TMC 313

BRICK ARCH CULVERT EXTENSION & REPAIR

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Chapter 1 General

C1-1 Purpose
This Manual details standard procedures to be followed for the extension and/or repairs to brick arch culverts on RailCorp’s network.

The procedures embrace foundation works, earthworks, brickwork repairs and concrete work.

C1-2 Who should use this manual
This Manual should be used by RailCorp personnel:

– responsible for the preparation of technical specifications for extensions and repairs to brick arch culverts;

– responsible for the implementation of construction works including in-house labour, supervisors, quality control personnel and contract administrators.

C1-3 References
TMC 302 Volume 1: Structures Repair Manual – General Requirements
TMC 302 Volume 3: Structures Repair Manual – Concrete & Masonry Structures
Chapter 2 Culvert Extensions

C2-1 Introduction

Extensions to culverts under the track may be necessary for the following reasons:

- rectification of formation shoulder widths, to retain the track ballast and to ensure track stability;
- widening of the formation to allow track upgrading and lifting;
- widening of the formation to allow additional tracks to be laid;
- widening of the formation to provide for access roads.

C2-2 Procedures

Standard procedures have been developed for the extensions of brick arch culverts. These include materials approved for use for the extensions, foundation preparation, connections between the existing and new culvert sections, backfilling and scour protection.

Typical details and technical notes are shown on standard drawing No. CV0048002A “Extension for Standard Brick Arch Oviform Culverts”.

Chapter 3  Culvert Repairs

C3-1  Introduction
The RailCorp network includes a large number of brick/masonry culverts. These culverts often date back to the original construction of the line and were generally built to Standard Drawing ST 73 (refer Appendix 1).

These types of structures can deteriorate owing to a range of causes such as foundation movement, abrasion, impact etc. These often result in cracking, fretting, spalling and distortion etc.

Reference should be made to Engineering Manual TMC 302 Volume 3 “Structures Repair Manual - Concrete and Masonry Structures” for a general description of the primary causes of deterioration and damage to brick and masonry structures.

The following part of this Manual outlines conventional techniques used for repairing brick and masonry arch culverts. It does not cover the investigations required to identify the mechanism that has caused the damage (e.g. ground movement) or its extent. It does also not cover the remedial measures required to eliminate the root cause of the problem (e.g. improvements to a waterway to reduce scouring).

Emphasis is placed on describing methodologies and techniques for the repair of the most common types of defects in brick and masonry culverts. Notes are also provided on some new techniques and methodologies that have potential but are not as yet approved for railway application.

C3-2  Primary types of defects in brick and masonry structures
The most common type of defects that can develop in brick and masonry structures are:
- cracking
- fretting
- spalling.

A detailed description of these defects is provided in TMC 302 Volume 3 “Structures Repair Manual – Concrete & Masonry Structures”.

C3-3  Causes of deterioration of culvert structures
There are two primary differences between bridges and culverts that are significant:
- culverts are generally considered as embankment supported structures, where the quality of the backfill and degree of compaction affect the side support and foundation support of the culvert (i.e. embankment and culvert act as a system);
- from a hydraulic perspective, culverts are generally designed to operate efficiently under submerged conditions (unlike bridges).

The primary causes of deterioration and distress of masonry/brick structures are:

C3-3.1  Ground movement
Foundation and differential settlement are one of the most common causes of cracking in brick structures. The ground movements are initiated by a variety of causes such as:
- poor foundation material;
- poor embankment compaction during construction;
- variation of soil properties across the site;
- inadequate site drainage; and
- soil erosion.
C3-3.2 Overloading

Structural distress due to overloading can occur due to a number of factors. Often the distress is localised and results in various types of cracking which can weaken the structure significantly or in some extreme cases lead to instability & collapse.

The distress can be caused by:
- overloading of trains;
- increased loading since structure was built (e.g. increased live load or increased height of fill);
- deterioration of materials in the structure;
- excessive hydraulic pressures building up behind culvert walls due to inadequate drainage; and
- flood debris loads.

C3-3.3 Thermal movements

Stresses resulting from differential temperature effects can result in cracking and distortion of brick arch culverts.

