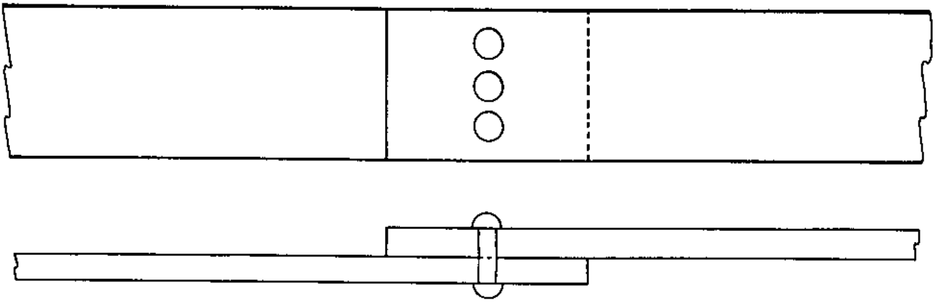

Fig. 13 Rivetted lap joint

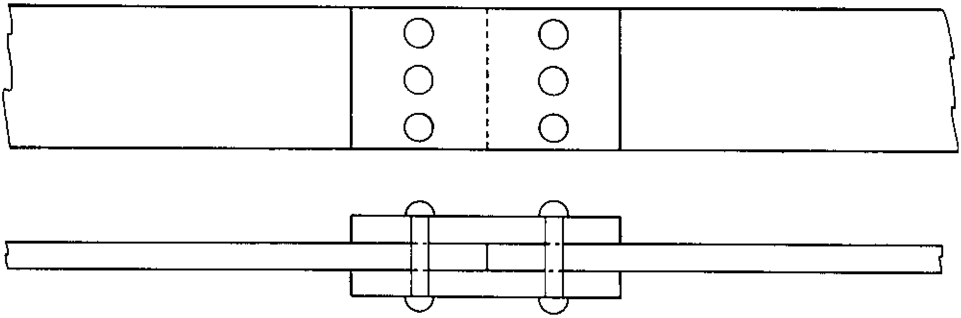

Fig. 14 Rivetted cover plates

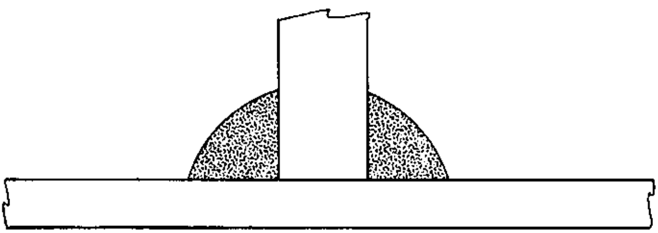

Fig. 15 Fillet welds

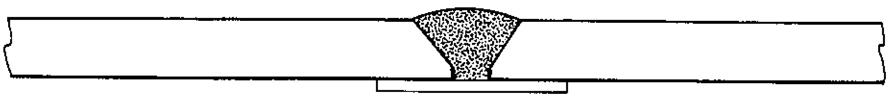

Fig. 16 Butt weld

occur, visible and invisible both in construction and in service so that welded joints merit particular attention during inspection. One reason for the susceptibility of welds to weakness is the setting up of residual stresses in the weld metal and the adjoining metal during the cooling period after the weld is made. Members which have successfully carried test or proof loads above their normal working load, and in which the loads do not reverse, are generally protected from harmful effects of residual stresses provided there is no deterioration of the member such as cracking or changes in the physical properties.

Welds are of two main forms: the fillet weld and the butt weld. The fillet weld (Fig 15) is external to the thickness of the member being joined and is usually used to join plates inclined to each other. It may be built up by one or more welding runs to the required dimension of throat and leg length. For the butt weld (Fig 16), the ends of one or both plates are usually prepared by chamfering edges to form a V-groove on one or both sides, and the additional metal is deposited within the thickness of the members. Butt joints may join the ends of members or the end of one to the surface of the other (T-butt weld). The groove may be filled in one or several runs to obtain uniformity of form and composition. In some cases where access is only available to the weld from one side a backing strip may be provided but this can affect the strength under fluctuating loads due to fatigue. Welding is prone to cracking from fatigue, induced by a large number of fluctuations of stress at levels which are well below those which would cause failure by a single application. Defects in welds enhance the fatigue risk. Welding repairs require very careful attention because of the adverse conditions in which the work is carried out, because of the risk of creating additional flaws in the parent metal and because the residual stresses produced may adversely affect the fatigue life of the component. Different qualities of steel require different welding methods and materials.

