Design Manual for Roads and Bridges

Highway Structures & Bridges
Inspection & Assessment

CS 460
Management of corrugated steel buried structures

(formerly BA 87/04)

Version 1.0.1

Summary
This document details the management requirements for corrugated steel buried structures.

Feedback and Enquiries
Users of this document are encouraged to raise any enquiries and/or provide feedback on the content and usage of this document to the dedicated National Highways team. The online feedback form for all enquiries and feedback can be accessed at: www.standardsforhighways.co.uk/feedback.

This is a controlled document.

Latest release notes

Document code	Version number	Date of publication of relevant change	Changes made to	Type of change
CS 460	1.0.**1**	April 2023	Core document	Incremental change to notes and editorial updates

Version 1.0.1; Published: April 2023] An error was identified in clause 1.3 which references CG 303. This corrected to CD 375.

Previous versions

Document code	Version number	Date of publication of relevant change	Changes made to	Type of change
CS 460	1	March 2020		
CS 460	0	June 2018		

Foreword

Publishing information

This document is published by National Highways.

This document supersedes BA 87/04, which is withdrawn.

Content on assessment has been moved to the revision of CS 459 [Ref 17.N].

Contractual and legal considerations

This document forms part of the works specification. It does not purport to include all the necessary provisions of a contract. Users are responsible for applying all appropriate documents applicable to their contract.

Corrugated steel buried structures (CSBS) are proprietary manufactured structures. The design and contractual procedures provided in CG 300 [Ref 16.N] apply.

Introduction

Background

This document details the management requirements for corrugated steel buried structures (CSBS).

A large number of CSBS act as culverts and underpasses below carriageways on the UK highway network. These structures require systematic management to ensure that they will achieve their design life. Further information on the identification and determination of the physical properties of CSBS that have commonly been installed in the UK is provided in Appendix A.

Assumptions made in the preparation of this document

The assumptions made in GG 101 [Ref 6.N] apply to this document.

Mutual recognition

Where there is a requirement in this document for compliance with any part of a British Standard or other technical specification, that requirement may be met by compliance with the Mutual recognition clause in GG 101 [Ref 6.N].

Abbreviations

Abbreviations

Abbreviation	Definition
AASHTO	American Association of State Highway and Transportation Officials
CIRIA	Construction Industry Research and Information Association
CSBS	Corrugated steel buried structure(s)
DMRB	Design Manual for Roads and Bridges
GRP	Glass reinforced plastic
MCHW	Manual of Contract Documents for Highway Works
NG for SHW	Notes for guidance on the Specification for Highway Works
SHW	Specification for Highway Works

Terms and definitions

Terms

Term	Definition
Structure	The combination of connected parts that form the Corrugated Steel Buried Structure (CSBS) and the surrounding fill.

1. Scope

Aspects covered

1.1 This document shall be used to determine the requirements for the management of corrugated steel buried structures (CSBS), with spans greater than or equal to 0.9 m and up to 8.0 m, including the inspections necessary to identify, plan and then undertake appropriate maintenance and repair work.

NOTE Inspection and maintenance works will have an increasing role in ensuring that ageing CSBS on the UK network remain in service.

Relevant documents

1.2 The following related DMRB documents shall be used in combination with this document:

1) CS 459 [Ref 17.N] 'The assessment of bridge substructures and foundations, retaining walls and buried structures';
2) CS 450 [Ref 5.N] 'Inspection of highway structures';
3) CM 431 [Ref 7.N] 'Maintenance painting of steelwork';
4) CG 302 [Ref 1.N] 'As built, operational and maintenance records for highway structures'; and,
5) CG 303 [Ref 15.N]'Quality assurance scheme for paints and similar protective coatings'.

1.3 CD 375 [Ref 4.N]shall be used for the design of corrugated steel buried structures.

1.4 The following parts of the Specification for Highway Works MCHW SHW [Specify Series] [Ref 9.N] and the accompanying Notes for Guidance MCHW NG [Specify] [Ref 8.N] shall be referred to, as necessary:

1) MCHW Series 1900 [Ref 10.N] for protection of steelwork against corrosion, including procedures for treatment.
2) MCHW Series 2500 [Ref 12.N] for specific CSBS requirements such as earthworks, steel and concrete components and drainage.
3) MCHW Series 5000 [Ref 11.N] for maintenance painting of steelwork.

Implementation

1.5 This document shall be implemented forthwith on all schemes involving management of corrugated steel buried structures on the Overseeing Organisations' motorway and all-purpose trunk roads according to the implementation requirements of GG 101 [Ref 6.N].

Health and safety

1.6 Where inspections or maintenance works involve working in confined spaces, the Confined Spaces Regulations UKSI 1997/1713 [Ref 18.N] must be followed.

1.7 The Health and Safety Executive (HSE) confined working space guidelines HSE INDG258 [Ref 3.N] shall be followed.

1.8 The requirements of GG 105 [Ref 2.N] shall be complied with in all asbestos management activities.

1.9 As part of the maintenance regime the structure's asbestos register shall be reviewed prior to undertaking any intrusive work on site.

1.10 If a structure is encountered which is presumed, known to, or has been identified as containing asbestos in the galvanising (or any other part of the structure) and which does not have an asbestos register or survey, then the survey shall be carried out and the register created.

Use of GG 101

1.11 The requirements contained in GG 101 [Ref 6.N] shall be followed in respect of activities covered by this document.

2. Inspection

Purpose

2.1 Corrugated steel buried structures (CSBS) shall be inspected to identify and record the integrity and condition of the structure and its components.

2.2 The inspection shall provide information on both the severity and extent of any change in the structure as originally installed, or last inspected, both from a structural and material perspective.

2.3 The results of the inspection shall be used to inform the management of the structure.

2.3.1 The results of an inspection should be used to specify the type and timing of further interventions to the structure.

NOTE 1 Interventions can include further inspections, maintenance, repair or upgrading works.

NOTE 2 CS 470 [Ref 12.I] provides requirements on the management of sub-standard highway structures.

2.4 The condition of ancillary structures (for example, headwalls and wing walls) shall be inspected where they might affect the function of the CSBS.

Assessment

2.5 A structural assessment shall be undertaken where the results of an inspection raise concerns over the stability and safety of the structure, for example:

1) excessive deviation from the as-built cross-section;
2) reduction in thickness of the steel shell; or,
3) where bolts are severely corroded.

2.5.1 The results of an inspection should be used to complete a structural assessment, as per the requirements of CS 459 [Ref 17.N].

Types of inspection

2.6 The four main categories of inspection (General, Principal, Special and Safety) as defined in CS 450 [Ref 5.N] shall be undertaken in accordance with the frequency requirements of CS 450.

NOTE Acceptance Inspections are required to identify and record any work that is outstanding under a contract and to agree which items of work need to be completed before the Overseeing Organisation takes over the ultimate responsibility for maintaining the structure.

Inspection records

2.7 The following information shall be recorded prior to the start of the inspection:

1) structure reference;
2) structure location;
3) grid reference;
4) date and type of inspection; and,
5) maintenance since last inspection, if known.

NOTE The structure reference can be the structure key and number.

2.8 The results of all inspections shall be recorded in the relevant asset data management system of the Overseeing Organisation.

2.8.1 The results of all inspections should be presented in a format that identifies the critical factors and allows easy comparison between reports.

NOTE The procedures and requirements for reporting can vary according to the category of inspection and, to some extent, on the findings of the inspection.

2.8.2 A detailed written report should be completed for Principal and Special Inspections.

2.9 The report shall include good quality colour photographs to record areas of substantial structural or material deterioration, with a record of the location and dimensions of the deterioration.

Inspection requirements

2.10 The items listed in Table 2.10 shall be inspected as part of General and Principal Inspections.

Table 2.10 Main inspection requirements

Item	Inspection requirements
General	Type of structure and manufacturer (where known) - see note 1.
Geometry	All key dimensions defining the geometry along the length of the structure, including the span, height, an estimate of the gradient and the skew relative to the carriageway.
Structural condition	General condition, alignment, cross-sectional shape, the integrity of joints and seams, signs of separation, longitudinal settlement and existence of reverse curvature.
Material condition	Where accessible, measurement of thickness of protective coatings, invert pavings and residual thickness of steel, along with a description of material integrity and the effects of corrosion.
Backfill condition	General description, noting presence of voids either around the structure or surface depressions, and including build-up of fines.
Aggressivity of the environment	Visual signs of aggressivity or contamination within the backfill, water in the culvert and groundwater, noting requirement for any measurements that may be required.
Note 1. The manufacturer of the structure can sometimes be identified through the bolt head markings.	

2.11 The ancillary structures listed in Table 2.11 shall be inspected as part of General and Principal Inspections.

Table 2.11 Inspection requirements for ancillary structures

Item	Inspection requirements
Aprons and headwalls	General statement on condition and whether or not the aprons and headwalls are fulfilling their function (for example, if the apron is still preventing water flowing through the backfill along the outside of the structure).
Concrete relieving slabs	Identification of any signs of settlement under leading or trailing edges and potential for voids forming under slabs.
Parapets and handrails	General statement of condition.
Embankments	Identification of any signs of instability which could affect the performance of the structure.
Drainage of embankment and carriageway	General statement of condition, identification of any likely problem areas such as broken gullies in the overlying carriageway.
Road surfacing	General statement of condition, identification of any problem areas such as settlement troughs and cracking adjacent to the structure.
Catch pits, drop inlets, trash screens, protective gates	General statement of condition and assessment of efficiency and requirement for cleaning.

2.12 The additional items listed in Table 2.12 shall be inspected as part of Principal and Special Inspections.

Table 2.12 Additional requirements for Principal and Special Inspections

Item	Inspection requirements
Steel	General statement on condition and, at Special Inspections, the intact thickness; condition around bolt holes and edges of seams; locations of deterioration and minimum residual thickness.
Galvanising	General statement on condition, and thickness where sound; locations of deterioration, and severity of deterioration.
Secondary coatings	General statement on condition, and thickness where sound; locations of deterioration, and severity of deterioration.
Invert paving	General descriptive statement; details of condition along the structure, whether it is unworn, worn but still providing protection to the structure, or, worn and shell exposed.

2.13 The defects listed in Table 2.13 shall be checked for as part of all inspections.

Table 2.13 Defects to be checked

Cause / defect	Appearance
Scour	In unpaved structures, coatings may be damaged along the invert, which may lead to the removal of galvanising below the water level followed by corrosion of the steel substrate.
Corrosion from leachate	Loss of galvanising and corrosion of steel substrate. Normally at the crown and springing line of a structure, appearing initially on the crests of the corrugations. Substantial corrosion of the invert can lead to large inward movements. Seepage of leachates can appear as white deposits around bolts and seams.
Washout of backfill	Backfill washed out through corroded sections. In extreme situations this can lead to large ground movements.
Voids in backfill	Stockpiles of fines in the invert.
Wet/dry cycles	Deterioration of coatings, which can be particularly noticeable in structures carrying little or no flow where coatings can be removed in a narrow band along the whole length of the structure.
Abnormal or excessive water flow	Damage to the coatings above the invert paving. Deposition of debris blocking the waterway leading to overtopping of the road. Turbulence in the stream, particularly at the inlet.
Damage to bitumen pavings	Deterioration at the ends of a pipe, particularly at bevelled ends. Cracking in bitumen. Broken invert paving.
Settlement	Cracking of buckling of the steel. Overtopping if containing water.
Impact	Broken or damaged invert pavings. Dents or impact damage to steel plates.
Atmospheric pollution	Deterioration of coatings.
Aggressive backfill (see note 1)	General corrosion or pitting corrosion.
Note 1. Aggressive backfill environments are outside the scope of CD 375 [Ref 4.N] for design of CSBS.	

NOTE 1 *The appearance and occurrence of defects can be more severe in structures that have not been provided with secondary protective coatings.*

NOTE 2 *Inspection requirements relate to accessible areas and do not allow for inspection of external surfaces, which could be more critical.*

2.14 Where distortion of the structure has occurred, the cause of distortion shall be determined.

2.14.1 Table 2.14.1 should be reviewed when determining the cause of distortion.

Table 2.14.1 Causes of distortion

Distortion category	Cause of distortion
Deterioration of structure	Structure not maintained properly and allowed to deteriorate to the extent that this leads to distortion.
Large ground movements	The depth or properties of the subsoil vary substantially; excavation has removed the lateral support to a structure; subsidence from mining works.
Poor construction practice	Poor quality backfill has been used; compaction has been inadequate; uneven loading occurred during compaction operations.
Uneven loading during use	Difference in the level of the embankment on either side of the structure; the applied highway loads vary along a structure.

Steel and coatings

2.15 The thickness of steel and secondary coatings (where present) shall be measured during a Special Inspection.

NOTE 1 Measurements of steel and coating thickness can also be made during Principal or General Inspections, for example, to assess the need for a more detailed inspection.

NOTE 2 When measuring the thickness of secondary coatings, the reading will generally be the combined thickness of the galvanising and secondary coatings. An adjustment can be made to account for the thickness of zinc, which is usually small compared with the thickness of the other coatings.

2.16 Core samples of steel shall be taken at Special Inspections when it is considered necessary to examine the condition of the coatings on the soil side.

2.16.1 Where corrosion is promoted by the ingress of leachates, core samples should be taken 150 mm above and below the points of major seepage.

2.17 Where exposed, the thickness of galvanising shall be measured during a Special Inspection.

2.17.1 The measuring device should be capable of providing a measurement of the distance between the face of the probe and the steel substrate.

Water and backfill

2.18 In exceptional circumstances where the findings of a Special Inspection recommend it, measurements of the water passing through the structure shall be obtained.

NOTE 1 Water measurements can include the variation in velocity, depth and chemical content of the water passing through a structure.

NOTE 2 Depending on the level of detail required, measurements can be taken at discrete time intervals or through the use of monitoring sensors.

