Manual

Design Criteria for Rehabilitation of Circular Corrugated Metal Culverts

September 2013

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Amendment Register

Issue / Rev no.	Reference section	Description of revision	Authorised by	Date
0.8	Whole	Initial release	Tony Giufre, Director (Bridge & Marine Engineering)	September 2013

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1 Introduction

1.1 Aim

Transport and Main Roads (TMR) is committed to providing structurally safe, sustainable access to all bridge and culverts on the road network. TMR recognises Circular Corrugated Metal Culverts (CCMC) form part of the transport network facilitating economic growth and social connection.

TMR will manage the risks associated with defective CCMC through rehabilitation and/or replacement in accordance with Australian and International practice and as documented in this document: Rehabilitation of Circular Corrugated Metal Culverts – Design Criteria (referred to as Design Criteria).

1.2 Background

In general galvanised corrugated metal culverts have had a design life of substantially less than TMR's 100 year target design life for new structures. While some of Queensland's culverts have performed well, others have deteriorated in periods as short as 10 years and now require replacement / rehabilitation, with approximately 25% of Queensland's metal culverts having a condition rating of 3 or 4 (i.e. in need of rehabilitation or replacement).

In Queensland's declared road network, there are approximately 1,100 metal culvert barrels with a diameter / span exceeding 1,200 mm, as well as many smaller metal culverts with diameters between 375 mm and 1,200 mm. Most of the metal culverts are steel but some are manufactured aluminium alloys.[1]

Circular culverts dominate the culvert stock (87%), with the balance being ovals or arches. Both the span of the metal culvert and the depth of fill vary substantially, as illustrated in Figure 1 for culverts with a diameter greater than 1,200 mm.

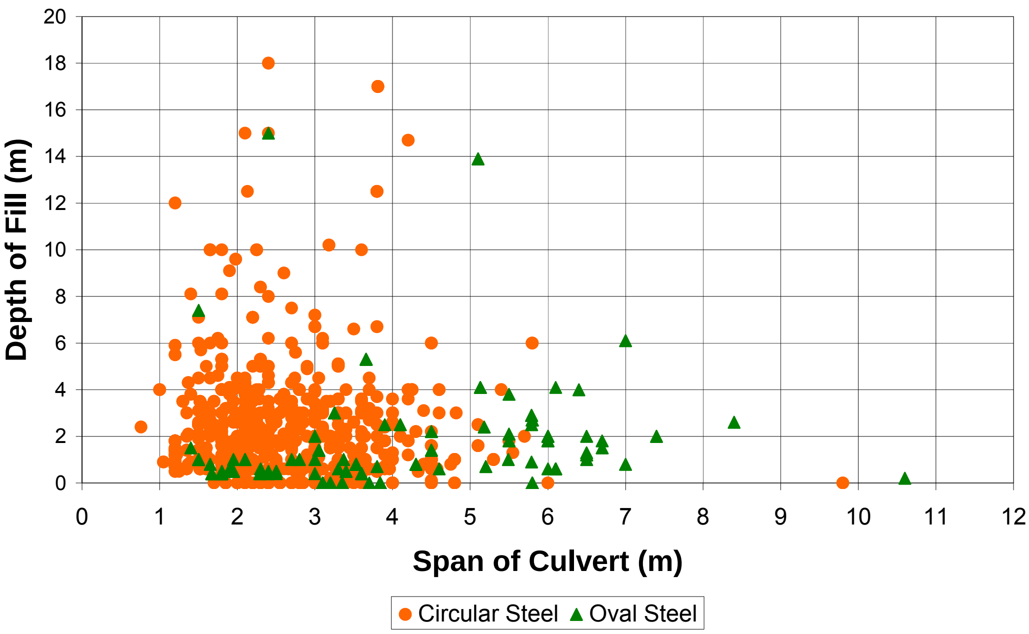
Of the 1,200 culverts:

- 90% of the circular culverts have diameters between 1 m and 4 m
- 90% of the oval / arch culverts have spans between 1.5 m and 6 m
- 90% of the fill depths above circular culverts are less than 4 m
- Spans can be as large as 11 m and fill depths can be as much as 18 m.

The rehabilitation of the Queensland's corrugated metal culverts is a significant, ongoing and important task – especially given that corrugated metal culverts are located on all types of declared roads, including national highways.

[1] It is noted that there have been some recent examples of severe corrosion of aluminium culverts in seemingly benign environments in both Australia and New Zealand.

Figure 1 - TMR Metal Culverts: depth of fill versus span for circular and oval culvert (Jan 2011)



1.3 Scope

1.3.1 In Scope

The purpose of this document is to ensure the safety of all road users is maintained in a responsible manner and that the existing defective CCMC structures are managed to minimise the potential risks associated with increased deterioration.

Over time, both traffic volumes and the legal weight of heavy/freight vehicles have been increasing on much of the road network. There have been a significant number of culvert structures inspected due to concerns regarding the structural capacity of the CCMC structures.

This Design Criteria provides specific design support for the rehabilitation of CCMC structures that:

- are in a condition state 3, 4 or 5 as determined in accordance with the TMR Bridge Inspection Manual
- have a diameters between 375 mm and 4,000 mm
- have a depth of fill less than 10 m
- have sound geotechnical conditions

This represents the vast majority of Queensland's corrugated metal culverts in need of rehabilitation.

1.3.2 Out of Scope

The following are out of scope for this document:

- culverts that exceed the criteria listed in Section 1.3.1
- assessment of existing culverts to determine the need for rehabilitation/replacement
- non-circular culverts (Arches)
- culverts with a diameter/span greater than 4,000 mm
- culverts with unusual geotechnical conditions (very good or very poor)

- routine maintenance of existing culverts in good condition.

Any CCMC structure that is considered out of scope for this Design Criteria is to be rehabilitated with advice from E&T Structures Division.

This document does not cover the management of CCMC structures in condition states 1 or 2.

1.4 Arrangement of design criteria

The Design Criteria is arranged as follows:

Section 2 discusses the risk management of deteriorated circular corrugated metal culverts (CCMC).

Section 3 discusses the options for the replacement/rehabilitation options available.

Section 4 presents the design criteria for the rehabilitation of CCMC.

Section 5 provides a very brief overview of the Rehabilitation Design Process. This is discussed in more detail in the Section 6 (Option Identification & Preliminary Design), Section 7 (Site investigations), Section 8 (Assessment of Options) and Section 9 (Final Design & Documentation)

A brief summary and a list of references can be found in Sections 10 and 11.

The Appendices contain supporting information such as: the behaviour of corrugated metal culverts and their failure mechanisms; hydraulics and environmental factors; durability; more detailed information about liners and the pressures / forces induced in culverts due to traffic loads; design methods / worked examples; case studies; a list of organisations specialising in the rehabilitation of corrugated metal culverts and a bibliography for further reading.

2 Risk management

2.1 Introduction

This section provides a brief overview of the risks associated with deteriorated CCMC and the risk management and construction options available for their management.

2.2 Risk

2.2.1 How corrugated metal culverts fail

Corrugated metal culverts fail in a number of ways, including:

- The collapse of the culvert due to a heavy vehicle inducing buckling or crushing of the corrugated metal pipe influenced by factors such as overloading, section loss due to corrosion, soil loss from behind the culvert wall, and softening of the soil due to increased moisture content.
- The creation of a chasm across the road due to the soil being washed away from around the culvert during wet periods. The soil can be lost due to overtopping, loss of headwalls, as well as loss of soil through perforations in the culvert.
- Combinations of the above.

2.2.2 Likelihood of failure

The likelihood of failure of corrugated metal culverts is influenced by the condition of the culvert (which varies with time), loading, and the amount of water flowing through or over the culvert. The likelihood of failure of a culvert in condition state rating of 1 or 2 is rare/unlikely. As the culvert's condition deteriorates (condition state rating 3, 4 or 5), the likelihood of failure increases until the likelihood of failure is “almost certain”. Descriptions of the likelihood and indicative frequencies are presented in Table 1.

Water flowing through or around culverts significantly increases the likelihood of failure. This is consistent with the observation that most corrugated metal culvert failures occur during periods of flood flows through the culvert. This is a consequence of the loss of soil and/or softening of the soil surrounding the culvert that is so essential for the culvert to sustain the loads from the fill and traffic. A culvert that supports traffic loads immediately after a flood is therefore less likely to fail once the stream flow has ceased and the soil has stiffened to the extent that more load is supported by the soil and less load is supported by the corrugated metal pipe.

Table 1 - Likelihood scale (from HB436:2004, Risk Management Guidelines Companion to AS/NZS 4360:2004, Table 6.4)

Level	Descriptor	Description	Indicative Frequency (expected to occur)
A	Almost certain	The event will occur on an annual basis	Once a year or more frequently
B	Likely	The event has occurred several times or more in your career	Once every three years
C	Possible	The event might occur once in your career	Once every ten years
D	Unlikely	The event does occur somewhere from time to time	Once every 30 years

Level	Descriptor	Description	Indicative Frequency (expected to occur)
E	Rare	Heard of something like this occurring elsewhere	Once every 100 years
F	Very rare	Have never heard of this happening	One in 1,000 years
G	Almost incredible	Theoretically possible but not expected to occur	One in 10,000 years

2.2.3 Consequences of failure

The consequences of failure range from minor to severe. The potential consequences include:

- Loss of life, injury and damage to vehicles as a consequence of depressions or chasms forming across the road and structural collapse.
- Closure of the road and diversion of traffic for the period of the closure. The impact on the alternate route should be considered.

Emergency works which include:

- Construction of a sidetrack and/or an emergency repair, possibly during a wet period in a locations where construction equipment may not be readily available. The construction and maintenance of a sidetrack during wet periods could be costly with safety requiring careful consideration.
- Design and construction of a permanent replacement structure.
- Impact on the TMR's budget as works may not be programmed.

2.2.4 Summary

The heavy vehicles that use a road pose a risk to the structural integrity of the culvert. Their presence also demonstrates the culvert's current ability to support heavy vehicles. However, this does not guarantee the future structural integrity of the culvert as its load carrying capacity reduces due to corrosion during periods of wet weather.

It is important to rehabilitate culverts of all sizes and covers. Irrespective of whether the culvert is large or small, and whether the cover is deep or shallow, dangerous depressions / holes/chasms in the road may result if a culvert fails. The loss of even a small culvert during a flood, for example, can lead to a flooded chasm across the highway that could result in serious injury, loss of life and/or a lengthy closure of the highway to traffic (e.g., refer to New South Wales Coroner's Court, 2008).

Without intervention, the likelihood of failure is almost certain. It is most likely that failure will occur during/after wet periods that generate flood flows through the culvert.

2.3 Risk management and construction options

2.3.1 Introduction

The risk management strategy of choice is sensitive to factors, such as:

- the assessed risks
- the cost of mitigating the risks
- the availability of resources

- competing priorities
- the importance of the route
- technical considerations.

Available risk management strategies range in cost and effectiveness and thus the choice of strategy will depend on technical and commercial factors that are beyond the scope of this Design Criteria. The discussion that follows provides additional information to assist in the selection of a risk management strategy for culvert replacement/rehabilitation. The discussion includes the following topics:

- approaches to culvert risk management
- construction methods
- pre-construction investigations
- available options

2.3.2 Approaches to culvert risk management

The available risk management approaches for corroded corrugated metal culverts include:

Risk Management Approaches	Comments
Do nothing	Generally unacceptable.
Restricting heavy vehicle mass and/or speed	Relevant for culverts with small and medium depths of fill. The effects of trucks are not significant when large depths of fill are involved. It is noted that culverts can collapse without traffic on the culvert. Reduces the consequences to the traffic should a depression / collapse occur. Some reduction in dynamic effects but this is likely to be small for buried structures.
Preventing heavy vehicle access to the road after periods of flood flow through the culvert until the culvert has been inspected and assessed as satisfactory	Manages the risks associated with soil being washed away from around culverts and leaving chasms or depressions in the road surface. Restricting access to heavy vehicles after flooding is standard practice. There is no guarantee that all roads can be closed during wet periods. Safely is paramount during these inspections.
Preventing heavy vehicle access to the road after periods of flood flow through the culvert until the culvert has been inspected, an axle load test undertaken and assessed as satisfactory	As above with the addition of a load test prior to reopening the road. Load testing provides a demonstration of the structural capacity of culverts after the flood. Helps manage the risks arising when soil is lost from around the culvert and compromising the strength of the culvert but the road surface remains intact. The axle load test would follow the visual inspection and involve the passage of a two axle rigid truck across the culvert at a slow speed, subject to the appropriate safety protocols. (Not appropriate for large culverts.)

Risk Management Approaches	Comments
Monitor and close the road when changes are observed.	This is reflected in a reduced inspection frequency as detailed in the Bridge Inspection Manual (BIM) Part 1. Monitor both: a) the road surface for depressions, and b) the vertical and horizontal “diameter” of the culvert. “Diameter” measurements need to be repeatable to be effective. There is no guarantee that the culvert will not collapse between inspections.
Prop the culvert	Generally not preferred. Principally for emergency scenarios. Propping is not preferred because of the disruption to stream flows, and its questionable reliability due to the potential loss of the props during floods and the change in the structural action of the culvert from principally ring compression to ring compression and bending in a section compromised by corrosion. In large fill depth scenarios, the props will be large (not readily available), and load distribution beams / foundations may be required.
Temporarily divert the traffic around the culvert	Construction of a side-track is an expensive undertaking, especially for road trains. Flood immunity is reduced in the short-term. May be necessary if the culvert has to be replaced rather than rehabilitated.
Eliminate the culvert	Generally not practical except on low volume roads. Either closing the road over the culvert or replace the culvert with a causeway with the associated safety and flood immunity implications.
Rehabilitate the culvert (objective is to achieve a 100 year design life)	Preferred – avoids the cost and disruption of a sidetrack. If a rehabilitation option with less than a 100 year design life is to be considered then the cost effectiveness compared to replacement should be considered.
Replace the culvert with a new culvert	Preferred – will either require a sidetrack or carefully staged construction with the associated cost implications.

2.3.3 Construction methods

The construction methods available for managing the risks of metal culverts include:

Risk Management Approaches	Construction Methods
Eliminate the culvert	Conventional road construction involving either removing the culvert and replacing with a causeway incorporating low flow pipes with a consequent reduction in flood immunity.

Risk Management Approaches	Construction Methods
Rehabilitate the culvert	Relining technologies are available utilising concrete and other materials with the aim of achieving an extension in the life of the culvert of 100 years. A major attraction of relining is that the work can be conducted under traffic without the cost of a sidetrack and/or excavation to remove the existing culvert In all cases, the waterway area is reduced and the velocity increases. Head losses may increase or decrease depending on the relative roughness of the liner and other hydraulic parameters. Consequently the hydraulics of the relined culvert needs to be evaluated to determine the viability of relining the culvert – especially for culverts on "waterways" where fish passage needs to be accommodated.
Replace the culvert	Remove the existing culverts and replace with conventional concrete culverts or reinforced concrete pipes with a 100 year design life. Replacement is usually the superior solution as it involves less technical risk, however it usually requires the expense associated with construction of a side track or carefully stage traffic management systems. Replacement can be achieved by: • Conventional construction methods: Construction of a temporary sidetrack or one-way operation, removal of the existing culvert and construction of the new culvert in stages. • Pipe jacking: Pipe jack reinforced concrete pipes over the existing culvert (so as to maintain or increase the waterway area and increase the flow capacity). Pipe jacking can also be used to add additional pipes should additional capacity be required. Pipe jacking around or adjacent to the culverts is not feasible due to the low cover of this culvert.

An options analysis is necessary to determine the optimum solution for each culvert rehabilitation / replacement project.

2.3.4 Summary

The approaches to culvert risk management need to be assessed for each culvert project. Available risk management strategies range in cost and effectiveness and thus the choice of strategy will depend on technical and commercial factors.

3 Replacement/rehabilitation options

There is an ever increasing array of techniques available to replace / rehabilitate corrugated metal culverts. This section provides an overview of the construction techniques / materials used in the replacement / rehabilitation of corrugated metal culverts. These options are discussed in three groups:

i. Culverts replaced while the traffic is diverted

ii. Culverts replaced under normal traffic

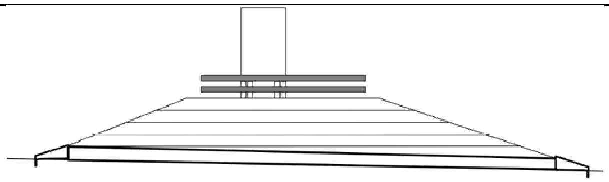
iii. Culverts rehabilitated under normal traffic.

