VOLUME 3 HIGHWAY STRUCTURES: INSPECTION AND MAINTENANCE

SECTION 3 REPAIR

PART 5

BA 88/04

MANAGEMENT OF BURIED CONCRETE BOX STRUCTURES

SUMMARY

This Advice Note provides guidance for the systematic management of buried concrete box structures. It discusses factors that affect durability. It gives advice on inspection for and measurement of defects and provides maintenance advice. It offers guidance on structural assessment and provides indicators for priority of repair works.

INSTRUCTIONS FOR USE

1. Remove existing contents pages for Volume 3.
2. Insert new contents pages for Volume 3 dated August 2004.
3. Insert BA 88/04 into Volume 3, Section 3, Part 5.
4. Please archive this sheet as appropriate.

Note: A quarterly index with a full set of Volume Contents Pages is available separately from The Stationery Office Ltd.

THE HIGHWAYS AGENCY

SCOTTISH EXECUTIVE

Llywodraeth Cynulliad Cymru
Welsh Assembly Government

WELSH ASSEMBLY GOVERNMENT
LLYWODRAETH CYNULLIAD CYMRU

DRD
Department for
Regional Development
www.drdni.gov.uk

THE DEPARTMENT FOR REGIONAL DEVELOPMENT
NORTHERN IRELAND

Management of Buried Concrete Box Structures

Summary: This Advice Note provides guidance for the systematic management of buried concrete box structures. It discusses factors that affect durability. It gives advice on inspection for and measurement of defects and provides maintenance advice. It offers guidance on structural assessment and provides indicators for priority of repair works.

REGISTRATION OF AMENDMENTS

Amend No	Page No	Signature & Date of incorporation of amendments	Amend No	Page No	Signature & Date of incorporation of amendments

REGISTRATION OF AMENDMENTS

Amend No	Page No	Signature & Date of incorporation of amendments	Amend No	Page No	Signature & Date of incorporation of amendments

VOLUME 3 HIGHWAY STRUCTURES: INSPECTION AND MAINTENANCE

SECTION 3 REPAIR

PART 5

BA 88/04

MANAGEMENT OF BURIED CONCRETE BOX STRUCTURES

Contents

1. INTRODUCTION

1.1 In the UK, buried concrete box structures are often used as culverts and underpasses through highway embankments. Most buried concrete box structures are performing well and have required little in the way of maintenance. However, a number of common defects were identified which, without proper maintenance, will reduce the service life of the structures. These include the lack of, or breakdown of, waterproofing systems and poor drainage of the surrounding backfill. In most cases the subsequent deterioration, i.e. the spalling of the concrete cover to the reinforcement, was associated with the ingress of groundwater. At a number of sites, differential ground movements had led to the cracking of boxes and to the failure of joints between individual units. Less common defects included the silting of inverts, undermining by scour, degradation of concrete by one or other chemical reactions and cracking induced by high loads.

1.2 Many of the documents for inspection, assessment and maintenance of concrete structures were written primarily for concrete bridge decks. Much of this information applies to managing buried concrete box structures and that information will be referenced.

1.3 This Advice Note provides additional information for managing buried concrete box structures to achieve a minimum whole life cost.

2. GUIDANCE ON INSPECTION

General

2.1 The in-service performance of buried concrete box structures should be monitored following requirements for highway structures given in BD 63 (DMRB 3.1.4) and BA 63 (DMRB 3.1.5). These documents are applicable to a range of highway structures and, although forming a comprehensive inspection and reporting schedule, are not particular to buried concrete box structures. For this reason the most commonly occurring defects with such structures are not specifically highlighted in BD 63 or BA 63. The following additional advice should fill this gap.

2.2 Note that BA 63 (DMRB 3.1.5) requires inspections for culverts greater than 1.8 metres span/diameter (2.0 metres in Scotland) if the cover below the road is less than 1 metre and inspections for all structures with spans greater that 3 metres. In Scotland all culverts greater than 2.0m span/diameter are inspected irrespective of the cover.

