Design Manual for Roads and Bridges

Highway Structures & Bridges
Design

CD 376
Unreinforced masonry arch bridges

(formerly BD 91/04)

Revision 0

Summary
This document covers the design of new unreinforced masonry arch bridges.

SUPERSEDED

Application by Overseeing Organisations
Any specific requirements for Overseeing Organisations alternative or supplementary to those given in this document are given in National Application Annexes to this document.

Feedback and Enquiries
Users of this document are encouraged to raise any enquiries and/or provide feedback on the content and usage of this document to the dedicated Highways England team. The email address for all enquiries and feedback is: Standards_Enquiries@highwaysengland.co.uk

This is a controlled document.

Contents

Release notes

Version	Date	Details of amendments
0	Mar 2020	CD 376 replaces BD 91/04. This full document has been re-written to make it compliant with the new Highways England drafting rules and has been aligned with Eurocodes and current best practice.

Foreword

Publishing information

This document is published by Highways England.

This document supersedes BD 91/04 which is withdrawn.

Contractual and legal considerations

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

Introduction

Background

Experience has shown that arch bridges are very durable structures and should require less maintenance in comparison to other bridge forms. Prior to the publication of BD 91/04, there had not been a standard covering the design of new unreinforced arch bridges.

BD 91/04 considered research into the behaviour of arch bridges that has been undertaken by a number of organisations including Transport Research Laboratory, British Rail Research and a number of universities. In BD 91/04, consideration was given to the results of most of this work. This research included Melbourne and Gilbert [Ref 6.I], Mair 1995 [Ref 1.I], Choo & Hogg 1995 [Ref 3.I], Cox & Halsall 1996 [Ref 2.I] and Owen, Peric, Petrinic, Brookes and James (Owen et al 1998 [Ref 4.I]).

Maintenance requirements have significant effects on whole life costs. The financial benefits arising from reduced maintenance requirements for unreinforced arch bridges should be considered when comparing the whole life costs of arch bridges with other types of bridges.

This document states the design requirements for arch bridges. It complements the masonry and associated work requirements for unreinforced masonry arch bridges, referred to hereafter as 'arch bridges', in the Specification for Highway Works MCHW SHW [Ref 14.N].

Assumptions made in the preparation of this document

The assumptions made in GG 101 [Ref 13.N] apply to this document.

Mutual Recognition

For the construction of arch bridges, 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 of the MCHW SHW [Ref 14.N].

Abbreviations and symbols

Abbreviations

Abbreviation	Definition
AIP	Approval in Principle
AW vehicles	Vehicles based on Authorised Weight (AW) or C&U Regulations
SLS	Serviceability Limit State
SV vehicles	Vehicles complying with The Road Vehicles (Authorisation of Special Types) General Order (STGO Regulation).
ULS	Ultimate Limit State

Symbols

Symbol	Definition
b	width of the arch ring under consideration
e	eccentricity of the centre of compression in the arch ring
f_k	characteristic compressive strength of masonry
h	overall thickness of the arch ring
E_d	design load effects
F_d	design value of an action
F_k	characteristic value of an action
P	axial force in arch ring
R_d	design value of resistance
S	length loaded with SV vehicle
V	shear force
γ_F	partial factor for actions
$\gamma_{G,\text{sup}}$	partial factor for permanent load in calculating upper design value
$\gamma_{G,\text{inf}}$	partial factor for permanent load in calculating lower design value
γ_M	partial factor for material
ψ	combination factor

Terms and definitions

Terms

Term	Definition
Abutment	The part of a bridge which provides resistance to horizontal and vertical forces from an arch ring.
Arch ring	A curved course of masonry, or series of masonry courses, which supports loads principally in compression.
Extrados	The convex surface of an arch ring.
Fill	The material placed above the extrados, which can include a pavement sub-base.
Foundation	That part of the structure in direct contact with and transmitting loads to the ground.
Intrados	The concave surface of an arch ring.
Limit states	States beyond which the structure no longer fulfils the relevant design criteria.
Masonry	An assemblage of structural units usually laid in-situ in which the structural units, usually clay bricks, concrete blocks or stones, are bonded and solidly put together with mortar.
Parapet base slab	The foundation which supports the bridge parapet.
Pavement	The bound material forming footpath/verge or carriageway and includes surfacing and roadbase as appropriate, but excludes sub-base.
Pier	An intermediate support between adjoining arch spans.
Rise	The vertical height from the springing level to the crown of the intrados.
Serviceability limit states	States that correspond to conditions beyond which specified service requirements for a structure or structural member are no longer met.
Skewback	The surface of an inclined springing.
Span	The clear distance between the faces of the abutments or piers.
Spandrel wall	The wall carried on the arch extrados, which retains the fill.
Springing	The plane from which an arch ring springs.
String course	A moulded course that projects from a wall.
Ultimate limit states	States associated with collapse or with other similar forms of structural failure.
Unreinforced masonry	Masonry which does not include steel or other reinforcement which is considered in the determination of its strength.
Voussoir	A wedge shaped masonry unit in an arch.
Wing wall	A wall at the abutment which extends beyond the spandrel walls to retain the earth behind the abutment.

1. Scope

Aspects covered

1.1 This document shall be used for arch bridges consisting of:

1) single or multiple spans;
2) square or skewed bridges;
3) with a span/rise ratio of between 2 and 10; and,
4) spans not exceeding 40m.

NOTE 1 Open spandrel arch bridges and arch bridges carrying railway loading are not covered by this document.

NOTE 2 Unreinforced concrete arch bridges are not covered by this document. However the principles contained in this document can be applied to unreinforced concrete arches. Appendix B gives more explanation on this topic.

Implementation

1.2 This document shall be implemented forthwith on all schemes involving unreinforced masonry arch bridges on the Overseeing Organisations' motorway and all-purpose trunk roads according to the implementation requirements of GG 101 [Ref 13.N].

