THE HIGHWAYS AGENCY

BA 57/95

THE SCOTTISH OFFICE DEVELOPMENT DEPARTMENT

THE WELSH OFFICE
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THE DEPARTMENT OF
THE ENVIRONMENT FOR NORTHERN IRELAND

Design for Durability

Summary: This document gives guidance on the design of bridges for improved durability and should be read in conjunction with Standard BD57.

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REGISTRATION OF AMENDMENTS

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VOLUME 1 HIGHWAY STRUCTURES: APPROVAL PROCEDURES AND GENERAL DESIGN

SECTION 3 GENERAL DESIGN

PART 8

BA 57/95

DESIGN FOR DURABILITY

Contents

Chapter

1. INTRODUCTION

Background

1.1 Feedback from the inspection and maintenance programme of highway structures has highlighted durability problems even where materials, specification and construction practices have been satisfactory. These problems can often be linked to a design philosophy in which minimising the initial cost was paramount. Inadequate consideration may have been given to the long term performance of the structure either in the choice of structural form or in the design of construction details. This has, in too many cases, resulted in maintenance problems requiring costly repair. Consequently the Overseeing Organisations are keen to promote the concept of design for durability, thereby shifting the emphasis to a lowest whole life cost design philosophy.

Definition of Serviceability, Durability

1.2 Serviceability is the ability of structures to fulfil, without restriction, all the needs which they are designed to satisfy. In the design of a highway structure, these needs include:-

i. the ability to carry without restriction all normal traffic permitted to use the structure.

ii. maintenance of user safety by provision of adequate containment, separation of classes of users, effective evacuation of surface water etc.

iii. maintenance of user comfort by avoiding excessive deflections, vibrations, uneven running surfaces etc.

iv. avoidance of public concern caused by excessive deflections, vibrations, cracking of structural elements etc.

v. maintenance of acceptable appearance by avoiding unsightly cracking, staining, deflections etc.

1.3 In the design of structures, however, the first of the above needs is supplemented by a separate check on the maximum load carrying capacity, known as the ultimate limit state. The ability to carry abnormal vehicles is also a need which the Overseeing Organisations' new structures must satisfy, but the occurrence of such loading is deemed to be infrequent and not relevant to the maintenance of the structure's serviceability.

1.4 Durability is the ability of materials or structures to resist, for a certain period of time and with regular maintenance, all the effects to which they are subjected, so that no significant change occurs in their serviceability. In the design of highway structures the target period during which structures must remain durable, corresponds to the design life as defined in BS 5400: Part 1.

1.5 Durability is influenced by the following factors:

i. design and detailing

ii. specification of materials used in construction

iii. quality of construction

1.6 The control of items (ii) and (iii) is achieved through the use of accepted standards and procedures. However the design of structures is not so readily associated with the achievement of durability, beyond such considerations as cover to reinforcement, crack width limitation or minimum steel plate thicknesses. This lack of attention to the durability aspect of design has resulted in a premature loss of serviceability in many highway structures.

Objective of Advice Note

1.7 The objective of this Advice Note is to improve the durability of highway structures by drawing to the attention of designers aspects of design which are relevant to the durability of structures, but not covered adequately in the existing requirements for the design of these structures.

Scope

1.8 The advice contained in this document, which elaborates and supplements the requirements of BD 57 (DMRB 1.3.8), covers areas of design and detailing which are relevant to design for durability. The Advice Note considers various ways in which the design can contribute to the durability of a structure and identifies aspects of structural form and detail which require special attention. Many items covered in this document are acknowledged by designers as being good practice but their use has not been as widespread as would be desirable. Certain aspects of inspection, maintenance, specification of materials and construction practices relating to durability, which are dealt with in more detail in the Specification for Highway Works (MCHW.1) and the Notes for Guidance (MCHW.2), are also briefly mentioned.

1.9 The main points of this Document concerning improved durability are included in BD 57 (DMRB 1.3.8). It should be emphasised that this Advice Note is not comprehensive and designers should use their judgement and experience to ensure that durability aspects are catered for adequately in new structures.

1.10 The figures incorporated in this Advice Note are only indicative. Designers should satisfy themselves as to the suitability of the suggested details to specific designs.

Implementation

1.11 This Advice Note is to be implemented forthwith for all schemes currently being prepared provided that, in the opinion of the Overseeing Organisation, this would not result in significant additional expense or delay progress. Design organisations should confirm its application to particular schemes with the Overseeing Organisation.

2. FACTORS AFFECTING DURABILITY

General

2.1 A survey of 200 highway concrete bridges, commissioned by the Department of Transport, The Maunsell Report (reference 1), identified a number of factors which contributed to the inadequate durability of many of the Department's structures. Most of them were in areas where amendments to existing specification requirements, or to inspection and maintenance procedures, should provide improved durability of structures in the future. The most important of these are briefly discussed below. However, there are a number of important aspects relating to durability which need to be addressed by improvements in conceptual design or in design detailing; these topics are often not adequately dealt with in BS 5400, and are discussed further in this document.

Drainage, Joints and Waterproofing

2.2 By far the most serious source of damage is salty water leaking through joints in the deck or service ducts, and poor or faulty drainage systems. Advice on the design of expansion joints is given in chapter 5 and methods of eliminating deck joints are suggested in chapter 3.

2.3 Also of crucial importance is the provision of an effective waterproofing system on the bridge deck. The most important properties of an effective waterproofing system are its waterproofing ability and its bond to the deck. It should be noted that if bonding is effective over the whole deck area, then any local lack of watertightness in the waterproofing layer is incapable of causing significant damage to the deck. Further advice is given in chapter 5.

2.4 An observed source of damage in highway structures is the splashing or spraying of salty water from de-icing salts on to bridge abutments, piers, parapet edge beams and deck soffits. Advice is given in paragraph 5.18 on the provision of additional concrete cover to reinforcement and impregnation to waterproof these areas.

Workmanship

2.5 A number of aspects of poor workmanship in concrete bridges were highlighted in the Maunsell Report. The most critical of these, from the point of view of durability, was the failure to achieve the specified concrete cover to steel reinforcement. This was found to be an extremely frequent problem, and was the cause of a great deal of deterioration, especially when it occurred in association with joint leakage etc. For further advice on concrete cover see paragraph 5.2.

2.6 Curing of concrete is probably the second most critical aspect of workmanship revealed by the survey. The vital role of curing in providing a dense concrete cover to the steel reinforcement cannot be emphasised too strongly. Problems of poor compaction, honeycombing etc, were in themselves less significant although they might compound the effects of other inadequacies. Compliance with the Specification for Highway Works (MCHW 1) would eliminate these problems in future.

Cracking

2.7 It was found that cracking due to early thermal effects was a widespread problem. For advice on this see paragraph 5.3.

