THE HIGHWAYS AGENCY BD 12/95

THE SCOTTISH OFFICE DEVELOPMENT DEPARTMENT

THE WELSH OFFICE
Y SWYDDFA GYMREIG

THE DEPARTMENT OF
THE ENVIRONMENT FOR NORTHERN IRELAND

Design of Corrugated Steel Buried Structures With Spans Not Exceeding 8 m (Including Circular Arches)

Summary: This Standard covers the design of corrugated steel buried structures of closed circular, closed multi-radii or circular arch cross sections, of bolted segmental or helically wound construction, and of span not exceeding 8 m.

In addition the Standard gives requirements for construction, installation, durability, Technical Approval and Type Approval.

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REGISTRATION OF AMENDMENTS

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VOLUME 1 HIGHWAY STRUCTURES: DESIGN (SUBSTRUCTURES AND SPECIAL STRUCTURES), MATERIALS

SECTION 2 SPECIAL STRUCTURES

PART 4

BD 12/95

DESIGN OF CORRUGATED STEEL BURIED STRUCTURES WITH SPANS NOT EXCEEDING 8 m (INCLUDING CIRCULAR ARCHES)

Contents

Chapter

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 12/88 and requires a Departmental Type Approval Certificate for all corrugated steel buried structures and clarifies and strengthens the requirements in regard to durability and maintenance. Circular arches on concrete foundations are now permitted and the relevant requirements are included in this standard.

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 the 104 and 105 Series of Clauses 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 of :-

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

cross sections and helically wound corrugated steel buried structures of closed circular cross section subject to the following requirements:-

a. The size and shape are within the limits specified in Table 1.

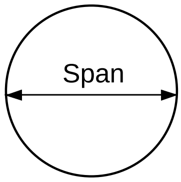
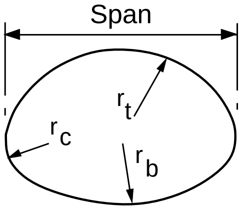
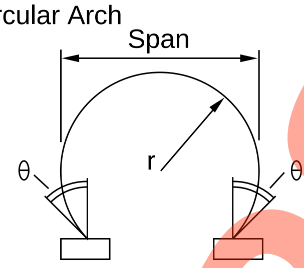
SHAPE	**RANGE OF SIZES**
Circular Structure 	0.9m to 8.0m span.
Multi-Radii Structure 	0.9m to 8.0m span. The shapes shall conform to: $\frac{r_b}{r_t} < 3.5$ & $\frac{r_c}{r_t} > 0.2$
Circular Arch 	2.0m to 8.0m span. The shapes shall conform to either: Type 1 Arch $30^\circ > \theta \geq 20^\circ$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

Table 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.

APPROVAL PROCEDURE

1.4 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.

1.5 All bolted segmental and helically wound corrugated steel buried structures and their components require a Departmental 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 Agrement Certificate shall include guaranteed minimum lockseam tensile strengths satisfying the requirements of Annex C of this Standard.

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1.6 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 except that Clauses A.2.4 and A.2.5 do not apply, and certification by the British Board of Agrement is mandatory.

1.7 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.

1.8 Where the Contractor chooses a proprietary protection coating with a designated design life, 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 design life appropriate to the circumstances stated in the Schedule of Employer's Requirements.

1.9 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).

IMPLEMENTATION

1.10 This Standard should 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 should 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.

SYMBOLS

1.11 The symbols used in this Standard are defined as follows:-

a (mm^2/mm)	Cross-sectional area of 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.
C_T (kN/m)	Total compressive hoop load in the wall of the circular arch structure per unit length acting upon the foundation
d_c (mm)	Depth of corrugation
D (mm)	Additional trench width required for circular arch structures
E (N/mm^2)	Modulus of elasticity of the structural steel.
E_s(N/mm^2)	Modulus of elasticity of the soil
F(mm/N)	Flexibility factor
Fmax (mm/N)	Limiting value of flexibility factor
f_a(N/mm^2)	Compressive hoop stress.
f_b(N/mm^2)	Theoretical transverse elastic buckling stress.
f_c(N/mm^2)	Nominal allowable buckling stress.
f_s(N/mm^2)	Stress derived from nominal seam strength (kN/m).
f_y(N/mm^2)	Minimum yield strength of the steel.
h(m)	Nominal height of fill above the structure.
h_t(m)	Height of fill above the crown of the structure including the thickness of any road construction.
I(mm^4/mm)	Cross-sectional moment of inertia of the corrugated steel per unit length, the cross-section being parallel to the length of the structure.
k(N/mm^3)	Coefficient of soil reaction.
k_e(N/mm^3)	Modified coefficient of soil reaction.