Use of GG 101

1.3 The requirements contained in GG 101 [Ref 13.N] shall be followed in respect of activities covered by this document.

2. Design principles and objectives

Basis of design

2.1 The design of an unreinforced arch bridge shall be carried out using the partial factor method in accordance with BS EN 1990 [Ref 10.N], in which a structure is shown to be safe by the application of partial factors to actions (γ_F) and to material strengths (γ_M).

NOTE The various features of an arch bridge are shown in Figures 2.1Na and 2.1Nb.

Figure 2.1Na Features of an arch bridge – elevation

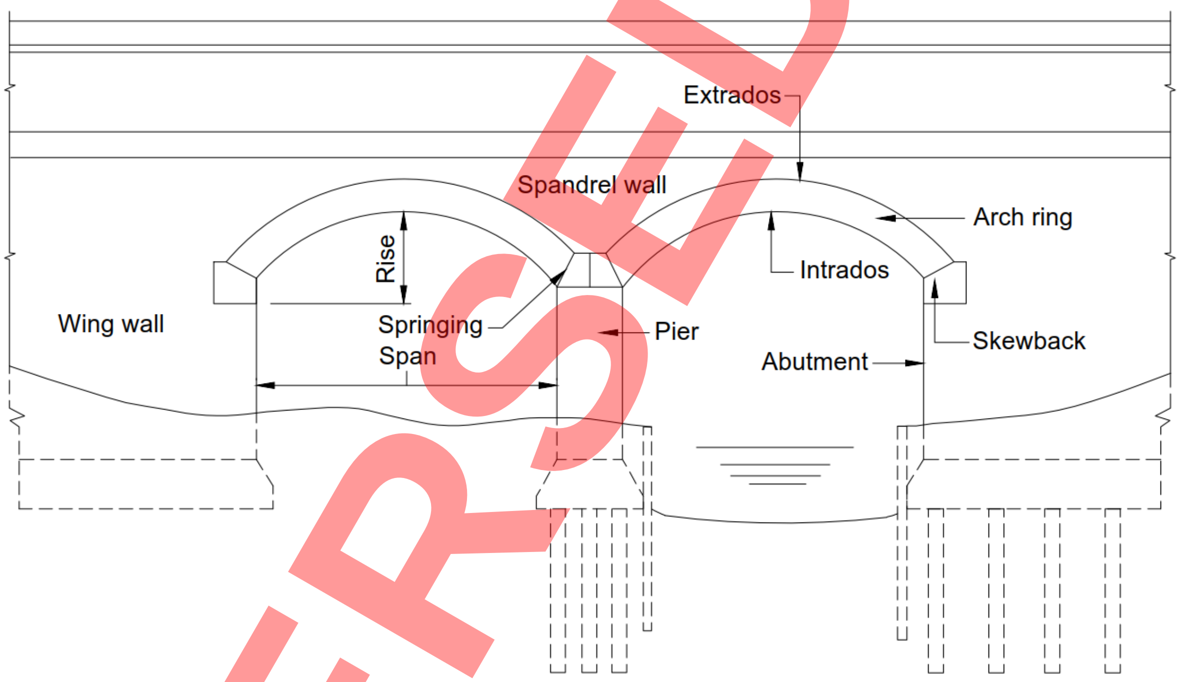
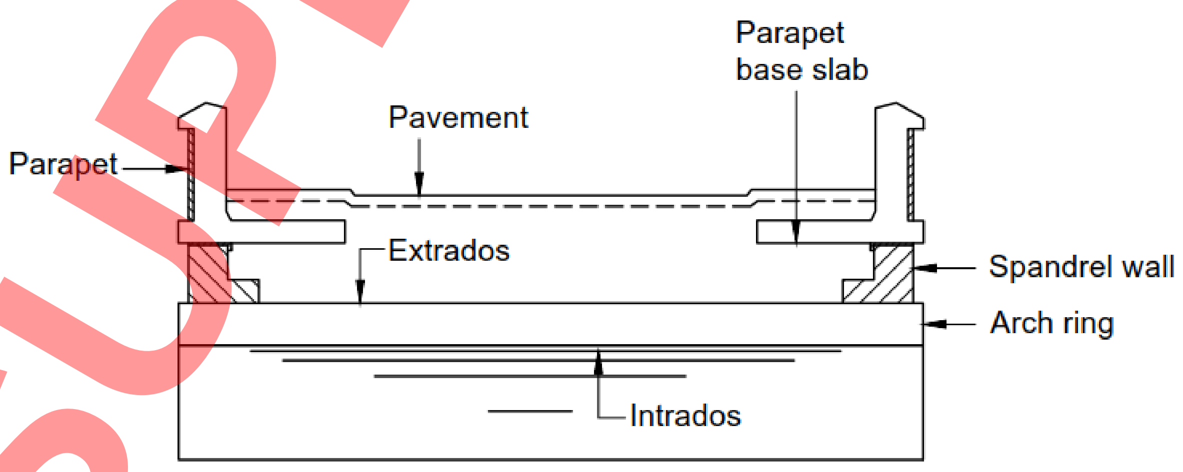


Figure 2.1Nb Features of an arch bridge - section



2.2 The design life of an unreinforced arch bridge shall be 120 years.

2.3 Each structure and each part of a structure shall, during construction and throughout its design life, fulfil basic requirements and limit states as defined in BS EN 1990 [Ref 10.N].

Limit states

2.4 The structure and associated earthworks, including the fill and foundations shall be designed for both the ultimate and serviceability limit states.

NOTE 1 Requirements for the ultimate and serviceability limit states are given in Section 4.

NOTE 2 The ULS for an arch includes the condition at which a collapse mechanism forms in the structure or when movements of any part of the structure lead to severe structural damage in other parts of the structure or services.

NOTE 3 SLS includes the condition beyond which there is a loss of utility including the following;

1) *deformation of the structure causing a loss of utility or adversely affecting its appearance to a point where public concern could be expected;*
2) *cracks become of such magnitude as to lead to a reduction in structural integrity.*

Design value of an action

2.5 The design value of an action, F_d shall be determined according to Equations 2.5a and 2.5b for permanent actions and variable actions respectively.