3.1 Culvert replacement with traffic diversion

This is the conventional approach where the road is closed, the embankment surrounding the culvert removed, a new structure constructed in its place, the embankment rebuilt and the pavement reinstated.

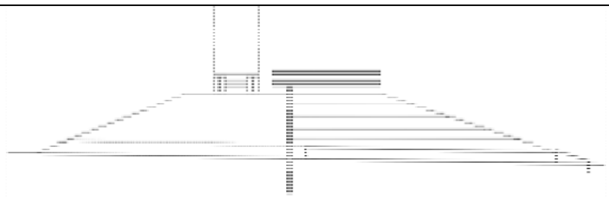
In some cases it may be possible to close half the road and replace half the culvert before repeating the procedure on the other half of the road. This strategy may be useful in lowly trafficked routes with small depths of cover.

A



Remove & replace with a new culvert with road closed.

B



Remove & replace with a new culvert with partial road closures.

Culverts are to be replaced rather than rehabilitated when:

i. *The culvert has lost its shape or collapsed to the extent that it is unsafe to enter the culvert*

ii. *The rehabilitated diameter would be less than 375 mm*[2]

iii. *The alignment of the rehabilitated invert will be such that the culvert is not free-draining*

iv. *There are road works being undertaken at the site (refer Road Drainage Manual Chapter 9)*

v. *The hydraulic, abrasion, scour and/or environmental (including fish passage) performance of the rehabilitated culvert is unacceptable, and*

vi. *The culvert is being rehabilitated is also being extended and unacceptable differential settlements between the existing culvert and the extension are expected.*

[2] 375 mm is TMR's preferred minimum diameter of culverts. Consider replacing as a matter of course rather than relining culverts smaller than 600 mm in diameter.

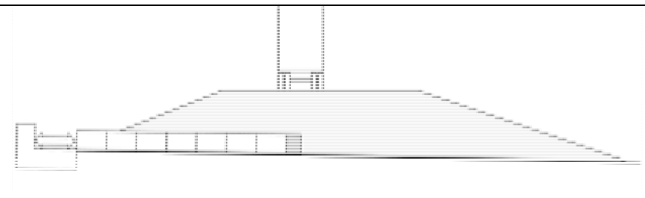
3.2 Culvert replacement under traffic

Trenchless technologies enable culverts to be replaced by tunnelling under the roads and highways and installing a new culvert in the tunnel.

Advantages of this method are that the culvert replacement can be conducted under traffic, and the replaced culvert is a new culvert with the diameter selected for the site.

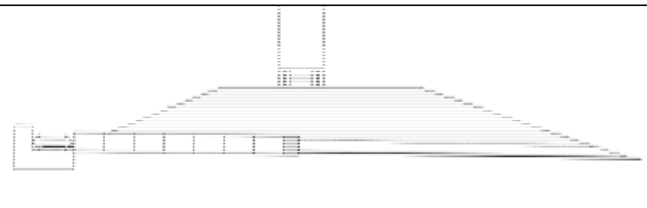
A disadvantage is that specialist technologies are required, new headwalls and flow channels may be required and the abandoned culvert filled.

C



Replace culvert on an adjacent alignment (micro tunnelling, auger boring, pipe jacking) under full traffic.

D



Replace culvert on the same alignment (pipe jacking) under full traffic.

These trenchless technologies are also useful in adding additional waterway area.

Three related trenchless culvert replacement options are discussed below.

3.2.1 Pipe jacking

Pipe jacking is a trenchless technology that can install pipes under roads without closing the road.

The bore is formed from a launch pit by pushing specially designed Reinforced Concrete Jacking Pipes (RCJP) or Steel Pipes behind a jacking shield (refer Figure 2). From within the shield the operator excavates the face in front of him before advancing the steerable jacking shield using laser guidance. The spoil is removed from the face by conveyor to spoil trolleys, which are winched back to the launch pit. The pipe joints are usually steel bands that fit into an external rebate in the RCJP with timber plywood rings to prevent concrete-to-concrete contact.

Pipe jacking provides the ability to remove man made obstacles such as existing culverts and boulders. It is typically used for diameters between 1,200 mm and 3,000 mm and for lengths less than 300 m. Intermediate jacking stations and lubrication using bentonite can be used to reduce the jacking force.

The advantages of this system are that it should not cause surface disruption[3] and can be used to bore through ground, to install a new pipe in place of an existing culvert, and (without the jacking shield) to line an existing culvert with a reinforced concrete pipe.

[3] It is noted that surface disruption has been observed in some cases.

The disadvantages are the minimum diameter, which is controlled by needing access to the face, and that the jacking shield cannot reverse – any obstacles must be removed to allow the recovery of the shield.

Figure 2 - Replacing the first of two barrels of a corrugated metal culvert using pipe jacking (Warrego Highway, Mindin Range)

(a) thrust block and hydraulic rams

(b) jacking shield

3.2.2 Auger boring

Auger boring is a trenchless technology that can install pipes under roads without closing the road.

The bore is formed from a launch pit by means of rotating cutting head. The spoil is removed back to the launch pit by helical auger flight sections within the steel casing being jacked into the ground. The new pipes are subsequently inserted into and grouted within this host steel casing.

Auger boring only offers limited steering capabilities and is used when precise accuracy is not crucial. It is typically used for diameters less than 900 mm and for lengths less than 50 m.

The advantages of this system are that it causes little or no surface disruption, augers remove the spoil, and the pipe of choice can be installed with the casing.

The disadvantages are the limited lengths and obstacles in the bore path. Should the auger become stuck, then a significant excavation may be required to recover the auger and complete the culvert. This may result in a disruption to traffic flow.

3.2.3 Micro tunnelling

Micro-tunnelling is a trenchless technology that can install pipes under roads without closing the road.

A laser guided steerable borer head forms the tunnel. The spoil is removed back to the launch pit by heavy-duty vacuum line within the steel casing being jacked into the ground. The new pipes are subsequently inserted into and grouted within this host steel casing.

Micro-tunnelling is typically used for diameters less than 1,000 mm and for lengths less than 150 m. Boring heads suitable for nearly all ground conditions, from soft clay and sand, up to 200 MPa rock are available.

The advantages of this system are that it causes no surface disruption, the spoil is removed by vacuum, most material can be tunnelled through, and the pipe of choice can be installed with the casing.

The disadvantages are the limited lengths and obstacles in the bore path, and that the borer head cannot reverse – any obstacles must be removed to allow the recovery of the head, with the possibility of significant excavation and traffic disruption.

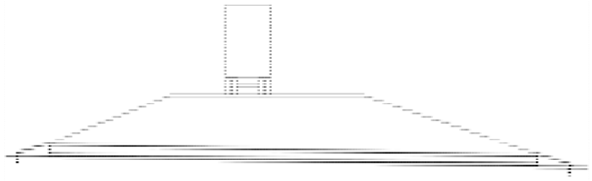
3.3 Culvert rehabilitation under traffic

Culverts can be rehabilitated by inserting liners within the culvert and grouting the liner in place.

A common advantage of relining culverts is that the culvert rehabilitation can be conducted under traffic. The approach eliminates the excavation associated with replacement options.

A disadvantage of all relining technologies reduce the diameter and hence the waterway area of the culvert. This leads to higher velocity flow with the associated scour, environmental and hydraulic issues. Often the liner is smoother that the host culvert and as a consequence there may or may not be increased afflux as a consequence of relining.

E



Reline culvert on the same alignment under full traffic.

Some of the relining options are discussed below.

3.3.1 Reinforced concrete pipe liners

Reinforced concrete pipes slid into the existing culvert on guides and grouted in place provides a new liner.

This is a variation of the pipe jacking method, but without the jacking shield. Also the thrust forces are much smaller.

The advantages of this method is that there are a large range of concrete pipes available suitable for internal diameters up to 3,000 mm and most fill depths. Note that a specific range of concrete pipes are manufactured specifically for pipe jacking.

The disadvantages are the weight of the pipes and the consequent installation infrastructure required to install the pipes, and the substantial loss in waterway area due to the thickness of the pipes and as a consequence of curved culvert alignments and/or distorted culverts.

3.3.2 Polymer precoated galvanised flexible metal culverts

A spirally wound galvanised steel culvert with a high-density polyethylene coating slid into an existing host culvert can also be used to achieve a trenchless rehabilitation.

The liner is slid into position along rails installed on the bottom of the host culvert.

After the liner has been installed cementitious grout is pumped behind the liner to fill voids behind the deteriorated host culvert and the annulus between the liner and the existing culvert.

Polymer precoated galvanised flexible metal culverts can be used to line culverts of any length with finished internal diameters exceeding 1,350 mm.

The advantages of this system are that it causes no surface disruption, relatively light weight components, the high-density polyethylene coating is corrosion resistant and moderately abrasion resistant, and profiles are available for large span culverts.

The disadvantages are that considerable waterway area can be lost if a culvert is curved in alignment and/or severely distorted, increased afflux and flow velocity due to its corrugated profile, the liner needs substantial bracing during the grouting operation, it is provided by a sole supplier, and it is a similar product (albeit with a polymer coating) to the culvert requiring rehabilitation.

3.3.3 Cast-in-situ reinforced concrete liners

A conventional steel reinforcement cage is fixed within the culvert and tunnel lining formwork braced from the existing culvert.

Concrete with the appropriate workability, strength and durability characteristics is pumped into the formwork.

The forms are stripped, the concrete cured and the process repeated along the length of the culvert.

The advantages of this system are that it causes no surface disruption, it is a known material that can be adjusted to suit the durability requirements of the site, a large range of culverts (e.g. small and high depths of fills, non-circular shapes) can be rehabilitated including spans up to 6 m.

The disadvantages are that considerable waterway area is lost, the quality of the concrete is sensitive to the concrete supply and installation technique, and it is provided by a sole supplier.

3.3.4 Other rehabilitation options

There are other options that are not recommended[4] for rehabilitating culverts without reference to Structures Division for advice. These include:

- Structural concrete lining of the invert
- Relining the culvert with:
  - Aluminium flexible metal culverts
  - Fibre reinforced concrete pipes
  - Galvanised flexible metal culverts
  - Glass reinforced plastics (GRP)
  - High density polyethylene pipes
  - Plastics cured in place chemically
  - Polypropylene pipes
  - Shotcrete
  - Spirally wound Polyvinyl Chloride (PVC)
  - Spirally would and expanded to fit PVC
  - Spirally wound steel reinforced High Density Polyethylene (HDPE).

Note: Plastic options such as PVC and HDPE are not approved for use by TMR due to the high frequency of vandalism (by fire) and the structural risks following vandalism and the cost of repair

[4] Reasons include: Life expectance less than 50 years, non-preferred or un-researched materials.

4 Design criteria

4.1 Introduction

The design criteria for the rehabilitation of TMR CCMCs are presented below.

4.2 Quality management

The design of any rehabilitation is to comply with the quality management requirements given in Clause 1.4 of the *Design Criteria for Bridges*.

The construction of any replacement or rehabilitated culvert is to comply with the quality requirements as detailed in the project specific contract documentation.

4.3 Hydraulics & environmental impacts

4.3.1 General

Hydraulic considerations and environmental factors may preclude some options or require additional waterway area.

The rehabilitated culvert must satisfy the requirements of the TMR *Road Drainage Manual* including, (but not limited to):

- Chapter 2 General Design Requirements
- Chapter 3 Strategic Planning & Development Control
- Chapter 5 Hydrology
- Chapter 9 Culvert Design
- Chapter 13 Erosion and Sediment Control
- Chapter 14 Operation, Maintenance & Remediation.

4.3.2 Erosion and afflux

Erosion and afflux shall be determined prior to finalisation of hydraulic calculations and based on the internal diameter of the liner derived from an accurate survey of each barrel of the culvert.

4.3.3 Downstream protection for road embankments at culverts

Road embankments with flood immunity less that 100 year ARI are to be evaluated to determine if embankment protection is necessary and, if necessary, upgraded as part of the culvert rehabilitation (*Road Drainage Manual*) in accordance with the Design Criteria.

4.3.4 Fish Passage

The movement of fish is to be considered as part of the rehabilitation as per the *Road Drainage Manual.*

4.4 Design life

The target design life for new culverts is 100 years.

The target design life for a rehabilitated culvert should be preferably 100 years. 50 years may be accepted if no alternative product is available with a 100 year design life.

The design life shall be interpreted that there is a 95% probability that during the design life the structure or element:

- Will not require major maintenance or replacement of elements
- Will be fully functional
- Will require minimal maintenance.

4.5 Durability

Any replacement/rehabilitated culvert is to be durable and shall consideration the following factors:

- Life: The target rehabilitation design life of 100 years
- Cause: The cause of the deterioration and the life of the existing culvert
- Performance: The performance of other culverts in similar environments
- Environment: The corrosivity of the environment, including the effects of current and expected local industries
- Permanent Water: Ponding, constant flow, tidal flows.

4.6 Design loads

4.6.1 Introduction

The minimum design loads, forces and load effect for the rehabilitation of culverts shall comply with AS 5100 Part 2*: Design Loads*.

The rehabilitated culvert shall be proportioned for the design loads, forces and load effects in accordance with AS 5100.2 and as set out in this Section.

4.6.2 Arch action

Rehabilitated culverts shall be designed on the basis that the soil does not arch over the culvert, irrespective of the depth of cover. This requirement applies to both the weight of the embankment and to live load pressures.

4.6.3 Dead load (G)

The liner shall be designed to support the self-weight of the liner, the grout, the existing culvert and potentially saturated soil.

For design purposes, the dead load shall be calculated based on:

i. the internal diameter of the liner

ii. an average unit weight of 22 kN/m^3 for the liner, grout, existing culvert, embankment, and pavement[5]

iii. an ultimate limit state load factor of 1.25 where the depth of fill has been measured by survey and 1.5 where other means have been used to determine the depth of fill.

4.6.4 Live load (Q)

The liner shall be designed for the worst road traffic load effects in accordance with AS 5100.2 Clause 6 and the HLP400 loading:

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[5] Note: The unit weight of soils of volcanic origin (e.g. pumice sand at 14 kNm^3) may be significantly lower while the unit weight of soils of oxide origin (e.g. iron ore at 27 kNm^3) may be significantly higher.

Table 2 - Live loads and ultimate limit state load factors

Live Load	Ultimate limit state load factor
W80	1.8
A160 – Single or multiple lanes as applicable	1.8
SM1600 traffic load, including the uniformly distributed component of the traffic load – Single or multiple lanes as applicable	1.8
HLP400	1.5
Construction traffic loads	2.0

Each of the above load cases shall be applied over the complete range of fill depths applicable for the rehabilitation design.

The live load shall be calculated as a uniform pressure at the level of the structure crown as based on the design parameters specified in AS 5100.2, including:

i. Number of design lanes (AS 5100.2 Cl 6.5)
ii. Accompanying lane factors (AS 5100.2 Cl 6.6)
iii. Dynamic load allowance for buried structures (AS 5100.2 Cl 6.7)
iv. Distribution of road traffic loads through fill (AS 5100.2 Cl 6.12)
v. Load factors, refer Table 2.

The live load pressures at the crown of a culvert and the ring compression forces for the above traffic loads are summarised in Appendix E and F.

4.6.4.1 Live load surcharge load to headwalls

The live load surcharge is to be applied to any headwalls in accordance with AS 5100.2 Clause 13.2.

4.6.4.2 Braking and centrifugal loads

No braking or centrifugal loads are required to be applied to a culvert.

4.6.4.3 Construction traffic

Construction loads shall be calculated using the axle loads expected and the cover height at the construction stage being considered[6] in accordance with AS 2041 Clause 4.3.1.

4.6.4.4 Jacking forces

Jacking forces are to be considered. Refer to specialist sub-contractors and Structures Division for advice.

4.6.4.5 Grouting/concreting

The liner/formwork and the bracing system shall be designed to resist the hydrostatic pressures applied by the grout/concrete used to fill the annulus between the liner and the existing culvert.

The grout/concrete is to be assumed to be fluid applying hydrostatic pressures over the depth of the current grout/concrete layer and the previous grout/concrete layer. The previous grout/concrete layer

[6] Note: The Contractor may specify special construction loads in accordance with Clause 12.1 of MRTS03

is to have set sufficiently to prevent indentation by a thumb pressed onto the surface of the grout/concrete prior to any new grout layers being added.

Grout/concrete placed prior to the previously set layer can be considered to support the outward movement of the liner without applying any additional loads. The inward movement of the liner is to be resisted by the liner and bracing.