NOTE 3 Further information can be found in BD 97 [Ref 18.I].

2.19 In exceptional circumstances, where the findings of a Special Inspection recommend it, samples of the backfill shall be obtained and tested.

2.19.1 Where testing suggests there is a risk to the structure, the backfill and external surfaces should be investigated further, with approval of the Overseeing Organisation.

NOTE Samples of backfill can be obtained from test pits at the ends of a structure or from boreholes along the line of a structure.

3. Maintenance

General

3.1 Maintenance of corrugated steel buried structures (CSBS) shall be undertaken where it is recommended based on the results of inspections and assessments.

NOTE 1 Timely preventative maintenance has proven itself to be the most economical means of extending the service life of a structure.

NOTE 2 Maintenance interventions for CSBS generally involve either refurbishment or structural strengthening.

NOTE 3 Further guidance on maintenance for typical deterioration mechanisms is given in Appendix B.

Change in hydraulic efficiency

3.2 The hydraulic efficiency of the structure shall be reviewed where it is altered as a result of installing a new lining or a new invert paving.

NOTE 1 Guidance on calculating hydraulic efficiency is given in the CIRIA C689 [Ref 2.I].

NOTE 2 Hydraulic actions on structures is covered by CD 356 [Ref 5.I].

Refurbishment

3.3 Refurbishment shall be undertaken in accordance with the relevant documents listed in Section 1, as well as BS EN ISO 8501-1 [Ref 14.N], and BS EN ISO 8501-2 [Ref 13.N]

3.3.1 The integrity of the sectional thickness should be verified (for example, by non-destructive testing or by coring) before undertaking refurbishment on old structures, which might have been subjected to corrosion on the external/soil side.

NOTE 1 The most common form of maintenance is the refurbishment of protective coatings and pavings.

NOTE 2 Where possible, the conditions that have caused the need for refurbishment need to be separated from the structure.

Surface preparation

3.4 Steel surfaces shall be cleaned and prepared prior to the application of secondary protective coatings.

3.4.1 Surfaces should be prepared to one of the following standards: clean steel, Sa2, bright steel or St3, as defined in MCHW Series 5000 [Ref 11.N].

3.4.2 Where it is not feasible to prepare the surface to the standards listed in clause 3.4.1, the surface should be abraded to remove all loose rust before applying a bitumen coating.

3.4.3 Where additional refurbishment or structural work is to be undertaken (for example, the installation of a new invert paving), surfaces that do not show signs of corrosion do not need to be prepared in accordance with MCHW Series 5000 [Ref 11.N], but should be cleared from detrimental contamination.

3.4.4 The preparation of galvanised coatings should be undertaken in accordance with the guidance in Table 3.4.4.

Table 3.4.4 Preparation of galvanised surfaces

Condition of galvanised coating	Preparation
Intact	Dry or wet cleaning.
Corroded in localised areas	Mechanical cleaning by abrading.
Corroded in large areas (or entirely) and steel substrate has corroded	Abrasive blast cleaning to remove corrosion products.

NOTE MCHW Series 5000 [Ref 11.N] includes requirements on all the preparation techniques described in Table 3.4.4.

Secondary coatings

3.5 Selection of primer and an associated top coat shall be based on consideration of the following:

1) standard of surface preparation to be achieved;
2) choice of top coat;
3) required life of the coating;
4) presence of moisture;
5) ambient temperature; and,
6) proof of the compatibility of coatings and primers for the appropriate service condition.

3.6 The quality assurance requirements within DMRB CG 303 [Ref 15.N] shall be used for all generic types of primer, paint and protective coatings.

NOTE 1 Appendix A of CG 303 contains Item Sheets for each generic type of coating.

NOTE 2 Maintenance of secondary coatings is likely to be a more significant issue in older structures. Structures predating the introduction of BD 12 in 1982 are unlikely to have been provided with sacrificial steel thicknesses on their inaccessible surfaces.

3.7 Where a bitumen coating is used, the finished thickness shall exceed 200 µm.

3.7.1 A coating of thixotropic bitumen may be suitable for refurbishing bituminous coatings.

3.8 The refurbishment of bituminous coatings shall include the removal of all areas of loose and brittle bitumen and the cleaning of the exposed galvanised surface.

3.8.1 The use of primer coats to the new bitumen coating will not normally be necessary for a weathered zinc surface, but a bright zinc surface should be passivated with a mordant wash, such as T wash.

3.9 For more extensive refurbishment, the use of secondary protective coatings other than bitumen-based products shall be assessed.

3.9.1 The alternatives to bitumen-based coatings listed in Table 3.9.1 may be used for culverts and underpasses.

Table 3.9.1 Alternatives to bitumen-based coatings

Structure type	Description
Culvert	The application of a suitable moisture-tolerant primer (for example, zinc phosphate epoxy blast primer), followed by a coal tar epoxy-based product having a total thickness in excess of 200 µm.
Underpass	The use of a zinc phosphate primer plus a high-build epoxy undercoat followed by a finishing coat of acrylic urethane; the use of a moisture-cured undercoat and a moisture-cured polyurethane finish.

NOTE For underpasses, it might be necessary for aesthetic reasons, to consider the coating of the entire interior rather than just the area in need of refurbishment.

Repair of invert pavings

3.10 Where minor damage has occurred to existing invert pavings, repair work shall be undertaken.

3.10.1 The repair of in-situ concrete pavings may be carried out using conventional repair techniques to the existing concrete, or by installing new profiled units.

NOTE New mass concrete, coated steel sheets or glass reinforced plastic (GRP) profiled units could be a simpler and more effective solution, especially where deterioration has occurred across the entire width of paving.

3.10.2 The on-site refurbishment of a factory-applied bitumen paving may be undertaken using a bitumen mix of similar specification, where the mix is heated on site and trowelled into place MCHW Series 5000 [Ref 11.N] for example, by implementing AASHTO M190 [Ref 1.I].

NOTE There is little experience in the UK of this technique. Its effectiveness is dependent upon the control exercised on the temperature of the heated repair material and the proper preparation of a clean and dry surface.

New invert pavings

3.11 Where serious deterioration has occurred, the installation of a new paving shall be undertaken.

3.12 All corroded areas shall be treated prior to placing a new paving.

3.13 The requirements of CD 375 [Ref 4.N] and MCHW Series 2500 [Ref 12.N] shall be complied with for the installation of new invert paving.

3.13.1 For more demanding service conditions a reinforced concrete paving (or similar) should be constructed.

NOTE 1 Raising the sides of the existing paving can enhance the structure.

NOTE 2 Peak water flow conditions can be estimated using CD 356 [Ref 5.I].

NOTE 3 In smaller span structures where the conditions of abrasion and flow are not severe, the use of unreinforced concrete (hand trowelled into place) can be effective.

Structural strengthening

3.14 Structures that have been assessed to have insufficient strength shall be strengthened in accordance with this document.

3.14.1 One or more of the following options for strengthening should be implemented:

1) structural invert paving;
2) relining;
3) grouting voids.

NOTE *Some useful information on techniques for enhancing structural stability are provided in the following references:*

1) *Abel-Seyad et al 1993 [Ref 15.I].*
2) *California Department of Transportation manual on culvert restoration techniques CALTRANS 1993 [Ref 4.I].*
3) *Culvert repair practices manual by Ballinger & Drake [Ref 3.I].*
4) *Alexander et al 1994 [Ref 14.I].*
5) *SETRA T3997 (1992) [Ref 13.I].*

3.15 Technical Approval procedures in CG 300 [Ref 16.N] shall be followed.

Structural invert paving

3.16 The requirements of CD 375 [Ref 4.N] and MCHW Series 2500 [Ref 12.N] shall be complied with for the installation of new structural invert paving.

3.16.1 A reinforced concrete invert paving may be provided as a strengthening element where the upper portion of the structure is sound but where the invert has deteriorated to such an extent that it fails structural assessment.

3.17 The structural paving and the connection to the shell of the CSBS shall be designed to resist the ring compression force as determined using CD 375 [Ref 4.N].

NOTE *The shear key between the paving and the structure can be provided through the use of suitable steel connectors either fixed through or welded to the plates, or in bolted structures by providing extensions to the bolts used to join the plates.*

3.17.1 Where shear connectors are welded directly to the structure, the metal surface coating should be reinstated after the welding operations, using either zinc-rich paint or cold galvanising.

3.17.2 Welding should not be used where it can adversely impact the coating on the external/soil side.

Lining

3.18 Lining shall be undertaken using one of the techniques described in Table 3.18.

Table 3.18 Options for relining a structure

Liner material	Notes
Spirally wound corrugated pipes	Sections may be winched or jacked through the existing structure. To improve hydraulic efficiency the lining may be provided with a paving. Use is limited to circular profiles with span of up to 3 m.
Plastic pipes	Such pipes have good hydraulic characteristics but they have limited strength and may be relatively expensive. Use is limited to circular profiles with a span of up to approximately 3 m diameter. They should not be used where they are susceptible to vandalism.
GRP units	These units are shaped to fit the profile of the structure and are easy to place and have excellent hydraulic characteristics. Their wall thickness can be varied to suit.
Bolted corrugated plates	Versatile size and shape. For arches, the lining may be jacked or winched along the bottom of the structure and then lifted into position by jacks. Generally only suitable where short lengths are to be lined since the product is designed to be assembled from the outside.
Steel liners	These are designed for use in tunnels and provide the simplest and most suitable means of lining larger CSBS with limited areas of deterioration. The plates are flanged and of a size that may be handled manually and all bolting is done from the inside. They may be manufactured to fit any profile. Steel liners are typically applicable for diameters or spans greater than 1.2 m.
Concrete liners	Precast reinforced concrete sections may be used to line larger diameter structures, particularly those with structural pavings. Sprayed concrete might also be applied to all or part of larger span structures, with the steel shell acting as the formwork. Requires careful planning and site trials may be needed to prove practicality of proposed solution.

NOTE 1 The cross-sectional area, shape and length of the structure to be lined can limit the choice of suitable materials, but other constraints include the existence of connections with ancillary structures.

NOTE 2 Some liners can be pre-assembled external to the structure and dragged or slipped into the existing structure.

3.18.1 Rigid liners may be used but it is preferable to use flexible liners since CSBS are designed as flexible structures.

3.18.2 Provision should be made for:

1) guide rails along which the liner can be dragged;
2) spacers or adjuster bolts to ensure that a sufficient annular space is maintained between the liner and the structure;
3) grout plugs around the periphery of the liner and at the crown at approximately 1.0 to 1.5 m centres.

3.19 The annular space between the structure and liner shall be grouted in place, avoiding flotation of the liner during the operation.

Grouting voids

3.20 Grouting of voids within the backfill shall be carried out where the need has been identified to enhance the stability of a structure.

3.20.1 Low injection pressures should be employed to avoid disturbance to any surrounding structures, services and the overlying carriageway.

3.20.2 Where water is seeping into the structure or flowing through joints into the backfill, an expanding water reactive grout may be used to provide a waterproof barrier.

NOTE Guidance on grouting is given in the CIRIA C514 [Ref 8.I] and BS EN 445 [Ref 7.I], BS EN 446 [Ref 6.I] and BS EN 447 [Ref 9.I].

3.21 Preventative steps shall be taken to ensure the grout does not pollute existing watercourses or penetrate drains and service ducts.

3.21.1 The Environment Agency and product manufacturers should be consulted on the suitability of grouts used adjacent to watercourses.

Other improvements

3.22 One or more of the following features shall be provided for water carrying structures, where the need has been identified:

1) drop inlets for rapid flows;
2) trash screens to remove solids; and,
3) mammal ledges and fish migration.

3.22.1 The design of these features should include consideration of the effects of their installation, for example, the effect on scour or the need for clearance above flood levels.

4. Indicators for management of maintenance works

General

4.1 The risk of a total or partial collapse shall be assessed when prioritising maintenance work.

4.1.1 The safety of road users and CSBS users (where relevant) should be reviewed when assessing the consequences of collapse.

4.1.2 Decisions on the management of and prioritisation should assess consequences of failure on the operation of the highway network.

4.1.3 The decision for undertaking maintenance work should be assessed based on the cost, the lifetime of the repair and the higher cost of delaying maintenance work or replacing the structure.

NOTE Further inspections or monitoring can be useful to obtain further information prior to committing funds for substantial maintenance works.

4.2 Serviceability issues (reduction in the level of service) shall be reviewed when prioritising maintenance work. Examples for serviceability issues include:

1) where longitudinal differential settlement of a culvert leads to silting up of the invert, which in turn could lead to flooding upstream; and,
2) where the breakdown of joint seals leads to seepage into an underpass and the subsequent ponding of water on the paving; this may produce a dangerous surface particularly in cold weather.

4.3 Economic issues (expensive future maintenance) shall be reviewed when prioritising maintenance work. Examples of economic issues include:

1) where a paving in a culvert has disintegrated to the point where the underlying metal is exposed to erosive and corrosive effects. In most cases the cost of repairing a paving is much less than repairing a badly corroded invert; and,
2) where the secondary coating has corroded to the point that the galvanised steel is exposed to corrosive effects. In most cases the cost of repairing a secondary coating is much less than the cost of repairing a badly corroded galvanised steel shell.

NOTE Further information on deterioration of in-service CSBS is given in Appendix B.