Equation 2.5a Design value of a permanent action

$$F_d = \gamma_F \cdot F_k$$

Equation 2.5b Design value of a variable action

$$F_d = \gamma_F \cdot \psi \cdot F_k$$

where:

γ_F is a partial factor for actions as given in Appendix A

ψ is a factor to account for the reduced probability of multiple variable actions reaching their characteristic values simultaneously, defined in BS EN 1990 [Ref 10.N]

F_k is the characteristic value of the action as given in Section 3

Design effects of actions

2.6 The design effects of actions, E_d , shall be obtained from the design values of actions, the design geometry, and the design material and product properties, in accordance with BS EN 1990 [Ref 10.N].

2.7 Analysis shall be undertaken to ascertain the effects of actions for each of the most severe conditions appropriate to the element under consideration.

2.8 The method of analysis shall meet the requirements of BS EN 1990 [Ref 10.N].

2.8.1 Analysis of the arch ring should include the following;

1) elastic shortening;
2) loss of stiffness due to cracking;
3) loss of stiffness due to creep; and,
4) other predictable deformations that could modify the effects of actions.

NOTE An indication of when allowance for these movements and deformations is likely is given in Section 4.

2.9 The effects of estimated displacements and rotations over a period of 120 years shall be included.

NOTE *The arch ring is sensitive to the effects of foundation movements.*

Design resistance

2.10 The design resistance, R_d , shall be defined as in Equation 2.10.

Equation 2.10 Design resistance

$$R_d = \text{function of } \left(X_k, \gamma_M, a_d\right)$$

where:

X_k	are the characteristic material and product properties
γ_M	are the partial factors for the material and product properties
a_d	are the design values for the geometry

NOTE *The value of γ_M for masonry is given in Section 4.*

2.11 The design resistance of the sub-soil and fill shall be verified in accordance with BS EN 1997-1 [Ref 9.N].

Verification

2.12 Equation 2.12 shall be satisfied for each limit state:

Equation 2.12 Limit state requirements

$$R_d \geq E_d$$

3. Actions

Permanent actions

3.1 Permanent actions shall be determined from the characteristic values in BS EN 1991-1-1 [Ref 4.N] multiplied by the partial factors in Appendix A.

Scour and hydraulic actions

3.2 Scour and hydraulic actions shall be determined in accordance with CD 356 [Ref 3.N].

Thermal actions

3.3 The reasons to include or omit thermal actions shall be recorded in the AIP.

3.3.1 Thermal actions may be omitted in arches with a span/rise ratio less than 6.

3.4 Where thermal actions are included, they shall be determined in accordance with BS EN 1991-1-5 [Ref 8.N].

NOTE The National Annex to BS EN 1991-1-5 [Ref 8.N] includes content specifically relating to masonry arch bridges.

3.4.1 Changes in uniform (effective) bridge temperature may be ignored when the total depth of pavement and fill above the extrados is 1.5 metres or greater.

3.4.2 For the purpose of establishing temperature differences, the depth of fill should be included in the depth of slab (h).

3.4.3 Heating (positive) temperature differences may be ignored when the total depth of pavement and fill above the extrados exceeds 500mm.

3.4.4 Cooling (negative) temperature differences on the extrados may be ignored when the total depth of pavement and fill above the extrados exceeds 500mm.

3.4.5 The coefficient of thermal expansion of the masonry to be used should be established by testing, or taken from Table 3.4.5.

Table 3.4.5 Coefficient of thermal expansion for masonry

Type of masonry	Coefficient of thermal expansion
Masonry with concrete units	10 x 10-6/°C
Masonry with clay units	6 x 10-6/°C
Masonry with reconstituted stone units	5 to 13 x 10-6/°C
Masonry with natural stone units	determined for the rock type to be used in the construction

Wind actions

3.5 The reasons to include or omit wind actions shall be recorded in the AIP.

NOTE Wind actions are not usually critical for masonry arch bridges.

3.6 Where wind actions are included, they shall be determined in accordance with BS EN 1991-1-4 [Ref 7.N].

Traffic actions

3.7 The traffic actions on masonry arches carrying roads shall be determined directly for:

1) individual vehicles; or,
2) combinations of vehicles.

3.7.1 Where the analytical model used does not model dispersal effects through the fill and surfacing, traffic loads may be dispersed through the pavement and fill to the extrados at a spread to depth ratio of 1 horizontally to 2 vertically.

3.8 Characteristic traffic actions shall be multiplied by the load factors γ_F in Appendix A to obtain design traffic actions.

3.9 For normal traffic based on authorised weight (AW) or C&U Regulations, the characteristic traffic actions shall be determined using assessment live loading (ALL) model 1 given in CS 454 [Ref 1.N] multiplied by a contingency factor of 1.1.

NOTE 1 The LM1 and LM2 load models in BS EN 1991-2 [Ref 6.N] do not satisfactorily model the effect of normal vehicles on masonry arches.

NOTE 2 The contingency factor accounts for future increases in traffic loads of up to 10%.

3.10 The requirements for abnormal traffic loading shall be recorded in the AIP.

NOTE Recommendations for abnormal loads for different types of highway are given in CD 350 [Ref 17.N].

3.11 Where abnormal traffic loads are required, characteristic actions shall be determined in accordance with load model LM3 in BS EN 1991-2 [Ref 6.N].

3.12 Normal traffic associated with the LM3 load models shall be represented by AW vehicle loading in accordance with ALL model 1 given in CS 454 [Ref 1.N] multiplied by a contingency factor of 1.1.

3.13 The impact factor shall be taken as 1.0 for the normal traffic in any lane occupied or straddled by the SV or SOV load model.

3.14 Only one SV load model shall be applied on any one superstructure.

3.15 SV load models shall be applied in their entirety and not truncated.

3.16 The SV load model shall be placed at any transverse position on the carriageway, with its side parallel to the kerb at the most unfavourable position to produce the most severe overall effect, either:

1) wholly within one notional lane; or,
2) straddling between two adjacent lanes.

