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**VOLUME 3 HIGHWAY STRUCTURES:
INSPECTION AND
MAINTENANCE**

SECTION 1 INSPECTION

PART 3

BA 50/93

**POST-TENSIONED CONCRETE
BRIDGES
PLANNING, ORGANISATION AND
METHODS FOR CARRYING OUT
SPECIAL INSPECTIONS**

SUMMARY

This Advice Note outlines the organisation and planning procedures for carrying out Special Inspections of post-tensioned concrete bridges. It includes advice on the application of general and specialised methods of inspection and testing.

INSTRUCTIONS FOR USE

This is a new document to be incorporated into the Manual.

1. Remove existing contents pages for Volume 3 and insert new contents pages dated July 1993.
2. Insert BA 50/93 into Volume 3, Section 1.
3. Archive this sheet as appropriate.



THE DEPARTMENT OF TRANSPORT

BA 50/93



THE SCOTTISH OFFICE DEVELOPMENT DEPARTMENT



THE WELSH OFFICE
Y SWYDDFA GYMREIG



THE DEPARTMENT OF THE ENVIRONMENT FOR
NORTHERN IRELAND

Post-tensioned Concrete Bridges

Planning, Organisation and Methods for Carrying Out Special
Inspections

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PART 3

BA 50/93

POST-TENSIONED CONCRETE BRIDGES: PLANNING, ORGANISATION AND METHODS FOR CARRYING OUT SPECIAL INSPECTIONS

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1. INTRODUCTION

Background

1.1 Post-tensioned concrete bridges are particularly vulnerable to corrosion and severe deterioration where internal grouting of tendon ducts is incomplete and moist air, water or de-icing salts can enter the ducting system. The ingress of water and salts into tendon ducts is most likely at joints in segmental construction, other construction joints and anchorages at the ends of members.

Existing post-tensioned concrete bridges with grouted tendon ducts are to be examined in a Special Inspection Programme over a five year period.

1.2 A series of Standards and Advice Notes is being prepared on the Special Inspection of Post-tensioned Concrete Bridges. This Advice Note forms part of the series. BD 54 (DMRB 3.1.2), The Prioritisation of Special Inspections, dated January 1993, has been published. Further documents will deal with other aspects of the Special Inspection Programme ie Assessment, Strengthening, Repair and Monitoring.

Scope

1.3 This Advice Note is intended to assist the Project Manager responsible for carrying out Special Inspections of Post-tensioned Concrete Bridges, hereafter called Special Inspections. It applies to all types of bridges, any part of which has been constructed using post-tensioning techniques with tendons contained in ducts which may or may not be grouted.

1.4 This document outlines the organisation and planning procedures which are necessary for undertaking Special Inspections. It includes advice on the application of general and specialised methods of inspection and testing. Guidance is also given on inspection routines, reporting requirements and appraisal of inspection reports.

1.5 The methods and procedural requirements set down here are generally advisory. However, some are mandatory since they are procedures required in other Departmental Standards.

Implementation

1.6 This Advice Note is intended to help Maintenance Agents (MA's) in the implementation of the programme of Special Inspections as mentioned in BD 54 (DMRB 3.1.2).

It is desirable for one organisation to be responsible for carrying out all three phases of the Special Inspection.

If a MA considers that it is unable to carry out all of the work on a structure (excluding testing which will be carried out by a specialist testing firm) it should inform the Overseeing Department at the earliest opportunity.

The names of specialist testing firms should be submitted for approval to the Overseeing Department in the usual way.

1.7 The general procedures for inspections and maintenance records for use in England are described in TRMM 2/88, Trunk Road and Motorway Structures - Records and Inspection. In Wales, WOTRMM 2/88 applies and in Northern Ireland BE 4/77 NIRS applies. Further advice on Principal Inspections, Special Inspections and Testing of Concrete Highway Structures is given in Departmental Advice Note BA 35 (DMRB 3.3). Departmental Standard BD 27 (DMRB 3.3) applies in England, Wales and Northern Ireland. In Scotland advice on inspections and testing is given in Technical Memorandum SB1/78 (DMRB 3.1).

1.8 For use of this Advice Note in Northern Ireland, the Overseeing Department shall be considered to be the Roads Service Headquarters and the Maintenance Agent shall be considered to be the appropriate Roads Service Divisional Office.

2. ORGANISATION

Inspection Management

2.1 The Project Manager for a Special Inspection should be a senior Chartered Engineer with specialist experience of post-tensioned bridge design and construction methods. The Project Manager will be expected to have wide experience of bridge inspection, testing and monitoring procedures. He should be responsible for the preparation of the programme for a Special Inspection and obtaining all necessary approval from the Overseeing Department and the preparation of the final report.

Inspection Team

2.2 The delegation of responsibility within the inspection team should be the responsibility of the Project Manager. Members of the inspection team should have a sound basic knowledge of the design of post-tensioned concrete structures, stressing procedures, grouting techniques and the operation of standard sampling and test equipment. Specific experience available within the inspection team should include the supervision of specialist methods of inspection for detection of reinforcement corrosion, voids in tendon ducts and corrosion of tendons, methods for concrete removal and instrumentation techniques.

Special Techniques

2.3 A variety of highly specialised techniques may be considered for the site investigations in a Special Inspection. Such techniques already exist for the detection of voids in ducts and the corrosion of tendons and the determination of the stress conditions in the concrete and steel, although there is a need to recognise their limitations. It is essential that the proposed use of all specialised techniques should be clearly identified in the programme for the site investigation and approval should be obtained from the Overseeing Department in advance of preparing any contract documents. Techniques in this special category should be based upon fundamental research and calibration tests, but due to their complexity, the interpretation of the data requires extensive experience of the method. Therefore, all site staff operating these techniques

should be described in the programme and full evidence of their relevant experience called for as part of the tendering process.

Safety

2.4 The Project Manager should make a suitable and sufficient assessment of the risks for the particular situation and inspection techniques involved, consulting the Environmental Health Officer, the Health and Safety Executive, the Police, and other interested parties, where appropriate. The assessment should cover the risks to the workforce and the public, with particular attention given to pedestrians, vehicular traffic, waterway and railway travellers as appropriate.

Where the assessment identifies particular problems for health and safety, a detailed statement should be prepared covering the procedures it is proposed to adopt to mitigate the risks. The statement should be approved by the Overseeing Department in advance of the works starting.

3. PROCEDURES

General

3.1 A Special Inspection should be carried out in three distinct phases. The basic steps in the two planning phases are illustrated in Figure 1. Each phase of the planning process is completed by a report, which reviews the findings, defines the work to be carried out and outlines the technical plan for the next stage of the Special Inspection.

The general procedure for a site investigation is illustrated in Figure 2. In many cases, it may be sufficient to carry out only the initial testing of the investigation. Where problems are encountered and additional testing is considered necessary, then further investigation should be undertaken.

If at any time during the Special Investigation there is immediate concern for public safety, the Project Manager should consider the actions that can be taken to maintain an appropriate level of public safety such as monitoring, traffic measures, close bridge to traffic or emergency propping given in paragraph 3.8. The respective representatives of the Overseeing Department should be notified and approval sought for subsequent actions.

Preliminary Desk Study

3.2 A preliminary desk study forms Phase 1 of a Special Inspection. It is required in order to determine the fundamental design and construction details and to review the previous inspection and maintenance records for the bridge. This information is essential so that construction details can be verified and previously recorded deterioration or repairs can be checked during a preliminary site inspection.

3.3 The basic design details required prior to a preliminary site inspection should include the type of deck, mode of articulation, degree of redundancy in the deck and the structural dimensions of the primary members. Information on the type of post-tensioning system, location of individual tendons and end anchorage positions is also needed in advance, since observed surface defects may be related to the internal prestressing details.

The construction records should be examined to determine the method and sequence of construction,

stressing and grouting and the type of deck waterproofing. These details may indicate the possible locations and reasons for defects in the bridge.

The original specification for the grout and concrete mixes should provide information on the expected cement content, water/cement ratio and compressive strength. Where possible, the construction records should be consulted to ascertain the type of cement, sand and aggregate used in the grout and concrete mixes, the curing times and the age of the sections at the time of stressing. Information on any additives, air-entraining agents or cement replacements will be particularly relevant. These details may indicate the likely permeability, durability and relative performance of the various sections in a bridge.

Where insufficient design or construction records exist, appropriate provision will need to be made in the subsequent site investigation for the determination of all material properties, section geometry, the prestressing system and reinforcement details at critical sections. In this context, the term critical section is used to describe areas at high risk from water ingress or areas where yield points may form in a potential collapse mechanism. Therefore, in general, critical sections will include end support regions, midspan areas, regions over intermediate supports and any form of construction joint transverse to a post-tensioned cable and duct.

