Rehabilitation Guideline for Corrugated Steel Culverts

This guide is intended as a useful technical resource for asset managers and project managers.

It is not intended as a lookup manual providing specific solutions for the rehabilitation of culverts, which would replace the RTA's usual procedures for project development

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About this release

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Any errors, omissions, comments or suggestions should be submitted to the Roads and Traffic Authority for possible inclusion in a future issue.

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1 INTRODUCTION

Corrugated steel culvert structures are sometimes used on the NSW road network as drainage culverts or underpasses for roads, pedestrians and animals.

These road assets are managed throughout their service lives in order to provide the community with the required level of service at the minimum whole of life cost. These assets will therefore be subject to a range of maintenance work across their service lives, from minor or routine maintenance works to control deterioration and achieve the expected service life, to much more significant works which rehabilitate or replace the existing asset.

Culvert rehabilitation usually takes place when the condition of the culvert has deteriorated to the point that its ongoing asset performance becomes uncertain or unpredictable. Rehabilitation work improves the culvert condition and extends its remaining service life, while replacement completely renews the culvert's asset condition and allows improvements to be made, such as increased capacity to reduce flow velocities.

Asset managers consider the life cycle maintenance needs for assets, and then determine the scope of maintenance work and supporting financial resources required from time to time, to limit the potential risk of service disruption for road users.

This guide focuses on rehabilitation and/or replacement of corrugated steel culverts, rather than minor maintenance works.

The purpose of the guide is to:

- Provide a useful resource for asset managers and project managers concerned with the maintenance of corrugated steel culverts.
- Increase the knowledge of current rehabilitation techniques.
- Provide information on investigation, design, construction, operation and safety issues to facilitate assessment and selection of appropriate solutions.
- Ensure maintenance works meet RTA requirements for asset and project management, and relevant statutory requirements.
- Outline RTA requirements for developing and managing culvert projects.

In particular, this guide provides advice on current rehabilitation technologies for assessing and developing culvert projects, with the objective of:

- Achieving required level of service.
- Minimising whole of life maintenance effort, given available funding.
- Achieving lower cost and more cost effective solutions.
- Protecting the environment and addressing environmental planning requirements.
- Complying with occupational health and safety requirements.

2 PERFORMANCE CONSIDERATIONS

Corrugated steel culverts are part of the road structure and are critical to the ongoing level of service expected of the road. The asset manager will determine the performance required of the culvert, considering the level of service expected of the road. The culvert performance requirements cover:

- Catchment hydrology and hydraulic capacity
- Structural capacity and integrity
- Public safety and OHS requirements
- Environmental needs.

This guide assumes that regular inspections of the culvert and routine maintenance have been carried out, but that the culvert's condition has deteriorated to the point that rehabilitation is necessary to ensure it continues to meet its performance requirements.

Most corrugated steel culverts are used as drainage structures. Other uses such as road, pedestrian and stock underpasses may have the secondary function of carrying stormwater.

Key performance considerations include water flow at the culvert, hydraulic capacity and structural condition of the culvert, as well as the condition of the embankment surrounding the culvert. Hence, the condition of existing culverts and proposed rehabilitation works need to be verified by engineers or staff with knowledge and experience in hydrology, hydraulics, structures and geotechnics. For example, insufficient hydraulic capacity could pose unacceptable risks, which may require culvert augmentation or significant open channel protection works particularly at the culvert outlet.

The information below has been provided primarily for use by asset managers and project managers. More detailed advice regarding catchment hydrology, culvert hydraulics, culvert structures and other considerations for the engineering design of corrugated steel culverts is contained in the Appendix B.

2.1 Premature Failure of Corrugated Steel Culverts

Culverts may fail before their expected service lives have been achieved for a variety of reasons including:

- Incorrect installation, comprising damage to the pipe, unsuitable backfilling and construction equipment, and insufficient protection against erosion of backfilling
- Installation in inappropriate site conditions, resulting in erosion of the invert, corrosion of the pipe and loss of backfilling support

There are three primary failure mechanisms:

1. Erosion of the backfilling by piping without corrosion of the steel
2. Erosion of the backfilling by piping from a corroded section of steel pipe, and

3. Corrosion of the metal pipe, such that it loses its structural integrity, followed by collapse of the steel culvert and the resulting loss of backfill support leads to collapse of the embankment.

2.2 Catchment hydrology and culvert implications

Culverts should be able to carry the design water flow without adverse community or environmental effects upstream or downstream. The probable consequences of a flood exceeding the design flow must be considered, including the risk of loss of life. The likely damage to the culvert and the road in extreme events must also be evaluated.

The impact of property development on catchment flows at culvert sites should be considered. Property development in the culvert catchment can increase the peak water flow at the culvert site, or if on site detention of stormwater has been provided there may be a small increase in peak flow but a considerable increase in the duration of the flow. In either case, abrasion of the culvert will occur.

A further matter of concern will be the route followed by flows, which are in excess of the culvert capacity. High flows will usually cross the road at or near the culvert location resulting in concerns about embankment erosion, pavement damage and safety. In some cases these flows may be diverted to an adjacent catchment. The potential impact on the second catchment must be considered very carefully.

The amount of groundwater flow that enters the stream and passes through the culvert should also be considered as:

- The culvert may be wet for considerable periods of time which could hasten the deterioration of some pipe materials and protective coating systems, particularly at the wet/dry line.
- A continuing water flow through the culvert could influence the choice of a rehabilitation technique.
- The watercourse could contain an aquatic fauna habitat to be preserved with provisions to assist fauna passage through the culvert.

The quality of surface and groundwater must be assessed due to the potential of the water to cause rapid deterioration of the pipe or pipe coatings. In particular, water which is in contact with acid sulphate soils, potential acid generating materials and saline areas has the potential to attack pipe materials, including steel and concrete.

Water flows which carry significant amounts of sand, gravel or rocks may erode the culvert wall, particularly around the invert.

Accordingly, watercourses and soils should be tested to establish the pH, resistivity and salt content of the water at a culvert to be rehabilitated, and the likelihood of significant amounts sand, gravel or rock in higher stream flows should be assessed.

2.3 Hydraulic performance of culverts

Corrugated steel culverts are usually circular in section but other shapes such as ovals and arches are used, and many include several pipes side by side. Culverts under divided roads with a depressed median will often include a pit or pipe junction to accept flows from the median.

The flow capacity of a culvert is related to the upstream and/or downstream water levels, the stream geometry, the culvert cross section, material, longitudinal slope and entry shape

The capacity of an existing culvert may often be improved by altering the entry conditions, including concrete lining of the invert area.

However liners inserted in the pipe usually reduce the available cross sectional area and despite the higher velocities due to the reduced friction of the liner, entry losses will increase and some increase in upstream water levels can be expected.