NOTE Typical examples of application of SV load model and AW vehicle loading are shown in Figures 3.16Na and 3.16Nb. Figure 3.16Na shows the case of the SV load model fitting in one lane and Figure 3.16Nb shows the case where it straddles lanes.

Figure 3.16Na Application of SV load model and AW vehicle loading (case where SV vehicle fits in a lane)

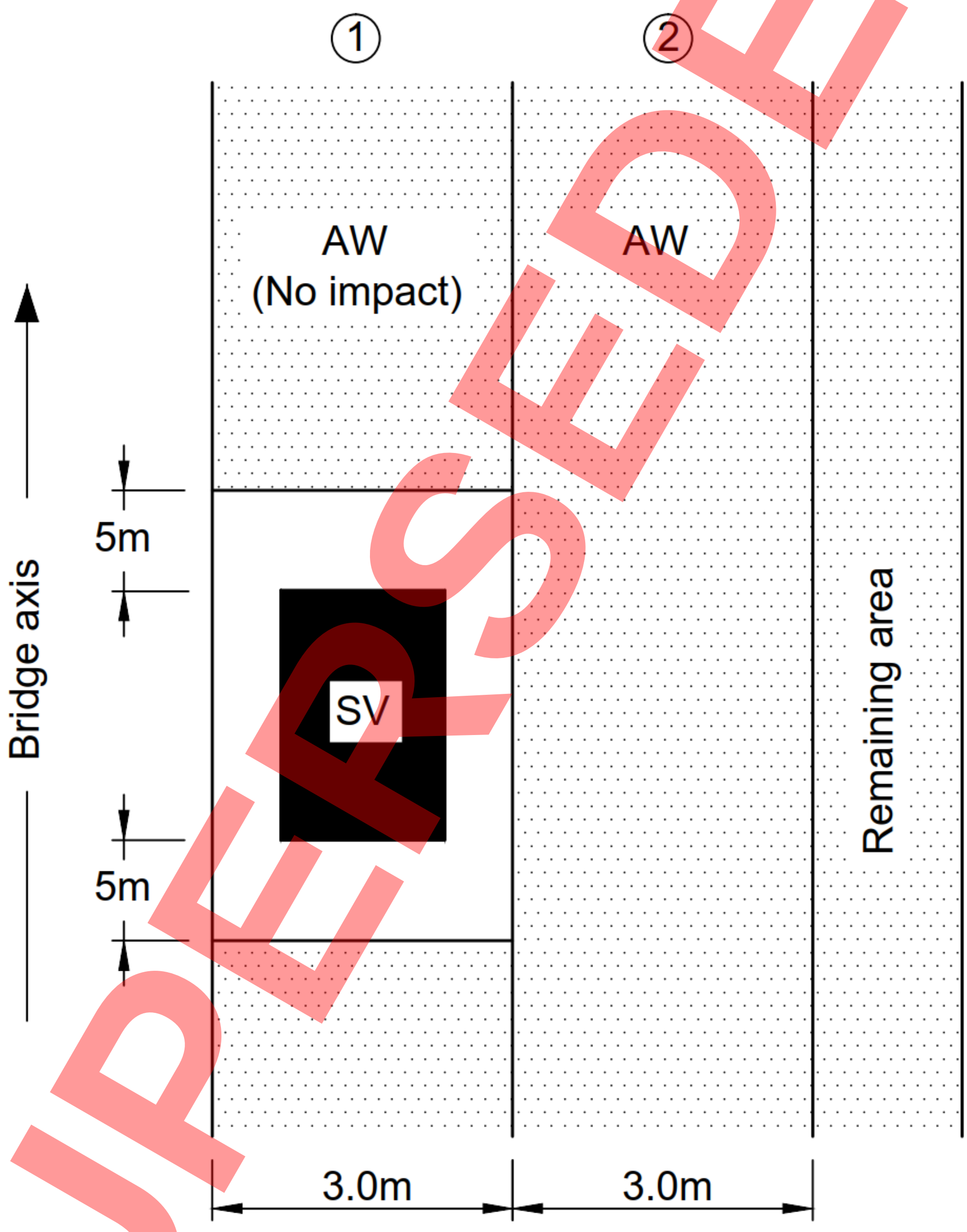
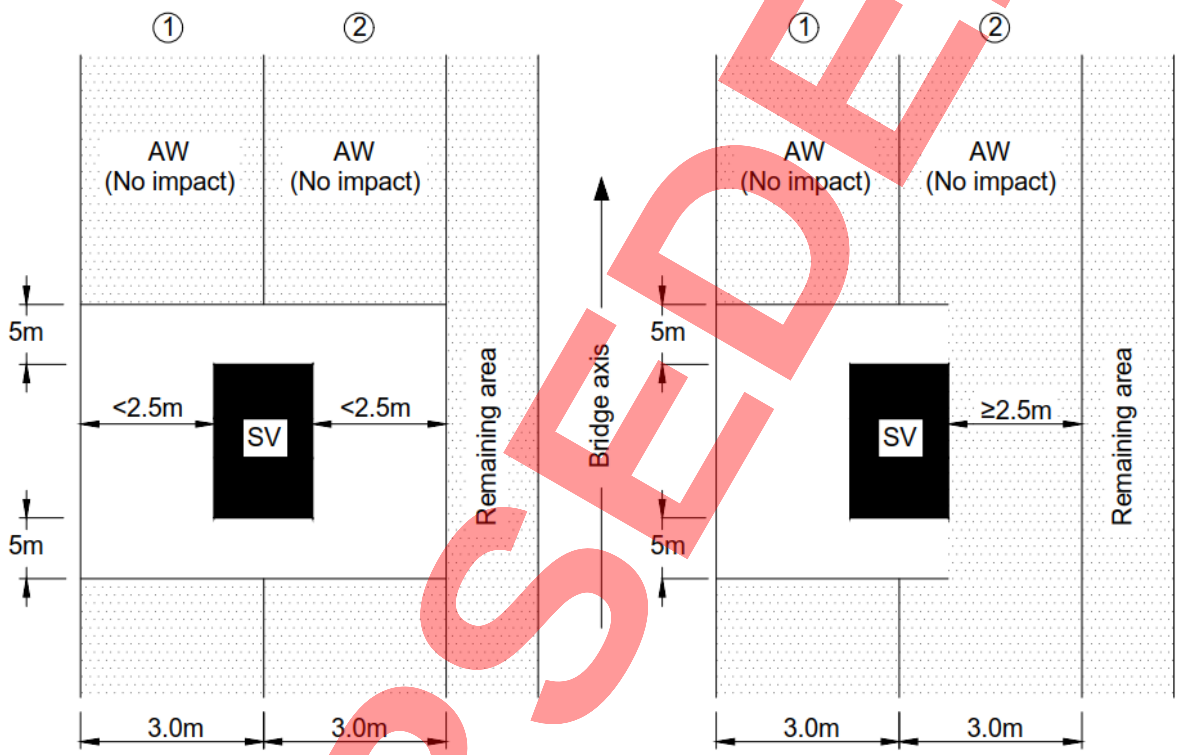