The hydrostatic pressure due to grout/concrete p shall be calculated as per Table 3.

Table 3 - Hydrostatic pressure due to grout / concrete

Description	Parameters	Ultimate limit state load factor
Grout	Fluid density of grout ρ = a minimum of 1,500 kg/m^3 or as determined by testing	
Concrete	Fluid density of concrete ρ = a minimum of 2,500 kg/m^3 or as determined by testing	
Hydrostatic pressure (p) where the maximum grout/concrete level is controlled by grout weirs and grout vents through the liner.	ρ = ρg(y+0.05 m) where y is the vertical distance below the surface level of the grout weir.	1.5
Hydrostatic pressure (p) where the maximum grout/concrete level is controlled by vent pipes with at least two times the cross-section area of the grout tubes.	ρ = ρg(y+0.05 m) where y is the vertical distance below the highest point of the vent pipes. The top of the vent tube shall be 250 mm above the highest point of the internal surface of the existing culvert.	1.5
Other grouting procedures	As agreed with TMR	As agreed with TMR

4.6.5 Earthquake load (EQ)

The rehabilitation of culverts with spans greater than 3,600 mm may need to be designed for earthquake loads. Refer to Engineering and Technology, Structures Section for advice.

4.6.6 Load combinations

The following loading scenarios are to be considered:

- Installation:
  - Jacking / winding forces
  - Grouting/concreting pressures – including grout layers and temporary bracing
- Operational: Embankment and live loads
- Saturated embankments and draw-down as appropriate

The design load is the worst combination of load from current height of fill to any proposed future height of fill. Note that decreasing the height of fill can lead to a more severe design load.

The serviceability, ultimate and stability limit states such as the flotation of the liner/formwork during grouting/concreting shall be considered.

4.7 Design methods

4.7.1 Introduction

Unfortunately, there are no design standards for the structural design of the liner to rehabilitate a culvert. The structural design approaches include:

i. Design the liner as if it were a new buried pipe assuming that the existing deteriorated culvert is of no structural value and that the grout used to fill the annulus between the liner and the original culvert is equivalent to the select fill that usually surrounds culverts. Minimum Australian Standard recommendations are discussed in the sections that follow.

ii. Design using the fundamental engineering principles. This involves understanding the material properties of the soil and the liner and utilising stage-construction soil-structure interaction software such as Plaxis to determine the moments, shears and axial forces that must be resisted and ensuring the proposed section is adequate. Buckling of the liner will also need to be considered. These are typical situations where standard lining solutions are not available. In these cases the expertise of Structures Section should be utilised.

4.7.2 Jacking reinforced concrete pipes & reinforced concrete pipe liners

Design Standard: AS 3725

Notes:

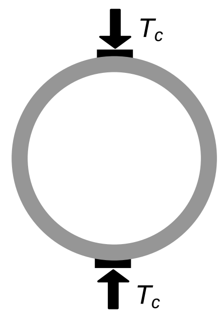
1. Single barrel (as per pipe jacking): W_g as per AS 3725 C6.3.3.4.
2. Multiple barrel (as per positive projection): W_g as per equation 2 of AS 3725 C6.3.3.1.
3. Bedding factor F =2 for pipe jacking, F = 3 for RCP liners and F_q = 1.5 as per AS 3725C9.3.3 and C10.2
4. The minimum pipe Class shall be Class 3 for liners and Class 4 for pipe jacking applications.

4.7.3 Cast Insitu structural concrete liners [7]

Design Standard: AS 3725, AS 4058 & AS 5100

Notes:

1. Either:
   a. Calculate W_g as per "jacking reinforced concrete pipes" for single or multiple barrel culverts as above.
   b. Determine proof load (T_c) using equation 8 of AS 3725 C10.2 and apply T_c applied over a 150 mm wide bearing strip to an unrestrained segment of the liner loaded across its diameter (as per the two-edge bearing method of AS 4058 Figure C4.)
   c. Serviceability limit state: Ensure crack width requirements of AS 5100.5 are met with T_c applied across the diameter.



[7] This method is preliminary only and will be subject to refinement during trials

d. The longitudinal reinforcement to control shrinkage and thermal cracking shall assume the liner is fully restrained.

e. Strength limit state: Ensure the strength limit state requirements of AS 5100.5 are satisfied with $1.5xT_c$ applied across the diameter. Adopt standard Φ factors.

2. Or: Design the liner as per AS 5100 using appropriate specialist non-linear finite element analyses to model the stages of the construction and the soil-structure interaction (refer to Structures Division for advice).

4.7.4 Polymer precoated galvanised steel corrugated metal liners

Design Standard: AS/NZS 2041.1

Notes:

1. The minimum acceptable fill depth above the obvert shall be the maximum of 750 mm and half the internal diameter of the liner.
2. Design is to be in accordance with *AS/NZS 2041.1 Section 5 Limit State Method*
3. The grouting procedure shall prevent flotation of the liner and limit the distortion of the liner to:
   a. The internal diameter of the liner shall not vary by more than 2% from the internal diameter of the liner measured immediately prior to grouting.
   b. The offset of the liner from the centre of a straight edge with a maximum length equal to 1/6th of the internal diameter of the liner shall not vary by more than 4% from the offset of the liner measured immediately prior to grouting.

4.7.5 Structural reinforced concrete inverts

Design Standard: AS 2041.1, AS 5100.5 & AS 5100.6

Notes:

1. Determine the ultimate ring compression force (N*) as per AS 2041.1
2. Design the invert and its connection to resist 1.15N* and the minimum design actions on connections as set out in AS 5100.6 C12.3.1
3. Regard structural reinforced concrete inverts as an emergency repair and not as a rehabilitation.

4.8 Headwalls

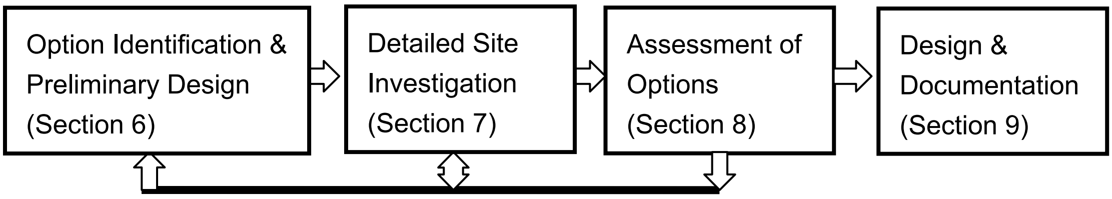
Rehabilitated culverts are to incorporate headwalls, aprons and cut-off walls.

The bevelled ends of culverts of diameter less than 3.0 m shall be replaced with headwalls or have erosion protection upgraded to current TMR standards as part of the rehabilitation.

5 The rehabilitation design process

The culvert rehabilitation design process is sometimes iterative as illustrated in Figure 3. The section of this guideline that relates to each step are shown in brackets.

Figure 3 - The rehabilitation design process



6 Option identification and preliminary design

The procedure to identify the rehabilitation option/s most likely to satisfy the construction, structural, durability and hydraulic restraints of a particular site is illustrated below and described in the sections identified:

1. Collect Background Information (Section 6.1)
2. Preliminary Fish Passage Analysis (Section 6.6)

   By Regional Environmental Officer
3. Estimate the External and/or Internal Diameter of the Liner (Section 6.2)
4. Preliminary Structural Analysis (Section 6.3)
5. Preliminary Durability Analysis (Section 6.4)
6. Preliminary Hydraulic Analysis (Section 6.5)
7. Preliminary Abrasion Analysis (Section 6.7)
8. Preliminary Design Option Report (Section 6.8)

6.1 Collect background information

Collate the available information, including: drawings, satellite images, inspection records, maintenance records, and local knowledge. The minimal documents required for background information include:

- Previous BIS Level 2 Inspection Reports
- BIS Level 3 Inspection Report
- Road plans.

Summarise critical data including the nominal diameter of the culvert and cover above the top of the culvert.

6.2 Estimate the diameter of a liner

In identifying the options available for rehabilitation of the culvert, the physical aspects of the culvert (i.e what can fit in the culvert?) must be resolved.

The choice of liner material and wall thickness can vary from site to site. The variables that have the most significant influence on the liner material and thickness are the diameter of the existing culvert and the depth of fill above the culvert.

The internal diameter of a liner (ID_L) can be substantially smaller than the nominal diameter of the host culvert, especially if the host culvert is distorted. Some guidance for estimating ID_L from the outside diameter of the liner (OD_L) is given below:

OD_L = Minimum diameter of a straight cylinder that can be inserted in the culvert. i.e., minimum diameter of the existing culvert (after considering protruding objects such as bolts) (ID_{EC}) less any deviations from alignment (*Dev*) and construction tolerance, say:

$OD_L \sim 0.95 \times (ID_{EC} - Dev)$

The internal diameter of the liner (ID_L) can be estimated from the *ODL* using Table 4. Note that other parameters such as the depth of fill mean that the values in Table 4 are approximate and should be confirmed during the final stages of the design. This method for determining OD_L is appropriate for culverts with diameter > 375 mm and constant diameter liners.

In the case of cast-in-situ reinforced concrete liners, the formwork can be built to suit the shape and size of the culvert. Minimum requirements for cover to the steel reinforcement suggest a minimum wall thickness of 170 mm. This thickness will increase in saltwater environments.

A high level of confidence about the final internal diameter of the culvert needs to be achieved before construction commences. A three dimensional site survey may be required, as discussed in Section 7.5.

Table 4 - Relationship between internal diameter (ID_L) and outside diameter (ODL) for various liner options

OD_L - Outside diameter of liner estimated from host culvert (mm)			ID_L -
Reinforced concrete pipe *	**HDPE precoated galvanised corrugated steel ^**	**Other**	**Estimated internal diameter**
445	415		375
535	490		450
620	565		525
700	640		600
790	715		675
870	790		750
945	865		825
1030	940		900
1200	1090		1050
1360	1240		1200
1530	1405		1350
1690	1555		1500
1860	1705		1650
2020	1855		1800
2190	2005		1950
2340	2155		2100
2660	2455		2400
2980	2755		2700
3310	3055		3000
	3655		3600

* Diameter generally restricted to production diameters - refer supplier for detailed information

^ Diameter is set by manufacturing process and may be varied - refer supplier for available diameters

6.3 Preliminary structural design

6.3.1 Section selection

The sections listed in Table 5 are typical sections available for use in CCMC rehabilitation by relining. Each section and material has strengths and weaknesses that need to be assessed for each site. This list is updated as products are approved for use by E&T Structures Section.

For construction options C, D, and E (i.e., the culvert is to be rehabilitated rather than removed), identify the structural option/s that are applicable for the site based on the culvert diameter and the cover to the crown of the culvert using Figure 4. Structurally suitable liners are those whose design curves lie outside the estimated internal diameter[8] and depth of fill parameters for the site. Note that the design curves change with the soil parameters.

Detailed design curves are listed in Appendix D for improved clarity. The area to the left of the design curve means the product is suitable for that depth of fill and diameter. The area to the right of the

[8] Estimation of the internal diameter of the liner is discussed in Section 6.2.

design curve means the product will be overstressed and is not suitable for the depth of fill and diameter.

Table 5 - Approved sections for CCMC culvert rehabilitation

S68 x 13 x 1.22 Poly S68 x 13 x 1.91 Poly S75 x 25 x 1.91 Poly S75 x 25 x 3.42 Poly	Polymer precoated (high density polyethylene) galvanised corrugated metal culverts inserted into the culvert and grouted. The sinusoidal profiles have pitches of 68 mm or 75 mm, profile depths of 13 mm or 25 mm and thicknesses of 1.22 mm, 1.91 mm or 3.42 mm. Note other standard profiles are available on long-term order.	1200 mm to 3600 mm ID
RCP Class 3 RCP Class 4 RCP Class 6 RCP Class 8	Class 3, 4, 6, 8, conventionally reinforced concrete pipes. Note that a minimum of Class 4 pipes are recommended for pipe jacking through soil or around embankments. Class 3 RCPs can be used as liners.	1200 mm to 3000 mm ID
Cast-in-situ RC liners[9]	Conventional reinforced concrete with circumferential and longitudinal steel reinforcement using formwork systems developed specifically for the task.	1500 mm to 4000 mm ID

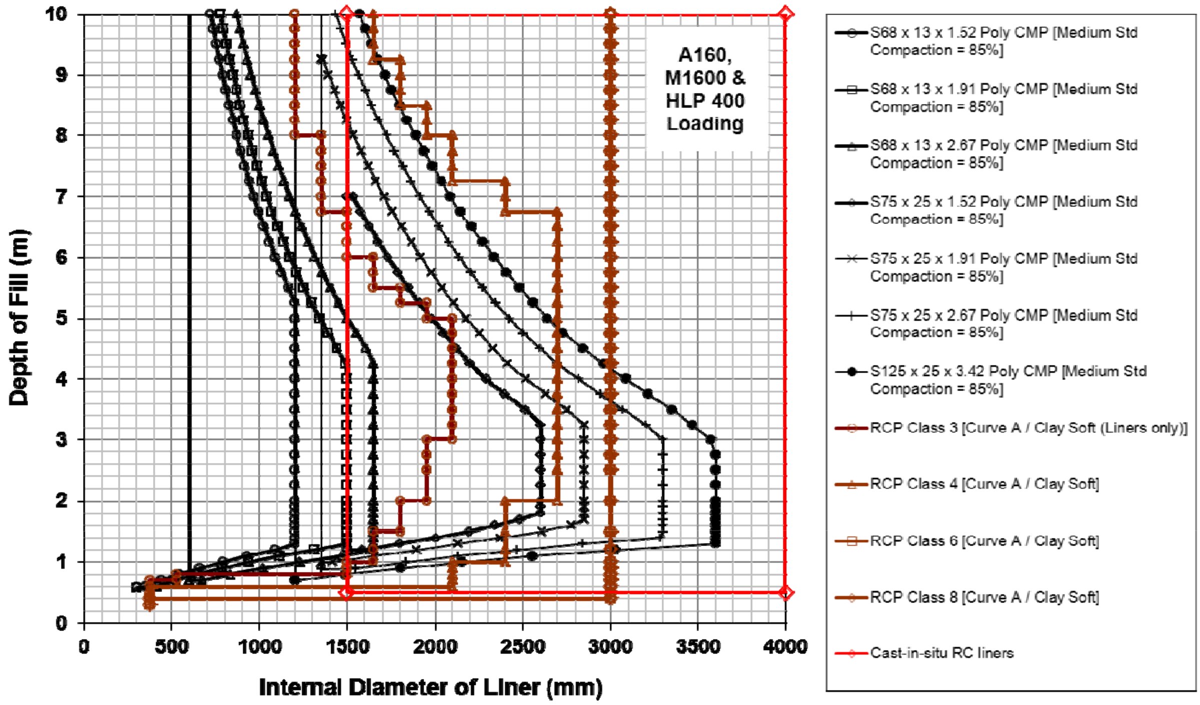
The data in Figure 4 is based on relatively low estimates of soil properties. Softer soil properties will reduce the load carrying capacity. Stiffer soil properties generally increase the theoretical load carrying capacity of a culvert. Any reliance on increased soil properties should be supported by a geotechnical investigation (refer Section 7.8 for further information) conducted in association with Structures Division.

Examples

Nominal (Internal) Diameter	Depth of fill above top of culvert (m)	Liner options (from Figure 4)
2400 mm	2.4 m	S75 x 25 x 1.91 polymer precoated galvanised corrugated metal pipe liner and grout Class 4 reinforced concrete pipe liner and grout Class 4 reinforced concrete pipe jacking Cast-in-situ reinforced concrete liner
750 mm	1.8 m	Micro-tunnelling on a new alignment and Class 3 RCP
1200 mm	2.0 m	Class 3 reinforced concrete pipe liner and grout Class 4 reinforced concrete pipe jacking
900 mm	5.0 m	Micro-tunnelling on a new alignment and Class 3 RCP
3600 mm	6.0 m	Cast-in-situ reinforced concrete liners Investigations in association with Structures Division to identify suitable options.

[9] Subject to successful outcome from trials. Wall thickness and reinforcement determined on a case by case basis. Minimum diameter controlled by safety and practical issues associated with working in the culvert. Maximum nominal diameter expected to be 6.0 m.

Figure 4 - Depth of fill above the crown of a culvert versus the internal diameter of the culvert for selected lining options and soil conditions[10]



6.3.2 Material options

The materials listed in Table 6 are suitable for the construction options presented in Section 3 of this document.