3.4 It is very important that all previous inspection reports should be reviewed to identify the known defects and separate them from more recent problems, which may be identified for the first time in the course of the Special Inspection. Particular attention should be paid to the purpose of any previous repairs to the bridge.

Details of any previous monitoring, reference points or datum readings may be valuable during the preliminary inspection. Similarly, information on the materials and techniques employed in carrying out previous repairs will be very helpful when judging their performance and relative value in future repairs of the same nature.

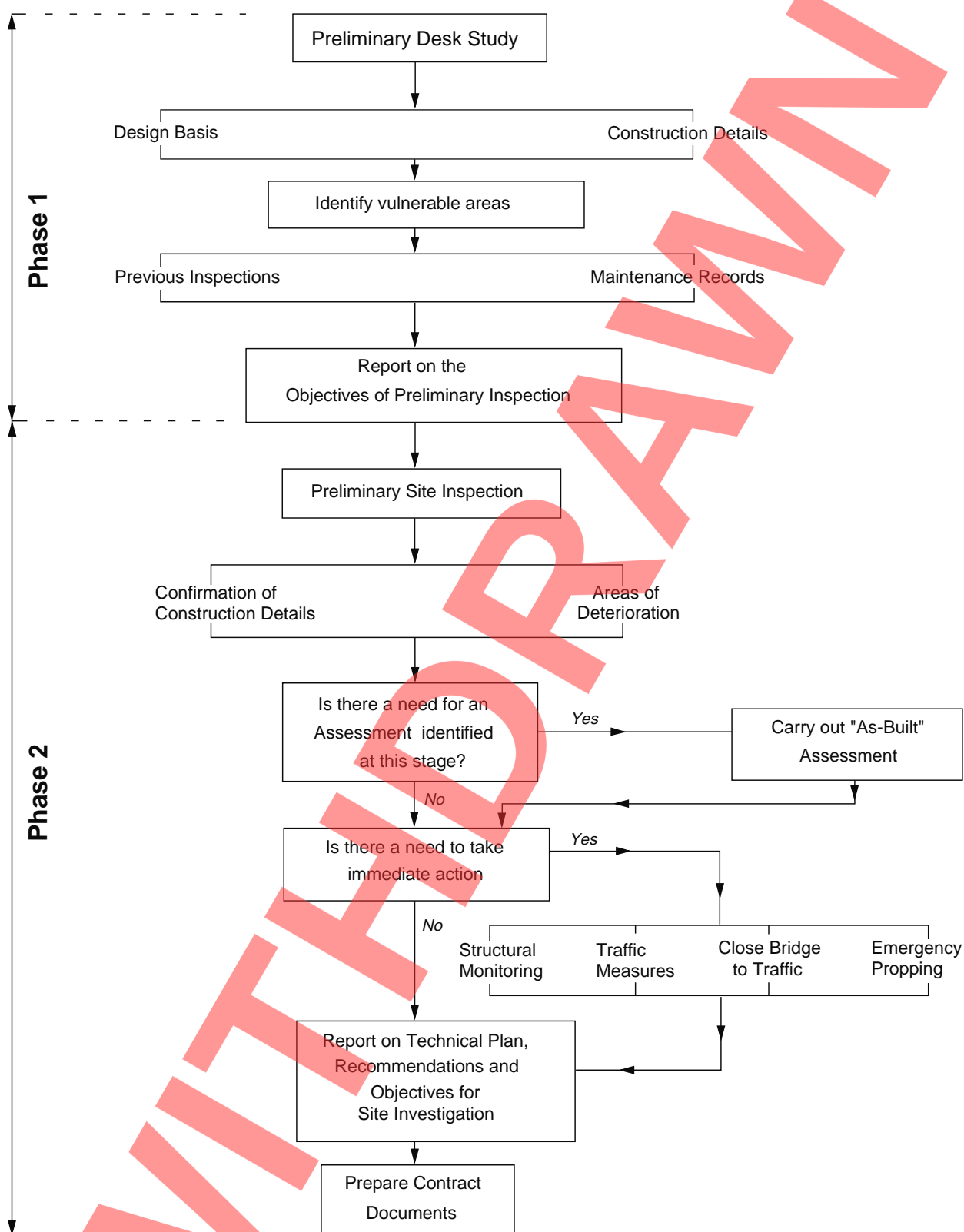


FIGURE 1 - BASIC STEPS FOR PLANNING A SPECIAL INSPECTION

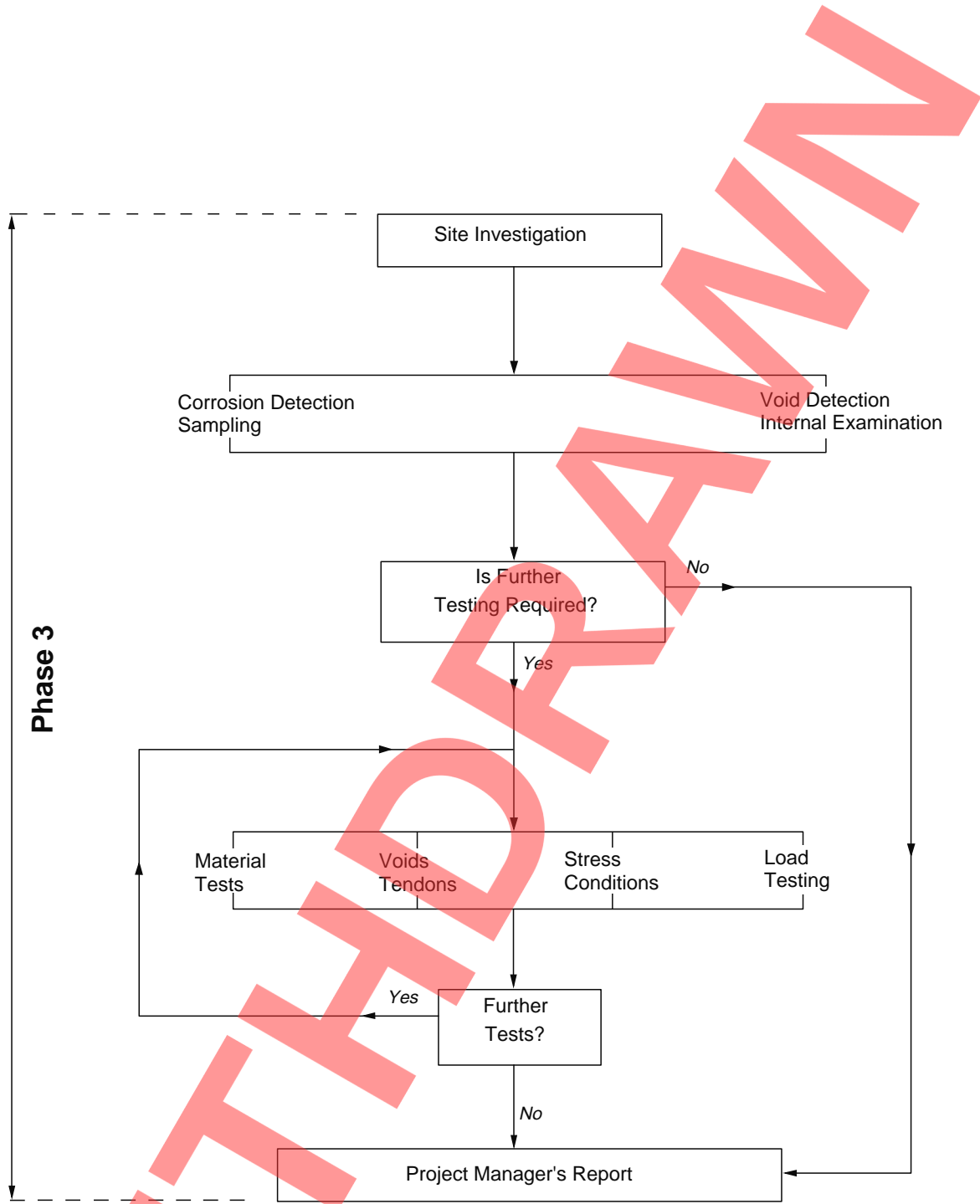


FIGURE 2 - GENERAL PROCEDURES FOR A SITE INVESTIGATION

A preliminary site inspection forms the basis of Phase 2 of a Special Inspection. The objectives of the preliminary inspection should be clearly identified in the Report, arising from the preliminary desk study. These objectives should be based upon the available design and construction information and the previous maintenance history of the bridge.

Preliminary Site Inspection

3.5 The initial aim of the preliminary inspection is to verify the type of bridge construction, form of articulation, geometry of the sections and locations of all construction joints. However, the primary purpose of this visual examination is to identify any areas showing signs of distress and plan an appropriate investigation programme to determine the causes and consequences of the deterioration (Technical Plan). The faults detected at this stage are likely to be cracking, deflections, water leakage and staining, breakdown of bearings and expansion joints, steel corrosion and losses of concrete section.