2.8 Cracking and damage due to Alkali Silica Reaction (ASR) was found to be rare.

3. IMPROVED DURABILITY - THE CONCEPTUAL STAGE

General

3.1 The type of structure selected for a particular location can have an important bearing on its durability. This section looks at certain types of construction which have performed well and considers their significance from the point of view of durability.

Continuous bridge decks and Integral Abutments

3.2 Continuous structures have been more durable than structures with simply supported decks, primarily because deck joints have allowed salty water to leak through to piers and abutments. In principle, continuous bridge decks should therefore be used wherever possible.

3.3 Traditionally, simply supported bridge decks have been used in areas where large settlements, such as that due to compressible soil strata or mining, was likely to be a problem. In view of the durability problems associated with deck expansion joints, consideration should be given to the use of continuous structures even where large differential settlements are anticipated. Due allowance should be made for the predicted movement, including hogging off bearings, in the design of deck elements. The degree of settlement which can be accommodated in continuous structures must be individually evaluated. Where these effects cannot be catered for using full continuity, partial continuity as described in paragraph 3.7 should be considered. The ability of continuous bridge decks to accommodate differential settlements is enhanced by the use of increased span/depth ratios, but care should be taken to avoid excessive liveliness, which may be induced by the use of very slender decks.

Continuous decks using precast prestressed beams.

3.4 There are two ways in which multi-span decks can be made continuous, thereby reducing deck joints: incorporating either full or partial continuity at intermediate supports. Partial continuity is achieved by providing continuity to the deck slab only, whereas full continuity involves the provision of fully continuous main beams or girders. In the case of reinforced concrete structures, post-tensioned prestressed structures and structural steel members, this poses no particular problem of design or detailing. In the case of composite bridge decks using precast prestressed beams the achievement of full continuity involves providing in-situ concrete over supports to the full depth of the beam and slab. Partial continuity is generally preferred to full continuity in such structures because of the difficulty in assessing the long term effects of prestress-induced deflection in full-continuity construction.

3.5 Figures 3.1 to 3.5 show five types of continuity construction which have been used in the UK and have performed satisfactorily. These details may be modified for use with structural steelwork. Continuity details other than those shown may also be used providing the designers are satisfied with their past performance.

3.6 Types 1, 2 and 3 have in-situ integral crossheads which may be designed to develop full continuity moments. Type 2 has been extensively used in North America and details of this method of construction can be found in reference 2.

3.7 Types 4 and 5 provide partial continuity through the deck slabs only. They are not designed to develop the full live load continuity moment but rather to eliminate expansion joints between each span. In the Type 4 detail, the various relative rotations and deflections at the support positions are accommodated within the connecting slab elements. This approach retains the simplicity and economy of simply supported construction whilst obtaining the various advantages of deck slab continuity. The Type 5 detail, on the other hand, does not accommodate support rotations and could be susceptible to cracking. These methods can be modified for use in composite bridge decks with steel beams. A joint detail similar to that shown in Figure 3.4 has been promoted in the UK by Dr A Kumar; more details can be found in references 3 and 4.

Integral abutments

3.8 As an extension to the concept of deck continuity, bridges can be designed with abutments connected to the bridge deck without movement joints for expansion or contraction of the deck. The form of construction known as integral construction, should be adopted in all cases where predicted relative settlements are sufficiently small to allow it, and where bridge spans are not too long to incur unacceptable problems in the design of the structure for thermal effects. It should be noted that the Overseeing Organisations' present bridge stock contains bridges of this type having overall lengths of up to 60m. In these situations both bearings and expansion joints can be eliminated and maintenance requirements reduced.

3.9 In designing a bridge with integral abutment walls, the load effects due to temperature changes, shrinkage and creep should be considered in conjunction with soil/structure interaction.

3.10 When using integral (portal type) abutments at the ends of long, including multi-span, bridges, thermal and other movements may be large enough to induce passive earth pressures behind the abutment walls, especially near the top. Although the design against these pressures may result in costly, heavily-reinforced sections, they are still preferable to the use of conventional expansion joints, and give much less trouble in service. There are some benefits in using slender abutment walls ("balanced" design), because flexure of the walls tends to relieve the earth pressure behind them.
Further guidance on the design of integral bridges is provided in BA 42, The Design of Integral Bridges.

3.11 In North America, multi-span continuous bridges with integral bank seats or short abutment walls are frequently used. A typical arrangement of this type of integral construction is shown in Figure 3.6 and more details can be found in reference 5.

Buried structures

3.12 Rigid buried concrete box construction, which is an extension of portal frame construction, may be preferable to a simply supported or a portal frame type structure for short span bridges. In some locations flexible designs incorporating corrugated steel buried structures may be suitable. In general, buried structures have important maintenance and durability advantages over conventional bridge structures. Being remote from the immediate road construction, they are less sensitive to all road influences, including the effects of de-icing salts. Maintenance of the highway is also easier because the structure imposes fewer restraints on highway maintenance operations. Where conditions are suitable, their use is recommended.

Box sections

3.13 The size of box sections in bridge decks, abutments and piers should be such that proper inspection and maintenance can be carried out within the box. Statutory provisions for access are contained in the Factories Act 1961 and Section 4 of the Approved Code of Practice (ACOP) "Management of Health and Safety at Work" (reference 6). This may dictate the minimum practical size of box sections. The minimum sizes of access openings required by the Act, or by other requirements, should be treated as absolute minima; wherever possible substantially larger openings should be provided.

3.14 If voids are too small to afford reasonable access, exceptional care must be taken to ensure that they are adequately sealed and free from other durability problems.

3.15 In catering for ventilation it is highly desirable, and often possible, to incorporate a level of natural illumination within boxes so that inspection is not totally reliant on artificial lighting.

Plain Concrete

3.16 As ferrous reinforcement is susceptible to durability problems, consideration should be given to the use of masonry or plain concrete construction by the choice of suitable types of structure.

3.17 Plain concrete or masonry arch structures may be feasible in some locations. In plain concrete arch structures the need for reinforced cantilevered spandrel walls may be avoided by using mass concrete infill over unreinforced arch vaults. Abutments and retaining walls in mass concrete should also be considered.

3.18 External cladding may be necessary to mask any unsightly cracking due to early thermal effects. The fixing of such cladding should be done using corrosion resistant materials of proven durability, for instance stainless steel, bronze or glass fibre inserts.

3.19 Where possible, the detailing of cladding systems should be such that cladding panels can be easily removed for the purpose of Principal Inspection of the structure, or for maintenance work.

Non-ferrous Reinforcement

3.20 As an alternative to the above, the control of early thermal cracking in plain concrete sections may be achieved by using corrosion resistant reinforcement. The stresses in such reinforcement may be calculated using short-term properties of the materials and ignoring the phenomenon of long-term loss of strength through creep. Creep is often significant with such reinforcement but is not considered relevant to the control of early thermal cracking which is reasonably short term.

3.21 For the design of primary structural members, the use of non-ferrous reinforcement such as glass or aramid fibres in a resin matrix may in due course provide a significant improvement in the durability of reinforced and prestressed concrete structures. The performance of these materials is currently being investigated.