Figure 3.16Nb Application of SV load model and AW vehicles loading (cases where SV vehicle straddles lanes)



Longitudinal loading

3.17 The reasons for including or omitting longitudinal traffic loads shall be recorded in the AIP.

3.17.1 Longitudinal loads may be omitted for single span structures.

3.17.2 Longitudinal loads may be omitted at SLS.

3.18 Where longitudinal loads are included, the load shall be applied at the road surface and parallel to it in one notional lane only.

3.19 Characteristic longitudinal loads shall be multiplied by the load factor γ_F of 1.35 to obtain the design longitudinal load.

3.20 Characteristic longitudinal loads associated with normal traffic loading shall be taken as 0.6 times the total vertical load in the heaviest loaded lane, subject to a maximum of 900kN.

3.21 Characteristic longitudinal loads associated with SV load models shall be taken from Table 3.21

Table 3.21 Characteristic longitudinal load for SV Vehicles

Length loaded (S) (m)	Characteristic longitudinal load (kN)		
	SV196	**SV100**	**SV80**
S < 1.2	129	118	93
1.2 ≤ S < 1.6	236	236	186
1.6 ≤ S < 2.4	257	236	186
2.4 ≤ S < 3.6	327	327	257
3.6 ≤ S < 4.8	363	363	286
4.8 ≤ S < 6.0	408	408	322
6.0 ≤ S < 7.2	436	436 (for S ≥ 6.0)	343 (for S ≥ 6.0)
7.2 ≤ S < 8.4	445		
8.4 ≤ S < 9.6	472		
9.6 ≤ S < 12.8	490		
12.8 ≤ S < 13.6	500		
13.6 ≤ S < 14.0	504		
14.0 ≤S < 19.6	508		
S ≥ 19.6	535		

3.22 The longitudinal loading corresponding to SV load models shall not be applied together with longitudinal AW vehicle loading.

Accidental vehicle loading

3.23 The elements of structure not supporting the carriageway shall be designed for accidental vehicle loads.

NOTE *Elements of structure not supporting the carriageway can include:*

1) *outer verges;*
2) *footways;*
3) *central reserves; and,*
4) *cycletracks.*

3.23.1 For normal traffic, the characteristic accidental vehicle loading should be taken as ALL model 1 from CS 454 [Ref 1.N] multiplied by the 1.1 contingency factor.

3.23.2 No other traffic load, except those loads due to changes in speed or direction of the vehicle traffic, e.g. longitudinal and skidding loads, should be applied in combination with accidental vehicle loading.

3.24 Characteristic accidental vehicle loads shall be multiplied by the load factor γ_F of 1.65 to obtain the design accidental vehicle loads at ULS.

3.25 Characteristic accidental vehicle loads shall be multiplied by the load factor γ_F of 1.2 to obtain the design accidental vehicle loads at SLS.

Footway and cycletrack loading

3.26 Characteristic footway or cycletrack loading shall be taken as a uniformly distributed load of 5kN/m^2.

3.26.1 Footway and cycletrack loading should be applied to the loaded length that gives the most onerous effect.

NOTE *The critical loaded length is not normally the full length of the span.*

3.27 Partial factors for footway or cycletrack loading shall be obtained from BS EN 1990 [Ref 10.N].

Accidental impact loads on bridge supports and superstructures

3.28 The bridge support and superstructure shall be designed for accidental impact loads in accordance with BS EN 1991-1-7 [Ref 5.N].

3.29 The headroom clearance shall be in accordance with CD 127 [Ref 2.N].

4. Design and resistances

General

4.1 The design of the arch bridge and its components shall be verified for the effects of the following:

1) permanent actions;
2) all possible combinations of variable actions; and,
3) accidental actions.

4.1.1 The structure may be analysed using any appropriate analytical model or computer program that captures the critical behaviours and failure modes for the arch structure.

NOTE *It has been shown by Melbourne and Gilbert [Ref 6.I] that ring separation can significantly reduce strength. However, in some cases, notably in skew arches, bonding the rings together can be difficult and significantly increase costs.*

4.2 For bridges with a span/rise ratio greater than 6, the analytical model shall consider the flexibility of the arch ring and supports (abutments and piers) together with the effects of creep, shrinkage and temperature.

Materials

Masonry strength and properties

4.3 The characteristic compressive strength of masonry f_k shall be determined in accordance with BS EN 1996 [Ref 12.N].

4.3.1 In the absence of more accurate determination, the short term elastic modulus of masonry may be taken as $900 \cdot f_k$.

4.3.2 In the absence of more accurate determination, the creep factor and shrinkage strain may be taken from Table 4.3.2.

