

Australian/New Zealand Standard™

Buried corrugated metal structures

Part 1: Design methods



AS/NZS 2041.1:2011

This Joint Australian/New Zealand Standard was prepared by Joint Technical Committee CE-025, Corrugated Metal Drainage Pipes and Arches. It was approved on behalf of the Council of Standards Australia on 12 July 2011 and on behalf of the Council of Standards New Zealand on 15 July 2011.
This Standard was published on 5 August 2011.

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This Standard was issued in draft form for comment as DR 10015.

Australian/New Zealand Standard™

Buried corrugated metal structures

Part 1: Design methods

Originated in Australia as AS A128—1962.
Subsequent Editions AS 2041—1984 and AS 2042—1984.
AS 2041—1984 and AS 2042—1984 jointly revised, amalgamated and designated AS/NZS 2041:1998.
AS/NZS 2041:1998 revised, in part, and designated AS/NZS 2041.1:2011.

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Jointly published by SAI Global Limited under licence from Standards Australia Limited, GPO Box 476, Sydney, NSW 2001 and by Standards New Zealand, Private Bag 2439, Wellington 6140

ISBN 978 0 7337 9898 6

PREFACE

This Standard was prepared by the Joint Standards Australia/Standards New Zealand Committee CE-025, Corrugated Metal Drainage Pipes and Arches, to supersede, in part, AS/NZS 2041:1998, *Buried corrugated metal structures*, AS 1762—1984, *Helical lock-seam corrugated steel pipes—Design and installation*, AS 3703.2—1989, *Long-span corrugated steel structures*, Part 2: *Design and installation*.

The objective of this Standard is to provide designers, manufacturers and installers of buried corrugated metal structures with requirements for the structural design of such structures for use in earthworks, primarily as drainage culverts or access ways.

This Standard is Part 1 of the AS/NZS 2041 series, *Buried corrugated metal structures*, which comprises the following parts:

AS/NZS

- 2041 Buried corrugated metal structures
- 2041.1 Part 1: Design methods (this Standard)
- 2041.2 Part 2: Installation
- 2041.4 Part 4: Helically formed sinusoidal pipes
- 2041.6 Part 6: Bolted plate structures

Other parts of the series being proposed include the following:

- Part 3: Assessment of existing structures
- Part 5: Helically formed ribbed pipes
- Part 7: Bolted plate structures with transverse stiffeners
- Part 8: Metal box structures

This Edition includes the following changes:

- (a) The design methods are now applicable to any of the products in the AS/NZS 2041 series of Standards.
- (b) Installation requirements have been moved to AS/NZS 2041.2.
- (b) Design criteria for aluminium included.
- (c) Clearer presentation of the design model.
- (d) Limit state method included (harmonized with the Canadian Highway Bridge Design Code).
- (e) Current Australian, New Zealand and selected overseas design loads, including earthquake loads.
- (f) Greater comprehensive discussion of durability issues.
- (g) Method included for approval of profiles other than sinusoidal profiles.
- (h) Notations have been brought in line with ISO 3898, Bases for design of structures—Notation—General symbols.
- (i) Background material guidance on the requirements of various clauses in the Standard included (Appendix B and Appendix E).

Design requirements are based on empirical formulae established by full scale testing. Details of the methods for full size testing to determine properties are also included.

In this document, the words ‘this Standard’ indicates AS/NZS 2041.1.

The terms ‘normative’ and ‘informative’ have been used in this Standard to define the application of the appendix to which they apply. A ‘normative’ appendix is an integral part of a Standard, whereas an ‘informative’ appendix is only for information and guidance.

Statements expressed in mandatory terms in notes to Tables and Figures are deemed to be an integral part of the Standard. Notes to the text contain information and guidance and are not considered to be integral parts of the Standard.

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FOREWORD

Buried corrugated metal structures are flexible members that rely on soil-structure interaction. Manufacture, design and installation to this series of Standards (AS/NZS 2041) should ensure such interaction occurs. This Foreword is intended to introduce the series, give information on the interaction of the various parts of AS 2041 series, background on how the Parts interact and emphasize the most important considerations for these buried corrugated metal structures.

The series is composed of a design Standard (AS/NZS 2041.1), an installation Standard (AS/NZS 2041.2), and product Standards (see Preface for a list of Parts). The product Standards describe a range of products from simple round helical pipes to bolted plate structures of varying shape (round, arched, elliptical, etc.).

The design Standard (AS/NZS 2041.1) covers the determination of the structural base metal wall thickness (by structural analysis) taking into account durability and other considerations.

Correct installation is essential to performance. Adequate compaction of selected appropriate fill material *must* be carried out in order to meet the design assumptions for strength. This is covered by the requirements of the installation Standard.

Design and construction following good engineering practice would include the following aspects:

- (a) Adequate investigation of the site conditions (soil, soil acidity, drainage, flow, foundations).
- (b) Expected life of the structure (structure size or significance, aggressivity of environment).
- (c) Appropriate material selection (metal durability, backfill properties, coating systems).
- (d) Structural design method appropriate for the structure size (e.g., small diameter pipe versus large span arch).
- (e) Design of any foundations or geotechnical considerations.
- (f) Manufacture of the metal structure (materials, fabrication and quality).
- (g) Material supply and assembly (supply of backfill, handling of flexible metal structure, transport, bolting together).
- (h) Methods and equipment for installation, backfilling and compaction (hand-held compactor versus heavy machinery).
- (i) Construction loads (heavy trucks or equipment).

This Standard (AS/NZS 2041.1) includes Appendices that give guidance on some of the above items.

The various product Standards describe the different products and refer to AS/NZS 2041.1 and AS/NZS 2041.2 for design and installation. These products are considered to perform satisfactorily when designed and installed using this series. The design method may not be appropriate for use with other profiles unless performance is confirmed by experimental investigation, as given in this Part (AS/NZS 2041.1). The products covered include the following:

- (i) *Various corrugation types*—sinusoidal corrugations with pitches ranging from 38 mm to 400 mm, and ribbed corrugations of various profiles.
- (ii) *Various metal types*—galvanized steel, and aluminium and polymer-coated steel.

- (iii) *Various manufacturing types*—helically wound pipes with a mechanically folded seam, plates (of standard size but varying curvature) bolted together to form a predetermined shape.

STANDARDS AUSTRALIA/STANDARDS NEW ZEALAND

Australian/New Zealand Standard
Buried corrugated metal structures

Part 1: Design methods

SECTION 1 SCOPE AND GENERAL

1.1 SCOPE

This Standard specifies structural design methods for buried corrugated metal structures of circular or other shape installed under a flexible pavement.

Buried corrugated metal structures are primarily intended for use in stormwater drainage and access tunnels, and for the support of roadway and railway and other loadings. Construction consists of corrugated section shapes buried in an embankment or in a trench situation. Correct installation in a soil envelope is essential to the performance of the structure.

The design methods in this Standard are intended to apply to the products described in the other parts of this AS/NZS 2041 series with profiles that satisfy the following criteria:

(a) $\frac{p}{H_c} \leq 8$

(b) $\frac{p}{w_r} \leq 5$

where

p = pitch of corrugation, in millimetres

H_c = height of corrugation rib, in millimetres

w_r = width of corrugation rib, in millimetres

These products range from small pipes to large arch-type structures, from off-the-shelf systems to significant long-span structures.

NOTES:

- 1 Guidelines on information that should be supplied by the designer and/or owner to the manufacturer and installer are given in Appendix A.
- 2 This Standard is intended to cover buried structures comprising a flexible corrugated metal wall and a soil envelope governed by soil-structure interaction. It must be recognized that both soil and metal structure play a vital part in the structural design; therefore proper installation is essential for the final performance. Background on the Standard material, including the ring compression theory, is given in Appendix B.
- 3 In order to ensure good performance, general design procedures should include site investigation, backfill material selection, flow design, durability assessment, structural design, handling and laying and, backfill compaction.
- 4 For non-flexible pavements, specialist advice should be sought.

1.2 EXCLUSIONS

The design methods in this Standard do not apply to the following:

- (a) Slotted drains.
- (b) Fluming.
- (c) Tanks.
- (d) Integral load-relieving roof slabs.
- (e) Internally pressurized structures.
- (f) Integrated composite steel and concrete structures.
- (g) Special bends, fittings, penetrations and perforations.

1.3 APPLICATION

This Standard shall be used in conjunction with AS/NZS 2041.2 and the appropriate product Standard of this series (i.e., AS/NZS 2041.4 or AS/NZS 2041.6).

NOTES:

- 1 This Standard includes information on design issues and requirements for structural design of the metal structure. Performance of the structure depends on correct installation (particularly adequate compaction of appropriate fill material around the metal structure) for which AS/NZS 2041.2 gives the appropriate requirements.
- 2 The design methods in this Standard are appropriate for use only with the products defined in the other parts of the AS/NZS 2041 series (see Clause 1.4). Expert advice should be obtained before such products are used with any other product.

1.4 NORMATIVE REFERENCES

The following are the normative documents referenced in this Standard:

NOTE: Documents referenced for informative purposes are listed in the Bibliography.

AS

1170	Structural design actions
1170.4—2007	Part 4: Earthquake actions in Australia
1397	Steel sheet and strip—Hot-dipped zinc-coated or aluminium/zinc-coated
1726	Geotechnical site investigations
2193	Calibration and classification of force-measuring systems
3500	Plumbing and drainage
3500.0	Glossary of terms
5100	Bridge design
5100.2	Part 2: Design loads
5100.7	Part 7: Rating of existing bridges

AS/NZS

1170	Structural design actions
1170.0:2002	Part 0: General principles
1734	Aluminium and aluminium alloys—Flat sheet, coiled sheet and plates
2041	Buried corrugated metal structures
2041.2	Part 2: Installation
2041.4	Part 4: Helically formed sinusoidal pipes
2041.6	Part 6: Bolted plate structures

AS/NZS

4600 Cold-formed steel structures

4680 Hot-dip galvanized (zinc) coating on fabricated ferrous articles

NZS

1170 Structural design actions

1170.5:2004 Part 5: Earthquake actions—New Zealand

ASTM

A742/A742M Standard Specification for Steel Sheet, Metallic Coated and Polymer
Precoated for Corrugated Steel PipeB746/B746M-02 Standard Specification for Corrugated Aluminium Alloy Structural Plate
for Field Bolted Pipe, Pipe Arches and Arches

Building Industry Authority

New Zealand Building Code

New Zealand Geotechnical Society

Guidelines for Field Description of Soils and Rocks in Engineering Use

Transit New Zealand

Bridge Manual

1.5 DEFINITIONS

For the purpose of this Standard, the definitions in AS 3500.0 and those below apply. Where a definition given in AS 3500.0 differs from the one given below, the definition herein applies.