K	Constant
K_a	Active earth pressure coefficient
m	Poisson's ratio of the structural steel
$M^*(N/mm^2)$	Constrained soil modulus.
$m_v(mm^2/N)$	Coefficient of volume compressibility.
N	Uncorrected SPT value
$P(kN/m^2)$	Radial soil pressure on a circular closed invert structure.
$P_b(kN/m^2)$	Radial soil pressure on the bottom of a multi-radii structure
$P_c(kN/m^2)$	Radial soil pressure on the corner of a multi-radii structure
$P_t(kN/m^2)$	Radial soil pressure on the top of a multi-radii structure
$P_d(kN/m^2)$	Design vertical superimposed dead load pressure.
$P_L(kN/m^2)$	Design vertical live load pressure.
P_1 (kN/m²)	Overburden pressure on top of footing of circular arch
P_2 (kN/m²)	Lateral earth pressure on the outside face of the footing of a circular arch
r(m)	Radius of circular structure.
r_b(m)	Radius at the bottom of a multi-radii structure
r_c(m)	Radius at the corner of a multi-radii structure
r_t(m)	Radius at the top of a multi-radii structure
S (m)	Span of the structure (diameter of circular structure).
t (years)	Life of sacrificial thickness of steel.
T(µm)	Thickness of sacrificial metal for each corroding face.
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
$\gamma(kN/m^3)$	Bulk unit weight of compacted fill.
γ_{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.
γ_{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.
γ_m	Partial safety factor that takes account of variabilities in material strength and uncertainties in the assessment of component strength.
Δ x(m)	Increase in horizontal diameter or span.
θ	Re-entry angle of circular arch measured between the vertical and the tangent to the arch wall at the top of the foundation
ν	Poisson's ratio of the soil.

2. DESIGN PRINCIPLES

2.1 Limit state principles have been adopted for design in this Departmental 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 are expressed as the product of nominal loads and the partial safety factor γ_{fL} .

2.3 Design load effects are expressed as the product of the effects of the design loads and the partial safety factor γ_{f3}.

2.4 Design resistance is expressed as the nominal strength of the component divided by the partial safety factor γ_m

2.5 The design load effects at the ultimate limit state must not be greater than the design resistance. 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.

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3. DESIGN LOADS

Dead Load of Steel

3.1 The self-weight of corrugated steel buried structures may be ignored.

Superimposed Dead Load

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

P_d = γ_{fL} x nominal vertical pressure

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

where γ = Bulk unit weight of compacted fill (kN/m^3)

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)

Appropriate values for γ_{fL} are given in Table 2.

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^2.

3.5 To determine the nominal vertical live load pressure, P_L on the structure due to any wheel load, dispersion 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 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 1. This applies to adjacent wheels on the same axle and, where the span is large enough, to wheels on succeeding axles.

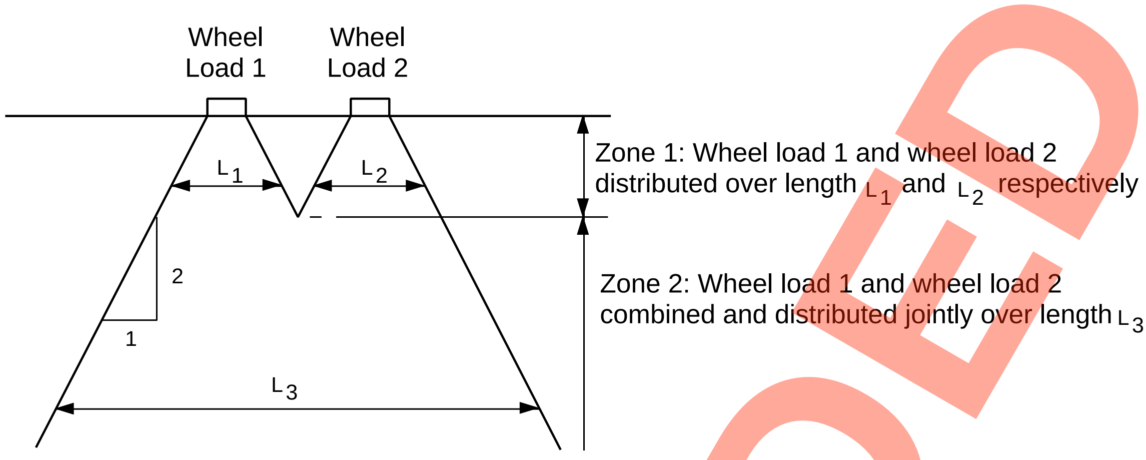

Figure 1 - Dispersion of Adjacent HB Wheel Loads

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.

3.8 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 may be ignored.

3.10 To obtain the design vertical live load pressure, P_L (kN/m^2), the nominal pressures shall be multiplied by the appropriate values of γ_{fL} given in Table 2.

LOAD	SLS γ_{fL}	ULS γ_{fL}
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 2 - γ_{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

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

Where C = Compressive hoop load in the wall of the structure per unit length (see Figure 2)

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

S = Span of the structure (m)

P_d = Design vertical superimposed dead load pressure at the ultimate limit state (kN/m^2)

P_L = Design vertical live load pressure at the ultimate limit state (kN/m^2)

a = Cross-sectional area of corrugated steel per unit length, (mm^2/mm) the cross-section being parallel to the length of the structure. 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