A6.5 *Bonding*

Another method of making structural connections which has been developed over the past 30 years is by means of resin adhesives. The bond produced is primarily a chemical bond as opposed to the mechanical bond produced by riveting and bolting. It differs from welding in that the jointing material is different in type and composition from the elements to be joined and in that it hardens at normal temperatures and no fusion of the bonding materials occurs. Resin adhesives are slow to harden at lower temperatures and the bond can be impaired by vibration and dampness until it has had time to set. Bonded joints can be used to transfer forces in compression and in shear up to the strength of the structural member, but their use is rare.

A7 Provisions for Movements

A7.1 *Definitions*

All bridges and their components will deflect, expand and contract, primarily under the influence of traffic and temperature. Unless these movements are accommodated at expansion joints and bearings, unacceptable stresses and strains may be generated in the structure.

A7.2 *Expansion Joints*

Expansion joints allow the parts on each side to move horizontally or rotate independently. The simplest is an open gap with various forms of strengthened edges to resist traffic impacts. The edges may be protected by metal plates strongly bolted down to the deck or by epoxy mortar nosings which rely on chemical bonding to hold them in place. For short spans, the gap and the movements will be sufficiently small to permit laying the road surfacing over the joint, giving the buried joint. Seals

APPENDIX B

Non Destructive Testing

B1 Introduction

Of the tests described in the following paragraphs, only a few are likely to be suitable for use by the bridge inspector. The use of radiography or radiometry will need the employment of specialist firms or organisations. The other tests could be carried out by a highway authority but would depend upon its resources in suitable staff and equipment and the availability of laboratory facilities.

Non-destructive testing can make a valuable contribution to the investigation of many problems that occur in bridges. It is important however that the nature of its contribution should be properly understood. It is not often that a single non-destructive testing technique will be able to give the engineer all the information he wishes to obtain. More commonly it will provide him with some additional evidence about a fault or problem which he already suspects; sometimes indeed it may do no more than to confirm his suspicions.

Non-destructive testing should not therefore be regarded as a diagnostic technique in itself but as part of a broad approach to the investigation of a problem. The drawings, the records of construction and testing, visual examination of the structure sometimes augmented by strain and deflection measurements and non-destructive testing should be regarded as being complementary to each other. Theories about the mode of behaviour or the type of fault can then be tested against the assembled evidence. Non-destructive testing is probably most valuable when used in a supporting role and its likely contribution to solving a problem must be carefully considered when planning the tests.

Non-destructive testing is a subject which is continuously progressing and developments for use in other industries may sometimes provide useful techniques for bridge inspection. It is difficult for any summary to be completely up to date and all that can be done is to give a general outline. Some methods are likely to be improved, others to be superseded and techniques not at present used for bridges may become available later.

A strict definition of non-destructive testing would confine it to techniques which do not in any way change the properties of the structure or alter it physically.

This definition is somewhat restrictive when applied to bridge inspection and the term non-destructive testing is widened in this Appendix to include, tests which involved removal of small samples by drilling or cutting but on a minor scale which will not impair the effectiveness of the structure.

The tests to be used depend very much upon the circumstances and condition of the particular bridge being investigated. For instance, if corrosion of reinforcement in concrete bridges is suspected then measurements of electrical potential and resistivity would be supplemented by measurement of the concrete cover, and of the permeability and chloride content of the concrete. If proof loading is to be carried out then not only should strains and deflections be measured but there may be a case for using acoustic emission to check whether cracks are propagating as the load is applied. If lamination is suspected in concrete then tests to detect it might be supplemented by the application of vibrational techniques together with the drilling of small diameter cores. The application of many of the non-destructive techniques described to the examination of faults in bridges is comparatively new and some of the older methods have not yet been widely used. Until there is experience of the application of these techniques to bridges on the wider scale it is difficult to make firm recommendations and it will be necessary for the engineer to consider each particular case on its merits.