All signs of deterioration should be examined to assess whether they warrant inclusion in the subsequent site investigation. A high priority should be given to areas adjacent to critical sections, as defined in Para 3.3. Particular attention should be paid to these areas during the inspection and an initial appraisal made of the risk of a sudden mode of collapse and the need to take action to maintain an appropriate level of public safety. Advice on possible actions and the need to involve the Overseeing Department is given in paragraph 3.8.

Consideration of Structural Form and Condition

3.6 Most forms of in-situ post-tensioned monolithic construction carry little risk of sudden structural collapse. Solid slabs and voided slab decks represent the safest form of construction. Monolithic beams with or without composite slabs and monolithic forms of box construction are all unlikely to collapse without prior warning. Providing there are no built-in planes of weakness arising from construction joints, there is a low probability of all the prestressing tendons across a deck failing at specific transverse sections.

In comparison with monolithic construction, all types of segmental bridge decks have a higher probability of a sudden mode of collapse. Many forms of segmental construction have been used for both simply supported and continuous bridge decks. The basic distinctions that can be made between them relate to the direction of the joint, the joint material and the width of the joint.

A classification system for segmental forms of deck construction is defined in Paras 3.9 to 3.14, to assist the Project Manager with an appraisal of possible modes of failure.

3.7 A variety of concrete bridge decks, both reinforced and prestressed have been constructed on the tied-down principle. A common form of this type of construction is the cantilever and suspended span decks, using half joints to support the suspended span. The cantilever sections are stabilised by an anchor side span, which can be tied down by vertical post-tensioning if the side span has insufficient self-weight to counter-balance the suspended span. Similar tied-down side spans have also been formed in continuous bridge decks, where the end spans could go into uplift under certain loading conditions. This category of structure, regardless of the form of deck construction, carries a high risk of a sudden mode of collapse, if the vertical post-tensioning should fail.

3.8 Where a bridge is considered to be in a high risk category and the preliminary inspection confirms the presence of deterioration at critical sections (as defined in Para 3.3), the Project Manager should immediately consider the actions that can be taken to maintain an appropriate level of public safety. The respective representative of the Overseeing Department should be notified and approval sought for subsequent actions.

Consideration may be given to installing monitoring equipment prior to the full site investigation. The main purpose of the monitoring equipment would be to provide an early warning system to detect non-linear behaviour and imminent collapse. It should be noted here that, in general, deflection monitoring is not an appropriate method for detecting incipient failure in segmental or tied-down bridge decks. Specific advice on monitoring requirements is given in Para 8.8.

In extreme cases, it may be necessary to close the bridge to traffic, until further information can be obtained from the site investigations. Alternatively, it may be sufficient to reduce the traffic loading and introduce emergency propping measures, whilst detailed information is gathered and more permanent solutions are sought.

Classification of Segmental Bridge Decks

3.9 The need to maintain an appropriate level of public safety leads to a system of classification for segmental post-tensioned bridge decks. The broad categories of segmental decks in Table 1 are intended to illustrate the degree of risk of a brittle mode of failure associated with various types of structures. Where the risk is high, special monitoring and testing procedures should be considered for the site investigation. Sudden failure is more likely where there is no secondary reinforcement across the joints.

3.10 A variety of segmental bridge decks have been constructed without any form of composite action. In the extreme case of simply supported segmental beams, it is necessary to consider monitoring methods to provide a reliable warning of imminent failure. A combination of specialist techniques can be applied, but the technical approach needs very careful planning and considerable experience. Longitudinal cracks may indicate that tendons have severed and re-anchored, and these cracks should be investigated and monitored with suitable instrumentation.

3.11 The probability of a sudden mode of collapse is reduced when simply supported segmental beams are transversely connected to form a grillage. There has to be a degree of load sharing and severe corrosion of longitudinal prestressing tendons along a potential fracture line before a failure can take place. Nevertheless, the risk is high if exposure conditions are severe and a general loss of prestress allows water to penetrate more easily into the joints. It should be noted that fracture lines across a grid may not be straight, so any long-term monitoring system has to be planned accordingly to take this into account.

3.12 Simply supported box girder bridge decks constitute another form of beam grillage in terms of failure mode and the probability of a rapid failure mechanism is still high. Therefore, the monitoring procedures considered for this form of deck should be similar in principle to a beam grillage deck.

| DECK TYPE | JOINT DIRECTION | ELEMENT TYPE | RISK OF BRITTLE MODE OF FAILURE |
|----------------------------------|-----------------------------|---|---------------------------------|
| Simply supported (non-composite) | Transverse | Beams | Very high |
| | Longitudinal and transverse | Beam grillage | High |
| | Transverse | Box girders | High |
| | Longitudinal | Monolithic beams with transverse prestressing | Very low |
| Simply supported (composite) | Transverse | Composite beams with in-situ top slab | Medium |
| | Transverse | Composite beams with in-situ top and bottom slabs | Low |
| Continuous | Transverse | Composite beam and slab, and box girders | Low |

Table 1 - Classification of Segmental Bridge Decks

3.13 Composite decks generally represent a much safer type of bridge structure, since the presence of an in-situ slab connecting precast segmental units provides a better degree of redundancy if isolated tendons should fail. Moreover, the slab helps to protect the beams from the ingress of chlorides.

Where a simply supported composite deck is also formed with an in-situ bottom slab, the formation of a central hinge is less likely. The presence of untensioned reinforcement should be sufficient to spread the risk of failure between adjacent segments. In addition, the bonded untensioned steel will also provide a degree of gradual yielding, so that a regular monitoring procedure should be adequate to detect the onset of any failure mechanism.

3.14 In general, continuous forms of segmental post-tensioned decks carry a lower probability of a sudden mode of failure. Due to continuity over the intermediate supports, it is necessary for a mechanism to form before a collapse can occur. Therefore, at least two complete decks sections must yield in an end span of a continuous deck. Internal spans require three hinges to form a mechanism so a collapse condition is more unlikely to develop, but it may still occur without visible warning.

Where continuous bridge decks are formed from a series of beam segments with a composite reinforced concrete top slab, there is normally a significant amount of bonded untensioned reinforcement crossing the transverse joints. Hence, there should be an additional reserve of strength in the vicinity of the piers and a sudden type of collapse is less likely.

Site Investigation

3.15 The technical plan and particular objectives for the site investigation should be defined in the Report, following the desk study and the preliminary site inspection. The general procedure for a site investigation is illustrated in Figure 2. In many cases, it may be sufficient to carry out only the initial testing of the investigation. Where problems are encountered and additional testing is considered necessary, then further investigation should be undertaken.

The main purpose of the site investigation is to determine the existing conditions at all critical sections, so that a realistic appraisal of the residual strength of the bridge can be made. Sufficient numerical information will be required in order that a present condition load assessment of the structure can be

undertaken.

The areas selected for detailed investigation should take into account the form of deck, construction details and the type of deterioration already detected. Particular attention is necessary in selecting the most appropriate techniques which are required to establish the presence of voids in ducts and the conditions of the grout, tendons and anchorages. Detailed guidance on the relative merits and application of various methods is given in Chapter 4.

The Project Manager should prepare an associated schedule of standard sampling and testing to detect the presence of corrosion activity and assess the condition of the concrete and reinforcement in the vicinity of critical sections under investigation. All routine material sampling, laboratory and site testing shall be carried out by specialist testing firms or laboratories approved by the National Measurement Accreditation Service (NAMAS) for the type of laboratory testing required, or by equivalent accreditation bodies of member states within the European Community.

The testing procedures shall be carried out in accordance with the recommendations given in Clause 7.3.2/7.3.3 of Departmental Advice Note BA 35/90 (DMRB 3.3). In Scotland, Appendix 3 to SB1/78 (DMRB 3.1) should be referred to for testing procedures. These standard tests on the bridge should be complementary to previous principal inspections and may not be required if sufficient information on material properties has recently been obtained.

3.16 Consideration should be given to any further material tests, the need to widen the search for voids in tendon ducts or the corrosion of tendons. An interim report may be required to summarise the initial results from the detailed investigation and produce recommendations for any additional testing that may be deemed necessary.

Depending upon the structural form of the bridge, the results of previous load assessments, or the perceived risk of a sudden collapse, it may be necessary to check local stress conditions in the steel or global stress conditions in the concrete. Where load distribution in the deck depends upon residual levels of transverse prestress, it may also be appropriate to apply incremental load testing techniques. However, it is very important that the maximum applied loading is restricted to serviceability levels to avoid damage to the structure.

The introduction of such specialist testing would require technical approval from the Overseeing

Department. The organisational requirements for highly specialised techniques are detailed in paragraph 2.3, while the principles of these methods and their limitations are described in Chapter 5.