Inspection and Maintenance

3.22 When considering structural forms, details and any relevant aspects in the design procedure, designers should ensure that the structure, as well as its components, can be effectively maintained. Early identification of durability problems by inspection should prevent severe and costly damage to a structure. Areas which are likely to be affected by de-icing agents or other corrosive elements must be accessible for inspection and, where necessary, be designed and detailed to allow for repair or possible replacement. Designers should refer to BA 35 (DMRB 3.3) for further details.

3.23 It is often cost-effective to incorporate in a structure facilities for routine inspection and maintenance. In providing access, the general objective should be to give the inspector a dry, comfortable and pleasant environment in which to work. Experience has shown that, where access is difficult and where working spaces are cramped, badly lit and ventilated, damp or otherwise uncomfortable to work in, inspection tends to be less frequent and the inspector's observational efficiency may be significantly impaired.

3.24 The following provisions for access should be made at the design stage:

a. Access for cleaning, maintenance and painting.

b. Access to parts that may require maintenance or replacement during the life of the bridge, for instance, bearings, joints, anchorage locations, drainage, pipes, manholes, lubrication of moving parts, lighting systems etc.

c. Access for jacking at bearings and for their removal and replacement.

d. Access to closed cells or box sections.

3.25 Access points should preferably be at each end of the structure at points which are easily accessible and do not require traffic control. Means of access could include gantries, walkways, scaffolding ladders, rails or 'cherry pickers'.

3.26 Public use of any of these access facilities and colonization of the areas in question by plants, animals and birds, should be prevented.

Bridge abutment galleries

3.27 Abutment details such as that shown in Figure 3.7 create inaccessible areas which are vulnerable to concrete contamination by de-icing salts through leakage at joints, and are difficult to inspect and maintain. In paragraph 3.8 the use of integral abutments is recommended wherever possible, for new designs. However,there will still be some locations where articulation at the ends of bridge decks is necessary. In such cases abutment galleries should be provided to facilitate inspection and maintenance of both rotational as well as expansion joints, bearings, abutment curtain walls and deck ends. A typical arrangement of an abutment gallery is shown in Figure 3.8. The width and headroom clearance of such galleries should preferably be at least 1000 x 1800mm respectively and never less than 800 x 1500mm.

3.28 Abutment galleries can be useful for the discharge and maintenance of drainage pipes through bridge decks and waterproofing to relieve water pressure within surfacing at joints. They may also assist bridge maintenance by facilitating access for future deck jacking. In mining areas, ground movement can close bridge expansion joint gaps and the provision of abutment galleries should reduce the extent of any remedial works which are necessary to free such joints.

3.29 Access to abutment galleries will be possible in some bridges between or alongside deck beams. Entry can also be arranged in some cases via doors in abutment or wing wall faces. Abutment galleries in most bridges will be permanently ventilated between bearings. Where this is not the case, ventilation should be provided, particularly if gas mains exist or are likely to be present in the vicinity of the bridge.

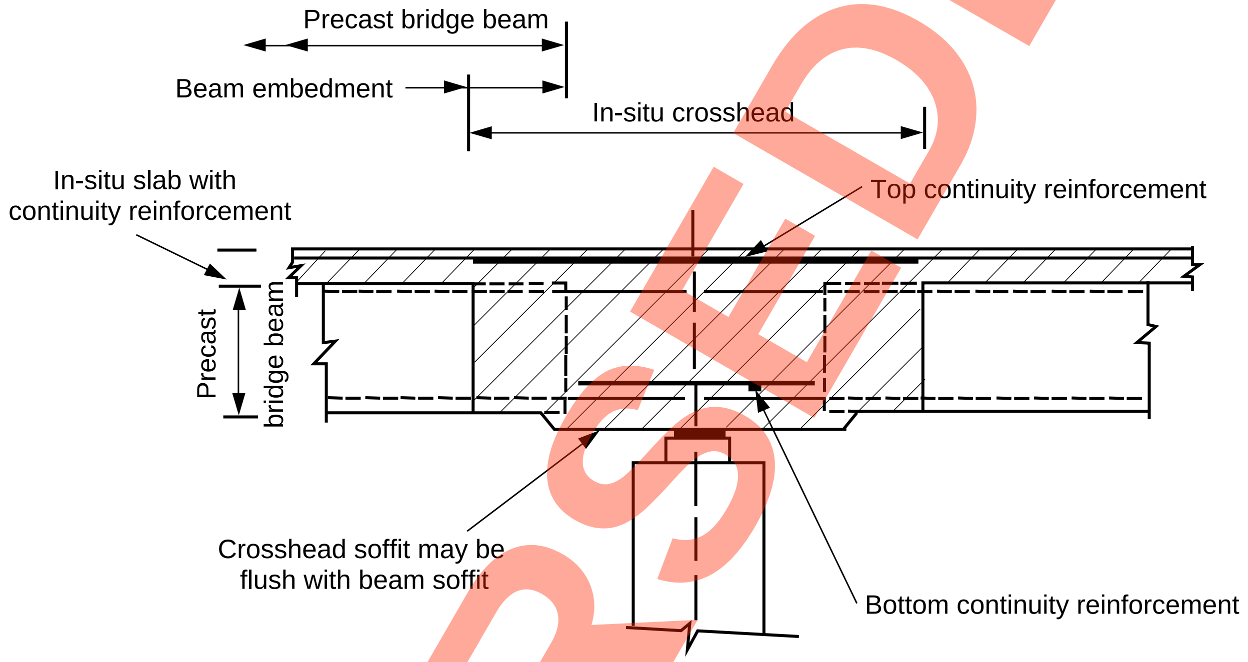

Figure 3.1 Continuity Detail Type 1 Wide in-situ Integral Crosshead

Typical features:

1. Beams are erected on temporary supports generally off pier foundations.
2. Permanent bearings are in a single line.
3. Continuity reinforcement is provided in the slab and at the top and bottom of bridge beams. The lapping of reinforcement is normally not difficult.