Identification of Common Defects

2.3 Buried concrete box structures may suffer from a number of common defects which, in the absence of proper maintenance, will reduce their service life. Although some problems occur with both cast insitu and precast structures, others are specific to the type of construction. The main areas of concern are as follows:

(a) Shrinkage cracks may be evident on cast insitu structures. These are usually a result of the construction process and in most cases do not present a problem. However, on occasions the cracks may extend through the full thickness of the walls and slabs, thus allowing ingress of water (either or both groundwater and carried effluent) to the reinforcing steel and threatening the long-term durability of the structure. In one case full depth cracks were due to concrete cube strength considerably exceeding the specified strength for which the crack control reinforcement was designed. Precast units are less likely to exhibit shrinkage cracking because better control during casting ensures a denser and more consistent finish. However, precast units require careful handling to avoid accidental damage during placement.

(b) Differential settlement is likely to occur under high embankments built on soft ground. This may lead to vertical cracking of a buried concrete box structure, which is inherently susceptible to differential ground movements unless it is provided with a sufficient number of adequately spaced movement joints. Insitu concrete box structures constructed with too large a spacing between joints are particularly prone to cracking by differential movements. With both insitu and precast concrete box structures, differential ground movements may also induce failure of the joints between units. Another common problem associated with differential movement is cracking of concrete in wing walls and at the opening of joints between the wing walls and box structure.

(c) Joints between structural units may fail with the joint seal debonding from one or both faces. Commonly, joint failure occurs through relatively modest differential movements between box sections. The deterioration of such joints allows the passage of water through the structure often in preference to the designed drainage routes. This in turn may lead to the concrete adjacent to a joint becoming spalled, with the associated risk of corrosion of the reinforcement. Cast insitu structures have the additional risk of deterioration of the construction joints between roof and side walls or side walls and base.

(d) Waterproofing of a structure may deteriorate allowing ingress of water; evidence suggests that waterproofing systems are most likely to fail in the vicinity of impaired construction joints. Structures with waterproofing membranes on their top slab and with drainage systems behind the side walls perform better than those without such features. Poor detailing on early structures, where the waterproofing membranes did not extend at least 200mm down the sidewalls, as now required by BD 31 (DMRB 2.2.12), may contribute to a breakdown in the waterproofing system. Failure of the drainage system may also lead to a build up of hydrostatic pressure and possible leakage of the waterproofing system (see also Section 4.1(b)).

(e) Detailing faults and poor workmanship during construction may lead to localised deterioration of the structure. The detailing of wing and head walls is sometimes a weak link in the overall design, leading to problems with cracking described above. In some cases the top slab has been damaged by careless installation of parapets and safety fences above the structure. In some instances, the holding down bolts have penetrated through the roof of the structure, thereby allowing the ingress of water. Identification of these problems at an early stage means that remedial work is minimal compared with that required when further deterioration occurs.

Identification of Less Common Defects

2.4 Although the following causes of defects are infrequent, where they do occur they can have a severe effect on the structural integrity so it is important to identify them correctly.

(a) Scour and undercutting of the end elevations may occur with a culvert carrying a watercourse. If scour is allowed to continue, the structure will be undermined.

(b) Mining of coal and other minerals may propagate ground movement in the vicinity of the structure. Information about mining activities should be held on the bridge record file. Because the vertical loads applied to a buried concrete box structure are distributed over its base, early signs of distress will be those associated with severe differential movement. If the structure is in a high-risk area, recent structural designs should have taken the effects of mining subsidence into account: therefore, older structures are most at risk.