Structural instability

4.4 The indicators listed in Table 4.4 shall be used to assess the priority of repair work.

Table 4.4 Indicators of structural repair work and recommended actions

Indicator	Action	Notes
Bolt failure	This is potentially a catastrophic mode of failure and investigations should be undertaken urgently. Immediate strengthening around the area of a failed bolt should be a priority.	The loss of bolts through corrosion should not be confused with bolts omitted during construction. Not all bolt holes in a CSBS will necessarily need a bolt.
Reverse curvature	Urgent repair work required	Most likely to occur soon after construction. Where reverse curvature has occurred in the invert, mass concrete may be appropriate to repair the structure.
Deflection under live loads	Urgent repair work required	Any noticeable deflection generated by the passage of live load over a structure is a clear indicator that the structure is either not strong enough or it has inadequate support from the ground.
Tearing or shearing at bolt holes, local buckling, separation of joints or seams	Urgent repair work required	All these mechanisms are usually definitive evidence that the shell of the structure is overstressed.
Excessive deviation from cross section	A structural assessment should be undertaken immediately to assess whether or not priority repair work is required. Where distortion was introduced at the construction stage but the in-service structure seems stable, it may be beneficial to monitor deformation over a given time.	Maximum acceptable deviation from the nominal cross section: closed invert, circular = 5% closed invert, multi-radii = 3% circular arch = 3% Excessive deflection can occur due to poor construction practice.
Presence of voids in the backfill	The presence of voids should be investigated as a matter or urgency. This might be identified by stockpiles of fines in the invert or by tapping the steel shell to detect 'hollow' areas. Ground penetrating radar may be used.	There are a number of mechanisms by which voids could form in and around the CSBS. Voids may be formed by wash out of material around the connection of side access gullies.

NOTE 1 *These indicators of structural instability are rarely seen, as a consequence of good practice in manufacturing and installation, along with robust requirements for durability.*

NOTE 2 *Some indicators only occur during or soon after construction, but can potentially develop due to the onset of corrosion, washout of backfill or as a result of other changes.*

Material condition

4.5 The indicators listed in Table 4.5 shall be used to assess the priority for maintenance work and the recommended action to be taken.

Table 4.5 Indicators of material condition and recommended actions

Indicator	Action	Notes
Seam corrosion	This is potentially a catastrophic mode of failure. Immediate repair work should be undertaken where the corrosion is particularly severe.	This is often found in multi-plate structures. Once initiated, the local rate of corrosion due to seepage of aggressive water can be particularly high.
Deterioration of paving	Immediate repair work should be undertaken where the invert is substantially perforated or where water flows beneath the invert. This should be a priority where paving was designed to provide structural support to the CSBS.	A paving should be repaired before it reaches a condition that it requires complete replacement. Where possible, maintenance and repair work should be undertaken where the paving contains minimal flow.
Reduction in cross section of the steel shell	A structural assessment should be undertaken and immediate repair work carried out where results of the analysis show the structure is unsafe.	The assessment should be based on the worst deteriorated section of the CSBS, but strengthening works might only be required at a particular cross section of the CSBS as the stability would not be compromised by some limited perforation of the steel shell.
Deterioration of ancillary structures	Repair should be undertaken where the deterioration of ancillary structures allow the flow of water outside a culvert.	Trash screens, drop inlets and catch pits should be maintained to ensure that they continue to operate as designed, and where they do not fulfil their function they should be repaired.
Corrosion of bolts	A structural assessment should be undertaken where there is heavy corrosion of bolts. Repair should be carried out where the effective strength of a bolt is <75% of its nominal strength.	It is likely that corrosion would be more critical around a bolt hole than a bolt.
Loss of secondary coating	Undertake an economic assessment for completing repair work.	Maintenance work should be undertaken where the secondary coating has been removed over a continuous length or substantial area of a CSBS.
Seepage	Undertake an economic assessment for completing repair work.	Seepage is commonly linked with corrosion of bolts and seams. There might be over-riding service requirements for reducing or eliminating seepage into the structure.

5. Normative references

The following documents, in whole or in part, are normative references for this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

Ref.	Document
Ref 1.N	National Highways. CG 302, 'As-built, operational and maintenance records for highway structures'
Ref 2.N	National Highways. GG 105, 'Asbestos management'
Ref 3.N	HSE Books, 2013. Health & Safety Executive. HSE INDG258, 'Confined space. A brief guide to working safely'
Ref 4.N	National Highways. CD 375, 'Design of corrugated steel buried structures'
Ref 5.N	National Highways. CS 450, 'Inspection of highway structures'
Ref 6.N	National Highways. GG 101, 'Introduction to the Design Manual for Roads and Bridges'
Ref 7.N	National Highways. CM 431, 'Maintenance painting of steelwork'
Ref 8.N	Highways England. MCHW NG [Specify], 'Manual of Contract Documents for Highway Works Volume 2: Notes for Guidance on the Specification for Highway Works'
Ref 9.N	Highways England. MCHW SHW [Specify Series], 'Manual of Contract Documents for Highway Works, Volume 1 Specification for Highway Works '
Ref 10.N	Highways England. MCHW Series 1900, 'Manual of Contract Documents for Highway Works, Volume 1 Specification of Highways Works, Series 1900, Protection of Steelwork against Corrosion'
Ref 11.N	Highways England. MCHW Series 5000, 'Manual of Contract Documents for Highway Works, Volume 1 Specification of Highways Works, Series 5000, Maintenance painting of steelwork'
Ref 12.N	Highways England. MCHW Series 2500, 'Manual of Contract Documents for Highway Works. Volume 1 - Specification for Highway Works. Series 2500 Special Structures'
Ref 13.N	BSI. BS EN ISO 8501-2, 'Preparation of steel substrates before application of paints and related products. Visual assessment of surface cleanliness. Preparation grades of previously coated steel substrates after localised removal of previous coatings','
Ref 14.N	BSI. BS EN ISO 8501-1, 'Preparation of steel substrates before application of paints and related products. Visual assessment of surface cleanliness. Rust grades and preparation grades of uncoated steel substrates and of steel substrates after removal of previous coatings'
Ref 15.N	National Highways. CG 303, 'Quality assurance scheme for paints and similar protective coatings'
Ref 16.N	National Highways. CG 300, 'Technical approval of highway structures'
Ref 17.N	National Highways. CS 459, 'The assessment of bridge substructures and retaining structures and buried structures'
Ref 18.N	The National Archives. legislation.gov.uk. UKSI 1997/1713, 'The Confined Spaces Regulations 1997'

6. Informative references

The following documents are informative references for this document and provide supporting information.

Ref.	Document
Ref 1.I	American Association of State Highway and Transportation Officals (AASHTO). AASHTO M190, 'Bituminous coated corrugated metal culvert pipe and arches'
Ref 2.I	CIRIA, 2010. Balkem et al. CIRIA C689, 'Culvert design and operation guide'
Ref 3.I	Federal Highway Administration (USE - FHWA), 1995. Ballinger CA & Drake PG. Ballinger & Drake, 'Culvert repair practices manual: vol I - final report, & vol II - appendices'
Ref 4.I	California Department of Transportation (CALTRANS), 1993. CALTRANS 1993, 'Culvert restoration techniques'
Ref 5.I	National Highways. CD 356, 'Design of highway structures for hydraulic action'
Ref 6.I	BSI. BS EN 446, 'Grout for prestressing tendons. Grouting procedure'
Ref 7.I	BSI. BS EN 445, 'Grout for prestressing tendons. Test methods'
Ref 8.I	CIRIA, 2000. CIRIA C514, 'Grouting for ground engineering'
Ref 9.I	BSI. BS EN 447, 'Grouting for prestressing tendons. Basic requirements'
Ref 10.I	American Iron and Steel Institute (AISI), USA, 1993. AISI Handbook, 'Handbook of the American Iron and Steel Institute'
Ref 11.I	Transportation Research Board, National Academy of Sciences, USA, 1984. Ikerd, Stephen R. Ikerd 1984, 'Invert replacement of corrugated metal structural plate pipe, Symp. on Durability of Culverts and Storm Drains'
Ref 12.I	National Highways. CS 470, 'Management of sub-standard highway structures'
Ref 13.I	TRL Ltd (English translation), 1992. SETRA. T3997 (1992), 'Metal culverts: guide for specialised surveillance, maintenance and repair'
Ref 14.I	Sate of Maine Dept of Transportation, Technical Services Div, USA, 1994. Alexander JA, Sandford TC & Seshadri A.. Alexander et al 1994, 'Rehabilitation of large diameter steel culverts''
Ref 15.I	McGraw-Hill, 1993. Abdel-Seyad G, Bakht B & Jaeger LG. Abel-Seyad et al 1993, 'Soil-Steel Bridges'
Ref 16.I	American Association if State Highway and Transportation Officials (AASHTO). AASHTO M36, 'Standard Specification for Corrugated Steel Pipe, Metallic-Coated, for Sewers and Drains'
Ref 17.I	American Association of State Highway and Transportation Officials (AASHTO), USA, 1998. AASHTO M167, 'Standard Specification for Structural Plate for Pipe, Pipe-Arches, and Arches'
Ref 18.I	Highways England. BD 97, 'The Assessment of Scour and Other Hydraulic Actions at Highway Structures'

Appendix A. CSBS in the UK

This Appendix provides information on the identification and determination of the physical properties of CSBS that have commonly been installed in the UK.

The information given in Figure A.1 and Tables A.1 to A.2 is intended to help identify the characteristics of a CSBS but, wherever possible, reference should be made to the product acceptance scheme.

A1 Product types

A1.1 Prefabricated pipes

A1.1.1 Riveted pipes

A relevant number of existing structures are formed from riveted pipes, comprising curved corrugated sheets riveted together at a factory, in lengths up to 20 feet (6.1 m) and in diameters up to 6 feet (1.8 m). However, such pipes have been superseded by helically wound pipes.

A1.1.2 Helically wound pipes

Factory-made helically wound pipes, which incorporate a lock seam instead of rivets, are typically used in lengths of 6 m and in diameters of up to 3 m. Manufacturer's trade names include Hel-cor and Helibore pipe. Consecutive lengths of helically wound pipes are typically joined using coupling bands.

A1.2 Bolted segmental CSBS

Bolted segmental CSBS are constructed from structural plates assembled on site to form round pipes, and multi-radial and arch structures. Trade names include Multiplate MP200 and T200. Larger sizes are available, although spans in excess of 8 m are relatively uncommon on the UK trunk road and motorway network.

A2 History

The first CSBS was installed in the UK in 1914 beneath a railway at Hastings. Further installations were infrequent until the 1930s when an American company (ARMCO) started to promote their products in the UK. The structures installed then were of relatively small diameter and imported from the USA.

In the mid to late 1940s, some bolted segmental structures were installed using war surplus material. In the 1950s, ARMCO built a factory at Newport, Gwent and following commissioning of the plant, the (then) Ministry of Transport was approached for approval for a range of products.

In 1955, approval was given for the installation of CSBS of up to 4.5 m diameter on all classes of highway. The Ministry accepted the use of the American Association of State Highway and Transportation Officials (AASHTO) specifications for all products including bitumen secondary protective coatings and invert pavings. These included the AASHTO M36 [Ref 16.I], AASHTO M167 [Ref 17.I] and AASHTO M190 [Ref 1.I] standards which at the time were the only widely accepted specifications covering the use of CSBS for highways. All CSBS were galvanised with a hot-dip zinc coating and in the UK the relevant standards covering steel manufacture and galvanising were used.

The manufacturer's recommendations for bolted segmental structures included the installation of concrete paving having a minimum thickness of 50 mm. At that time the Ministry did not make coatings or invert pavings obligatory, but they were actively promoted by ARMCO and, indeed, were used on the majority of installations in the UK.

ARMCO remained the principal supplier of CSBS until the 1980s when a number of European manufacturers entered the UK market. These included Tubosider UK Ltd who set up a production facility in Warrington. Other manufacturers trading in the UK included an Italian-based company, Arc Sipra SRL, and a Swedish-based company, Galvan Fabrikan.

In the mid-1980s ARMCO sold its European-based manufacturing plants as single national companies. In the UK, ASSET International Ltd purchased the Newport plant; Hamco Dinslaken Bausysteme GmbH the Dinslaken plant in Germany; and Finsider took over the ARMCO operation in Italy.

In the 1990s ASSET International Ltd, Tubosider UK Ltd, Arc Sipra SRL, and Hamco Dinslaken Bausysteme GmbH obtained Department of Transport Type Approval Certificates for their CSBS systems.

The first major motorway project where CSBS were installed in quantity was during the early 1960's for the Lydiate Ash to Quinton section of the M5. Another early motorway project was the Trans-Pennine section of the M62.

Motorways on which CSBS have been installed include the following: A1M, M1, M10, M11, M18, M180, M19, M20, M23, M25, M3, M4, M40, M42, M55, M56, M6, M69, M74, and M8. CSBS have also been installed on many dual- and single-carriageway roads.

The span of a considerable number of CSBS on the network is less than 4 m, however it is not uncommon to find larger-span structures and, although exceptional, structures with spans of up to 12 m have been installed.

A3 Design documents

In 1982, the Department of Transport (DTp) issued its first design standard, now CD 375 [Ref 4.N], covering CSBS along with an accompanying Advice Note (BA 12). Durability requirements were addressed in these documents and a design life of 120 years was to be achieved through a combination of:

1) an approved secondary coating;
2) a zinc coating;
3) a layer of sacrificial steel; and
4) a paving to protect the invert of culverts.

The service life of the secondary coatings, and the rate of deterioration of the galvanising and sacrificial steel were all based on the in-service environmental conditions. Sacrificial steel was mandatory except for the interior surface of pipes which were classified as accessible and therefore deemed to be maintainable.

The BD 12/82 document was applicable to bolted segmental and helically wound corrugated steel structures having spans ranging from 0.9 to 7.0 m for circular and pipe arch profile structures, and from 2.0 to 7.5 m for underpass profile structures. Underpass profile structures and pipe arch profile structures, are both bolted segmental structures and for this reason from the 1995 edition of the BD 12 they were combined together as multi-radii structures.

BD 12 was revised and reissued in 1989 and the scope of that standard was largely as defined in the 1982 issue except that now the span of structures ranged from 0.9 to 8.0m for circular and pipe arch structures, and 2.0 to 8.0 m for underpass profile structures.