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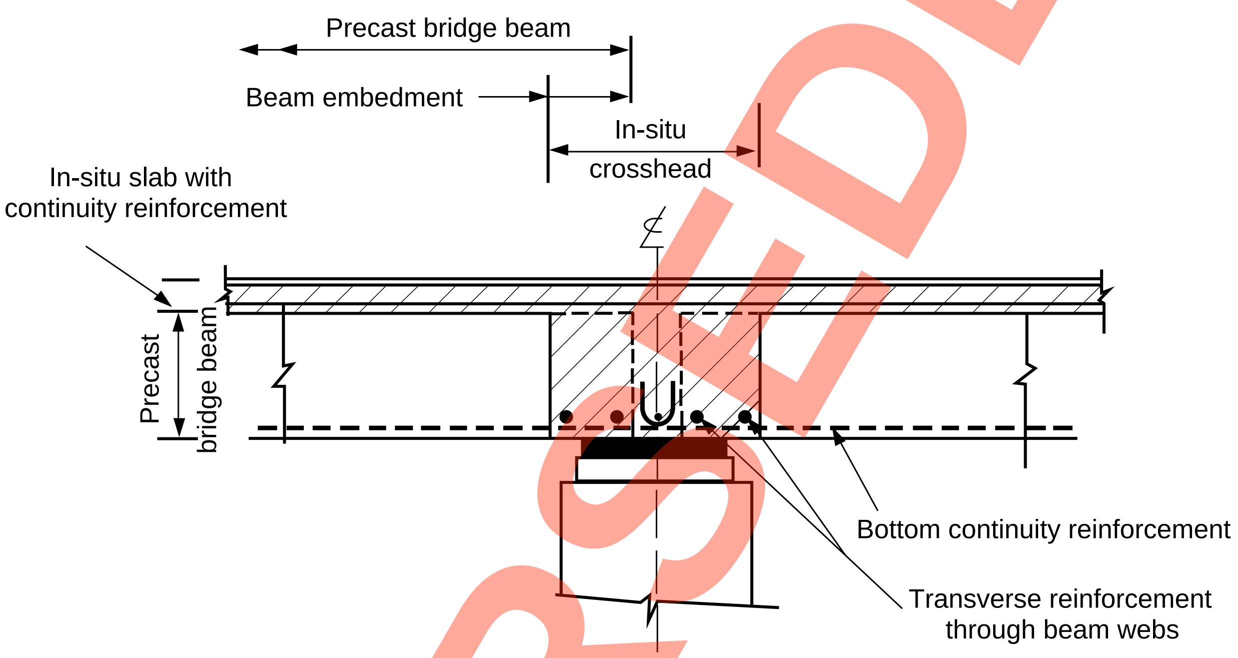

Figure 3.2 Continuity Detail Type 2. Narrow in-situ Integral Crosshead

Typical features:

1. Temporary supports are not required
2. Permanent bearings may be in single or twin line.
3. Continuity reinforcement is provided in the slab and at the bottom of bridge beams. The lapping of reinforcement is difficult.

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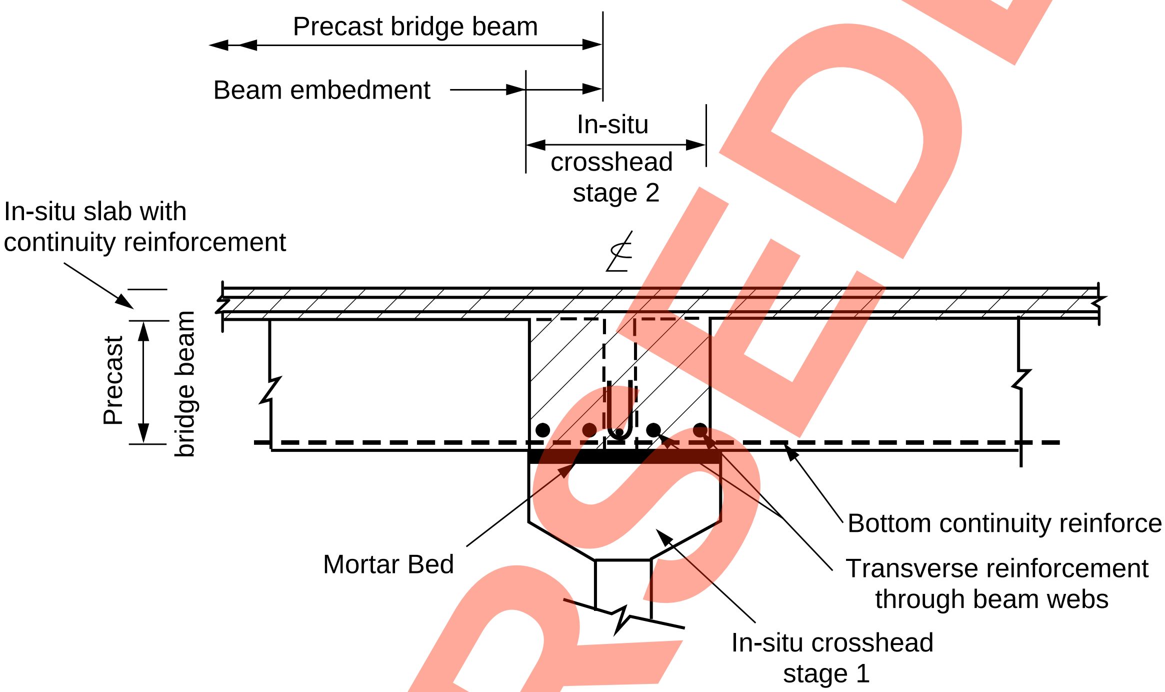

Figure 3.3 Continuity Detail Type 3. Integral Crosshead Cast in Two Stages

Typical features:

1. Beams are supported on stage 1 crosshead during erection.
2. Crosshead to be monolithic with pier.
3. Crosshead soffit is normally lower than beam soffit.
4. Reinforcement is similar to types 1 and 2 depending on the cross section of the stage 1 crosshead.

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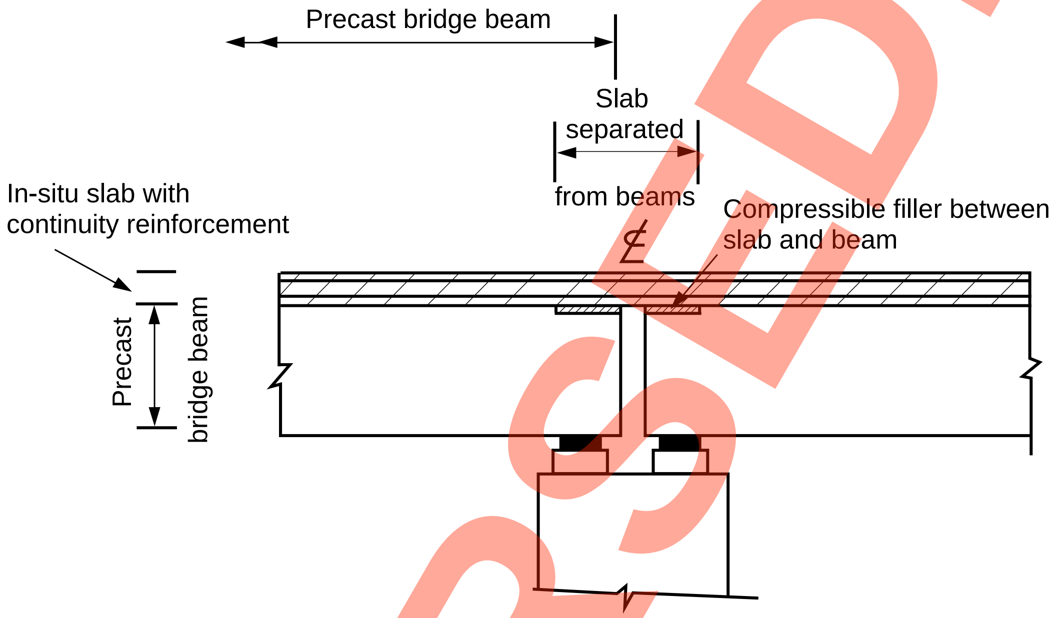

Figure 3.4 Continuity Detail Type 4 Continuous Separated Slab

Typical features:

1. Separate bearings and diagrams are provided for each span.
2. Deck slab is separated from support beams for a short length to provide rotational flexibility.
3. There is no continuity reinforcement between ends of beams and there is no moment continuity between spans.