C3-3.4 Sulphate attack

Deterioration of brickwork can result when cementitious mortars react with sulphates leaching from the brickwork or from backfill containing high concentrations of sulphate. Deterioration is generally over a long period and often culminates in expansion of the mortar in the brick joints.

This results in spalling and cracking and deformation of culverts.

C3-3.5 Poor materials

Unsuitable brickwork or weak mortars can result in culvert deterioration. Weak mortars resulting from low cement content or unsuitable sand often turn out to be porous and can be easily eroded with the passage of time.

Salts in clay bricks can produce efflorescence which looks unsightly but doesn’t damage bricks structurally to any great degree.

Salts in groundwater that penetrate brickwork can crystallise just below the brickwork surface. The pressure developed can result in spalling of the surface of the brickwork, and lead to a general deterioration of the brickwork. This type of problem is exacerbated in coastal marine environments.

C3-3.6 Abrasion & impact

Fast flowing streams, containing pebbles and rocks, can abrade surfaces of culvert inverts.

Fast flowing streams can also carry heavy floating objects (e.g. trees/logs), which can produce impact damage on the upstream head walls of brick culverts.

C3-3.7 Scour

Inadequate original design (e.g. hydrology/hydraulic) or changed conditions (e.g. nearby new developments) can result in culverts being unable to cater for current conditions. Inadequate waterways can result in embankments acting as dams, and in extreme circumstances major scour and washaways. Major scour at outlets can result in loss of foundation support and structural damage. Where there is a history of problems of this nature, appropriate technical advice (hydrology, hydraulics, structural, geotechnical) should be sought.

C3-4 Specific common types of brick culvert deterioration

The most common types of deterioration of brick culverts are listed below:
C3-4.1 Longitudinal cracking
This type of cracking is commonly caused by differential settlement across the culvert causing overstressing of the brickwork, and poor compaction of backfill. This can also result in longitudinal cracking along the arch ring. Cracking can sometimes be observed of the upper sections of culverts (e.g. 2 & 10 o’clock). The cracking may be partially or fully through the arch ring, which in effect can create a structural pin.

Structural advice as to the stability and structural soundness of the structure should be sought.

C3-4.2 Lateral/ circumferential cracking
This type of cracking is often caused by differential settlement along the culvert. The lateral cracking can be partially or, in severe cases, fully through the arch ring. This can result in the culvert acting as separate segments along the barrel.

C3-4.3 Arch ring separation cracking
This type of cracking generally follows the mortar bedding planes, leading to the separation of the individual brick arch rings.

C3-4.4 Diagonal cracking
This type of cracking is often caused by settlement at the ends of the barrel of culverts. The cracks follow a diagonal path starting at the lower areas of the culvert (i.e. closer to the invert) and continuing up towards the centre of the arch.

C3-4.5 Distortions/ misalignment
Distortions and misalignments (vertical & horizontal) of culverts are primarily due to uneven foundation settlements and non-uniform compaction of backfill on either side of the culvert.

C3-4.6 Wing wall/ headwall settlement
Wing wall settlement can transfer loads and stresses to adjacent culvert ends, resulting in cracking in this vicinity. Scour under the wing wall apron can exacerbate the problem.

C3-4.7 Damage & loss of bricks & mortar
Impact damage due to heavy floating debris (e.g. logs) can occur during periods of very heavy rain or flooding. This can result in severe spalling and dislodgement of brickwork.

Spalling due to other causes such as sulphate attack and poor materials can be identified and repaired where appropriate.

C3-5 Assessment of deterioration
C3-5.1 Engineering assessment
Where severe deterioration or damage has been observed, it is very important that an engineering assessment be undertaken by professional staff competent of making structural judgements. Strength and stability should be assessed and measures put into place to secure safety. Measures such as propping and preventing trains traversing the culvert may be required to be implemented. Public safety should be the major consideration.