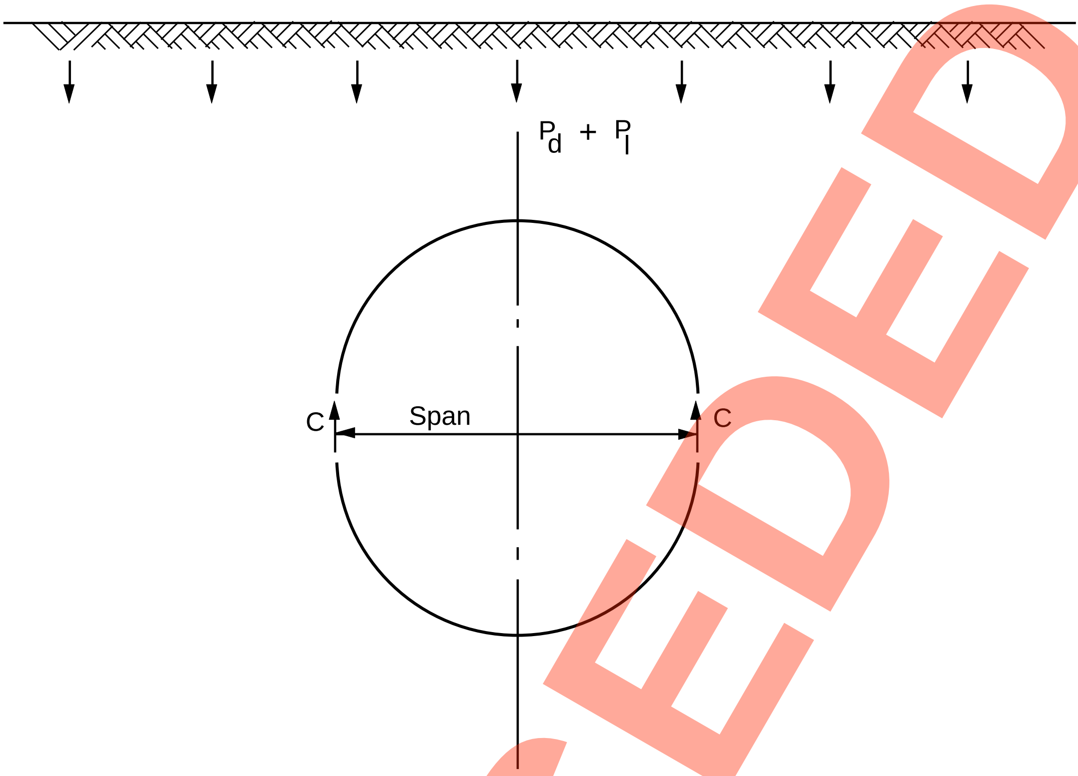

Figure 2 - Compressive Hoop Load

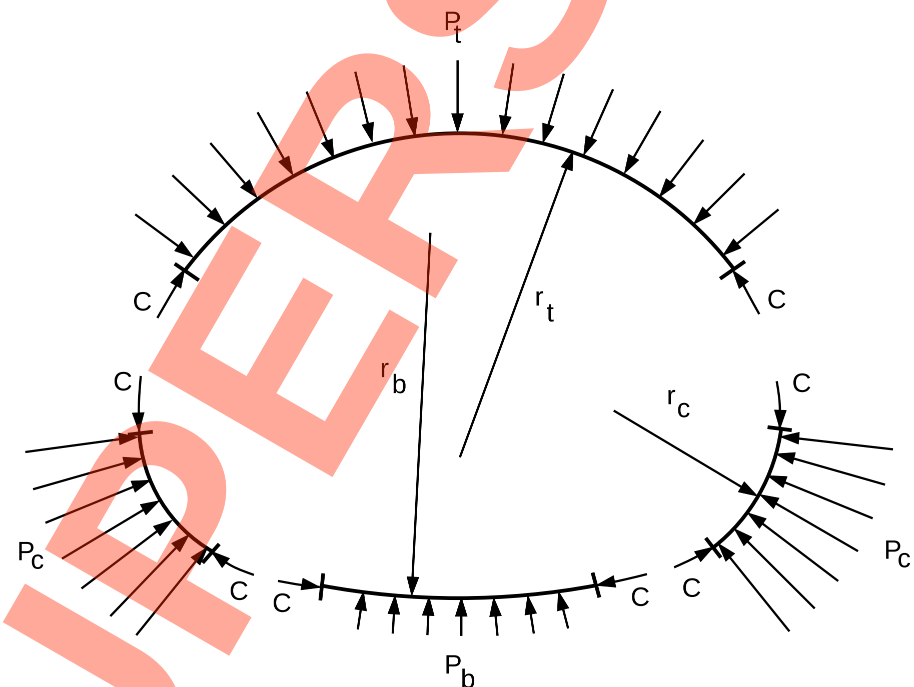

Figure 3 - Structure Radii, Hoop Load and Radial Soil Pressures for Closed Invert Structures

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 3 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.

4.3 Radial Soil Pressure for Closed Invert Structures

This is calculated as follows:-

a. **Circular Structures**

External radial soil pressure $P = \frac{C}{r} = P_d + P_L$ (kN/m^2)

b. **Multi-radii**

Radial soil pressure on the top $P_t = \frac{C}{r_t}$ (kN/m^2)

Radial soil pressure on the corner $P_c = \frac{C}{r_c}$ (kN/m^2)

Radial soil pressure on the bottom $P_b = \frac{C}{r_b}$ (kN/m^2)

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-radii structures
r_c = Radius of the corner (m)) (see Figure 3)
)
r_b = Radius of the bottom (m))

4.4 Foundation Loading - Circular Arches Serviceability Limit State only)

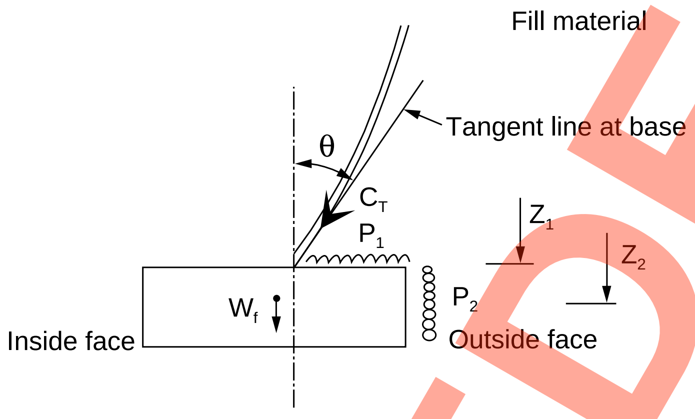

Figure 4 - Loadings on Foundations

(a) **Thrust**

The total thrust C_T, in the wall of the structure, acting upon the foundation at an inclined angle of θ 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 γ_{f3} is given in Table 3