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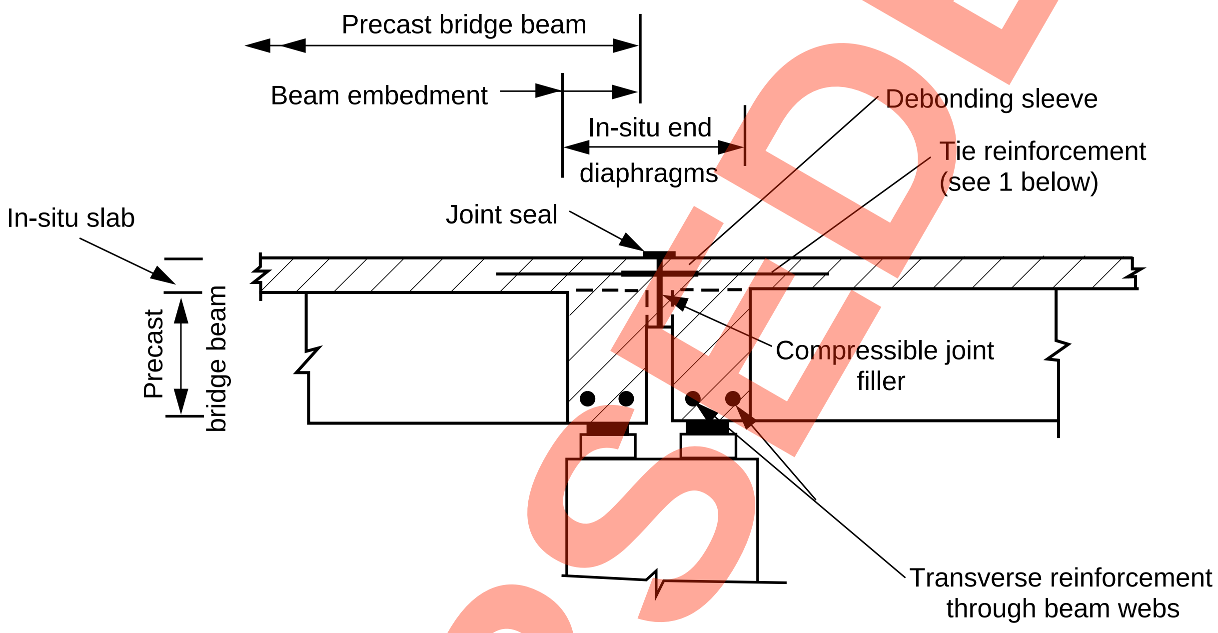

Figure 3.5 Continuity Detail Type 5 Tied Deck Slab

Typical features:

1. The tie reinforcement at mid-depth of the slab is debonded for a short length either side of the joint to permit deck rotation. There is no moment continuity between spans.
2. Slabs between spans are separated using compressible joint fillers but deck waterproofing and deck surfacing are continuous and special seals are provided over the joint for double protection.
3. Separate bearings and end diagrams are provided for each span.

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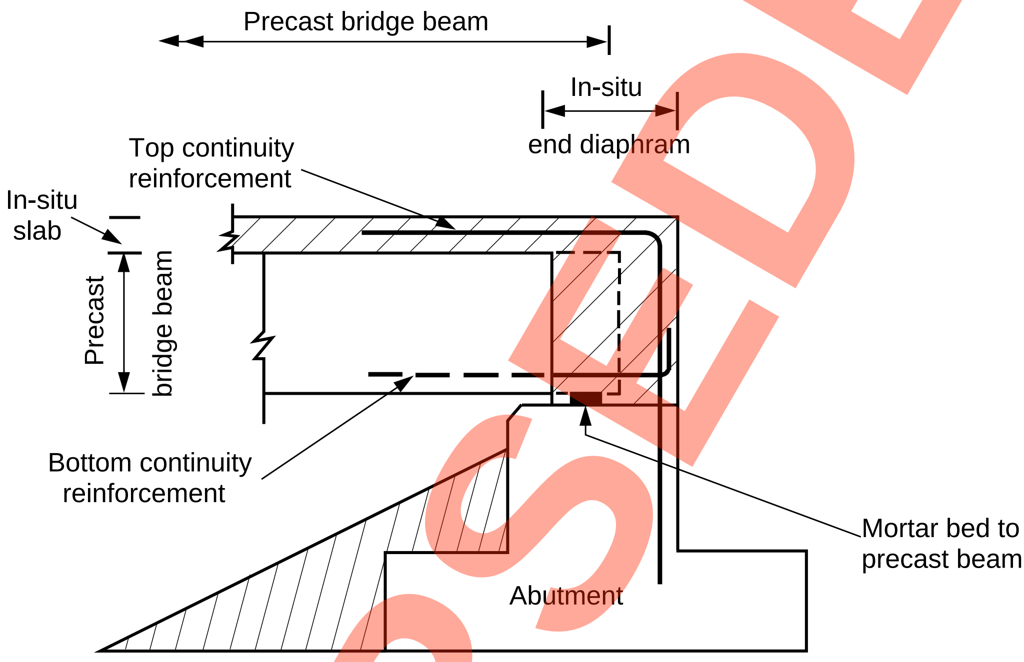

Figure 3.6 Integral Abutment

NOTES

1. The bridge beam shown above is a precast concrete beam with composite deck. Similar integral abutment arrangement may be adopted for steel-concrete composite construction.
2. The abutment should be short and small to avoid excessive passive earth pressure during the thermal movement of the deck.
3. Drainage and service pipes behind the abutments should have flexible joints as settlement of backfill may take place.