Where information is needed on the strength of the materials used in a bridge, two problems arise. Firstly the removal of samples for strength tests may permanently weaken the structure, particularly in fatigue. Secondly, it is not usually practicable to make sufficient tests to provide adequate data on the variability of strength. A few tests can be useful in giving a broad indication of the quality of the materials. The Engineer's approval should always be obtained before any samples are removed. He will have to consider the likely value of the results in relation to possible damage to the structure and whether indirect methods of assessing strength might not be more appropriate.

B2 Non-destructive testing for the examination of concrete bridges

B2.1 *The strength of concrete from surface tests*

Several methods of test are available. [1] [2] [3]* The Schmidt hammer is an impact hammer consisting of a plunger, which is held in contact with the concrete, and a spring loaded mass which strikes the free end of the plunger and rebounds. The extent of the rebound (the 'rebound number') gives an indication of the strength of the concrete at the surface position where the measurement is made. The measurements are influenced by the finish to the concrete and should be made on a smooth surface. The correlation is influenced by the properties of the concrete and accuracy of the order of plus or minus 15% is claimed.

As an inspection technique, the hammer may be used to compare the quality of concrete in different parts of the bridge or between different bridges if the concretes are similar. It should always be remembered that only surface concrete is being tested. The results should not be used for calculating the strengths of the structure but, wth caution, they could be used as confirmation of results obtained by other means.

The compressive strength of insitu concrete may also be assessed by the Windsor Probe, which is a device which drives a steel probe into the concrete using a constant amount of energy. The length of probes projecting from the concrete is measured and a result is based on the average of three measurements.

A simple pull-out test to assess the strength of in-situ concrete has been developed by the Building Research Establishment. It requires a hole 6mm in diameter and 30–35mm in depth to be drilled into the concrete. A 6mm diameter wedge anchor bolt with an expanding sleeve is tapped into the hole to a depth of 20mm and the compressive strength of the concrete is estimated from the torque that has to be applied to the wedge anchor to produce internal cracking.

B2.2 *Core drilling*

Cores can provide information on concrete strength, compaction and on cracks.[4] Cores of 50mm diameter can be drilled but a diameter of not less than 100mm is usually needed for strength tests. A skilled operator is needed, particularly for drilling small cores, and a number of firms undertake this work. Core drilling, can weaken the structure and should be carried out only on the authority of the engineer.

B2.3 *Electromagnetic devices for measuring concrete cover*

An electromagnetic technique can be used to locate reinforcing steel and to determine the depth of cover up to about 120mm. It is sometimes possible to estimate the size of bars with this technique but this depends on cover and bar spacing. The device consists of 2 coils placed on the concrete surface. An alternating current is passed through one coil and the induced current in

*See reference on page 51

Sometimes stretched wires are used to transmit the deflection from the bridge deck down to ground level where gauges can be more easily installed. Where a high degree of accuracy is needed a precise water level or sometimes laser techniques may be needed. Where lower accuracy is adequate a precise level may be used. It may be necessary to supplement the measurement of deflections by measurements of rotation or change of slope, and for this purpose a number of commercially produced inclinometers are available.

On many highway bridges it may be difficult to provide sufficient load to produce measurable strains and deflections. When the strains, in particular, are small it may be found that on subsequent loadings the original readings are not repeated. Changing temperatures during the measurements will produce thermal strains which can be of the same order as those due to loading. Careful consideration needs to be given to the method of loading and the likely strains and deflections before any tests are carried out. It may be necessary to select a time of day and weather when thermal strains are small.