1.5.1 Action

Set of concentrated or distributed forces acting on a structure (direct action), or deformation imposed on a structure or constrained within it (indirect action).

NOTE: The term load is often used to describe direct actions.

1.5.2 Action effects (internal effects of actions, load effects)

Effects of actions on structural members (e.g., internal force, moment, stress, strain) or on the whole structure (e.g., deflection, rotation).

1.5.3 Compaction

The process of soil densification, at a specified moisture content, through the application of load by rolling, tamping, rodding or vibration with mechanical or manual vibration equipment.

1.5.4 Corrugation

Sinusoidal and ribbed profile section shapes.

1.5.5 Deep corrugation

Structural plate corrugations with a pitch greater than or equal to 380 mm and a depth greater than or equal to 130 mm.

1.5.6 Depth of corrugation

Measured as the vertical distance from a straightedge resting on the corrugation crests (or top of the ribs) parallel to the axis of the structure, to the bottom of the intervening valley (or outside surface of the flat portion).

1.5.7 Design cover

The clear minimum depth of material above the top of the structure (i.e. top of corrugation) and the—

- (a) pavement surface of road;
- (b) base of sleepers for railway traffic loads and surface of track formation for heavy vehicles or equipment running on the track formation;
- (c) top of trench or embankment, where Items (a) and (b) are not applicable; or
- (d) base of a stockpile.

1.5.8 Design working life

The duration of the period during which a structure or a structural element is assumed, when designed, to perform its intended purpose with expected maintenance but without major repair being necessary.

1.5.9 Diameter, internal

The minimum clear dimension measured from internal crest to internal crest.

1.5.10 Durability allowance

The additional structural base metal wall thickness, determined through durability design, in order for a structure to have, at the end of its design working life, a structural base wall thickness of at least the structural wall thickness.

1.5.11 Fill, embankment

Fill placed beyond the specified zone of compacted select fill, in accordance with the job specification.

1.5.12 Fill, flowable

A mixture of granular material, fly ash, cement and water proportioned to achieve a compressive strength similar to select fill.

1.5.13 Fill, select

Specified properties and grading placed and compacted in layers around and over the corrugated metal structure, as specified in this Standard.

1.5.14 Flexibility factor

A measure of wall flexibility of the corrugated metal structure for the purpose of achieving handling and installation without permanent deformation of the metal structure.

1.5.15 Foundation

Naturally occurring or prepared soil or rock underlying the installation and embankment.

1.5.16 Haunch

- 1 Part of the periphery of pipe-arches and underpasses between the crown and invert with relatively small radius of curvature, or the zone outside the lower side wall of a structure.
- 2 For metal box structures, the part of the periphery between the crown and side with relatively small radius of curvature.

1.5.17 Height of fill (*h*)

The vertical distance between the neutral axis of the corrugation at the top of the structure and the—

- (a) pavement surface of road;

- (b) base of sleepers for railway traffic loads and surface of track formation for heavy vehicles or equipment running on the track formation;
- (c) top of trench or embankment, where Items (a) and (b) are not applicable; or
- (d) base of a stockpile.

NOTE: The height of fill is used to calculate the design permanent loads on the structure.

1.5.18 Imposed action

A variable action resulting from the intended use or occupancy of the structure.

1.5.19 Liquefaction

Transformation of saturated loose cohesionless soils (mainly sands and silts) from a solid state to a liquefied state as a consequence of ground movements, mainly from earthquakes, leading to a loss of strength and stiffness.

1.5.20 Load

The value of a force appropriate to an action.

1.5.21 Minimum structural base metal wall thickness

The structural base metal wall thickness to satisfy structural, durability, handling and installation requirements.

1.5.22 Permanent action

Action that is likely to act continuously and for which variations in magnitude with time are small compared with the mean value.

1.5.23 Pitch of corrugation

The distance measured from crest to crest of corrugations (or from centre to centre of the ribs) at 90° to the direction of the corrugation (or rib).

1.5.24 Protective coating

A coating designed to protect the substrate from the environment.

NOTE: Types of protective coating include aluminized, galvanized, polymer, bituminized and epoxy coatings.

1.5.25 Ring compression

The circumferential compressive force in the structure wall, per unit length, as a result of external dead and live load pressures.

1.5.26 Shallow corrugation

Corrugation with a pitch and depth that do not fall under the deep corrugation definition.

1.5.27 Skew number

A number denoting the angle between the centre-line of the road, railway or other embankment and the centre-line of the structure, measured in a clockwise direction.

1.5.28 Soil classification

Classification system for soil types as given in AS 1726 or the New Zealand Geotechnical Society *Guideline for Field Description of Soil and Rock in Engineering Purposes*.

NOTE: A simplified description of the soil types referred to in this Standard is given in Table 1.1.

1.5.29 Structural base metal wall thickness

The minimum wall thickness to satisfy the structural requirements of this Standard.

1.5.30 Track formation

The earthworks for a railway track (excludes ballast).

1.5.31 Width

- 1 A measurement of the inside of the rib.
- 2 A measurement outside the rib that meets or exceeds the minimum width plus two wall structural base metal wall thicknesses.

TABLE 1.1
SOIL TYPES

Soil group number	Soil types	Grain size	Soil classification symbol (see Note)
I	Well-graded gravel or sandy gravel	Coarse	GW
	Poorly graded gravel or sandy gravel		GP
	Well-graded sand or gravelly sand		SW
	Poorly graded sand or gravelly sand		SP
II	Clayey gravel or clayey-sandy gravel	Medium	GC
	Clayey sand or clayey-gravelly sand		SC
	Silty sand or silty-gravelly sand		SM

NOTE: For soil classification, see AS 1726.

1.6 NOTATION

The symbols used in this Standard, including their definitions, are listed below.

Unless a contrary intention appears, the following applies:

- (a) The symbols used in this Standard shall have the meanings ascribed to them below, with respect to the structure, or member, or condition to which a clause is applied.
- (b) Where non-dimensional ratios are involved, both the numerator and denominator shall be expressed in identical units.
- (c) The dimensional units for length, force and stress, in all expressions or equations, shall be taken as millimetres (mm), newtons (N) and megapascals (MPa) respectively, unless otherwise noted.
- (d) An asterisk (*) placed after a symbol as a superscript (e.g., M_y^*) denotes a design action effect due to the design load.

Symbol	Definition
A	= cross-sectional area of the wall of the metal structure per unit length, in the longitudinal direction, in millimetres squared per millimetre run of structure
A_c	= cross-sectional area of the concrete per unit length, in the longitudinal direction, in millimetres squared per millimetre run of structure
A_v	= vertical component of the ultimate limit state earthquake acceleration, expressed as the vertical acceleration ratio
A_{vp}	= vertical component of the permissible stress earthquake acceleration, expressed as the vertical acceleration ratio

Symbol	Definition
A_w	= cross-sectional area of fill material above the structure but below the crown of the structure (measured from the neutral axis of the corrugated section), in metres squared
a	= wheel footprint width across the traffic/traffic lane, in metres
b	= wheel footprint length across the traffic/traffic lane, in metres = minimum transverse backfill distance, in millimetres
c	= ratio of horizontal to vertical dimension for load dispersion
C_1	= tandem axle coefficient, dimensionless
C_c	= coefficient of gradation
C_s	= axial stiffness parameter
C_u	= minimum coefficient of uniformity
$C(T)$	= elastic site hazard spectrum for horizontal loading as a function of a period (T)
$C_v(T)$	= elastic site hazard spectrum for vertical loading
$C_h(T)$	= spectral shape factor for the site subsoil class appropriate to the site, as given in AS 1170.4 or NZS 1170.5
$C_h(0.0)$	= spectral shape factor for the site subsoil class appropriate to the site, using $T = 0.0$, for locked in structures as given in AS 1170.4 or NZS 1170.5
DLA	= dynamic load allowance
d	= separation of wheel loads, in metres
d_c	= corrugation depth, in millimetres
d_h	= effective horizontal geometrical dimension of metal structure (to the neutral axis of the corrugation) defined in Figures 1.5(A) and 1.5(C), in millimetres = span of buried corrugated metal structure
d_v	= effective vertical geometrical dimension of structure (to the neutral axis of the corrugation) defined in Figures 1.5(A) and 1.5(C), in millimetres
E	= Young's modulus of elasticity for steel or aluminium, in megapascals
E_c	= modulus of elasticity of the concrete, in megapascals
E_d	= design action effect
$E_{d,conc}$	= design action effect in the concrete
$E_{d,metal}$	= design action effect in the metal structure
E_s	= secant modulus of soil stiffness, in megapascals
E_{sm}	= modified secant modulus of soil stiffness, in megapascals
E_p	= vertical permissible stress earthquake action
E_u	= vertical ultimate earthquake action
F	= action effect for wall compression, in kilonewtons per metre run of structure = axial metal structure wall compression due to permanent and construction actions, in kilonewtons per metre run of structure

Symbol	Definition
	= action effect for wall compression which is equal to greater of $[\gamma_G G, \gamma_Q Q_c]$ and $[\gamma_G G, \gamma_E E_u]$, in kilonewtons per metre run of structure
F_{ax}	= axle load of vehicle for the live load stage being considered, in kilonewtons
F_f	= flexibility factor, in millimetres per newton
$F_{f,max}$	= maximum flexibility factor, in millimetres per newton
F_G	= unfactored wall compression due to permanent action, in kilonewtons per metre run of structure
F_h	= horizontal arch footing force, in kilonewtons per metre run of structure
F_l	= line load equivalent to the vehicle axle load, in kilonewtons per metre run of structure
F_p	= load applied to the pipe to produce a given percentage deflection, in newtons per metre run of structure
F_Q	= unfactored wall compression due to imposed action (design vehicle live load on finished structure), in kilonewtons per metre run of structure
F_r	= ring compression force, in kilonewtons per metre run of structure
F_{sr}	= fatigue stress range for fatigue resistance
F_v	= vertical arch footing force, in kilonewtons per metre run of structure
f_a	= allowable compressive stress, in megapascals
f'_c	= characteristic compressive (cylinder) strength of concrete at 28 days
f_u	= minimum ultimate tensile strength, in megapascals
f_{uc}	= ultimate compressive wall stress, in megapascals
f_{uc1}	= modified ultimate compressive strength, in megapascals
f_y	= minimum yield strength (cold-formed) of the metal structure wall, in megapascals
G	= permanent action
H'	= half the vertical distance from the crown to spring line, in millimetres
H_c	= height of corrugation rib, in millimetres
h	= height of fill cover from ground surface to neutral axis of corrugated section, in millimetres
h_b	= minimum height of structural backfill cover over the crown neutral axis of the metal structure as specified by the designer but not less than h_{min} minimum cover, in millimetres
h_e	= effective cover height for bending, in millimetres
h_{min}	= minimum cover, to highest point of metal structure, in millimetres
h_s	= mean stockpile height measured to the back of the stockpile, in millimetres
I	= second moment of area of the corrugated section, in millimetres to the fourth power per millimetre run of structure
	= structure importance level as given in AS 1170.4
I_e	= effective second moment of area of the corrugated section, in millimetres to the fourth power per millimetre run of structure