Table - 6 Culvert materials for construction options

Material	Design Life (years)	Construction Option (refer Section 3)				
		A	B	C	D	E
Reinforced concrete pipe	100	✓	✓	✓	✓	✓
Reinforced concrete box culvert	100	✓	✓			
Cast-in-situ structural concrete liners with steel reinforcement (not shotcrete)	100					✓
Polymer precoated galvanised corrugated metal culverts	>50	✓	✓			✓
Other	N/A	✓	✓			✓

Construction options A and B require the culverts to be designed as for new construction and the design is therefore not included in this document. Refer to the *Road Drainage Manual* for the design of newly constructed culverts.

Contact details of suppliers delivering the above construction options are presented in Appendix H.

[10] Note: the reinforced concrete curves presented here are applicable only to single barrel culverts used in a pipe jacking scenario. The results are non-conservative for other scenarios such as multiple parallel pipe jacked pipes, pipes installed in trenches, or under embankments.

6.4 Preliminary durability analysis

In general, galvanised corrugated metal culverts have a design life substantially less than TMRs 100 year target design life for new structures. While some of Queensland's culverts have performed well, others have deteriorated in periods as short as 10 years.

The rehabilitation of a culvert is a substantial investment. Thus it is important to rehabilitate in a manner that achieves a 100-year design life (refer Section 4.4).

To achieve desired design life, it is important to identify those materials that will provide a target design life of the rehabilitated culvert of preferably 100 years, bearing in mind that the poor durability is the probable reason the culvert is being rehabilitated. A 50 year target design life may be accepted if no alternative product is available with a 100 year design life.

The durability of the rehabilitated culvert can vary from site to site and materials chosen. Durability investigations (corrosion and abrasion) to be undertaken for each culvert and shall consider information collated from:

i. *Local knowledge: Durability or lack of durability exhibited by the culvert material types in the environment or similar environments, and*

ii. *Investigation: Investigations of the corrosivity of the soil and water, the abrasion potential and comparing this information against durability models.*

Corrosion investigations are of particular importance in the following circumstances:

i. *Where it is proposed to use materials without a proven track record*

ii. *In environments considered severely corrosive or extremely corrosive as per Table 7*

iii. *Where there is permanent water (ponding or constant flow, or high groundwater flow)*

iv. *In marine or salt spray environments*

v. *In aggressive soils (expansive clay soils, saline or sulphate soils)*

vi. *Where damaging chemicals are considered likely to be present.*

Table 7 - Corrosiveness of soils

(MTO Gravity pipe design guidelines, 2005, Table 3.3)

Soil Type	Description of Soil	Aeration	Drainage	Colour	Water Table
I Mildly Corrosive	1. Sands or sandy loams 2. Light textured silt loams 3. Porous loams or clay loams thoroughly oxidized to great depths	Good	Good	Uniform colour	Very low
II Moderately Corrosive	1. Sandy loams 2. Silt loams 3. Clay loams	Fair	Fair	Slight mottling	Low
III Extremely Corrosive	1. Clay loams 2. Clays	Poor	Poor	Heavy texture Moderate mottling	0.6 m to 1 m (2 feet to 3 feet) below surface
IV Severely Corrosive	1. Muck 2. Peat 3. Tidal marsh 4. Clays and organic soils	Very poor	Very poor	Bluish-gray mottling	At surface or extreme impermeability

Based on the information provided, Table 8 provides an indication of the suitable materials for a range of standard environments.

Table 8 - Culvert types for various exposure conditions

Exposure condition	Reinforced concrete pipes	Polymer precoated galvanised corrugated steel pipes
Saltwater	✓	
Aggressive soil (e.g. low pH, high chloride, high sulphate)	✓	
Invert in fresh water for prolonged periods	✓	
Typical condition (i.e. none of the above)	✓	✓

Further information regarding durability is provided in Appendix C.

6.5 Preliminary hydraulic analysis

Hydraulic and environmental considerations may dictate the rehabilitation / replacement strategy. The rehabilitated culvert is to comply with the requirements of the Road Drainage Design Manual. The process is broadly outlined below. Assistance from E&T Structures Section may be required.

6.5.1 Preliminary hydrology

Estimate flood flows through the culvert for various average recurrence intervals, based on collated information including future changes in land / road use:

Q_1 fish passage, embankment overtopping, flood immunity, erosion

Q_2 fish passage, abrasion, embankment overtopping, flood immunity, erosion

Q_5 embankment overtopping, flood immunity, erosion

Q_{10} embankment overtopping, flood immunity, erosion

Q_{20} embankment overtopping, flood immunity, erosion

Q_{50} embankment overtopping, flood immunity, erosion

Q_{100} embankment overtopping, flood immunity, erosion

6.5.2 Preliminary hydraulics

For the average recurrence intervals listed above, estimate the culvert barrel velocity, upstream afflux, and downstream afflux based on upstream control and downstream control for both the existing culvert and the proposed rehabilitated culvert. Values of Manning's "n" for various corrugated metal culverts are presented in Appendix D.

6.5.3 Analysis

Determine acceptability with respect to:

i. Afflux;

ii. Embankment overtopping

iii. Erosion

Determine the extent of a hydraulic survey, if required.

6.5.4 Recommendations

Based on the analysis conducted, options and recommendations for the rehabilitation are to be developed and presented.

6.6 Preliminary fish passage analysis

Relining corrugated metal culverts usually results in smaller diameter smoother culverts with consequent higher flow velocities. The flow through the culvert may change from being outlet controlled to inlet controlled and therefore be characterised by a hydraulic jump at the outlet or within the pipe. These higher velocities and hydraulic jumps may need to be addressed to ensure fish can successfully cross the culvert. Fish passage can become the controlling option for the rehabilitation of the culvert and may require additional waterway area to be provided.

Constructing or reconstructing (or significantly repairing) any waterway barrier across a (freshwater or tidal) waterway requires a development approval under the *Integrated Planning Act 1997* and the *Fisheries Act 1994*. Under this legislation the application will be refused unless movement of fish across the waterway barrier is adequately provided.

Not all culverts are located on a “waterway” as defined by the Fisheries Act. Culverts that are not located on a “waterway” do not need to comply with the requirements for fish passage. Consequently an Environmental Officer should be engaged to assess whether the site is a waterway or not at the earliest opportunity, preferably before any hydraulic investigation is undertaken.

Further information and guidance are provided in the *Road Drainage Manual* and from the *Fish Habitat Management Operational Policy (FHMOP 008) – Waterway barrier works development approvals (2009)* issued by Queensland Fisheries (part of Department of Agriculture, Fisheries and Forestry) this document is available http://www.daff.qld.gov.au/28_142.htm correct as of December 2012.

The Department of Agriculture, Fisheries and Forestry have released the following related publications:

“*Code for self-assessable development – Minor waterway barrier works Part 3: Cuvlert crossings”, Code number: WWBW01 (April 2013)*

6.7 Preliminary abrasion analysis

To determine the abrasion levels, the site must be assessed in accordance with the *Road Drainage Manual* (Chapter 13) and observations from the BIS Level 2 and Level 3 inspections.

Determine the abrasion level from Table 9.

Table 9 - Pipe flow abrasion levels

(MTO Gravity Pipe Design Guidelines, 2005, Table C8)

Abrasion Level	Description
1	Non-abrasive – No bedload
2	Low abrasion – Minor bedloads of sand & gravel and velocities of 1.5 m/s or less or storm sewer applications
3	Moderate abrasion – bedloads of sand and gravel with velocities between 1.5 and 4.5 m/s.
4	Severe abrasion – Heavy bedloads of gravel and rock with velocities exceeding 4.5 m/s.

Use Table 10 to assess the abrasion for typical re-lining materials.

Table 10 - Abrasion assessment

Material	Abrasion Assessment
Reinforced concrete pipes	Limit use of this material to moderate abrasion scenarios with maximum 2 year average recurrence interval flow velocity of 2.5 m/s to 3.0 m/s.
Structural concrete	
Polymer precoated galvanised flexible metal culverts	Limit use of this material to moderate abrasion scenarios with maximum 2 year average recurrence interval flow velocity of 4.5 m/s.

Selecting a material that does not satisfy the abrasion assessment criteria will reduce the design life of the re-lining.

Concrete inverts are often recommended for increasing the abrasion resistance. If they are to be added then the potentially detrimental impact on the durability of the culvert must be considered. The fixings for the concrete invert should be appropriately durable and should be planned before the culvert liner is installed. Fixings that penetrate "flexible" liners should be in place before the liner is grouted.

Identify any abrasion investigations that should be conducted as part of the Site Investigations.

6.8 Preliminary design option report

The designer is to complete a preliminary design option report for the rehabilitation project. The report is to include the information detailed below. A draft contents page is attached in Appendix H for reference.

6.8.1 Options

Based on the options identified and the analyses undertaken, select the recommended option/s for further analysis.

Prepare an engineering estimate for each option.

6.8.2 Site investigations

The design needs to detail the requirements and outputs for the site investigation.

7 Site investigations

7.1 Introduction

The following should be considered where additional site investigations are required.

7.2 Alternative routes / sidetracks / partial road closures

Identify / confirm suitability of any alternative routes.

- Walk sidetrack options and identify any restraints such as:
- Underground services
- Overhead services
- Geotechnical conditions
- Road geometry – horizontal and vertical curves, sight lines, grades, transitions
- Stream crossings
- Traffic control
- Owners of the land.

Review any proposals to replace the culvert under half road closures.

7.3 Durability

Collect sufficient information to assess the durability of the rehabilitated culvert options including:

- Stream water pH[11] and resistivity
- Soil pH and resistivity
- Total dissolved salts
- Samples of any unusual corrosion products
- Any other information required to understand the cause of the corrosion of the existing culverts.

7.4 Abrasion

Collect sufficient information to assess the abrasion resistance of the rehabilitated culvert options including:

- A review of the abrasion performance of the existing culverts
- Information on the grading of the material transported through the culvert – silts, sand, gravel, rocks, and boulders.

7.5 Survey for culvert geometry

Accurate assessment of the geometry of the existing culvert is essential to determine the finished geometry of any liners prior to construction to confirm the hydraulics of the culvert.

[11] Refer TMR Test Method Q121

The extent and type of survey will depend on the options being considered. Accurate three dimensional surveys will be necessary when the diameter of the liner must be set and material ordered before construction commences.

For liners where the diameter is set before construction (e.g., reinforced concrete pipe liners, cast-in-situ reinforced concrete liners and polymer precoated galvanised corrugated steel liners):

- Diameters are typically greater than 1,200 mm in diameter.
- A three-dimensional survey sufficient to determine largest diameter straight cylinder that can be inserted in the culvert at an appropriate grade must be undertaken. This will generally require surveys of cross-sections at 2 m centres with 8 points per cross-section. The survey should include bevel ends, and deliberately target points observed to potentially encroach on the diameter of the relining cylinder (e.g., bulges, bolts). Laser scanning, provided it picks up projections such as bolts, may also be used. The survey data should be consistent with importing into 3 dimensional CAD software such as 12D.
- The three-dimensional survey shall include the road surface for 20 m on either side of the culvert with particular care taken to collect sufficient information to identify the minimum cover to each culvert barrel.
- The geometry of any headwalls and other hydraulic control features are to be included in the survey.
- For culverts with a nominal diameter less than 900 mm:
  - These culverts are too small for safe entry. Utilise robots and scanning technology where appropriate.

General:

- The details of the current culvert: profile of corrugations (pitch x height), wall thickness
- Confirmation that the culvert has not been previously relined
- Details of headwalls, aprons and cut-off walls.

7.6 Survey for culvert voids

Voids behind culvert walls are unacceptable. By providing a path for water to flow through the embankment, any void will compromise both the embankment and the interaction between the soil and the culvert essential to support load and hence the potential loss of the embankment.

Inspect the culvert and identify:

- Any dips / depressions in the road above the culvert. These are a good indicator of voids / soil loss and therefore an unsafe culvert that needs immediate action (especially if they increase over time). Similarly, evidence of regular use of asphalt overlays / repairs may indicate a growing depression and an unsafe culvert.
- Sink holes and wash outs in the embankments.
- Perforations in the culvert wall due to corrosion, poor construction, opening of joints and the like.
- Areas where the shape of the culvert has been compromised, particularly if the walls have slid past each other.

- Areas that sound “drummy” or “hollow” when tapped with a hammer.
- Mark the limits of any voids on the inside of the culvert with a durable marker, taking particular care to identify the highest points in each void.

Soil lost from the embankment and/or from around the culvert must be reinstated as part of the remedial works.

The most common strategy applied to fill voids around the culvert is to allow the fluid grout used to grout the liner in place to flow into the voids behind the wall of the culvert under gravity. This can only fill the voids when the grout can flow into each void and the air can escape from each void during each layer of the grouting operation. Any voids that are above the level of any air venting point will not be filled during this style of grouting operation. Hence filling the voids will be required holes to be made in the liner at the high point of each void that has been marked during the inspection.

Alternate methods of void rehabilitation will be required in situations where it is judged that the voids cannot be sufficiently filled using fluid grout flowing under gravity through holes drilled in the liner.

7.7 Survey for culvert hydraulics

A quality survey of the stream, culvert and embankment may be required to provide sufficient information to enable the hydraulic and environmental considerations to be accurately addressed.

The recommended survey requirements follow.

7.7.1 General:

- Locate positions and levels of objects that are likely to be sensitive to flooding.
- Locate positions and levels of flood debris considered relevant.
- In all cases, take photographs of:
  - The inlet and the view looking upstream
  - The outlet and the view looking downstream
  - The inside of the culvert
  - A panorama taken from road level above the culvert
  - Other locations that illustrate the survey cross-sections and the condition of the waterway.

7.7.2 For very simple watercourses:

- If the watercourse is very simple (or only an approximate answer is needed), the hydraulic analysis can be completed with a single cross section at the culvert site. In this case, the water level can be calculated using Manning's equation with a known or calculated water surface profile. This simple method is much less accurate than methods using downstream cross sections, but may be sufficient in some situations.
- This simplified approach would commonly be restricted to small culverts.
- In this case, the survey should provide a single cross section immediately downstream of the culvert site. The cross section should extend sufficiently to reach the highest expected flood level at the crossing and should be at right angles to the flow or along the road alignment. A streambed profile may also be useful to improve the estimation of the flood slope that is used in Manning's equation.

7.7.3 For a watercourse:

- Downstream of the crossing, the general requirement is to survey five cross-sections spaced approximately 100 m apart. These cross sections should be at right angles to the flow and should extend to higher than the highest expected flood level, so that the model can represent all of the flow. The maximum surveyed level is usually higher than the bank level of the stream, since over-bank or floodplain flow is common. The cross sections should represent the downstream reach sufficiently to allow the backwater model to accurately calculate the flood level immediately downstream of the culvert. In some circumstances, some changes may be needed if the watercourse is small or large or there are other special features. These five cross sections however are adequate for most situations.
- Upstream of the crossing, five cross sections are also suggested, also spaced about 100 m apart. These upstream cross sections ensure that the afflux or the impact of the crossing on flood levels can be calculated accurately.
- As well as the cross sections, the streambed profile over the reach of the river upstream and downstream of the bridge site (included with the cross sections above) should also be surveyed. This helps in the estimation of the flood profile, as well as to identify locations where there are changes in bed slope.
- A survey at the road alignment itself should include the cross section at the culvert and immediately upstream and downstream. There should be a survey of the profile of the road crown and any drainage structures / headwalls.

7.7.4 For complex flood plains:

- The recommended survey requirements for complex floodplains are extensive and should be developed in association with Structures Division (Hydraulics). Complex floodplains are ones where there is no clearly defined channel or flow path and floodplain flow occurs over a wide expanse. Generally in these cases, the road crosses a wide floodplain where there may be flow in a main channel as well as other minor channels and floodplain extents. There are usually several bridges and culverts spaced along the road. It is often difficult to identify the exact flow paths and distribution of flows. Most culverts aren't in this category.