B2.12 *Radiography*

Radiography can be described simply as photography using a type of radiation, normally gamma radiation for concrete, which will penetrate through the concrete. A source of radiation is placed to one side of the concrete and a film is attached to the other side. Steel which, because of its higher density, impedes the transmission of radiation more than concrete, shows up on the negative as lighter than the surrounding concrete and conversely voids shown up as darker areas. The negatives are usually examined in a viewer although positives (ie prints) can be obtained. The picture shows all the steel and voids throughout the depth of the concrete examined in a projected view so that if there is more than one layer of reinforcement or tendons, these are superimposed and careful interpretation is needed.

The use of radioactive isotopes is subject to very stringent safety precautions and it will usually be necessary for an area around that to be examined to be cleared of personnel and closed off by ropes or barriers. This may mean that such work may only be done outside normal working hours and/or with road closures.

Radiography can only be carried out by a specialist firm or organisation licensed to store, move and use the radioactive isotopes. It should be specified that the work be done in accordance with BS 4408: Part 3.[3] Particular attention should be given to marking out the source and film positions so that these are accurately located relative to each other.

Information should also be provided upon the type of source to be used (normally cobalt 60, caesium 137, or iridium 192), the type of film, the source to film distance and other details such as whether intensifying screens will be used. The procedure must be approved by HM Factory Inspectorate and it may be advisable to consult them at an early stage in planning the work.

There are practical limits to the use of radiography for concrete. The maximum thickness which can be radiographed is about 500 to 600mm. For checking the adequacy of the grouting of ducts it must be possible for the radiation beam to be passed horizontally through the concrete and there must be access to both sides. The object being examined, reinforcement or tendon etc, must be as close to the film as possible and the source/object distance must be markedly greater than the object/film distance. Radiography of concrete is expensive and only a limited area can be covered by one exposure.

A combination of a preliminary survey by covermeter, followed by selected radiography may be of advantage if the object is to check size and position of reinforcement.

The use of radiation generators instead of radioactive sources is a possible development for application to bridges. A betatron generator has already been used for this purpose abroad and linear accelerators which are used in the aircraft industry might also be applied to concrete structures.

B2.13 *Radiometry*

The principles of radiometry are similar to those of radiography except that the source is of lower density and the film is replaced by a detector such as a Geiger or scintillation counter, which is used to scan the area of interest. Radiometric methods are used to determine the density of concrete from the attenuation of radiation transmitted through it. Attenuation increases with increasing density. Either direct transmission or backscatter techniques can be used; in the latter the source and detector are on the same face.

2.14 *Pressure-Vacuum Technique*

The volume of voids in a post-tensioning duct, the continuity of voids along the duct and the leakage in to the duct may be investigated by pressure/vacuum technique through holes drilled in to the duct[14]. Close supervision of the hole drilling is needed to reduce the risk of damage to the tendons. Therefore this technique should only be done under the direction of the Engineer.

B2.15 *Vibrational techniques*

These techniques use the vibrational response of a structure as a means of detecting the presence or development of defects. Forced vibration over a range of frequencies [15] or traffic induced vibration [16] are used to provide the excitation and the response of the structure is measured by accelerators.

B2.16 *Acoustic emission*

When a structure is first loaded, or loaded to a higher value than before, the resulting deformation of the material may release strain energy and this produces stress waves which can be detected with suitable transducers. By placing several transducers on the structure, the sources of the emission may be located. Acoustic emissions may be produced by several different causes including crack growth, local crushing, bar slip and corrosion. The technique has been used mainly on homogeneous materials such as steel and its application to concrete structures increases the difficulty of interpreting the results. It is a highly specialised technique and the reliability of the information obtained depends very much upon skill in analysing and interpreting the results.

B2.17 *Leakage through waterproof membranes*

An electrical resistance technique may be used to locate leakage through waterproofing membranes [17]. The resistance is measured between the reinforcement in the concrete deck and contact points on the bituminous surface formed by sponges saturated with water containing a wetting agent. A high resistance indicates that the waterproof membrane is intact but lower values indicate leakage. Measurements are made over a grid of points and contours of electrical resistance plotted. The results need careful interpretation and allowance must be made for apparent leakage due to the conditions at the edges or joints.

