

## **DESIGN MANUAL FOR ROADS AND BRIDGES**

### **SUMMARY OF CORRECTION – BD 12/01 Volume 2, Section 2, Part 6 DESIGN OF CORRUGATED STEEL BURIED STRUCTURES WITH SPANS GREATER THAN 0.9 METRES AND UP TO 8.0 METRES**

In November 2001, page 7/1 – 7/2, was issued incorrectly. (The page number was incorrect as it read 7/1 – 7/4). Please amend this page by crossing out page number 7/4, and writing 7/2.

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**VOLUME 2    HIGHWAY STRUCTURES  
DESIGN:  
(SUBSTRUCTURES,  
SPECIAL STRUCTURES  
AND MATERIALS)**

**SECTION 2    SPECIAL STRUCTURES**

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**PART 6**

**BD 12/01**

**DESIGN OF CORRUGATED STEEL  
BURIED STRUCTURES WITH SPANS  
GREATER THAN 0.9 METRES AND UP  
TO 8.0 METRES**

**SUMMARY**

This Standard covers the design and construction requirements for corrugated steel buried structures with spans greater than 0.9 metres and up to 8.0 metres.

**INSTRUCTIONS FOR USE**

This revised Standard is to be incorporated in the Manual.

1. This document supersedes BD 12/95, which is now withdrawn.
2. Remove existing contents page for Volume 2 and insert new contents page for Volume 2 dated November 2001.
3. Remove BD 12/95, which is superseded by BD 12/01, and archive as appropriate.
4. Insert BD 12/01 in Volume 2, Section 2, Part 6.
5. 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 DEVELOPMENT DEPARTMENT**



**THE NATIONAL ASSEMBLY FOR WALES  
CYNULLIAD CENEDLAETHOL CYMRU**



**THE DEPARTMENT FOR REGIONAL DEVELOPMENT  
NORTHERN IRELAND**

# **Design of Corrugated Steel Buried Structures with Spans Greater Than 0.9 Metres and up to 8.0 Metres**

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**REGISTRATION OF AMENDMENTS**

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

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# 1. INTRODUCTION

1.1 This Standard gives the design and construction requirements for corrugated steel buried structures that act compositely with the surrounding material to resist loading. It describes the procedures to be followed that permit the Contractor to choose a proprietary structure that meets the Overseeing Organisation’s requirements. It follows the principles of BD 12/95 and requires a current Type Approval Certificate for all corrugated steel buried structures, updates durability requirements and clarifies the requirements in regard to excavation and filling, handling and installation and end treatment. Further clarification is made to the presentation of the formulae given in this document.

## Equivalence

1.2 The construction of corrugated steel buried structures will normally be carried out under contracts incorporating the Specification for Highway Works (MCHW1). In such cases products conforming to equivalent standards or technical specifications of other states of the European Economic Area and tests undertaken in other states of the European Economic Area will be acceptable in accordance with the terms of Clauses 104 and 105 in Series 100 of that Specification. Any contract not containing these Clauses must contain suitable clauses of mutual recognition having the same effect regarding which advice should be sought.

## Scope

1.3 This Standard covers bolted segmental corrugated steel buried structures, with spans greater than 0.9 metres and up to 8 metres, which are straight in plan, and which are of:

bolted segmental construction with cross sections being:

- (i) closed circular
- (ii) closed multi-radii
- (iii) circular arch; or

helically wound construction with cross sections being:

- (i) closed circular

subject to the following requirements:

- a. The size and shape are within the limits specified in Table 1.1.

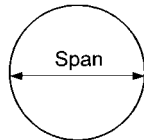
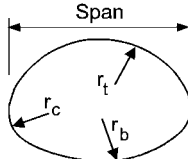
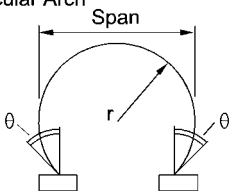
SHAPE	RANGE OF SIZES
<p>Circular Structure</p> 	>0.9m to 8.0m span.
<p>Multi-Radii Structure</p> 	<p>&gt;0.9m to 8.0m span.</p> <p>The shapes shall conform to:</p> $\frac{r_b}{r_t} < 3.5 \quad \& \quad \frac{r_c}{r_t} > 0.2$
<p>Circular Arch</p> 	<p>2.0m to 8.0m span.</p> <p>The shapes shall conform to either:</p> <p>Type 1 Arch <math>30^\circ &gt; \theta \geq 20^\circ</math></p> <p>Type 2 Arch <math>20^\circ &gt; \theta \geq 10^\circ</math></p>

Table 1.1 - Structure Shapes and Sizes covered by this Standard

- b. The depth of cover measured from the finished road surface or final ground level to the crown of the structure is not less than span/5 or 650mm whichever is greater. However, where a reinforced concrete slab is provided at finished road surface, a lesser depth of cover will be acceptable (see Clause 12.1 below).
- c. The environment is “non-aggressive” or “aggressive” as defined in Chapter 8. An environment which is classed as “very aggressive” is outside the scope of this Standard and specialist advice should be sought.

This Standard does not cover the use of corrugated steel buried structures in the repair of other types of structure, for example, as a liner for brick arch structures. In these situations, specialist advice should be sought from the manufacturers of corrugated steel structures.

### Environmental Considerations

1.4 The Overseeing Organisation's requirements for environmental design shall be taken into account in designing corrugated steel buried structures. Volume 10 of DMRB (Environmental Design) gives advice on the use of underpasses by multiple species of small mammals and fish. It illustrates various forms of culvert design to facilitate free passage of these species. Often these considerations are fundamental to the determination of the span, headroom, cross-section invert and gradient of the structure.

### Approval Procedure

1.5 Corrugated steel buried structures are proprietary manufactured structures and the design and contractual procedures required by Standard SD4 (MCHW 0.2.4) shall be followed.

1.6 All bolted segmental and helically wound corrugated steel buried structures and their components require a current Type Approval Certificate (MCHW1 Clause 104.9). Helically wound corrugated steel buried structures and their components shall also have a current British Board of Agrément, Roads and Bridges, Certificate or equivalent (MCHW1 Clauses 104.5 and 104.6) for the end-use described in this Standard. The British Board of Agrément (BBA) Certificate or equivalent shall include guaranteed minimum lockseam tensile strengths satisfying the requirements of Annex C of this Standard.

1.7 Prior to being offered on a Contract, the manufacturer of the corrugated steel buried structure shall have obtained a Type Approval Certificate from The Highways Agency. The procedure for obtaining the Type Approval Certificate for bolted segmental structures is described at Annex A. The procedure for obtaining the Type Approval Certificate for helically wound structures is also as described at Annex A and current certification by the British Board of Agrément is mandatory.

1.8 Where the Contractor proposes a proprietary system of invert protection, the proprietary invert system shall have a current British Board of Agrément Roads and Bridges Certificate or equivalent for the end-use as indicated in the Schedule of Employer's Requirements included in the Outline Approval in Principle.

1.9 Where the Contractor chooses a proprietary protection coating with a designated life intended to contribute towards the durability requirement of the structure, a current British Board of Agrément Roads and Bridges Certificate or equivalent shall be provided confirming its life under service conditions appropriate to the circumstances stated in the Schedule of Employer's Requirements.

1.10 The materials used for corrugated steel buried structures, their manufacture and their assembly and construction on site shall be in accordance with the Specification for Highway Works (MCHW1).

### Contract/Design Procedure

1.11 A flow diagram for a typical contract/design procedure is given in Figure 1.1 to assist users of this Standard.

### Implementation

1.12 This Standard shall be used forthwith on all schemes for the construction and improvement of trunk roads, including motorways, currently being prepared, provided that, in the opinion of the Overseeing Organisation this would not result in significant additional expense or delay. Design Organisations shall confirm its application to particular schemes with the Overseeing Organisation. In Northern Ireland the use of this standard shall apply on those roads designated by the Overseeing Organisation.

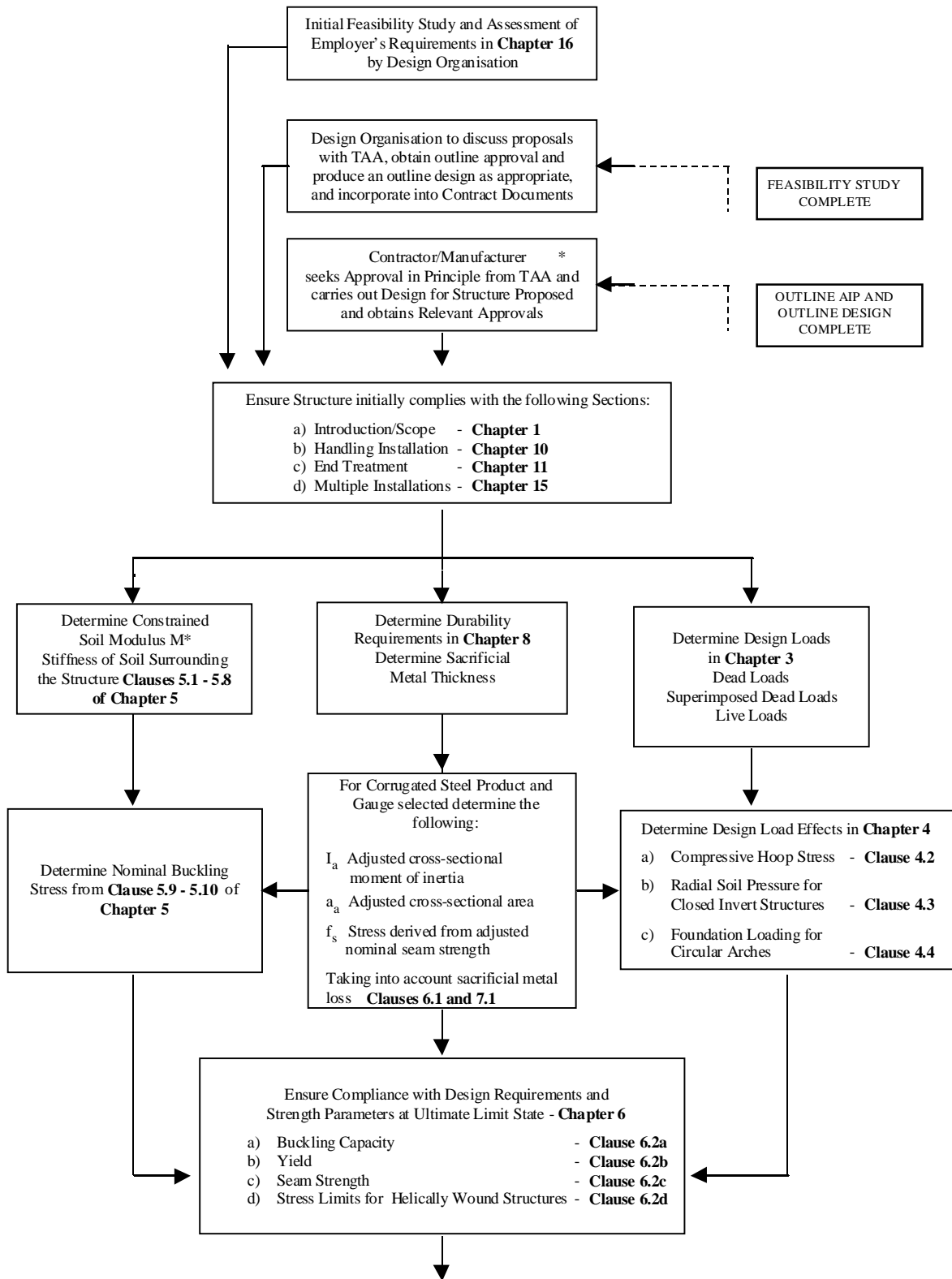
### Mandatory Requirements

1.13 Sections of this document which form mandatory requirements of the Overseeing Organisation are highlighted by being contained within boxes. The remainder of the document contains advice and enlargement which is commended to designers for their consideration.

<b>Symbols</b>		$f_y$ (N/mm <sup>2</sup> )	Minimum yield strength of the steel.
1.14 The symbols used in this Standard are defined as follows:		$h$ (m)	Nominal height of fill above the structure.
$a$ (mm <sup>2</sup> /mm)	Cross-sectional area of corrugated steel per unit length, the cross section being parallel to the length of the structure.	$h_t$ (m)	Height of fill above the crown of the structure including the thickness of any road construction.
$a_a$ (mm <sup>2</sup> /mm)	Adjusted cross-sectional area of corrugated steel per unit length based on the remaining wall thickness after deduction of sacrificial metal thickness required by Chapter 8.	$I$ (mm <sup>4</sup> /mm)	Cross-sectional moment of inertia of the corrugated steel per unit length, the cross-section being parallel to the length of the structure.
$B$ (mm)	Diameter of plate used in plate load test.	$I_a$ (mm <sup>4</sup> /mm)	Adjusted cross-sectional second moment of area of the corrugated steel per unit length, the cross-section being parallel to the length of the structure.
$C$ (kN/m)	Compressive hoop load in the wall of the structure per unit length.	$I_d$	Depth correction factor for plate load test.
$C_T$ (kN/m)	Total compressive hoop load in the wall of the circular arch structure per unit length acting upon the foundation.	$k$ (N/mm <sup>3</sup> )	Coefficient of soil reaction.
		$k_c$ (N/mm <sup>3</sup> )	Modified coefficient of soil reaction.
		$K$	Constant.
$d_c$ (mm)	Depth of corrugation.	$K_a$	Active earth pressure coefficient.
$D$ (mm)	Additional trench width required for circular arch structures.	$m$	Poisson's ratio of the structural steel.
$E$ (N/mm <sup>2</sup> )	Modulus of elasticity of the structural steel.	$M^*$ (N/mm <sup>2</sup> )	Constrained soil modulus.
$E_s$ (N/mm <sup>2</sup> )	Modulus of elasticity of the soil.	$m_v$ (mm <sup>2</sup> /N)	Coefficient of volume compressibility.
$F$ (mm/N)	Flexibility factor.	$N$	Uncorrected SPT value.
$F_{max}$ (mm/N)	Limiting value of flexibility factor.	$P$ (kN/m <sup>2</sup> )	Radial soil pressure on a circular closed invert structure.
$f_a$ (N/mm <sup>2</sup> )	Compressive hoop stress.	$P_b$ (kN/m <sup>2</sup> )	Radial soil pressure on the bottom of a multi-radii structure.
$f_b$ (N/mm <sup>2</sup> )	Theoretical transverse elastic buckling stress.	$P_c$ (kN/m <sup>2</sup> )	Radial soil pressure on the corner of a multi-radii structure.
$f_c$ (N/mm <sup>2</sup> )	Nominal allowable buckling stress.	$P_t$ (kN/m <sup>2</sup> )	Radial soil pressure on the top of a multi-radii structure.
$f_s$ (N/mm <sup>2</sup> )	Stress derived from adjusted nominal seam strength (kN/m) based on the remaining wall thickness after deduction of sacrificial metal thickness required in Chapter 8.	$P_d$ (kN/m <sup>2</sup> )	Design vertical superimposed dead load pressure.