After 1989, BD 12 was revised again in 1995 and 2001, and again the scope was largely the same as before but the categories of structure covered changed; specific mention of underpass profile structures was removed, but these documents now covered circular arch structures on concrete footings having re-entrant angles between 10° and 30°. The span of structures ranged from 0.9 to 8.0m for circular and multi-radii structures, and from 2.0 to 8.0 m for circular arch structures. In 2018 a further revision of BD 12 aligned the technical content to the Eurocodes' approach to design, without changing the structural types involved.

In the 1989, 1995, 2001 and 2018 versions of BD 12, there were no accompanying advice notes.

Circular arch structures had been constructed on the UK highway network up until the advent of the 1982 edition of BD 12: previously, they were most often used as flood relief structures.

In BD 12 editions successive to the 1982 document, efforts were made to improve the durability of the structures. The need for improvement was evident from the performance of in-service CSBS. Structures installed prior to the introduction of BD 12 in 1982 were not designed with any sacrificial steel and despite the wide use of secondary coatings, some installations predating 1982 did not fully comply with current durability requirements, and still do not nowadays. All post 1982 structures can be assumed to have a sacrificial steel thickness on inaccessible surfaces, but this might not be the case for internal accessible surfaces deemed to be maintainable.

The 1989, 1995 and 2001 editions of BD 12 required British Board of Agrément (BBA) certification of the multi-plate and helically wound construction systems (the certificates cover aspects affecting durability, such as coatings and invert pavings). Relevant certificates were:

1) ASSET International Ltd - BBA Certificates 90/R055 and 91/R059 ; coatings and invert pavings were based on the AASHTO M190 [Ref 1.I] standard;
2) Tubosider Ltd - BBA Certificate No. 91/R062; coatings were based on Monoguard and invert pavings on the AASHTO M190 [Ref 1.I] standard.

A4 Coatings and pavings

Since the 1950s hot-dip bitumen coatings and pavings conforming to the AASHTO M190 [Ref 1.I]standard have been used (the 1976 version of the standard was adopted by the 1982 edition of BD 12). Until recently ASSET International Ltd (following their predecessors ARMCO) used the AASHTO M190 standard for bitumen coatings for all their structures and also for invert pavings in their helically wound product as indeed did Tubosider Ltd in their helically wound product.

The AASHTO M190 standard requires, as a minimum, a bitumen paving to cover 25 % of the circumference of a circular structure and 40 % of a multi-radii structure.

Hot-dip bitumen applied in accordance with the AASHTO M190 standard is normally 1.3 mm thick, whilst CG 303 [Ref 15.N] for cold-applied material required a 700 µm thickness. However, older bituminous and coal-tar coatings have been applied in situ in 100 to 200 µm thick layers.

As an alternative, also cold-applied bitumen-based coatings have been used by ARMCO, and subsequently ASSET International Ltd, applying coatings such as Trumble 5X and Bitumastic 50. Even if cold-applied bitumen coatings provided a hard wearing coating with a better abrasion resistance than hot-dip bitumen coatings to the M190 standard, they have since been withdrawn.

During the 1950s and 60s a few structures were installed in which the field-applied coating could contain asbestos fibres. Subsequently, a product called Intex was used as a field-applied coating and also to refurbish damaged or worn areas on CSBS with hot-dip bitumen coatings to the M190 standard.

In the 1980s, Tubosider Ltd introduced a cold-applied modified bitumen-based protective coating called Monoguard, which was produced by Laybond Products Ltd. This was used on their helically wound product in conjunction with a bitumen paving.

Other coating systems which were used occasionally in the UK include:

1) epoxy coatings like the factory applied coating supplied by Hamco Dinslaken Bausysteme GmbH; and,
2) PVC (polyvinyl chloride)-based plastisol coatings. Helically wound products used in Holland and parts of Germany are now commonly formed from plastisol coated steel, which is manufactured by Bergschenhoek BV in Zevenbergen, Holland.

Both the hot-dip bitumen coating and paving used by ASSET International Ltd and the Monoguard coating and bitumen paving used by Tubosider had BBA Roads and Bridges Certificates. However, following the introduction of the 1995 edition of BD 12, which did not require the application of a secondary protective coating, both manufacturers (in most cases) relied solely on the life of the sacrificial steel and zinc coating to provide an adequate service life for their products. The 2001 edition of BD 12 required secondary protective coatings to be applied to each face. The 2018 edition, required a sacrificial steel thickness applied to each face, but only suggests galvanising and/or secondary coating. In addition, where galvanising and/or secondary coating are applied, they can be taken into account for the design life of the structure only if protected.

Concrete pavings of 50 mm thickness (above the crest of the corrugation) were also recommended by ARMCO and this was adopted in the 1982 edition of BD 12. The subsequent editions of BD 12 increased the thickness of the concrete paving to a maximum of 170 mm under high flow conditions where waterborne solids exceed 100 mm in size. The rules governing concrete strength, reinforcement size and layout, depths of cover, and the requirements for construction joints were given in each edition of BD 12. A concrete paving to the specification given in BD 12 was the only alternative to a hot-dip bitumen paving, although the 1982 version of BA12 provided some alternative ideas for invert protection.

A5 Data

A5.1 Rivets

Table A.1 provides a brief description of the arrangement of riveted pipes formed with corrugated steel plates, generally found in the UK. In addition, the longitudinal seams of these pipes, were riveted using the following arrangement:

1) for pipes with diameter less than 42"(< 1 m) 2 no. rivets per corrugation.
2) For pipes with diameter larger than 42 in., four rivets per corrugation.

Table A.1 Typical dimension of riveted CSBS pipes in the UK

Corrugated steel plate dimensions, mm (Imperial units)	Plate thickness, mm (Imperial units)	Rivet type, mm (Imperial units)
68 x 13 (2 1/3 in. x 1/2')	1.5 and 2.0 (0.064 in. an 0.079 in.)	7.9 cold driven (5/10 in.)
	2.7; 3.5; 4.2 0.109 in.; 0.138 in.; 0.168 in.)	9.5 (3/8 in.)

A5.2 Bolts

CSBS formed from bolted segmental plates utilised either grade 8.8 or 10.9 steel bolts. These high tensile steel bolts were used to ensure that the seams failed through distortion and tearing of the plates around the bolts rather than through bolt failure.

Different configurations of bolt, nut and washer have been used. In some configurations, washers were placed below the nuts and bolt heads to prevent damage to coatings during assembly.

The heads of the bolts, could also be shaped to fit the profile of the corrugation. In this way the tightening of the nuts and bolts was facilitated, and could be performed from the inside of structure without access to the soil side.

Later structures used 'Euro' bolts, where the bolt heads were designed to grip the plates to allow torquing without access to the soil side: this facilitated rapid assembly as well as improving seam strength. The nuts to 'Euro' bolts incorporate a profiled flange shaped to provide close contact with the structural plates and to reduce damage to coatings. Where nuts of this type are found in a structure this typically indicates that it was assembled with 'Euro' bolts.