Other factors to be addressed in the hydraulic design of culverts include the inlet and outlet velocities. Inlet velocities affect the sizes of particles (silt, sand, rock), which may be drawn into the culvert and the exit velocity may cause erosion at the outlet. The use of a liner may increase the outlet velocity significantly requiring the installation of an appropriate energy dissipater.

The possibility of blockages should also be considered in culvert design. The important factors affecting the likelihood of blockages include types of materials which could enter the floodwater upstream of the culvert and the size of the culvert. Vegetation, soils and litter are common causes of blockage. An allowance for blockage, which reduces flow by between 20 per cent and 50 per cent of the design value, is sometimes suggested but it is recommended that each case be treated on its merits. Most blockages occur at the culvert entry and trash racks may assist provided they are regularly cleared of accumulated debris to prevent the debris from increasing upstream water levels or washing of the debris into the culvert.

Blockages will raise the upstream water level and may prolong the time taken for the flood waters to pass. Both these factors will increase the severity of any soil erosion in the embankment.

2.4 Structural performance

Given that corrugated steel culverts are flexible structures, the support of the surrounding soils is a major contributor to their ability to carry loads. Accordingly, they should be viewed as a system where the type and state of the soil around the structure is of similar importance to the state of the wall. In some cases rehabilitation of the surrounding soil may be the only work required to restore a culvert to a satisfactory condition.

For corrugated steel culverts the loads, stresses and deformations in the radial and circumferential directions are the only ones normally considered. The corrugations allow the culvert to accommodate small deformations in the longitudinal direction without distress. Corrugated steel culverts are sometimes installed with a pre-camber to accommodate differential consolidation of the embankment. Nevertheless, excessive deformation, particularly when concentrated over a short length, can cause distress of the wall.

The load on a culvert through an embankment is not significantly affected by traffic once the cover exceeds about 5 metres.

Where plastic pipe or pipe liners are used the stability of the plastic material under ultraviolet light must be considered at headwalls and pits. The risks of a chemical spill or fire in terms of the structural performance of the new pipe must also be evaluated. The hydraulic and structural requirements where liners are joined to headwalls or the inside of another pipe need consideration.

The head loss at the entry to a culvert gives rise to uplift (buoyancy) forces in this area. Corrugated steel culverts have failed by bending upwards at the entrance and liners may be prone to the same problem.

2.4.1 Culvert structures

The head of water, which causes the water to flow through the pipe, is also applied to the embankment. This can result in the erosion of material around the pipe, usually commencing at the downstream end and progressing upstream ("piping") but holes in the pipe wall can lead to voids in their vicinity. Piping commences with the loss of finer soils and, as this assists water flow in the area, the process can rapidly accelerate and carry away larger and larger particles. These voids can extend upwards as the roof material collapses and the void may thus reach the surface above.

Headwalls and bulkheads can assist in preventing loss of material but rigid concrete bulkheads must be used with caution because they cause local loss of flexibility of the pipe. A **bulkhead** is a wall across a pipe trench, extending into the trench walls to increase the length of the groundwater flow path and hence decrease the flow velocity in the pipe embedment material. Bulkheads are also referred to as seepage or cut-off collars, trench plugs, trench stops and anchors.

The head of water and the duration of flow through the embankment will be increased by culvert blockages.

Multi-cell culverts present particular problems because the length of embankment subject to possible piping is increased. Another factor is that the collapse of one cell will remove much of the side support to the adjacent conduits and can precipitate progressive collapse.

The loss of soil at a culvert may eventually lead to pavement damage and damage to the embankment. Ultimately a partial collapse of the embankment may occur, probably during heavy rain or flood.

Deterioration of corrugated steel culvert walls is usually a result of corrosion or erosion of the invert area by sand, gravel or rock particles carried by the water. Silt movements, either as a result of loss of the surrounding soil or otherwise, also damage these culverts.

To protect corrugated steel culvert inverts from erosion it is common practice to provide a concrete lining to the bottom portion of the pipe circumference. Application of the concrete is usually by spraying. Unless the concrete is mechanically fastened to the pipe, the concrete relies on its weight to remain in place. Instances of the loss or displacement of this concrete lining have been identified. The damage is often in the downstream portion of the culvert. It is possible that hydrostatic pressures in the surrounding soil, penetrating through holes in the pipe invert, have assisted to lift the lining.

2.4.2 Underpasses

Underpasses are paved to assist passage by vehicles, pedestrians and animals. Arch types of corrugated steel culverts are supported on concrete footings, which may or may not be visible above the pavement. Movement or failure of the footings is a possible defect in arch systems used for underpasses or culverts.

2.4.3 Rehabilitation

Rehabilitation of corrugated steel culverts must be designed to carry the imposed loads without relying on badly deteriorated pipe sections to carry any of the loads. Also, sections expected to use up their remaining service life within the life span of the rehabilitation design, cannot be expected to contribute to the load capacity of the culvert.

2.5 Public safety

Safety concerns for corrugated steel culverts are generally common to all culvert and underpass structures. These include:

- The hazard of vehicles running off the road and hitting a headwall or culvert.
- Safety of pavements damaged by subsidence over a culvert.
- The impaired function of safety barriers damaged by subsidence.
- Risks to authorised or unauthorised pedestrians using a culvert or underpass, such as drops or barriers at culvert outlets.
- The possibility of collapse of the culvert and/or the embankment and the implications for road users and people downstream and properties.
- Hazards to road users when a flood overtops the embankment.

2.6 Occupational health and safety

Personnel working on the rehabilitation of corrugated steel culverts will be exposed to a variety of hazardous conditions. These include the risks involved in working close to traffic, steep access routes, exposure to contaminated materials and risks as a result of being in confined spaces.

Prior to entering a culvert the requirements of the RTA OH&S Policy Manual No. 2.6 Confined Spaces must be considered and applied. This policy requires;

1. Appropriate risk assessment and controls including atmospheric testing & the identification of energy sources.
2. Appropriate training of personnel.
3. Appropriate protective & rescue equipment.
4. Appropriate entry procedures.

Unless a recent inspection (documented) concluded that the culvert was safe to enter it should be assumed that the culvert is unsafe and an inspection carried out to ascertain the state of the pipe. The inspection, including a risk assessment, must be carried out in accordance with the RTA Culvert Inventory Collection Guideline.

No entry should be made into a pipe when rain is falling in the catchment or rain is forecast.

If it is determined that a pipe or pipe group is unsafe signs should be placed at each end of the culvert warning of the danger.

Occupational Health and Safety (OHS) requirements for contracts are contained in RTA QA Specifications G21 and G22. These are 'pro-forma' model specifications, which must be customised for each project.

Risks which may require special consideration include:

Asbestos
Some bituminous coatings used in the past to protect corrugated steel contain asbestos. Removal of the coating inside the conduit may be complicated by the state of the structure. A special plan will be necessary where the coating is on the outside of the barrel and is exposed during rehabilitation.