$P_L$ (kN/m <sup>2</sup> )	Design vertical live load pressure.	$\gamma_{fl}$	Partial safety factor that takes account of the possibility of unfavourable deviation of the loads from their nominal values and of the reduced probability that various loadings acting together will all attain their nominal values simultaneously.
$P_1$ (kN/m <sup>2</sup> )	Overburden pressure on top of footing of circular arch.		
$P_2$ (kN/m <sup>2</sup> )	Lateral earth pressure on the outside face of the footing of a circular arch.		
$P_3$ (kN/m <sup>2</sup> )	Overburden pressure on top of footing inside circular arch.	$\gamma_{f3}$	Partial safety factor that takes account of inaccurate assessment of the effects of loading, unforeseen stress distribution in the structure, and variations of dimensional accuracy achieved in construction.
$Q^*$	Design Loads (Refer to BS 5400: Part 1).		
$r$ (m)	Radius of circular structure.		Partial safety factor that takes account of variabilities in material strength and uncertainties in the assessment of component strength.
$r_b$ (m)	Radius at the bottom of a multi-radii structure.	$\gamma_m$	
$r_c$ (m)	Radius at the corner of a multi-radii structure.		
$r_t$ (m)	Radius at the top of a multi-radii structure.	$\Delta_q$ (N/mm <sup>2</sup> )	Change in pressure applied by the plate (plate load test).
$R^*$	Design Resistance (Refer to BS 5400: Part 1).	$\Delta_s$ (mm)	Change in average settlement of the plate (plate load test).
$S$ (m)	Span of the structure (diameter of circular structure).	$\Delta_x$ (m)	Increase in horizontal diameter or span.
$S^*$	Design Load Effects (Refer to BS 5400: Part 1).	$\theta$	Re-entry angle of circular arch measured between the vertical and the tangent to the arch wall at the top of the foundation.
$t$ (years)	Life of sacrificial thickness of steel.		
$T$ ( $\mu$ m)	Thickness of sacrificial metal for each corroding face.	$\nu$	Poisson's ratio of the soil.
$W_f$ (kN/m)	Self weight of foundation per unit length.		
$y$ (m)	Excavation width measured from the walls of the structure.		
$Z_1$ (m)	Depth from road surface/ground level to top of foundation.		
$Z_2$ (m)	Depth from road surface/ground level to mid height of foundation.		
$\gamma$ (kN/m <sup>3</sup> )	Bulk unit weight of compacted fill.		

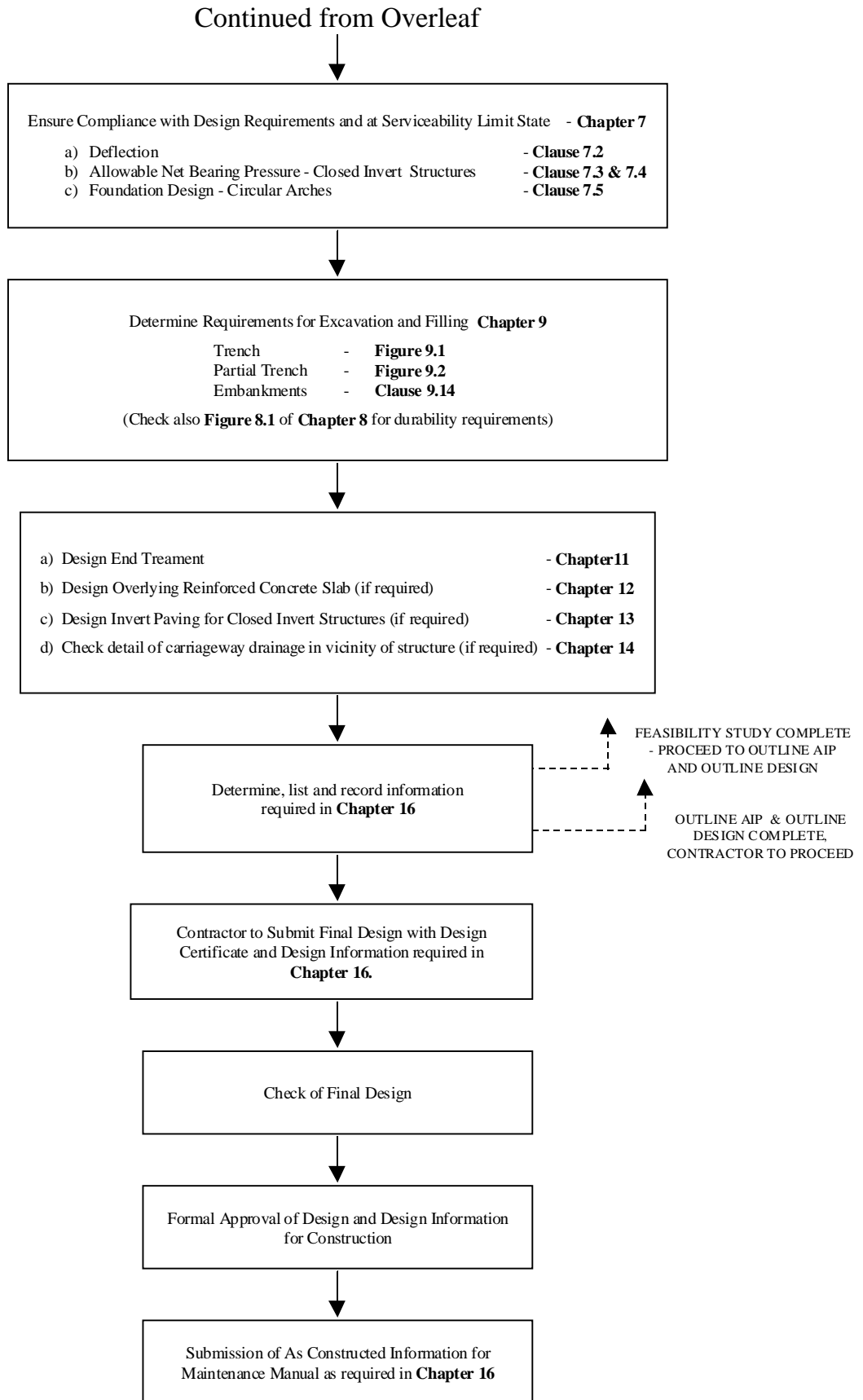
Figure 1.1 Flow Diagram for Contract/Design Procedure



\* Outline Approval in Principle Form and Approval in Principle Form shall both incorporate the listings of Employer's Requirement as set out in Chapter 16

Continued  
Overleaf

**Figure 1.1 Flow Diagram for Contract/Design Procedure**



## 2. DESIGN PRINCIPLES

2.1 Limit state principles have been adopted for design in this Standard. The limit states adopted are:

- a. Ultimate limit states represented by:
  - i. The strength of the structure as determined by the yielding and buckling behaviour of corrugated steel buried structures, and
  - ii. The strength of a longitudinal bolted seam as determined by tests on bolted plate assemblies.
- b. Serviceability limit states represented by:
  - i. A limiting deflection expressed as a maximum percentage change in the span dimension beyond which cause for public concern may be expected and remedial action to protective coatings and finishings may be required.
  - ii. The allowable net bearing pressure of the foundation material for closed invert structures.
  - iii. The allowable net bearing pressure of the foundation material beneath the concrete foundations of circular arch structures.

2.2 Design loads ( $Q^*$ ) are expressed as the product of nominal loads and the partial safety factor  $\gamma_{fl}$ .

2.3 Design load effects ( $S^*$ ) are expressed as the product of the effects of the design loads and the partial safety factor  $\gamma_{f3}$ .

2.4 Design resistance ( $R^*$ ) is expressed as the nominal strength of the component divided by the partial safety factor  $\gamma_m$ .

2.5 The design load effects ( $S^*$ ) at the ultimate limit state must not be greater than the design resistance ( $R^*$ ). In addition, at the serviceability limit state the deflection must not be greater than

the limiting value given in this Standard and the settlement of the foundation material must not adversely affect the performance of the structure.

2.6 As the allowable net bearing pressure of soil is not normally expressed in characteristic (or nominal) strength terms, the checks involving allowable net bearing pressure shall be undertaken with unfactored nominal loads.

2.7 For the ultimate limit state the following load combinations shall be considered:

- a. Dead Loads together with Live Loads.
- b. Dead Loads together with Temporary Construction Loads.

2.8 For the serviceability limit state, Dead Loads shall be considered together with Live Loads.

2.9 The steel section chosen for the walls of the structure must satisfy both the strength and deflection requirements of Chapters 6 and 7 and also the durability requirements of Chapter 8 in terms of sacrificial steel. The steel thickness required to satisfy these criteria may be different at different points around the circumference of the structure. Care shall be taken during assembly to ensure the correct positioning of plates of different thickness.

### 3. DESIGN LOADS

#### Dead Load of Steel

- 3.1 a) The self-weight of corrugated steel buried structures may be ignored for the Ultimate Limit State requirements and Serviceability Limit State requirements as defined in Chapter 6 and Chapter 7 respectively.
- b) During the construction, the self-weight of corrugated steel buried structures shall be considered if temporary strutting or ties are required to support the structure. (Refer to Clause 10.5.)
- c) In the case of end treatments, the self-weight of corrugated steel buried structures, including headwalls, ring beams and collars etc, shall be taken into account. (Refer to Chapter 11).

Values for  $\gamma_{fl}$  are given in Table 3.1.

#### Superimposed Dead Load

3.2 The design vertical pressure on the structure due to the superimposed dead load is given by:

$$P_d = \gamma_{fl} \times \text{nominal vertical pressure}$$

$$= \gamma_{fl} \gamma h \text{ (kN/m}^2\text{)}$$

where  $\gamma$  = Bulk unit weight of compacted fill (kN/m<sup>3</sup>)

and  $h$  = Nominal height of fill above the structure (m), to be taken as  $h_t + 0.25r$  for circular structures and circular arches, and  $h_t + 0.25r_t$  for multi-radii structures

where  $h_t$  = Height of fill (m) above the crown of the structure, including the thickness of any road construction

$r$  = Radius of closed circular structure or circular arch structure, (m)

$r_t$  = Radius at the top of a multi-radii structure, (m)

Values for  $\gamma_{fl}$  are given in Table 3.1.

#### Live Loads

3.3 Nominal live loads shall be the HA or HB loading whichever is the more onerous, applied in accordance with BS 5400: Part 2, as implemented by BD 37 (DMRB 1.3). HA loading shall consist of a single nominal wheel load of 100kN. HA UDL and KEL need not be considered. For Trunk Roads including Motorways, HB loading shall consist of a minimum of 45 units. For other classes of roads refer to BD 37. There is no requirement for co-existing HA and HB wheel loadings to be considered either in the same or adjacent lanes.

3.4 On the carriageway each wheel load shall be assumed to be uniformly distributed over a contact area, circular or square in shape based on a nominal tyre inflation pressure of 1.1N/mm<sup>2</sup>.

3.5 To determine the nominal vertical live load pressure,  $P_L$  on the structure due to any wheel load, dispersion in three dimensions may be assumed from the limits of the contact area on the carriageway to the level of the crown of the buried structure at a slope of 2 vertically to 1 horizontally as shown in Figure 3.1. This pressure shall be taken to act over the whole span. A wheel load not directly over the structure shall be included if its dispersion zone falls over any part of the structure.

3.6 In the case of the HB vehicle only, the dispersion zones of individual HB wheel loads shall be combined and distributed jointly as indicated in Figure 3.1. This applies to adjacent wheels on the same axle and, where the span is large enough, to wheels on succeeding axles.

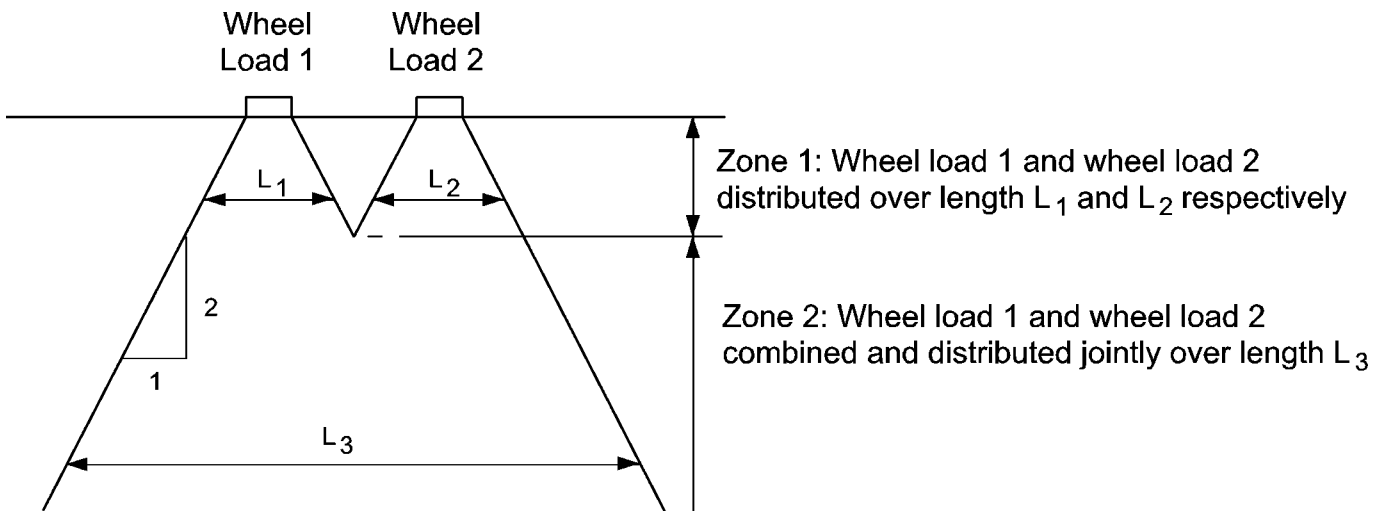


Figure 3.1 - Dispersion of Adjacent HB Wheel Loads

3.7 Where a reinforced concrete structural slab is proposed in accordance with Clause 1.3(b) and Clauses 12.1 to 12.5 of this Standard, dispersion of any wheel load as described in Clause 3.5 may be assumed to occur throughout the depth of the structural slab at a slope of 1 vertically to 1.5 horizontally. Below the level of the bottom of the structural slab, dispersion of the wheel loads may be assumed to occur at a slope of 2 vertically to 1 horizontally.

Alternatively, the nominal live load pressures acting on the culvert may be assessed by a suitable multi-layer elastic analysis, using one of the methods given in Chapter 6 of “Elastic Solutions for Soil and Rock Mechanics” by H G Poulos and E H Davis, (1) which takes into account the relative stiffness of the structural slab and the layers of material between the slab and the crown of the culvert.

3.10 To obtain the design vertical live load pressure,  $P_L$  (kN/m<sup>2</sup>), the nominal pressures shall be multiplied by the appropriate values of  $\gamma_{fl}$  given in Table 3.1.

3.8 The nominal vertical live load pressure on the structure due to tracked construction vehicles or large rubber tyred earthmoving vehicles shall be determined at a depth of cover of one fifth of the span of the structure, or 1m, whichever is greater.

3.9 Braking loads and temperature effects shall be ignored.

LOAD	SLS $\gamma_{fl}$	ULS $\gamma_{fl}$
Dead Load Concrete, End Treatment Only (Chapter 11)	1.0	1.2
Dead Load, Corrugated Steel Only (Chapters 6 & 7 and Clause 10.5)	1.0	1.2
Superimposed Dead Loading	1.1	1.3
HA wheel load	1.2	1.5
HB loading	1.1	1.3
Temporary Construction Loading	-	1.3
All loads for Radial Soil Pressure Calculation	1.0	-
All loads for determining thrust acting on circular arch foundations for bearing pressure calculation	1.0	-

SLS: Serviceability Limit State

ULS: Ultimate Limit State

**Table 3.1 -  $\gamma_{fl}$  - Partial Safety Factors for Loads**

## 4. DESIGN LOAD EFFECTS

4.1 The design load effects involved in the design of the corrugated steel buried structures covered by this Standard are the compressive hoop stress  $f_a$  (all structures) and the radial soil pressure  $P$  (closed invert structures), which shall be calculated from the design load pressures using the formulae given below based on the ring compression theory, where the compressive hoop stress in the wall of the structure is assumed to be uniform around its periphery and the radial soil pressure at any point is assumed to be inversely proportional to the radius of curvature at that point.