Figure A.1 Typical profiles of CSBS commonly installed in the UK

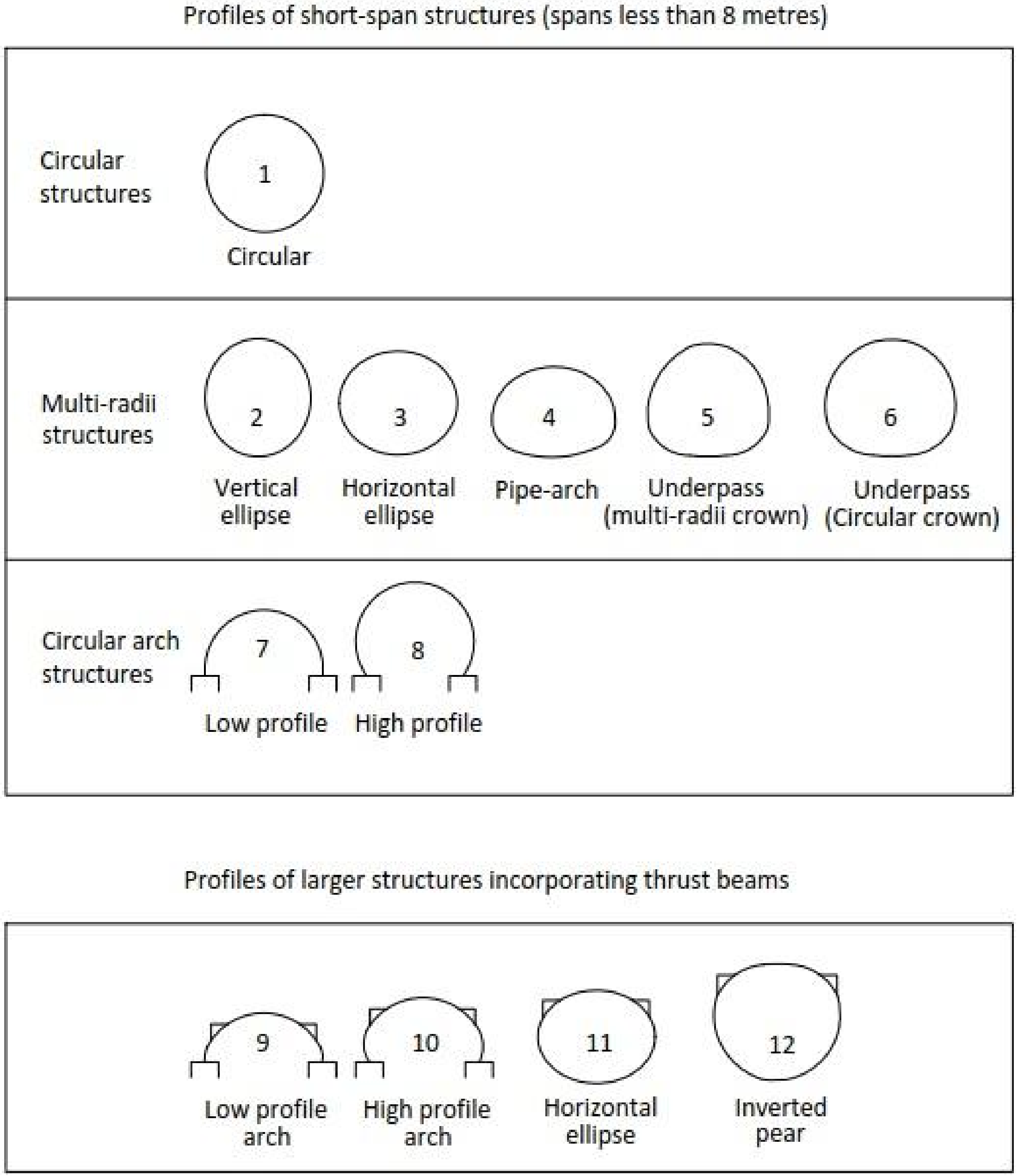


Figure A.2 Terminology related to surrounding fill and soil

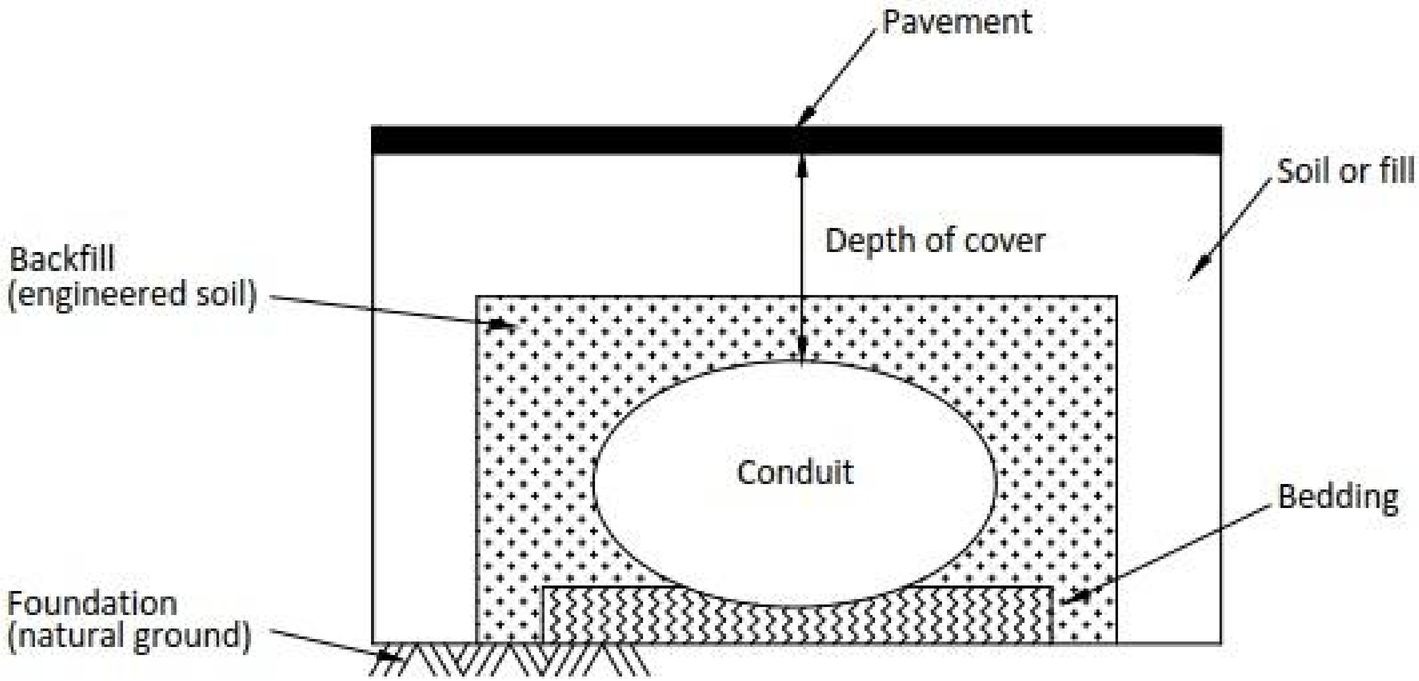


Figure A.3 Terminology relating to the cross section of closed invert structures

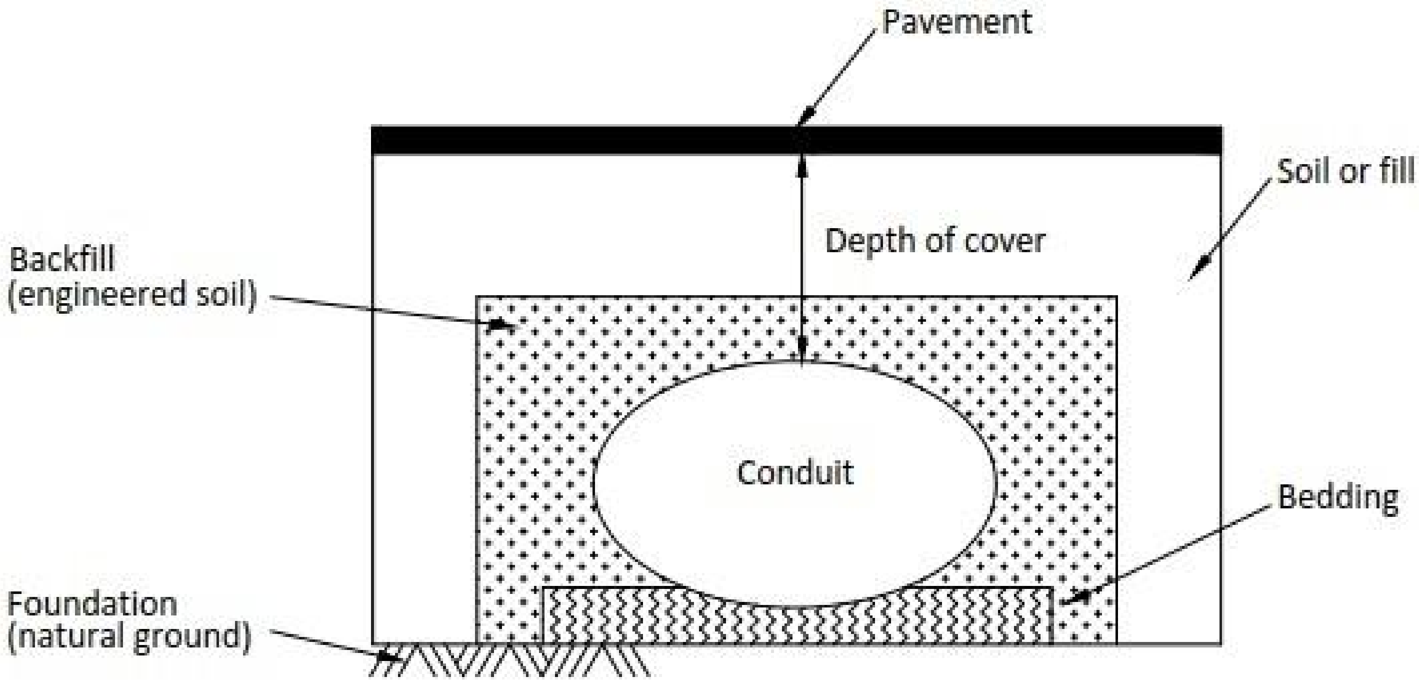


Figure A.4 Terminology relating to the cross section of arch structures

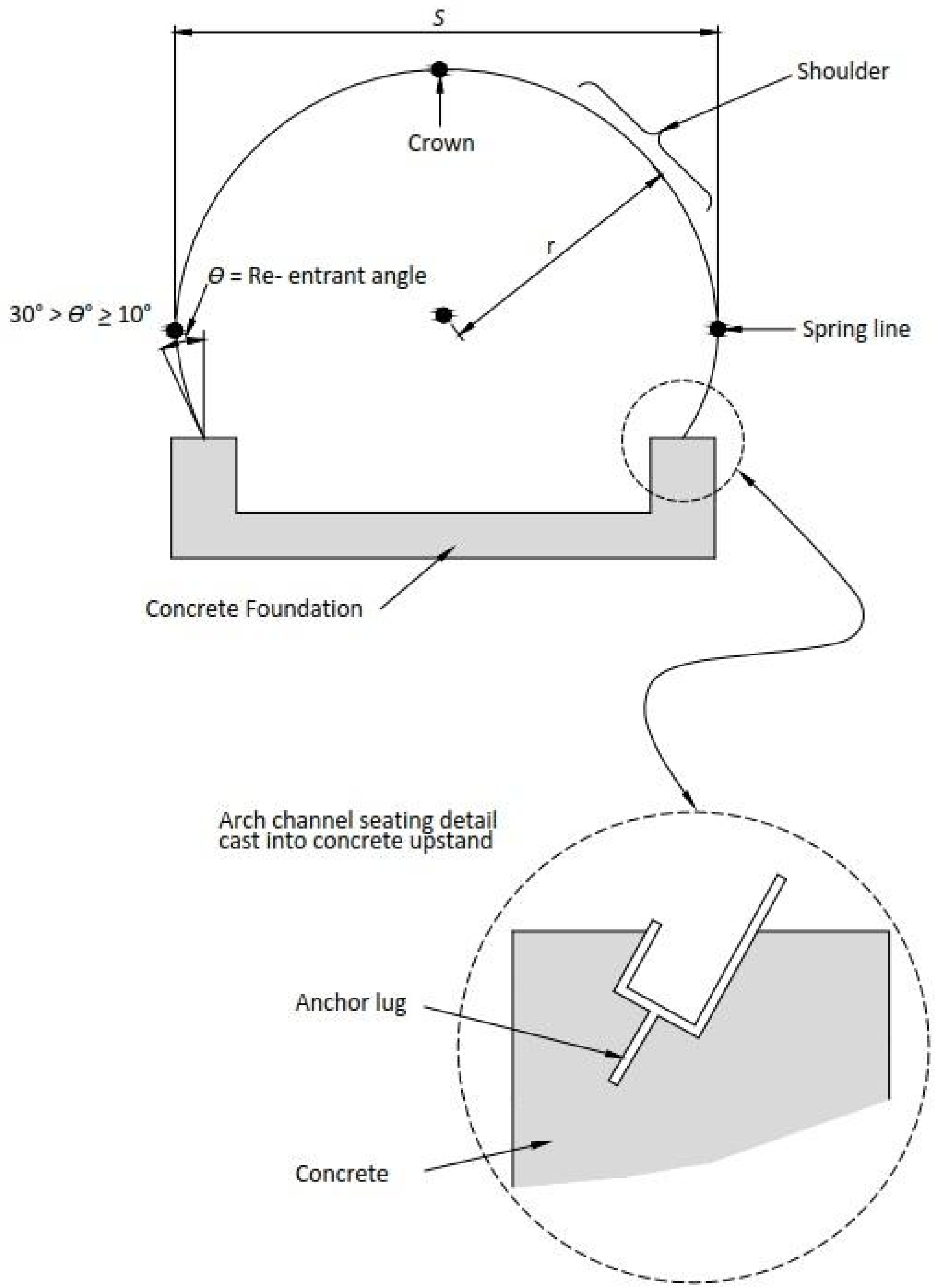


Figure A.5 Terminology relating to the corrugation profile

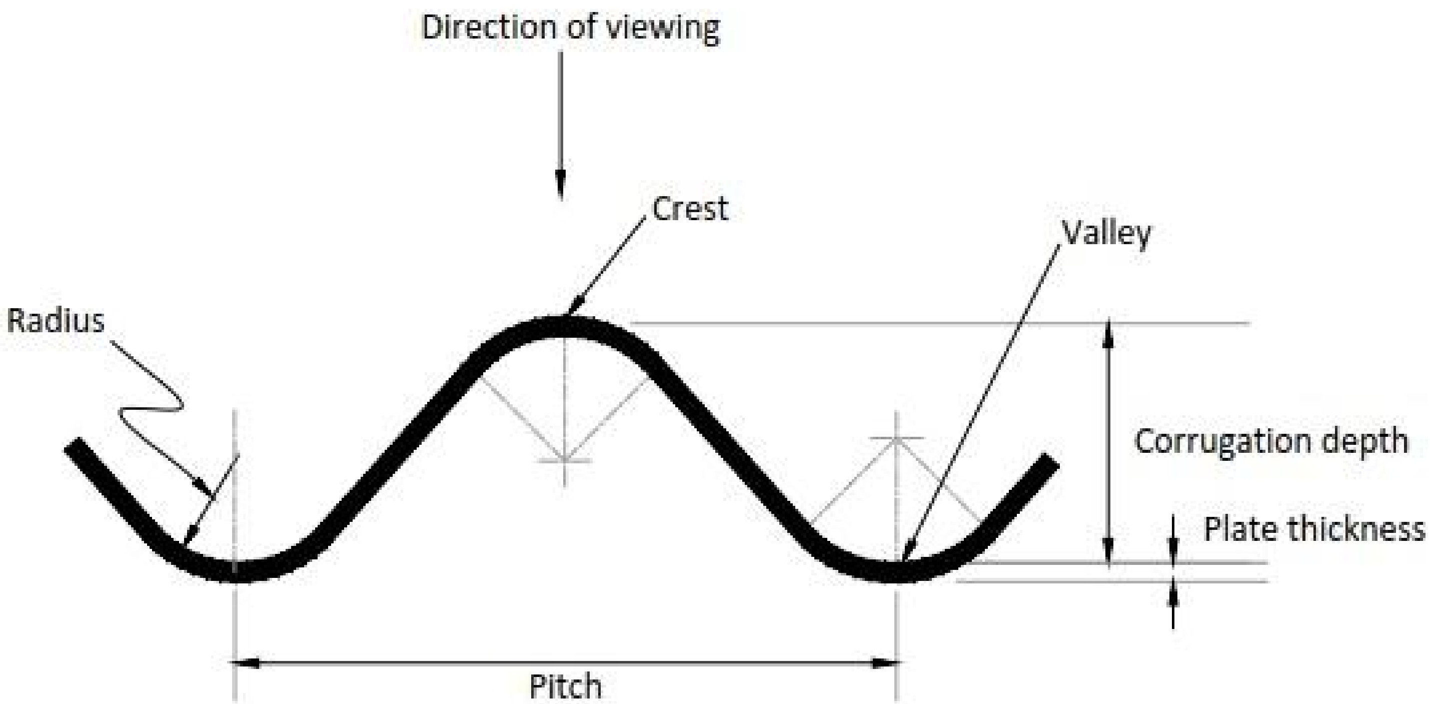


Table A.2 Identification of common types of CSBS

Corrugation size mm (Imperial units)	Approximate range of spans metres (Imperial units)	Thickness range of steel plate mm (Gauge size)	Shape (see Figure A1)
Riveted - prefabricated 20 ft (6.0 m) standard lengths			
68 x 13* (2 2/3 in. x 2 in.)	0.9 - 1.8 (36 in.- 72)	1.5, 1.9 ,2.7 ,3.4, 4.2 (16, 14, 12, 10, 8 gauge)	1 & 4
Spirally corrugated lock seam - normally supplied in 6.0 m lengths			
68 x 13	0.9 - 1.2	1.5, 2.0, 2.5, 3.0, 3.5	1
100 x 20	0.9 - 3.0	1.5, 2.0, 2.5, 3.0, 3.5	1
125 x 25	1.2 - 3.6	1.5, 2.0, 2.5, 3.0, 3.5	1
Bolted			
68 x 13	0.9 - 2.0	1.5, 2.0, 2.7, 3.5	1 & 4
100 x 20	0.9 - 3.0	1.5, 2.0, 2.5, 3.0, 3.5	1 & 4
100 x 22	0.9. - 3.6	1.5, 2.0, 2.5, 3.0, 3.5	1 & 4
152 x 32	1.2 - 3.5	2.0, 3.0, 4.0	1 & 4
152 x 51* (6 in. x 2 in.)	1.5 - 7.0 (5 ft - 24 ft)	2.7, 3.5, 4.2, 4.7, 5.5, 6.2, 7.0, (12, 10, 8, 7, 5, 3, 1 gauge)	1 - 7, 9 - 12
200 x 55	3.5 - 12.0	2.75, 3.25, 4.0, 4.75, 5.5, 6.25, 7.0, 7.75, 8.0	1 - 12
Note: * Denotes product originally manufactured to Imperial dimensions			

In Table A.2 the gauge thicknesses are based on the US Standard Gage for Sheet and Plate Iron and Steel (Black) as established by Act of Congress, July 1, 1893 (with revisions, 1945). The metric values provided above are the nominal thickness of ungalvanised steel plate as produced in the UK. Wrought iron plates will be thicker than steel plate for an equivalent gauge thickness. A more exact conversion from the US Standards Gage to the metric equivalent for both galvanised and ungalvanised steel plate is provided in the handbook of the American Iron and Steel Institute 1993 AISI Handbook [Ref 10.I].

Seam strengths quoted in Tables A.3, A.4 and A.5 are derived from Type Approval Certificates (DTp, 1991 to 1996) or where appropriate manufacturers' literature is available. Where a product has been produced by more than one manufacturer then the lowest seam strength value has been quoted.