(c) Degradation of reinforced concrete may result from chemical reactions between constituents of the cement and the aggregate or between constituents in the concrete and surrounding soils or ground water. Alkali silica reaction is an expansive reaction of the alkali in cement and silica in the aggregate: it can induce extensive cracking of concrete. Other reactions which may occur include the oxidation of reduced sulfur compounds (such as pyrite) in structural backfill to produce the thaumasite form of sulfate attack on buried concrete. Further information of this severe form of sulfate attack is given in BRE Special Digest 1. The presence of chloride ions, derived from de-icing salts, may promote the corrosion of the steel reinforcement. Apart from the latter, cases of deterioration of the concrete in box structures by any of the above mechanisms are few and far between but, where identified, expert advice may need to be sought on appropriate remedial measures.

(d) Cracking through excessive loading might be seen on structures with particularly low depth of cover and which were not designed to carry HB loads. Such cracks might open and close with the passage of particularly heavy vehicles, but the crack may widen with time and its edges might be fretted away by movements or weathering. In such cases expert advice may need to be sought.

Identification of Source of Deterioration

2.5 To ensure that the appropriate maintenance works are planned, costed and undertaken effectively, it is essential to identify the cause of any deterioration. It is particularly important to distinguish between problems of durability and those of structural performance, thus it is essential to identify the source of any cracking.

Recording Data

2.6 The Highways Agency uses Structures Management Information System (SMIS) to record data for all its highway structures. In Scotland for a Principal Inspection a general arrangement should be provided marked up to show where and from which direction photographs of Priority 4 or 3 defects have been taken. Details of the defects are recorded in Trunk Road Bridges Database (TRBDB) in the “Principal Inspections for Maintenance Works Works Prioritisation” reporting system. The following advice is given for those authorities not using SMIS or other prescribed databases.

2.7 Figure 2.1 is the type of diagram that may be used in an inspection report. Areas of deterioration should be highlighted and descriptive notes added to the sketch. The diagram should be backed-up by good quality photographs.

2.8 The amount and type of data to be collected and recorded varies with the type of inspection and the degree of deterioration encountered but, in many cases, an extensive testing regime may not be necessary. The type of data may include some of the following:

- Extent and condition of any exposed reinforcement
- Extent and severity of cracking
- Depth of carbonation
- Depth of penetration of chloride ions
- Areas of seepage, presence of leachates and deposits and their chemical composition
- Extent and location of any areas of permeable concrete
- Soundness of surface – for example using "hammer" tests
- Results of half-cell potential surveys
- Resistivity measurements
- Depth of cover to reinforcements
- Condition of joints and seals.