Symbol	Definition
i	= radius of gyration of corrugated section (or the effective radius of gyration), in millimetres
k_1, k_2	= factor used for calculating the dead load moment
k_3	= reduction factor for modifying wall strength in multiple structure installations = factor used for calculating live load moments in metal box structures
k_4	= factor used in calculating equivalent line loads resulting from imposed axle loads, in metres = factor used for calculating live load moments in metal box structures
k_5	= factor representing the relative stiffness of the metal structure wall with respect to the adjacent soil
k_6	= factor for soil stiffness variation from crown to side (reduction factor for buckling stress in the metal structure wall to account for the variation of soil stiffness from the crown to the side)
k_7	= factor for calculating relative wall stiffness
k_f	= arching factor used to calculate axial force in the wall due to permanent actions
k_l	= pressure factor for dispersion of load footprint with depth
k_{M1}	= parameter used in calculating moments in wall of metal structure wall
k_{M2}	= parameter used in calculating moments in wall of metal structure wall
k_{M3}	= parameter used in calculating moments in wall of metal structure wall
k_{M4}	= parameter used in calculating moments in wall of metal structure wall
k_{M5}	= parameter used in calculating moments in wall of metal structure wall
k_p	= probability factor as given in AS 1170.4 or NZS 1170.5 appropriate to the annual probability of exceedance
k_R	= haunch moment reduction factor for metal box structures
k_s	= stockpile influence factor, which accounts for stockpile geometry and arching within the stockpile material
k_{ss}	= soil stiffness factor
l_l	= length of dispersed load at crown measured longitudinally, in metres = distribution width at cover h when determining DLA, in metres
l_t	= length of dispersed load at crown measured transversely, in millimetres = distribution length at cover h when determining DLA, in metres
L_L	= line load equivalent to the live load, in kilonewtons per metre
M	= action effect for bending moments resulting from fill to crown level, fill to h and the live load applied, in kilonewton metres per metre run of structure = action effect for bending moment, in kilonewton metres per metre run of structure
M_c	= moment in the metal structure resulting from the live load applied, in kilonewton metres per metre run of structure
M_{cD}	= crown bending moment due to dead load, in kilonewton metres per metre run of structure

Symbol	Definition
M_{cf}	= total factored dead plus seismic crown bending moment in a metal box structure, in kilonewton metres per metre run of structure
M_{cG}	= intensity of bending moment in the crown due to dead loads, in kilonewton metres per metre
M_{cL}	= crown bending moment due to live load, in kilonewton metres per metre
M_{cQ}	= intensity of bending moment in the crown due to live loads, in kilonewton metres per metre
M_E	= additional ULS moment in a metal box structure due to earthquake loading, in kilonewton metres per metre run of structure
M_f	= moment in the metal structure resulting from fill to the crown level, in kilonewton metres per metre run of structure = maximum moment due to factored loads in metal box culverts, in kilonewton metres
M_G	= sum of the intensities of unfactored bending moments at the crown and haunch in a metal box structure due to dead load, in kilonewton metres per metre run of structure
M_{G1}	= sum of unfactored bending moments in crown and haunch in a metal box structure due to dead load below h_{min} , in kilonewton metres per metre run of structure
M_{G2}	= sum of the unfactored bending movements in crown and haunch in a metal box structure due to dead load to above h_{min} , in kilonewton metres per metre run of structure.
M_{hD}	= haunch bending moment due to dead load, in kilonewton metres per metre
M_{hf}	= total factored dead and seismic haunch bending moment in a metal box structure, in kilonewton metres per metre run of structure
M_{hG}	= intensity of bending moment in the haunch due to dead loads, in kilonewton metres per metre
M_{hL}	= haunch bending moment due to live load, in kilonewton metres per metre
M_{hQ}	= intensity of bending moment in the haunch due to live loads, in kilonewton metres per metre
M_L	= sum of the intensities of bending moments at the crown and haunch in a metal box structure due to live load, in kilonewton metres per metre run of structure
M_r	= moment in the metal structure resulting from fill to height (h), in kilonewton metres per metre run of structure
M_p	= unfactored plastic moment capacity (resistance) of the corrugated section, in kilonewton metres per metre run of structure
M_{Pf}	= factored plastic moment, in kilonewton metres per metre
M_{Q1}	= sum of the unfactored bending moments in crown and haunch in a metal box structure due to axle load (line load equivalent) of the live load, in kilonewton metres per metre run of structure
M_{Q2}	= sum of the unfactored bending moments in crown and haunch in a metal box structure due to uniformly disturbed component of the live load
m_f	= multiple lane or multiple track factor

Symbol	Definition
N	= local wheel load normal to surface, in kilonewtons
$N(T,D)$	= near fault factor as given in NZS 1170.5
N_s	= unfactored axial compressive capacity (resistance) of the corrugated section, in kilonewtons per metre run of structure
n_f	= flexibility number used in calculating moments in a metal structure wall
n_y	= design working life, in years
P	= unfactored wheel, axle or track load applied over the footprint, in kilonewtons
p	= pitch of corrugation, in millimetres
p_a	= allowable haunch soil pressure, in kilopascals
p_u	= maximum ultimate haunch pressure (resistance), in kilopascals
p_b	= pressure on the bottom radius, in kilopascals
p_G	= pressure on the crown due to permanent action, in kilopascals
pH	= $-\log_{10}$ (hydrogen ion concentration)
p_h	= haunch pressure, in kilopascals
p_Q	= pressure at the crown of the structure resulting from the imposed load on the surface distributed over the area at depth (h) (including the dynamic load allowance) distributed in accordance with Clause 4.4, in kilopascals
p_s	= pressure resulting from the weight of stockpile above the structure, in kilopascals
P_{UDL}	= live load uniform component, in kilonewtons per metre
p_t	= total design pressure at the crown, in kilopascals
Q	= imposed action
Q_c	= imposed action during construction
q	= tyre pressure, in kilopascals
R	= rise of box culvert, in metres
R_{AL}	= axle load correction factor for a metal box culvert
R_b	= resistivity of the backfill, in ohm-centimetres
R_{bm}	= ultimate characteristic flexural strength of a longitudinal correction, in kilonewton metres per metre run of structure
R_{bs}	= characteristic seam strength (resistance) in compression of bolted longitudinal seams, in kilonewtons per metre run of seam
R_c	= concrete strength correction factor for a metal box culvert
R_f	= 1.2 for metal box culverts having spans less than 8000
R_s	= effective rise of pipe-arch, arch and special shape or effective diameter of pipe, measured to neutral axis of corrugation profile, in millimetres
R_u	= ultimate capacity of the wall of the metal structure in compression, in kilonewtons per metre run of structure

Symbol	Definition
r	= radius of curvature of metal structure (to the neutral axis of the corrugation), in millimetres
r_b	= bottom radius (neutral axis of corrugation), in millimetres
r_c	= corner radius, sometimes called the shoulder (neutral axis of corrugation), in millimetres
r_e	= an equivalent radius, in millimetres
r_h	= haunch radius (neutral axis of corrugation), in millimetres
r_s	= side radius (neutral axis of corrugation), in millimetres
r_t	= top radius (neutral axis of corrugation), in millimetres
S_b	= clear internal span for metal box structures. measured to internal crests, in millimetres
S_m	= minimum transverse clear spacing between adjacent structures in multiple installations, in millimetres
S_s	= clear internal span of pipe-arch, arch and special shapes or internal diameter of pipe, measured to internal crests, in millimetres = axial strength of a longitudinal connection for seam strength for metal box structures, in kilonewton metres
t	= structural base metal thickness without coatings, in millimetres = minimum depth of relieving slab above box culvert, in millimetres
t_b	= relieving slab depth for box culvert, in millimetres
V	= total factored footing force acting in the direction of the box culvert straight side, in kilonewtons per metre
V_H	= horizontal footing reaction of box culvert, in kilonewtons per metre
V_V	= vertical footing reaction of box culvert, in kilonewtons per metre
W	= unfactored weight of the column of earth and other permanent materials above the structure per unit length, in kilonewtons per metre run of structure
W_{pl}	= plastic section modulus of the corrugated section, in millimetres to the third power per millimetre run of structure
W_s	= unfactored weight of the column of stockpile material above the structure at the base of stockpile per unit length, in kilonewtons per metre run of structure
w	= lane width, in metres
w_r	= width of corrugation rib, in millimetres
Z	= earthquake hazard factor as given in AS 1170.4 or NZS 1170.5
α_D	= dead load factor
α_L	= live load factor
β	= safety factor for seam strength
Δ_y	= measured change of the inside diameter in the direction of load application, in millimetres
ϕ	= angle between the side wall and a vertical plane for a box culvert

Symbol	Definition
ϕ_j	= material resistance factor for connections
ϕ_{hc}	= material resistance factor for plastic hinge during construction in service
ϕ_h	= material resistance factor for plastic hinge
ϕ_c	= material resistance factor for compressive strength
$\phi_c R_u$	= design resistance (capacity) of the wall of the metal structure in compression, in kilonewtons per metre run of structure
γ_b	= unit weight of backfill soil above the metal structure (fill), in kilonewtons per metre cubed
γ_E	= factor for earthquake action in New Zealand
γ_G	= load factor for combination of permanent actions
γ_Q	= factor for combination of imposed actions
γ_s	= unit weight of stockpile material, in kilonewtons per metre cubed
σ_v	= average vertical soil stress level, in kilopascals
θ_o	= angle of a radial line from vertical dividing the lower and upper buckling zones in a buried soil metal structure measured, in radians
θ_{bs}	= re-entrant angle for arches, in degrees
θ_t	= angle between the vertical centre-line and the line connecting the tangent point at the extremity of the top arc and the centre of r_t (half the arc), in degrees
κ	= the crown moment coefficient used to calculate the crown and haunch bending moments in a metal box structure
Ω	= wall stress safety factor