Table A.3 Data for CSBS commonly installed in the UK

Corrugation size mm (Imperial size)	Thickness mm (Gauge size)	Area of section mm^2/m	Moment of inertia mm^4/mm		Nominal seam strengths kN/m		
68 x 13 (2 2/3 in. x 2 in.) Connection types: M12 bolts: 5/16" rivets on 16_{Ga} and 14_{Ga}: 3/4-in. rivets on 12_{Ga} to 8_{Ga}					1.5 bolts /corr	2 rivets /corr	4 rivets /corr
	1.5 (16_{Ga})	1620	31		173	244	315
	1.9 (14_{Ga})	2160	41		249	266	435
	2.7 (12_{Ga})	2917	57		466	342	683
	3.5 (10_{Ga})	3783	76		573	358	715
	4.2 (8_{Ga})	4515	94		-	374	749
100 x 20				*	1 bolt /corr	1.5 bolts /corr	2 bolts /corr
	1.5	1641	80	S	-	336 (M14)	437 (M14)
				A	227 (M16)	-	425 (M16)
	2	2188	107	S	-	488 (M14)	622 (M14)
				A	261 (M16)	-	472 (M16)
	2.5	2736	135	S	-	609 (M14)	779 (M14)
				A	323 (M16)	-	602 (M16)
	3	3284	164	S	-	760 (M14)	985 (M14)
				A	486 (M16)	-	888 (M16)
	3.5	3832	193	S	-	962 (M16)	1281 (M14)

Table A.3 Data for CSBS commonly installed in the UK (continued)

Corrugation size mm (Imperial size)	Thickness mm (Gauge size)	Area of section mm^2/m	Moment of inertia mm^4/mm	Nominal seam strengths kN/m		
100 x 22				1.5 bolts /corr	2 bolts /corr	
Connection type: M14 bolt; Grade 8.8	1.5	1660	91	330	430	-
	2	2210	123	530	690	-
	2.5	2770	153	734	952	-
	3	3320	186	765	1038	-
	3.5	3880	219	938	1220	-

Note: * Products of the following manufacturers:

1) S ArcSipra SRL (formerly ARMCO Finsider)
2) A ASSET International Ltd (formerly ARMCO).

Table A.4 Data for CSBS commonly installed in the UK

Corrugation size mm (Imperial size)	Thickness mm (Gauge size)	Area of section mm^2/m	Moment of inertia mm^4/mm	Nominal seam strengths kN/m	
125 x 25	1.5	1660	143	This corrugation only currently available in spirally corrugated lock seam pipe.	
	2	2210	191		
	2.5	2760	240		
	3	3320	289		
	3.5	3875	337		
152 x 32 Connection type: M16 bolt				3 bolts /corr	4 bolts /corr
	2	2210	281	568	710
	3	3317	425	961	1272
	4	4424	573	1375	1830
152 x 51 (6 in. x 2 in.) Connection type: M19 bolt; Grade 8.8 up to 4.7m span, and Grade 10.9 up to 7.0m span. Note: Imperial product, but produced as an equivalent metric product by Arc Sipra SRL				2 bolts /corr	4 bolts /corr
	2.7 (12_{Ga})	3348	1007	890	-
	3.5 (10_{Ga})	4343	1313	1232	-
	4.2 (8_{Ga})	5215	1585	1609	-
	4.7 (7_{Ga})	5838	1782	1689	-
	5.5 (5_{Ga})	6836	2101	1994	2944
	6.2 (3_{Ga})	7711	2385	2204	3540
	7.0 (1_{Ga})	8711	2715	-	3664

Table A.5 Data for CSBS commonly installed in the UK

Corrugation size mm	Thickness mm	Area of section mm^2/m	Moment of inertia mm^4/mm	Nominal seam strengths kN/m			
				*	2 bolts /corr	3 bolts /corr	4 bolts /corr
200 x 55 Connection type: M20 bolts: Grade 8.8 or 10.9	2.75	3248	1242	A	582	657	719
				T	517	684	-
				H	-	774	937
	3.25	3840	1471	A	752	819	934
				T	680	822	-
				H	-	1029	1278
	4	4729	1819	A	961	1264	1368
				T	900	1241	-
				H	-	1214	1479
	4.75	5618	2171	A	1255	1428	1874
				T	1248	1688	-
				H	-	1515	1870
	5.5	6509	2526	A	-	1872	2221
				T	1454	1991	-
				H	-	1876	4717
	6.25	7401	2866	A	-	2049	2479
				T	1562	2237	2930
				H	-	2113	2673
	7	8293	3251	A	-	-	2859
				T	1706	2387	2911
				H	-	-	3105
	8	9490	3745	T	1789	2388	3166

Note: * Products of the following manufacturers:

1) A ASSET International Ltd (formerly ARMCO).
2) T Tubosider United Kingdom Ltd.
3) H Hamco Dinslaken Bausysteme GmbH.

Appendix B. Deterioration of in-service CSBS

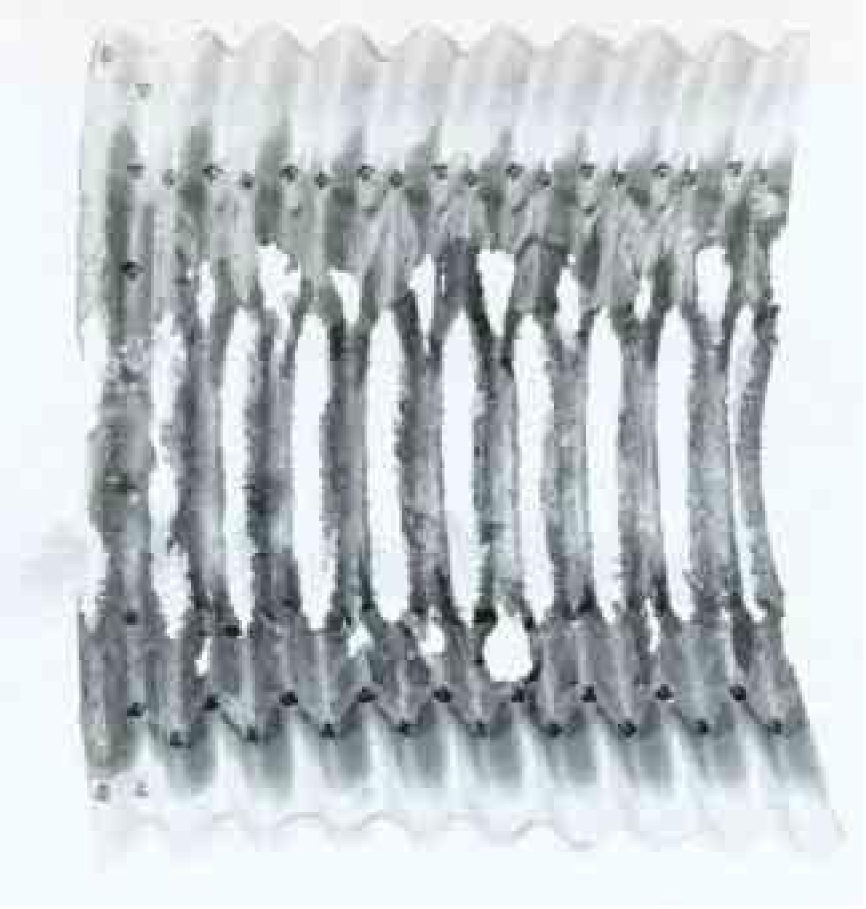
This Appendix covers the common types of deterioration seen in CSBS in the UK and describes methods of refurbishing deteriorated structures. It also provides some examples of structures exhibiting typical forms of deterioration.

B1 Invert scour

Scour can occur in CSBS used as culverts, that do not have a paving and are subject to flows of water where the velocity is sufficient to carry sand, gravel and stones through them, potentially causing extensive deterioration of the invert of a CSBS. The scouring due to waterborne debris can also remove or damage the protective coatings to the steel, exposing it to rapid corrosion.

Figure B1 shows the deterioration in the invert of a 1.8 m-diameter CSBS. This structure was subsequently replaced with a larger diameter helically wound corrugated-steel pipe incorporating a reinforced concrete paving. If the deterioration had been less severe it might have been possible to install a reinforced concrete structural paving.

Figure B.1 Example of extreme corrosion in the invert of a structure subject to scour (this 30 year old structure was not provided with a paving or bitumen coating)



For CSBS subject to scour, invert pavings should be maintained as required and should have a sufficient extent to contain the stream during peak flow conditions.

The invert of larger span structures can be buried under a natural stream bed, and thus difficult to inspect. Peak water flows can scour this natural bed causing deterioration to the buried surfaces, and this might not be seen during an inspection.

A number of helically wound and riveted structures were constructed with a bitumen invert paving or in situ-reinforced or mass concrete pavings.

If there is significant metal loss which causes the structure to fail the assessment, a structural paving in accordance with CD 375 [Ref 4.N] can be installed, provided that the upper part of the CSBS is in a sound condition.

Even if the structure passes its assessment, it may still be more economical to provide a concrete invert paving where it is difficult to achieve the required refurbishment for corrosion protection. A procedure for installing a non-structural reinforced concrete paving is as follows:

1) Refurbish the surface of the steel plates to the 'Clean Steel' or 'Sa2' classification given in MCHW Series 5000 [Ref 11.N] by blast cleaning;
2) Coat the steel plates with cold-applied bitumen;
3) Place the reinforced concrete paving to the requirements of CD 375 [Ref 4.N];
4) Shape the top edge of paving to prevent ponding of water against the wall of the CSBS;
5) Seal the top edge of invert paving by coating the interface between the steel plates and concrete paving with a cold-applied bitumen paint.

B2 Overtopping of the invert paving

A common problem is that the invert paving is not high enough to protect the structural plates. Causes of this problem include:

1) turbulent flow due to the poor alignment of the structure with the existing water course, and;
2) a reduction in invert paving level due to differential settlement along the line of the CSBS.

A poor alignment might arise from the intention to keep the length of the structure to a minimum.

Deterioration may arise through scour by the action of debris carried by the water and by frequent wetting and drying.

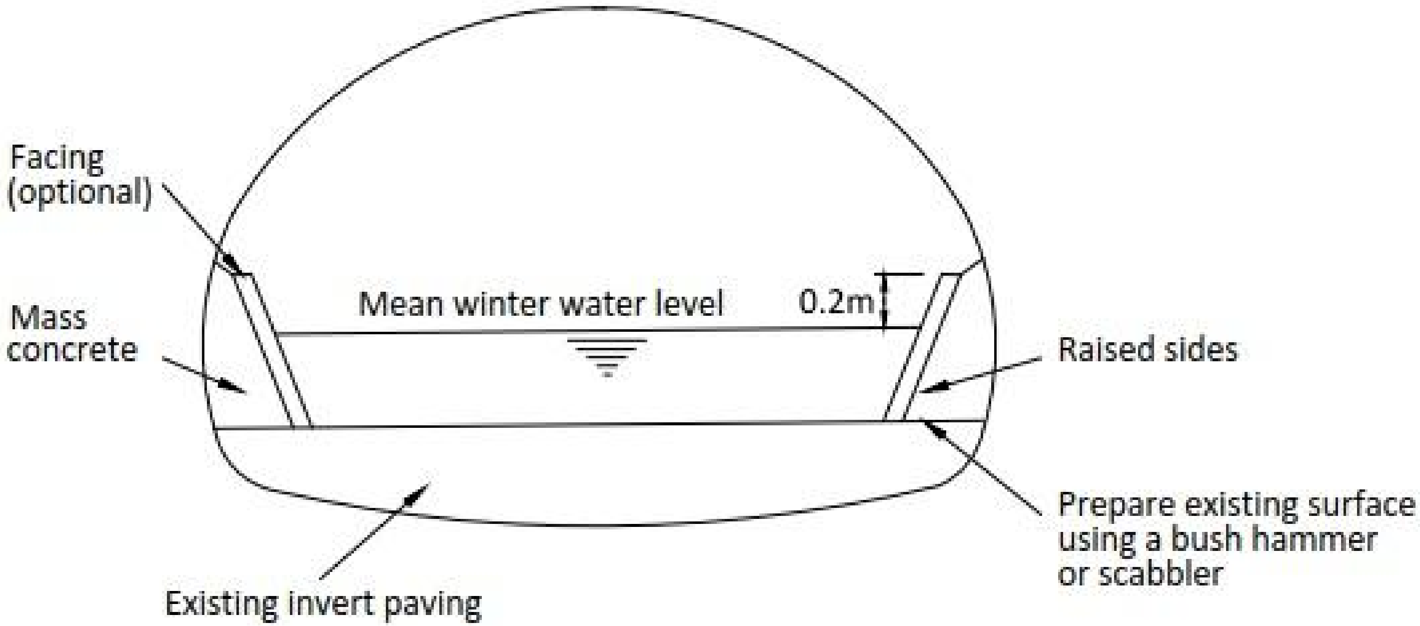
Figure B2 shows typical deterioration of a bitumen coating caused by frequent cycles of wetting and drying. Figure B3 shows the deterioration of the bitumen coatings above the paving in a pipe arch structure due to overtopping through turbulent flow. In Figure B3 the bitumen coating was in good condition elsewhere in the structure.

Figure B.2 Deterioration of bitumen coating along the wet/dry line in low flow condition

Figure B.3 Damaged bitumen coating caused by overtopping of paving during turbulent flow

Figure B4 shows, the details of raising the sides of paving within a pipe arch structure that was constructed with a flat reinforced concrete paving.

Figure B.4 Extension of an invert paving



B3 Deterioration of bitumen paving

Bitumen pavings are generally hard wearing and resistant to scour by waterborne debris. The most common form of deterioration of bitumen pavings takes the form of cracking as the bitumen hardens with age and loses its more volatile constituents. This is usually most evident at the ends of the structure (particularly those with bevelled ends) exposed to direct sunlight and potentially turbulent water flows. Figure B5 shows an example of the form of deterioration.

Figure B.5 Cracking in a bitumen paving due to exposure to sunlight

Where the steel in the invert has deteriorated substantially the use of a structural reinforced concrete paving should be considered rather than the replacement of the structure.

Where the deterioration of the structure is slight then the paving may be replaced or repaired. There are a number of ways to repair a damaged bitumen paving including replacing the damaged areas with one of the following:

1) hot-applied bitumen trowelled into place;
2) cold-applied bitumen based product, such as cold rolled asphalt; or,
3) reinforced concrete.