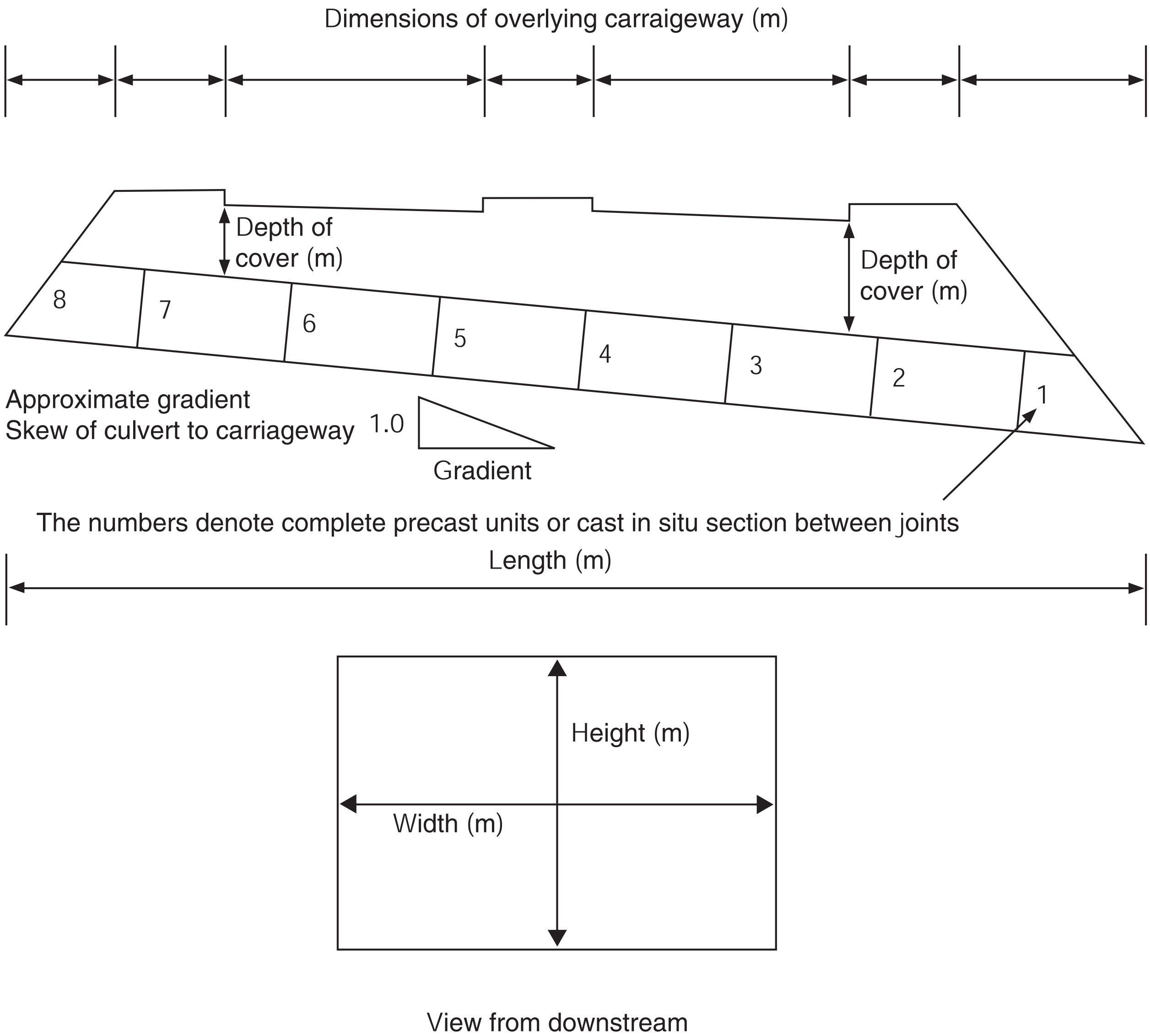

Figure 2.1 Example of a diagram that may be used in an inspection report

NOTE: Not applicable where SMIS is used

3. GUIDANCE ON STRUCTURAL ASSESSMENT

General

3.1 Unless buried concrete box structures are thought to have a reduced load capacity as a result of serious deterioration, foundation deficiency, inadequacy of backfilling material or damage, as determined from inspections, they **shall not be assessed** if they are:

(a) culverts and buried structures of 3 metres span or less with cover of 1 metre or more (see BD 34 (DMRB 3.4) and BD 46 (DMRB 3.4.1));

(b) culverts and buried structures of less than 1.8 metres span (2.0 metres in Scotland) and multi-cell culverts of 5 metres span or less (see BD 34 (DMRB 3.4) and BD 46 (DMRB 3.4.1));

(c) non-masonry culverts or structures which are buried to an extent that highway loading is only of marginal significance when compared with the magnitude of earth pressure and permanent (dead) loads acting on the structure.

Documentation for Assessment

3.2 The assessment of highway structures is covered by a number of documents within the DMRB. These include BD 21 (DMRB 3.4.3), BA 16 (DMRB 3.4.4), BA 55 (DMRB 3.4.9), BD 44 (DMRB 3.4.14) and BA 44 (DMRB 3.4.15). Alkali silica reaction and corrosion in concrete structures are covered in BA 52 (DMRB 3.4.10) and BA 51 (DMRB 3.4.13) respectively. Most of these documents were written primarily for bridge decks and so some of the rules and advice within them are not directly applicable to buried concrete box structures.