(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, γ is unit weight of overburden (kN/m^3), and γ_{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, γ_{f3} = 1 for SLS

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

(c) **Self Weight**

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

Type of Structure	Values of γ_{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 3 - γ_{f3} Partial Safety Factors

5. STRENGTH PARAMETERS

Constrained Soil Modulus

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

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

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

5.2 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. Alternatively the methods described in 5.3 and 5.4 may be used, as appropriate, during the ground investigation.

5.3 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

$$\gamma_m = 1.3$$

5.4 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.

5.5 The M* value for design shall then be obtained from Table 4, based on the in-situ test result and also taking into consideration the excavation width, and the compaction required in MCHW1.

5.6 For structures constructed in embankments, the M* value for design shall be obtained from Table 4 taking into account the compaction required.

5.7 When the Contractor proposes a value of M* for design, in excess of $33\mathrm{N/mm^2}$, 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.

CLOSED INVERT STRUCTURES

Partial or Total Trench

Constrained Soil Modulus (M*) of Existing Soil † (N/mm^2)	Required Excavation Width on each side of structure	Required Compaction for Backfill Materials ‡	M* Value for Design Use (N/mm^2)
< 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 of Total Trench

Constrained Soil Modulus (M*) of Existing Soil † (N/mm^2)	Required Excavation Width on each side of structure	Required Compaction for Backfill Materials ‡	M* Value for Design Use (N/mm^2)
≤ 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++

† Obtained from in-situ test

‡ To be determined from BS 1377 Part 4

\+ See Clause 9.5

⊕ See Clause 9.6

++ See Clause 5.7

Table 4 - Design Values of Constrained Soil Modulus (M*)

Nominal Buckling Stress

5.8 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.

5.9 The nominal allowable buckling stress f_c shall be determined from the following formulae;

$$f_c = \frac{f_y}{1 + \frac{f_y}{f_b}} \quad (\text{N/mm}^2)$$

where f_b = Theoretical transverse elastic buckling stress (N/mm²) 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

$$f_b = \frac{2}{a}\sqrt{\frac{kEI}{(1-m^2)}} \quad \text{provided} \quad \frac{1000\ S}{4\sqrt{\frac{EI}{(1-m^2)\,k}}} > 4$$

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

$$f_b = \frac{2}{a}\sqrt{\frac{k_e EIh}{(1-m^2)S}} \quad \text{provided} \quad \frac{1000\ S}{4\sqrt{\frac{EI\,h}{(1-m^2)k_e S}}} > 4$$

where k = Coefficient of soil reaction (N/mm^3)

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

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

and k_e = Modified coefficient of soil reaction (N/mm ^{3})

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

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

E = Modulus of Elasticity of steel
= 205 x 10^3 N/mm²

I = Cross-sectional moment of inertia per unit length (mm^4/mm)of the corrugated steel sheet about its neutral axis, the section being parallel to the length of 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.

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

a = Cross-sectional area of corrugated steel per unit length (mm^2/mm) (as defined in Clause 4.2)

m = Poisson's ratio of steel = 0.3.

M* = Constrained soil modulus design value N/mm^2) as determined from the requirements of Clauses 5.1 to 5.7.

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6. ULTIMATE LIMIT STATE REQUIREMENTS

6.1 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 5.9.

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 Highways Agency 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 nominal seam strength, of the longitudinal bolted joint, divided by γ_m of 2.0. The nominal seam strength shall be as obtained from tests carried out in accordance with Annex B.

d. In the case of a helically wound structure, a stress of 370 N/mm^2 divided by γ_m of 2.0.

7. SERVICEABILITY LIMIT STATE REQUIREMENTS

Deflection

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

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

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

P_L = Design vertical live load pressure at the serviceability limit state (kN/m^2)

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^2) as determined from the requirements of Clauses 5.1 to 5.7.

and E and I are as defined in Clause 5.9

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

7.2 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^2, 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. Definitions of these terms are given in BS 8004, Clause 1.2.

7.3 Where the radial corner pressure P_c exceeds the allowable net bearing pressure, consideration shall be given to deepening and/or widening the trench in accordance with Clause 9.2.

7.4 Circular Arches - Foundation Design

Foundations shall be in accordance with BS 8004. 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 (see Clause 7.2 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 10.7).

Reference should also be made to Clause 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 729 using a minimum average coating weight in accordance with BS 729 (1971) Table 1. Any bolt holes must be punched or drilled before the plates are galvanised. Any cuts made to the structure on site shall be protected by cold applied galvanising.

8.3 The galvanised steel surfaces of corrugated steel buried structures shall be classed either as 'maintained' or 'other' for the purpose of corrosion protection and durability.

8.4 A 'maintained' surface must be an accessible surface in a structure of span 1.5m or greater, that the Schedule of Employer's Requirements, included in the Outline Approval in Principle, states will be maintained on a regular basis. A 'maintained' surface must be capable of regular inspection and maintenance, taking into account the current requirements of the Health and Safety legislation.