The most straightforward maintenance measure, where the deterioration of the steel is not excessive, is to increase the height of the invert paving on the sides. A recommended procedure is as follows:

1) Remove any loose secondary coating and corrosion products;
2) Refurbish the galvanised steel or exposed steel surface as appropriate. The standard of surface preparation should be compatible with the protective coating to be applied.;
3) Apply an additional compatible protective coating. For most structures, it would be appropriate to protect bare steel with a cold-applied zinc-rich paint followed by a cold-applied bitumen-based product.;
4) Alternatively, for a hot-dip galvanised structure, its surface should be cleaned in accordance with MCHW Series 5000 [Ref 11.N] and followed by applying a compatible primer or an adhesion promoter and finally by epoxy paint;

5) Protect the inner surface of the structure by providing a concrete lining on the sides to at least the level of the mean winter flow plus 200 mm, or greater if necessary to contain turbulent flow;

6) Seal the joint between the top of the raised part of the concrete lining and the wall of the CSBS by coating the interface with a cold-applied bitumen or coal-tar free pitch epoxy product.

Alternatively, pre-coated galvanised steel or pre-shaped glass-reinforced plastic sheets could be fixed into the invert as a liner and the resulting void between the liner and CSBS filled with a cementitious grout or water-reactive polyurethane foam. Details of this procedure are shown in Figure B6.

The manufacturers of CSBS may be able to supply pre-shaped steel liner plates. Alternatively, straight, thin sheets of coated steel may be laid and pulled into the correct curvature using the circumferential fittings fixed to the CSBS. Adjacent sheets would need to be joined with bolts or rivets. Glass reinforced plastic liners would need to be pre-shaped to the profile of the structure and joined along its length.

Where bitumen pavings are to be repaired, the steps to be taken are as follows:

1) Divert the water flow and dry the invert.;
2) Remove all loose bitumen and clean the exposed surface of the CSBS.;
3) Coat the galvanised surface or exposed steel with a cold-applied bitumen-based paint.; and,
4) Repair or replace the paving or fix liner sheets.

The use of liner plates might be a particularly effective method of paving repair because:

1) The use of reinforced concrete to repair a short length of damaged bitumen paving may be problematic as bitumen pavings placed to the AASHTO M190 [Ref 1.I] standard are only required to be 3 mm above the crest of the corrugations of the CSBS whereas reinforced concrete pavings placed to the requirements of CD 375 [Ref 4.N] need to be at least 100 mm above the crest. This difference can result in an obstruction in the water channel and cause turbulent flow inside the structure. It may be preferable to replace the whole of the bitumen paving with a reinforced concrete paving where a significant length of the original bitumen paving is damaged, as long as the hydraulic capacity of the structure is not impaired by the increased height of the paving.
2) Few repairs have been made to bitumen pavings with hot-applied bitumen or asphalt-based products. Thus the ease of application and the durability of the repair are, largely, untried.

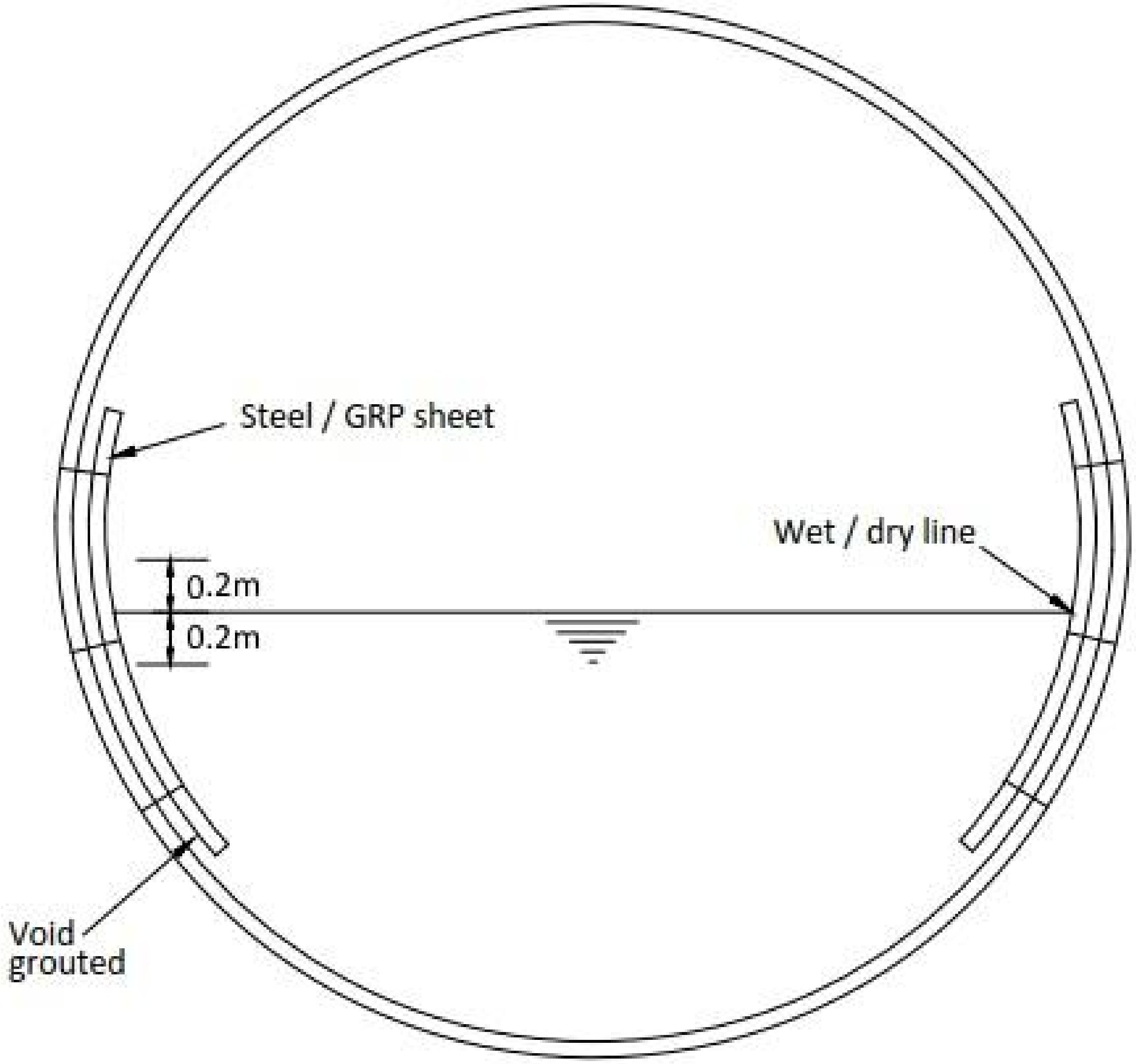
B4 Deterioration along the wet/dry line

CSBS acting as culverts are susceptible to deterioration along the wet/dry line. This is often most pronounced in structures with standing water, or with little or no flow, where the secondary coating has been removed in the wet/dry zone and yet remains in perfect condition either side of this zone.

Secondary coatings formed from hot-dip bitumen to the AASHTO M190 [Ref 1.I] standard seem particularly susceptible, and are often completely removed within the wet/dry zone.

Removal of the secondary coating leads to deterioration of the zinc coating and hence to corrosion of the underlying steel. This mechanism may result in a narrow band of corrosion running along the whole length of a structure.

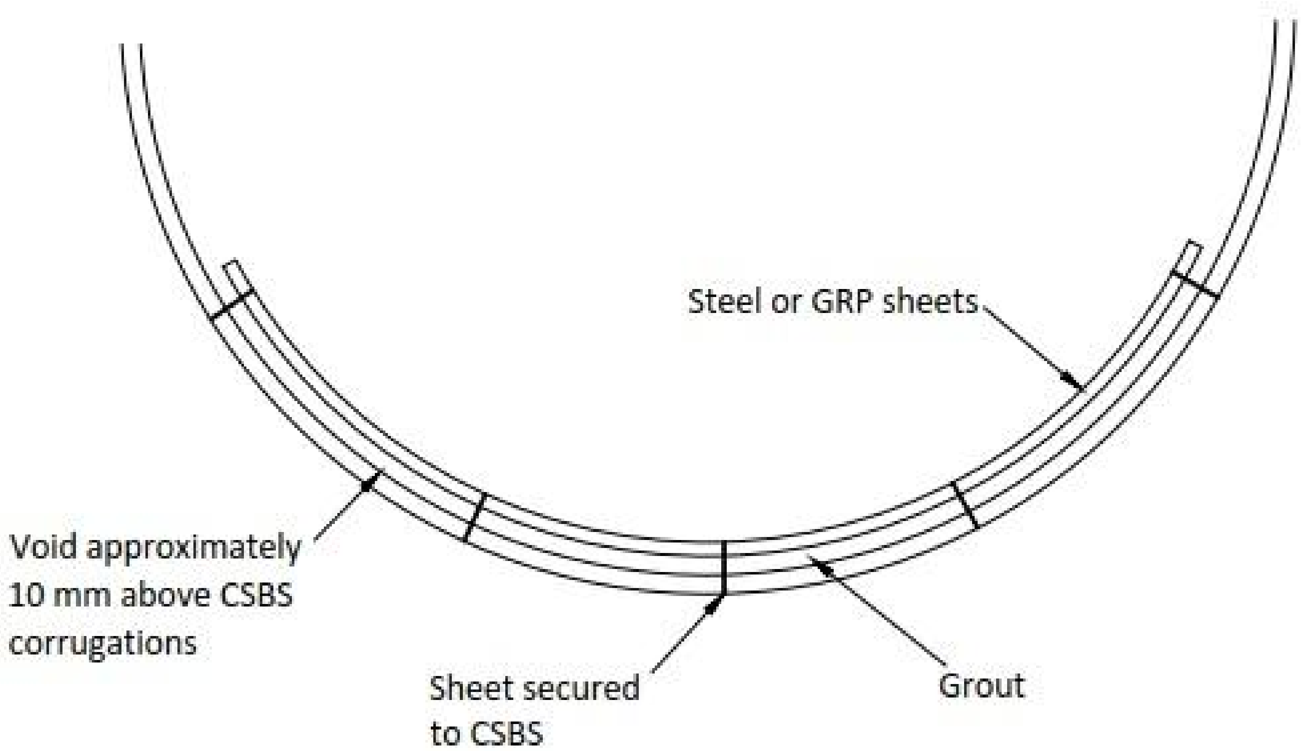
Figure B.6 Use of liner plates to protect wet/dry line



Coatings that are reapplied to the wet/dry zone are likely to be quickly removed and again expose the underlying zinc coating and steel to the environment. The placement of a paving to contain the flow would protect the wet/dry zone, but there are a number of cheaper options. For example, the use of pre-coated galvanised steel or glass-reinforced plastic (GRP) sheets as shown in Figure B7. This can be done in the following manner:

1) Remove any loose secondary coatings and clean exposed surface.;
2) Coat the galvanised surface or exposed steel with a cold-applied bitumen-based paint or suitable secondary coating;
3) Secure the pre-coated galvanised steel or GRP sheets to the culvert walls to cover at least the wet/dry zone up to the height of the mean winter water level plus 200 mm; and,
4) Fill the void between the wall of the CSBS and the sheet with, for example, a cementitious grout or water-reactive polyurethane.

Figure B.7 Use of liner plates to protect an invert



B5 Deterioration due to seepage

Bolted segmental structures are particularly prone to seepage of water from the backfill into the structure either through the bolt holes or through the joints where the plates overlap.

Few CSBSs in the UK have been constructed with joint seals, but where they do exist, the secondary protective coatings such as bitumen may reduce seepage.

Where seepage occurs, water may originate from the overlying carriageway, roadside verge or from ground water flowing through the backfill. Deicing salts or leachates may be carried into the structure and these may cause rapid deterioration around the points of entry.

The degree of corrosion may depend, to some extent, upon the source of the seepage. Where water laden with de-icing salts percolates down from the surface, the corrosion may be limited to areas of the CSBS immediately below the carriageway edge or central reserve on a divided carriageway.

Figure B8 shows the interior of a 35-year old plain galvanised bolted segmental CSBS where deterioration is particularly severe below the edges of the carriageways. Excavation and exposure of the outside of the structure at this point showed that the exterior had suffered no corrosion. On the soil side, the thickness of the remaining zinc was about 60% of its nominal original thickness despite the fact that no external secondary coat had been used.