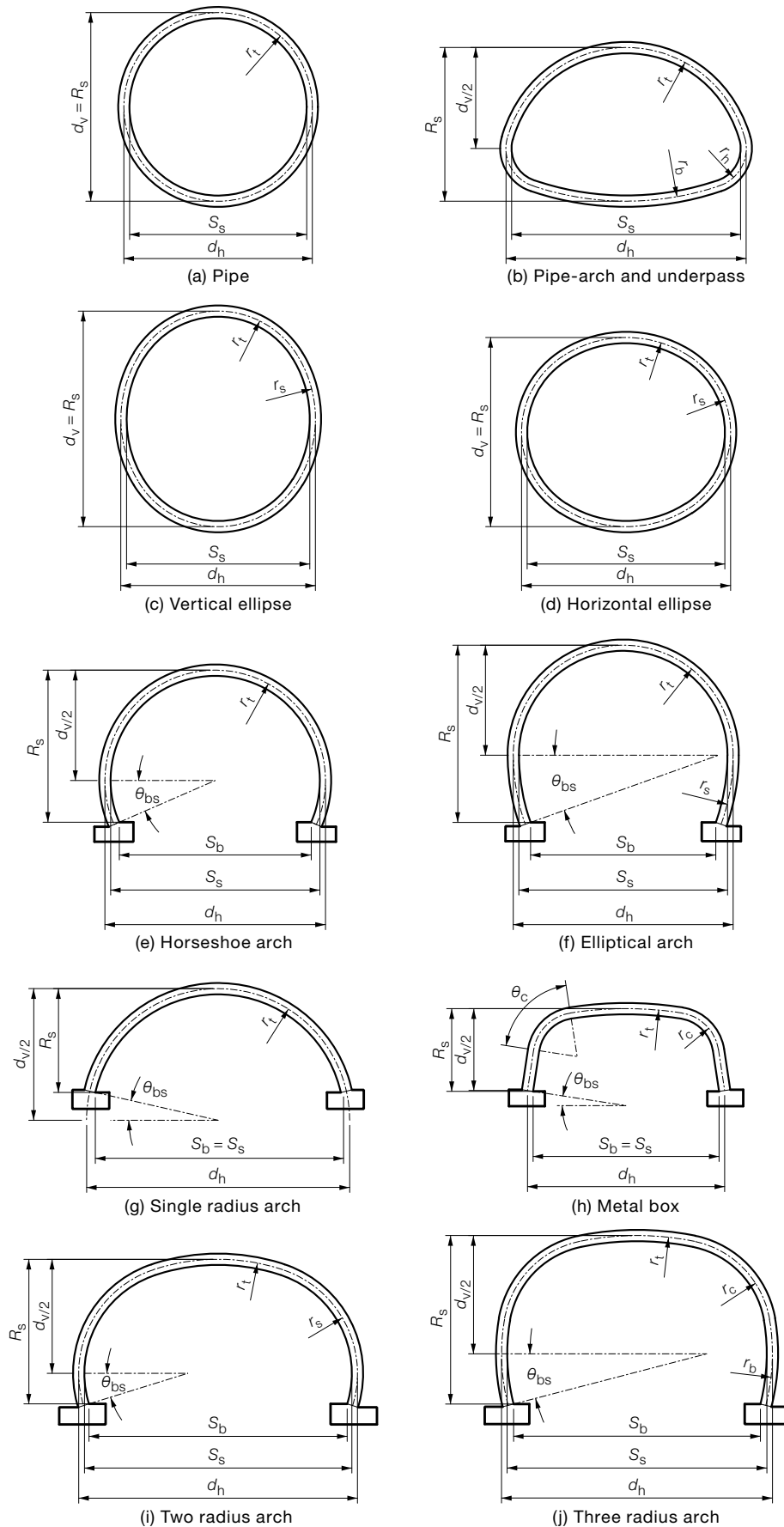
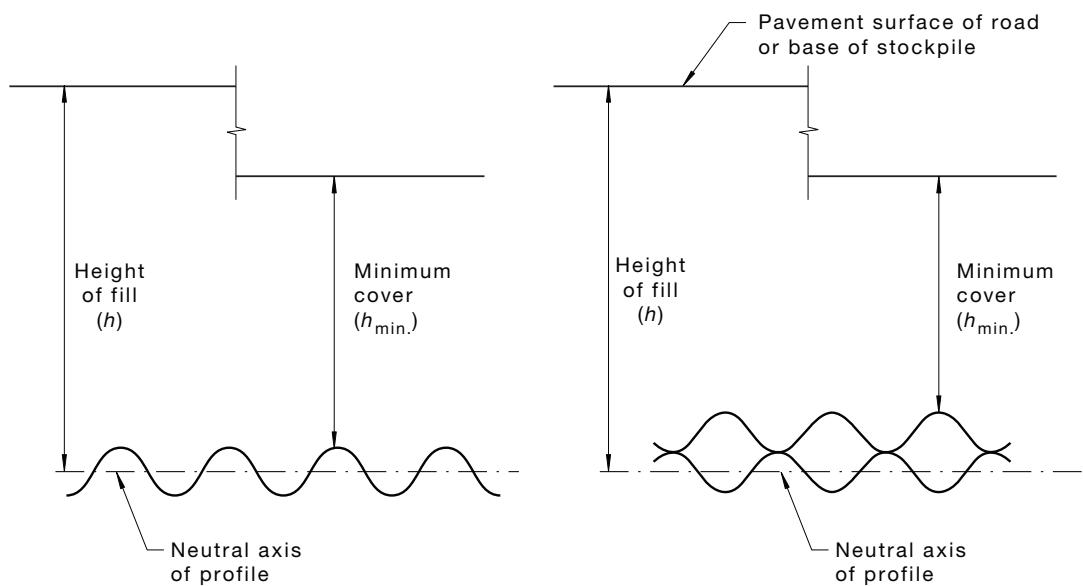
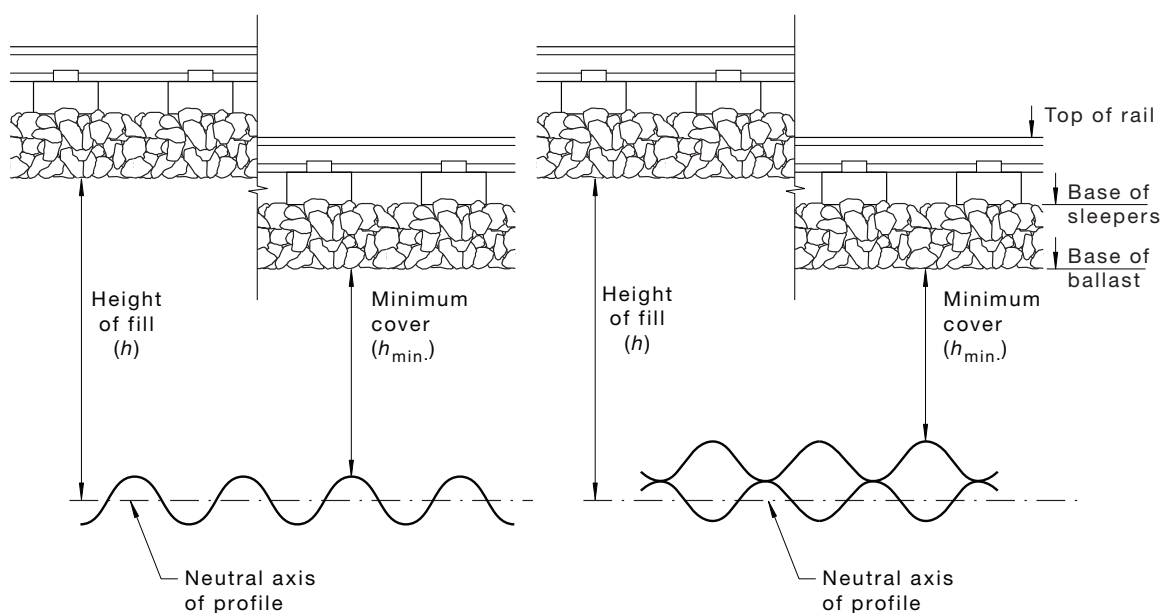


FIGURE 1.5(A) CRITICAL DIMENSIONS OF BURIED CORRUGATED METAL STRUCTURES



(a) For roadways and stockpiles



(b) For railways

FIGURE 1.5(B) DEFINITION OF DESIGN COVER (h_{min}) AND HEIGHT OF FILL (h)