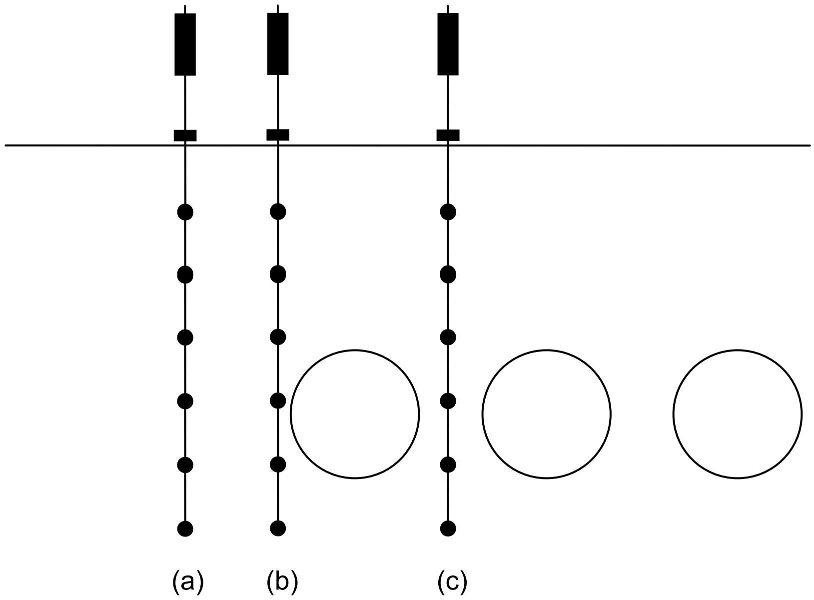
7.8 Geotechnical

Geotechnical investigations may be required to:

- Determine the modulus of elasticity of the soil surrounding the existing culvert for input into the soil-structure interaction design of the liner;
- Identify the geotechnical conditions likely to be encountered during the installation of a new culvert on an alternate route.
- Investigate expansive soil issues.

The design of culvert rehabilitation requires an estimate of the soil modulus of elasticity in the vicinity of the culvert. This is often inferred from Dynamic Cone Penetrometer tests (Test Method Q114B) or SPT test results taken at regular intervals from the surface of the road to a level 1 m below the invert of the culvert from a borehole offset. Suggested locations are as indicated in Figure 5. Refer to the Structures Section for further advice.

Figure 5 - Geotechnical sampling locations at 1 m centres: (a) 1.5 m from face of culvert, (b) as close as possible to the culvert, and (c) between culverts



8 Assessment of options

Assess the options identified during the preliminary design in the light of the Site Investigation. This assessment will include:

i. Reviewing site investigation data
ii. Determining the internal diameter of the liner based on the survey results
iii. Updating the hydraulic analysis to reflect the liner diameter and survey information. Refining the options to satisfy the hydraulic, environmental and abrasion requirements
iv. Eliminating / adjusting options that are inconsistent with the durability and abrasion assessments
v. Reviewing structural capacity of refined options
vi. Where appropriate consulting with specialist contractors (refer Appendix J)
vii. Updating engineering estimates, and
viii. Developing recommendations.

Report the recommended option. In some cases further site investigation or additional options may need to be identified and assessed.

9 Final design & documentation

Following review and acceptance of the recommended option:

i. Prepare and submit a development application under the *Integrated Planning Act 1997* and the *Fisheries Act 1994* (if required)

ii. Finalise the design of the culvert rehabilitation including ancillary items such as erosion protection and new head walls in accordance with sound engineering and the requirements of this Design Criteria

iii. Prepare drawings as required

iv. Assemble standard and supplementary specifications

v. Update engineers estimate

vi. Deliver scheme.

10 Summary

There is an increasing need to cost-effectively replace / rehabilitate deteriorating corrugated metal culverts.

This Design Criteria provides the technical information required to assist TMR manage the risks associated with defective CCMC through rehabilitation and/or replacement in accordance with Australian and International practice.

Appendix A: Behaviour of corrugated metal culverts

Introduction

This Appendix provides an introduction into the behaviour of corrugated metal culverts and how they fail.

How corrugated metal culverts support load

Flexible culverts, such as corrugated metal culverts, rely on the support of the surrounding soil to support the embankment and traffic above the culvert, deriving a major portion of their load-carrying capacity through soil-structure interaction. Consequently, the surrounding soil is an essential structural element of flexible culverts – without the interaction with the surrounding soil, flexible culverts cannot sustain the embankment and traffic loads.

During construction, flexible metal culverts readily distort and require considerable care and experience to install. This sensitivity is a consequence of the flexibility of the unrestrained culvert, which readily distorts because the loads bend the walls of the flexible culvert. This flexibility is measured by the parallel plate test where a tube of culvert material is loaded across its diameter.

During construction, flexible culverts distort. Careful construction processes and the bending strength of the culvert wall control this distortion. Once the flexible culvert is encapsulated within the embankment, the soil provides the support necessary to prevent this distortion (Pritchard, 2008).

In the parallel plate test, the vertical deflection is associated with a horizontal deflection at the spring line. This process is often referred to as “ovaling” where the reduction in the vertical diameter is similar to the increase in the horizontal diameter. When the culvert is surrounded by soil, the ovaling is restrained by the horizontal stiffness of the ground at the springline. Thus the culvert is being subjected to vertical compression forces due to the loading and horizontal compression forces due to the restraint provided by the soil – essentially, compression forces in the soil surround the culvert. Thus ring compression forces in the culvert wall become important and the stiffness of the culvert increases substantially.

As the depth of fill is increased further, both the soil adjacent to the pipe and the culvert deflect and the culvert must support its share of the applied loading as a ring compression load. The ring compression load due to the embankment (FG) is typically calculated from a relationship of the following form:

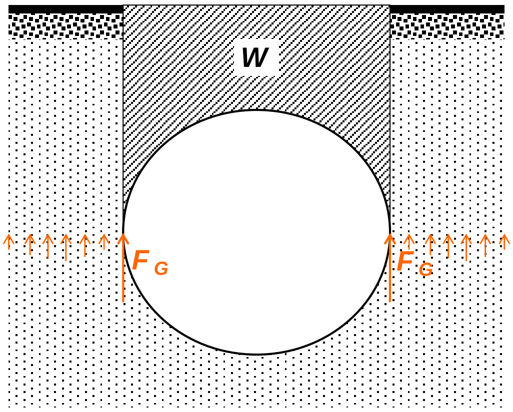
$$2F_G = KxW \text{ or} \qquad (1)$$

$$F_G = 0.5KxW \qquad (2)$$

where: *W* = the weight of the soil prism above the springline (3 and 9 o’clock) of the culvert (refer Figure 6), and

K = a constant dependent on the properties of the soil and the culvert.

Figure 6 - Soil prism (W) and ring compression force (F_G)



Vertical equilibrium indicates that the weight of the soil above the springline must be resisted by integral of the vertical soil pressures and $2F_G$. If there are no shear stresses along the vertical boundaries of W, then K = 1.0 and $F_G = 0.5W$.

Arguments abound over the appropriate value of K, with many arguing that K < 1 because the soil arches over the culvert, particularly for large depths of fill over the culvert. Terzaghi (AS/NZS 2566.1 Supplement 1) conducted experiments in the 1920s involving measuring the force exerted on the floor of a slot as it was lowered away from the soil above which showed that K < 1. This became known as the silo effect and can still be found in the Commentary to AS 2566.1.

Haggag (1989), whose research forms the basis of the current Canadian Bridge Design Codes provisions for the design of flexible metal culverts, states that the ring compression load depends on many parameters including:

1. The ratio of the hoop stiffness of the culvert to the stiffness of the soil
2. The flexural stiffness of the culvert and the stiffness of the soil support
3. The shape of the culvert
4. The ratio of the depth of fill to the diameter of the culvert
5. The quality of the backfill
6. The extent of the engineered backfill around the pipe
7. The stiffness of the foundation stratum below the culvert.

Haggag observes that the ring compression force generally exceeds the loading applied at the crown level (i.e., K > 1) – an observation at odds with the view that the soil arches over the culvert once the fill depth exceeds a certain level.

In the case of multiple barrel culverts there is little opportunity for arching and so K is unlikely to be less than 1.0.

Wheel loads are distributed through the soil as pressure. In the case of substantial fill depths, live loads can be considered as applying uniformly distrusted (p_Q) at the crown of the culvert and the ring compression forces due to the life load (F_Q) is estimated in a manner analogous to the calculation of F_G:

$$F_Q = 0.5Kxp_QxD \qquad (3)$$

For shallow fill depths, the culvert carries the entire wheel load and bending is induced in the culvert as well as the ring compression force.

How corrugated metal culverts fail

A failure of a corrugated metal culvert saw five people drown on 8th June 2007, when their car drove into a chasm on the Old Pacific Highway near Somersby, NSW, plunging into the floodwaters below. Investigators appointed to provide expert advice to the coroner concluded that *the cause of the collapse of the embankment above the culvert was the failure to adequately maintain the culvert* (MacMahon, 2008).

The expert's reporting to the Coroner in the case of the Old Pacific Highway failure *were in agreement as to the mechanism that resulted in the failure of the road. They described the process as follows* (MacMahon, 2008):

- *'The mechanism of collapse commenced with the abrasion/corrosion of the inverts of the corrugated steel pipes,*
- *Once the invert had been substantially perforated, the water flowing through the pipes began to wash soil out from around and beneath the pipes, causing voids around and eventually over the pipes,*
- *The ongoing loss of embankment fill material, as it was washed away by the flowing water through the culvert, progressively reduced the stability and integrity of the embankment,*
- *The progressive loss of embankment fill material and creation of voids caused subsidence to occur on the road surface above the pipes,*
- *The rain event on 8 June 2007 combined with the pre-existing instability and loss of integrity caused by the formation of the voids above and around the pipes resulted in the collapse of the embankment above the culvert and subsequent complete washout of the embankment fill material.*

This failure process highlights the following:

- The importance of ensuring that soil is not lost from behind the wall of any culvert, but in particular flexible culverts such as corrugated metal culverts that rely on the interaction with the soil to provide support, and
- That the loss of soil, even from around a small culvert, can result in a large eroded chasm with the potential for catastrophic consequences,
- That culverts of all sizes need to be managed, particularly those under large depths of fill.

While this failure was initiated by an abraded / corroded invert, there are also examples of corroding obverts where snap-through buckling is of concern, especially when the lost bending and axial strength from corrosion is combined with the bending effects induced because of low depths of fill over the culvert.

Examples of both of these deterioration mechanisms can be found in Queensland corrugated metal culverts. Figure 7 illustrates the more common corrosion and/or abrasion damage to inverts. Figure 8 and Figure 9 show examples of severe corrosion to the structurally critical upper half of the culvert.

Figure 7 - A deteriorated invert in a corrugated metal culvert showing substantial perforations

Figure 8 - A culvert exhibiting perforations due to corrosion to the upper portion of the culvert

Figure 9 - An aluminium culvert exhibiting local crushing due to corrosion of the upper portion of the culvert

Appendix B: Hydraulics & Manning's "n"

Introduction

This Appendix provides some information that may be of assistance in calculating the hydraulics performance of rehabilitated culverts. It highlights the most relevant portions the TMR *Road Drainage Manual* and provides some additional information pertaining to the hydraulic roughness of corrugated metal culverts.

General

Hydraulic considerations and environmental factors may dictate the viable solution options.

It is crucial that the hydraulics of the rehabilitated culvert is acceptable in order to guard against factors such as:

- the loss of embankments from overtopping
- unacceptable scour
- inundation
- abrasion / sedimentation
- ponding
- fish passage.

The following sections of the TMR *Road Drainage Manual* provide further advice regarding the hydraulic design of culverts:

- Chapter 2 General Design Requirements
- Chapter 3 Strategic Planning & Development Control
- Chapter 5 Hydrology
- Chapter 9 Culvert Design
- Chapter 13 Erosion and Sediment Control, and
- Chapter 14 Operation, Maintenance & Remediation.

Some additional information regarding the roughness of various different profiles of corrugated metal pipes is presented below.

In cases where advanced hydraulic analyses are required, advice should be sought from Structures Section.

Manning's "n" for Corrugated Metal Culverts

The Ministry of Transport Ontario "*MTO Gravity Pipe Design Guidelines – Circular Culverts and Storm Sewers*" (2005) provides information regarding Manning's "n" for different metal culvert and plastic pipes. A summary is presented in Table 11 and further details follow.

Table 11 - Manning Roughness Coefficients ('n') for Circular Pipe (Table C6, MTO Gravity Pipe Guidelines, September 2005)

Pipe Material Type	Manning Roughness Coefficients (Range)	Manning Roughness Coefficients (Default)
Concrete		
Precast pipe	0.011-0.013	0.012
Wood forms, rough	0.015 – 0.017	0.016
Wood forms, smooth	0.012 – 0.014	0.013
Steel forms	0.012 – 0.013	0.012
Steel Pipe		
Corrugated Steel Pipe		
68x13 mm helical		
Unpaved: 600 to 2000 mm diameter	0.016 – 0.021	Refer to Table C2
125x25mm helical		
Unpaved: 1200 to 3000 mm diameter	0.021 – 0.025	Refer to Table C2
Structural Steel Plate		
152x51mm corrugation (annular)		
Unpaved: 1500 - 3000 mm diameter	0.032 – 0.033	Refer to Table C2
Spiral Rib Steel Pipe		
19x19x190mm spiral rib		
Unpaved	0.012	0.012
High Density Polyethylene Pipe		
Smooth Inside Wall	0.011 – 0.013	0.012
Corrugated Inside Wall	0.017 - 0.024	Refer to Table C3
Polyvinyl Chloride – Smooth Inside Wall	0.011 – 0.013	0.012

Reference: Ministry of Transportation Ontario, "1997, "MTO Drainage Management Manual, Part 3", pg. 36 and Recommendations from CSP Manufacturer's.

Table 12 - Manning's "n" value for selected corrugated metal culvert profiles – page 1 of 2 (Table C2.0, MTO Gravity Pipe Guidelines, September 2005)

Nominal & Actual Inside Diameter[2](Avg.) (mm)	Corrugation (PitchxDepth)/ Profile (mm)	Manufacture Type[4]	Joint Type Available[6]	Manning 'n' Value	Available Thickness [1, 3] (mm)
150	38 x 6.5	H	CC, UC/F	0.012	1.3, 1.6
200	38 x 6.5	H	CC, UC/F	0.012	1.3, 1.6
250	38 x 6.5	H	CC, UC/F	0.012	1.3, 1.6
300	68 x 13	H	CC,UC G,F	0.013	1.6, 2.0
400	68 x 13	H	CC,UC G,F	0.014	1.6, 2.0
450	68 x 13	H	CC,UC G,F	0.014	1.6 – 2.8
	19 x 19 x 190	SR	SCC,G	0.012	1.6 – 2.0
500	68 x 13	H	CC,UC G,F	0.015	1.6 – 2.8
	19 x 19 x 190	SR	SCC,G	0.012	1.6, 2.0
525	19 x 19 x 190	SR	SCC,G	0.012	1.6, 2.0
600	68 x 13	H	CC,UC G,F	0.016	1.6 – 2.8
	19 x 19 x 190	SR	SCC,G	0.012	1.6 – 2.8
675	19 x 19 x 190	SR	SCC,G	0.012	1.6 – 2.8
700	68 x 13	H	CC,UC G,F	0.017	1.6 – 2.8
	19 x 19 x 190	SR	SCC,G	0.012	1.6 – 2.8
750	19 x 19 x 190	SR	SCC,G	0.012	1.6 – 2.8
800	68 x 13	H	CC,UC G,F	0.017	1.6 – 2.8
	19 x 19 x 190	SR	SCC,G	0.012	1.6 – 2.8
825	19 x 19 x 190	SR	SCC,G	0.012	1.6 – 2.8
900	68 x 13	H	CC,UC G,F	0.018	1.6 – 3.5
	19 x 19 x 190	SR	SCC,G	0.012	1.6 – 2.8
975	19 x 19 x 190	SR	SCC,G	0.012	1.6 – 2.8
1000	68 x 13	H	CC,UC G,F	0.019	1.6 – 4.2
	19 x 19 x 190	SR	SCC,G	0.012	1.6 – 2.8
1050	19 x 19 x 190	SR	SCC,G	0.012	1.6 – 2.8
1200	68 x 13	H	CC,UC G,F	0.020	2.0 – 4.2
	125 x 25	H	CC,UC G,F	0.021	2.0 – 3.5
	19 x 19 x 190	SR	SCC,G	0.012	2.0, 2.8
1350	19 x 19 x 190	SR	SCC,G	0.012	2.0, 2.8
1400	68 x 13	H	CC,UC G,F	0.021	2.8– 4.2
	125 x 25	H	CC,UC G,F	0.022	2.0 – 3.5
	19 x 19 x 190	SR	SCC,G	0.012	2.0, 2.8
1500	125 x 25	H	CC,UC G,F	0.022	2.0 – 3.5
	152 x 51	SPP	BS	0.033	3.0 – 7.0
	19 x 19 x 190	SR	SCC,G	0.012	2.0, 2.8