Identifying the causes of the damage is very important in order that long term durable solutions can be developed.
C3-5.2 Field inspection and preliminary assessment procedure

The inspection and assessment procedure is:

− In the first instance, it should be ascertained if a more detailed examination/inspection is required. Perhaps track closures, power outages, special equipment, or specialist resources may need to be organised, prior to the detailed examination proceeding;
− Examine old inspection reports and past history of the culvert;
− Organise a visual inspection of the culvert and record the type and extent of damage;
− Assess the possible causes for deterioration or damage;
− Thoroughly map the location, extent and crack characteristics (width, direction etc). Record brick movement & fracture;
− Establish if a crack is growing or dormant, as this will determine the types of repairs that are suitable to fix the problem. In some cases monitoring over an extended period may be the best strategy to adopt. The utilisation of strain gauges may be appropriate for particular situations;
− Engineering judgement will need to be applied to determine the best course of action, particularly where major distortions, strength and stability are issues. Apply appropriate structural analysis techniques where warranted;
− Check that the structure is performing as intended;
− Check for deterioration due to leaching, fretting, abrasion, local crushing of brickwork.

C3-6 Justification for repairs

The need, justification, extent and the nature of repairs should be established by the asset owner.

The need for repairs can be justified on a number of grounds:

C3-6.1 Structural strength & stability

Strength and stability are of paramount importance as they affect safety. Strength and stability calculations need to be carried out by competent staff as soon as major defects affecting these characteristics are identified. In extreme cases, consideration should be given to reducing loads on the affected structure by introducing measures such as speed restrictions, or in some cases, track closure whilst a more detailed structural assessment is carried out.

Where significant damage is sustained affecting strength or stability, repairs will need to be carried out as soon as practicable. In certain circumstances, consideration will need to be given to permanent speed restrictions or renewal.

C3-6.2 Durability

The long term durability of structures is of major importance to asset owners. If substantial deterioration is being experienced (e.g. major loss of mortar, substantial cracking, excessive ground settlement, material soundness etc.), repairs to the culvert and associated works (e.g. works pertaining to arresting settlement etc.) will need to be considered. Understanding the cause (e.g. reasons for scouring) and applying appropriate remedies are vital in ensuring long term durability.

In certain situations, some repairs will need to be undertaken to ensure that minor deterioration doesn’t escalate into major damage (e.g. significant cracks developing into major cracks).

Other factors that will need to be considered in deciding the level and extent of repairs include factors such as class of line, volume of traffic, degree and frequency of loading, plans for renewal in the future, etc.

C3-6.3 Aesthetics

Whilst generally not a major issue for masonry culverts, there may be cases where structures are highly visible to the public and some repair effort will need to be applied to improve appearance.
(e.g. pedestrian culvert). The context and surrounding environment of the precinct will be major factors in the decision making process regarding the form of repairs.

C3-6.4  **Functional performance**

Repairs, upgrading, or maintenance may be required if the functional performance of the culvert is impaired, or does not meet current needs. A blocked culvert can lead to flooding upstream and damage to railway embankments. Other affected nearby landholders and parties may take legal action if they perceive that inadequate or poorly maintained infrastructure has caused or contributed to damage.

Asset owners should be aware of the capacity and characteristics of their infrastructure, particularly as it relates to the safety of rail operations. Changed conditions (e.g. urban development) may require consideration for amplifying (e.g. increasing waterway) existing culverts to meet current needs.

C3-7  **Repair methods**

As noted in Par. C3-2, the most common defects that can occur in masonry/brickwork culverts are cracking, fretting and spalling.

The following is a summary of sound practice for particular situations. Further details of repair procedures can be obtained by reference to TMC 302 Volume 3 “Structures Repair Manual – Concrete & Masonry Structures”.

In adopting any of the common repair techniques listed below, consideration will need to be given to various conditions and restrictions applicable to each particular site. Typical aspects include:

− culvert condition;
− extent and type of culvert damage;
− cause of culvert damage;
− access to site for the proposed plant, materials & equipment;
− working access for removal of debris, cleaning, and to the area of culvert to be repaired;
− rail traffic volume, and rail traffic live loads;
− adequacy of current waterway;
− soil chemistry;
− properties & compaction of backfill, properties of water;
− length and cost of potentially available track possession/s;
− potential for damage to the repairs during the construction phase (e.g. vibration, loading);
− degree of cleanliness that can be practically achieved for the culvert, or culvert element, prior to implementing repair;
− installation difficulties during construction (e.g. permanent water in culvert);
− availability of specialist contractors and equipment.