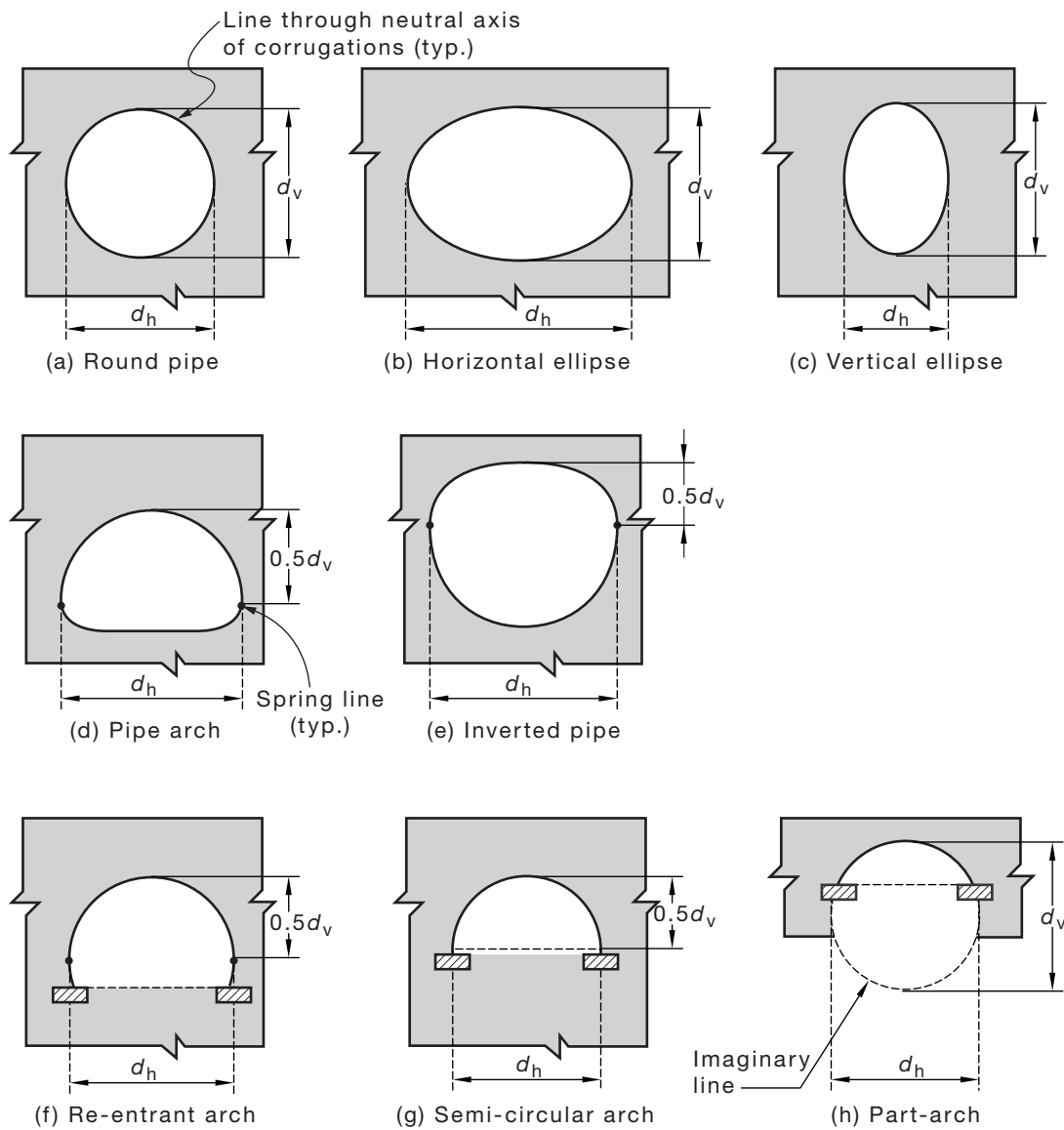
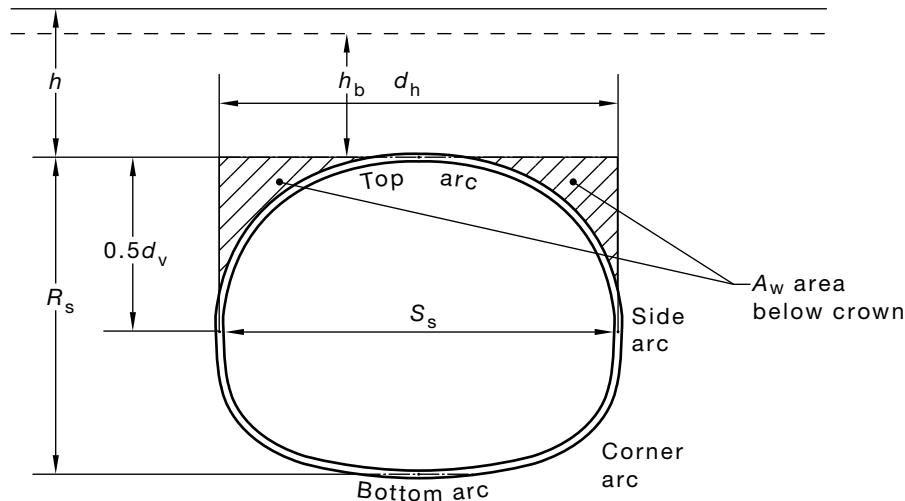


FIGURE 1.5(C) GENERAL DIMENSIONS OF BURIED CORRUGATED METAL STRUCTURES

FIGURE 1.5(D) CROSS-SECTIONAL FILL MATERIAL BELOW CROWN (A_w)

1.7 MARKING

The information shall be marked on the product. The marking shall be permanent, and applied in a conspicuous position that is visible after installation, and shall include the following:

- Name of the manufacturer.
- Date of manufacture, including the month and year.
- Plate steel grade, thickness and profile to the appropriate Standard, and Standard number. (i.e., AS/NZS XXXX).

NOTES:

- For example, XXX, 2011/07, 2.5-R19 $\times$ 19 to AS/NZS XXXX.
- Manufacturers making a statement of compliance with this Australian/New Zealand Standard on product, packaging or promotional material related to that product are advised to ensure that such compliance is capable of being verified.

1.8 ALTERNATIVE DESIGN METHODS AND MATERIALS

New sections of properties that are not mentioned in this Standard may be used, provided it can be demonstrated that the resulting new sections satisfy the requirements specified in this Standard.

Supporting data, including literature review, case histories and data from test programs, shall be provided to the relevant joint Australian and New Zealand Standards committee for perusal and comment.

Service life durability shall be a consideration in any assessment of new materials.

SECTION 2 GENERAL REQUIREMENTS

2.1 DESIGN PROCESS

The design process shall be as follows:

NOTE: Flow charts for structural design in accordance with this Standard are provided in Appendix C.

- (a) Classify the structure in accordance with Clause 2.4.
- (b) Select the structure type and shape (see AS/NZS 2041 series)—
 - (i) pipe diameter; or
 - (ii) structure type, class and span (see Note 3).

NOTES:

- 1 Durability should be considered as part of the selection process, particularly for material and coating (see Clauses 3.1 and 3.2).
- 2 Some structure shapes have controls on geometry and require minimum structural base metal wall thickness.
- 3 Standard structure shape and dimensions may be obtained from the manufacturer.

- (c) Consider the design in accordance with Clause 2.3.
- (d) Specify the minimum cover in accordance with Clause 2.5.
- (e) Minimum spacing for multiple structures in accordance with Clause 2.6.
- (f) Durability (see Section 3).
- (g) Determine the applicable loads (see Section 4) as follows:
 - (i) Permanent action.
 - (ii) Imposed action—finished structure.
NOTE: Appendix D provides comparisons of various live load pressures to allow structural design where the worst load case does not apply.
 - (iii) Imposed action—during construction.
 - (iv) Earthquake action (where applicable).
- (h) Specify design method (ring compression or limit state), as given in Clause 2.8, as follows:
 - (i) Ring compression (see Section 7).
 - (ii) Limit state (see Section 5).
 - (iii) Limit state for metal box structures (see Section 6).
 - (iv) Finite element method.
- (i) End treatment (see Section 8).
- (j) Invert protection (see Section 9).
- (k) Detail any installation requirements (e.g., footings or pipe-arch support, end beams).
- (l) Prepare instructions or drawings for installation including any design assumptions (see Clause 2.2).

2.2 DESIGN INSTRUCTIONS

At the end of the design process, drawings or instructions detailing the information required to perform installation of the structure shall be produced.

The design assumptions, such as design loads, construction loads and associated cover limits, extent and properties of backfill, shall be included in the design drawings or instructions.

2.3 DESIGN CONSIDERATIONS

Prior to carrying out structural design, a number of factors affecting the structure will need to be considered. This may involve a site visit and investigation of the soil, backfill, water quality and geotechnical conditions. The following items shall be considered:

- (a) Intended use—
 - (i) for structures for traffic tunnels—clearance considerations;
NOTE: Where internal clearances are critical, adequate allowance should be made for cumulative manufacturing and installation tolerances and seam bolts on internal corrugation crests.
 - (ii) for hydraulic structures—flow considerations (e.g., area, velocity, flow characteristics, debris, scour, headwater depths);
NOTE: Information on design of the drainage system for hydraulics and flow may be found in the AUSTROADS *Guide to Road Design—Part 5: Drainage Design* Publication No: AGRD 05/10, Federal Highway Administration, Hydraulic Design, Series No. 5 or in *Transit New Zealand Bridge Manual*.
 - (iii) animal access; and
 - (iv) fish passage.
- (b) Site conditions.
- (c) Ease of access.
- (d) Availability and type of backfill material (see also AS/NZS 2041.2).
- (e) Difficulty of replacement at end of life (see also Clause 2.4).
- (f) Possibility of change in the depth of cover due to maintenance or other causes (e.g., erosion of material, regrading or overlay of road surface).
- (g) Risk of corrosion and abrasion (e.g., pH, resistivity, grade, ponding of water).
- (h) Expected loads, including construction equipment (see Section 4).
- (i) Foundation conditions.
- (j) Potential for differential settlement.
- (k) Mining subsidence.
- (l) Ground deformation from earthquakes.
NOTE: The design of the earthworks is critical to the performance of buried corrugated metal structures, especially in high earthquake hazard areas ($Z \geq 0.15$). Measures may have to be taken to control supporting materials along the length of the structure to reduce the risk of major differential deformations. Such measures may include expanding the zone of controlled fill material and protection of slopes against collapse.
- (m) Risk of ground deformation from other sources.
- (n) Special installation requirements.

NOTE: For design considerations and background information on the AS/NZS 2041 series, see Appendix B.

2.4 STRUCTURE CLASSIFICATION AND DESIGN WORKING LIFE

Unless such information is specified, buried corrugated metal structures shall be—

- (a) classified as given in Table 2.4; and
- (b) assigned a design working life (n_y).

TABLE 2.4
CLASSIFICATION OF STRUCTURE TYPE

Importance level	Description	Comment	Structure examples (see Note)
1	Low consequence for loss of human life <i>or</i> small or moderate economic, social or environmental consequences	Minor structures (failure not likely to endanger human life)	Low risk, farm structures, easy to replace, $d_h < 800$ mm
2	Medium consequence for loss of human life <i>or</i> considerable economic, social or environmental consequences	Normal structures and structures not falling into other levels	All structures not in levels 1, 3 or 4
3	High consequence for loss of human life <i>or</i> very great economic, social or environmental consequences	Major structures	Structures supporting main line railway (including suburban electrified system) or arterial or higher traffic volume roads or grade separated structures
4		Special structures (post disaster functions or dangerous activities)	Access tunnel to an emergency post-disaster shelter
5	Exceptional	Circumstances where reliability must be set on a case by case basis	See AS/NZS 1170.0

NOTE: Consideration should be given to the importance of any structures supported by the buried corrugated metal structure (see AS/NZS 1170.0)

2.5 MINIMUM COVER

2.5.1 General

To ensure a stable soil arch is maintained over the structure crown and concentrated loads do not bear directly on the structure, a minimum cover shall be required, as specified in Clause 2.5.2, 2.5.3 or 2.5.4, as applicable.

The minimum cover requirements as specified in Clauses 2.5.2, 2.5.3 and 2.5.4 apply to structures designed using either the limit state method (Section 5) or the ring compression method (Section 7). Minimum cover for structures designed using the limit state method for metal boxes are contained in Section 6. Minimum cover for structures using finite element analysis (FEA) are not specified; however, most FEA cannot accurately model local wheel load failure under very low covers.

2.5.2 Minimum cover ($h_{\min}$) for railway loads

Minimum cover for railway loads shall be as follows:

- (a) For bolted plate structures with shallow corrugations, unless the structure is designed by an approved rigorous method other than limit states or ring compression, the minimum cover ($h_{\min}$) as shown in Figure 1.5(B) and measured from base of ballast, shall be the greater of—
- (i) 700; or
 - (ii) $\frac{d_h}{6} \times \sqrt{\frac{d_h}{d_v}}$; or ... 2.5.2(1)
 - (iii) $400 \times \left(\frac{d_h}{d_v}\right)^2$... 2.5.2(2)

where

d_h = effective horizontal geometrical dimension of the metal structure (to the neutral axis of the corrugation), in millimetres

d_v = effective vertical geometrical dimension of the metal structure (to the neutral axis of the corrugation), in millimetres

NOTE: Some railway authorities may specify varying cover limits, depending on the usage of the railway and the installation practices.