8.5 'Other' galvanised steel surfaces are all the surfaces of corrugated steel buried structures not classed as 'maintained' for the purpose of corrosion protection and durability. Such galvanised steel surfaces comprise those buried by other materials (Clause 8.10) and those exposed to the atmosphere (Clause 8.11). If exposed to the atmosphere, they may be either wet or dry. 'Other' surfaces will not require maintenance during their design life.

Measures to achieve Design Life

8.6 'Maintained' surfaces shall be coated with an additional protective coating applied to the galvanised steel surface to protect it against corrosion. This coating will also facilitate inspection and maintenance by pinpointing areas which require attention. The additional protective coating may be factory or site applied and shall have a service life of at least six years in aggressive conditions such as a high build surface tolerant epoxy coating applied at 200 microns wet film thickness or equivalent. The additional protective coating shall not make any contribution to the design life of the structure and does not require a British Board of Agrement Certificate.

8.7 'Maintained' galvanised steel surfaces, as defined in Clause 8.4., and provided with additional protective coating do not require to be provided with any sacrificial thickness of steel.

8.8 All 'other' galvanised steel surfaces shall be deemed to corrode at the rates of corrosion given in Clauses 8.13 and 8.15.

8.9 These 'other' surfaces 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 and contributions from galvanising and any optional secondary protective coating with BBA or equivalent Certification.

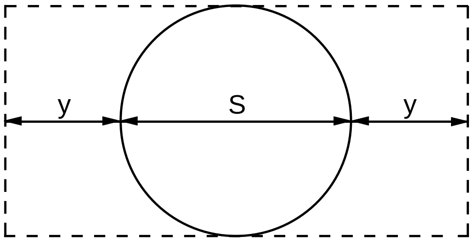
Corrosivity Classification of 'Other' Surfaces.

8.10 Buried Surfaces

8.10.1 Buried surfaces shall be classified in the Schedule of Employer's Requirements, either according to the properties of the surrounding soil or of the ground water where present, as determined from the ground investigation where applicable.The classification shall be the more severe of the two. The selected fills, Classes 6K, 6L and 6M described in MCHW1 Clause 623, provide a non-aggressive environment when dry but any water present will determine the classification based on its properties.

8.10.2 The surrounding soil shall be classified using the points system for each property, shown in Table 5, and the ground water shall be classified according to the highest aggressivity indicated for any property in Table 7. The properties shall be assessed using the test methods listed in Table 6. Additionally, where the culvert carries a continuous flow of water or other fluid, classification of the water/other fluid according to Table 7 shall be used to classify both surfaces if it is more severe than the classification of the surrounding soil or ground water.

8.10.3 For structures constructed partly or totally in trench, the existing soil within the zone shown in Figure 5 shall be tested for corrosivity classification purposes.



y = 0.4 + 0.23S m

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

Figure 4 - Corrosivity Classification Zone for the External Buried Surface

8.10.4 The inner surface of the structure should be regarded as a 'buried' surface beneath any part that is to be covered e.g. when a structure is used as a vehicular underpass. 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.

8.11 Exposed 'Other' Surfaces

8.11.1 Exposed 'other' surfaces shall be classified in the Schedule of Employer's Requirements according to the aggressivity of any water or other fluid carried using the criteria in Table 7, and also according to the corrosivity of the atmosphere using the criteria in Table 8. The overall classification shall be determined by the more severe of the two.

8.11.2 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.

8.11.3 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. However, any other significant environmental factors concerning the location shall also be taken into account eg pollution from a nearby industrial plant may override the general classification.

Life of Protective Coatings and Sacrificial Steel Thickness for 'Other' Surfaces

8.12 In calculating the design life of the structure, the life of the 'other' surfaces shall be the sum of the life of the sacrificial steel and the life of the galvanised coating and of any optional secondary protective coating.

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

8.14 A secondary proprietary protective coating applied to the galvanised steel components is optional but where it is intended to contribute to the overall design life of the structure, its life shall be as determined in the relevant BBA Roads and Bridges or equivalent certificate for the coating used.

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

	T	=	$22.5t^{0.67}$, for non-aggressive environments; and
	T	=	$40.0t^{0.80}$, for aggressive environments,
where	T	=	thickness of sacrificial steel on each surface (µm),
	t	=	life of sacrificial thickness of steel in years.

Invert Protection

8.16 In addition to the requirements of Clauses 8.12 to 8.15, the invert of all structures carrying water or other fluid shall be protected from the effects of abrasion or erosion by either:-

a. A reinforced concrete paving (See Clauses 13.1 to 13.6) with a minimum thickness of 100mm for invert gradients of up to 2%, in structures of span less than or equal to 2m, and with a minimum thickness of 125mm for invert gradients of greater than 2% and for all structures with spans greater than 2m.

or b. 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.

8.17 Invert protection shall be applied to the wetted periphery of the structure for the winter base flow plus 200mm on each side. Where invert protection is in concrete, and exceeds 25% of the total circumference for circular structures or 40% of the total circumference for multi-radii structures, or as appropriate for a circular arch structure, formwork shall be used in its installation. 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.

8.18 Subject to the agreement of the appropriate river authority when it is anticipated that water-borne stones or other fragments in excess of 100mm diameter would otherwise be carried through the structure during normal or flood conditions, boulder screens shall be installed at the inlet to prevent this.

Invert Protection Below Circular Arch Structures

8.19 Reinforced concrete invert paving as described in the relevant parts of Clause 8.16 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.

8.20 If 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 8.17.

8.21 **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.