Bituminous coatings on corrugated steel culverts should therefore be tested for the presence of asbestos before undertaking any work which could disturb the coating. Specifications and drawings for works on culverts with asbestos in the coating should include prominent warnings.

Access
Culvert access will usually involve traversing a steep batter slope. Construction of a safe access track or tracks may be necessary before commencing rehabilitation work.

Holes in the invert
The work may include working in a culvert with holes in the invert and with flowing water obscuring the bottom of the structure. Holes will have sharp uneven edges and soil erosion below the invert will make the water depth greater at the holes.

Working underground
The rehabilitation work or a coincident event could trigger collapse or partial collapse of the corrugated steel culvert. Propping of the culvert or working from a shield may be necessary.

Working in or near water
Slipping, hypothermia and drowning are potential hazards.

Ventilation
Adequate ventilation will be necessary at all times and particularly for work which produces toxic fumes.

Lighting
The provision of adequate artificial lighting will usually be necessary.

Electricity
Corrugated steel culvert walls are good conductors. The presence of water will also increase the hazards of electricity, particularly for personnel working in water. Low voltage lighting and air driven power tools should be considered.

Flora and fauna
Culverts are often in areas of dense vegetation including some species which can scratch or sting exposed skin. Snakes and stinging insects (including spiders) may live in, or in the vicinity of, the culverts. Bats will sometimes adopt culverts for roosting.

Winches
Winches may be used in rehabilitation works and appropriate provisions should be made in the specification for the use, installation, inspection, maintenance and repair of winches.

Demolition
Demolition and removal of the corrugated steel culvert and appurtenances may be required.

Traffic
The hazard of a vehicle crashing into a culvert or underpass entry is of particular significance when work is underway in the area.

2.7 Environmental impacts

A preliminary review of environmental factors should be undertaken before making a final decision on the rehabilitation method to be adopted. Where relevant, the assessment should include consideration of the following:

- Cleaning processes (grit blasting, high pressure jet, chemical solvents) and necessity of installing sediment traps, screens or other facilities.
- Diversion of stream/temporary cofferdam.
- Habitat damage.
- Fish and aquatic life that may be affected.
- Grout/overflow of grout or other products that could influence water pH or other qualities.
- Access methods and working space.
- Construction equipment and storage of materials that may have an adverse effect on the adjacent area.
- Noise.

3 ASSET MANAGEMENT RESPONSIBILITIES

The RTA takes a long term risk based approach to the management of its assets and allocates funds for maintenance works to ensure that a consistent level of service is maintained across the State at the lowest whole of life cost. Within each asset type, priorities for projects are determined based on risk assessment at the State level.

Each region proposes maintenance works for its assets based on local inspections, current needs and risks, life cycle analysis and overall priorities given the available funding. *Asset Management Circulars* and *Project Selection Guidelines* are available to assist regions in this regard.

The RTA's requirements for the management of culverts are set out in the policy Culvert Management Framework IAM-POL-603, which outlines the inventory collection and risk assessment procedures. The inventory information is available for use by asset managers in planning maintenance works and allocating financial resources.

Rehabilitation and replacement works are more significant projects than routine maintenance works and so are specifically identified in works programs. Where a rehabilitation or replacement work is proposed, the asset manager will engage and brief a project manager on the project requirements, including the scope, cost and performance requirements.

The asset manager is responsible for preparing the project brief, including determination of the scope, financial resourcing and performance requirements for the project.

The project manager is responsible for developing and delivering the project in accordance with the requirements of the brief issued by the asset manager.

4 COMMON REHABILITATION METHODS

The methods outlined in this document are commonly used in Australia. As time and experience with the rehabilitation and replacement of corrugated steel culverts accumulates, new techniques may be developed.

This guide should not be interpreted as discouraging the development of new methods.

The rehabilitation methods described in this section are:

- Soil rehabilitation,
- Concrete invert,
- Concrete in-situ lining,
- Concrete slip lining,
- Spiral wound plastic structural lining,
- HDPE slip lining,
- GRP slip liner,
- GRP cured in place lining,
- Remove and replace,
- Pipe jacking, and
- Pipe bursting.

4.1 Soil rehabilitation

The requirements for successful rehabilitation of the soil around a culvert or underpass are that:

- Voids are filled with a material that is strong enough to carry all loads from the traffic and overburden.
- Water seepage paths through the soil around the culvert are treated to reduce seepage velocities sufficiently to prevent the risk of “piping” through the soil.
- Materials used in the rehabilitation of the soil are not aggressive to the corrugated steel culvert structure and are not aggressive to the material used to rehabilitate or replace the existing culvert structure.

These requirements are not always compatible and two or more techniques may be necessary. For example, a headwall may be used to reduce flow through the soil and a grout used to fill the voids.

Voids, which have reached the surface, may sometimes be satisfactorily treated by further excavation, and placement and compaction of material with suitable properties in layers. A geotextile may be required to act as a filter between the new material and the surrounding soils or at the surface of the corrugated steel culvert. Some voids may be filled in a similar way by excavation from the surface.

Where pumping is required to fill voids, the requirement is for a material which is liquid during placement but which will solidify once in place and show low shrinkage during solidification and curing. Suitable materials include cement and/or fly ash grouts or Controlled Low Strength Materials (CLSM) with or without compatible additives to assist fluidity, control shrinkage or enhance other attributes. Information on CLSM is included in AS/NZS 3725.

Resin based grouts may also have advantages in certain circumstances but their compatibility with the structure and surroundings, their environmental suitability and their durability must be considered before use.

It has been reported from the USA that some fly ash is acidic. Brief enquiries have not found any reports of acidic fly ash in NSW but the possibility should be considered.

Pump pressures during grouting must be strictly controlled to avoid buckling of the structure wall.

Flow paths through the soil may be lengthened by the use of an upstream concrete headwall and bulkheads. To be fully effective headwalls must extend to at least the design inlet water surface level. However, the consequences of higher flood levels must be considered. Concrete bulkheads will be difficult to install retrospectively in deep embankments and their stiffness may cause problems for corrugated steel culverts with shallow cover where traffic loads form a significant part of the load on the culvert.

Flow through soils may be reduced significantly by the use of bentonite as a bulkhead but the method of injecting the bentonite into the soil will need to be considered for each project to ensure effective cut off.

Drainage will be necessary between bulkheads to avoid excessive groundwater pressures. Culverts are usually at or near a sag point and care must be taken to ensure soil rehabilitation does not interfere with subsoil pavement drainage.

Drains incorporating geotextiles or other filters may be installed into the wall of the conduit.