For bolted plate structures with deep corrugations, the minimum cover ($h_{\min}$) shall be the smaller of 1500 mm and the minimum design cover for shallow corrugations, but of the same structure size.

- (b) Where non-railway vehicles or equipment will run on the track formation, the minimum cover from surface of track formation shall be the value for highway vehicles or off-highway vehicles, as applicable.

2.5.3 Minimum cover ($h_{\min}$) for highway loads

Minimum cover for highway loads shall be as follows:

- (a) For bolted plate structures with shallow corrugations, unless the structure is designed by an approved rigorous method other than limit state or ring compression, the minimum cover ($h_{\min}$), as shown in Figure 1.5(A) and measured from pavement surface, shall be the greater of
- (i) 600; or
 - (ii) $\frac{d_h}{6} \times \sqrt{\frac{d_h}{d_v}}$; or ... 2.5.3(1)
 - (iii) $400 \times \left(\frac{d_h}{d_v}\right)^2$... 2.5.3.(2)

For bolted plate structures with deep corrugations, the minimum cover ($h_{\min}$) shall be the smaller of 1500 mm and the minimum design cover for shallow corrugations, but of the same structure size.

2.5.4 Minimum cover for construction, aircraft, stockpile mine vehicles and abnormal loads

Minimum cover for construction, aircraft, stockpile, mine vehicles and abnormal loads shall comply with the following:

- (a) The minimum cover shall be calculated for the design loads.
- (b) The minimum cover shall be greater than or equal to the relevant highway or railway minimum cover.
- (c) Prior to construction commencing a design check shall be undertaken for the actual construction equipment to determine if additional cover is required (see Notes 1 and 2).

NOTES:

- 1 Specialist engineering advice should be sought to determine the minimum cover for these loads.
- 2 This information should be included on any installation drawings or instructions.
- 3 Minimum cover for temporary construction loads need not include additional durability allowance.

2.6 MINIMUM SPACING BETWEEN STRUCTURES

Spacing for multiple installations shall be sufficient to ensure adequate backfill support is provided to the structures and the fill above. Spacing shall be as specified in the design but shall be not less than the minimum spacings given in Table 2.6.

TABLE 2.6
MINIMUM SPACING FOR MULTIPLE STRUCTURES

Structural backfill location	Structural backfill type	Minimum transverse clear spacing between adjacent structures (S_m) mm						
		Structure type						
		All structures except for metal box culverts					Metal box culverts	
		$d_h \leq 600$	$600 < d_h \leq 3000$	$3000 < d_h \leq 8000$	$8000 < d_h \leq 12000$	$d_h > 12000$	$d_h \leq 8000$	$d_h > 8000$
Between adjacent structures	Compacted	600	800	1000	1200	To be determined by limit state design or numerical modelling	1000	To be determined by numerical modelling
Between adjacent structures	Flowable	150	200	300	750		300	

NOTES:

- 1 The limits in the above Table should be modified as necessary to account for variables such as alternative construction practices (i.e. structure pre-assembly or poor foundation soils).
- 2 These limits may be inadequate where earthquake effects are important and may need to be increased when significant earthquake effects are expected.
- 3 The limit state design method takes account of the effect of spacing on buckling of the corrugated metal structure.

2.7 MINIMUM EXTENT OF STRUCTURAL SELECT FILL—STRUCTURAL BACKFILL

The structural backfill in single-conduit structures under different fill conditions shall extend transversely at least the length specified in Table 2.7 on each side beyond the spring lines of the conduit, and vertically up to the minimum design depth of cover required.

For multi-conduit structures, structural backfill shall be provided between the adjacent conduits and shall extend transversely beyond the outer conduits, at least the applicable distance specified in Table 2.7. In the vertical direction, the structural backfill shall extend up to the minimum design dept of cover required.

TABLE 2.7
MINIMUM TRANSVERSE DISTANCE OF BACKFILL FOR SINGLE-CONDUIT BURIED CORRUGATED METAL STRUCTURES

Structural backfill location	Structural backfill type	Minimum transverse backfill distance (<i>b</i>), mm						
		Structure type						
		All structures except for metal box culverts					Metal box culverts	
		$d_h \leq 600$	$600 < d_h \leq 3000$	$3000 < d_h \leq 8000$	$8000 < d_h \leq 12000$	$d_h > 12000$	$d_h \leq 8000$	$d_h > 8000$
Trench in rock	Compacted	600	800	1000	1200	1200	1000	1200
Trench in rock	Flowable	150	200	300	750	750	300	750
Trench in good soil	Compacted	600	800	1000	1200	1200	1000	1200
Trench in poor soil	Compacted	600	$d_h/2$ but not less than 600	$d_h/2$ but not less than 1500	$d_h/2$ but not less than 3000	$d_h/2$ but not less than 5000 (see Note 1)	1000	$d_h/2$ (see Note 1)
Embankment construction	Compacted	600	$d_h/3$ but not less than 800	$d_h/3$ but not less than 1500	$d_h/3$ but not less than 3000	$d_h/3$ but not less than 5000 (see Note 1)	1000	$d_h/5$ (see Note 1)

NOTES:

- Minimum transverse backfill distance for structures with $d_h > 12000$ mm (or metal boxes with $d_h > 8000$ mm) may be larger (but not smaller) than the above values if required by the designer.
- Structures with a crown radius to side radius ratio >5 shall also satisfy the minimum transverse backfill distances for metal box culverts.
- Compacted backfill is select fill compacted by mechanical means.
- The minimum transverse backfill width for trench using compacted backfill is governed by sufficient space for the safe operation of walk behind mechanical compaction equipment. Depending on site equipment, the distances in this Table may be greater (but not lesser) than those above, as required by the designer. The contractor may be required to compact thinner lifts using this equipment to demonstrate that design compaction is achieved.
- Flowable backfill is a controlled low strength material with equivalent strength to structural backfill compacted by mechanical means but placed in a similar manner to wet concrete.
- Good soil is material of equivalent or superior strength to the specified structural backfill. Refer to 'structural backfill' requirements as specified in AS/NZS 2041.2. Geotechnical analysis of good soil shall be provided to the designer for approval.
- Poor soil is trench wall material of lesser strength to specified structural backfill. Refer to 'structural backfill' requirements as specified in AS/NZS 2041.2.
- Material described as 'not acceptable', as specified in the 'structural backfill' requirements of AS/NZS 2041.2 may also be unsuitable for the 'secondary' trench or embankment material beyond the structural backfill envelope defined above and may need to be removed and replaced with more suitable material.
- For structures with $d_h > 15000$ mm, the designer shall check the effect on the structure of the 'not acceptable' material outside the structural backfill zone using the numerical modelling. The material outside the structural backfill zone shall be considered unsuitable if the unfactored change in d_h or R_s from numerical modelling exceeds 2% of the specified dimensions.
- For vertical ellipses where the vertical is the greater dimension, $d_h = d_v$.

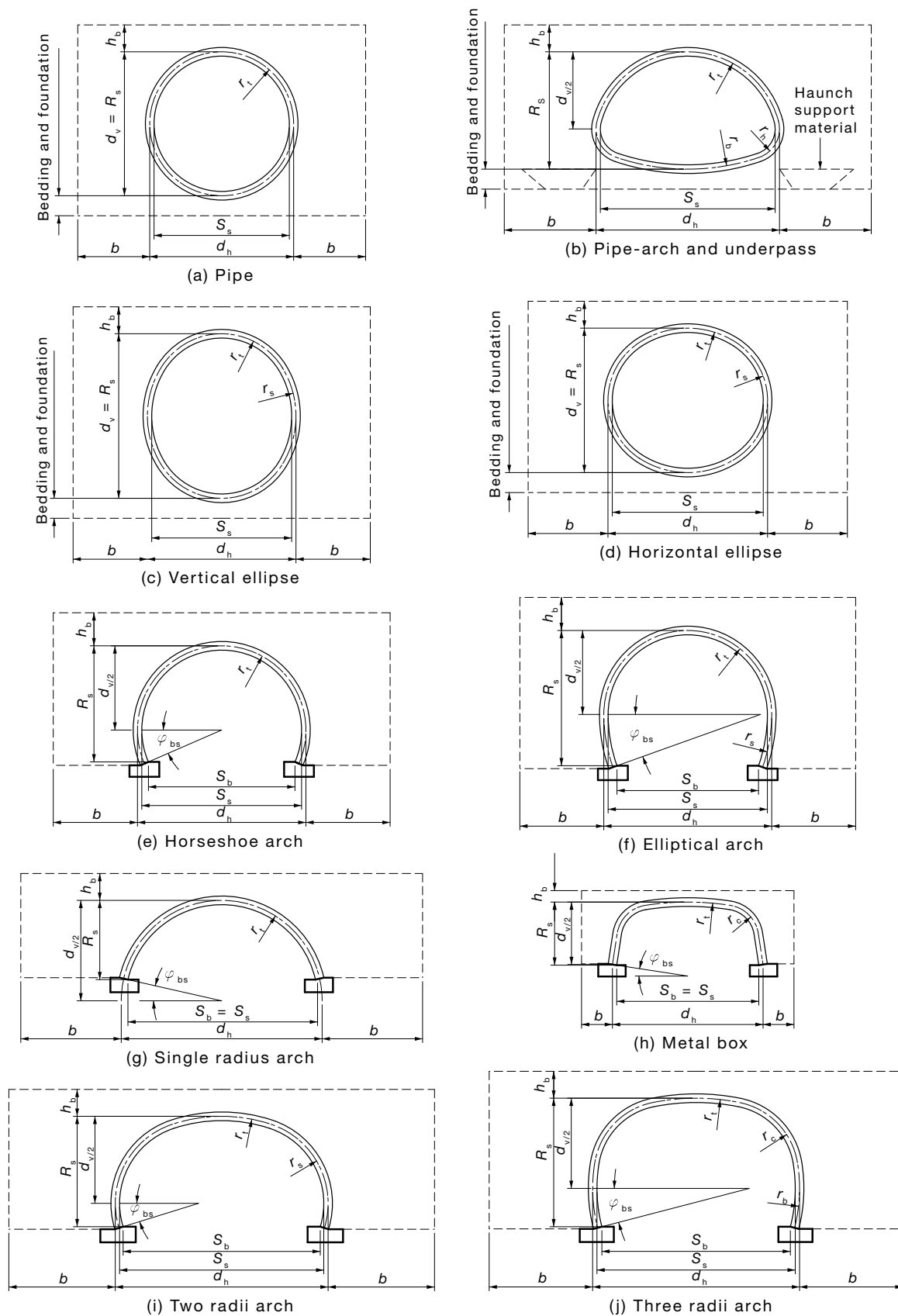


FIGURE 2.7 EXTENT OF SELECT FILL IN TRENCH CONDITIONS

2.8 DESIGN METHODS

2.8.1 General

Buried corrugated metal structures shall be designed using the design methods given in Table 2.8.1.