### 4.2 Compressive Hoop Stress

$$\text{Compressive hoop stress } f_a = \frac{C}{a_a} \gamma_{f3} \text{ (N/mm}^2\text{)}$$

Where  $C$  = Compressive hoop load in the wall of the structure per unit length (see Figure 4.1)

$$= \frac{S (P_d + P_L)}{2} \text{ (kN/m)}$$

$S$  = Span of the structure (m)

$P_d$  = Design vertical superimposed dead load pressure at the ultimate limit state (kN/m<sup>2</sup>)

$P_L$  = Design vertical live load pressure at the ultimate limit state (kN/m<sup>2</sup>)

$a_a$  = Adjusted cross-sectional area of corrugated steel per unit length, (mm<sup>2</sup>/mm) the cross section being parallel to the length of the structure. (Refer to adjustments required in Clause 6.1 and 7.1). If the cross-sectional area varies along the length of the structure, the minimum shall be used, except that the re-rolled ends of helically wound culvert lengths shall not be considered to affect the

cross-section unless they extend for more than 250mm at the end of each length.

$\gamma_{f3}$  = is to be taken as the appropriate value given in Table 4.1 for the particular type of structure and the limit state involved. The values in the table take account of the influence of the relative stiffness of the particular structural form, the amount of deformation occurring before the various limit states are reached, and the variation of stress distribution in the particular type of structure.

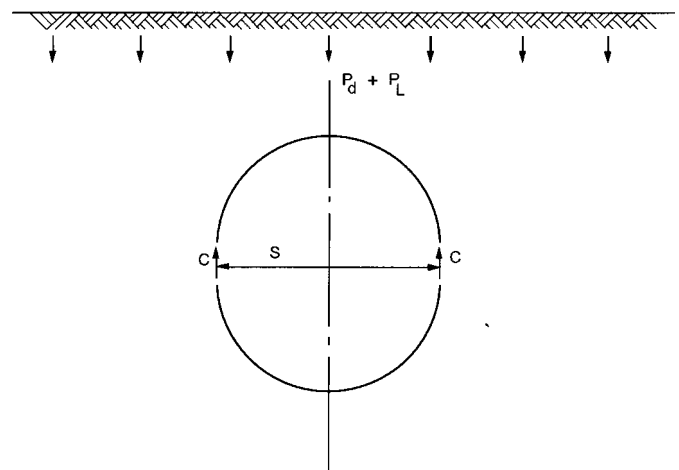


Figure 4.1 - Compressive Hoop Load

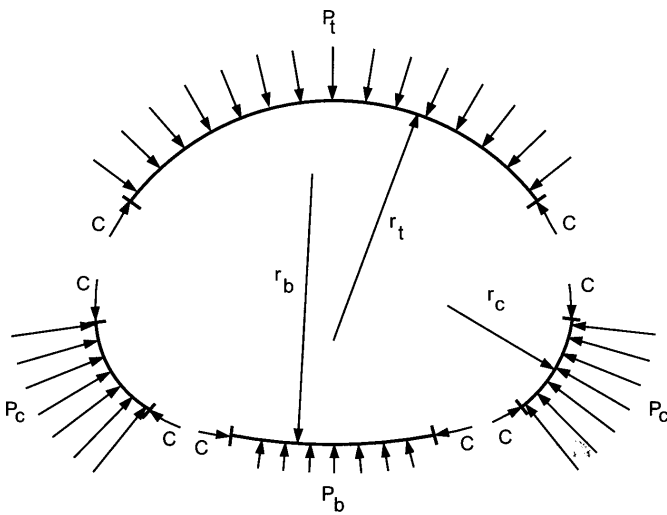


Figure 4.2 - Structure Radii, Hoop Load and Radial Soil Pressures for Closed Invert Structures

**4.3 Radial Soil Pressure for Closed Invert Structures**

This shall be calculated as follows:

**a. Circular Structures**

External radial soil pressure

$$P = \frac{C}{r} = P_d + P_L \text{ (kN/m}^2\text{)}$$

**b. Multi-radii**

Radial soil pressure on the top

$$P_t = \frac{C}{r_t} \text{ (kN/m}^2\text{)}$$

Radial soil pressure on the corner

$$P_c = \frac{C}{r_c} \text{ (kN/m}^2\text{)}$$

Radial soil pressure on the bottom

$$P_b = \frac{C}{r_b} \text{ (kN/m}^2\text{)}$$

where C is as defined in Clause 4.2 but calculated using  $P_d$  and  $P_L$  from unfactored nominal loads (see Clause 2.6)

- r = Radius of circular structure (m)
- $r_t$  = Radius of the top (m) ) of Multi-
- $r_c$  = Radius of the corner (m) ) radii
- $r_b$  = Radius of the bottom (m) ) structures
- (see ) Figure
- 4.2)

Reference should be made to Chapter 7, Clause 7.3 for the allowable net bearing pressure of the foundation material.

**4.4 Strip Foundation Loading - Circular Arches (Serviceability Limit State only)**

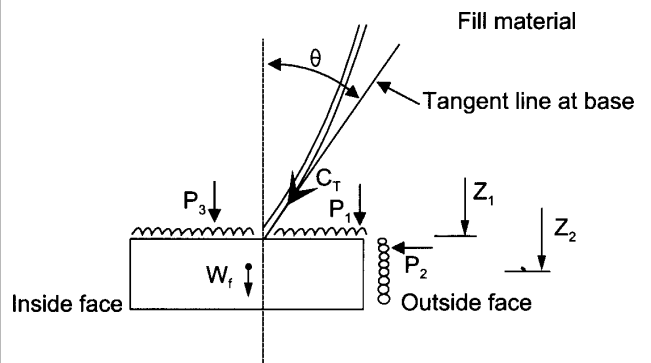


Figure 4.3 - Loadings on Foundations

**(a) Thrust**

The total thrust  $C_T$ , in the wall of the structure, acting upon the foundation at an inclined angle of  $\theta$  to the vertical is given by:

$$C_T = C\gamma_{f3} \text{ (kN/m)}$$

where C is given in Clause 4.2 except that  $P_d$  and  $P_L$  are at the Serviceability Limit State and  $\gamma_{f3}$  is given in Table 4.1

**(b) Earth Pressure from Fill**

The overburden pressure  $P_1$ , on the top of the footing is given by:

$$P_1 = \gamma_{f3} \gamma Z_1 \text{ (kN/m}^2\text{)}$$

where  $Z_1$ (m) is depth from road/ground level to top of foundation,  $\gamma$  is unit weight of overburden (kN/m<sup>3</sup>), and  $\gamma_{f3} = 1$  for SLS

The lateral earth pressure,  $P_2$  acting on the outside face of the footing is given by:

$$P_2 = \gamma_{f3} K_a \gamma Z_2 \text{ (kN/m}^2\text{)}$$

where  $Z_2$ (m) is depth from road/ground level to mid height of foundation,  $K_a$  is active earth pressure coefficient, and  $\gamma_{f3} = 1$  for SLS

The lateral pressure acting on the inside face of the footing may be ignored.

Vertical and horizontal pressures resulting from live loading surcharge on the carriageway may be ignored when assessing  $P_1$  and  $P_2$ .

Consideration shall be given to avoiding differential settlement between the foundation and the side fill such that the side fill settles to a greater extent. This may cause the overburden pressure on top of the footing to be larger than the calculated  $P_1$  value, and cause additional loading on the foundation. Refer to Clause 7.5.

**(c) Vertical Pressure on Inside Face**

The vertical pressure on top of the footing,  $P_3$ , shall include any superimposed dead loadings. The vertical pressure,  $P_3$ , shall also include any nominal live loads due to vehicular, rail or pedestrian traffic and these nominal live loads shall be in accordance with BS 5400: Part 2 as implemented by BD 37 (DMRB 1.3).

**(d) Self Weight**

The self weight of the foundation is  $W_f$  per unit length (kN/m).

**(e) Allowable Net Bearing Pressure for Foundation Design**

Reference shall be made to Chapter 7, Clause 7.5 for the allowable net bearing pressure of the foundation material.

**4.5 Other Types of Foundations for Circular Arches**

Circular arch structures can also be constructed on a suitably designed base slab which supports both walls of the structure simultaneously.

To reduce the effects of the lateral earth pressure  $P_2$ , and loads from the structure, struts may be adopted between strip foundations.

Type of Structure	Values of $\gamma_{f3}$			
	ULS			SLS
	Buckling	Yield	Seam	Thrust on foundations
Multi-radii and bolted circular closed invert	1.15	1.15	1.15	-
Circular Arch Profile, Type 1 20° to 30° re-entry	1.15	1.53	1.53	1.33
Circular Arch Profile, Type 2 10° to 20° re-entry	1.75	2.3	2.3	2.0
Helically Wound	1.10	1.10	-	-

Table 4.1 -  $\gamma_{f3}$  Partial Safety Factors

## 5. STRENGTH PARAMETERS

### Constrained Soil Modulus

5.1 When the structure is to be installed partially or wholly in trench the  $M^*$  of existing materials, within a distance equal to the span on each side of the structure, shall be determined, during the ground investigation for the scheme. Normally the method given in Clause 642 MCHW1 shall be used for plate load testing, for non-cohesive soils. Alternatively the methods described in 5.4 and 5.5 may be used, as appropriate, during the ground investigation.

5.2 The constrained soil modulus  $M^*$  represents the stiffness of the soil surrounding the structure, whether backfill or existing material and is given by:

$$M^* = \frac{(1 - \nu) E_s}{(1 + \nu)(1 - 2\nu)} \quad (\text{N/mm}^2)$$

where  $\nu$  = Poisson's ratio of the soil (to be taken as 0.3 when determining  $M^*$ ) and  $E_s$  = Modulus of elasticity of the soil ( $\text{N/mm}^2$ )

5.3 When carrying out plate load testing using the method given in Clause 642 MCHW1 for non-cohesive soils the Modulus of elasticity  $E_s$  of the soil shall be determined used the formula:

$$E_s = \frac{\pi}{4} (1 - \nu^2) B \frac{\Delta_q I_d}{\Delta_s} \quad (\text{N/mm}^2)$$

where  $B$  = diameter of plate used in the plate load test (mm)

$\Delta_q$  = change in pressure applied by the plate ( $\text{N/mm}^2$ )

$\Delta_s$  = change in average settlement of the plate (mm)

$I_d$  = depth correction factor (taken as 1.0 when test complies with Clause 642 MCHW1)

$\nu$  = Poisson's ratio of the soil (to be taken as 0.3)

5.4 The  $M^*$  for non-cohesive soils may be determined using the results from standard penetration resistance tests (SPT) carried out in accordance with BS 1377: Part 9. In this case the  $M^*$  of the existing soil shall be determined from the relationship:

$$M^* = \frac{0.39N^{1.4}}{\gamma_m}$$

where  $N$  = uncorrected SPT value and

$$\gamma_m = 1.3$$

5.5 For undrained cohesive soils,  $M^*$  may be determined by measuring the coefficient of volume compressibility,  $m_v$ , in accordance with BS 1377 Part 5 and using the formula:

$$M^* = \frac{1}{m_v}$$

The in-situ effective overburden pressure at the level of the crown of the structure shall be used in the test.

5.6 The  $M^*$  value for design shall then be obtained from Table 5.1 based on the in-situ test result and also taking into consideration the excavation width, and the compaction required in MCHW1.

5.7 For structures constructed in embankments, the  $M^*$  value for design shall be obtained from Table 5.1 taking into account the compaction required.

5.8 When the Contractor proposes a value of  $M^*$  for design, in excess of  $33\text{N/mm}^2$ , the Contractor shall substantiate the proposed value by testing the backfill during the back - filling operation, using the method given in Clause 642 MCHW 1 for plate load testing.

### CLOSED INVERT STRUCTURES

Partial or Total Trench

Constrained Soil Modulus (M*) of Existing Soil † (N/mm <sup>2</sup> )	Required Excavation Width on each side of structure	Required Compaction for Backfill Materials ‡	M* Value for Design Use (N/mm <sup>2</sup> )
< 15	Span	85% max dry density	20
	Span	90% max dry density	33 - 80++
≥ 15 but ≤ 33	Minimum +	90% max dry density	As existing soil
	Span	90% max dry density	33 - 80++
> 33	Minimum +	90% max dry density	33
	Span	90% max dry density	33 - 80++

Embankment

-	-	85% max dry density	20
-	-	90% max dry density	33 - 80++

### CIRCULAR ARCH STRUCTURES

Partial or Total Trench

Constrained Soil Modulus (M*) of Existing Soil † (N/mm <sup>2</sup> )	Required Excavation Width on each side of structure	Required Compaction for Backfill Materials ‡	M* Value for Design Use (N/mm <sup>2</sup> )
≤ 33	Span	90% max dry density	33 - 80++
> 33	Minimum ⊕	90% max dry density	33
	Span	90% max dry density	33 - 80++

Embankment

-	-	90% max dry density	33 - 80++
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† Obtained from in-situ test

+ See Clause 9.8

‡ To be determined from BS 1377 Part 4, using the vibrating hammer method.

⊕ See Clause 9.9

++ See Clause 5.8

Table 5.1 - Design Values of Constrained Soil Modulus (M\*)

**Nominal Buckling Stress**

5.9 The method for determining nominal allowable buckling stress ( $f_c$ ) is based on the work of G G Meyerhof (Meyerhof and Baikie, 1963). An adjustment to the theoretical transverse elastic buckling stress ( $f_b$ ) is made to allow for imperfections of the pipe wall. ( $f_y$ ) is the minimum yield strength of the steel.

5.10 The nominal allowable buckling stress  $f_c$  shall be determined from the following formulae:

$$f_c = \frac{f_y}{1 + \left(\frac{f_y}{f_b}\right)}$$

where  $f_b$  = Theoretical transverse elastic buckling stress (N/mm<sup>2</sup>) to be taken as follows:

- a. When the depth of cover above the crown of the structure is greater than or equal to the span of the structure

$$f_b = \frac{2}{a_a} \left[ \frac{kEI_a}{1 - m^2} \right]^{0.5} \text{ provided } \frac{1000S}{\left[ \frac{EI_a}{(1 - m^2)k} \right]^{0.25}} > 4$$

- b. When the depth of cover above the crown of the structure is less than the span of the structure

$$f_b = \frac{2}{a_a} \left[ \frac{k_e EI_a h}{(1 - m^2)S} \right]^{0.5} \text{ provided } \frac{1000S}{\left[ \frac{EI_a h}{(1 - m^2)k_e S} \right]^{0.25}} > 4$$

where  $k$  = Coefficient of soil reaction (N/mm<sup>3</sup>)

$$= \frac{0.333M^*}{1000r} \text{ for circular structures}$$

$$= \frac{0.333M^*}{1000r_t} \text{ for multi-radii structures}$$

and  $k_e$  = Modified coefficient of soil reaction (N/mm<sup>3</sup>)

$$= \left[ 1 - \left( \frac{r}{r+h} \right)^2 \right] k, \text{ for closed circular and circular arch structures}$$

$$= \left[ 1 - \left( \frac{r_t}{r_t+h} \right)^2 \right] k, \text{ for closed multi-radii structures}$$

$E$  = Modulus of Elasticity of steel  
= 205 x 10<sup>3</sup> N/mm<sup>2</sup>

$I_a$  = Adjusted cross-sectional moment of inertia per unit length (mm<sup>4</sup>/mm) of the corrugated steel sheet about its neutral axis, the section being parallel to the length of structure. (Refer to adjustments required in Clauses 6.1 and 7.1) If the cross-sectional moment of inertia varies along the length of the structure, the minimum shall be used. The re-rolled ends of helically wound culvert lengths shall not be considered to affect the value of  $I$  to be used unless they extend for more than 250mm at the end of each length. The effect of the helix angle of helically wound culverts on  $I_a$  may be neglected.