B3 Non-destructive testing for the examination of steel bridges

B3.1 *Thickness testing*

Testing for the thickness of members subject to corrosion can be carried out either by direct measurement where access is available, or alternatively by special

The first of these methods is by the use of a strong permanent magnet, the poles of which are placed either side of the area to be tested. The test area is then coated or covered with a magnetic powder and if any cracks or other defects close to the surface are present they show up as linear defects in the coating or powder on the surface. A second version of this permanent magnet method is the use of an electro-magnet with power supplied by an external current.

The second main type of magnetic crack detection is the case where the magnetic field is induced by the passage of a high current through the steel sample itself by the use of electric probes. The intensity of the current is related to the strength of magnetic field produced and this determines the sensitivity of the technique for the detection of defects. The current may be either AC or DC although in general AC techniques are better for detecting surface defects and DC techniques permit defects just below the surface to be found. To enable the high current to be passed into the steel at low voltages any paint or dirt must be cleaned locally at the probe contact points. Care must also be taken that craters due to arc strikes are not produced or left at the probe contact points. Any such craters must be removed by grinding.

The third main method of producing the magnetic field is by induction, in which a coil is wound around the test area and the field produced by passing a current through the coil.

In all of these cases the presence of defects is indicated on the surface by the coating or magnetic powder.

B3.10 *Ultrasonic testing*

Ultrasonic testing involves the introduction of a high frequency sound beam into the area under test and monitoring either reflections from within a welded joint or the attenuation of the sound beam on transmission through the joint.

The normal ultrasonic testing techniques are the pulse echo methods in which signals returned from internal flaws are monitored. The equipment is initially calibrated on standard test blocks so that the distance from the probe to a defect or reflecting surface is shown directly on the equipment screen. By using probes which introduce the sound beam into the joint at different angles, and by measuring the distance of the probate from a datum point at the joint and noting the distance along the path to a defect the position of the defect can be identified. Estimations of the size of internal defects can usually be made either by exploring the perimeter of the defect with the sound beam or by noting the magnitude of the response from the defects. Estimations of the type of defect can also be made by experienced operators by noting the response pattern to different incident beams.

Ultrasonic testing is a highly skilled operation requiring trained and experienced personnel. It is particularly suitable for detection, identification and sizing of internal defects, including planar defects in steel joints above about 10mm thickness. Problems may arise with surface roughness, the presence of reinforcement or backing strips, and when access is limited to only one side of a joint. Nevertheless the basic method in the hands of skilled operators is an extremely valuable non-destructive testing tool. General methods of ultrasonic testing are described in BS 3923 (20) and BS 4336 (21).

The use of ultrasonic testing for detection of laminations in steel also relies upon the pulse echo technique in general but, again, standard testing methods are defined. Relevant information on lamination testing and criteria are given in British Standard document DD.21. (Quality gradings for steel plates) (22).

Ultrasonic testing by transmission methods and other variations of ultrasonic testing are less commonly used and should be the subject of special advice.

B3.11 *Radiography*
Radiography involves passing X-rays or gamma rays through the region of interest and projecting the resulting image onto a film. The presence of any defects in welded joints is shown on the film by differences in the intensity of radiation reaching the film. Where cracks, voids or other faults of this type are present less radiation is absorbed by the steel and more is transmitted to the film so that the defects show up as dark lines or shaded areas. Local increases in thickness such as weld reinforcement, backing strips etc absorb more radiation and less reaches the film so that such areas show up as lighter zones. The sensitivity for the technique of the detection of defects depends upon the relative loss of thickness caused by the defect in the direct path of the radiation. Thus narrow defects inclined to the path of radiation are not readily detected.

Radiography is most suitable for detecting either three dimensional non-planar defects, or detecting planar defects which are aligned with the beam of radiation.

As noted in the section on radiography for concrete bridges, there are very stringent requirements for the use of radioactive isotopes and x-ray equipment and it will usually be necessary for an area round that under examination to be cleared of personnel and closed off by ropes and barriers. All procedures must be approved by HM Factory Inspectorate and it may be advisable to consult them at an early stage in planning the work.