Figure B.8 Deterioration to side plates in a plain galvanised bolted segmental CSBS caused by seepage below the edge of the carriageway

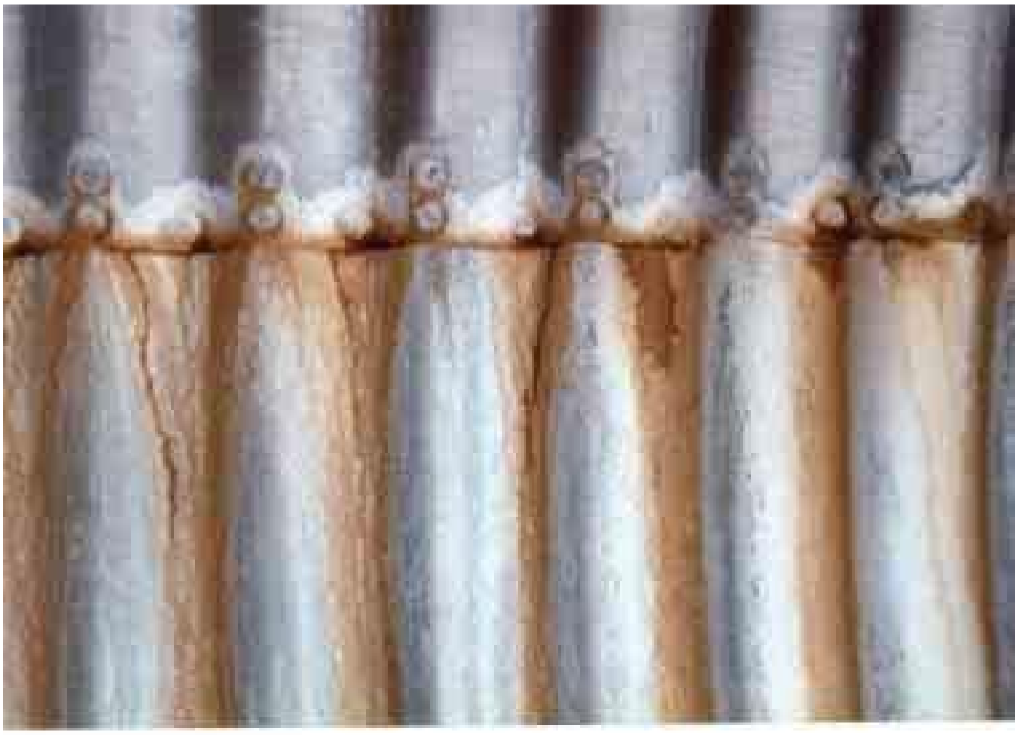


Figure B9 shows the deterioration in a 25-year-old plain galvanised arch structure. Water laden with deicing salts has percolated into the structure below the edges of the carriageway. Corrosion is most noticeable around bolt holes and plate edges in the crown and also where it has ponded in the seating channel of the arch. The rest of the structure is in good condition.

Figure B.9 Deterioration at the arch seating of a plain galvanised arch structure due to seepage and ponding of water containing de-icing salts

The maintenance to the structures with deterioration caused by seepage and ponding water could be carried out as follows:

1) Grout the backfill close to points of seepage with a water-reactive polyurethane grout or similar to eliminate or reduce seepage.;
2) Remove corrosion by sand or shot blasting to achieve a clean steel finish.;
3) If the appearance of the structure is important, i.e. an underpass, then a visually attractive finish could be applied to the structure by applying an appropriate primer and coating system; for example, a zinc phosphate primer followed by a high-build primer and an acrylic finishing coat.;
4) If the appearance of the structure is unimportant, then the finish to the structure could be formed from a moisture-tolerant primer followed by a suitable coating such as cold-applied bitumen.
5) If the deterioration is severe but localised then liner plates can be used to strengthen the structure. Figure B10 shows the use of liner plates in an underpass.

Figure B.10 Use of liner plates to repair a bolted segmental CSBS showing deterioration below the edge of the carriageway due to seepage of water containing deicing salts

B6 Structural instability of the invert

Structural instability of the invert can arise in a number of ways, but for ageing structures it can often be caused by excessive material degradation.

A possible solution to increase the stability is the provision of a structural paving. Details of various arrangement for structural pavings are shown in Figures B11 to B14, and as indicated in Alexander et al 1994 [Ref 14.I] and in 'Invert replacement of corrugated metal structural plate pipe' Ikerd 1984 [Ref 11.I].

Figure B.11 Damaged bitumen coating caused by overtopping of paving during turbulent flow

Figure B.12 Reinforced concrete paving (after Abdel-Sayed et al, 1993)

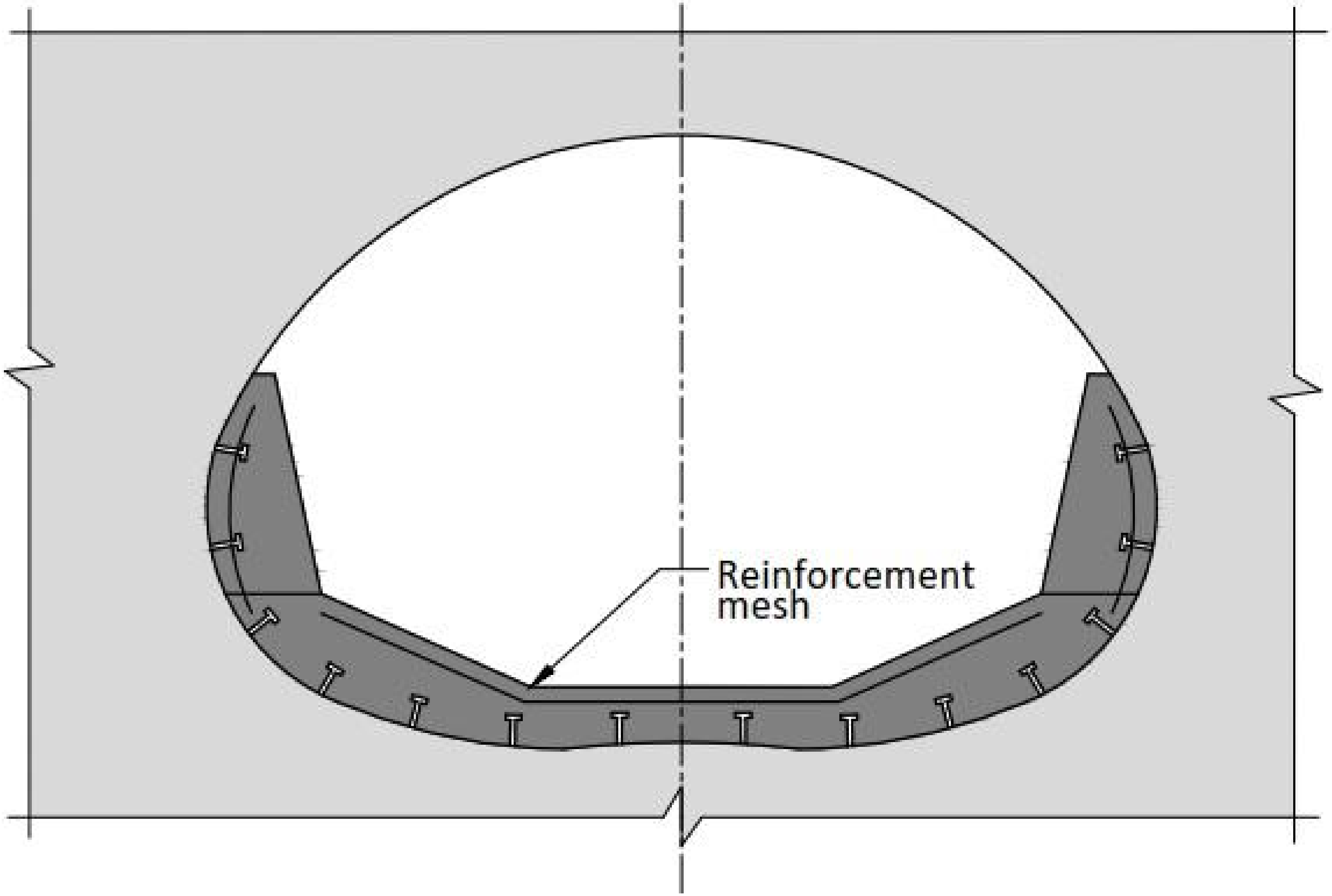


Figure B.13 Shotcrete reinforced concrete paving (after Abdel-Sayed et al, 1993)

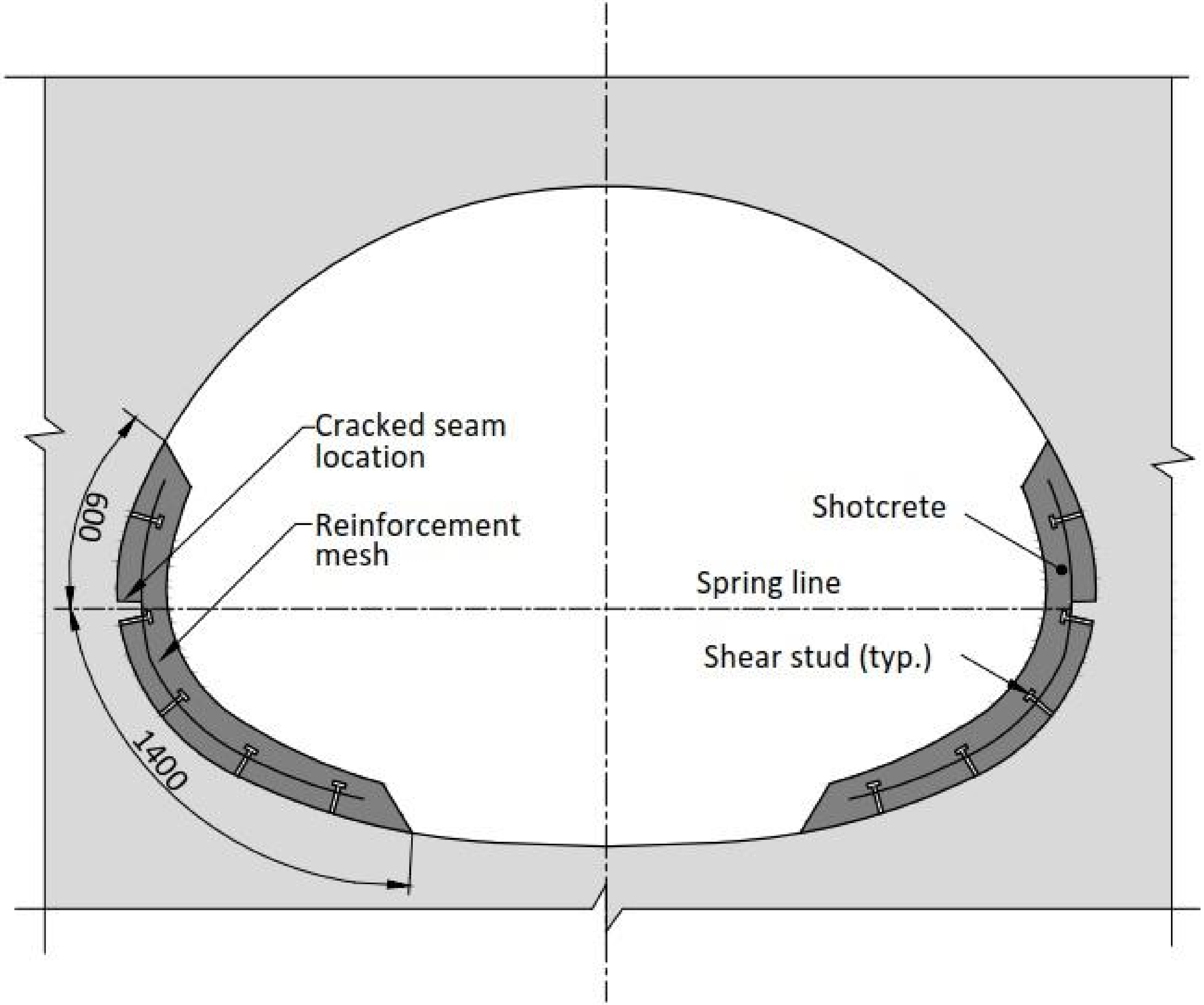


Figure B.14 Reinforced concrete paving in a circular arch as used in Ohio (after Alexander et al, 1994)

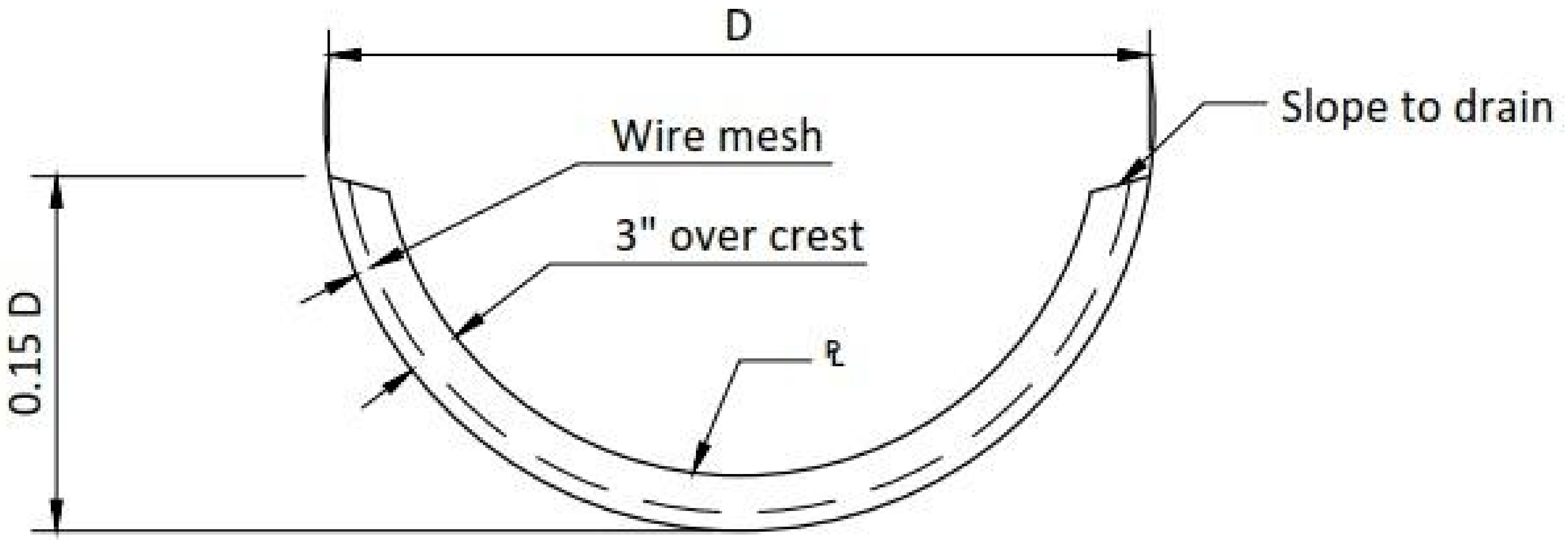


Figure B.15 Reinforced concrete paving as used in Hawaii (after Alexander et al, 1994)