$h$  = Nominal height (m) of fill above the structure (as defined in Clause 3.2)

$a_a$  = Adjusted cross-sectional area of corrugated steel per unit length (mm<sup>2</sup>/mm) (as defined in Clause 4.2)

$m$  = Poisson's ratio of steel = 0.3.

$M^*$  = Constrained soil modulus design value (N/mm<sup>2</sup>) as determined from the requirements of Clauses 5.1 to 5.8.

$r$  = Radius of circular structure (m)

$r_t$  = Radius at the top of multi-radii structure (m)

$S$  = Span of the structure (diameter of circular structure) (m)

## 6. ULTIMATE LIMIT STATE REQUIREMENTS

6.1 The design shall be based on adjusted sectional properties and adjusted nominal seam strengths based on the residual metal thickness after deduction of the appropriate thickness of sacrificial metal loss, as determined in Chapter 8.

6.2 At the ultimate limit state, the compressive hoop stress,  $f_a$ , shall not exceed any of the following:

- a. The nominal allowable buckling stress,  $f_c$ , divided by  $\gamma_m = 1.3$  where  $f_c$  is given in Clause 5.10.
- b. The minimum yield strength,  $f_y$ , of the steel divided by  $\gamma_m = 1.3$ . The value of  $f_y$  will be that nominated and guaranteed by the manufacturer for inclusion in the Type Approval Certificate for the products. (See Annex A, Clause A.2.3.)
- c. In the case of a bolted segmental structure, the stress,  $f_s$ , derived from the adjusted nominal seam strength (as required in Clause 6.1), of the longitudinal bolted joint, divided by  $\gamma_m$  of 2.0. The nominal seam strength shall be as obtained from tests carried out in accordance with Annex B, normally provided by the proprietary manufacturers for standard metal thicknesses. Adjusted seam strength for intermediate values of residual metal thickness may normally be derived by linear interpolation between values provided for the greater and lesser values of metal thickness (in increments no greater than 0.75mm), and for the appropriate number of bolts.
- d. In the case of a helically wound structure, a stress of 370 N/mm<sup>2</sup> divided by  $\gamma_m$  of 2.0.

## 7. SERVICEABILITY LIMIT STATE REQUIREMENTS

### Deflection

7.1 The design shall be based on adjusted sectional properties which allow for the loss of the appropriate thickness of sacrificial metal loss as determined in Chapter 8.

7.2 At the serviceability limit state, the increase in the horizontal diameter or span(S) of the structure,  $\Delta_x$ , determined using the following formula, shall not exceed 5%.

$$\Delta_x = \frac{0.083 (P_d + KP_L) S^4 \times 10^6}{8EI_a + (0.02M^*S^3 \times 10^9)} \quad (\text{m})$$

where  $P_d$  = Design vertical superimposed dead load pressure at the serviceability limit state (kN/m<sup>2</sup>)

$P_L$  = Design vertical live load pressure at the serviceability limit state (kN/m<sup>2</sup>)

$K$  = 1.4, where  $P_L$  is derived from wheel loads which, at the level of the crown of the structure, have a total distributed width less than the span (see Clause 3.5)

or  $K$  = 1.0, for all other cases

$M^*$  = Constrained soil modulus design value (N/mm<sup>2</sup>) as determined from the requirements of Clauses 5.1 to 5.8

$S$  = Span of the structure (diameter of circular structure) (m).

and  $E$  and  $I_a$  are as defined in Clause 5.10.  $S$  is defined in Clause 4.2.

### Allowable Net Bearing Pressure of the Foundation Material for Closed Invert Structures

7.3 The radial soil pressure,  $P$ , for closed circular structures shall not exceed the allowable net bearing pressure of the foundation material. The radial corner pressure  $P_c$ , for multi - radii

structures, shall not exceed the allowable net bearing pressure of the foundation material or 300 kN/m<sup>2</sup>, whichever is less.  $P$  and  $P_c$  are derived from  $C$  (compressive hoop load) calculated from unfactored nominal loads (see Clause 4.3). The allowable net bearing pressure of the foundation material shall be taken to be one third of the ultimate bearing capacity calculated in accordance with BS 8004, as implemented by BD 74 (DMRB 2.1.8). Definitions of these terms are given in BS 8004, Clause 1.2, as implemented by BD 74 (DMRB 2.1.8).

7.4 Where the radial corner pressure  $P_c$  exceeds the lesser of 300kN/m<sup>2</sup> or the allowable net bearing pressure, consideration shall be given to deepening and/or widening the trench in accordance with Clause 9.2. Account may be taken of the reduction in the value of maximum radial soil pressure with distance from the face of the structure within the bedding material. The reduced pressure may be calculated as  $P_c$  times the radius of the corner plates, divided by minimum distance from the centre of radius of the corner plates to the edge of the fill. In any event the radial corner pressure  $P_c$  in contact with selected bedding or fill material shall not exceed 400kN/m<sup>2</sup>.

### 7.5 Circular Arches - Foundation Design

Foundations shall be in accordance with BS 8004, as implemented by BD 74 (DMRB 2.1.8). The bearing pressures generated beneath the foundation shall be calculated for the loadings given in Clause 4.4. The allowable net bearing pressure shall be taken to be one third of the ultimate bearing capacity calculated in accordance with BS 8004, as implemented by BD 74 (DMRB 2.1.8) (see Clause 7.3 above). The maximum bearing pressure shall not exceed the allowable net bearing pressure. Overturning and sliding shall be in accordance with BS 8002 "Earth Retaining Structures". Guidance is also found in "Bridge Foundations and Sub-structures" (Building Research Establishment 1979).

Checks shall be carried out to ensure the above criteria are met when the structure is not subjected to live loading.

Footings should not be supported on piled foundations or otherwise constructed in such a manner that differential settlement would occur between the structure and adjacent embankment, thereby placing additional loading on the structure.

The design of the reinforced concrete foundation shall be in accordance with BS 5400: Part 4 as implemented by BD 24 (DMRB 1.3.1) The detailed design shall be such as to ensure adequacy of connection between the corrugated steel plates and the foundation both during construction and in service (see also Clause 10.6).

Reference shall also be made to Clause 8.17 and 8.18 for additional requirements

## 8. DURABILITY

### General and Definitions

8.1 The design life of corrugated steel buried structures shall be 120 years.

8.2 All surfaces shall be protected by a hot-dip galvanised coating to BS EN ISO 1461: 1999 using a minimum average coating weight in accordance with BS EN ISO 1461: 1999 Table 2. Prior to galvanising, all the structural steel plates shall be fully fabricated, ie cut to size, corrugated, curved, and the bolt holes punched or drilled. The exception to this is the raw edge incorporated into the folded lockseam as part of the manufacturing process of helically wound pipe (formed from pre-galvanised strip to BS EN 10142: 2000). Where site cutting is unavoidable, any exposed edge must be protected with a cold applied zinc rich paint prior to the application of a secondary protective coating.

Helically wound pipe may be formed from electrolytically galvanised steel strip precoated with a suitable secondary protective coating prior to corrugating, curving and crimping. This secondary coating must survive the production process intact and be fully incorporated into the crimp seam. Such a manufacturing system shall have a current British Board of Agrément (BBA), Roads and Bridges Certificate, or equivalent.

8.3 Secondary protective coatings shall be applied to all galvanised steel surfaces. The minimum requirement for a secondary protective coating applied to galvanised steel surfaces shall be a bituminous coating as defined in BD 35 (DMRB 2.4.1) and applied in accordance with that Standard. Protective coatings intended to provide the minimum requirement shall have a current Highways Agency registration in accordance with the procedures described in BA 27 (DMRB 2.4.2). It is not intended that the life of this minimum secondary protective coating shall be taken into account when calculating the required sacrificial steel thickness in accordance with clauses 8.10 to 8.13. Where it is intended that the life of a secondary protective coating shall be taken into account to reduce the required sacrificial steel thickness, that secondary protective coating shall

have a current British Board of Agrément (BBA), Roads and Bridges Certificate, or equivalent, certifying its life before it requires major maintenance. The minimum life of a certified secondary protective coating under service conditions shall be 20 years before it requires major maintenance.

### Measures to achieve Design Life

8.4 Secondary protective coatings may be applied to galvanised surfaces either in the factory, or on site during construction. The method of application of the secondary protective coating shall be as described in BD 35 or in the current British Board of Agrément (BBA), Roads and Bridges certificate, or equivalent. To reduce damage en route to site the manufacturer shall recommend methods for transport and handling of the coated components and structures. A suitable method shall be identified for the repair and patching of damage to coatings caused during transport and construction, and also for making good any deterioration in service.

8.5 In selecting the type of secondary protective coatings to be applied to the basic galvanised steel structure the designer shall take into account not only the environment into which the structure is to be placed but also the effect on the coating of (i) the span of the structure (the greater the span the greater the environmental exposure of the interior coatings), (ii) its location, and (iii) its accessibility for future maintenance.

8.6 Galvanised steel surfaces shall be deemed to corrode at the rates of corrosion given in Clauses 8.11 and 8.13.

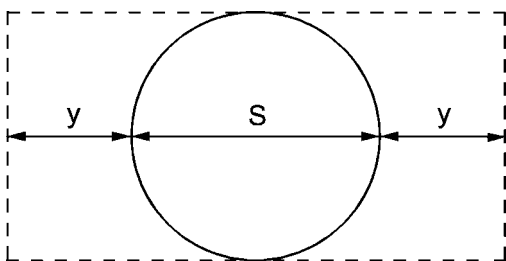
8.7 Each surface of the structure shall be provided with a sacrificial thickness of steel to achieve the required 120 year design life, taking into account the corrosivity of the environment, contributions from galvanising and contributions from secondary protective coatings with a current British Board of Agrément (BBA), Roads and Bridges Certificate or equivalent.

**Corrosivity Classification of Surfaces**

**8.8 Buried Surfaces**

8.8.1 Buried surfaces shall be classified in the Schedule of Employer’s Requirements, either according to the properties of the surrounding soil or of the effluent water carried, or of the ground water where present, as determined from the ground investigation where applicable. The classification shall be the most severe of the three. It should be appreciated that effluent water and/or groundwater can penetrate through bolt holes and seams to affect equally both internal and external surfaces of the culvert. The selected fills, Classes 6K, 6L and 6M described in MCHW1 Clause 623, shall provide a non aggressive environment when dry and used to replace soils within the zone indicated in Clause 8.8.3, but any water present will determine the classification based on its properties. Refer also to Clause 14.3.

8.8.2 The surrounding soil, invert fill, silt deposits and select fill types in Clause 8.8.1 shall be classified using the points system for each property, shown in Table 8.1, and the ground water shall be classified according to the highest aggressivity indicated for any property in Table 8.3. The properties shall be assessed using the test methods listed in Table 8.2. Additionally, where the culvert carries a continuous flow of water or other fluid, classification of the water/ other fluid according to Table 8.3 shall be used to classify both surfaces if it is more severe than the classification of the surrounding soil or ground water.



$$y = 0.4 + 0.23S$$

where S = span of the structure  
and both S and y are in metres

**Figure 8.1 - Corrosivity Classification Zone for the External Buried Surface**

8.8.3 For structures constructed partly or totally in trench, the existing soil within the zone shown in Figure 8.1 shall be tested for corrosivity classification purposes.

8.8.4 The inner surface of the structure shall be regarded as a buried surface beneath any part that is to be covered eg when a structure is used as a vehicular underpass or has invert protection. Any water or fill present shall be used to determine corrosivity classification as in Clauses 8.8.1 and 8.8.2. Both inner and outer surfaces beneath this covered part shall be classified for aggressive conditions if it is likely that road salt or other chemicals in solution will come into contact with them from whatever source. Refer also to Clause 14.3.

**8.9 Exposed Surfaces**

8.9.1 Exposed surfaces shall be classified in the Schedule of Employer’s Requirements according to the aggressivity of any water or other fluid carried by the structure or the aggressivity of the ground water (to allow for water percolation through joints or bolt holes) using the criteria in Table 8.3, and also according to the corrosivity of the atmosphere using the criteria in Table 8.4. The overall classification shall be determined by the most severe of the three.

8.9.2 Consideration shall be given to the effect on exposed surfaces of the presence of chloride ions from road salt. It has been found that chloride can persist in the water carried throughout the year including the summer months and may percolate through joints or bolt holes.

8.9.3 The harshness of the atmospheric environment shall be determined by the Design Organisation from the map “Relative Values of Acid Deposition in the United Kingdom 1986 - 1991” published by ADAS, Reading (3). The corrosivity (acid deposition) value shall be taken as the average of the values indicated by the chart grid square in which the proposed structure is sited and the three nearest adjoining squares. The atmospheric environment for the exposed surfaces shall be determined from this corrosivity value using Table 8.4. However, any other significant environmental factors concerning the location shall also be taken into account eg wind blown salt spray near the coast or pollution from a nearby industrial plant may override the general

classification, or constitute a very aggressive environment.

#### **Life of Protective Coatings and Sacrificial Steel Thickness for All Surfaces**

8.10 The design life of the structure shall be the sum of the life of the sacrificial steel, the life of the galvanised coating and the life of the secondary protective coating.

8.11 The life of the galvanised coating shall be calculated from the rate of corrosion which shall be taken as  $4\mu\text{m}/\text{year}$  in non-aggressive environments and  $14\mu\text{m}/\text{year}$  in aggressive environments. Galvanising thickness may be assumed to be  $1\mu\text{m}$  for each  $7.15 \text{ g}/\text{m}^2$  coating weight.

8.12 The life of a secondary protective coating applied to the galvanised steel components shall be as determined in the current British Board of Agrément (BBA), Roads and Bridges Certificate or equivalent for the coating used.

8.13 The sacrificial thickness of steel required to provide 120 years life less the life of the coatings, shall be calculated from the formulae:

$$T = 22.5t^{0.67}, \text{ for non-aggressive environments; and}$$

$$T = 40.0t^{0.80}, \text{ for aggressive environments,}$$

where  $T =$  thickness of sacrificial steel on each surface ( $\mu\text{m}$ ),

$t =$  life of sacrificial thickness of steel in years.

#### **Invert Protection**

8.14 In addition to the requirements of Clauses 8.10 to 8.13, the invert of all structures carrying water or other fluid shall be protected from the effects of abrasion or erosion by adopting one of the following protection systems:

- a. A reinforced concrete paving (See Clauses 13.1 to 13.7) with a minimum thickness of 100mm for structures of span less than or equal to 2m, and with a minimum thickness of 125mm for all other structures.

- b. As an alternative to a reinforced concrete pavement the following may be used for all spans and gradients:

- i. Paving blocks of 60mm minimum thickness bedded on a compacted Type 1 sand bed, with concrete flaunchings used at the edges to provide a transition between the pavements and the sides of the CSBS.