An important soil rehabilitation exercise will be the backfilling of any abandoned corrugated steel culverts. Voids outside the culvert wall must be filled as described above but the inside will also require filling. This may require a significant volume of material and, if a benefit such as a reduction in the size of the new facility is possible, a smaller diameter insert through the abandoned corrugated steel culvert will also reduce the volume of material to be placed and may improve safety during the filling operation.

Techniques for filling abandoned coal workings can be adapted for this purpose - for example, the Charlestown Bypass and Swansea Bends projects in the Newcastle area.

4.2 Concrete invert

If the corrugated steel culvert is in reasonable condition above the invert area but is eroded in the invert area a new/replacement concrete invert may add several years to the life of the structure. Generic designs have been produced for new or relatively undamaged corrugated steel culverts but site specific designs should be provided where heavy erosion or perforation of the invert has occurred.

In assessing maintenance options, the value of this option should be compared with the concrete in situ lining option described in Section 4.3 below.

The work should progress incrementally along the invert length. Circumferential stiffeners or other suitable propping should be installed along the culvert to protect it during the work, and removed as each increment of work is completed.

For application of sprayed concrete (shotcrete), refer to RTA R22 & RTA B82.

The following points need to be considered:

- A suitable grade and concrete mix must be chosen in light of future erosion attack and water/soil properties and should be at least 100mm thick.
- A positive connection must be made between the concrete and the corrugated steel culvert wall. This connection must be designed to carry the full thrust from the wall.
- Construction joints must be sufficiently watertight to prevent piping of the surrounding soil. Waterstops which swell when in contact with water are simpler to install than traditional waterstops.

- The top of the concrete must slope away from the wall and a thick, durable and flexible coating is recommended across the concrete/metal join - about 300mm on both sides of the joint. A sealer at the joint may also be appropriate.
- Paving limits typically vary from 90 to 120 degrees for the internal angle (Refer Figure C1, AS/NZS 2041:1998).
- If the invert has eroded to the point where large holes exist and the underlying soils are suitable it may be possible to avoid any loss of hydraulic capacity by dropping the invert level.
- Soil remediation may also be necessary – see Section 4.1.

Advantages

- Comparatively low cost and relatively quick to undertake work.
- Light equipment and the possible use of concrete pumps located on the verge simplify access requirements.
- No upper size limit to the corrugated steel culvert to be rehabilitated.

Disadvantages

- Propping of the existing structure may be necessary for safety reasons. Props may have a significant effect on the hydraulic capacity of a culvert and would trap debris. Temporary circumferential stiffeners may be an option which overcomes this disadvantage.
- The life of this type of repair will be limited to the life of the corrugated steel culvert above the invert.
- If future re-lining is likely, the cost of removing the invert lining or extending it to a full concrete lining could be a consideration.

Specific exclusions

- Concrete invert is not suitable for corrugated steel culvert which is in poor condition above the invert area.
- It is not suitable in areas where water/soils are aggressive to concrete.
- As work must be undertaken inside the structure, this technique is not suitable for structures with internal height of less than 1.5 metres.

4.3 Concrete in situ lining

If the corrugated steel culvert is in poor condition but is reasonably straight and has no significant bulges in the wall a full in situ concrete lining should be considered. Site specific designs should always be provided because of the range of shapes, sizes and embankment heights, which will be encountered.

The work should progress incrementally along the invert length. Circumferential stiffeners or other suitable propping should be installed along the culvert to protect it during the work, and removed as each increment of work is completed.

Points to be considered include:

- A suitable grade and concrete mix must be chosen in light of future erosion attack and water/soil properties, and should be at least 100 mm thick.
- Concrete placing will usually be by shotcreting – refer to RTA R22 and RTA B82.
- As the shotcrete is to provide a structural lining or upgrade the capacity of the culvert, the design should be in accordance with AS 5100.
- The new lining must be designed to carry all loads without contribution from the corrugated steel culvert. The design must allow for the distorted shape of the corrugated steel culvert.
- Steel reinforcement and mesh is held in place with the aid of steel studs or rods connected to the host pipe by welding or self tapping screws.
- Construction joints must be sufficiently watertight to prevent piping of the surrounding soil. Waterstops which swell when in contact with water are simpler to install than traditional waterstops.
- If the invert has eroded to the point where large holes exist and the underlying soils are suitable it may be possible to avoid any loss of hydraulic capacity by dropping the invert level.
- Soil remediation may also be necessary – refer to Section 4.1.

Advantages

- Comparatively low cost and relatively quick to undertake rehabilitation work.
- Light equipment will simplify access requirements.
- No upper size limit to the corrugated steel culverts to be rehabilitated.
- The life of this type of repair can be chosen to match or exceed that of the other drainage assets on the road.

Disadvantages

- Loss of cross section.
- Temporary propping of the existing structure may be necessary during the period of the work for safety reasons. Props may have a significant effect on the hydraulic capacity of a culvert and would trap debris.

Specific exclusions

- Not suitable for corrugated steel culverts which are significantly distorted.
- Not suitable in areas where water/soils are aggressive to concrete.
- As work must be undertaken inside the structure, this technique is not suitable for structures with internal height of less than 1.5 metres.

4.4 Concrete slip lining

Corrugated steel culverts with circular cross section may be rehabilitated by inserting a precast concrete liner into the barrel. While butt jointed precast concrete drainage pipes or fibre reinforced concrete pipes complying with AS 4058 or AS 4139 may be satisfactory in some instances, pipes designed for jacking would normally be used.

Pipes are pushed into place along rails (usually timber), which guide and support the liner until grouting of the space between the liner and the corrugated steel culvert is completed. The rails remain in place at the completion of the work.

Due to the weight of the pipes, equipment for pushing the pipes will need to be accommodated at one end of the pipe.

Rubber ring joints are essential and the limited deflection of these joints will limit the extent that the liner can follow the line of a distorted culvert - approx 5 degrees deflection per pipe length.

The design must be verified to ensure that the completed installation will carry the imposed loads.

Soil remediation may also be necessary – refer to Section 4.1.

Advantages

- No lower size limit to the culvert to be rehabilitated.
- The life of this type of repair will be similar to other concrete culverts.
- May not be necessary to enter existing culvert.

Disadvantages

- Significant loss of cross section.
- Jacking pipe sizes are currently limited to a maximum diameter of 3 metres.
- The weight of the pipes where access is difficult.

Specific exclusions

- Not suitable where the reduced cross section is unacceptable and improvements to the inlet are not viable to maintain capacity.
- Not suitable where the existing culvert is significantly distorted.
- Not suitable in areas where water/soils are aggressive to concrete.

4.5 Spiral wound plastic structural lining

These liners are formed by spirally winding a continuous strip of plastic into the deteriorated corrugated steel culvert and locking or welding the edges of the strip together to form a pipe. Pipes between 150 and 3000 millimetres nominal diameter can be formed in this way.