3.17 The results of Phase 3 of a Special Inspection should be reviewed in the Project Manager's Report. In addition, the structural condition, risk assessment and monitoring requirements should be summarised to form a basis for future management of the bridge. The quantitative information gathered during the investigation should be recorded in a suitable form for future reference and recommendations made for subsequent load assessment of the structure. Further guidance on the requirements for this report is given in Chapter 8.

WITHDRAWN

4. METHODS OF INSPECTION

General

4.1 Methods of inspection for post-tensioned concrete bridges range from a visual inspection to complex non-destructive and semi-destructive methods. The methods adopted in a site investigation should commence with a simple visual examination and routine surface and material tests under Phase 3 of a Special Inspection. Progression to the more complex methods of the Special Inspection may be justified if there is evidence of tendon corrosion and a risk of sudden failure in a structure. However, it should be realised that serious corrosion of the tendons can occur without any visual evidence.

An indication of general corrosion of the reinforcement in the concrete, may be taken as indicative of the potential for corrosion occurring in the prestressing steel. Therefore, the methods of determining corrosion risk, as outlined in Departmental Advice Note BA 35 (DMRB 3.3), (SB1/78 in Scotland) provide a valuable precursor to the use of other inspection techniques. In particular, high concentrations of chloride ions increase the probability of tendon corrosion. Therefore, chloride ion content of the concrete should also be determined.

Non-destructive testing can be used to assist in the detection of voids in the tendon ducts. If no voids are found this does not preclude the possibility of corrosion occurring. However, in fully grouted ducts any corroded and broken wires will quickly re-anchor and the risk of full loss of prestress should be reduced. An assessment of the potential for a sudden mode of collapse should be undertaken, as outlined in paragraphs 3.6 to 3.14, and the necessity for further investigations should be determined.

If voids are found and the conditions within the concrete are conducive to corrosion of the steel then internal examination of the tendons should be undertaken. The method for gaining access to the tendon duct should be chosen considering the position of the duct and the degree of damage that will be caused. In all cases, drilling holes should be carried out with the agreement of the Project Manager and utmost care must be taken to ensure that the tendon is not damaged.

Visual Examination

4.2 The visual examination of post-tensioned bridges should be carried out according to the advice given in Chapter 6. The inspection should be carried out in such a way as to identify actual and potential areas of distress. As such, the inspections should be performed by persons with experience of post-tensioned structures as specified in paragraphs 2.1 to 2.3.

Prestressed bridges are normally designed to avoid cracks in the concrete. As such, the development of cracks can have serious durability implications and may indicate a loss of prestress. Cracks along the line of tendon ducts may be indicative of corroded and broken wires or tendons. Such cracks may be formed by the bursting forces that are generated as a broken wire slips and then re-anchors.

Signs of general corrosion on the surface of the concrete may be indicative of conditions within the concrete which are conducive to corrosion of the tendons. The presence of any water leakage through the deck should be recorded and the source located. Detailed advice on the possible cause and interpretation of visual defects is given in Chapter 6.

Void Detection

4.3 The detection of voids in post-tensioning ducts is important in isolating potential areas where corrosion of the tendon may occur. The methods of detection can be non-destructive and a guide to the use of such techniques is included in BS 1881: Part 201. Determining the position of any voids, prior to an internal examination to ascertain the condition of the tendon, should restrict the degree of damage caused to the structure. However, the only certain method of determining the tendon condition is by exposing it for visual inspection.

Endoscope

4.4 The endoscope is an optical instrument which enables inaccessible places, such as the interior of post-tensioning ducts, to be inspected. Access to the duct may be gained by the drilling of 25mm diameter holes through the concrete. Where possible, a hole should then be made in the duct using a hand-held chisel. The number and position of the holes drilled will depend upon the cable profile and the ease of access for drilling. Holes should be drilled as close to the anchorages as possible, at midspan and at either side of high points where voids are most likely to have formed.

The tendon can be visually inspected by viewing through for example either a rigid tube with reflecting prisms or a flexible tube with a fibre optic system. The major limitation of this technique is the difficulty of access for the drilling of holes into the duct. Drilling should be carried out only with the agreement of the Project Manager. The Project Manager should then ensure that there is close supervision of the drilling operation by a suitably experienced member of the Inspection Team to prevent damage to the tendon.

An endoscope survey carried out using small diameter inspection holes drilled at carefully chosen locations offers a reliable method of checking the condition of tendons. However, the tendon condition can only be inspected locally to the drilled hole and therefore corrosion elsewhere could go undetected.

Pressure-vacuum Testing

4.5 The techniques of pressure and vacuum testing enable the volume and continuity of voids and leakage into a duct to be determined. Access has to be gained to the top of the duct by drilling 25mm diameter holes through the concrete. A small hole should then be made in the duct using a chisel. The number and position of the holes drilled will depend upon the cable profile and the ease of access for drilling. Holes should be drilled as close to the anchorages as possible, at midspan and at either side of any high points where voids are most likely to have formed.

The continuity of any voids found is determined by evacuating each hole in turn and measuring any pressure change at the remaining holes. The volume of the voids is estimated by using a water gauge connected to the evacuated holes and measuring the height of water drawn up a perspex tube. Leakage out of the duct is measured by pressurising it and measuring the input flow rate required to maintain a set pressure.

Errors can arise in the estimation of the volume of the voids if there is leakage from the duct. In addition, the pressure within a partially grouted duct after it has been evacuated is not uniform. The major limitation of this technique is the difficulty in making holes into the duct particularly at the end anchorages where the amount of bursting steel makes drilling difficult.

In all cases, drilling holes should be carried out with the agreement of the Project Manager and utmost care must be taken to ensure that the tendon is not damaged. No information can be gained on the condition of the tendon using this method of testing alone. Therefore an endoscope survey, as described in paragraph 4.4, or an open visual examination should also be undertaken.

Radiography

4.6 The method of radiography utilises gamma rays or high energy X-rays as an energy source which will penetrate the concrete. Photographic film, placed on the opposite side of the concrete from the source, will be exposed to varying degrees of radiation depending on the variation in density of the material under examination. Thus, steel shows up on the negative as lighter than concrete because its higher density impedes the radiation to a greater extent, while voided areas show up as darker images. A limitation on the use of this technique is that it is essential to have access to both sides of the concrete. The thickness of concrete penetrated is limited to 500mm with a gamma ray source. High energy X-rays are more suitable for examining concrete thicknesses up to 1m. Current developments include, for example, a Betatron radiation generator which can be applied to bridges.

This non-destructive method is the most direct means of providing pictorial evidence of the interior of the concrete. However, the technique is not able to detect corrosion sites with any degree of accuracy although broken wires and cables can be detected.

General guidance on the use of radiography is given in BS 1881: Part 205. However, the extensive safety precautions and highly specialised equipment used in radiography makes it essential that this work is only carried out by experienced radiographers with knowledge of working with concrete. The Health and Safety Executive should always be consulted before radiographic methods are employed.

Other Methods

4.7 The surface penetrating radar system works on the principle of the reflection of short duration pulses from interfaces between materials with different dielectric constants such as bars, voids and ducts. Unfortunately, although radar can be used to accurately locate the position of metallic tendon ducts, the ducts mask any reflection from within. Therefore, this technique is not at present able to determine tendon condition or deficiencies in the grout in structures with metallic ducts. This limits its use considerably.

4.8 The impact-echo method is currently an experimental technique that relies on the propagation of a stress pulse through the concrete, which is reflected by internal discontinuities or external boundaries. The pulse is introduced into the concrete by a mechanical impact on the surface and the reflected waves are measured at the surface by a receiving transducer.

The major limitation of this technique appears to be that the boundaries of a defect cannot be determined precisely since points within the object will interact with the propagating waves. Although the method has been widely researched, it has not yet been fully proven for general applications. The specialised equipment and difficulties in interpreting the results makes it essential that this type of work is performed by experienced operators.

4.9 The method of reflectometry utilises the relationship between the electrical parameters and defects in tendons. A high frequency signal is input at one end and received at the same end. Changes in impedance are used to indicate the type of deterioration in terms of a reduction in tendon section and voids in the surrounding grout.

Although this technique has been validated and used elsewhere it has yet to be proven in practice in the United Kingdom. The major limitation of the technique is the need to have access to one end of the tendon. Where there are a number of faults in the tendon, the first fault encountered may mask the others.

The specialised equipment and difficulties in interpreting the results makes it essential that this type of work is performed by experienced operators. Any exposure of the end anchorages of the tendons must be carried out with the utmost care and under the supervision of the Project Manager.