- ii. Precast slabs or natural stone set into mass concrete having a minimum thickness of 300mm. The pavement may be profiled to suit local requirements, for example the inclusion of a channel to retain water under low flow conditions; shaping to simulate a natural channel; and the provision of animal runs. Weirs or eddy pools may be included within the structure to provide resting places for fish etc. passing through the structure. Upstanding stone set into the concrete may also be used for this purpose.

- iii. A liner plate manufactured from, for example, galvanised steel sheet or glass reinforced plastic (GRP) and pre-shaped to the profile of the invert, may be secured to the CSBS. The void between the liner plate and the invert shall be filled with a cementitious grout or other water resistant material.

- c. A proprietary system giving an equivalent level of invert protection and certified as suitable for the end-use by the British Board of Agrément or equivalent body, who will also certify its design life.

- d. For structures with little or no flow, and which are therefore likely to hold standing water, the following may be used as alternatives to pavements:

- i. A coating certified as suitable for the end use by a current British Board of Agrément, Roads and Bridges Certificate, or equivalent, may be used. The design life shall be stated on the certificate.

- ii. The use of liner plates secured to the structure to cover fluctuations of at least 200mm above and below the range of water depths. The liner plates may be formed from, for example, galvanized steel strip coated with a bitumen-based product (or other suitable protective coating) or from GRP. The plates may be shaped to follow the curvature of the walls of the structure and if required may be of sufficient size to completely cover the invert. Any gap between the liner and the structural shell should be filled with, for example, concrete or cementitious grout or other water resistant filler, to seal the interior surface of the structure. The liner plates may be provided with grouting points to facilitate the filling of the void. If a secondary protective coating is used to protect galvanised steel liner plates, its design life given in a current British Board of Agrément, Roads and Bridges Certificate, or equivalent, may be taken into account.

8.15 Invert protection shall be applied to the wetted periphery of the structure for the winter base flow plus 200mm on each side or 25% of the total circumference for circular structures or 40% of the total circumference for multi-radii structures whichever is greater. Where the invert protection is in concrete and exceeds 25% of the total circumference for circular structures or 40% of multi-radii structures, or as appropriate for a circular arch structure, formwork shall be used in its installation. Any gap between the pavement and the structural plates shall be sealed with an appropriate sealant. The point at which the pavement meets the structural plates shall be shaped to prevent ponding of water against the structural plates. To prevent accelerated differential corrosion of the steel culvert, particularly at the wet/dry line, paved inverts must be inspected at regular intervals when maintenance/replacement shall be carried out as appropriate.

8.16 Subject to the agreement of the appropriate river authority or Environment Agency, screens shall be installed at the inlet of a culvert when it is

anticipated that water-borne stones or other debris in excess of 100mm diameter would otherwise be carried through it during normal or flood conditions. For a culvert installed with a gradient greater than 2 per cent, it is desirable to remove water-borne stones or fragments of less than 100mm diameter through installation of drop inlets or catchpits.

#### **Invert Protection Below Circular Arch Structures**

8.17 Reinforced concrete invert paving as described in the relevant parts of Clause 8.14 shall be provided, where necessary, to protect the arch foundations and foundation material from scour, abrasion or chemical attack from flowing water or other fluid if present. The design of the paving shall take account of hydraulic factors, the foundation material and the nature of the stream/river bed.

8.18 Where the level of winter flow is above the foundation level, the invert paving shall also be applied to the corrugated steel as described in Clause 8.15. The most vulnerable area of an arch structure to deterioration is at the springing and great care shall be taken to avoid water entrapment at this point. A typical detail is shown in Figure 8.2. The detail adopted should avoid entrapment of water on the soil side of the structure and, where concrete upstands are used, against the inside of the arch structure: any gap between the structural plates and the pavement must be thoroughly filled and waterproofed. This seal shall be designed to be maintainable. Care shall be taken to ensure that any of the work done to protect the CSBS will not adversely affect its structural performance.

#### **8.19 Impact Protection**

- a. In the case of structures to be used by vehicles consideration shall be given to protecting the sides of the structure by kerbing and/or by means of an appropriate vehicle restraint system which should not be connected to the sides of the structure. Advice on a suitable system may be obtained from the Overseeing Organisation. Some measure of protection to the crown/soffit should be provided by suitable design of headwalls or ring beams and by alerting drivers to the headroom restriction by means of visual and/or audible warning systems.

- b. Where water carrying structures are to be used by water craft, adequate protection against impact and abrasion shall be incorporated in the form of rubbing boards etc. Suitable provision shall be made for maintaining and replacing such items as necessary.

#### 8.20 Reinforced Concrete Foundations

The Overseeing Organisation's requirements for reinforced concrete are contained in Series 1700 of MCHW1. The concrete mix shall be Grade 30 or higher. Further guidance is given in Series NG1700 of Notes for Guidance on the Specification for Highway Works MCHW2. Detailed guidance on the assessment of ground aggressivity to concrete is given in Part 1 of BRE Special Digest SD1 "Concrete in aggressive ground" (2001). The ground to be assessed should include the surrounding ground, the groundwater, the general embankment fill and the backfill material, and any contained water or effluent to be carried by the structure. It should be noted that the ground properties to be assessed and classification procedure in respect of concrete are different to those recommended for steel structures in Tables 8.1, 8.2 and 8.3 of this Standard. Detailed guidance on the specification of concrete for foundations in aggressive ground is given in parts 2 and 3 of BRE Special Digest SD1. Provision is made in the Digest for the use of various cement and cement combinations in conjunction with aggregates of differing carbonate content. The Digest also recommends additional protective measures for concrete where ground water is mobile and sulfate concentrations are high.

PROPERTY	MEASURED VALUE	POINTS
Soil Type	Fraction passing 63µm sieve $\leq 10\%$ Plasticity Index (PI) of fraction passing 425µm sieve $\leq 6$	+ 1
	Fraction passing 63µm sieve $> 10\%$ PI of fraction passing 425µm sieve $\leq 6$	0
	Any grading PI of fraction passing 425µm sieve $> 6$ but $< 15$	- 1
	Any grading PI of fraction passing 425µm sieve $\geq 15$	- 2
	Organic matter $> 1.0\%$ or material containing peat, cinder or coke	- 3
Resistivity (ohm - cm)	$\geq 10,000$	+ 2
	$< 10,000$ but $\geq 3,000$	+ 1
	$< 3,000$ but $\geq 1,000$	- 1
	$< 1,000$ but $\geq 100$	- 3
	$< 100$	- 4
pH of soil	$6 \leq \text{pH} \leq 9$	0
	$5 \leq \text{pH} < 6$	- 2
	Less than 5 or more than 9	- 4
Water-soluble sulfates (WS) (g/l as SO <sub>4</sub> )	$\leq 0.24$	0
	$> 0.240$ but $\leq 0.60$	- 1
	$> 0.60$ but $\leq 1.20$	- 2
	$> 1.20$	- 4
Chloride ion (ppm)	$\leq 50$	0
	$> 50$ but $\leq 250$	- 1
	$> 250$ but $\leq 500$	- 2
	$> 500$	- 4
Oxidisable sulfides (OS) (% as SO <sub>4</sub> )	$\leq 0.05$	0
	$> 0.05$ but $\leq 0.12$	- 1
	$> 0.12$ but $\leq 0.24$	- 2
	$> 0.24$	- 4

**POINTS TOTAL**

0 or more  
- 1 to - 4  
- 5 or less

**CORROSIVITY CLASSIFICATION**

Non aggressive  
Aggressive  
Very aggressive

**Table 8.1 Corrosivity Classification of Surrounding Soil**

PROPERTY	TEST METHOD
Soil Type:	
Grading	BS 1377 : Part 2
Plasticity Index (PI)	BS 1377 : Part 2
Organic Matter	BS 1377 : Part 3
Resistivity	Clause 637, MCHW1
pH	BS 1377 : Part 3
Water-soluble sulfate and oxidisable sulfides	TRL Report 447 Test Nos 1, 2 and 4
Chloride ion content	BS 812 : Part 117

Table 8.2 - Test Methods for properties required in Table 8.1 and Table 8.3

**NOTES (TABLES 8.1 AND 8.2)**

1. When sampling for organic matter determination, great care must be taken to avoid contamination with top soil, roots or overlying made ground. If contamination cannot be avoided, reduce the number of negative points awarded in Table 8.1.

CORROSIVITY CLASSIFICATION	PROPERTIES OF WATER OR EFFLUENT		
	pH	Chloride ion (ppm)	Water-soluble Sulfate (WS) (g/l as SO <sub>4</sub> )
Non-Aggressive	6 ≤ pH ≤ 9	≤ 50	≤ 0.24
Aggressive	5 ≤ pH < 6	> 50 but ≤ 250	> 0.24 but ≤ 0.60
Very Aggressive	Less than 5 or more than 9	> 250	> 0.60

Table 8.3 - Corrosivity classification of ground water, carried water and other contained fluids

Average Corrosivity Value (Acid Deposition Value from ADAS map)	Classification of the Atmospheric Environment
≤ 2 > 2 but ≤ 4 > 4	Non-Aggressive Aggressive Very Aggressive

Table 8.4 - Classification of Surfaces Exposed to the Atmospheric Environment

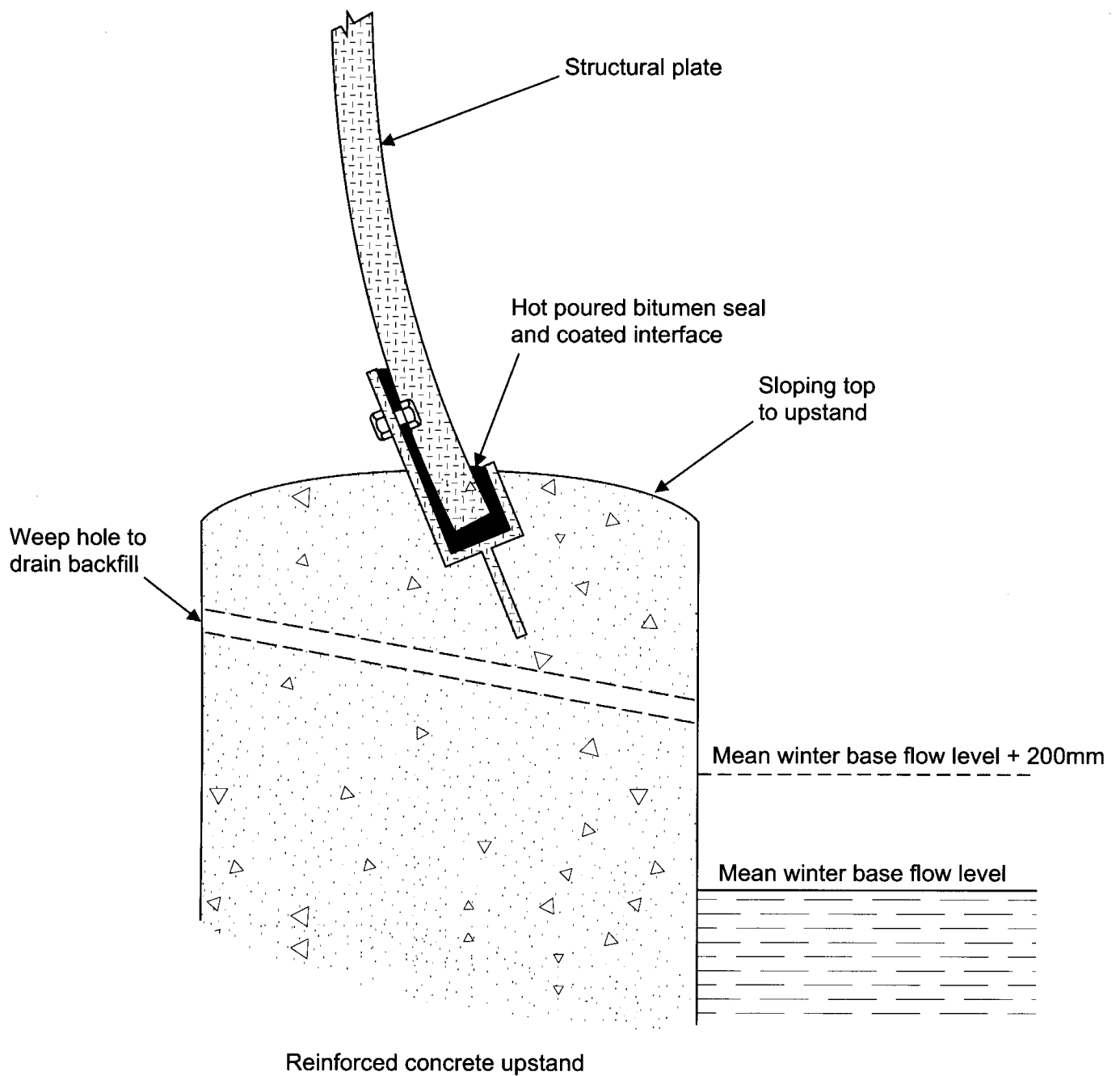


Figure 8.2 Detail of upstand to circular arch structure

## 9. EXCAVATION AND FILLING

### Excavation for Bedding of Closed Invert Structures

9.1 Excavation for the bedding of closed invert corrugated steel buried structures shall extend to a depth below invert level of not less than one tenth of the span and to a width not less than 800mm (500mm for structures up to 3m span) beyond the span on each side, provided that the allowable net bearing pressure at this depth exceeds the maximum radial soil pressure ( $P$  or  $P_c$ ). In any event the excavation width should be not less than the extent of side fill required in Table 5.1. The excavation shall extend a length not less than 300mm beyond each end of the structure (see Figures 9.1 and 9.2).

9.2 Where the allowable net bearing pressure of the foundation material at the excavation level given above is less than the maximum radial soil pressure ( $P$  or  $P_c$ ), the excavation shall be continued to such a depth that the allowable net bearing pressure at the new excavation level is not less than the maximum radial soil pressure. Account may be taken of the reduction in the value of maximum radial soil pressure with distance from the face of the structure as described in Clause 7.4. The allowable net bearing pressure of the bedding material must not be exceeded. When additional excavation is necessary it shall be wider than the limits given in Clause 9.1 by an amount on each side equal to the extra depth (see Figures 9.1 and 9.2).

9.3 Excavation in hard material shall extend to an additional depth of not less than 300mm below the level indicated in Clause 9.1 plus 40mm for each metre of cover, in excess of 8m, above the crown of the completed structure up to a maximum additional depth of 600mm.

### Excavation of the Foundation Level for Circular Arches

9.4 The excavation for the foundation level shall extend to a width not less than 800mm (500mm for circular arches up to a 3m span) beyond the span on each side and in any event to be not less than the extent of side fill required in Table 5.1.

9.5 Additional excavation may be necessary to suit the foundation size selected and the working space required for construction of the foundation and backfilling the structure.

9.6 In cases where the net allowable bearing pressure of the foundation material at an excavation level results in an impractical size of foundation, as calculated in accordance with Clause 7.5, the excavation level may be continued to such a depth to locate an improved net allowable bearing pressure of the foundation material. The additional excavation can be replaced with suitable foundation material as indicated on Figures 9.1 and 9.2. Alternatively, the depth of the foundation may be increased. In both cases the foundations shall be designed in accordance with Clause 7.5.

9.7 The depth of excavation to the foundation level is measured from the top of the foundation and is defined as  $(1000+D)$ mm (see Figures 9.1 and 9.2). In such a case, the width of excavation at the foundation level shall be  $(500+D)$ mm for circular arches up to 3m span and  $(800+D)$ mm for circular arches of span 3m or greater, beyond the span on each side (see Figures 9.1 and 9.2).