Page 1 of 2

Table 12 - Manning's "n" value for selected corrugated metal culvert profiles – page 2 of 2 (Table C2.0, MTO Gravity Pipe Guidelines, September 2005)

Nominal & Actual Inside Diameter[2](Avg.) (mm)	Corrugation (PitchxDepth)/ Profile (mm)	Manufacture Type[4]	Joint Type Available[5]	Manning 'n' Value	Available Thickness [1, 3] (mm)
1600	68 x 13	H	CC,UC G,F	0.021	2.8– 4.2
	125 x25	H	CC,UC G,F	0.023	2.0 – 3.5
	19 x 19 x 190	SR	SCC,G	0.012	2.0, 2.8
1660	152 x 51	SPP	BS	0.033	3.0 – 7.0
1800	68 x 13	H	CC,UC G,F	0.021	3.5-4.2
	125 x 25	H	CC,UC G,F	0.024	2.0 – 3.5
	19 x 19 x 190	SR	SCC,G	0.012	2.8
1810	152 x 51	SPP	BS	0.033	3.0 – 7.0
1970	152 x 51	SPP	BS	0.033	3.0 – 7.0
2000	68 x 13	H	CC,UC G,F	0.021	4.2
	125 x 25	H	CC,UC G,F	0.025	2.0 – 3.5
	19 x 19 x 190	SR	SCC,G	0.012	2.8
2120	152 x 51	SPP	BS	0.032	3.0 – 7.0
2200	125 x 25	H	CC, G,F	0.025	2.0 – 3.5
	19 x 19 x 190	SR	SCC,G	0.012	2.8
2280	152 x 51	SPP	BS	0.032	3.0 – 7.0
2400	125 x 25	H	CC, G,F	0.025	2.0 – 3.5
	19 x 19 x 190	SR	SCC,G	0.012	2.8
2430	152 x 51	SPP	BS	0.032	3.0 – 7.0
2590	152 x 51	SPP	BS	0.032	3.0 – 7.0
2600	19 x 19 x 190	SR	SCC,G	0.012	2.8
2700	125 x 25	H	CC, G,F	0.025	2.0 – 3.5
2740	152 x 51	SPP	BS	0.032	3.0 – 7.0
3000	125 x 25	H	CC, G,F	0.025	2.8– 3.5

Notes:

1. Outside Diameter Calculated to be Inside Diameter + Wall thickness + Corrugation Depth Wall Thickness
2. Custom diameters are available for relining of existing pipes.
3. Wall thickness Specified as 1.3, 1.6, 2.0, 2.8, 3.5 and 4.2 mm for CSP. For actual dimensions, wall thickness should be taken as 1.12, 1.40, 1.82, 2.64, 3.35, and 4.08 mm, respectively for CSP (CSPI, 2003). For SPP, wall thickness' for dimensioning should be taken to be 3, 4, 5, 6, and 7 mm.
4. Corrugation Profile Types: H = Helical, SR=Spiral Rib, SPP = Structural Plate Pipe
5. Joint Types (CSA G401-01): CC = Corrugated Coupler; UC = Universal Coupler, SCC = Semi Corrugated Coupler, BS = Bolted Seam, G = Gaskets, F = Filter Cloth. Special Couplers available for severe or unusual site conditions and relining.
6. Annular (Riveted) manufacture type may be supplied provided higher Manning 'n' value of 0.024 is used.
7. Materials and sizes listed in the table above were available at the time this manual was produced (April 2005). Designers should verify that the information and standards referenced in the table are still applicable, and the pipe types still available.

Reference: Corrugated Steel Pipe Institute, 2005 and CSA G401-01

Figure 10 - Equivalent pipe diameters (Figure B1, MTO Gravity Pipe Guidelines, September 2005)

MTO Gravity Pipe Design Guidelines September 2005

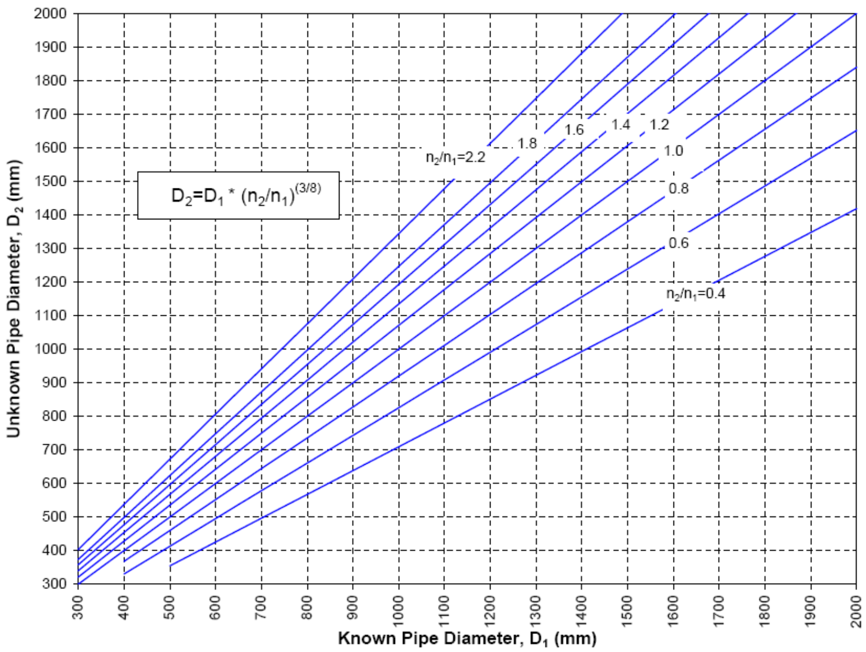


Figure B1 - Determination Of Equivalent Pipe Diameters Step-by-Step Design Procedure

Notes:
1. Figure based on Manning Equation assuming circular pipe, full flow conditions, constant slope, and constant total flow
2. Actual flow conditions may vary and warrant a more detailed analysis

Evaluation of the Manning roughness coefficients presented in Table 11 indicates that the flow capacity of a lined culvert flowing full generally exceeds the flow capacity of the host corrugated metal culvert flowing full. However, the associated increased velocities will increase the entry and exit losses, thereby reducing the flow capacity. Thus it is not possible to make any general statements regarding the flow capacity of SRP lined culverts compared with the original metal culvert. Such determinations can be made using the methods presented in the Drainage Design Manual.

Appendix C: Durability

Introduction

The rehabilitation of a culvert is a substantial investment. Thus it is important to rehabilitate in a manner that achieves a 100-year design life (refer Section 4.1).

While there may be sufficient hydraulic capacity to rehabilitate the culvert once by relining, it is unlikely that a second rehabilitation will be possible due to restrictions in the flow. Even concrete inverts can restrict the options and waterway area of the relined culvert.

Typically corrugated metal culverts are being rehabilitated because the corrosion / abrasion has lead to unacceptable risks should the culvert remain in service. It is therefore prudent to ensure that the rehabilitated culvert has adequate durability. A discussion of the durability of the primary options follows.

Structural concrete inverts

Concrete inverts have traditionally been used for two purposes. Firstly as abrasion protection for the invert and secondly as a structural replacement for a corroded / abraded invert.

Experience has shown that rehabilitating corroded inverts with structural concrete have a life of 5 to 20 years, as corrosion occurs at the junction between the concrete and the corrugated metal culvert.

In addition, the ring compression forces that prevents the culvert collapsing need to be transferred from the steel to the concrete in a manner that is consistent with the eccentricities involved. This structural connection between the steel and the concrete is difficult to achieve in a manner that does not compromise the durability of the culvert and that can be readily inspected.

Structural concrete inverts are emergency life extension projects rather than rehabilitation projects and are discouraged.

Reinforced concrete pipes

Conventionally reinforced concrete pipes are a standard product with a targeted design life of 100 years.

The durability design shall be in accordance with MRTS25 *Manufacture of Precast Concrete Pipes*.

Structural concrete linings

The durability design of cast-in-situ reinforced concrete shall be 100 years in accordance with MRTS70 *Concrete* and AS 5100.5. The minimum exposure classification shall be B2. In scenarios where the exposure classification is greater than B2, the support of Structures Section should be sought.

Lining a culvert with conventional cast-in-situ reinforced concrete is typically uneconomic because of the high cost of fixing the reinforcement and formwork within the culvert. Extremely large culverts are a possible exception.

In general, shot-crete liners are not recommended for culvert rehabilitation. The quality of the result is operator dependent and characterised by: rough uneven surfaces; variable density – low density near the surface tending towards higher densities at depth; “shadows” or voids behind the reinforcement; high permeability; and poor durability.

Corrugated metal culverts as liners

Rehabilitating a galvanised metal culvert by relining it with a galvanised metal culvert is not recommended.

Polymer precoated galvanised steel may be used in non-corrosive / normal / mildly corrosive conditions provided they satisfy the durability requirements of AS 2041.1. Table 13 is an extract from AS 2041.1 and provides some guidance for the selection of material types for buried corrugated metal structures. For further information refer to AS 2041.1.

Table 13 - Selection of material type for buried corrugated metal structures (AS/NZS 1041.1 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 ≥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.

Appendix D: Structural design and design curves of liners

This Appendix provides some additional information for the design of liners for the rehabilitation of culverts[12].

Corrugated metal liners

Design as if the culvert was a flexible steel culvert to AS/NZS 2041.1 *Buried corrugated metal structures Part 1: Design methods*.

The steel reinforcement is assumed to support the loads and the structural contribution of the relatively soft high-density polyethylene is neglected.

The steel used in polymer precoated galvanised corrugated metal culvert liners differs from that of standard galvanised metal culverts. A yield strength of the steel of 22.7.5 MPa is applicable (refer AS 2041.4 Table 3.3(A).

Geometry of polymer precoated galvanised corrugated metal liners to AS 2041.4

The section properties of polymer precoated galvanised corrugated metal culverts are presented in Table 18 (refer AS 2041.4 Table 3.3(B) to (E)). The profiles available in 2012 with the polymer precoating are shaded in Table 18.

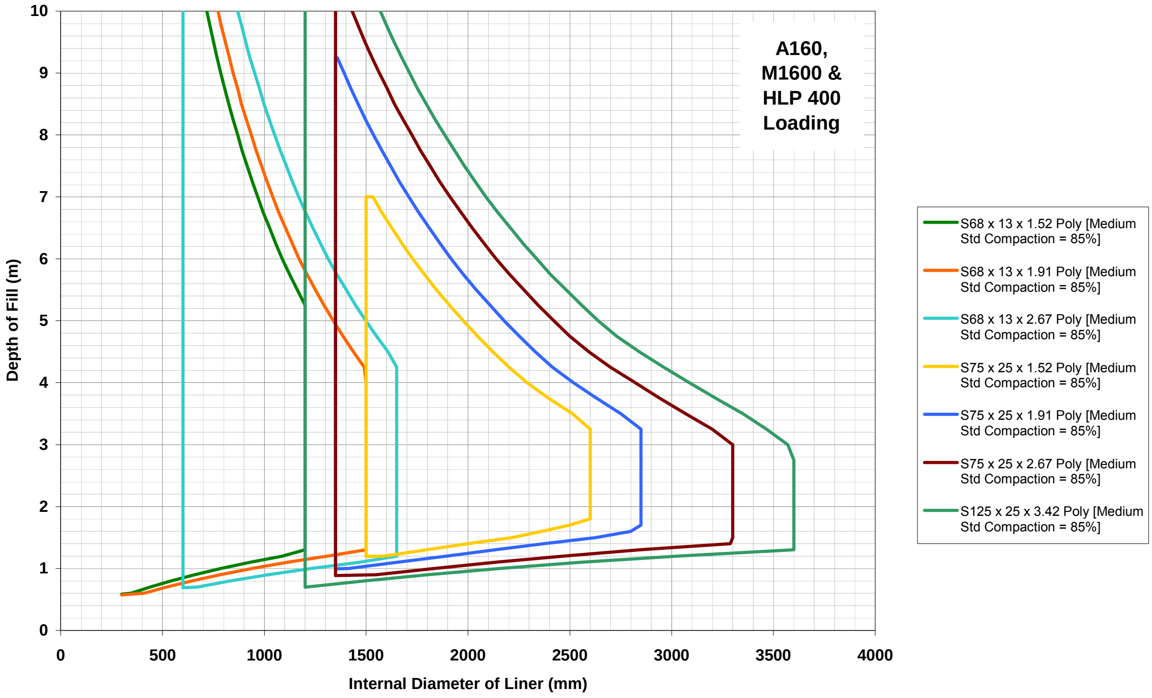
Table 14 - Section properties of corrugated metal liners

Profile	**Area**	**Second moment of area**	**Elastic section modulus**	**Radius of gyration**	**Plastic section modulus**	**Dist to centroid from inner face**	**Range of Available Diameters**	
	A	I	W_{el}	i	W_{pl}	d_c	IDMin	IDMax
	mm^2/mm	mm^4/mm	mm^3/mm	mm	mm^3/mm	mm	mm	mm
S38 x 6.5 x 0.92 Poly	0.974	4.11	1.13	2.05	1.76	3.25		
S38 x 6.5 x 1.22 Poly	1.3	5.5	1.45	2.06	2.36	3.25		
S38 x 6.5 x 1.52 Poly	1.62	6.88	1.75	2.06	2.95	3.25		
S68 x 13 x 1.22 Poly	1.32	24.66	3.54	4.32	5.06	6.5		
S68 x 13 x 1.52 Poly	1.65	30.77	4.33	4.32	6.31	6.5	300	1200
S68 x 13 x 1.91 Poly	2.06	38.65	5.29	4.33	7.93	6.5	300	1500
S68 x 13 x 2.67 Poly	2.88	54.41	7.08	4.35	11.18	6.5	600	1650
S68 x 13 x 3.42 Poly	3.7	70.33	8.72	4.36	14.48	6.5		
S68 x 13 x 4.18 Poly	4.52	86.53	10.25	4.37	17.87	6.5		
S75 x 25 x 1.52 Poly	1.89	141.92	10.54	8.66	14.51	12.5	1500	2600
S75 x 25 x 1.91 Poly	2.37	178.42	13.07	8.68	18.23	12.5	1350	2850
S75 x 25 x 2.67 Poly	3.31	251.65	17.93	8.71	25.65	12.5	1350	3300
S75 x 25 x 3.42 Poly	4.26	325.88	22.61	8.75	33.16	12.5		
S75 x 25 x 4.18 Poly	5.21	401.65	27.15	8.78	10.81	12.5		
S125 x 25 x 1.52 Poly	1.69	145.08	10.54	9.28	14.1	12.5		
S125 x 25 x 1.91 Poly	2.11	181.97	13.04	9.28	17.68	12.5		
S125 x 25 x 2.67 Poly	2.95	255.47	17.82	9.3	24.81	12.5		
S125 x 25 x 3.42 Poly	3.79	329.32	22.38	9.32	31.98	12.5	1200	3600
S125 x 25 x 4.18 Poly	4.64	404.03	26.77	9.34	39.24	12.5		

Figure 11 presents the results of a design calculation for the available profiles for sample parameters. Combinations of diameter and depth that lie within the curves are acceptable. The vertical line to the left is the minimum installation diameter.

[12] The design of rehabilitation liners is still under development and consequently the processes will change as experience increases and research continues.

Figure 11 - Design charts for polymer precoated corrugated metal culverts designed to AS 2041.1 (Medium soils to 85% standard compaction)



The Secant modulus of soil stiffness (Es) used in the calculation is derived from AS 2041.1:2011 Table 5.5.1(B) for the soil type under consideration (refer Table 15).

Table 15 - Secant Modulus of Soil Stiffness (Es) (AS 2041.1:2011 Table 5.5.1(B))

Soil type	Standard compaction	Vertical stress level (σ_v), kPa					
		7	35	70	140	280	420
1—Coarse	100	16.2	23.8	29.0	37.9	51.7	64.1
	95	13.8	17.9	20.7	23.8	29.3	34.5
	90	8.8	10.3	11.2	12.4	14.5	17.2
	85	3.2	3.6	3.9	4.5	5.7	6.9
2—Medium	95	9.8	11.5	12.2	13.0	14.4	16.4
	90	4.6	5.1	5.2	5.4	6.2	7.7
	85	2.5	2.7	2.8	3.0	3.5	4.8
3—Fine	95	3.7	4.3	4.8	5.1	5.6	6.2
	90	1.8	2.2	2.4	2.7	3.2	3.6
	85	0.9	1.2	1.4	1.6	2.0	2.4

NOTE: Type 3 soils are included in this Table for reference purposes only. Type 3 soils are not considered appropriate as select fill for buried corrugated metal structures (see AS/NZS 2041.2).