3.3 An assessment might be undertaken according to the design standard (i.e. BD 31 (DMRB 2.2.12)) but, as stated in BA 55 (DMRB 3.4.9), the application of unmodified rules given in that standard is likely to underestimate the load-carrying capacity of the structure.

Guidance

3.4 The assessment of the performance of buried structures should follow the recommendations given in BA 55 (DMRB 3.4.9) which advises that **substructures need not be assessed by calculations unless they show evident signs of distress**. If qualitative assessments show up defects which affect load-carrying capacity, then assessment by calculation is normally carried out to the requirements of BD 21 (DMRB 3.4.3) and BD 31 (DMRB 2.2.12). With these calculations, more emphasis is placed on ultimate rather than serviceability limit states and in most cases reductions in the partial factors of safety used for design can be adopted because assessment can be based on known performance and material properties. BA 55 (DMRB 3.4.9) provides guidelines on the amendments that could be made to design rules given in BD 31 (DMRB 2.2.12) to make them more suitable for assessment purposes. These are covered below:

(a) BD 21 (DMRB 3.4.3) is to be used instead of BD 37 (DMRB 1.3). Loads for particular vehicles that use the in-service structure are given in BD 21 Annexes D and E.

(b) The failure of a structural element to meet its serviceability check does not mean that any remedial action is required. Guidance on this is given in BA 34 (DMRB 3.4). BA 34 states that a serviceability failure might affect the management of a structure e.g. the frequency and type of inspections. It also refers to checks on crack widths in concrete. Furthermore, only load combination 1 (from BD 37 (DMRB 1.3)) should be considered unless there are signs of tilting, possibly resulting from braking forces. This seems a reasonable consideration, but note that tilting of a buried concrete box structure is an extremely unlikely event and if any such movements were noticeable under live loading it would be prudent to undertake remedial works as a matter of urgency.

(c) Only the ultimate limit state of the soil should be checked. (The likelihood of any structure failing by sliding on its base or overturning about one of its bottom edges is remote: but where it is suspected to occur see (b) above. Furthermore, although serviceability calculations may not be particularly useful, it could be beneficial to install instrumentation to monitor settlement with time as this might provide some indication of the likelihood of further damage to the concrete box. Although costs of setting up instrumentation, say, may be considered expensive, the benefits gained may avoid the need for costly repair works, which may otherwise have unnecessarily been carried out.)

(d) Where there are signs of movement or tilting of a structure, assessment should be carried out using braking forces and unequal earth pressures. (This is not unreasonable, but such an assessment is likely to be unnecessary, see (b) and (c) above.)

3.5 Additional information to that listed in Section 2.8 is required for assessing structural stability including the following:

- strength of concrete;
- the residual strength of the steel reinforcement, this will entail investigation of the size and properties of the steel reinforcement;
- the depth of cover and the properties of the overburden and surrounding soils.

3.6 **It should be emphasised most strongly that calculations should only be undertaken where a buried concrete box structure shows severe deterioration, evidence of distortion or continuing movement.** Furthermore, it would be more useful to install instruments to monitor movements than undertake calculations (see 3.4 (c) above). Note that rarely will it be necessary to check serviceability conditions by calculation, because this is better assessed visually, i.e. from monitoring or physical surveys of the structure.

4. OPERATIONAL AND MAINTENANCE ISSUES

Operational Issues

4.1 It is best practice to deal with the following, where applicable, on a routine basis to prolong the life of a buried concrete box structure:

(a) Silting of an invert commonly occurs with culverts built on waterlogged ground or where flow rates are low. This makes it difficult to inspect the condition of the invert and hence ensure it remains in good order. Clearance of silt, debris and vegetation using mechanical plant needs to be supervised and carried out with care to avoid damaging the structure.