The liner may have a fixed diameter or may be expandable to closely fit inside the culvert. The plastic strip is usually smooth on the inside and ribbed on the outside and for larger diameters the plastic may be reinforced with steel in the ribs.

The liner must be designed to carry all imposed loads without any assistance from the existing culvert. The design must also allow for any shape distortions, which would result from the shape of the corrugated steel culvert and for creep and other aging aspects of the liner material.

The gap between the liner and the corrugated steel culvert must be fully grouted.

Soil remediation may also be necessary – refer to Section 4.1.

Advantages

- Allows installation where construction access is limited.
- No lower size limit to the culvert to be rehabilitated.
- Resistant to some aggressive environments.
- The life of this type of repair is unknown but expected to be several decades.
- May not be necessary to enter existing culvert.

Disadvantages

- Some loss of cross section.
- If the liner is not a close fit within the corrugated steel culvert it will have a tendency to float during grouting.
- May be adversely affected by chemicals and therefore susceptible to damage from a chemical spill.
- May be damaged by fire.
- Uplift at the entry must be accommodated.

Specific exclusion

- If the host pipe is significantly deformed, a spiral liner may not have enough structural strength to prevent further collapse.

4.6 HDPE slip lining

Slip lining involves inserting a high density polyethylene (HDPE) pipe into the steel culvert. Joints are butt welded outside the corrugated steel culvert before being pushed or pulled into place along timber or plastic rails.

Around 1% extra length of pipe should be pulled in to allow for stretching and temperature variations.

The liner must be designed to carry all imposed loads without any assistance from the existing culvert. The design must also allow for creep and other aging aspects of the liner material.

The gap between the liner and the corrugated steel culvert must be fully grouted.

Soil remediation may also be necessary – refer to Section 4.1.

Advantages

- Polyethythene has a high abrasion resistance.
- No lower size limit to the culvert to be rehabilitated.
- Resistant to some aggressive environments.
- The life of this type of repair is unknown but expected to be several decades.
- May not be necessary to enter existing culvert.

Disadvantages

- Some loss of cross section.
- If the liner is not a close fit within the culvert it will have a tendency to float during grouting.
- Smooth walled pipe is limited to a maximum of 1 metre nominal diameter and profiled wall pipe to 3 metres nominal diameter. The largest sizes may be difficult to obtain.
- May be adversely affected by chemicals and therefore susceptible to damage from a chemical spill.
- May be damaged by fire

Specific exclusions

- Extruded HDPE pipes are made in a limited range of incremental diameters (approx 75 to 100 mm steps). Availability, especially in the larger sizes, can be an issue where relatively short sections are required.
- Not suitable where access at the end of the culvert is limited – requires a staging area 1.5 to 2 times the length of the pipe to be inserted (usually 12m lengths). Pipes can be cut and welded during insertion in accordance with Appendix F of AS/NZS 2566.2 but it can be time consuming and costly.

- Not suitable for badly distorted corrugated steel culverts.

4.7 GRP slip liner

Glass fibre reinforced plastic slip lining is similar to HDPE slip lining. Mechanical joints are used. The current maximum size is 1.2 metres nominal diameter.

4.8 GRP cured in place lining

Glass fibre reinforced plastic cured in place rehabilitation is undertaken by installing of a resin impregnated, flexible tube into the existing conduit, inflating it to fit the existing wall and then curing the product by means of hot water or light.

The liner must be designed to carry all imposed loads without any assistance from the existing culvert. The design must also allow for any shape distortions, which would result from the shape of the corrugated steel culvert and for creep and other aging aspects of the liner material.

The gap between the liner and the culvert must be fully grouted but this may be difficult as the liner will partly enter the corrugations of the corrugated steel culvert.

A means of collection and disposal must be in place for water contaminated during the installation and curing phases.

Soil remediation may also be necessary – refer to Section 4.1.

Advantages

- No lower size limit to the culvert to be rehabilitated.
- Resistant to some aggressive environments.
- The life of this type of repair is unknown but expected to be several decades.
- May not be necessary to enter existing culvert.

Disadvantages

- Some loss of cross section.
- Successful grouting may be difficult because the liner will be in contact with the corrugation crests.
- A limited range of diameters is available.
- Not suitable for badly distorted culverts.
- May be adversely affected by chemicals and therefore susceptible to damage from a chemical spill.
- May be damaged by fire

Specific exclusions

May not be suitable where the flow is abrasive because the resulting GRP liner profile will be corrugated.

4.9 Remove and replace

Remove and replace techniques are similar to those generally used in the construction of new roads.

Replacement costs are usually higher than rehabilitation of existing culverts, except for those under shallow embankments.

Advantages

- Life of the structure will be that of a new structure.
- Any necessary enhancement of the asset's performance will be simplified.
- Soil rehabilitation will be simplified, especially where construction is by cut and cover.

Disadvantages

- Lane or road closures and/or side tracks are required.
- Temporary drainage path will be required for the watercourse.
- Time of construction may be longer, with higher costs.
- Space will be required to stockpile excavated material and trench support may be required to reduce the quantity of excavation material.
- Where the replacement structure is on a new alignment the existing culvert will need to be filled and the surrounding soil rehabilitated.

Specific exclusions

- Where no alternative watercourse is viable and/or no alternative traffic route or staging is practical.
- High embankments could make the cost of excavation prohibitive.

4.10 Pipe jacking

Pipe jacking is a method of installation, which uses jacks to force a specially designed type of precast concrete pipe through the soil. The process may be assisted by removal of material at the leading end via the pipe, using tunnel boring machines, augers or other methods.

Pipes must be designed to carry the superimposed loads of the soil and traffic, and the thrust forces from the jacks.

Jacking may be around an existing corrugated steel culvert if space, geotechnical conditions and the alignment of the existing culvert permit or it may be undertaken adjacent to the existing culvert.

While precast concrete pipe is normally used in jacking, other precast shapes (including box sections) can be used. Also these shapes may be constructed in situ beside the embankment and then installed by jacking.

Procedures for pipe jacking are available from the Concrete Pipe Association of Australia (CPAA) '*Concrete Pipe Jacking*'.

Jacking typically involves 2 or 4 jacks with capacities up to 300 tonnes and a stroke of 1200mm. A thrust block is required at the insertion end.

Soil remediation may be necessary where the new pipe is jacked around the existing culvert. Where the new culvert is on a new alignment, soil remediation may be required around the abandoned culvert as well as filling the inside. – refer to Section 4.1.

Advantages

- No lower size limit to the culvert to be rehabilitated.
- No disruption to traffic.
- Structure may be designed for improved performance.

Disadvantages

- Precast pipes are limited to 3 metres nominal diameter.
- Construction nearby may require diversion of the waterway or track and will require backfilling of the existing culvert. Backfilling may be reduced or avoided if a slip lining is placed in the existing culvert.