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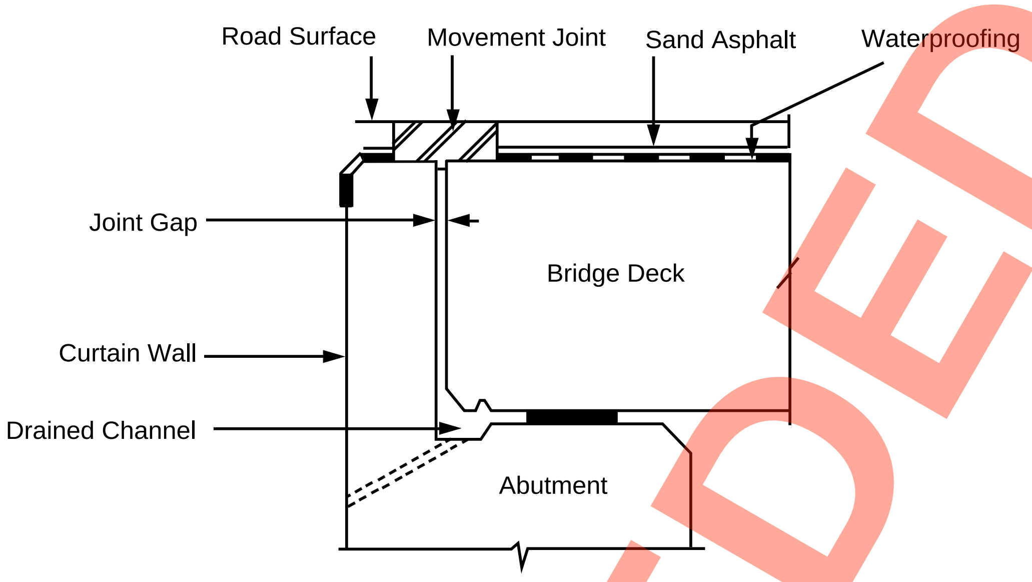

Figure 3.7 Inaccessible Bearing Shelf (This Detail is Not Recommended)

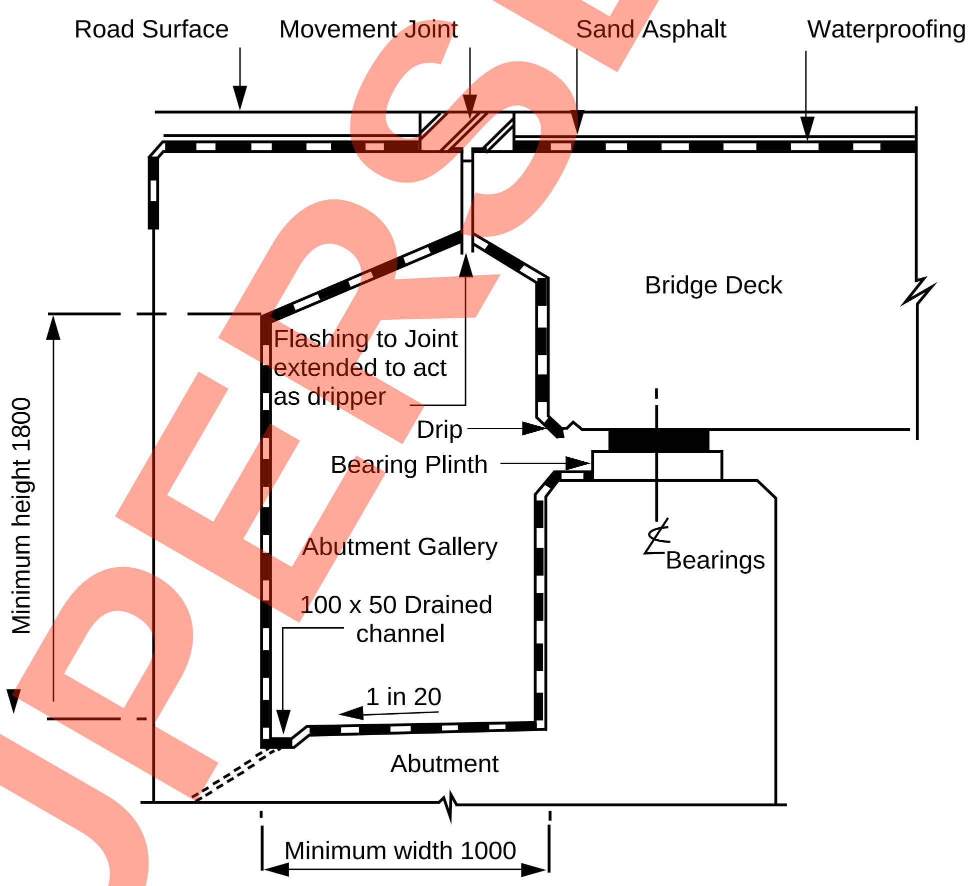

Figure 3.8 Abutment Gallery

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4. IMPROVED DURABILITY - PROBLEM AREAS

General

4.1 It is apparent from recent surveys on bridges that there are some structural forms and elements which are more susceptible to durability problems than others. This section gives advice on the use of these forms and considers other areas which require special attention.

Half-Joints and Concrete Hinges

4.2 Half-joints, both in steel and in concrete, usually present severe maintenance problems. They are difficult to inspect and repair and should not be used for new designs unless there is absolutely no alternative. Where half-joints are used, steel and concrete surfaces should be given additional protection. Adequate provision must be made for drainage, inspection and maintenance.

4.3 Concrete hinges are highly stressed areas where, because of the amount of reinforcement present, compaction of concrete is difficult. The steel in the hinges is vulnerable to corrosion from the ingress of salty water. Concrete hinges should not be used for new designs unless there is absolutely no alternative. Where concrete hinges are used, they should be visible for inspection and maintenance.

Pre-tensioned prestressed concrete construction

4.4 Precast pre-tensioned concrete members have generally proved to be durable. Apart from concern about occasional problems, for example, horizontal cracking of the beam in the end zones, the poor performance of some bridges constructed with these members has been associated with the use of simply supported spans. The remedies for that are discussed in Chapter 3.

4.5 De-bonded tendons at the ends of precast beams should be adequately protected against corrosion.

Post-tensioned concrete construction

4.6 Unlike precast pre-tensioned concrete, construction using post-tensioned members has not proved to be particularly satisfactory in terms of durability. Virtually all post-tensioned bridges built to date have been of the grouted duct type, and problems have been encountered in a number of these largely due to their greater vulnerability to corrosion of tendons as a result of inadequate grouting of the ducts. This reduced durability has caused particular concern since the deterioration often cannot be identified in the course of regular bridge inspections; this means that serious loss of carrying capacity may remain undetected, with consequent risk to public safety. In some instances there may be little or no warning of collapse in prestressed bridges, and this makes the risk of undetected deterioration more serious. The use of grouted duct post-tensioning is therefore not at present recommended.

Segmental construction

4.7 In-situ joints between precast segments are the areas most at risk from penetration by water and de-icing agents. This may lead to severe local corrosion of prestressing strands. Another problem which has not been widely recognised by designers is the additional prestress loss due to large elastic compression and subsequent creep deformation of the joint material and closure of cracks at interfaces. As a result, the final level of prestress in segmental construction may be somewhat less than normal post-tensioned members.

4.8 It has been observed that if the compressive stress across a mortar joint is less than 2 to 3 N/mm^2, the joint may show "partially cracked" section behaviour and high local strains may develop in any steel passing across the joint. There is also a likelihood of salty water entering the joint and corroding reinforcement. Deterioration of the joint is not easily detectable and failure may occur in a sudden and brittle manner.