PROPERTY	MEASURED VALUE	POINTS
Soil Type	Fraction passing 63 µm sieve ≤ 10% Plasticity Index (PI) of fraction passing 425 µm sieve ≤ 6	+ 1
	Fraction passing 63 µm sieve > 10% PI of fraction passing 425 µm sieve ≤ 6	0
	Any grading PI of fraction passing 425 µm sieve > 6 but < 15	- 1
	Any grading PI of fraction passing 425 µm sieve ≥ 15	- 2
	Organic matter > 1.0% or material containing peat, cinder or coke	- 3
Resistivity (ohm - cm)	≥ 10,000 < 10,000 but ≥ 3,000 < 3,000 but ≥ 1,000 < 1,000 but ≥ 100 < 100	+ 2 + 1 - 1 - 3 - 4
pH of Soil	6 ≤ pH ≤ 9 5 ≤ pH < 6 Less than 5 or more than 9	0 - 2 - 5
Soluble Sulphates (ppm)	≤ 200 > 200 but ≤ 500 > 500 but ≤ 1,000 > 1,000	0 - 1 - 2 - 4
Chloride ion (ppm)	≤ 50 > 50 but ≤ 250 > 250 but ≤ 500 > 500	- 0 - 1 - 2 - 4
Sulphide and Hydrogen Sulphide	No discolouration) Slight to moderate darkening) of lead acetate Rapid blackening) paper	0 - 2 - 3

POINTS TOTAL	CORROSIVITY CLASSIFICATION
0 or more	Non-aggressive
- 1 to - 4	Aggressive
- 5 or less	Very aggressive

Table 5 Corrosivity Classification of Surrounding Soil

PROPERTY	TEST METHOD
Soil Type: Grading Plasticity Index (PI) Organic Matter	 BS 1377 : Part 2 BS 1377 : Part 2 BS 1377 : Part 3
Resistivity	Clause 637, MCHW1
pH	BS 1377 : Part 3
Soluble Sulphates	BS 1377 : Part 3
Chloride ion content	BS 812 : Part 117
Sulphide and Hydrogen Sulphide	Standard textbook of qualitative inorganic analysis eg. Ref. 2

Table 6 - Test Methods for properties required in Table 5 and Table 7

<u>**NOTES (TABLES 5 AND 6)**</u>

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 5.

2. The method for sulphide determination embodied in Table 5 is not mandatory. Other methods given in the Standard textbooks may be used provided they lead to a points ranking.

CORROSIVITY CLASSIFICATION	PROPERTIES OF WATER OR EFFLUENT		
	pH	Chloride ion (ppm)	Soluble Sulphates (ppm)
Non-Aggressive	6 ≤ PH ≤ 9	≤ 50	≤ 200
Aggressive	5 ≤ PH ≤ 6	> 50 but ≤ 250	> 200 but ≤ 500
Very Aggressive	Less than 5 or more than 9	> 250	> 500

Table 7 - 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 - Classification of Surfaces Exposed to the Atmospheric Environment

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). The excavation shall extend a length not less than 300mm beyond each end of the structure.

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. This additional excavation shall be wider than the limits given in Clause 9.1 by an amount on each side equal to the extra depth.

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 equal to the extent of side fill required in Table 4. Additional excavation may be necessary to suit the foundation size selected and the working space required for construction of the foundation. 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 7.4, the excavation level may be continued to such a depth to locate an improved net allowable bearing pressure of the foundation material. The size of the foundations shall then be re-calculated in accordance with Clause 7.4. The depth of excavation to the foundation level is measured from the top of the foundation and is defined as (1000+D)mm (see Figure 6). 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 Figure 6).

Trench Width for Closed Invert Structures

9.5 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 15N/mm^2, when the trench width may be reduced to that required for the lower bedding material ie 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.

Trench Width for Circular Arches

9.6 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 33 N/mm², when the trench width may be reduced to the span plus 500mm + D(mm) each side for structures up to 3m span, or span plus 800mm + D(mm) each side for larger spans and shall meet the requirements for excavation widths specified in Clause 9.5 and shown in Figure 6.

Filling - General

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

Filling - Bedding for Closed Invert Structures

9.8 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) for multi-radii structures. If this cannot be met and the structure is erected on a flat or partially preshaped bedding, care must be taken to ensure that the lower bedding material is properly placed and compacted under the haunches.