(b) Drains may become blocked leading to a build up of hydrostatic pressure and possible breakdown of the structure's waterproofing. Pipes and weep holes should be inspected on a regular basis and if found to be blocked they should be cleaned. For buried concrete box structures, which function as either a vehicular access or a pedestrian subway, internal gullies and drainage pipes should be routinely inspected and maintained.

(c) Vandalism may damage the internal fabric of a structure and is usually a local hazard confined to structures where pedestrian access is possible. Superficial damage to lights, fittings, and drainage and by fire are in most cases not structurally significant but their early repair may prevent further deterioration. The effects of graffiti on unprotected concrete does not in itself present other than an aesthetic problem, but the process of cleaning by abrasion or aggressive solvents may cause minor surface damage if inappropriate treatment is used.

(d) Cracking of mortar joints may occur and joint seals can perish. Where this occurs they should be repaired or replaced to prevent deterioration due to the ingress of water or effluent.

Cost Issues for Routine Maintenance

4.2 Currently the annual cost of routine maintenance of buried concrete box structures (less than £1k per annum per structure at 2000 prices) averages out at less than about 1% of the cost of replacing them. This level of maintenance covers both works to repair common defects (where they were of a localised nature) as listed in Sections 2.3 and 2.4, and also to maintain satisfactory operation of the buried concrete box structure as described in Section 4.1. In essence most works consisted of clearing silt and obstructions, unblocking drains and removal of graffiti. The replacement of perished seals and cracked mortar joints was also quite common. In some cases minor repairs with epoxy cements had been made to small areas where spalling had exposed the reinforcement. In some instances where full height cracks had developed due to differential movements, the cracked areas had been broken out all the way around the structure and the gap filled with a sealant; thus effectively creating a movement joint.

4.3 Following the definition presented in CIRIA Report 122 (Ferry and Flanigan, 1991) a buried concrete box structure is an asset that would be categorised within "those with a relatively long life expectancy and low irregular operational and maintenance costs". Because initial capital costs predominate, the small recurrent costs of maintenance fade into insignificance and on this basis regular maintenance is the better option than early replacement of a structure.

Management of More Critical Defects

4.4 BA 55 (DMRB 3.4.9) advises that **buried concrete box structures need not be assessed by calculations unless they show evident signs of distress**. If, however, qualitative assessments show up defects which affect load carrying capacity, then assessment by calculation is normally carried out as described in Section 3.4. With these calculations, more emphasis is placed on ultimate rather than serviceability limit states and in most cases reductions in the partial factors of safety used for design can be adopted because assessment can be based on known performance and material properties. Furthermore, a more detailed method of analysis of the structure may be carried out since this sometimes prevents unnecessary expenditure on the strengthening or replacement of perfectly serviceable structures.

4.5 Tilting of a buried concrete box structure is an extremely unlikely event but if any such movements are noticeable under live loading it would be prudent to undertake remedial works as a matter of urgency.

Cost Issues for More Extensive Renovation

4.6 Where assessment by calculation has shown the buried concrete box structure has a critical defect, a more detailed or advanced method of analysis of the structure may be carried out since this sometimes prevents unnecessary expenditure on the strengthening or replacement of perfectly serviceable structures.

4.7 More extensive renovation may be necessary in a few cases, particularly to older structures constructed at a time when design standards were not so demanding as they are now. Extensive renovation works involving renewal of the soffit or waterproofing system, or strengthening using a reinforced concrete saddle needs careful consideration to determine whether site specific constraints make replacement a more attractive option. Site specific constraints and considerations include the following:

(a) For a culvert, the cost of temporarily diverting the watercourse. For underpasses and subways, alternative routes for vehicular and pedestrian through traffic may be required.

(b) Traffic management and traffic delays: these might be substantial for structures on the trunk road and motorway network.

4.8 The following may also need to be considered:

(a) A number of structures were built without contiguous waterproofing systems and have had such systems installed in the past decade or so. Costs for such works are in the region of £1k per metre run of box (2000 prices): but this does not include the cost of traffic management works.