NOTE: The ring compression method has been retained as a simplified design method.

TABLE 2.8.1
DESIGN METHODS

Structure types	Span (d_h) mm	Design method	
Helically formed sinusoidal pipes (AS/NZS 2041.4)	≤ 3600	Section 5 or Section 7	Limit state method or ring compression method
	> 3600	Section 5	Limit state method
Helically formed ribbed pipes	≤ 3600	Section 5 or Section 7	Limit state method or ring compression method
	> 3600	Section 5	Limit state method
Bolted plate structures (AS/NZS 2041.6)	All single installations ≤ 3600	Section 5 or Section 7	Limit state method or ring compression method
	All other structures	Section 5	Limit state method or numerical modelling
Bolted plate structures with transverse stiffeners	All sizes	Section 5	Limit state method or numerical modelling
Metal box structures	All sizes	Section 6	Limit state method for metal box structures or numerical modelling

NOTE: There may be situations outside the scope of the limit state method and ring compression method where finite element analysis may be used for the design.

2.8.2 Limit state method

The limit state method (see Section 5) shall be applied as follows:

- Check the applicable combinations of actions (see Clause 5.3).
- Determine the material resistance factors and material properties of the selected metal structure by reference to the product Standard, that is AS/NZS 2041.4 and AS/NZS 2041.6 (see Clause 5.4.1).
- Calculate action effects (see Clause 5.5).
- Calculate capacity and verify limit state for compression failure (see Clause 5.6.1).
- Determine capacity and verify limit state for connections (see Clause 5.6.2).
- Select structural base metal wall thickness including structural thickness and durability allowance (see Clause 5.7).
- Calculate capacities and verify limit state for plastic hinge during construction (see Clause 5.6.3).
- Where appropriate, design transverse stiffeners.
- Check footing forces for arches. Check haunch bearing pressure for pipe-arches and underpasses (see Section 5).

2.8.3 Ring compression method

The ring compression method (see Section 7) shall be applied as follows:

- (a) Calculate load pressures and total design pressure (see Clauses 7.3 and 7.5).
- (b) Check haunch pressure for pipe-arch shapes (see Clause 7.6).
- (c) Calculate ring compression (F_r) in the corrugated metal section (see Clause 7.7).
- (d) Determine the properties of the selected metal structure by reference to the product Standard.
NOTE: For product Standards, see AS/NZS 2041.4 and AS/NZS 2041.6.
- (e) Check ultimate seam strength for bolted structures (see Clause 7.9).
- (f) Calculate ultimate compressive wall stress (f_{uc}) (see Clause 7.10).
- (g) Calculate minimum structural base metal wall thickness, including durability allowance (see Clause 7.12).
- (h) Check handling stiffness (see Clause 7.13).
- (i) Where appropriate, calculate arch footing forces for arches (see Clause 7.15).

2.8.4 Numerical modelling

Because of the soil-structure interaction, the response of the culvert is complex. Hence, numerical modelling should be undertaken by a special-purpose, two-dimensional (or three dimensional) finite element (or finite difference) computer program developed to perform deformation and stress analyses for geotechnical applications. General purpose finite element packages are often unsuitable for numerical modelling of the response of metal culverts.

The backfilling process and compaction procedures are critical to the response of the culvert. Culverts should be modelled using an incremental backfilling process.

Parameters that significantly influence the behaviour and response of the culverts are the following:

- (a) General classification of backfill material. Modulus and cohesion of the backfill material are significant in numerical modelling but difficult to specify.
- (b) Compaction pressure during backfilling.
- (c) Thickness of backfill layer.
- (d) Symmetric or non-symmetric backfilling and compaction procedures.

Design methodology during numerical modelling shall provide for the variations present in all actual backfilling procedure (for example, non-symmetric loading and variation in compaction pressure).

Because culverts are flexible and constructed in a soil medium, nominally similar structures may produce a range of responses in terms of hoop force, moment and deformation due to subtly different construction practices. It is important to recognize the ineffectiveness of predicting a single, detailed response. Hence, the focus in practical design methods has to focus on general culvert behaviour in terms of an envelope of likely responses during backfilling.

Numerical modelling shall be undertaken by a specialist design engineer competently trained in the use of the numerical modelling package. An untrained person can produce erroneous results from a numerical modelling computer package.

NOTE: Further description and details on numerical modelling are given in Appendix I.

SECTION 3 DURABILITY

3.1 SCOPE OF SECTION

This Section defines environments in which the metal structures described in the AS/NZS 2041 series are known to perform satisfactorily and provides means of predicting the expected life given the metal type and protective measures.

It provides methods for determining any additional structural base metal wall thickness (the durability allowance) necessary to ensure a high probability that the structure will have the required structural base metal wall thickness at the end of its design working life (n_y). The relevant authority will nominate the design working life.

NOTES:

- 1 Guidance on durability design and protective systems is provided in Appendix E.
- 2 If aggressive or corrosive conditions are encountered, specialist advice should be sought.

3.2 BACKGROUND

Buried corrugated metal structures are subjected to corrosion and abrasion. Generally, corrosion occurs on the surface against the soil and corrosion and abrasion occurs principally on the inside face at the bottom of the structure (at the invert).

Some circumstances may lead to corrosion where flowing water contacts the structure or corrosion of the surface exposed to the air, which is usually due to agents in the air or water such as salts, metals or other corrosive chemicals.

Conditions where water or wet silt is in contact for long periods with galvanized steel should be avoided, as loss rates for galvanizing may be significantly higher than those given in Table 3.7(A).

When transported water contains a bed load of sand or gravel, the invert will be subjected to abrasion.

For many applications, the fill material in which the structure is installed may contain aggressive agents, which will subject the surface against the soil to corrosion attack. The pH value of the backfill and its resistivity value (R_b) will largely determine the corrosion rate of the structure.

Strategies that assist in extending the expected life include the following:

- (a) Durability allowance.
- (b) Protective coatings that resist corrosion and abrasion.
- (c) Selection of less aggressive backfill.
- (d) Concrete lining of invert to resist abrasion.
- (e) Use of open bottom structures (e.g., arches or box culverts) that avoid invert abrasion.

Materials and structure types should be selected carefully in the following situations due to corrosion considerations (see Table 3.4):

- (i) Permanent water (ponding or constant flow, or high groundwater flow).
- (ii) Marine or salt spray situations.
- (iii) Aggressive soils (expansive clay soils, saline and sulfate soils).

- (iv) Highly acidic or alkaline environments.

NOTES:

- 1 For pH ranges, see Table 3.4.
- 2 Extreme examples of these environments, where galvanized steel structures may not be appropriate, are not covered in this Section.

3.3 COATINGS

The material resistances of coatings shall be in accordance with Tables 3.4, 3.7(A), 3.7(B), 3.7(C), 3.7(D) and 3.7(E). The coatings shall comply with the following:

- (a) *From AS/NZS 2041.4:*

- (i) Galvanizing to Z600 in accordance with AS 1397.
- (ii) Aluminium cladding metal classification Alclad 3004-H34 (7072 cladding and 3004 core) in accordance with AS 1734.
- (iii) Polymer coating to ASTM A742.

- (b) *From AS/NZS 2041.6:*

- (i) Hot-dip galvanizing for general articles in accordance with AS/NZS 4680.
- (ii) Clad aluminium alloy with substrate metal classification 5052 and 6061-T6 in accordance with AS/NZS 1734 and ASTM B746.

NOTES:

- 1 This Clause does not preclude the use of alternative coating materials.
- 2 To establish the effectiveness of other coatings, an appropriate testing program using samples representative of production should be carried out. Sufficient data should be collected to establish the expected life of structures with the given coating. Reference may be made to the ISO 12944 series, and Ocean City Research, *Evaluation methodology for CSP coating/invert treatments*, 1996.

3.4 CORRUGATED METAL STRUCTURES—MATERIALS

Material type may be selected from Table 3.4. Other base metal protective coatings may be used, provided the effect on the expected life of the structure can be determined with the same level of accuracy as those nominated in Table 3.4.

NOTE: For information on protection in atmospheric corrosive environments, see AS/NZS 2312.

TABLE 3.4
SELECTION OF MATERIAL TYPE FOR BURIED CORRUGATED
METAL STRUCTURES (Notes 1 and 2)

Material and coating	Non-corrosive/ Normal conditions	Mildly corrosive	Corrosive	Non-abrasive/Low abrasion	Moderate abrasion	High abrasion
Galvanized steel with steel invert, water in contact with steel during normal flow	Y	Y	N	Y	N	N
Galvanized steel with concrete invert lining	Y	Y	N	Y	Y	Y
Galvanized steel with no invert, water not in contact with steel during normal flow	Y	Y	N	Y	Y	Y
Aluminium	Y	Y	See Note 1(e)	Y	N	N
Aluminium with concrete invert lining	Y	Y	See Note 1(e)	Y	Y	Y
Aluminium with no invert, water not in contact with aluminium during normal flow	Y	Y	See Note 1(e)	Y	Y	Y
Polymer precoated galvanized steel	Y	Y	See Note 1(f)	Y	Y	N
Polymer precoated galvanized steel with concrete invert lining	Y	Y	See Note 1(f)	Y	Y	Y

NOTES:

- 1 The terms used in the headings are defined as follows:
 - (a) Non-corrosive—material acceptable when pH 5–12, resistivity $\geq 10\,000$ ohm-cm.
 - (b) Normal conditions—material acceptable when pH 5–8, resistivity 2000–10 000 ohm-cm.
 - (c) Mildly corrosive—material acceptable when pH 5–8, resistivity 1500–2000 ohm-cm.
 - (d) Corrosive (galvanized steel)—material acceptable when pH 5–10, resistivity >1500 ohm-cm.
 - (e) Corrosive (aluminium)—material acceptable when pH 4–9, resistivity >500 ohm-cm, except where structures are exposed to sea water, resistivity >35 ohm-cm
 - (f) Corrosive (polymer precoated)—material acceptable when pH 3–12, resistivity >100 ohm-cm.
 - (g) Non-abrasive—No bed-load regardless of velocity.
 - (h) Low abrasion—Minor bed-load of sand and gravel, velocity <1.5 m/s.
 - (i) Moderate abrasion—Bed-load of sand, small stone and gravel, velocity >1.5 and <4.6 m/s.
 - (j) High abrasion—Heavy bed-load of gravel and rock, velocity >4.6 m/s.
- 2 Abrasion velocity should be evaluated on the basis of frequency (average recurrence interval) and duration. Consideration should be given to a frequent storm such as a 2 y event (average recurrence interval) or to the mean annual discharge or less when velocity determination is necessary.
- 3 The values in the Table are the ranges within which the material has given satisfactory performance.
- 4 Where cementitious material is used in conjunction with the aluminium structures, a barrier coating/membrane (e.g. epoxy paint system) shall be applied at the aluminium/cement interface unless all of the following conditions are met:
 - (a) Long-term (cured) pH of the cementitious material is ≤ 9 .
 - (b) No additives or contaminants are present in the cementitious material. These may result in a more corrosive environment.
 - (c) The cementitious material usually remains dry throughout the life of the structure (e.g. ring beam) or is relatively impermeable.
 - (d) The environment is non-corrosive and is not marine, saltwater or salt spray.
 Good quality well-placed/compacted concrete usually satisfies conditions (a), (b) and (c) above.
- 5 All steel reinforcing and other dissimilar metals (other than those accepted in other parts of this Standard) shall be electrically isolated from the aluminium structure. This may be achieved by protective coating or by physical separation via plastic packers/chairs.