Table 4.3.2 Creep and shrinkage

Type of Unit	Creep coefficient	Shrinkage strain
Clay	1.5	0
Stone	1.0	0
Concrete	3.0	$500x10^{-6}$
Reconstituted Stone	3.0	$500x10^{-6}$

NOTE *The creep coefficient is the ratio of creep strain to short term elastic strain.*

Arch ring - ultimate limit state

General

4.4 The arch ring shall be verified for structural failure modes using ULS design actions.

NOTE *The arch ring failure modes can include:*

1) buckling;
2) instability; and,
3) rupture.

Direct stresses

4.5 The tensile strength of masonry shall be ignored in the analysis.

4.6 Where the moment at a section is such as to cause the centre of compression to be outside the middle third, the section shall be assumed to be cracked with a reduced area resisting compressive forces.

4.7 The maximum compressive stress in the ring shall not be taken as greater than $0.6\frac{f_k}{\gamma_M}$, with γ_M taken as 1.5.

4.7.1 The maximum compressive stress limitation may be verified using Equation 4.7.1.

Equation 4.7.1 Compressive stress in the arch ring or masonry element

$$P \leq 0.4 \cdot b \cdot f_k \cdot (h - 2 \cdot e)$$

where:

P	is the compressive force in the masonry due to ultimate design load effects
b	is the width of the arch ring under consideration
f_k	is the characteristic compressive strength of masonry
h	is the overall thickness of the arch ring or masonry element
e	is the eccentricity of the centre of compression in the arch ring or masonry element

NOTE Equation 4.7.1 includes an allowance for γ_M *.*

Shear

4.8 Shear forces on a radial plane through the arch ring shall be verified at all positions on the arch ring in accordance with Equation 4.8.

Equation 4.8 Shear forces in the arch ring

$$V \leq 0.4 \cdot P$$

where:

P	is the compressive force in the arch ring due to ultimate design load effects
V	is the shear force due to ultimate design load effects

Arch ring - serviceability limit state

4.9 The methodology and criteria for designing the arch ring at SLS, or the reason to not explicitly carry out verifications at the SLS, shall be recorded in the AIP.

4.9.1 Where SLS verifications are needed, they may be carried out by either:

1) carrying out a rigorous analysis according to a methodology and criteria agreed with the Overseeing Organisation and recorded in the AIP; or,
2) satisfying both Equations 4.9.1a and b.

Equation 4.9.1a SLS eccentricity limit

$$e \leq 0.25h$$

where:

e	is the eccentricity of the centre of compression
h	is the overall thickness of the arch

Equation 4.9.1b SLS stress limit

$$\sigma \leq 0.4 f_k$$

where:

σ	is the compressive stress
f_k	is the characteristic compressive strength of masonry

4.9.2 Where the span/rise ratio is less than 6, SLS verifications may be omitted if the structure is designed at the ULS using the higher values of the partial factors for traffic loading given in Appendix A.

4.9.3 Bridges with a span/rise ratio greater than 6 should include SLS verifications.

Spandrel walls, wing walls and abutments

4.10 Spandrel walls, wing walls and abutments shall be designed in accordance with the requirements of this section and PD 6694-1 [Ref 15.N].

4.11 The stability of wall elements shall be verified at the ULS for:

1) overturning;
2) sliding; and,
3) bearing (where appropriate).

4.11.1 The earth pressures to be used for stability verifications should be based on:

1) concrete or foamed concrete fill - hydrostatic pressure of wet concrete;
2) class 6N, 6P, 7A or 7B fill - active earth pressure.

NOTE Class 6N, 6P, 7A and 7B fill is specified in MCHW Series 600 [Ref 5.I].

4.12 The structural design of wall elements shall be verified at the ULS and the SLS.

4.12.1 The earth pressures to be used for the wall structural design should be based on:

1) concrete or foamed concrete fill - hydrostatic pressure of wet concrete;
2) class 6N, 6P, 7A or 7B fill - at rest earth pressure.

NOTE Class 6N, 6P, 7A and 7B fill is specified in MCHW Series 600 [Ref 5.I].

4.13 When fill comprises earthworks materials, the effects of live load induced earth pressures shall be taken into account.

4.13.1 The horizontal effects on retaining walls of live load on carriageways and footpaths may be taken to be zero when the fill is concrete or foamed concrete.

4.14 Spandrel walls, wing walls and abutments shall be designed for actions arising from vehicle collision with parapets.

4.15 The effect of actions acting on the arch ring from the spandrel wall shall be derived, including longitudinal spanning behaviours.

NOTE The deepest section of the spandrel wall adjacent to the pier or abutment wall can tend to span longitudinally to the abutment pier or to the ring in the next span.

4.16 Cracking shall be avoided by the provision of expansion joints or by designing the walls to be flexible enough to accommodate design movements without cracking.

NOTE Lime mortar construction can provide flexibility for the spandrel walls and wing walls.

4.16.1 Where spandrel walls and wing walls extend for 15m or more, expansion joints at centres not exceeding 10m should be provided.

Piers

Ultimate limit state

4.17 The tensile strength of masonry shall be ignored at the ULS.

4.18 Where the moment at a section is such as to cause the centre of compression to be outside the middle third, the section shall be assumed to be cracked with a reduced area resisting compressive forces.

4.19 The maximum compressive stress in the masonry shall not be taken as greater than $0.6\frac{f_k}{\gamma_M}$, with the material partial factor γ_M taken as 1.5.

4.19.1 The maximum compression stress limitation may be verified using Equation 4.7.1.

4.20 Shear forces on a plane through the masonry element shall be verified at all positions on the element such that Equation 4.8 is satisfied.

4.21 Where the height of a pier exceeds 12 times its thickness, the effect of displacements shall be evaluated.

NOTE The limiting stress state at the base of piers is often governed by the foundations.

Serviceability limit state

4.22 The methodology and criteria for designing the piers at SLS, or the reason to not explicitly carry out verifications at the SLS, shall be recorded in the AIP.