4.9 Shortening due to shrinkage may also occur at the ends of each precast unit. This could cause additional opening at the joints prior to stressing and hence reduce the compressive stresses at the interfaces and encourage cracking.

4.10 Designers should be aware that because of water seepage through joints between segments, grouted duct prestressing in segmental construction is

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particularly susceptible to tendon corrosion.

External Post-tensioned Tendons

4.11 Post-tensioned tendons positioned outside the concrete have the advantage of being accessible for inspection and replacement. Where external post-tensioned tendons are used, they should be properly protected and have adequate facilities and access for inspection, maintenance and replacement. The sequence of cable replacement should be allowed for at the design stage.

Voided slabs

4.12 The adoption of pseudo-slab and similar structures using void formers to achieve the final cross-section has lead to some serious problems, usually related to the buoyancy of the formers during construction and the difficulty of compaction under the voids. Special precautions should be taken in the design and construction of this type of structure.

5. IMPROVED DURABILITY - DETAILED REQUIREMENTS

General

5.1 The life of a bridge can be considerably enhanced at little additional expense by sound detailing of structural elements. This section gives advice on aspects of detailed design which should enhance durability.

Reinforced Concrete

5.2 BD 57 (DMRB 1.3.7), increases the concrete covers to reinforcement specified in BS5400: Part 4: Table 13. However, in sensitive or critical areas of the structure such as in the region below expansion joints, serious consideration should be given to the use of concrete covers greater than those specified in BD 57. It should be noted too that the requirements of BS 5400: Part 4, do not penalise the designer for using greater cover than the Table 13 values with respect to crack width calculations; the definition of C_{nom} in clause 5.8.8.2 makes it clear that the designer may ignore extra cover in calculating crack widths. It should be noted that as BS 5400: Part 4 already makes provision for an additional 10 mm cover for lightweight aggregate concrete, the BD 57 requirement for additional concrete cover does not apply.

5.3 The minimum areas of main and secondary reinforcement given in BS 5400: Part 4 Clause 5.8.4 are, in many instances, not adequate to limit the cracking of concrete caused by the dissipation of heat of hydration while the concrete is immature. Designers should refer to the requirements given in BD 28 (DMRB 1.3), Early Thermal Cracking of Concrete. In designing reinforcement for early thermal effects the designer should bear in mind that the strength and cement content of the as-built concrete may be a good deal higher than that specified in the contract drawings. As the cement content has a significant effect on the heat evolution during hydration, the temperature effects due to the likely maximum cement content should be used.

5.4 Cement replacements, such as pulverised fuel ash and ground granulated blastfurnace slag, may reduce early thermal effects and improve

resistance to chloride ingress, sulphate attack and Alkali-Silica Reaction.

5.5 Where local cracking of the concrete may occur due to restraint from adjacent elements, eg at corners of two-way slabs, reinforcement should be carefully detailed to control such cracking. In some cases, a detailed investigation of the stresses in these areas may be necessary.

Prestressed Concrete

5.6 In post-tensioned structures, one location which is of particular concern is the anchorage of tendons. Designers should ensure that sufficient anti-bursting reinforcement is provided and that the layout of the anchorage zone reinforcement is not congested or likely to cause difficulties in placing and compacting concrete. Increased concrete cover should be provided to ensure effective protection to the steel.

5.7 Post-tensioned externally prestressed structures should be detailed to facilitate replacement or re-stressing of an individual tendon, without restricting traffic flow across the bridge. The provision of special monitoring devices to detect loss of pre-tensioning or corrosion should be considered. External tendons should be positioned so that they can be easily inspected and maintained.

Drainage and Waterproofing Systems

5.8 Drainage and waterproofing play a vital role in the durability of structures. Designers should refer to BD 47 (DMRB 2.3.4) and BA 47 (DMRB 2.3.5) when designing drainage and waterproofing of concrete bridge decks.

5.9 Drainage systems should be designed to minimise the risk of blockage and be accessible for cleaning. They should be robust enough to withstand damage during cleaning, as this has been an important cause of problems on many existing bridges. They should also be resistant to damage from chemical spillage on the road surface. The drainage of water from bridge decks and waterproofing layers should normally be done using closed systems which lead the water positively to the main highway drainage system. Allowing water from deck drainage to fall freely from open ended downpipes should be avoided for the following reasons:-

i. In windy conditions such water may become finely atomized and spray onto the structure, even when downpipes project well below the soffit line.

ii. Freely discharged water may contaminate river courses.

iii. Freely discharged water may cause local damage to the soil surface below the bridge.

iv. Water from open ended downpipes may fall onto a carriageway or footway beneath and freeze, causing a hazard to both pedestrians and vehicles. There is also a danger that icicles may form on open ended downpipes and fall onto vehicles and pedestrians.

5.10 Drainage systems integral with the structure, for instance gulleys cast into beams and pipes cast into columns, should not be used. Essential drainage runs through deck slabs should be made as short as possible.

5.11 Drainage systems should be provided with adequate facilities for rodding and cleaning operations. Rodding access should be provided so that rodding lengths are straight or virtually straight, and do not normally exceed 45m on straight runs. Careful thought should be given to the practical needs of cleaning and maintenance operations, and full details provided accordingly. All gullies should be fully trapped.

5.12 Drainage of bridge decks should never be directed into the drainage layers in the vicinity of piers and abutments since salty water from the bridge deck may cause corrosion of the reinforcement in the substructure. Moreover, accumulated road silts and debris may eventually clog the drainage layers.

5.13 The durability of a bridge can be improved by taking the following precautions:-

a. The top surface of bridge decks should have adequate falls to avoid ponding especially in the vicinity of deck joints. Drainage outlets should be formed using adequately sized products, at regular intervals.

b. Additional measures, such as coating and extra waterproofing layers etc, may be considered necessary where a concentration of de-icing agents is likely to occur.

c. Areas around kerbs, parapets and service traps are most vulnerable to water seepage and should be carefully detailed.

d. Access holes should be located on the underside of bridge decks to avoid water leakage into the deck. When this is not possible, properly sealed or/and positively drained manholes may be used but only with the agreement of the Overseeing Organisation.

e. Drainage should be provided at piers and abutments including the back of abutments.

f. Holes should be provided to drain the voids of bridge decks, such as box beams and cellular and voided slabs, as water may find its way into these voids causing corrosion and deterioration.

g. Box members should be provided with sealed access hatches or manhole covers to prevent leakage into the box. Adequate and effective ventilation and drainage holes should also be provided to reduce condensation and eliminate any ponding inside the box as a result of a possible ingress of water. Ventilation and drainage holes should be detailed to prevent access and colonisation by birds and animals.

5.14 The following concrete surfaces should be waterproofed:

i. Vertical faces at deck ends and abutment curtain walls.
ii. Top faces of piers and abutment bearing shelves.
iii. Inaccessible areas which may be subject to leakage; for instance beam ends.