- Temporary provision must be made to carry the reaction forces from the jacks.
- Jacking around an existing culvert may require special provisions to allow floods to pass.
- A significant amount of material will need to be removed from the site.
- Any annulus remaining around the outside of the new pipe after jacking must be grouted.

Specific exclusions

- Embankments with variable fill (eg hard rock and soft clay) which prevent jacking.
- Shallow embankments, which may heave with jacking.
- Jacking around an existing culvert requires a 600mm larger diameter pipe and costs may be large where it has large headwalls. Also rock under the existing culvert invert may prevent this jacking technique.
- Jacking on an alternative alignment requires an alignment which suits watercourse geometry and hydraulic requirements.

4.11 Pipe bursting

In this technique a “bursting head” in front of the new pipe breaks the existing corrugated steel culvert and pushes the broken pieces into the surrounding soil. This technique allows a new culvert to be installed by pipe jacking a similar diameter pipe to the existing culvert

The new conduit must be designed to carry all imposed loads and installation loads. As flexible pipes are used the design must be in accordance with AS/NZS AS/NZS 2556.1.

While the compression of the soil in the vicinity of the existing structure will reduce the size of any surrounding voids, soil remediation may still be required – refer to Section 4.1.

Advantages

- No lower size limit to the steel culvert to be rehabilitated.
- No disruption to traffic.
- Structure may be designed for similar performance to the existing culvert

Disadvantages

The technique is currently limited to circular pipes up to about 1 metre nominal diameter.

Specific exclusion

Shallow embankments, which may heave with bursting.

4.12 Other possibilities

Other possibilities, which may be of use on occasion, include:

- Traditional soft ground tunnelling.
- Replacement of the corrugated steel culvert by a bridge (similar to Section 4.9 Remove and replace).

5 PROJECT MANAGEMENT REQUIREMENTS

5.1 RTA's MinorProject tools

Culvert rehabilitation and replacement projects should be managed in accordance with the RTA's Infrastructure Life Cycle Management System, using the MinorProject tools. The MinorProject Information and Planning Manual, ILC-MP-M-001, can be found in TechInfo on the RTA's Intranet site.

MinorProject contains easy-to-follow directions on the project management process as well as advice on responsibilities, approvals and reporting. It provides 4 key phases for managing a project:

- Initiation
- Development
- Implementation
- Finalisation.

The first phase or initiation phase, is the responsibility of the asset manager as it involves project scoping and funding considerations, and ends with a project brief and engagement of a project manager. The project manager is responsible for the other three phases, including seeking and obtaining the asset manager's agreement to any proposed scope changes and proceeding past any hold points.

MinorProject provides the flexibility required for management of corrugated steel culvert projects, while providing a framework to ensure successful project outcomes.

For instance, the technology and equipment available for rehabilitation and replacement of corrugated steel culverts is continually evolving with new techniques and equipment appearing regularly. Hence, there is a clear need for the asset manager and project manager to work closely on these projects to ensure that the most cost effective solutions are obtained and limited maintenance funds are used most effectively.

Accordingly, a project manager may be engaged to assist during the planning and project submission process by examining options or confirming the scope, concept design and cost estimate of a candidate project.

The key considerations in applying MinorProject tools, specifically to corrugated steel culvert rehabilitation and replacement projects, are outlined in Sections 2 and 3 of this document.

5.2 Asset management context

It is important to appreciate that funding for maintenance works is allocated on the basis of the life cycle of the asset, current maintenance needs and risks across the road network. Hence, implementation of a more expensive work than planned at one location means that some other high priority maintenance work may need to be deferred.

Project managers should therefore consider carefully any proposal to change the project scope from that included in the asset manager's brief and seek to minimise the flow on impacts to other priority maintenance works if a change is considered essential. Any scope changes require the prior acceptance of the asset manager.

Project managers should always seek low cost solutions, which meet the requirements of the project brief and are cost effective. However, they should give asset managers an opportunity to consider alternative solutions, of which the project manager may be aware, that could provide significant additional benefits for a marginal increase in cost.

It should be noted that generally an asset manager would not expect a project scoped as a rehabilitation work to cost nearly as much as one scoped as a replacement work. Also, a project scoped as a rehabilitation work would not be expected to include capacity enhancements.

APPENDICES

APPENDIX A – CULVERT DESIGN CONSIDERATIONS

1. Catchment hydrology

It is essential that corrugated steel culverts carry the design flood without adverse community or environmental effects upstream or downstream. The probable consequences of a flood exceeding the design flow must also be considered, including the risk of loss of life. The likely damage to the culvert and the road in extreme events must also be evaluated.

Selection of the Average Recurrence Interval (ARI) of the design flood must have regard to current land uses and zonings and the NSW Government's Flood Prone Land Policy which is described in the '*Floodplain Development Manual*'(DIPNR 2005). Consideration must also be given to council flood management policies prepared in accordance with the *Floodplain Development Manual*. The *Floodplain Development Manual* stresses the need to make allowance for the effects of all floods up to, and including, the Probable Maximum Flood (PMF). This does not mean that culverts should be designed for such floods but it does mean that the possible consequences of such a flood should be reviewed, particularly the risk to human life. The possibility of an embankment failure should be considered along with the potential effects of a "dam break" wave on the downstream area.

Further advice on determining design catchment flows is contained in *Australian Rainfall and Runoff.*

In many recent property developments on site detention of stormwater (OSD) has been provided. OSD is intended to maintain the stormwater peak runoff at pre-development levels so that downstream the peak flow is little changed. In any event the volume of stormwater will be increased and thus the time of flow lengthened. This may increase the period of abrasion of the culvert and the time available for the embankment soil to be eroded.

An important factor in choosing the ARI is the function of the road over the culvert, particularly its function in emergencies. Viable alternative routes during floods may need to be considered along with the possibility of floods at other points along the road. Where two sections of a road may flood simultaneously the risk to people stranded between these sections during a rising flood must be taken into account for all floods up to and including the PMF.

A further matter of concern will be the route followed by flows, which exceed the design flow of the culvert. High flows will usually cross the road at or near the culvert location and embankment erosion, pavement damage and safety will be the primary concerns. In some cases these flows may be diverted to an adjacent catchment and the impact on the second catchment must be considered very carefully.

The base flow (ground water flow) through the culvert is important for constructability, durability and environmental reasons:

1. If the base flow continues through dry periods the culvert invert will be wet for some or all of the time and this will hasten the deterioration of some pipe materials and protective coating systems. The wet/dry line is likely to be an area of accelerated corrosion.

2. A continuing base flow is a factor to be considered in choosing a rehabilitation technique.

3. If the watercourse is an aquatic fauna habitat the NSW Department of Primary Industries may have requirements for the preservation of the habitat, including provisions to assist passage through the culvert.