### Trench Width for Closed Invert Structures

9.8 The trench width shall be not less than three times the span ( $S$ ) of the structure, unless the constrained soil modulus ( $M^*$ ) of the existing soil is greater than the values adopted for design (see Table 5.1) when the trench width may be reduced to the minimum required for the lower bedding material, that is normally the span plus 500mm each side for structures up to 3m span, or span plus 800mm each side for larger spans, or as otherwise required in Clause 9.2 and shown in Figure 9.1. A partial trench condition occurs when the level of existing soil suitable for retention within a distance of a span either side of the structure lies between the crown of the structure and the underside of the lower bedding. Refer to Figure 9.1. Partial trenches can be treated similarly to trenches; alternatively the excavation shall extend to a distance equal to the span on each side of the structure. Reference to Clause 8.8.3 is also necessary.

**Trench Width for Circular Arches**

9.9 The trench width shall be not less than three times the span (S) of the structure, unless the constrained soil modulus ( $M^*$ ) of the existing soil, within this extent, is greater than or equal to the values adopted for design (see Table 5.1), when the trench width may be reduced to the minimum required for the width of excavation specified in Clause 9.7 and shown in Figure 9.1. A partial trench condition occurs when the level of existing soil suitable for retention within a distance of a span either side of the structure lies between the crown of the structure and the underside of the lower bedding. Refer to Figure 9.2. Partial trenches can be treated similarly to trenches; alternatively the excavation shall extend to a distance equal to the span on each side of the structure. Reference to Clauses 8.8.3, 9.4 and 9.7 is also necessary.

**Filling - General**

9.10 The earthworks requirements for the selected fills and their compaction requirements are given in Series 600 MCHW1.

**Filling - Bedding for Closed Invert Structures**

9.11 As far as possible, the lower bedding material (Class 6K in Table 6/1 MCHW1) shall be shaped to fit the invert such that it supports 20% of the circumference of circular structures or the whole of the portion of cross section of radius  $r_b$  (see Table 1.1) for multi-radii structures. If this cannot be met and the structure is erected on flat or partially preshaped bedding, care must be taken to ensure that the lower bedding material is properly placed and compacted under the haunches.

9.12 The upper bedding material (Class 6L in Table 6/1 MCHW1) is as described in Series 600 MCHW1.

**Filling - Surround for All Structure Types**

9.13 The surround material (Class 6M in Table 6/1 MCHW1) as described in Series 600 MCHW1 shall be used for filling all excavations, except those in hard material for which lower bedding material (Class 6K) shall be used, with minimum excavation. In all cases (for embankments and trenches and partial trenches) surround fill shall

extend to a height of not less than a fifth of the span or 650mm whichever is the greater, above the crown of the structure, or to the formation level of the road if this is lower. See Clause 9.16 for requirement for placing of fill.

9.14 In embankments the surround material shall be used for a minimum distance equal to the span on each side of the structure. In trenches the surround material shall be used for a minimum distance as defined in Clause 9.8 or 9.9 on each side of the structure. For partial trenches (where the level of the existing ground suitable for retention is lower than the crown of the structure) the surround material in the trench may be used for a minimum distance as defined in Clause 9.8 or 9.9. Alternatively, the fill shall extend to a distance equal to the span of each side of the structure. The surround material above the level of the existing soil suitable for retention in partial trench conditions shall be used for a minimum distance equal to the span on each side of the structure. (See Figures 9.1 and 9.2.)

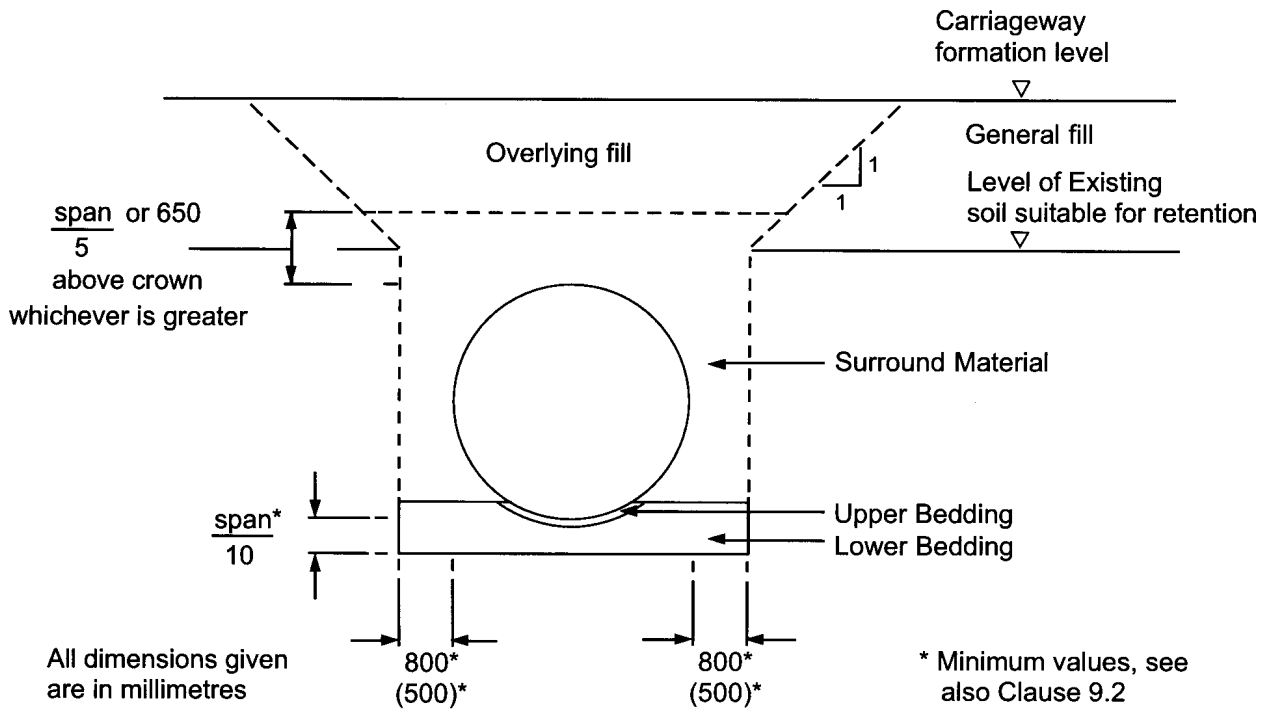
**Filling - Overlying Fill above All Structural Types**

9.15 The overlying fill material as described in MCHW1 Series 600 shall be used for embankment construction in the zone over the structure shown in Figures 9.1 and 9.2. Argillaceous rocks such as shales and mudstones, slag and PFA shall not be used as fill or road sub-base materials in this zone.

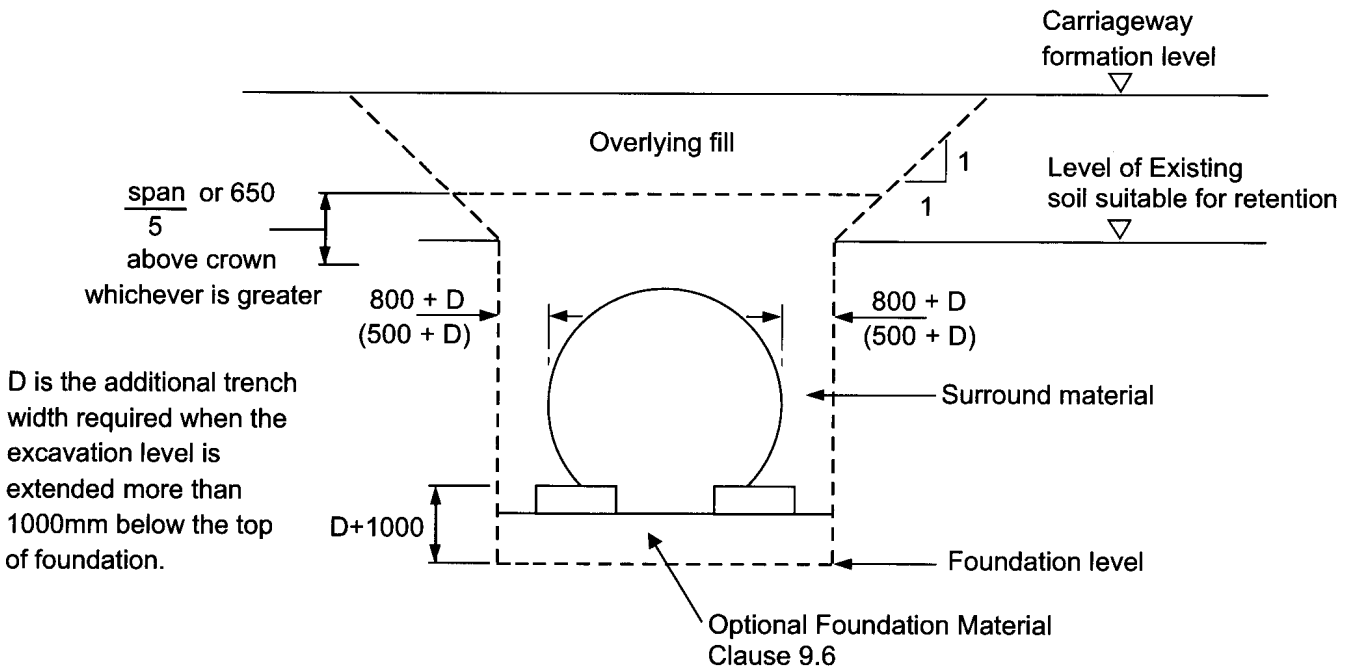
**Filling - Deposition, Spreading and Compaction**

9.16 Surround fill and fill placed above the level of the crown of the structure, as described in Clause 9.13 to 9.15, shall be deposited, spread and compacted in such a manner that any out of balance forces transmitted to the culvert are kept to a minimum. This will require that trafficking by construction plant is not all in one direction and that the compacted surface of the fill is kept as near horizontal as practicable.

9.17 Compaction of the surround material shall comply with the requirements given in Series 600 MCHW1 except that in some circumstances it may be more economical to relax the requirement to 85% of the maximum dry density. (See Table 5.1.)



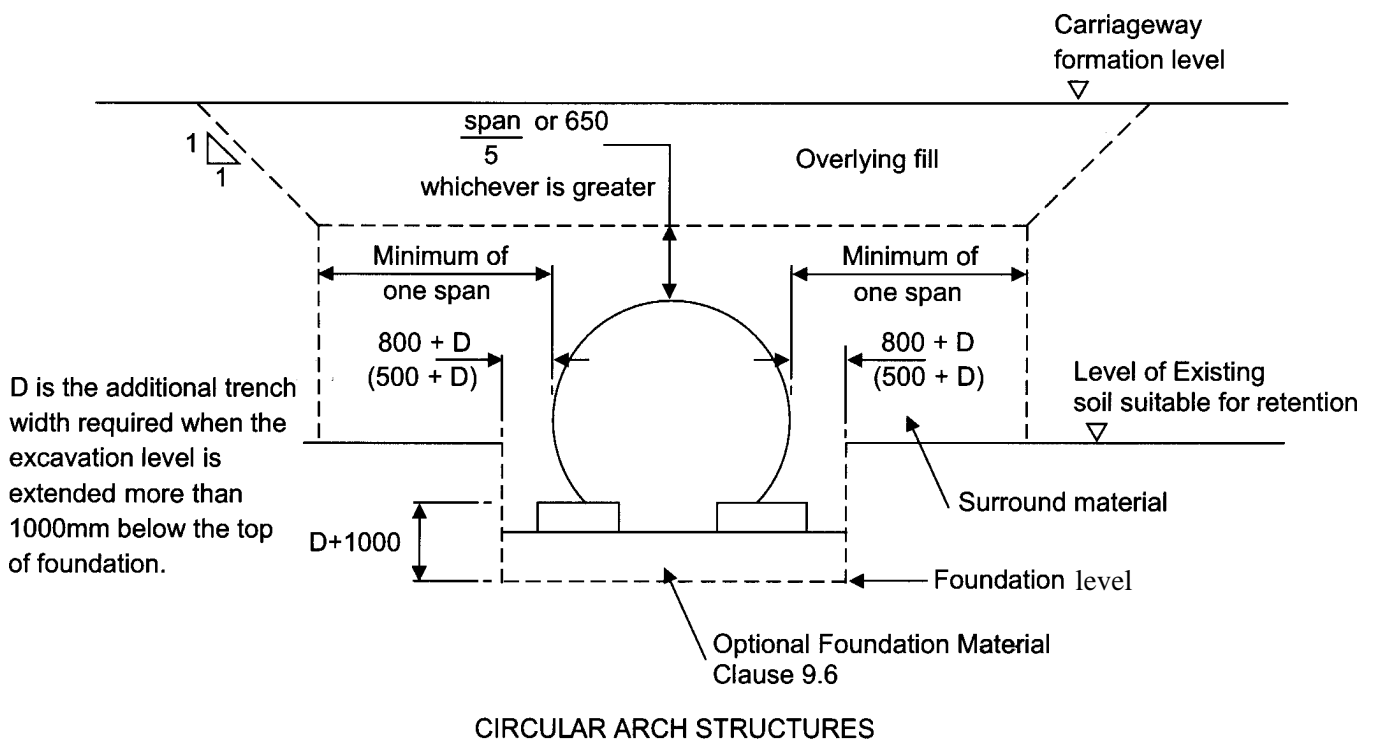
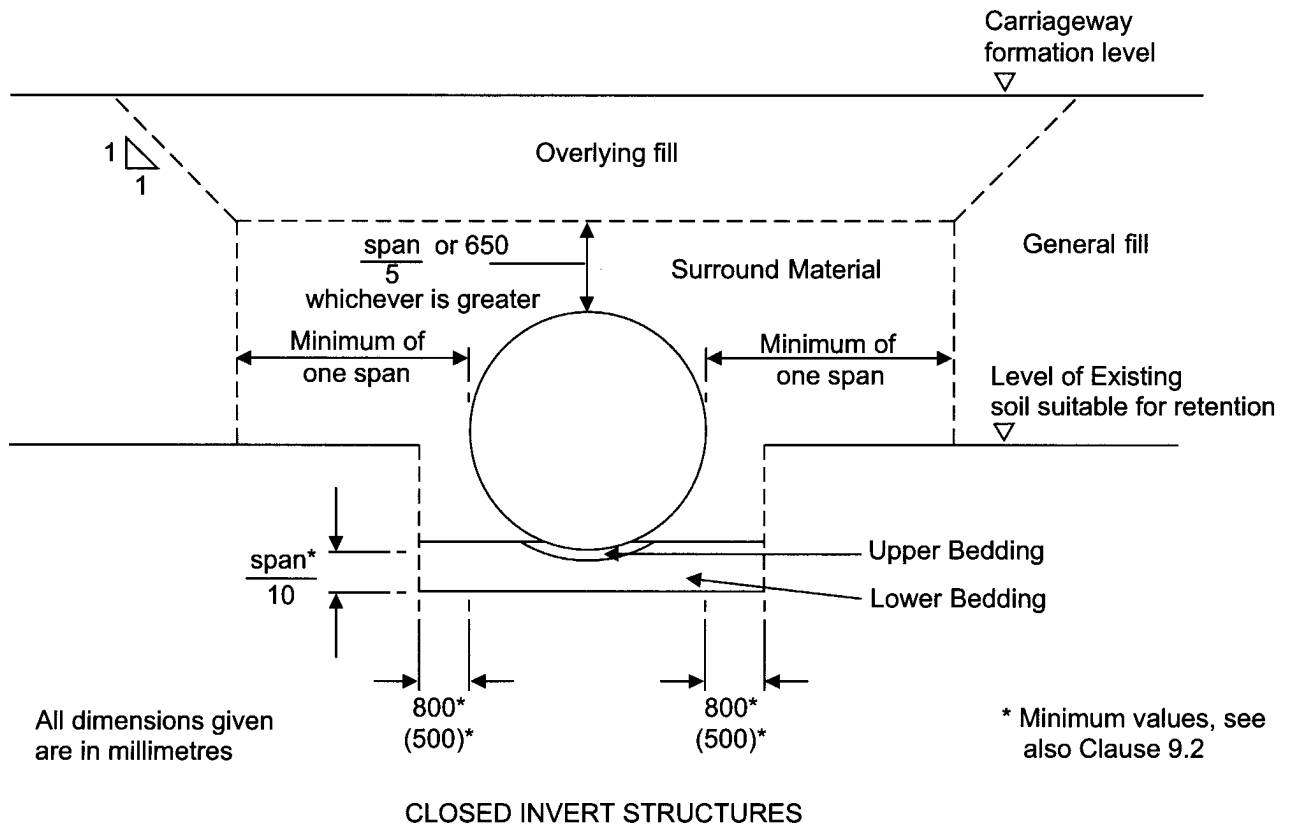
CLOSED INVERT STRUCTURES