Where waterproofing membranes may be directly subject to foot traffic, they must be sufficiently robust to withstand such use, and should not be slippery.

Expansion Joints

5.15 Designers should refer to BD 33 (DMRB 2.3) and BA 26 (DMRB 3.3) when designing and detailing expansion joints and drainage provisions in bridge decks.

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5.16 To prevent salty water from penetrating downward to the substructure, expansion joints should be watertight. However, these joints will eventually leak and therefore designers should not only apply protective coating to surfaces at risk, but also provide drainage under the joints in the form of abutment galleries as described in paragraph 3.28.

5.17 Careful detailing around expansion joints in bridge decks can make a major contribution to the durability of a structure. Failure of deck expansion joints often leads to severe corrosion of adjacent parts of the structure. The areas around a joint should be detailed in such a way that they do not provide traps for water and that an effective system is provided to remove the water quickly. All the elements should be detailed so that they are accessible for inspection and maintenance.

Splash zones

5.18 Designers should be aware that the splash zone of river or road piers and abutments are particularly susceptible to deterioration. In some situations salty water may be splashed up to the soffit of overbridges causing deterioration and corrosion. In addition the spray may result in a retention of salt in the soil adjacent to the carriageway thus causing severe chloride attack to the concrete sub-structure. Special precautions should be taken in these areas by the application of protective coating, for instance chemical impregnation, and additional cover to steel reinforcement should be provided (See paragraph 5.2)

Other details

5.19 It is essential to provide drip checks at all edge beams, deck ends over abutments and other locations such as copings to retaining walls, to prevent water from running back along horizontal surfaces. Where, for reasons of concrete cover, the provision of groove type drips is not practicable continuous unreinforced concrete downstands or continuous non-ferrous angle sections properly fixed to deck edges, may be used as drippers. BA 33 (DMRB 2.4) shows a prefabricated drip strip for use on existing structures.

5.20 Bridge decks should be designed to project beyond the substructure to prevent salty water from running down columns and abutments.

5.21 The designer should always consider the ease of construction of the proposed details. For example, adequate provision should be made for compacting concrete and painting of structural steel.

Impregnation of Concrete Surfaces

5.22 Impregnation of concrete surfaces provides effective protection against the ingress of chlorides. Requirements for impregnation procedures are given in BD 43 (DMRB 2.4) and BA 33 (DMRB 2.4).

6. DETAILED REQUIREMENTS - STEEL BRIDGES

General

6.1 Where steels are welded in areas of high restraint and where tensile stresses occur perpendicular to a plate surface, eg in cruciform joints, corners of box sections and heavily welded sections, lamellar tearing could occur. In such situations, designers should pay proper attention to weld joint design and use steels with guaranteed through-thickness properties.

6.2 Welds for temporary attachments can act as stress raisers and increase the risk of fatigue. Such welding should not be allowed in critical areas. Temporary attachments should be removed and welds ground flush. (See 1800 NG 1801)

6.3 Transverse bracing members between parallel girders are often subjected to stress reversal due to live loads. Therefore the effects due to fatigue at their connections with main girders should be considered in design.

6.4 Simple connections and weld details, which are easier to inspect and maintain, should be used wherever possible.

6.5 Intermittent fillet welds should not be used,except in situations where the welded connections are completely protected from the weather, for example, where they are wholly inside a closed box structures; in such cases appropriate fatigue checks should be carried out. Intermittent welding , where one or both sides of the connection are exposed to the outside atmosphere, cannot be properly protected against the ingress of water into the welded joint by capillary action or penetration of water through the connection.

6.6 Steelwork should be detailed so that it is self-draining and prevents the accumulation of water. Areas where dirt and debris may collect should be avoided.

Painting

6.7 The most common method of corrosion protection of steelwork is by painting. Designers should refer to MCHW Volume 5 Section 2 for maintenance painting and the Specification for Highway Works (MCHW 1) and the Notes for Guidance (MCHW 2) for the Overseeing Organisations' requirements on painting of steelwork.

6.8 Designers should be aware that the success of corrosion protection depends not only on the protective system specified but also on the surface preparation, quality control and the effectiveness of the painting operation. Steel components should therefore be designed and detailed with the recognition that they must be capable of being effectively prepared, painted, inspected, cleaned and repainted.

Metal coating of steelwork

6.9 Galvanising and suitable sprayed metal coatings can give effective corrosion protection to steelwork. Designers should refer to the Specification for Highway Works (MCHW 1) and the Notes for Guidance (MCHW 2) for their use.

6.10 In specifying galvanising for high tensile steel such as bolts, post-tensioning bars and cables which are subjected to high fluctuating stresses, designers should be aware of the danger of hydrogen embrittlement associated with galvanising.

Steel Box Sections

6.11 The recommendations of Section 3.13 apply equally to steel box sections.

6.12 The interior of steel box sections should be painted a light colour to improve visibility.

7. REFERENCES

(1) The Performance of Concrete Bridges: G Maunsell & Partners, HMSO.

(2) National Corporative Highway Research Program Synthesis of Highway Practice 322, 'Design of Precast Prestressed Bridge Girders Made Continuous'. Transportation Research Board, National Research Council, Washington, DC 1990.

(3) Kumar, A. Detailed Design of Composite Concrete Bridge Superstructures. British Cement Association, 1988.

(4) Kumar, A. Composite Concrete Bridge upper-Structures. British Cement Association, 1988.

(5) National Cooperative Highway Research Program, Synthesis of Highway Practice 141, Bridge Deck Joints. Transportation Research Board, National Research Council, Washington, DC, 1989.

(6) Approved Code of Practice (ACOP): Management of Health and Safety at Work.

(7) BS 5400 Steel, Concrete and Composite Bridges: Parts 1 and 4.

(8) The Design Manual for Roads and Bridges

BD 28 (DMRB 1.3), Early Thermal Cracking of Concrete.

BD 33 (DMRB 2.3.6), Expansion Joints for Use on Highway bridge Decks.

BD 43 (DMRB 2.4), Criteria and Material for the Impregnation of Concrete Highway Structures.

BD 47 (DMRB 2.3.4), Waterproofing and Surfacing of Concrete Bridge Decks.

BD 57 (DMRB 1.3.7), Design for Durability.

BA 26 (DMRB 2.3.7), Expansion Joints for Use on Highway Bridge Decks.

BA 33 (DMRB 2.4), Impregnation of Concrete Highway Structures.

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

BA 42 (DMRB 1.3.1) The Design of Integral Bridges
(TO BE PUBLISHED)

BA 47 (DMRB 2.3.5), Waterproofing and Surfacing of Concrete Bridge Decks.

(9) The Manual of Contract Documents for Highway Works

Specification for Highway Works (MCHW.1)

Notes for Guidance on the Specification for Highway Works (MCHW.2)

Maintenance Painting of Steel Highway Structures (MCHW 5.2)

8. ENQUIRIES

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

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