Water quality, surface and groundwater must be taken into account. Matters of concern are the potential of the water to cause rapid deterioration the pipe or pipe coatings. Areas of acid sulphate soils, potential acid generating materials and salinity are all of concern because of the potential to attack pipe materials, including steel and concrete. Soft water may inhibit the ability of galvanise steel to form a protective coating.

A watercourse which carries significant loads of sand, gravel or rocks may also erode the culvert wall, particularly around the invert. The presence of aggressive soils in the culvert area may require special measures to be adopted to protect the rehabilitated culvert.

All watercourses and soils should be tested to establish the pH and salt content of the water at a culvert, which is to be rehabilitated. Observations should be made to establish the possibility of significant sand, gravel or rock load during regular rainfall events and floods.

2. Culvert hydraulics

Corrugated steel culverts are usually circular in section but other shapes such as ovals and arches are used where there are advantages to be gained. Many culverts consist of several pipes side by side, usually, but not always, with the same cross section and the same invert levels. Culverts under divided roads with a depressed median will often include a pit or pipe junction to accept flows from the median.

Culverts are complex hydraulic structures. The publication *'Waterway Design – A Guide to the Hydraulic Design of Bridges, Culverts and Floodways*' provides valuable information to assist designers. Ven Te Chow and Henderson have written textbooks on open channel hydraulics which include information on culvert flow. (See reference list for details.)

The main parameters which determine the flow capacity of a culvert include the upstream and/or downstream water levels, the stream geometry and the culvert cross section, material, longitudinal slope and entry shape. At the design flow, culverts may be designed to flow full or part full and the major control on the capacity may be the upstream water level, the resistance to flow in the conduit or the downstream water level.

Where the capacity of a culvert is determined by the upstream water level the culvert is said to be under inlet control and the capacity of the culvert will be independent of culvert grade or the roughness of the inner surface, at least over a wide range of values. Flow in these culverts is part full from a point some distance downstream of the entry and therefore the flow velocity downstream will be higher than that at the inlet. The actual downstream velocity will vary according to the pipe roughness and grade.

High tailwater levels (outlet control) may control the culvert capacity but, in this case, pipe friction and entry losses will affect the upstream water surface levels.

At sites where the tailwater level is variable, such as tidal estuaries or along major rivers where the peak flow in the culvert may not coincide with that in the river, the flow in the culvert may vary according to the conditions applicable at the time. In some locations reverse flows may occur. The design of culverts in flood storage areas may be dictated by the peak reverse flow required to maintain flood storage capacity. In tidal areas the effects of elevated ocean levels from various causes may also influence culvert design.

Culverts represent a constriction in the flow path and will usually cause an increase of water levels for some distance upstream. This increase (compared with the pre-existing water surface level for the same flow) is known as afflux or backwater. It is usually the permissible afflux at the design flow, which dictates the size of the culvert. Calculation of the afflux at the culvert entry is part of the culvert design process but determination of the upstream limit of the backwater effect is usually carried out using a computer model such as HEC-RAS (US Army Corps of Engineers). An approximate method for estimating the limit of the backwater effect, useful for preliminary design purposes, is included in *'Australian Rainfall and Runoff'*.

The capacity of an existing culvert may often be improved by altering the entry conditions. This may be useful where culvert rehabilitation will result in a reduced culvert diameter or where a reduced afflux is required.

Many corrugated steel culverts are provided with a concrete lining in the invert area to improve the hydraulics for low flows and to protect against erosion. Hydraulic calculations for losses at entry should be based on the reduced cross section provided by this type of pipe. Pipe full friction losses should be calculated using the weighted average of the n (for Manning's equation) or k (Colebrook White) values of the corrugated pipe and the concrete lining (suggested methods are discussed by Ven Te Chow). Part full calculations should use the friction values in a similar manner to that used for channel and overbank flow areas in a natural stream.

However, it should be appreciated that while liners may increase velocities, higher velocities also increase entry losses which can increase upstream water levels.

Other factors which must be addressed in the hydraulic design of culverts include the inlet and outlet velocities. Inlet velocities affect the sizes of particles (silt, sand, rock), which may be drawn into the culvert and the exit velocity may cause erosion at the outlet. Use of a liner can increase outlet velocities significantly and require the installation of appropriate energy dissipation devices.

The possibility of blockages must be considered in culvert design. Important factors affecting the likelihood of blockages include the type of materials which could enter the floodwater upstream of the culvert and the size of the culvert. While vegetation, soils and litter are common causes of blockage, doors and shipping containers are also reported to have partly blocked culverts.   An allowance for blockage, which reduces flow by between 20 per cent and 50 per cent of the design value, is sometimes suggested but it is recommended that each case be treated on its merits. Most blockages occur at the culvert entry. Trash racks may assist provided they are regularly cleared of accumulated debris to prevent the debris from increasing upstream water levels or washing of the debris into the culvert.

Blockages will raise the upstream water level and may prolong the time taken for the flood waters to pass. Both these factors will increase the severity of any soil erosion in the embankment.

3. Functional characteristics of underpasses

Corrugated steel culverts are sometimes used as underpasses for vehicles, cyclists, pedestrians or stock. Underpasses may have multiple uses – for example, a stock crossing may also be used by farm machinery and serve as a stormwater drain.

The RTA *Road Design Guide* (RDG) includes recommendations for road and pedestrian underpasses while recommendations for bicycle facilities are included in Part 14 of the Austroads *Guide to Traffic Engineering Practice* and the RTA *NSW Bicycle Guidelines*. Requirements for stock underpasses will usually be a matter for negotiation with those having a right to use the facility but there may be legal documents, which describe or limit the rights of the RTA and the users.

4. Structural design

The structural design of corrugated steel culverts is covered by Australian Standards AS 1762, AS/NZS 2041 and AS 3703.2.

AS/NZS 2566.1 covers flexible pipes but it does not give design guidelines for corrugated metal pipes, arches and non-circular shapes.

AS 1762 covers helical locked seam corrugated steel pipes which meet the requirements of AS 1761 while AS/NZS 2041 covers manufacture and design of bolted corrugated steel culverts of various shapes.

AS 3703.2 applies to long-span corrugated structures manufactured in accordance with AS 3703.1. Long-span corrugated structures complying with AS 3703.1 have external longitudinal stiffeners and may have end stiffening collars and concrete footings. The design of stiffeners, collars and footings is not covered by AS 3703.2.

It is important to realise that the load on a corrugated steel culvert through an embankment is not significantly affected by traffic once the cover exceeds about 5 metres. For details refer to the Australian Standards listed above.

The effect of ultraviolet light on plastic pipes and liners requires consideration as well as the impact of chemical spills and fire

The relevant Australian Standard may assist in assessing the structural integrity of a corrugated steel culvert, which is corroded or has other defects provided the state of the surrounding soil is also known.