9.9 The requirements for the upper bedding material (Class 6L) are given in Series 600 MCHW1.

Filling - Surround for All Structure Types

9.10 The surround material (Class 6M) 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.

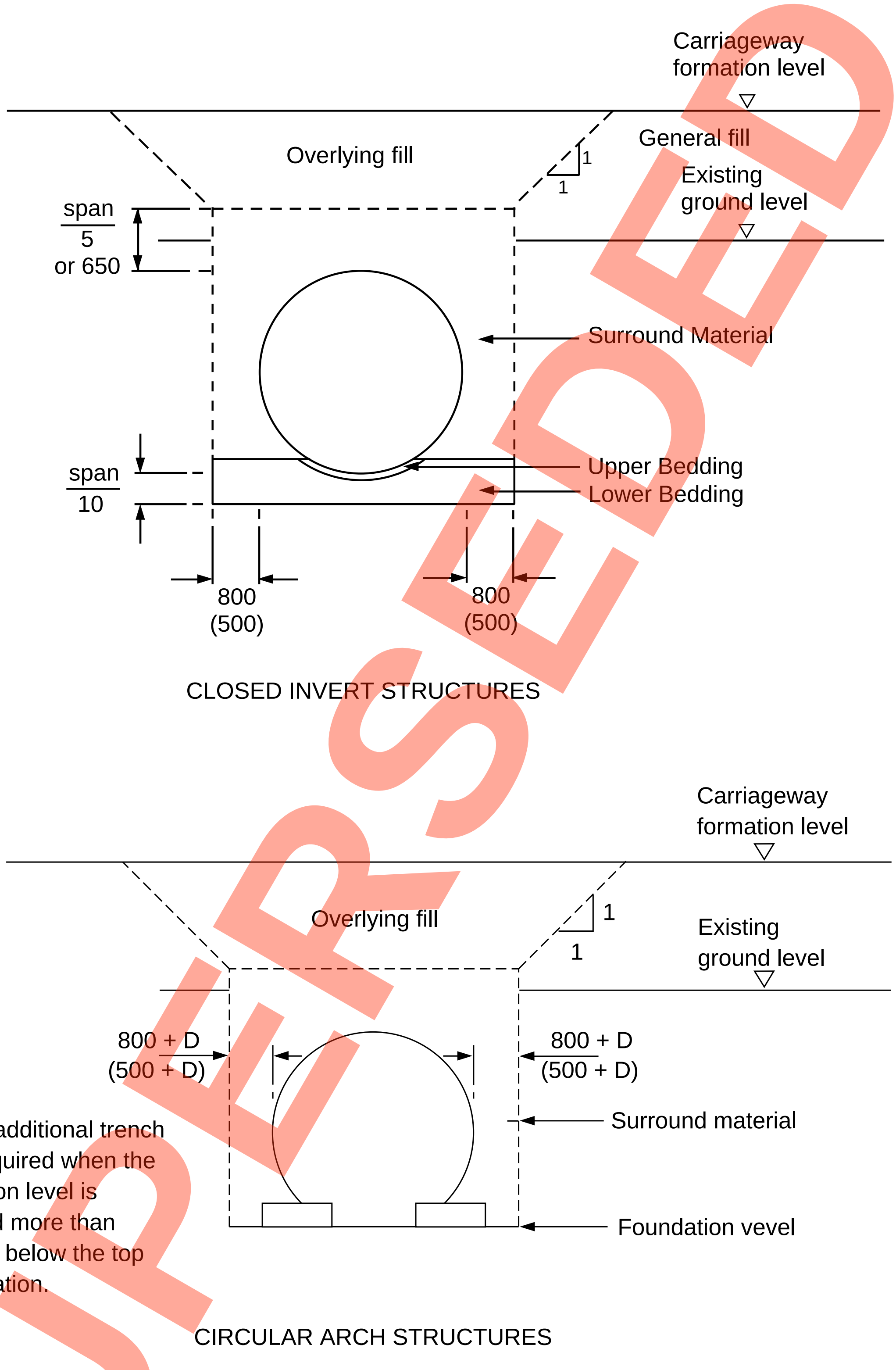
9.11 The surround material shall be used for a minimum distance equal to the span on each side of the structure. In embankments as well as in trenches this shall extend to a height of not less than a fifth of the span or 650mm whichever is the greater, above the crown of the structure, or to the formation level of the road if this is lower.

9.12 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 4).

Filling - Overlying Fill above All Structural Types

9.13 The overlying fill material as described in MCHW1 Series 600 shall be used for embankment construction in the zone over the structure shown in Figure 6. Argillaceous rocks such as shales and mudstones, slag and PFA shall not be used as fill or road sub-base materials in this zone.

9.14 Fill placed above the level of the crown of the structure, as described in Clause 9.11 and 9.13, 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.



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

Figure 6 - Typical Fill Requirements for Minimum Excavation Option as described in Chapter 9

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:

$$F = \frac{S^2 \times 10^6}{EI} \text{ (mm/N)}$$

where S = Span of the structure (m)
E = Modulus of Elasticity of steel = 205 x 10^3 N/mm^2
I = Cross-sectional Moment of inertia per unit length, (mm^4/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.

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

10.3 Values of F_{max} in mm/N established from site experience fit the relationship:-

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

but with a minimum of 0.115 and a maximum of 0.25.

10.4 The procedure for obtaining F_{max} for a particular depth of corrugation (where F_{max} (calc) is the value given by the formula in Clause 10.3) is therefore as follows:-

a. If $0.25 \geq F_{max}$ (calc)) ≥ 0.115: take F_{max} as F_{max} (calc).

b. If F_{max} (calc) > 0.25: take F_{max} as 0.25.

c. If F_{max} (calc) < 0.115: take F_{max} as 0.115

10.5 If the structure is a multi-radii structure the value of F_{max} obtained from Clause 10.4 shall be multiplied by 1.5 to take account of the greater rigidity of such structural shapes, e.g. if F_{max} (calc) > 0.25 : take F_{max} as 0.375 . The values of F_{max} obtained from Clause 10.4 shall be used for closed circular and circular arch structures.

10.6 The value of F from Clause 10.1 shall then be compared with the value of F_{max} from Clauses 10.4 and 10.5:-

a. If F is less than or equal to F_{max}, the structure is acceptable.

b. If F exceeds F_{max} 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.

Foundations for Circular Arches

10.7 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 7.4.

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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 11.4 and regard shall be paid to the aesthetic appearance of the structure.