(b) An alternative is to reline the structure with, for example, a glass reinforced plastic liner. Williams (1998) reports the relining of culverts with a span of up to about 2 metres: costs were about £2k per metre run for relining each of two cells of a culvert at Kenton Road in Brent. In this case significant traffic management and statutory undertakers' costs were avoided.

Management of Environmental Issues

4.9 Where work is to be carried out on the structure, environmental issues such as fish migration and mammal ledges should be given consideration.

4.10 Where the integrity of structural concrete can be adversely affected by urea, animal slurry, diesel spillage etc. sacrificial linings should be given consideration.

5. REFERENCES

BRE Special Digest 1 (2001). Concrete in aggressive ground. Construction Research Communications Ltd, 151 Rosebery Avenue, London EC1R 4GB

British Standards Institution (1978). Steel, concrete and composite bridges. BS 5400: Part 2, Specification for loads. British Standards Institution, London.

Design Manual for Roads and Bridges (DMRB). The Stationery Office, London.

BA 16 The assessment of highway bridges and structures (DMRB 3.4.4)

BA 34 Technical requirements for the assessment and strengthening programme for highway structures. Stage 1 – Older short span bridges and retaining structures (DMRB 3.4)

BA 35 Inspection and repair of concrete highway structures (DMRB 3.3)

BA 44 The assessment of concrete highway bridges and structures (DMRB 3.3)

BA 51 The assessment of concrete structures affected by steel corrosion (DMRB 3.4.13)

BA 52 The assessment of concrete structures affected by alkali silica reaction (DMRB 3.4.10)

BA 55 The assessment of bridge substructures and foundations, retaining walls and buried structures (DMRB 3.4.9)

BA 63 Inspection of highway structures (DMRB 3.1.5)

BD 21 The assessment of highway bridges and structures (DMRB 3.4.3)

BD 27 Materials for the repair of concrete structures (DMRB 3.3)

BD 31 The design of buried concrete box and portal frame structures (DMRB 2.2.12)

BD 34 Technical requirements for the assessment and strengthening programme for highway structures. Stage 1 – Older short span bridges and retaining structures (DMRB 3.4)

BD 37 Loads for Highway Bridges DMRB (1.3)

BD 44 The assessment of concrete highway bridges and structures (DMRB 3.3)

BD 46 Technical requirements for the assessment and strengthening programme for highway structures – stage 2 – modern short span bridges (DMRB 3.4.1)

BD 62 As built, operational and maintenance records for highway structures (DMRB 3.2.1)

BD 63 Inspection of highway structures (DMRB 3.1.4)

Ferry D J O and Flanagan R (1991). Life cycle costing – a radical approach. CIRIA Report 122. Construction Industry Research and Information Association, London.

The Concrete Society (2000). Diagnosis of deterioration in concrete structures – identification of defects, evaluation and development of remedial action. Concrete Society Technical Report 54. The Concrete Society, Crowthorne.

Williams P A (1998). Culvert strengthening. Highways and Transportation Vol 45, No 11, pp19 – 21. Institution of Highways and Transportation.

6. ENQUIRIES

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

Divisional Director Safety, Standards and Research Division Highways Agency 5 Broadway Birmingham B5 1BL	J PEARMAN Divisional Director

Chief Road Engineer Scottish Executive Victoria Quay Edinburgh EH6 6QQ	J HOWISON Chief Road Engineer

Chief Highway Engineer Transport Directorate Welsh Assembly Government Llywodraeth Cynulliad Cymru Crown Buildings Cardiff CF10 3NQ	M J A PARKER Chief Highway Engineer Transport Directorate

Assistant Director of Engineering The Department for Regional Development Roads Service Clarence Court 10-18 Adelaide Street Belfast BT2 8GB	D O'HAGAN Assistant Director of Engineering