Internal Examination

4.10 Once voids and potential corrosion of post-tensioning tendons have been identified, the most direct way of establishing the degree of damage is by an internal examination of the duct. There are a number of ways by which access can be gained to post-tensioning ducts in order that an internal examination can be carried out. The degree of damage caused to the structure will depend upon the method of exposure chosen. Any exposure of the tendon should be carried out under the direction of the Project Manager and utmost care must be taken to ensure that the tendon is not damaged.

Percussive Methods

4.11 Closely supervised percussive methods, such as hand-held and small machine mounted impact breakers, provide an effective method for exposing post-tensioning ducts. The damage caused to the concrete section may be irregular and strict control must be exercised over the exposure of the ducts. Exposure of the tendon should be carried out using a hand-held chisel to ensure no damage is caused. These methods should be limited to the exposure of easily accessible tendons in order to limit the level of damage caused. In addition, microcracking of the exposed concrete surface layers is likely and subsequent repair procedures will need to take this into account.

Diamond Core Drilling

4.12 Diamond core drilling offers an effective way of exposing post-tensioning ducts. However, the use of this technique relies upon the operative knowing when the core drill has made contact with the duct, in order to stop drilling. An alternative is the use of a drill with an automatic cut-out which should stop once the duct is reached. A hand-held chisel should be used to expose the tendon. Every effort should be made to ensure that the cooling water does not penetrate the duct.

High Pressure Water Jetting

4.13 High pressure water jets can be used to expose lengths of post-tensioning ducts and then only after rotary drilling of pilot holes have established the precise location. Every effort should be made to ensure that the water cannot penetrate the duct. Therefore, if leaks in the ducts are suspected this method of exposure should not be used.

Cutting of the concrete using this method is likely to produce irregular shaped holes. Although water jetting with a grit additive offers better control for concrete cutting, it is particularly dangerous since it can also cut through the prestressing steel. Hence, it should not be permitted for this purpose.

Grit Blasted Holes

4.14 Dry grit blasting can be used to form access holes in the concrete in a similar manner to high pressure water jetting. The use of a vacuum pump to carry away the debris negates the problems caused by dust and fly back of material. Caution has to be exercised when using this technique since the duct and tendon may be damaged. However, the lack of water makes this a more attractive option in particular situations.

Material Testing

4.15 During the internal examination, grout samples from the duct should be tested to determine the degree of carbonation which has occurred and whether it has been contaminated with chlorides. If the grout is found to be wet, contaminated with chlorides or carbonated then there is a risk of local corrosion occurring.

5. STRESS CONDITIONS

General

5.1 Determination of steel stresses and concrete stresses at critical sections may be used to give an indication of the local and general levels of residual prestress. Sufficient measurements should be taken to ensure confidence in the results. The current live load performance and behaviour of the deck in the long-term may be checked using a carefully controlled load test and monitoring of the structure at critical positions.

Steel Stresses

5.2 The current levels of stress in individual prestressing tendons can be determined directly by hole drilling using electrical resistance strain gauges. The technique relies on the principle of stress-relief and is an adaptation of the centre-hole technique. The diameter of the hole drilled may be 1-3mm, depending upon the form of the prestressing tendon. The centre-hole method gives a very accurate picture of the particular wires drilled, but the results must then be extrapolated to the whole tendon. The stress measured is the total stress, it is necessary to subtract locked-in manufacturing stresses. Steel stress measurements on grouted tendons represent conditions for about 1m on either side of the test location and a representative number should be taken if reliable average values are required.

The centre-hole technique, although partially destructive, may be used on a bridge in service. Alternatively, the residual prestress may be determined by a complete release of stress in selected wires or strands. Several wires in a tendon may be cut by closely controlled use of a hack-saw if access is possible. The main benefits of this method are cheapness and direct measurements of the residual pre-strain in individual wires or tendons, it is necessary to think very carefully before cutting any wires on a bridge in service.

Concrete Stresses

5.3 Specialist methods have been developed to provide in-situ measurements of concrete stresses using instrumented coring and slot-cutting techniques. The results obtained from such stress relief methods represent the total stress conditions in the concrete.

Cores of 75-150mm diameter may be drilled into the concrete and the stress release determined using carefully selected strain gauge patterns.

A likely lower-bound value for the concrete modulus may be determined from compression tests on the concrete cores. Additionally a hydraulic jacking system may be inserted into the hole produced by the coring process, to provide an in situ determination of the elastic modulus. This form of test provides an in-plane measurement of the modulus and represents an upper-bound composite value created by the surrounding prestressing tendons, reinforcement and concrete.

The main advantage of the instrumented coring technique for the assessment of existing levels of concrete stress is that principal concrete stresses can be determined in both magnitude and direction. Although total concrete stresses are obtained, the likely magnitude and presence of self-equilibrating internal concrete stresses due to secondary effects can also be determined during coring.

The slot-cutting technique for concrete stress determination may be carried out in several ways. Narrow slots, 300-500mm in length, can be produced using a diamond saw mounted on a travelling rig and cooled by water. Strain measurements taken across the slot on either side of the slot can be converted into stresses using laboratory calibrations and the local elastic modulus determined by hydraulic jacking or compression tests from a complementary core test.

An alternative method of slot cutting employs a mounted air-cooled diamond saw in conjunction with very thin semi-circular flat jacks which are used to restore the stress state uni-axially. The main advantage of this form of slot-cutting technique using pressure compensated jacks is that a value of elastic modulus is not required to be known.

The concrete core and slot-cutting methods give a useful guide to the overall concrete stress levels at a given point. Where parallel beams are connected by in situ concrete or mortar joints, the slot-cutting methods cause minimal damage to the structure and can provide a measurement of the effect transverse prestress across the longitudinal joint. Both coring and slot cutting have a stress raising effect and required careful making good to prevent ingress of water and road salts.

Cutting of the reinforcement in a structure should be avoided. Apart from local damage to the structure, highly stressed reinforcement may cause debonding and local micro-cracking at the concrete surface. Any strain gauge measurements on the surface are therefore likely to be invalidated.

The various methods have different levels of sensitivity and the selected techniques should be appropriate to the anticipated levels of concrete stress and the accuracy required in the determination. It is very important to realise that concrete stress measurements do not provide a means for identifying local strand failures in a section. Therefore, the proper use of concrete stress measurements is to provide an indication of the global levels of residual prestress in a deck.

Load Testing

5.4 The main purpose of load testing any form of bridge deck is to determine the effective levels of transverse load distribution and correlate the structural analysis with the assessed structural action. Very significant reserves of strength can be present in some bridge decks due to secondary effects such as membrane forces, edge stiffening, end restraint and composite action.

Local damage caused by the failure of a small number of prestressing tendons cannot, in general, be determined by load testing. However, the global behaviour of a bridge deck can be verified by a carefully selected pattern of loading. It is very important that the magnitude and positions of the applied loading is maintained at levels representing serviceability conditions but no higher. The loading should be applied in controlled increments and the deck response monitored by an appropriate pattern of strain gauges in order that the test does not cause any damage to the bridge.

Deflection monitoring and dynamic stiffness measurements are generally not appropriate for load testing and are unlikely to detect the onset of non-linear behaviour in segmental structures. Load testing should not be used to assess the deterioration in shear strength of a post-tensioned bridge.

6. STRUCTURAL INSPECTION

Objectives

6.1 The main objective of the structural inspection is to determine the cause and extent of deterioration for the purpose of assessing structural integrity. The results of this inspection may also form the basis for remedial measures and strengthening works in the future.

The inspection should be carried out by experienced inspectors who should systematically record the serviceability problems and be able to interpret the significance of the faults. Particular attention should be paid to determining the presence of, and reason for, any cracks and the location of water leakage through the deck. The conditions surrounding all end anchorage zones, half joints and construction joints should also receive special examination.

Cracking

6.2 The location and direction of cracks are often a valuable first indication of the present condition of a structure. Useful advice on diagnosing non-structural cracking may be found in the Concrete Society publication 'Non-structural Cracking of Concrete - 1992'. Typical cracks found in prestressed concrete structures are summarised in Table 2, together with the possible causes to which they may be attributed. A particular crack can be the result of a combination of several defects.

It is important to identify the source of cracking, since it will lead to a more precise determination of the actual structural damage. Cracks which appear to be critical to the structural integrity of the bridge should be monitored at regular intervals to check the development of further deterioration. Such information will be necessary for the future condition assessment of the residual strength of a section.

6.3 Transverse flexural cracks may be an indication of a significant loss of prestress or tendon failure in the midspan or intermediate support region of a deck. However, the force in a fractured tendon is mainly transferred to adjacent tendons and it is likely that the only significant damage will be in the re-anchorage zones on each side of the fracture. The damage to the concrete section will depend primarily upon the grouting in the duct and the amounts of

surrounding shear reinforcement.