CIRCULAR ARCH STRUCTURES

Figures in brackets refer to structures of up to 3m span

Figure 9.1 - Typical Fill Requirements for Minimum Excavation Option as described in Chapter 9, for a Trench Condition



Figures in brackets refer to structures of up to 3m span

Figure 9.2 - Typical Fill Requirements for Minimum Excavation Option as described in Chapter 9, for a Partial Trench Condition

## 10. HANDLING AND INSTALLATION

10.1 Structures must have enough rigidity to permit practical handling and installation. For this purpose a flexibility factor, F shall be calculated from the formula:

$$F = \frac{S^2 \times 10^6}{EI}$$

where S = Span of the structure (m)  
E = Modulus of Elasticity of steel  
= 205 x 10<sup>3</sup> N/mm<sup>2</sup>  
I = Cross-sectional Moment of inertia per unit length, (mm<sup>4</sup>/mm) of the corrugated steel sheet about its neutral axis, the section being parallel to the length of the structure. If the cross sectional moment of inertia varies along the length of the structure, the minimum shall be used. The re-rolled ends of helically wound culvert lengths shall not be considered to affect the value of I to be used unless they extend for more than 250mm at the end of each length. The effect of the helix angle of helically wound culverts on I may be neglected.

10.2 For acceptable performance during installation, the flexibility factor, (F) must be less than a limiting value (F<sub>max</sub>), which depends on the depth of corrugation (d<sub>c</sub>). For the purposes of this Clause the depth of corrugation (d<sub>c</sub>) is defined as the depth in millimetres from any peak to the adjacent trough in the corrugation.

10.3 For circular structures, circular arches and multi-radii structures with  $1.3 > \frac{r_c}{r_t} > 0.7$  where

r<sub>c</sub> is the corner radius and r<sub>t</sub> is the top radius, the value of F<sub>max</sub> shall be calculated from the formula:

$$F_{\max} = 0.29 - 0.0034 d_c$$

but with a minimum of 0.115mm/N and a maximum of 0.25mm/N. d<sub>c</sub> is defined in Clause 10.2.

10.4 For multi-radii structures with  $0.7 > \frac{r_c}{r_t} > 0.2$ ,

as defined in Clause 10.3 the value of F<sub>max</sub> shall be calculated from the formula:

$$F_{\max} = 0.435 - 0.0051 d_c$$

but with a minimum of 0.173mm/N and a maximum of 0.375mm/N. d<sub>c</sub> is defined in Clause 10.2.

10.5 If  $F \leq F_{\max}$  the structure is acceptable. In the case where  $F_{\max} < F$  the structure is not acceptable and either the span S must be reduced, the flexural rigidity EI must be increased or temporary supports must be used. If temporary supports are used (Clause 3.1b) then a temporary works design is required to ensure local overstressing and distortion of the corrugated steel is avoided. Partial safety factors in Clause 3.10 (Table 3.1) shall be used in conjunction with appropriate values of γ<sub>f3</sub> (Table 4.1).

### Foundations for Circular Arches

10.6 The connection between the corrugated steel plates and the reinforced concrete foundation is normally achieved using a seating channel supplied by the manufacturer. The seating channel shall be capable of transmitting loads from the corrugated steel plates into the foundation both during construction of the structures and in service. Reference shall be made to the requirements of Clause 7.5.

## 11. END TREATMENT

11.1 End treatments shall be included within the designated outline as defined in SD4 (MCHW 0.2.4). All end treatments shall be designed in accordance with Clauses 11.2 to 11.6 and regard shall be paid to the aesthetic appearance of the structure.

11.2 Reinforced concrete collars, headwalls, or retaining walls shall be designed to support the face edges of the corrugated steel where the skew angle of the corrugated steel structure exceeds  $15^\circ$ , the bevel of square ends exceeds 2:1 (eg embankment flatter than 1 in 2), or the cut end supports highway loading. In these instances the reinforced concrete elements shall be designed to offer adequate support to the corrugated steel shell where it is discontinuous and unable to act in ring compression normal to the centre line of the corrugated steel structure. The structural adequacy of the corrugated steel plates is to be considered. Structural steel ring beams, collars, and spreader beams may be utilised, together with ties anchored into the fill, and shall be designed to the appropriate Standards. Reinforced concrete elements shall be designed according to BS 5400: Part 4 as implemented by BD 24 (DMRB 1.3.1). Account shall be taken of the effects of the construction sequence, loads from the corrugated steel plates being directly supported, other loads from the corrugated steel structure, the self weight of the reinforced concrete, earth pressures, the effects of ground creep and settlement, and hydraulic loadings. Partial safety factors in Tables 3.1 and 4.1 shall be adopted as appropriate. If temporary works are necessary the requirements of Clause 10.5 shall be adopted.

11.3 In other instances the backfill and free edges of other corrugated structures shall normally be protected by end treatments such as headwalls or collars. The loading considerations for the design of the end treatment shall be the same as those required in Clause 11.2.

11.4 Consideration should be given to the weight of the wet concrete when forming the headwall, ring beam or collar during construction. In some circumstances, it may be necessary to install temporary supports.

11.5 For hydraulic structures, measures shall be taken to secure the metal edges at inlet and outlet against hydraulic forces.

11.6 In the case of hydraulic structures, the headwall, ring beam or collar shall be designed to take into account the possible effects of scour of the material beneath the invert of the structure.

11.7 The designer shall identify on the Contract drawings any construction sequence assumed in the design.

## 12. OVERLYING REINFORCED CONCRETE SLAB

12.1 Where the depth of cover measured from the finished road surface to the crown of the structure is less than the greater of span/5 or 650mm (Clause 1.3b), a reinforced concrete slab may be used within the thickness of the carriageway pavement above the corrugated steel culvert or underpass with a reduced thickness of cover above the crown of the structure. A minimum thickness of 150mm of surround material (Clause 9.13, Class 6M in Table 6/1 MCHW1) shall be placed and compacted between the crown of the structure and the underside of the slab.

12.2 The length of the reinforced concrete slab shall be sufficient to extend beyond each side of the structure for a distance of 3 metres or half the span of the structure whichever is greater.

12.3 Where the carriageway pavement is reinforced concrete, the slab may constitute the concrete pavement continued over the crown of the structure. In this case, the thickness of the slab (minimum 200mm) and reinforcement shall be in accordance with HD 26: Pavement Design (DMRB 7.2.3.)

12.4 Alternatively the concrete may form the lower half of a composite pavement, normally overlain by 100mm of flexible surfacing. Again thickness and reinforcement shall be in accordance with HD 26 or with BS 5400: Part 4 as implemented by BD 24 (DMRB 1.3.1).

12.5 It is important to ensure adequate compaction of the fill material under the ends of the slab to prevent the formation of voids leading to the production of dynamic load effects under trafficking.

## 13. CONCRETE INVERT PAVING FOR CLOSED INVERT STRUCTURES

13.1 When a concrete invert paving in accordance with Clause 8.14 is to be used, it shall be as described in the following Clauses.

13.2 The concrete shall be Class 30/20 as described in MCHW1 Series 1700.

13.3 The concrete invert paving shall be reinforced with a steel fabric complying with MCHW1 Series 1700 having mesh dimensions not greater than 150mm x 300mm and a nominal wire size not less than 5mm. All laps in the mesh shall be at least 150mm. The steel fabric shall be securely fixed to the structure by means of fixings at the bolt positions. It shall extend to within a distance not greater than 100mm, nor less than 40mm inside the edges of the concrete on each side. A nominal cover of 45mm shall be provided to all other faces, including that to the crest of the corrugations in the structural steel.

13.4 The invert shall be cast in lengths not exceeding 10 metres with the provision of a water bar between adjacent panels and the joints sealed with a joint sealant to Clause 2303 MCHW 1.

13.5 Prior to commissioning, a flaunch (mortar slope) shall be applied at the plate/pavement interface to seal gaps and avoid the problem of standing water on ledges adjacent to the shell of the CSBS.

13.6 At each end of the structure the concrete invert paving shall be either:

- a. Terminated with a toe that returns at least 200mm under the structural steel forming the structure. The steel fabric shall be folded under the lips of the structure to suit. The toe shall be detailed with a thickness of not less than that required for the paving, as determined from Clause 8.14, or
- b. Detailed to suit any headwall arrangement eg paving reinforcement lapped with headwall reinforcement.

13.7 All foreign matter, (but not any secondary proprietary protective coating unless indicated otherwise in the Type Approval Certificate or British Board of Agrément (BBA), Roads and Bridges Certificate referred to in Clause 1.6) and free standing water shall be removed from the surfaces to be paved, before commencing work.

## 14. CARRIAGEWAY DRAINAGE

14.1 All measures shall be taken to avoid contaminated carriageway water (impregnated with road salts) collecting on the buried face of the structure. In the vicinity of the structure, carriageway drainage shall be constructed with watertight joints and tested as described in the 500 Series MCHW1, and the trenches lined with a heavy-duty impervious membrane prior to backfilling. Carriageway drainage filter drains (including fin drains), soakaways, and where possible, gullies and chambers, shall not be sited near the structure. A zone bounded by planes projected at a slope of 1 horizontally to 1 vertically from the extremities in plan of the structure will normally be sufficient for these requirements.

14.2 Carriageway drainage outfalls shall be sited downstream of the structure.

14.3 If, exceptionally, the requirements of Clauses 14.1 and 14.2 are not achieved it shall be assumed that contaminated water will affect both the inner and outer faces of the corrugated steel structure, giving rise to the surfaces being classified for aggressive conditions in accordance with Clauses 8.8 and 8.9.

## 15. MULTIPLE INSTALLATIONS

15.1 Adjacent structures shall be separated sufficiently for mechanical equipment to operate between them for adequate compaction. In the absence of special measures, the spacing shall not be less than:

- |                        |     |  |
|------------------------|-----|--|
| circular structures    | i)  | up to 2m span - one half of the span of the larger structure or 600mm whichever is greater.  |
|                        | ii) | 2m to 8m span - 1m.  |
| multi radii structures | i)  | up to 3m span - one third of the span of the larger structure or 600mm whichever is greater. |
|                        | ii) | 3m to 8m span - 1m.  |

## 16. TECHNICAL REQUIREMENTS AND DESIGN CHECKLIST

16.1 The procedures to be followed when specifying a proprietary manufactured structure are given in Standard SD4 (MCHW 0.2.4). The particular requirements for corrugated steel buried structures are described here.

16.2 The Design Organisation, prior to inviting tenders, normally submits an Outline Approval in Principle containing a Schedule of Employer's Requirements which should include the following information:

- i. Location plan and name of structure.
- ii. Environmental considerations (see clause 1.4).
- iii. Long Section along centre-line of structure.
- iv. Finished levels of carriageways and side slopes within designated outline.
- v. Skew of structure.
- vi. Minimum width of structure.
- vii. Minimum headroom of structure.
- viii. Hydraulic requirements or clearance envelope, if any, and requirement for invert protection.
- ix. Gradient of invert.
- x. End detail requirements, including any requirement for reinforced concrete headwalls.
- xi. Highway loading requirements.
- xii. The value of constrained soil modulus  $M^*$  to be assumed for existing soil.
- xiii. Allowable net bearing pressure for foundation material.
- xiv. The corrosivity (aggressivity) classification of existing soil, ground water, contained water/effluent, the atmosphere and of any fill material (or silt) to be placed inside the structure in contact with the corrugated steel. A drawing is also required showing the corrosivity

classification for each surface type on the structure on a suitably marked up cross section. The extent of each surface type (including maintained surfaces) shall be clearly indicated.

- xv. Protection of structures against vehicle impact.
- xvi. Public safety requirements including lighting and protection for pedestrians round headwalls.
- xvii. Aesthetic requirements including colour of coatings.
- xviii. Identification of any elements in addition to the corrugated steel plating requiring design.
- xix. Any other essential requirements.

Special requirements should be avoided. However where the circumstances are such that they are justified then care must be taken to avoid requirements implicitly favouring the system of a particular manufacturer.

16.3 Subsequent to the award of contract and prior to the commencement of construction, the Contractor normally completes the AIP form (containing the Schedule of Employer's Requirements), the design and the design certificate, and submits these for approval/appraisal. The full design normally contains the following additional information relating to the particular proprietary product which forms the basis of the design. For bolted segmental structures the list includes:

- a. Structure Geometry:
  - Structure type/shape
  - Internal span
  - Internal height
  - Radii.

- b. Materials:
- Steel specification
  - Corrugation dimensions
  - Nominal thicknesses of steel and galvanising
  - Additional protective coatings (if any)
  - Proprietary secondary protective coatings (if proposed) - thickness and other relevant details
  - Invert protection system details - concrete or proprietary system.
- c. Bolts and Nuts:
- Specification
  - Arrangement at joints
  - Torque.
- d. Footings of Circular Arches (if relevant):
- Geometry
  - Concrete type
  - Reinforcement
  - Allowable net bearing pressure of foundation material
  - Means of connecting structure to footing.
- e. End Treatment:
- Geometry
  - Concrete type and reinforcement (if required)
  - Means of connection to structure.
- f. Construction sequence.
- g. Confirmation of foundation depth and material.
- h. Internal fill in contact with wall of structure:
- Soil properties, bulk density, grading and corrosion classification in accordance with Chapter 8.
- i. The current Type Approval Certificate and current British Board of Agrément Roads and Bridges or equivalent Certificate or Certificates - as required in Clauses 1.6 to 1.9.
- And for helically wound pipes:
- a. Structural Geometry:
- Internal diameter.
- b. Materials:
- Corrugation dimensions
  - End corrugation dimensions
  - Nominal thicknesses of steel and galvanising
  - Coupling band details
  - Proprietary protective coatings (if proposed) - thickness and other relevant details
  - Invert protection system details.
- c. End Treatment:
- Geometry
  - Concrete type and reinforcement (if required)
  - Means of connection to structure.
- d. Construction sequence.
- e. Confirmation of foundation depth and material.
- f. Internal fill in contact with wall of structure:
- Soil properties, bulk density, grading and corrosion classification in accordance with Chapter 8.
- g. The current Type Approval Certificate and current British Board of Agrément Roads and Bridges or equivalent Certificate, as required by Clauses 1.6 to 1.9.
- 16.4 The Contractor shall additionally supply with his design the following information relating to the design requirements of the earthworks:
- Lower Bedding Material:
- Constrained soil modulus ( $M^*$ ).
  - Compaction (% of maximum dry density).
  - Durability classification to Clause 8.8.2.
- Surround Material:
- Constrained soil modulus ( $M^*$ ).
  - Compaction (% of maximum dry density).
  - Durability classification to Clause 8.8.2.