Precast concrete pipe liners

Design to *AS/NZS 3725 Design for installation of buried concrete pipes*, assuming that the loading scenario is consistent with pipe jacking scenario (refer *AS 3725 Cl 6.3.3.4 Jacked (thrust) or bores pipes condition*) and the live loads and load distribution are consistent with MRTS25 and AS 5100.2.

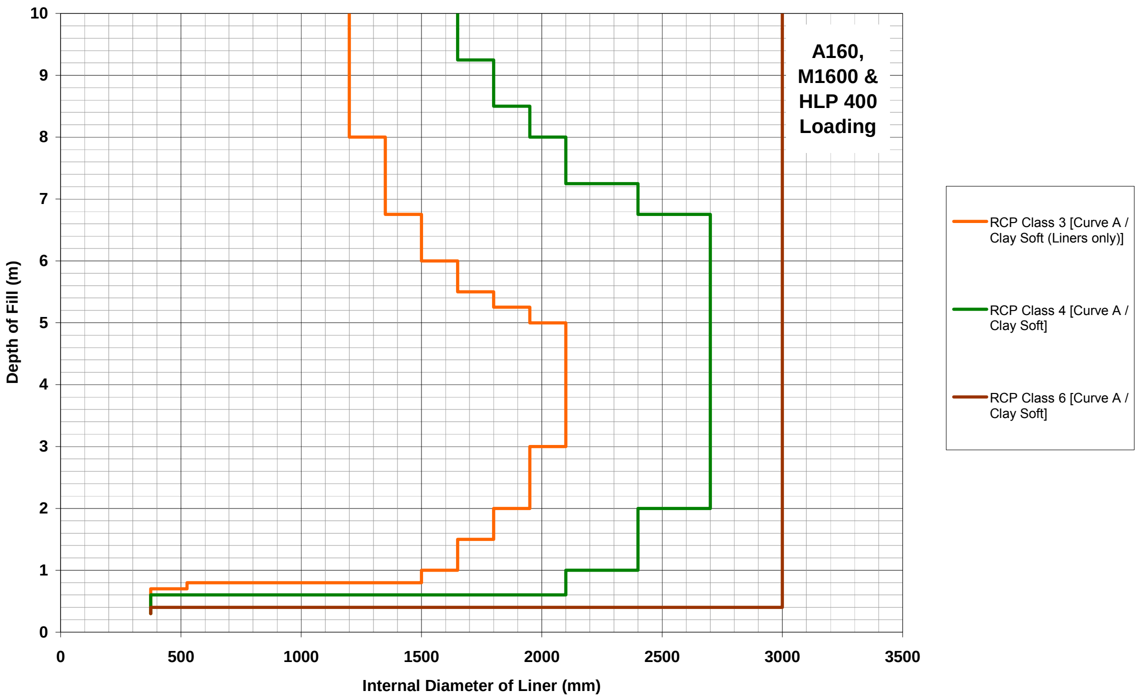
Note that the design charts presented in this report are NOT applicable to installations in trenches or prior to the construction of embankments. They are only applicable to the pipe jacking scenario where they are inserted through a competed stable embankment.

Figure 12 presents the results of a design calculation for the available profiles for sample parameters. Combinations of diameter and depth that lie to the left of the curves are acceptable.

Note that the advice from the pipe jacking industry is that Class 4 pipes are the minimum Class of reinforced concrete pipes that should be jacked through an embankment or around a culvert, although in certain circumstances it may be acceptable to jack Class 3 pipes as liners.

Figure 12 - Design charts for reinforced concrete pipes designed to AS 3725 (Curve A & soft clay) pipe jacking scenario.

Note: applicable only to single barrle culverts used in a pipe jacking scenario. The results are non-conservative for other scenarios such as multiple parallel pipe jacked pipes, pipes installed in trenches, or under embankments.



The soil parameter options available in AS 2725 are summarised in Table 16 and Table 17.

Table 16 - Type of soil (AS 3725:2007 Table 3)

Type of soil	Parameter c
Clay Soft	2
Clay Firm	15
Clay Stiff	50
Sand Very Loose	0
Sand Loose	5
Send Dense	15
Loam Saturated	5

Table 17 - Curve parameters (AS 3725:2007 Supplement Table C1)

Curve	$K\mu'$
Curve A = wet clay (cohesive soils)	0.11
Curve B = clayey sand (mildly cohesive soils)	0.15
Curve C = sand and gravel (cohesionless)	0.19

Structural inverts: Cast-in-situ reinforced concrete

Structural concrete inverts are not considered a rehabilitation strategy due to the limited life extension usually achieved, the questionable nature of the connections between the structural concrete and the corrugated metal culvert, and the inability to inspect the critical regions of the culvert. For those occasions where it is considered appropriate to use a structural invert to extend the life before rehabilitation or replacement the following information is provided.

This solution is only viable when it has been demonstrated by measurement that there is insignificant (say < 10%) loss in section in the areas that will not be strengthened by the structural invert.

The reinforcement shall satisfy the minimum requirements of AS 5100.6 for shrinkage, temperature and flexural reinforcement and be designed for a minimum exposure classification of B2.

The structural invert and its connection to the corrugated metal culvert shall resist 1.15N* and the minimum design actions on connections as set out in AS 5100.6 C12.3.1 where the ultimate ring compression force (N*) is determined as per AS 2041.1

The design shall consider the effects of eccentricities between the original culvert wall and the structural invert.

Regard structural reinforced concrete inverts as a life extension and not as a rehabilitation.

Cast-in-situ reinforced concrete liners

In circumstances such as large diameter corrugated metal culverts (or arches) or large depths of fill above the culvert, rehabilitation involving the construction of a structural concrete liner may be appropriate[13]. Cast-in-situ reinforced concrete liners are suitable for internal host diameters of 1500 mm to 4000 mm and depths of fill from 0.5 m to 10 m [14]. Wall thicknesses and steel reinforcing will change from culvert to culvert.

The cast-in-situ concrete liners are to be designed in accordance with Section 4.7.3 of this document.

Bracing and Grouting

Grouting of liners induces substantial pressures while the grout remains in its fluid state.

Liners may need to be braced before grouting and the grouting conducted in layers with each layer setting before subsequent layers are being added. The bracing system and grouting procedure shall be designed to:

a) Hold the Liner in place during grouting

b) Prevent floatation of the Liner during grouting

c) Ensure that the braced cross-section dimension of the assembled Liner prior to grouting shall not differ from the specified values by more than ±2% (to be confirmed)

d) Satisfy the strength limit state at all stages of grouting

e) Ensure that the final shape does not differ from the specified shape by more than ±2%

[13] Subject to successful outcomes of trials
[14] Larger diameters and greater depths of fill may be viable. Refer to Structures Section for advice.

This is usually the responsibility of the specialist contractor. It is particularly important for flexible liners, some of which can readily distort under grout pressures.

Section 4 provides the recommended pressures applied by the grout for the design of the liner and its bracing system.

Appendix E: Live load pressures

The average bearing pressure for various depths below the road surface (H) are presented in Table 18 and Figure 13 at serviceability limit state loads and in Table 19 and Figure 14 for ultimate limit state loads. These results include: dynamic load allowance, accompanying lane factors, load distribution and load factors in accordance with AS 5100.2.

The design pressures for 3 or more loaded lanes are less critical than two lanes loaded.

The HLP400 loading is critical for fill depths greater than 1.6 m at the serviceability limit state. The HLP400 loading is critical for fill depths greater than 2.5 m for the ultimate limit state.

Table 18 - Serviceability limit state live load pressure (kPa) versus depth of fill above the crown of the culvert (H)

H (m)	W80	A160 (1 Lane)	A160 (2 Lanes)	M1600 (1 Lane)	M1600 (2 Lanes)	SM1600 (1 & 2 Lanes)	HLP 400
0.6	**128.8**	**128.8**	104.3	102.1	83.0	**128.8**	89.0
0.7	**99.1**	**99.1**	85.3	78.5	67.8	**99.1**	72.8
0.8	**78.4**	**78.4**	71.2	62.1	56.6	**78.4**	60.7
0.9	**63.5**	**63.5**	60.3	50.4	48.0	**63.5**	51.5
1.0	**52.3**	**52.3**	51.7	41.9	41.5	**52.3**	44.4
1.2	37.0	37.0	**39.1**	33.4	35.2	**39.1**	34.0
1.4	27.4	27.4	**30.5**	27.2	30.2	**30.5**	26.9
1.6	21.0	21.9	24.3	23.5	**26.1**	**26.1**	24.2
1.8	16.5	18.0	19.8	20.7	**22.8**	22.8	**23.1**
2.0	13.2	15.0	16.3	18.3	**20.0**	20.0	**22.1**
2.5	8.7	10.8	12.0	14.6	**16.4**	16.4	**19.9**
3.0	6.1	8.1	9.4	12.0	**14.0**	14.0	**18.0**
3.5	4.6	6.3	7.6	10.3	**12.5**	12.5	**16.4**
4.0	3.5	5.1	6.3	9.1	**11.3**	11.3	**15.1**
4.5	2.8	4.2	5.3	8.1	**10.3**	10.3	**13.9**
5.0	2.3	3.5	4.5	7.2	**9.4**	9.4	**12.8**
6.0	1.6	2.5	3.4	5.9	**7.9**	7.9	**11.1**
7.0	1.2	1.9	2.7	5.0	**7.0**	7.0	**9.7**
8.0	0.9	1.5	2.2	4.4	**6.2**	6.2	**8.6**
9.0	0.7	1.2	1.8	3.9	**5.6**	5.6	**7.7**
10.0	0.6	1.0	1.5	3.4	**5.1**	5.1	**6.9**
12.0	0.4	0.7	1.1	2.8	**4.2**	4.2	**5.7**
14.0	0.3	0.5	0.8	2.3	**3.6**	3.6	**4.7**
16.0	0.2	0.4	0.7	2.0	**3.1**	3.1	**4.0**
18.0	0.2	0.3	0.5	1.7	**2.7**	2.7	**3.5**
20.0	0.2	0.3	0.4	1.5	**2.4**	2.4	**3.0**

Figure 13 - Serviceability limit state live load pressure versus depth of fill above the crown of the culvert

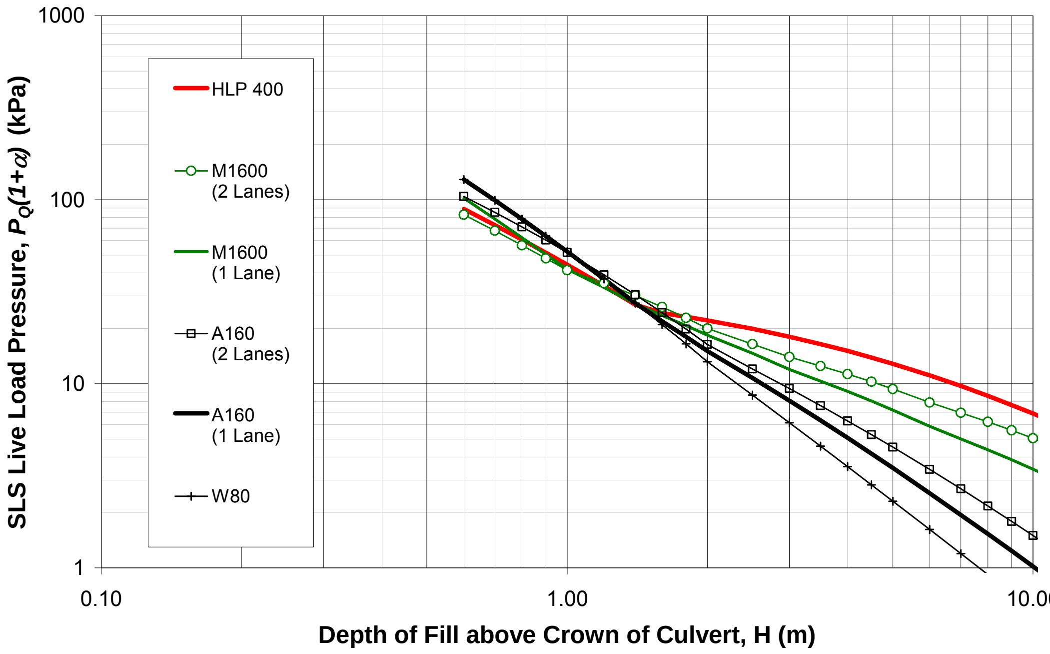
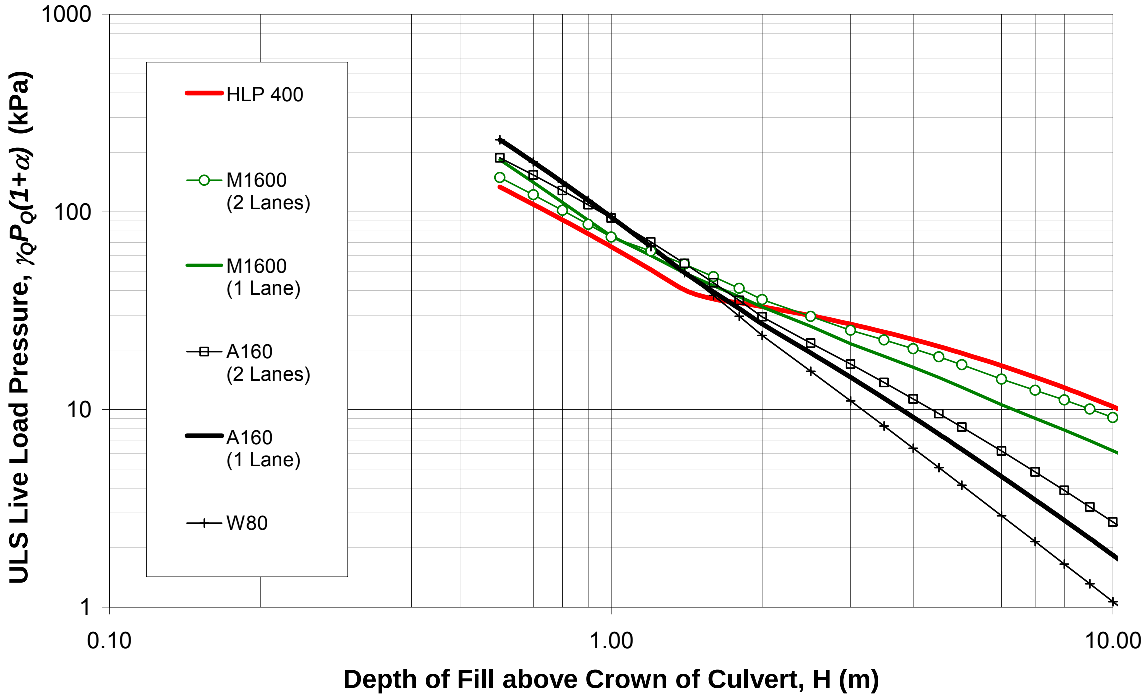


Table 19 - Ultimate limit state live load pressure (kPa) versus depth of fill above the crown of the culvert (H)

H (m)	W80	A160 (1 Lane)	A160 (2 Lanes)	M1600 (1 Lane)	M1600 (2 Lanes)	SM1600 (1 & 2 Lanes)	HLP 400
0.6	**231.9**	**231.9**	187.7	183.8	149.3	**231.9**	133.5
0.7	**178.4**	**178.4**	153.6	141.2	122.0	**178.4**	109.1
0.8	**141.2**	**141.2**	128.1	111.8	101.8	**141.2**	91.1
0.9	**114.2**	**114.2**	108.5	90.7	86.4	**114.2**	77.3
1.0	**94.1**	**94.1**	93.0	75.4	74.6	**94.1**	66.5
1.2	66.7	66.7	**70.4**	60.1	63.4	**70.4**	50.9
1.4	49.3	49.3	**54.9**	49.0	54.3	**54.9**	40.3
1.6	37.7	39.4	43.8	42.3	**47.0**	**47.0**	36.3
1.8	29.6	32.4	35.6	37.3	**41.0**	**41.0**	34.6
2.0	23.7	27.1	29.4	33.0	**36.0**	**36.0**	33.1
2.5	15.6	19.4	21.7	26.3	**29.6**	29.6	**29.8**
3.0	11.1	14.6	17.0	21.5	**25.2**	25.2	**27.0**
3.5	8.2	11.4	13.7	18.6	**22.5**	22.5	**24.7**
4.0	6.4	9.1	11.3	16.3	**20.3**	20.3	**22.6**
4.5	5.1	7.5	9.5	14.5	**18.5**	18.5	**20.8**
5.0	4.1	6.3	8.1	13.0	**16.9**	16.9	**19.3**
6.0	2.9	4.6	6.2	10.6	**14.2**	14.2	**16.7**
7.0	2.1	3.5	4.8	9.0	**12.5**	12.5	**14.6**
8.0	1.7	2.8	3.9	7.9	**11.2**	11.2	**12.9**
9.0	1.3	2.2	3.2	6.9	**10.1**	10.1	**11.5**
10.0	1.1	1.8	2.7	6.2	**9.1**	9.1	**10.3**
12.0	0.7	1.3	2.0	5.0	**7.6**	7.6	**8.5**
14.0	0.5	1.0	1.5	4.2	**6.4**	6.4	**7.1**
16.0	0.4	0.8	1.2	3.5	**5.5**	5.5	**6.1**
18.0	0.3	0.6	1.0	3.0	**4.8**	4.8	**5.2**
20.0	0.3	0.5	0.8	2.7	**4.3**	4.3	**4.6**

Figure 14 - Ultimate limit state live load pressure versus depth of fill above the crown of the culvert



Appendix F: Live load ring compression forces and working load on culvert

Ring compression force

The ring compression force for various depths of fill and culvert diameters is presented in Table 20 and Figure 15.