The presence of significant bursting stresses at a fracture point may be indicated by longitudinal surface cracks along the line of a broken tendon. Where a tendon fails in the region of an end anchorage, structural damage may take several forms.

Local splitting along the line of a fully grouted duct is likely to be well contained, since the areas of shear reinforcement and end anchorage bursting steel should be more than adequate. However, tendons at the ends of a deck are often inclined and there may be a significant reduction in the contribution to shear capacity, leading to inclined shear cracks in the webs of beams.

6.4 Inclined shear cracks in webs may also occur in bending moment cross-over regions in continuous bridge decks, where prestressing tendons for sagging or hogging moment regions may be anchored. A quantitative assessment of damage in this type of region may require both concrete stress measurements using coring techniques and direct measurements of steel stress in the local shear reinforcement.

6.5 Severe structural cracking can also occur in prestressed bridge decks as a direct consequence of vehicle impacts. Apart from the local crushing at the point of impact, it is possible for secondary shock waves to generate large scale longitudinal cracking in the bottom flanges of beam and slab decks. Diagonal shear cracks may also develop in the webs of beams which are supported on the lateral restraint bearings.

Water Leakage

6.6 The bridge deck drainage system should be the subject of a thorough visual examination. All gullies, downpipes and manholes should be checked to determine whether the system is working effectively. Ideally, checks should be carried out during intervals of heavy rain and subsequent dry periods. Careful note should be made of the influence of the carriageway surface condition, including cracks or pot-holes. The location of any surface ponding on the deck should be recorded and related to midspan and intermediate support regions.

6.7 Surface water on the deck may enter the footways and any central reservation areas along the kerblines. Water and de-icing salts may remain trapped in these areas or penetrate into service bays, service ducts or voids within the deck construction. Water may also flow towards the ends of the deck and remain trapped against upstands formed at the deck expansion joints.

The introduction of drainage holes into the soffit of a deck may permit trapped water to escape. Strict safety precautions should be exercised in drilling any exploratory drainage holes, since the trapped water may be alkaline and, in extreme cases, may cause severe burning of the skin or damage to eyes. Specific advice on draining voids within bridge decks is given in Chapter 10 Departmental Advice Note BA 35 (DMRB 3.3).

6.8 During the detailed inspection, all signs of water leakage through cracks in the deck slab, construction joints, expansion joints and half joints should be systematically recorded, along with comments relating to the cause and source of the water. Similarly, all surface leaching should be recorded together with any signs of discolouration which may indicate the presence of internal rusting or other contaminants.

Deflections

6.9 The effect of broken tendons in grouted or partially grouted ducts is unlikely to produce any visible or measurable deflections. Broken tendons do not constitute a significant loss in stiffness in a beam or deck cross-section, since the adjacent tendons will take up the force released, producing only a local change in steel and concrete strain. Where the tendon ducts in a beam are ungrouted, broken tendons will release their force along the entire length and the resulting loss in prestress can produce a significant change in deflections and end rotation.

6.10 The presence of hogging deflections in the midspan region of a post-tensioned bridge deck is normally indicative of a satisfactory level of residual prestress. Where sagging deflections are observed, it suggests there may be excessive losses in prestress due to creep, shrinkage or temperature effects. Additional sources of prestress losses may be due to a large number of in-situ joints between precast segments or the use of concrete with a low elastic modulus.

6.11 It is important that the deflected shape of a bridge deck should be recorded, particularly for long-

span structures. The profile of the edge beams along the soffit, the bottom flange or the parapet string course may form a convenient reference line. A careful note of the temperature conditions should be taken and any future deflection measurements recorded under similar circumstances. In deep sections, such as box-girder decks, it may be necessary to record temperature gradients at the same time.

Concrete Spalling

6.12 Concrete spalling may occur for a variety of reasons and careful note should be taken of the location and orientation of all surface spalling. The most common cause is likely to be corrosion of ordinary reinforcement producing surface delaminations. Corrosion of prestressing tendons may or may not be expansive, depending upon the supply of moisture and oxygen and the type of iron oxide formed. If corrosion of the tendons has caused splitting of the concrete surface layers, the cracking is likely to be more deep rooted compared to that caused by corrosion of ordinary surface reinforcement.

Large-scale concrete spalling may be observed where water filled voids in tendon ducts have frozen. Local spalling of the concrete surfaces may also occur due to stress concentrations arising from bursting stresses, misfit between segments or misalignment of tendon ducts across joints between precast units.

Steel Corrosion

6.13 Normal methods for detecting the potential for corrosion and the presence of excessive amounts of chloride should be sufficient. These tests and procedures are fully described in Clause 7.3 Departmental Advice Note BA 35 (DMRB 3.3), (SB1/78 in Scotland). No general non-destructive procedures currently exist for detecting corrosion in prestressing tendons and serious corrosion of the tendons may exist without any visual signs of distress.

| STRUCTURAL SECTION | LOCATION | CRACK DIRECTION | POSSIBLE CAUSE |
|-------------------------------------|--------------|--------------------------------|--|
| Soffit (beam or slab) | End of span | Longitudinal | Bursting stresses. Lack of end block reinforcement. ASR in concrete. |
| | Midspan | Longitudinal Transverse | ASR in concrete. Broken tendons. Loss of prestress. Excess live load. |
| Web | End of span | Diagonal | Shear stresses. Loss of prestress. |
| | | Longitudinal | ASR in concrete. Duct flotation. Broken tendon. Frozen water in ducts. |
| Web (cantilever/continuous beam) | Over support | Vertical | Loss of prestress. |
| Top flange (T-beam/box beam) | Midspan | Transverse | Differential shrinkage. |
| | Over support | Longitudinal | ASR in concrete. Broken tendon. |
| | | Transverse | Differential shrinkage. Loss of prestress. Excess live load. |

Table 2 - Typical Cracks in Prestressed Concrete Sections
(Not an exhaustive Table)

Construction Joints

6.14 The type of construction joints within a bridge structure should be identified and recorded in separate categories. The condition of joints between precast units and the materials used to complete the joint should be carefully noted. In-situ joints between precast units may be formed with dry packed mortar, concrete or epoxy resins. Plain construction joints between deck pours may be simple dry joints and the joint direction could be vertical, horizontal, stepped or inclined. The lengths and widths of all joints should be recorded.

6.15 All construction joints in post-tensioned structures represent a potential plane of weakness. Concrete sections may act in a partially-cracked manner, when compressive stresses across the joint fall between 1-2 N/mm². All joints should be examined throughout their length to search for signs of microcracking or water-staining. The start and finish of any cracking or water penetration may be significant and should be recorded in detail. Any areas causing concern should be noted and marked for potential monitoring in the future.

Deck Bearings

6.16 The inspection of the bearings should be carried out with the objective of confirming the movements of a bridge structure are occurring as intended without damage to the deck, the fixings or the sub-structure. The parapet fencing and carriageway surfacing should be checked for signs of movement or rotation at both ends of a bridge and at all intermediate supports. Similarly, all bearings should be examined for signs of movement and rotation, irrespective of their intended design function. The condition of the materials in the bearings and all forms of deterioration should be noted.

The integrity of any fixings to the bearings should be noted and any local failures recorded. Holding down bolts may be required to carry occasional uplift forces in some forms of bearing and the performance of these bearings should be observed under live load.

General loss of prestress in continuous or semi-continuous post-tensioned structures may lead to significant increases in the axial forces carried by uplift bearings or tied-down post-tensioned anchors.

7. INTERNAL INSPECTION

General

7.1 The methods of inspection described in Chapter 4 for internal examination of post-tensioning systems may be used alone or in combination, according to the type of problem being investigated. The method employed will be particularly dependent upon site access, safety and the type of structure.

Duct Positions

7.2 The first priority in performing a detailed internal examination is to establish the actual location of tendon ducts at each section under investigation. During construction, tendon ducts may float upwards between tie-points. Typical vertical movements can be 25-50mm, but displacements exceeding 100mm are not uncommon in some forms of construction.

Duct displacements are a potential cause of serious damage during investigations involving any form of hole drilling. Tendons may be hard against the bottom of a duct at any position due to duct flotation. Therefore, drilling holes into the bottom of a tendon duct at midspan to use an endoscope is unlikely to prevent the tendons being damaged. Allowance should also be made for horizontal displacements of tendon ducts.

Grout Integrity

7.3 The detection of voids within a grouted tendon duct may be achieved using the non-destructive and semi-destructive methods described in paragraphs 4.3 to 4.9. However, a full inspection of the void can only be made by internal examination using the various methods described in paragraphs 4.10 to 4.14. The methods adopted for exposure of the grout should be chosen to allow the condition and properties to be examined in an undisturbed state and samples to be removed in sealed containers. Supervision of the exposure and removal of specimens is of paramount importance.