11.2 Reinforced concrete headwalls shall be used to support the free edges, where the skew angle of the corrugated steel structure exceeds 15º, or the bevel of square ends exceeds 2:1 (eg embankment flatter than 1 in 2). When structures/headwalls are skewed, the offset portion of the metal structure shall be supported by the headwall. Reinforced concrete headwalls shall be designed according to BS 5400: Part 4 as implemented by BD 24 (DMRB 1.3.1).

11.3 The backfill and free edges of other corrugated structures shall be protected by end treatments such as headwalls, ring beams, structural steel collars, ties or ground anchorages and these shall be designed to the appropriate part of BS 5400 or to relevant Departmental Design Standards.

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

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 (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 which ever 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 should 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 surfacings. Again thickness and reinforcement should 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, 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 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 8.16a, or

b. Detailed to suit any headwall arrangement e.g. paving reinforcement lapped with headwall reinforcement.

13.6 All foreign matter, (but not any secondary proprietary protective coating unless indicated otherwise in the Type Approval Certificate or BBA Certificate referred to in Clause 1.5) and free standing water shall be removed from the surfaces to be paved, before commencing work.

14. CARRIAGEWAY DRAINAGE

14.1 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.

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 should 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 APPROVAL

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 shall, prior to inviting tenders, submit an Outline Approval in Principle containing a Schedule of Employer's Requirements which shall include the following information:-

i. Location plan and name of structure.
ii. Long Section along centre-line of structure.
iii. Finished levels of carriageways and side slopes within designated outline.
iv. Skew of structure.
v Minimum width of structure.
vi. Minimum headroom of structure.
vii. Hydraulic requirements or clearance envelope, if any, and requirement for invert protection.
viii. Gradient of invert.
ix. End detail requirements, including any requirement for reinforced concrete headwalls.
x. Highway loading requirements.
xi. The value of constrained soil modulus M* to be assumed for existing soil.
xii. Allowable net bearing pressure for foundation material.
xiii. Corrosivity (aggressivity) classification of existing soil, ground-water, contained water/effluent, the atmosphere and of any fill material to be placed inside the structure in contact with the corrugated steel.
xiv. Identification of maintained surfaces (if any).
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 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 implicity favouring the system of a particular manufacturer.

16.3 Subsequent to the award of contract and prior to the commencement of construction, the Contractor shall complete the AIP form, the design and the design certificate and submit these for approval by the Engineer. The full design shall contain the following additional information relating to the particular proprietary product which forms the basis of the design. For bolted segmental structures the list shall include:-

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 Highways Agency of the Department of Transport Type Approval Certificate and current British Board of Agrément or equivalent Certificate or Certificates - as required in Clauses 1.5 to 1.8.

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 Highways Agency of the Department of Transport Type Approval Certificate and current British Board of Agrément or equivalent Certificate or Certificate, as required by Clauses 1.5 to 1.8.

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).

Surround Material
- Constrained soil modulus (M*)
- Compaction (% of maximum dry density).

16.5. The further stages in the post award contract procedures shall be as given in Chapter 4 of Standard SD4 (MCHW 0.2.4).

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 7: Section 2 - Pavement Design and Construction
HD 26: Pavement Design (DMRB 7.2.3)

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 1991 (MCHW1)

17.3 **British Standards**

BS 729: 1971 (1986) - Specification for hot dip galvanized coatings on iron and steel articles.
BS 812: Part 117: 1988 - Method for Determination of Water Soluble Chloride Salts.
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 5400: Steel, Concrete and Composite Bridges.
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).

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, Farm

Buildings Research Team, Coley Park, Reading, Berkshire RG1 6DE .

17.5 Bibliography

1. "Bridge Foundations and Sub-structures ", Department of the Environment, Building Research Establishment, London 1979: Her Majesty's Stationery Office.

2. 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.

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

T A ROCHESTER
Chief Highway Engineer

The Deputy Chief Engineer
The Scottish Office Development Department
National Roads Directorate
Victoria Quay
Edinburgh EH6 6QQ

N B MacKENZIE
Deputy Chief Engineer

The Director of Highways
Welsh Office
Y Swyddfa Gymreig
Government Buildings
Ty Glas Road
Llanishen
Cardiff CF4 5PL

K J THOMAS
Director of Highways

Director of Roads Service
Department of the Environment for
Northern Ireland
Roads Service Headquarters
Clarence Court
10-18 Adelaide Street
BT2 8GB

W J McCOUBREY
Director of Roads Service

PROCEDURE AND CONDITIONS FOR OBTAINING A TYPE APPROVAL CERTIFICATE FOR BOLTED SEGMENTAL CORRUGATED STEEL BURIED STRUCTURES

A1. The manufacturer or supplier will be required to obtain a Highways Agency of the Department of Transport Type Approval Certificate for any bolted segmental structure before it may be offered in a tender. Separate Certificates must be obtained for each type of bolted segmental structure.

A2. The following evidence and information is required by Bridges 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 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.

A.2.2. Confirmation that all the requirements of this Standard are satisfied.

A.2.3. The minimum yield strength fy (N/mm^2) 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. 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 Departmental Type Approval Certificate.

A.5. Applications for Type Approval of bolted segmental products from suppliers and manufacturers should be made to Bridges Engineering Division (BE). 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 BE 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 ISO 9002: 1994.

When all the above information has been verified, a Type Approval certificate is issued. All corrugated steel buried structures which have been given Highways Agency 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.

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 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 Department.

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

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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 of the Department of Transport 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 Department 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.

SPECIFICATION FOR TENSILE STRENGTH OF LOCKSEAMS IN HELICALLY WOUND CORRUGATED STEEL

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.