Construction of corrugated steel culverts for the RTA is covered in QA Specification R22, first issued in 1991 as QA Specification R8. This specification has no specific requirements for aluminium structures. R22 requires that bedding and select fill zones must have a PI less than 12 and be free of individual particles with a dimension larger than 25 mm for fill and 12 mm for bedding material. Other specified limitations on the material are designed to avoid severe corrosion of the pipe.

APPENDIX B - GROUTING

Many rehabilitation techniques require the use of grout. Grout is a slurry made by mixing Portland cement with water and, where beneficial to the ease of placing the grout or to the end use, fly ash, fine aggregate, bentonite and other admixtures may be included in the water/cement slurry.

For corrugated steel culvert rehabilitation work low shrinkage is usually desirable. The adverse effects of shrinkage may be minimised by admixtures or by grouting in stages.

Various resin based compounds are available which are sometimes referred to as grouts and their use may be considered where their compatibility with the structure and surroundings, their environmental impact and their durability are suitable for the purpose. Because resin based grouts are liquids they may penetrate finer gaps than cement grouts but this is not usually a requirement for corrugated steel culvert rehabilitation.

Fly ash injected by air fluidisation has been used as a bulk fill material and may be useful in some circumstances such as filling redundant corrugated steel culverts. An alkaline material (eg Portland cement or slaked lime) is required to ensure setting of the fly ash.

There are three reasons for using grout in the rehabilitation of corrugated steel culverts:

1. To re-establish structural support between the surrounding soil and the existing culvert by filling voids.

2. To fill voids which may cause pavement failure.

3. To fill the gap between the existing corrugated steel culvert and a new liner.

In addition, cementitious grout may help retard corrosion of the existing culvert and/or reduce infiltration through the wall of the pipe.

Grout will not need to have a high strength. For filling voids a strength similar to that of well compacted soil will be sufficient; significantly higher strengths may adversely affect the soil/structure system. Where the grout is to be used to fill a gap between the pipe and a new liner the grout strength and other properties should be chosen to suit the rehabilitation method. Where proprietary liner systems are used the recommendations of the supplier should be adopted.

Cement grouting aluminium or aluminium/zinc coated steel culverts should not be undertaken without expert advice as adverse chemical reactions are possible.

Grouting procedure

Grout is injected by gravity feed from a hopper or by pumping. Pressures must be very closely monitored to prevent any of the following failure modes:

- Heaving of the pavement or damage to the embankment beyond the pavement limits.

- Failure of the existing structure because of the combination of soil load, traffic load and internal pressure (when grouting the space between a new liner and the existing corrugated steel culvert) or external pressure (when filling voids outside the corrugated steel culvert).

- Failure of a new liner by buckling under the pressure between the liner and the existing corrugated steel culvert.

Grout specific gravity will usually be between 1.3 and 1.8 and, unless the specific gravity is known, pressures less than 10 kPa/metre depth near the middle of a wide shallow embankment should be adopted for safety against pavement or embankment damage unless studies show that a higher pressure can be permitted. Towards the batters the lateral restraint of the soil will reduce and under the batters the depth will also reduce. In these areas very low pressures may be needed to avoid local embankment failures. Unless the embankment is relatively impervious or is impervious in some zones, grout flow will be in every direction from the point of injection. Staged injection may assist in ensuring grout penetrates the desired areas.

Failure because of external grout pressure around the existing corrugated steel culvert (in association with other loads) should be considered where the structure is sufficiently intact to sustain significant external pressure. Where the corrugated steel culvert has significant perforations the application of significant external pressure may not be possible. Similarly, internal pressure on the existing corrugated steel culvert will only be possible if its walls are reasonably intact and, where this is the case, the internal pressure load condition should be assessed.

Failure of a new liner by buckling, because of external pressure, is possible. The buoyancy of the liner must also be addressed, as must the means of sealing the ends of the liner to prevent grout loss.

When grouting the spaces outside a new liner it must always be remembered that a complex load sharing system will exist until the grout gains the design strength required to allow it to carry all loads.

Grouting must continue until the grout completely fills the space as evidenced by consistent grout flows from an outlet vent at a higher elevation or by other reliable means.

Care must be taken to avoid grout penetrating spaces which must remain clear such as utility ducts and subsoil drains.

The grout must be checked visually at outlets to ensure that it has not been diluted by water and air has been expelled before grout injection ceases.

APPENDIX C - REFERENCES

1. Department of Infrastructure, Planning and Natural Resources (DIPNA), *’Floodplain Development Manual. The development of flood liable land*‘ 2005.
2. Institution of Engineers, Australia, *’Australian Rainfall and Runoff*‘, revised edition 1987 and subsequently re-issued.
3. Austroads, *’Waterway Design. A Guide to the Hydraulic Design of Bridges, Culverts and Floodways*‘, 1994.
4. Ven Te Chow *’Open-channel Hydraulics*‘, McGraw Hill, 1959, re-issued 1988.
5. Henderson, F. M. *’Open Channel Flow*‘, Macmillan, 1966.
6. Standards Australia, ’AS/NZS 2556.1:1998; *Buried flexible pipelines Part 1: Structural design*’.
7. Standards Australia, ’AS 1762-1984: *Helical lock-seam corrugated steel pipes — design and installation*’.
8. Standards Australia, ’AS/NZS 2041:1998; *Buried corrugated metal structures*’.
9. Standards Australia, ’AS 3703.2 *Long-span corrugated steel structures Part 2: Design and installation*’.
10. American Society for Testing and Materials (AASTM), ’A979/A979M – *Standard Specification for Concrete Pavements and Linings Installed in Corrugated Steel Structures in the Field*‘, Annual Book of Standards Vol. 01.06.
11. RTA, *'QA Specification R22 Corrugated Metal Structures’*.
12. RTA, *’QA Specification B82 Shotcrete’*.
13. Austroads, *’Guide to Traffic Engineering Practice, Part 14 - Bicycles*‘, 1999.
14. RTA, *’NSW Bicycle Guidelines*‘, 2003
15. Standards Australia, ’AS 1761-1985 *Helical lock-seam corrugated steel pipes’*.
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21. Standards Australia, ’AS/NZS 3725:2007, *Design for installation of buried concrete pipes*’.
22. West Virginia Department of Transportation, *’Design of Alternate Pipe Materials*‘, Design Directive DD-503, March 2003.
23. Standards Australia, ’AS/NZS 3725:2007 *Design for installation of buried concrete pipes*’.

Note: Standards, RTA Specifications and similar documents (including *Australian Rainfall and Runoff*) are frequently revised and re-issued. The issue dates quoted are those current at the time this guideline was prepared. Before using any of these documents a check must be made to ensure that the latest version is used.