It is important to determine the in-situ moisture content, colour and composition of the grout. Where tendon ducts are partially filled, a cement grout is likely to be white rather than grey due to the effect of carbonation. A grout may be completely dry and solid

within a duct or it may be a wet paste or shattered and broken in appearance. The composition of the grout, alkalinity, chloride content and the presence of additives should all be determined from dry samples removed from a duct.

Tendons

7.4 The exposure of post-tensioned tendons may be achieved by using the methods described in paragraphs 4.10 to 4.14. It is essential that the entire process of concrete removal, opening of internal ducts and removal of grout should be closely supervised at all times by experienced inspectors.

In order to examine tendons in an undisturbed state and to avoid damage to the prestressing steel, the grout around the tendons should be carefully removed by hand methods. The type and size of the tendons in the duct should be confirmed and the presence of any form of surface corrosion or pitting carefully recorded. The position of the tendon within the duct and the packing of wires or strands in a tendon should be noted, since this may provide useful evidence of duct displacements during construction.

7.5 The repair of all access holes made for the internal examination of tendon ducts requires very careful consideration at the time of planning the inspection. Priming of the exposed steel may be an advisable precaution, depending upon the condition and the local environment. Shrinkage compensated repair grouts and mortars should be adopted for filling holes and consideration given to the addition of a surface repair coating as a further precaution against the ingress of water and chlorides. Specific advice on local repairs to post-tensioned structures will be given in the Departmental Advice Notes on Strengthening, Repair and Monitoring. General guidance is given in Departmental Standard BD 27 (DMRB 3.3), Materials for the Repair of Concrete Highway Structures. (Not applicable for use in Scotland).

Anchorage

7.6 Exposure of post-tensioned anchorages located at the ends of decks, or similarly restricted areas such as deck half-joints may be carried out using carefully selected water jetting or grit blasting methods. The exposure procedure should be a gradual process, which allows visual examination or the use of endoscope techniques at various intervals.

Full supervision of the exposure should be undertaken by experienced inspectors and the work carried out by specialist operators, in accordance with the requirements of Chapter 2. In particular, all personnel should be made aware of the requirements of paragraph 2.4 and avoid standing behind the anchor plates during water or grit blasting operations.

The areas selected for exposure at an anchorage may be behind the anchor plates and immediately adjacent to the end block zone. Removal of concrete within the bursting zone of the anchorage should be avoided, since this localised region is by definition, likely to be highly stressed. Particular care should be taken not to fracture the end anchorage plate or end wedges of the post-tensioning system.

The condition of the end anchorage zone and anchor plate should be recorded and fragments of the surrounding concrete or mortar protection should be examined and removed for laboratory examination to detect the presence of chlorides. Repairs to the end anchorage areas should follow the advice outlined in paragraph 7.5 and the recommendations given in the Departmental Advice Notes on Strengthening, Repair and Monitoring.

8. REPORTING OF INSPECTION

Preliminary Desk Study

8.1 This report should contain the findings from the preliminary desk study described in Chapter 3. It should include a summary of the essential design, construction and maintenance details, presented in a systematic format in an Appendix to the main report. The conclusions from this report should contain the objectives for the preliminary inspection.

The design details should include four principal groups of information:

- a) List of available drawings.
- b) Form of construction.
- c) Type of concrete.
- d) Prestressing and reinforcement.

A sample proforma, FORM A1, for recording the design information is included in Annex A.

The construction records should be summarised on a separate proforma, under four main headings:

- a) List of record drawings.
- b) Form of construction.
- c) Type of concrete.
- d) Construction information.

A sample proforma, FORM A2, for recording the construction information is shown in Annex A. The differences between design and actual construction should be carefully noted.

The maintenance history of the structure should also be summarised on a separate proforma, FORM A3, included in Annex A. The information is required under two main headings:

- a) List of previous reports.
- b) Summary of previous defects.

The number of pages required will depend upon the size of the structure and the extent of the problems detected during previous inspections.

Preliminary Site Inspection

8.2 This report should contain the findings from the preliminary site inspection described in Chapter 3. Any variations in the construction details or new areas of

serious deterioration should be identified and recorded in an appendix to the main report, in a similar format to the maintenance history. The main text of the report should include an initial evaluation of the potential risk of a sudden collapse and the need for regular monitoring. The conclusions should form the basis of the technical plan for the site investigation.

The inspection data should be grouped into two main headings:

- a) Amendments to construction information.
- b) Principal areas and defects requiring site investigation.

A sample proforma, FORM A4, for recording the basic information from the preliminary inspection is included in Annex A.

Site Investigation

Project Manager's Report

8.3 This final report should include the results from all previous routine material tests and tests conducted to detect the risk of reinforcement corrosion, additional testing and specialist tests that may be carried out in the final phase of the Special Inspection. The results from any further standard tests should be incorporated in the standard proforma A5-A7, and should supplement the information previously gathered in the Preliminary Site Investigation. The results of the Special Inspection should be fully discussed and reviewed.

The site investigation records should be summarised on three separate proforma, FORMS A5, A6, A7 in Annex A. The detailed information provided should be under three main headings:

- a) Tests for corrosion risk - FORM A5.
- b) Concrete material tests - FORM A6.
- c) Results from internal examination - FORM A7.

8.4 Where special methods are introduced to determine in-situ stress conditions, the basic information should be summarised on the standard proforma, FORM A8, in Annex A. Where stress conditions are investigated, the results should be collected under four separate headings:

- a) Temperature conditions.
- b) Steel stresses.
- c) Principal concrete stresses.
- d) Secondary concrete stresses.

Where possible, estimates should be made of the prestress losses in a structure. The results from any load testing should be fully discussed and interpreted in relation to the condition of the structure and the in-situ stress measurements.

Structural Condition

8.5 The overall condition of the structure should be fully appraised following the detailed inspection and site investigation. Particular attention should be drawn to the elements of the structure which have suffered from cracking and water leakage.

The significance of defects in the prestressing system should be carefully assessed in terms of long-term durability and the consequences of structural failure. Where voids are discovered in the grouting, the alkalinity and the presence of any moisture or chlorides should be considered in order to assess the potential for corrosion of the tendons. The possible benefits of injecting further grout into voided areas should be reviewed in terms of the potential improvement in durability and ultimate strength.

Broken wires or strands from several tendons may not represent a significant loss in strength in some forms of bridge deck. Broken tendons are likely to re-anchor over short distances of 1-2m, but this depends upon the magnitude of the force released, the integrity of the grout and the adjacent shear reinforcement. Therefore, the re-distribution of forces in the region of a broken tendon should be carefully reviewed in terms of these basic parameters and the condition of adjacent tendons.

Risk Assessment

8.6 The initial risk assessment carried out after the preliminary site inspection should be completely reviewed and due account taken of all defects, particularly at critical sections. The structural consequences arising from all broken and corroded tendons should be carefully examined. Where grouting of tendon ducts is voided, structural failure may occur at a critical section, even if the tendons are fractured at other locations.

The risk of failure at all critical sections should be assessed individually. Potential collapse mechanisms involving failures at various critical sections should be considered, bearing in mind the present condition and the potential for further deterioration at each section in the future.

Monitoring Requirements

8.7 The type and extent of the defects in a structure may require the introduction of frequent inspections and regular monitoring of critical sections. Where any form of monitoring is considered, the frequency of readings and the measurement of temperature conditions should be carefully planned according to the location of the faults and the type of construction.

Where joints in segmental structures occur at critical locations or there are known defects in the vicinity, proposals should be prepared for regular monitoring. In these circumstances, it is necessary to establish datum values for the in-situ concrete stresses adjacent to the joint location and to install a strain gauge monitoring system across the joint. A programme for regular monitoring and interpretation of the results should be prepared in order to provide advance warning of significant changes in structural behaviour.

Recommendations for Load Assessment

8.8 Details of all major cracks, losses of concrete section and corroded reinforcement and broken tendons should be correlated so that the effect on serviceability and ultimate capacity of sections can be appraised. Cracks in joints between precast segments may relate to a general loss of prestress and subsequent reduction in load distribution behaviour within a deck. Recommendations should be prepared to provide guidance on the likely loss in section properties and reductions in strength of all sections suffering from deterioration.

Preliminary Recommendations for Bridge Management

8.9 Future management of the structure should be determined according to the extent of the existing defects and the potential for future deterioration. The proposed management of the structure should also be influenced by the results of the risk assessment and the monitoring requirements.

Recommendations should be made on the frequency and type of future inspections. Where serious defects exist or further corrosion of tendons is inevitable, suggestions should be made for the introduction of repairs, strengthening works or forms of replacement.

Summary Report

8.10 A summary report should be included in the Project Manager's Report. This report should contain a brief description of the structure, the prestressing system and the scope of the Special Inspection. The principal results arising from the preliminary desk study, preliminary site inspection and the site investigation should be presented.