3.5 DURABILITY DESIGN—STRUCTURE TYPES

Structures shall be designed for durability using the methods set out in Table 3.5.

TABLE 3.5
DURABILITY DESIGN METHOD

Structure		Durability design method (see Clauses 3.4 and 3.5)	
Importance level (refer to Table 2.4)	Span (d_h) mm	Steel	Aluminium
1	<600	Simplified procedure	Simplified procedure
	≥600	Simplified procedure or detailed procedure	Simplified procedure and consider salts and abrasion (see Table 3.7.2(C))
2	<600	Simplified procedure if local experience indicates satisfactory performance	Simplified procedure if local experience indicates satisfactory performance
	≥600, <3600	Simplified procedure or detailed procedure (see Note)	Simplified procedure or detailed procedure and consider salts and abrasion (see Table 3.7.2(C))
	≥3600	Detailed procedure	Detailed procedure
3, 4 and 5	All sizes	Detailed procedure	Detailed procedure

NOTE: For large projects with multiple pipes, the detailed procedure shall be used.

3.6 DURABILITY DESIGN—SIMPLIFIED PROCEDURE

3.6.1 General

For any structure not conforming to the conditions in Clauses 3.6.2 and 3.6.3 below, the design shall be in accordance with the detailed procedure given in Clause 3.7.

NOTE: The simplified method is intended to be used where the conditions of installation are known in general but no testing has been carried out. The soil pH may be estimated using simple methods. Where there is any uncertainty whether the conditions are met, a detailed analysis should be carried out.

3.6.2 No durability allowance

Where the following criteria are met, no durability allowance is required:

- The structures are of galvanized steel.
- The structures are of lesser importance—less than 1.5 m in height or width and not expensive to replace.
- Design working life (n_y) is less than or equal to 30 years.
- No permanent water.
- Not exposed to airborne salts, salt or brackish water within 20 km of the coast and not on an estuary.
- No corrosive run-off from mines/industry in the area.
- The fill is usually dry and is free-draining.
- The local (native) soil pH is within the range of 5 to 8.
- The local (native) soil is not saline nor does it contain sulfates.
- The fill material around the pipe is within the pH range of 5 to 8.

- (k) Abrasion is low.

NOTE: For guidance on abrasion rates, see Notes 1 and 2 to Table 3.4.

3.6.3 1 mm durability allowance

Where the following criteria are met, the durability allowance shall be 1 mm:

- (a) The structures are of galvanized steel.
- (b) The structures are of lesser importance—up to 3.0 m span and not expensive to replace.
- (c) Design working life (n_y) is less than or equal to 50 y.
- (d) No permanent water.
- (e) Not exposed to airborne salts, salt or brackish water within 20 km of the coast and not on an estuary.
- (f) No corrosive run-off from mines/industry in the area.
- (g) The fill is usually dry and is free-draining.
- (h) The local (native) soil pH is within the range of 5 to 8.
- (i) The local (native) soil is not saline or containing sulfates.
- (j) The fill material around the pipe is within the pH range of 5 to 8.
- (k) Abrasion is low.

NOTE: For guidance on abrasion rates, see Notes 1 and 2 to Table 3.4.

3.6.4 Aluminium structures—No durability allowance

Where the following criteria are met, no durability allowance is required:

- (a) All structures are of aluminium.
- (b) The structures are of lesser importance—less than 1.5 m in height or width and not expensive to replace.
- (c) Design working life (n_y) is less than or equal to 30 years.
- (d) No permanent water.
- (e) Not exposed to airborne salts, salt or brackish water within 20 km of the coast and not on an estuary.
- (f) No corrosive run-off from mines/industry in the area.
- (g) The fill is usually dry and is free-draining.
- (h) The local (native) soil pH is within the range of 4 to 9.
- (i) The local (native) soil is not saline or containing sulfates.
- (j) The fill material around the pipe is within the pH range of 4 to 9.
- (k) Abrasion is low.

NOTE: For guidance on abrasion rates, see Notes 1 and 2 to Table 3.4.

3.7 DURABILITY DESIGN—DETAILED PROCEDURE

The durability allowance and other protections to achieve the design life shall be assessed in accordance with Clause 3.7.1 and 3.7.2.

3.7.1 Aggressive environments

In an aggressive environment such as mining, concentrations of elements present in the soil shall be checked.

NOTES:

- 1 Some elements in solution can increase the corrosion rate; if this is the situation, seek specialist advice.
- 2 These elements may also contaminate the run-off water, having the potential to generate corrosion at the internal surface.

If necessary to meet the design working life (n_y), this shall be addressed by one or more of the following:

- (a) Increasing the select fill zone.
- (b) Providing a durability allowance.
- (c) Providing an additional protective coating.

3.7.2 Determination of design durability allowance

For the determination of durability allowance, additional protective coating or invert lining shall comply with the following:

- (a) The corrosion loss against the select, flowable or modified fill shall be determined as follows:
 - (i) Where the pH and resistivity of the select fill are within the limits of Table 3.7.2(A) (non-aggressive select fill), determine the soil-side galvanizing life and the soil-side steel loss rate from Table 3.7.2(A).
 - (ii) Where the pH and resistivity of the select fill are near the limits given in Table 3.7.2(A), the select fill may be aggressive and the sulfate ion and chloride ion concentration shall be checked as follows:
 - (A) For chloride ions ≤ 200 mg/kg (by weight) and sulfate ion ≤ 1000 mg/kg, use loss rates given in Table 3.7.2(A) below.
 - (B) For chloride ion > 200 mg/kg or sulfate ion > 1000 mg/kg, or both, use loss rates as given in Tables 3.7.2(B) and 3.7.2(D).

NOTE: An increase in the level of concentrations of salts is proportional to a reduction in resistivity of the soil.
 - (iii) Where the pH and resistivity of the select fill are outside the limits given in Table 3.7.2(A), the material is considered to be highly aggressive and the metal structures in this Standard are not recommended. Select an alternative select fill within the limits of Table 3.7.2(A).

NOTE: If the effects of the native soil cannot be isolated from the select fill, then the native soil condition should be included in the design life. Where the surrounding native soil is aggressive in nature, any alternative select fill should isolate the structure from migration of the aggressive agents.
- (b) Where abrasion, ponding or trickle flows may affect the structure or where the internal surface will be subject to aggressive corrosion, consideration shall be given to lining the invert.

NOTE: The need to line the invert may be checked by observing the invert condition of other buried corrugated metal structures in the area. Agents in the local soil or water may add to the rate of deterioration of the invert. The level of constant flow and the volume, velocity and frequency of high flow together with the bed load present will also be factors to be considered.

- (c) The atmospheric corrosion loss on the interior surface of the structure above the level to which water regularly rises is generally considered negligible.

NOTE: Where extreme environmental conditions prevail, refer to AS 2312.

- (d) Any other lining or other protection that is necessary (e.g., invert lining, lining and additional coating) shall be determined.

NOTES:

- For coatings other than zinc in Tables 3.7.2(B) and 3.7.2(E), specialist advice should be obtained to determine the coating loss rate.
- Further information on durability is provided in Appendix E.

TABLE 3.7.2(A)
EXPECTED LIFE AND METAL LOSS RATES FOR GIVEN pH
AND RESISTIVITY OF SOIL AND WATER IN CONTACT

Resistivity of backfill (R_b) ohm-cm	Acceptable pH range		Galvanizing loss rates $\mu\text{m/y}$	Steel loss rates $\mu\text{m/y}$	Aluminium loss rates
	Galvanized steel	Aluminium			
10 000 or more	5–12	4–9	15 for first 2 y, 4 for subsequent years	12	Negligible
2000–10 000	6–10	4–9			
500–2000	5–10	4–9	—	—	

NOTES:

- This Table shall not to be used for ponded water and wet silt.
- Measurements of chloride and sulfate ions concentrations should be taken where site conditions approach the limits given above. Acceptable concentrations in the select fill are normally chloride ions less than or equal to 200 mg/kg by weight, and sulfate ions less than or equal to 1000 mg/kg by weight.
- Where coatings are used, obtain expert advice on the pH ranges for which they are suitable.
- For aluminium in contact with soils and water exhibiting properties within the pH limits 4 to 9, the metal loss rate becomes almost negligible after 2–5 years due to blockage of corrosion pits with insoluble corrosion products. For soils and waters with pH outside the 4–9 range or with high concentrations of soluble salts, a protective coating shall be required to prevent accelerated corrosion. Studies done for the Florida Department of Transport show aluminium structures in a saltwater environment have loss rates in the range of 1 to 5 $\mu\text{m/y}$, provided clean free-draining backfill is used.
- In mining areas, concentrations of some metals in solution can increase corrosion.
- Cement-modified soils and flowable fill typically exhibit pH 9 and resistivity values below 1000 ohm-cm in poorly drained conditions, and above 2000 ohm-cm in drained conditions. For moderate or high concentrations of cement, the pH may be considerably higher than 9; however, this varies significantly with type. Testing should be used to determine the pH resistivity.
- Any recycled materials shall be checked for heavy metals.
- Soft water has a significant effect on the galvanized coating but does not impact the longevity of aluminium- or polymer-coated structures. For loss rates indicated in this Table for galvanized steel, the natural water shall contain a calcium carbonate concentration (CaCO_3) of least than 50 ppm, unless invert protection or additional coatings are used.