The ring compression forces make no allowance for arching (positive or negative) and are the maximum ultimate ring compression force for W80, A160, M1600 and HLP 400 loads. The loads also include the dynamic load allowance, accompanying lane factors, one and two lanes and load factors, with the maximum ring compression force being presented. The loads are distributed through the soil as per the AS 5100 truncated prism method.

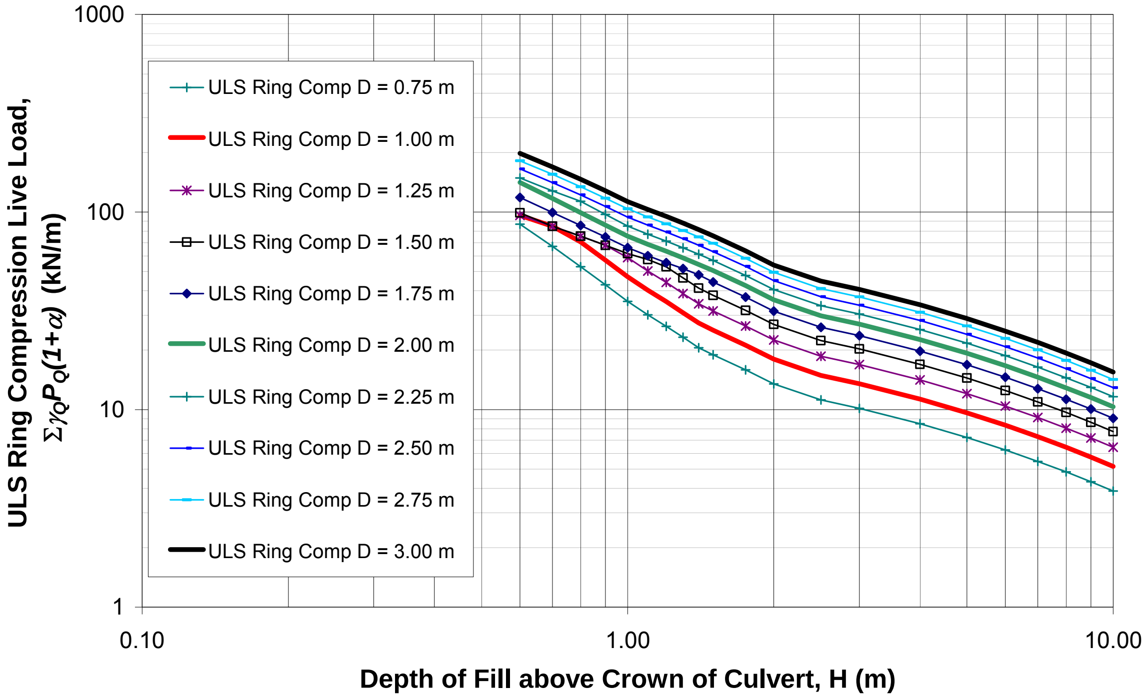
In the case where the fill depth is shallow and the culvert diameter is large, more than one axle can apply load to the culvert and the ring compression force is less than would be calculated by simply multiplying the pressure by the diameter/2. This effect is also incorporated. The ring compression force is assumed to be uniformly distributed over the length of the truncated load distribution prism.

This data is useful in the design of buried flexible culverts.

Table 20 - Ultimate limit state ring compression force (kN/m) versus the depth of fill above the crown of the culvert (H) for selected culvert diameters for W80, A160, M1600 and HLP 400 loads.

H (m)	ULS Ring Comp D = 0.75 m	ULS Ring Comp D = 1.00 m	ULS Ring Comp D = 1.25 m	ULS Ring Comp D = 1.50 m	ULS Ring Comp D = 1.75 m	ULS Ring Comp D = 2.00 m	ULS Ring Comp D = 2.25 m	ULS Ring Comp D = 2.50 m	ULS Ring Comp D = 2.75 m	ULS Ring Comp D = 3.00 m
0.60	87.0	96.2	96.2	99.1	118.5	141.5	148.7	165.2	181.7	198.2
0.70	66.9	84.8	84.8	84.8	99.5	117.1	127.9	141.1	155.2	169.3
0.80	52.9	70.6	75.5	75.5	85.5	99.4	113.3	122.1	134.3	146.5
0.90	42.8	57.1	68.0	68.0	74.8	85.9	97.2	106.8	117.5	128.1
1.00	35.3	47.1	58.8	61.6	66.0	75.4	84.8	94.3	103.7	113.1
1.10	30.2	40.3	50.3	57.6	60.1	68.7	77.3	85.8	94.4	103.0
1.20	26.4	35.2	44.0	52.8	55.4	63.4	71.3	79.2	87.1	95.0
1.30	23.2	31.0	38.7	46.4	51.7	58.6	65.9	73.3	80.6	87.9
1.40	20.6	27.4	34.3	41.2	48.0	54.3	61.1	67.9	74.7	81.5
1.50	18.9	25.3	31.6	37.9	44.2	50.5	56.8	63.1	69.4	75.8
1.75	15.9	21.2	26.5	31.8	37.1	42.4	47.7	53.0	58.3	63.6
2.00	13.5	18.0	22.5	27.0	31.5	36.0	40.5	45.0	49.5	54.0
2.50	11.2	14.9	18.6	22.4	26.1	29.8	33.6	37.3	41.0	44.7
3.00	10.1	13.5	16.9	20.3	23.7	27.0	30.4	33.8	37.2	40.6
4.00	8.5	11.3	14.1	17.0	19.8	22.6	25.4	28.3	31.1	33.9
5.00	7.2	9.6	12.0	14.5	16.9	19.3	21.7	24.1	26.5	28.9
6.00	6.2	8.3	10.4	12.5	14.6	16.7	18.7	20.8	22.9	25.0
7.00	5.5	7.3	9.1	10.9	12.8	14.6	16.4	18.2	20.1	21.9
8.00	4.8	6.4	8.1	9.7	11.3	12.9	14.5	16.1	17.7	19.3
9.00	4.3	5.7	7.2	8.6	10.1	11.5	12.9	14.4	15.8	17.2
10.00	3.9	5.2	6.5	7.7	9.0	10.3	11.6	12.9	14.2	15.5

Figure 15 - Ultimate limit state ring compression force versus the depth of fill above the crown of the culvert for selected culvert diameters for W80, A160, M1600 and HLP400 loads.



Working load on culvert

The working load on the culvert due to live load (W_q) for various depths of fill and culvert diameters is presented in Table 21and Figure 16 where Wq is as defined in AS 3725 Design for installation of buried concrete pipes.

The maximum working load on the culvert due to live load is presented for W80, A160, M1600 and HLP 400 loads. The loads also include the dynamic load allowance, accompanying lane factors, one and two lanes and load factors. The loads are distributed through the soil as per the AS 5100 truncated prism method (not AS 3725).

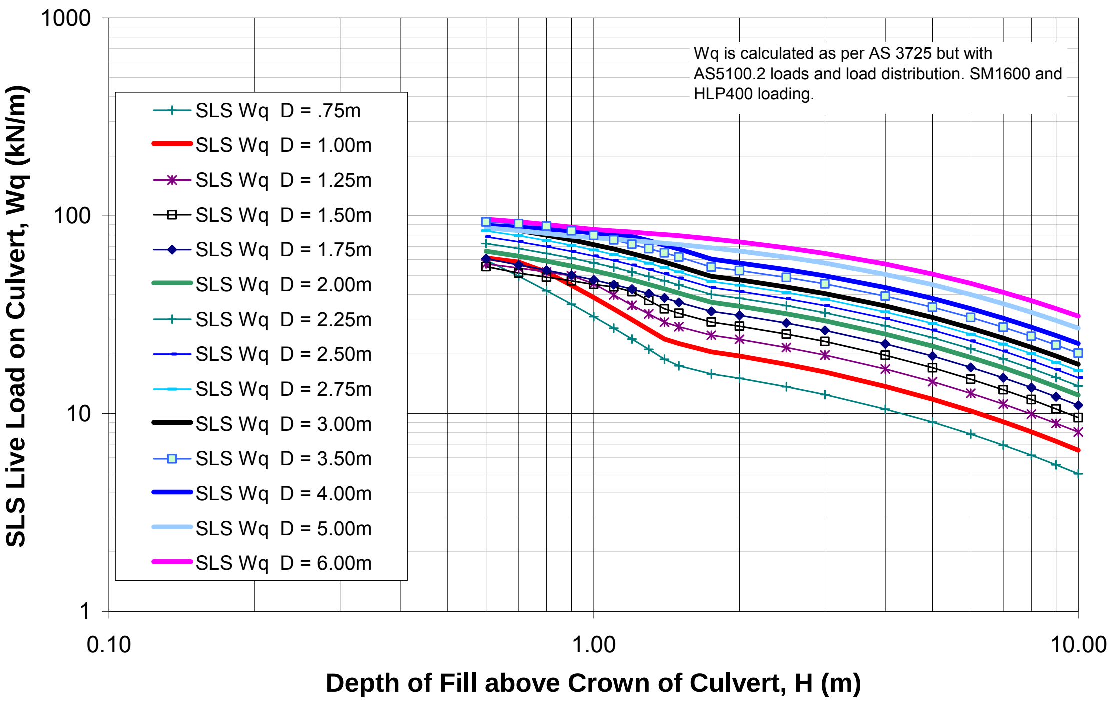
In the case where the fill depth is shallow and the culvert diameter is large, more than one axle can apply load to the culvert and the ring compression force is less than would be calculated by simply multiplying the pressure by the diameter. This effect is also incorporated. The working load (W_q) is assumed to be uniformly distributed over the length of the truncated load distribution prism continued to a depth of 0.75 times the diameter of the culvert. For further information refer AS 3725 Figure 10.

This data is useful in the design of reinforced concrete pipe liners and cast-in-situ reinforced concrete liners.

Table 21 - Serviceability limit state working load on culvert due to live load (W_q) versus the depth of fill above the crown of the culvert (H) for selected culvert diameters for W80, A160, M1600 and HLP 400 loads.

H (m)	SLS Wq D = .75m	SLS Wq D = 1.00m	SLS Wq D = 1.25m	SLS Wq D = 1.50m	SLS Wq D = 1.75m	SLS Wq D = 2.00m	SLS Wq D = 2.25m	SLS Wq D = 2.50m	SLS Wq D = 2.75m	SLS Wq D = 3.00m	SLS Wq D = 3.50m	SLS Wq D = 4.00m	SLS Wq D = 5.00m	SLS Wq D = 6.00m
0.60	59.7	61.2	57.1	55.3	60.7	66.2	72.4	78.3	83.9	89.2	93.13	89.5	86.9	96.2
0.70	49.5	58.3	54.4	51.3	56.3	62.4	68.3	73.9	79.2	84.2	91.05	87.5	84.1	93.2
0.80	41.7	51.9	52.0	48.9	53.0	58.9	64.5	69.8	74.9	79.6	88.55	85.6	81.4	90.3
0.90	35.7	44.5	49.7	46.8	50.1	55.7	61.0	66.0	70.8	75.4	83.87	83.8	78.8	87.5
1.00	30.9	38.6	45.4	44.9	47.4	52.7	57.8	62.6	67.1	71.5	79.54	82.0	77.4	85.2
1.10	27.0	33.8	39.8	43.7	44.9	49.9	54.7	59.3	63.7	67.8	75.50	80.2	76.1	84.0
1.20	23.8	29.8	35.3	41.2	42.5	47.4	51.9	56.3	60.4	64.4	71.75	78.5	74.9	82.7
1.30	21.1	26.5	31.9	37.2	40.4	45.0	49.3	53.5	57.4	61.2	68.24	74.7	73.8	81.5
1.40	18.8	23.8	29.0	33.8	38.4	42.7	46.9	50.8	54.6	58.2	64.96	71.1	72.6	80.3
1.50	17.4	22.6	27.4	32.1	36.5	40.6	44.6	48.4	52.0	55.4	61.89	67.8	71.5	79.1
1.75	15.9	20.5	24.9	29.0	32.9	36.5	40.0	43.3	46.4	49.4	55.02	60.3	68.8	76.3
2.00	15.1	19.5	23.7	27.6	31.4	34.9	38.3	41.4	44.5	47.4	52.75	57.7	66.3	73.7
2.50	13.7	17.7	21.6	25.2	28.7	32.0	35.1	38.1	40.9	43.7	48.74	53.4	61.7	68.8
3.00	12.5	16.2	19.7	23.1	26.3	29.4	32.3	35.1	37.8	40.4	45.21	49.7	57.6	64.5
4.00	10.5	13.7	16.8	19.7	22.5	25.2	27.8	30.3	32.6	34.9	39.27	43.3	50.6	56.9
5.00	9.0	11.8	14.5	17.0	19.5	21.9	24.2	26.4	28.5	30.6	34.48	38.1	44.8	50.7
6.00	7.9	10.3	12.7	14.9	17.1	19.2	21.3	23.2	25.2	27.0	30.56	33.9	40.0	45.4
7.00	6.9	9.1	11.2	13.2	15.1	17.0	18.9	20.7	22.4	24.1	27.30	30.3	35.9	41.0
8.00	6.2	8.1	9.9	11.8	13.5	15.2	16.9	18.5	20.1	21.6	24.55	27.3	32.5	37.2
9.00	5.5	7.2	8.9	10.6	12.2	13.7	15.2	16.7	18.1	19.5	22.22	24.8	29.6	33.9
10.00	5.0	6.5	8.1	9.5	11.0	12.4	13.8	15.1	16.4	17.7	20.21	22.6	27.0	31.1

Figure 16 - Serviceability limit state working load on culvert due to live load (W_q) versus the depth of fill above the crown of the culvert (H) for selected culvert diameters for W80, A160, M1600 and HLP 400 loads.



Appendix G: Corrugated metal culvert rehabilitation suppliers

The contractors listed in Table 22 supply specialist culvert rehabilitation services. Their details are provided for information only. Their inclusion on the listing does not imply approval of the contractor will be granted for a particular project.

Table 22 - Listing of specialist culvert rehabilitation contractors.

System	Product name	Contractor
Replacement by auger boring, micro tunnelling, and pipe jacking		Tunnel Boring Australia Pty Ltd Unit 5, 53-57 Link Drive Yatala, Qld 4207 **t** 07 3801 8813 **e** mail@tunnelboring.com.au **w** www.tunnelboring.com.au
		Tunnelcorp Pty Ltd Unit 35, 28 Burnside Rd Yatala, Qld 4207 **t** 1300 886 635 **e** contact@tunnelcorp.com.au **w** www.tunnelcorp.com.au
Polymer precoated galvanised flexible metal culverts	Trenchcoat	Atlantic Civil Products Pty Ltd 13 Industrial Ave, Bohle, Qld, 4818 **t** 4789 6700 **e** mrushbrook@atlanticcivil.com.au **w** www.atlanticcivil.com.au
Cast-in-situ reinforced concrete liners	Tunneline	Trenchless ITS 4/8 Shannon Place Virginia, QLD, 4014 **t** (07) 3865 6100 **e** iank@itst.com.au **w** http://www.itstrenchless.com.au/

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