The main conclusions arising from the Special Investigation should include summary statements on the structural condition, risk assessment and future monitoring requirements. Recommendations should be made on the effects of deterioration on section strength, future management of the structure and the need for remedial measures or the possibility of replacement.

9. REFERENCES

1. TRMM 2/88, Trunk Road and Motorway Structures - Records and Inspection
(for use in England).
2. Technical Memorandum (Bridges) SB 1/78 - The Inspection of Highway Structures (DMRB 3.1)
(for use in Scotland).
3. WOTRMM 2/88 Welsh Office Trunk Road and Motorway Structures - Records and Inspections
(for use in Wales).
4. Technical Memorandum (Bridges) BE 4/77 NIRS - The Inspection of Highway Structures
(for use in Northern Ireland).
5. BS 1881: Part 201: Guide to the use of non-destructive methods of testing hardened concrete.
6. BS 1881: Part 205: Recommendations for the radiography of concrete.
7. Concrete Society "Non-structural Cracking of Concrete - 1992"
8. Design Manual for Roads and Bridges
Volume 3: Section 1: Inspection

BD 54 Post-tensioned Concrete Bridges. Prioritisation of Special Inspections (DMRB 3.1.2)

SB 1/78 Inspection of Highway Structures [and Amendment No 1 dated July 1990]
(for use in Scotland only)

Volume 3: Section 3: Repair

BD 27 Materials for the Repair of Concrete Highway Structures (DMRB 3.3)
(Not applicable for use in Scotland)

BA 35 Inspection and Repair of Concrete Highway Structures (DMRB 3.3)

10. ENQUIRIES

All technical enquiries or comments on this Advice Note should be sent in writing as appropriate to:-

Head of Bridges Engineering Division
The Department of Transport
St Christopher House
Southwark Street
London SE1 0TE

P H DAWE
Head of Bridges Engineering Division

The Deputy Chief Engineer
Roads Directorate
The Scottish Office Industry Department
New St Andrew's House
Edinburgh EH1 3TG

J INNES
Deputy Chief Engineer

Head of Roads Engineering (Construction) Division
Welsh Office
Y Swyddfa Gymreig
Government Buildings
Ty Glas Road
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Cardiff CF4 5PL

B H HAWKER
Head of Roads Engineering
(Construction) Division

Assistant Chief Engineer (Works)
Department of the Environment for
Northern Ireland
Commonwealth House
Castle Street
Belfast BT1 1GU

D O'HAGAN
Assistant Chief Engineer (Works)

SAMPLE PRO-FORMAS

FORM A1 - Design Details

FORM A2 - Construction Details

FORM A3 - Maintenance Records

FORM A4 - Preliminary Site Investigation Record

FORM A5 - Site Investigation Record - Tests for Corrosion Risk

FORM A6 - Site Investigation Record - Concrete Material Tests

FORM A7 - Site Investigation Record - Results from Internal Examination

FORM A8 - Site Investigation Record - In Situ Stress of Conditions

WITHDRAWN

Annex A

DESIGN DETAILS

FORM A1

Name of Bridge:

National Grid Ref:

Bridge Number:

STKEY:
(England Only)

Location of Design Details:

Date of Design:

LIST OF DRAWINGS

| Title | Drawing Number | Date |
|-------|----------------|------|
| | | |
| | | |
| | | |
| | | |

FORM OF CONSTRUCTION

Number of Spans:

Span No.:

Angle of Skew:

Length:

Curved on Plan:

Width:

| TYPE OF CONCRETE | Classification | Compressive Strength |
|------------------|----------------|----------------------|
| Precast | | |
| In situ | | |
| Grout | | |

PRESTRESSING AND REINFORCEMENT

Type of Prestressing System:

Prestress Forces:

Anchorage Positions:

Stressing Sequence:

Prestress Losses:

Secondary Steel: Flexural:
Shear:
Top Slab:
Bottom Slab:

CONSTRUCTION DETAILS

FORM A2

Name of Bridge:

National Grid Ref.:

Bridge Number:

STKEY:
(England Only)

Location of Design Details:

Date of Design:

LIST OF DRAWINGS

| Title | Drawing Number | Date |
|-------|----------------|------|
| | | |
| | | |
| | | |

FORM OF CONSTRUCTION

Variations from design:

Type of services in deck:

Gas, Electricity, Water, BT, Mercury, Sewage

| TYPE OF CONCRETE | Strength | Modulus | Density | Aggregate | Sand | Cement | W/C ratio | Mixtures |
|------------------|----------|---------|---------|-----------|------|--------|-----------|----------|
| Precast | | | | | | | | |
| In situ | | | | | | | | |
| Grout | | | | | | | | |

CONSTRUCTION INFORMATION

1. Method

2. Sequence

3. Age at time of stressing

4. Stressing sequence

| | Location | Direction | Number | Width | Joint | Material |
|----------------------|----------|-----------|--------|-------|-------|----------|
| 5. Stressing records | | | | | | |
| 6. Grouting records | | | | | | |
| 7. Joint details | | | | | | |

MAINTENANCE RECORDS

FORM A3

Name of Bridge:

National Grid Ref:

Bridge Number:

STKEY:

Location of Maintenance Records:

(England Only)

| PREVIOUS INSPECTION AND REPORTS | | | | | | | | | | | |
|---------------------------------|---------------------|------------------|---------------------------------------|----------------|------------|----------|-----------|--------|----------|-------------------|---------|
| Title | | | Date | | | | Author | | | | |
| | | | | | | | | | | | |
| SUMMARY OF PREVIOUS DEFECTS | | | | | | | | | | | |
| Location/ direction | Dimensions/ area | Date Recorded | Cause/comments from Inspection Report | | | | | | | | |
| | | | Cracks | Water Leaks | Deflection | Spalling | Corrosion | Joints | Bearings | Pre- stressing | Repairs |
| | | | | | | | | | | | |

PRELIMINARY SITE INSPECTION RECORDS

FORM A4

Name of Bridge:

Bridge Number:

Location of Maintenance Records:

National Grid Ref:

STKEY:

(England Only)

Weather Condition:

Date of Inspection:

| AMENDMENTS TO CONSTRUCTION INFORMATION | | |
|--|------------------|----------------------|
| Form of Construction | Type of Concrete | Construction Details |
| | | |

| PRINCIPAL AREAS AND DEFECTS REQUIRING SITE INVESTIGATION | | | | | | | | | | | |
|--|---------------------|------------------|--|----------------|------------|----------|-----------|--------|----------|-------------------|---------|
| Location/ direction | Dimensions/a rea | Date Recorded | Cause/comments from Preliminary Inspection | | | | | | | | |
| | | | Cracks | Water Leaks | Deflection | Spalling | Corrosion | Joints | Bearings | Pre- stressing | Repairs |
| | | | | | | | | | | | |

FORM A5

National Grid Ref.:

STKEY:
(England Only)

Investigation Team:

SITE INVESTIGATION RECORD

FOR

of Bridge:

National Grid Ref.:

Number:

STKEY:
(England Only)

igation Team:

TESTS FOR CORROSION RISK

| ication | Test Date | Weather | Ref No | Cover Meter Survey | Half-cell Potential | Concrete Resistivity |
|---------|-----------|---------|--------|-----------------------|------------------------|-------------------------|
| | | | | | | |

FORM A6

National Grid Ref:

STKEY:

(England Only)

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Part 3 BA 50/93

SITE INVESTIGATION RECORD

FORM A7

Name of Bridge:

National Grid Ref:

Bridge Number:

STKEY:

Investigation Team:

(England Only)

RESULTS FROM INTERNAL EXAMINATION

| Location | Test Date | Voids in Grout | Duct Inspection | | | Anchorage | Grout Material | | | |
|----------|-----------|----------------|------------------|-------------------|-----------------|-----------|----------------|-------------|-----------|------------|
| | | | Tendon Corrosion | Duct Displacement | Tendon Position | Condition | Composition | Colour/ M/C | Chlorides | Alkalinity |
| | | | | | | | | | | |

SITE INVESTIGATION RECORD

FORM A8

Name of Bridge:

National Grid Ref:

Bridge Number:

STKEY:

Investigation Team:

(England Only)

| IN SITU STRESS CONDITIONS | | | | | | | | | | |
|---------------------------|-----------|---------|------------------------|-----------|----------------------------------|------------------------------------|-------------------------------------|-------------------------------------|--------------|---|
| Location | Test Date | Weather | Temperature Conditions | | Steel Stresses | | Principal Concrete Stresses | | | Secondary Stresses N/mm ² |
| | | | Structure °C | Air °C | Prestresses N/mm ² | Reinforcement N/mm ² | σ ₁ N/mm ² | σ ₂ N/mm ² | φ degrees | |
| | | | | | | | | | | |