4.22.1 Where SLS verifications are needed, they should be carried out by either:

1) carrying out a rigorous analysis according to a methodology and criteria agreed with the Overseeing Organisation; or,
2) satisfying both Equations 4.9.1a and b.

4.22.2 SLS verifications may be omitted if the structure is designed at the ULS using the higher values of the partial factors for traffic loading given in Appendix A, and the pier is not slender.

4.22.3 A pier should be assumed to be slender if the SLS line of thrust is such as to cause the centre of compression to be outside the middle third.

Foundations

4.23 The design bearing capacity shall be verified using the design parameters for the soil or fill material in accordance with BS EN 1997-1 [Ref 9.N] and PD 6694-1 [Ref 15.N].

4.24 Foundation displacements and rotations shall be limited so as not to cause serviceability or ultimate limit state failures of the arch ring.

4.25 Where the structure is subject to hydraulic actions, the foundations shall be designed in accordance with CD 356 [Ref 3.N].

Parapets

4.26 Parapets shall be designed in accordance with CD 377 [Ref 16.N].

4.26.1 Masonry parapets should not be used to restrain errant vehicles.

4.27 Parapets shall be supported on an independent foundation with the following properties:

1) capable of resisting the actions acting on it; and,
2) not bear directly on the spandrel walls or wing walls.

5. Normative references

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

Ref 1.N	Highways England. CS 454, 'Assessment of highway bridges and structures'
Ref 2.N	Highways England. CD 127, 'Cross-sections and headrooms'
Ref 3.N	Highways England. CD 356, 'Design of highway structures for hydraulic action'
Ref 4.N	BSI. BS EN 1991-1-1, 'Eurocode 1 - Actions on Structures - Part 1-1: General actions- Densities, self weight, imposed loads for buildings'
Ref 5.N	BSI. BS EN 1991-1-7, 'Eurocode 1 - Actions on structures - Part 1-7 General actions - Accidental actions'
Ref 6.N	BSI. BS EN 1991-2, 'Eurocode 1. Actions on structures. Traffic loads on bridges'
Ref 7.N	BSI. BS EN 1991-1-4, 'Eurocode 1: Actions on structures. Part 1-4: General actions – Wind actions'
Ref 8.N	BSI. BS EN 1991-1-5, 'Eurocode 1: Actions on structures. Part 1-5: General actions – Thermal actions'
Ref 9.N	BSI. BS EN 1997-1, 'Eurocode 7: Geotechnical design - Part 1: General rules'
Ref 10.N	BSI. BS EN 1990, 'Eurocode: Basis of structural design'
Ref 11.N	BSI. BS EN 1991, 'Eurocode 1: Actions on structures' , 2002
Ref 12.N	BSI. BS EN 1996 , 'Eurocode 6: Design of masonry structures'
Ref 13.N	Highways England. GG 101, 'Introduction to the Design Manual for Roads and Bridges'
Ref 14.N	Highways England. MCHW SHW, 'Manual of Contract Documents for Highway Works Volume 1: Specification for Highway Works'
Ref 15.N	BSI. PD 6694-1, 'Recommendations for the design of structures subject to traffic loading to BS EN 1997-1:2004'
Ref 16.N	Highways England. CD 377, 'Requirements for road restraint systems'
Ref 17.N	Highways England. CD 350, 'The design of highway structures'
Ref 18.N	BSI. NA to BS EN 1991-2, 'UK National Annex to Eurocode 1: Actions on structures – Part 2: Traffic loads on bridges'

6. Informative references

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

Ref 1.I	Paper presented at First International Conference on Arch Bridges, Bolton, 3-6 September 1995, but not included in published proceedings. Mair, A.J. Mair 1995, 'A New UK Design Standard for Unreinforced Arch Bridges'
Ref 2.I	The Brick Development Association 1996. Cox, D. and Halsall, R. Cox & Halsall 1996, 'Brickwork Arch Bridges'
Ref 3.I	Arch bridges. Melbourne C Ed. Thomas Telford. 1995. pp 529-536. Choo, B.S. and Hogg, V. Choo & Hogg 1995, 'Determination of the serviceability limit state in arches'
Ref 4.I	Second International Arch Bridge Conference, Venice, Italy, October 1998. Owen, D.R.J., Peric, D., Petrinic, N., Brookes, C.L. and James, P.J. Owen et al 1998, 'Finite/Discrete Element Models for Assessment and Repair of Masonry Structures'
Ref 5.I	Highways England. MCHW Series 600, 'Manual of Contract Documents for Highway Works, Volume 1 Specification for Highway Works. Series 600 Earthworks'
Ref 6.I	The Structural Engineer Vol. 73. No 3. 7 Feb 1995 pp3 9-47. Melbourne, C. and Gilbert, M. Melbourne and Gilbert, 'The behaviour of multi-ring brickwork arch bridges'

Appendix A. Partial factors for actions

A1 Partial factors for actions

Table A.1 Partial factors for actions

Actions	Load model	Limit states			
		STR, GEO		EQU[4]	SLS
		Design Approach 1[1] Combination 1	Design Approach 1[1] Combination 2		
Permanent actions					
Concrete, stone or masonry	Dead load	As defined in BS EN 1990 [Ref 10.N]	As defined in BS EN 1990 [Ref 10.N]	As defined in BS EN 1990 [Ref 10.N]	1.0
Foamed concrete fill	Superimposed dead load	1.35 (Adverse, $\gamma_{G,sup}$) 0.95 (Relieving, $\gamma_{G,inf}$)	1.00	1.05	1.0
Other Fill	Superimposed dead load	As defined in BS EN 1990 [Ref 10.N]	As defined in BS EN 1990 [Ref 10.N]	As defined in BS EN 1990 [Ref 10.N]	1.0
Surfacing	Superimposed dead load	As defined in BS EN 1990 [Ref 10.N]	As defined in BS EN 1990 [Ref 10.N]	As defined in BS EN 1990 [Ref 10.N]	1.0
Variable actions					
Normal traffic[2] (including traffic surcharge effects)	ALL model 1 with contingency factor	1.65 with SLS verification 2.0 with no SLS verification[5]	1.41 with SLS verification 1.71 with no SLS verification[5]	1.65 with SLS verification 2.0 with no SLS verification[5]	1.0
Abnormal traffic and accompanying normal traffic (including traffic surcharge effects)	LM3 as defined in NA to BS EN 1991-2 [Ref 18.N]	1.35 with SLS verification 1.7 with no SLS verification[5]	1.15 with SLS verification 1.45 with no SLS verification[5]	1.35 with SLS verification 1.7 with no SLS verification.[5]	1.0
Other actions	As defined in the relevant parts of BS EN 1991 2002 [Ref 11.N].	As defined in BS EN 1990 [Ref 10.N]	As defined in BS EN 1990 [Ref 10.N]	As defined in BS EN 1990 [Ref 10.N]	1.0