For practical results to be achieved it is necessary to have access to both sides of the joint under examination with the radioactive source placed on one side and the film placed immediately against the joint on the opposite side. Different techniques for radiography are described in BS 2600[23] and BS 2910[24].

B3.12 *Eddy current testing*
In this form of testing a probe with inductive coils is placed at or close to the surface of the steel and induces eddy currents in the steel. If faults or defects are present, close to the surface, they affect the flow of the eddy currents in the steel and this, in turn, affects the loading on the probe and produces a response in the measuring circuits. This form of testing is particularly suitable for surface cracks or defects and with careful calibration can be used to estimate the depth of such cracks. The Amlec crack detection equipment is a related form of this type of testing.

All eddy current equipment requires calibration on sound details of the same geometrical form as those to be tested for the presence of defects.

B3.13 *Chemical analysis*
In cases where it is necessary for checks on weldability of a steel or to provide further information on the type of steel this can be done by chemical analysis of drillings or scrapings removed from the member concerned. Care must be taken in collecting such samples to avoid contamination and to be sure that only the materials from the member under consideration are collected for analysis.

For structural steels it will usually be sufficient to analyse for carbon, manganese, silicon, sulphur and phosphorous. Drillings or scrapings should only be removed from areas for which agreement has been given by the Engineer.

B3.14 *Acoustic emission*
This form of testing is a method of listening for any changes or deterioration as it occurs in the structure. Probes are attached to the structure at specific locations and the equipment detects any bursts of sound produced by the growth of defects already present. The technique is still in course of development and requires a considerable number of probes to cover large areas of a structure. It can be used with advantage to

DEPARTMENT OF TRANSPORT

BE 10 (DB)
(July 1979)

Trunk Road & Motorway Structure Inspection Report.

AGENT AUTHORITY .... INSP. BY ....

BRIDGE NAME ....

Description of Condition & Work Recommended, by Item Number.

1

2

BRIDGE NUMBER

0	0	A	A	0	0	0	0	0	M	0	0	0	0	0	A	0	0	0	0	3
1	1	B	M	1	1	1	1	1	S	1	1	1	1	1	B	1	1	1	1	4
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3	3	D		3	3	3	3	3		3	3	3	3	3	D	3	3	3	3	6
4	4	E		4	4	4	4	4		4	4	4	4	4	E	4	4	4	4	7
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7	7	H		7	7	7	7	7		7	7	7	7	7	H	7	7	7	7	10
8	8	J		8	8	8	8	8		8	8	8	8	8	J	8	8	8	8	11
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CONDITION REPORT
(GOOD, FAIR, POOR)

Item					
1	Foundations	G	F	P	13
2	Invert/Apron	G	F	P	14
3	Fenders	G	F	P	15
4	Piers/Columns	G	F	P	16
5	Abutments	G	F	P	17
6	Wing Walls	G	F	P	18
7	Retaining Wall/Revetment	G	F	P	19
8	Approach Embankments	G	F	P	20
9	Bearings	G	F	P	21
10	Main beams	G	F	P	22
11	Transverse beams	G	F	P	23
12	Diaphragms/Bracings	G	F	P	24
13	Concrete slab	G	F	P	25
14	Metal deck plates	G	F	P	26
15	Jack arches	G	F	P	27
16	Arch ring	G	F	P	28
17	Spandrels	G	F	P	29
18	Tie rods	G	F	P	30
19	Drainage system	G	F	P	31
20	Waterproofing	G	F	P	32
21	Surfacing	G	F	P	33
22	Service ducts	G	F	P	34
23	Expansion joints	G	F	P	35
24	Parapets/Handrails	G	F	P	36
25	Access gantry	G	F	P	37
26	Walkways/Ladders	G	F	P	38
27	Machinery	G	F	P	39

MAP REF.

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TYPE & DATE OF INSPECTION

GENERAL G

PRINCIPAL P

SPECIAL S

MONTH		YEAR
1	7	79
2	8	80
3	9	81
4	10	82
5	11	83
6	12	84

Remedial work recommended last time carried out Y or N 40

Work recommended this time None or Some (see at left) 41

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