16.5 The further stages in the post award contract procedures are given in Chapter 4 of Standard SD 4 (MCHW 0.2.4).

16.6 Following construction copies of the following will be required for inclusion in the maintenance manual and health and safety file:

1. The completed AIP used for design.
2. A set of as constructed drawings, including a record of the final structure profiles achieved.
3. A design summary for information listed in Clauses 16.3 and 16.4.
4. Other relevant information.

## 17. REFERENCES

### 17.1 Design Manual for Roads and Bridges

- Volume 1: Section 1 Approval Procedures  
BD 2: Part 1 - Technical Approval of Highway Structures (DMRB 1.1)
- Volume 1: Section 3 General Design  
BD 24: Design of Concrete Bridges. Use of BS 5400 Part 4(DMRB 1.3.1).  
BD 37: Loads for Highway Bridges (DMRB 1.3)
- Volume 2: Section 2 Substructures  
BD 74 Part 8 – Foundations (DMRB 2.1.8)
- Volume 2: Section 4 Paints and other Protective Coatings  
BD 35 Quality Assurance Scheme for Paints and Similar Protective Coatings
- Volume 2: Section 4 Paints and other Protective Coatings  
BA 27 Quality Assurance Scheme for Paints and Similar Protective Coatings
- Volume 7: Section 2 Pavement Design and Construction  
HD 26: Pavement Design (DMRB 7.2.3)
- Volume 10: Environmental Design.

### 17.2 Manual of Contract Documents for Highway Works

- Volume 0: Section 2 Implementing Standards  
SD4 Procedures for Adoption of Proprietary Manufactured Structures (MCHW 0.2.4).  
Section 3 Advice Notes  
SA1 Lists of Approved/Registered Products (MCHW 0.3.1)
- Volume 1: Specification for Highway Works  
HMSO 1998 (MCHW1) with revisions to 2001

### 17.3 British Standards

- BS 812:** Part 117: 1988 - Method for Determination of Water Soluble Chloride Salts. Replaced by BS EN 1744-1:1998 but remains current
- BS 1377:** 1990 - Methods of Test for Soils for Civil Engineering Purposes.  
Part 2: Classification tests.  
Part 3: Chemical and electro-chemical tests.

- Part 4: Compaction-related tests.  
Part 5: Compressibility, permeability and durability tests.
- Part 9: In-situ tests.  
**BS EN ISO 1461** 1999. Hot dip galvanised coatings on fabricated iron and steel articles - Specifications and test methods.
- BS EN 1744** Tests for chemical properties of aggregate.
- BS EN 1744-1** 1998 - Chemical analyses  
**BS 7371:** Coatings on metal fasteners  
Part 1: 1991: Specification for general requirements and selection guidelines  
Part 6: 1998: Specification for hot dipped galvanised coatings  
**BS 5400:** Steel, Concrete and Composite Bridges.  
Part 1 1988: General Statement.  
Part 2: 1978: Specification for Loads.  
Part 4: 1990: Code of Practice for Design of Concrete Bridges.  
**BS 5930:** 1981 - Code of Practice for Site Investigations  
**BS 8002:** 1994 - Earth Retaining Structures  
**BS 8004:** 1986 - Foundations  
**BS EN ISO 9002:** 1994. Quality Systems. Model for quality assurance in production, installation and servicing. (Formerly BS 5750:Part 2).
- BS EN 10142** 2000. Specification for continuously hot-dip zinc coated low carbon steel strip and sheet for cold forming: technical delivery conditions. (Replaces BS 2989: 1982).
- BS EN 10143** 1993. Continuously hot-dip metal coated sheet steel and strip. Tolerances on dimensions and shape. (Replaces BS 2989:1992)

### 17.4 Other Documents (reference number)

1. Poulos, H. G. and Davis E. B. - "Elastic Solutions for Soil and Rock Mechanics" - John Wiley and Sons, 1974, Chapter 6.
2. Vogel, A. I. - "Vogel's Qualitative Inorganic Analysis - Sixth Edition (revised by G. Svehla)" - Longman, 1987 (pp 159 - 161).

3. "Relative Values of Acid Deposition in the United Kingdom 1986 - 1991" - available from ADAS Consultancy Ltd, ADAS Bridgets, Martyrs Worthy, Winchester, Hants SO21 1AP.
4. TRL Report 447 "Sulfate specification for structural backfills" Reid J.M., M.A. Czerwko, J.C. Cripps and D. M. Hiller, Transport Research Laboratory, Crowthorne. (2001)

#### **17.5 Bibliography**

1. Meyerhof G. G. and Baikie L. D. - "Strength of Steel Culvert Sheets Bearing against Compacted Sand Backfill" Highway Research Board, Research Record No. 30, 1963. HRB, 2101 Constitution Avenue, Washington DC 240418.
2. "Bridge Foundations and Sub-structures", Department of the Environment, Building Research Establishment, London 1979: Her Majesty's Stationery Office.
3. BRE Special Digest SD1. Concrete in aggressive ground. (2001).

## 18. ENQUIRIES

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

Chief Highway Engineer  
The Highways Agency  
St Christopher House  
Southwark Street  
London SE1 0TE

G CLARKE  
Chief Highway Engineer

Chief Road Engineer  
Scottish Executive Development Department  
Victoria Quay  
Edinburgh  
EH6 6QQ

J HOWISON  
Chief Road Engineer

Chief Highway Engineer  
The National Assembly for Wales  
Cynulliad Cenedlaethol Cymru  
Crown Buildings  
Cathays Park  
Cardiff CF10 3NQ

J R REES  
Chief Highway Engineer

Director of Engineering  
Department for Regional Development  
Roads Service  
Clarence Court  
10-18 Adelaide Street  
Belfast BT2 8GB

G W ALLISTER  
Director of Engineering

## ANNEX A: PROCEDURE AND CONDITIONS FOR OBTAINING A TYPE APPROVAL CERTIFICATE FOR CORRUGATED STEEL BURIED STRUCTURES

A1. The manufacturer or supplier will be required to obtain from The Highways Agency of the Department of Transport, Local Government and the Regions, a Type Approval Certificate for any bolted segmental or helically wound structure before it may be offered in a tender. Separate Certificates must be obtained for bolted segmental and helically wound structures.

A2. The following evidence and information is required by Safety, Standards and Research, Civil Engineering Division, The Highways Agency:

- A.2.1. A full technical specification of the product supported by two copies of the Manufacturer's Design Manual and any relevant current British Board of Agrément Roads and Bridges Certificates or equivalent. In the case of arch profile structures, the arrangements to connect the corrugated steel plates to the reinforced concrete shall be fully described. In the case of helically wound structures, a current British Board of Agrément Roads and Bridges Certificate is mandatory.
- A.2.2. Confirmation that all the requirements of this Standard are satisfied.
- A.2.3. The minimum yield strength  $f_y$  (N/mm<sup>2</sup>) of the steel forming the structure.
- A.2.4. The results of tests carried out to determine the nominal seam strengths (kN/m) to be used in the design of the structure. These tests shall be carried out and reported on as described in Annex B.
- A.2.5. A specification for the bolts and nuts employed and the European or national Standard(s) which they meet. The recommended range of torque values (kN.m) applied to the bolts shall be stated.

A.2.6. The results of tests carried out to determine the tensile strengths (kN/m) of the lockseams in helically wound corrugated steel. The lockseams tests shall be able to withstand the forces as described in Annex C.

A.2.7. Evidence that the manufacturer operates a Quality Control System conforming to BS EN ISO 9002:1994.

A.3. The continuing validity of the Certificate is conditional upon an acceptable quality of workmanship and materials being maintained and upon satisfactory findings from checks and tests which The Highways Agency or its authorised representatives will make from time to time either on site or at the manufacturer's premises.

A.4. Any variation in the specification of a product that has been submitted to The Highways Agency should be notified immediately. Failure to do so may result in the withdrawal of the Type Approval Certificate.

A.5. Applications for Type Approval of bolted segmental products from suppliers and manufacturers should be made to The Highways Agency, Safety, Standards and Research, Civil Engineering Division. The basis for the granting of type approval of corrugated steel buried structures by the Highways Agency is:

A.5.1. Verification that the applicant has submitted all the evidence required by Clause A2.

A.5.2. Verification that the technical specification of the product meets the requirements of the Standard.

A.5.3. Verification that the requirements of the Standard are met.

A.5.4. Verification that the stated minimum yield strength is achievable for the steel grade specified in the technical specification of the product.

A.5.5. Verification that the nominal seam strength/bolt configuration has been correctly derived in accordance with Annex B following evaluation by The Highways Agency, Safety, Standards and Research, Civil Engineering Division of the acceptability of the seam strength test results in terms of their technical reliability.

A.5.6. Verification that the nuts and bolts meet the applicant's stated national standard and have been used in the tests in A.5.5. above.

A.5.7. Verification that the manufacturer operates a Quality Control System conforming to BS EN IOS 9002: 1994.

A.6. Applications for Type Approval of helically wound products from suppliers and manufacturers should be made to The Highways Agency, Safety, Standards and Research, Civil Engineering Division. The basis for the granting of type approval of corrugated steel buried structures by the Highways Agency is:

A.6.1. Verification that the applicant has submitted all the evidence required by Clause A2.

A.6.2. Verification that the technical specification of the product meets the requirements of the Standard.

A.6.3. Verification that the requirements of the Standard are met.

A.6.4. Verification that the stated minimum yield strength is achievable for the steel grade specified in the technical specification of the product.

A.6.5. Verification that the lockseam strength meets the requirements of Annex C. A current British Board of Agrément (BBA) Certificate or equivalent shall be submitted to The Highways Agency, Safety, Standards and Research, Civil Engineering Division in accordance with Clause 1.6.

A.6.6. Verification that the manufacturer operates a Quality Control System conforming to BS EN IOS 9002: 1994.

A.7. When all the above information has been verified, a Type Approval Certificate is issued. All corrugated steel buried structures which have been given Type Approval are listed in Advice Note SA1 (MCHW 0.3.1 Annex B). Type Approval previously granted is liable to be withdrawn at any time following non-compliance with any of the requirements set out in this Annex.

## ANNEX B: LONGITUDINAL SEAM STRENGTH FOR BOLTED SEGMENTAL STRUCTURES

B.1. For bolted segmental structures, the manufacturer shall submit to The Highways Agency of The Department of Transport, Local Government and the Regions the results of tests on longitudinal bolted joints to determine the nominal seam strengths to be used in the design of the structures. These will be required for each combination of plate thickness and bolt arrangement to be certified. The tests shall be performed at a laboratory accredited by NAMAS or equivalent, for the appropriate compression testing and carried out in accordance with the procedures set out below. Tests in accordance with national standards of European Economic Area states which are equivalent to the tests stated in this document will be deemed to be acceptable.

### B.2. Test Samples

B.2.1. For each plate thickness and bolt arrangement to be tested, at least three samples, each with a longitudinal seam across it, shall be prepared from materials which are fully representative of the manufactured product, except that the samples need not have any protective coating. The samples shall be formed from corrugated but uncurved steel plates and each will include an even number of corrugations with a minimum of two.

B.2.2. Two parallel flat end-plates are to be welded to the two edges normal to the plane of the corrugated plate, to act as compression bearing surfaces. The flat end-plates shall be rectangular and shall extend at least 30mm in each direction beyond the welded ends of the corrugated sample. The welded length shall not exceed a distance of half the longitudinal bolt spacing beyond the last bolt in each direction.

B.2.3. The sample shall be of sufficient length to allow the permitted joint displacement without the corrugated plates touching the opposite end plate and the weld.

B.2.4. The bolt arrangement shall be representative of the joints proposed. The bolts shall be torqued to a value agreed with The Highways Agency.

### B.3. Test Procedure

B.3.1. The seam strength tests shall be undertaken by a laboratory accredited by the National Measurement and

Accreditation Services, NAMAS, or equivalent to undertake compression tests in the load range required for the tests.

B.3.2. A compression testing machine of suitable capacity and capable of applying the load at a uniform rate and maintaining it during slipping of the joint shall be used. It shall be equipped with bearing platens which are to be at least as large as the sample. Any horizontal movement of the sample shall be prevented. Unless the machine can record both load and deflection, two dial gauges reading accurately to 0.1mm shall be mounted between the platens on either side of the sample and on its longitudinal centre line.

B.3.3. The sample shall be placed in the machine so that the applied load will not be eccentric to the sample. It shall then be loaded in approximately 20 equally spaced load increments which are to be determined on the basis of previous experience. In the absence of such experience, a trial test should be carried out. Alternatively, when the load can be applied automatically it shall be applied continuously with the rate of deformation not exceeding 5mm per minute and the load displacement recorded automatically.

B.3.4. Unless the load has been applied automatically as described in B.3.3. above, a record of load and deflection shall be taken and plotted, the deflection being the average recorded by the two dial gauges.

### B.4. Nominal Seam Strength

B.4.1. The seam strength for each sample tested shall be determined from the least of the following:

- i. The load (kN) recorded at failure,
- ii. The load (kN) corresponding to a joint displacement in the direction of loading equal to the lesser of the amplitude of the corrugation or 40mm,
- iii. Three times the load corresponding to one third of the displacement at failure.

B.4.2. The nominal longitudinal seam strength (kN/m) of a particular combination of plate thickness and bolt arrangement shall be taken as the average of three seam strength test results, provided the lowest value is within

10% of the highest. Results from samples that fail by shearing of the bolts shall not be allowed.

#### **B.5. Reporting of Test Results**

The manufacturer shall submit to The Highways Agency a report prepared by the testing establishment giving the following details:

NAMAS Accreditation Certificate or equivalent for compression testing in the range required.

Sample identification marks and numbers.

Statement of test procedure.

Plate thickness and corrugation details.

Bolt type, size and arrangement and strength designation.

Method of forming the bolt holes and hole size.

Plot of load against displacement for each test.

Description of the mode of failure for each test.

Ultimate load and corresponding displacement for each test.

Load at displacement equal to the amplitude of the corrugation or 40mm (as appropriate).

Proposed nominal seam strength (kN/m) for each corrugation/bolt arrangement.

Photographs of each test sample after failure.

#### **B.6. Retention of Samples**

After testing the samples shall be retained by the manufacturer for a period of at least three months following receipt by The Highways Agency of the report required by Clause B.5. The samples shall be stored in such a way that they can be readily inspected if required.

## ANNEX C: SPECIFICATION FOR TENSILE STRENGTH OF LOCKSEAMS IN HELICALLY WOUND CORRUGATED STEEL STRUCTURES

C1 Lockseams shall be able to withstand tensile forces across the seam, according to steel sheet thickness, as tabulated below:

Nominal Sheet Thickness (mm)	Minimum Tensile Force across Seam (kN/m)
1.00	36
1.30	51
1.60	65
2.00	88
2.80	136
3.50	182
4.20	234

For intermediate sheet thicknesses, the minimum tensile force required may be determined by linear interpolation.