Table A.1 Partial factors for actions (continued)

Note 1: In BS EN 1997-1 [Ref 9.N] Design Approach 1, partial factors are applied to actions and to ground strength parameters in two combinations, denoted Combination 1 and Combination 2. Combination 1 and Combination 2 can be critical for different aspects of the same verification. Note 2: The effect of the overload factor is already accounted for in the values of the partial factors. Note 3: The set of partial factors from BS EN 1990 [Ref 10.N] for Combination 1 or Combination 2 is defined in BS EN 1997-1 [Ref 9.N] Design Approach 1. Further guidance is provided in PD 6694-1 [Ref 15.N]. Note 4: The set of partial factors for the EQU limit state is defined in BS EN 1990 [Ref 10.N]. Note 5: See section 4 - If an SLS verification is not undertaken the greater partial factors are applicable.

Design Manual for Roads and Bridges

Highway Structures & Bridges
Design

CD 376
England National Application Annex to CD 376 Unreinforced masonry arch bridges

(formerly BD 91/04)

Revision 0

Summary
There are no specific requirements for Highways England supplementary or alternative to those given in CD 376.

Feedback and Enquiries
Users of this document are encouraged to raise any enquiries and/or provide feedback on the content and usage of this document to the dedicated Highways England team. The email address for all enquiries and feedback is: Standards_Enquiries@highwaysengland.co.uk

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Contents

Release notes

Version	Date	Details of amendments
0	Mar 2020	Highways England National Application Annex to CD 376.

Design Manual for Roads and Bridges

Highway Structures & Bridges
Design

CD 376
Northern Ireland National Application Annex to CD 376 Unreinforced masonry arch bridges

(formerly BD 91/04)

Revision 0

Summary
This National Application Annex contains Department for Infrastructure Northern Ireland specific requirements for unreinforced masonry arch bridges.

Feedback and Enquiries
Users of this document are encouraged to raise any enquiries and/or provide feedback on the content and usage of this document to the dedicated team in the Department for Infrastructure, Northern Ireland. The email address for all enquiries and feedback is: dcu@infrastructure-ni.gov.uk

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Contents

Release notes

Version	Date	Details of amendments
0	Mar 2020	Department for Infrastructure Northern Ireland National Application Annex to CD 376.

Foreword

Publishing information

This document is published by Highways England on behalf of Department for Infrastructure, Northern Ireland.

Contractual and legal considerations

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

Introduction

Background

This document states additional design requirements and advice for arch bridges not on motorway and all-purpose trunk roads. It complements the masonry and associated work requirements for unreinforced masonry arch bridges, referred to hereafter as 'arch bridges', in the Specification for Highway Works MCHW SHW [Ref 2.N].

Assumptions made in the preparation of this document

The assumptions made in GG 101 [Ref 1.N] apply to this document.

NI/1. Parapets

NI/1.1 Parapets shall be designed in accordance with CD 377 [Ref 3.N].

NI/1.1.1 Masonry parapets should not be used to restrain errant vehicles on motorway and all-purpose trunk roads.

NI/1.1.2 For structures not on motorway and all-purpose trunk roads unreinforced masonry parapets may be used at the discretion of the Overseeing Organisation.

NI/1.2 Parapets shall be supported on an independent foundation with the following properties:

1) capable of resisting the actions acting on it; and,
2) not bear directly on the spandrel walls or wing walls.

NI/1.2.1 For structures not on motorway and all-purpose trunk roads unreinforced masonry parapets may be formed as extensions to spandrel walls at the discretion of the Overseeing Organisation.

NI/2. Normative references

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

Ref 1.N	Highways England. GG 101, 'Introduction to the Design Manual for Roads and Bridges'
Ref 2.N	Highways England. MCHW SHW, 'Manual of Contract Documents for Highway Works Volume 1: Specification for Highway Works'
Ref 3.N	Highways England. CD 377, 'Requirements for road restraint systems'

Design Manual for Roads and Bridges

Highway Structures & Bridges
Design

CD 376
Scotland National Application Annex to CD 376 Unreinforced masonry arch bridges

(formerly BD 91/04)

Revision 0

Summary
There are no specific requirements for Transport Scotland supplementary or alternative to those given in CD 376.

SUPERSEDED

Feedback and Enquiries
Users of this document are encouraged to raise any enquiries and/or provide feedback on the content and usage of this document to the dedicated Transport Scotland team. The email address for all enquiries and feedback is: TSStandardsBranch@transport.gov.scot

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Contents

Release notes

Version	Date	Details of amendments
0	Mar 2020	Transport Scotland National Application Annex to CD 376.

Design Manual for Roads and Bridges

Llywodraeth Cymru
Welsh Government

Highway Structures & Bridges
Design

CD 376
Wales National Application Annex to CD 376 Unreinforced masonry arch bridges

(formerly BD 91/04)

Revision 0

Summary
There are no specific requirements for Welsh Government supplementary or alternative to those given in CD 376.

Feedback and Enquiries
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Contents

Release notes

Version	Date	Details of amendments
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