Specific recommendations cannot be made as to which repair options will suit particular culvert sites, because of the many factors that will need to be considered in the decision making process.

For some deteriorated culverts a combination of repair options e.g. grouting part of the culvert and patching another part will provide the most cost effective solution. However, the range of specific developed options included in this manual should cater for the majority of situations likely to be encountered.

Due to access problems, the smaller standard culverts will not be suitable for repairing with some of the common repair techniques (e.g. grouting, patch repairs, spray concrete).

For the larger culverts, some of the repair techniques e.g. sleeving with conventional lining pipe will result in a considerable loss of waterway area, which in general will be unacceptable.
Sleeving systems – using either conventional lining pipes or proprietary products - can not at this stage be regarded as common repair techniques for railway applications. Much more care needs to be exercised in establishing the degree and extent of structural damage to the existing brick culvert.

The principal function of the lining pipe will need to be established. This could be a lining pipe for the grout, a structural element carrying the primary loads, or one carrying some of the main loads.

Sleeving with a conventional lining pipe could be carried out with a relatively weak pipe, which is acting principally as formwork for the grout, or a strong pipe which has the capacity to resist all the loads.

Some proprietary products utilise PVC as lining materials. The acceptability of plastics as a durable material for railway culvert applications will need to undergo further investigation.

C3-7.1 Investigation & assessment of repair options

Investigation and assessment procedure is:

− Utilise structure inspection reports and other information to determine the severity, type, extent, and location etc of the damage;
− Establish the causes of the problem as previously discussed. Utilise specialist reports where available (e.g. geotechnical, structural, etc);
− Analyse and establish the characteristics of the structure (e.g. strength capacity [load rating], stability, condition, durability, etc.) and decide on the urgency of repairs. Appropriate engineering advice must be sought before undertaking major repairs, or supporting severely damaged culverts;
− Assess alternative repair options and construction methods and techniques. Take into account the applicability of the proposed/ planned engineering option for the particular culvert (e.g. level of vibration due to train operations affecting proper hardening of grout);
− Consider the need for aspects such as track possessions, power outages, flagmen, assistance from outside parties (e.g. service authorities), communication, and risk assessment;
− Decide on the option to be adopted and then prepare or organise an estimate of repairs and formulate a repair delivery strategy (e.g. resources, timetable etc);
− Implement the repairs.

Epoxy injection, sprayed concrete and to a lesser extent grouting, require skilled personnel in order to be carried out successfully. The use of specialised contractors is generally warranted for these activities.

C3-7.2 Repairing Cracks

It is important in the assessment phase to establish if the cracks are currently still moving/ growing or whether the movement has ceased (‘dead cracks’).

Repairing moving/ growing cracks can be ineffective as the cracks are very likely to reappear in the future.

Cracks that basically follow mortar joints can often be repaired by raking out the joint and repointing the brickwork.

Where large cracks pass through a significant amount of brickwork, consideration should be given to removing the severely damaged bricks and replacing them.

Sealing minor cracks in culverts is generally unwarranted unless the cracks can contribute to further deterioration of elements of the culvert (e.g. embedded steelwork that can be subject to corrosion).
C3-7.2.1 Epoxy injection of dead cracks

This type of technique is particularly suitable for smaller inactive cracks where structural soundness needs to be restored. Cracks as narrow as .05mm and up to 5mm wide can be bonded and sealed by injecting a low viscosity epoxy. Cracks greater than 5mm generally require a mix of epoxy and mineral filler, or alternatively a Portland cement grout.

The technique involves sealing the cracks and then drilling holes at intervals along the cracks, fitting them with entry nipples and then injecting epoxy under pressure. Generally epoxy repairs are much less effective where moisture, water or contaminants are present.

This technique would be unsuitable for the barrels of smaller culverts where access would be a limiting factor.

Where possible, the extent and depth of the cracking should be established. Cracks that pass right through culvert walls can be difficult to repair if the injection medium leaks into the surrounding backfill. Care needs to be taken to ensure that drainage systems are not blocked by escaping grout.

C3-7.2.2 Grouting of dead cracks

This type of technique is suitable for inactive wide cracks.

The composition of the Portland cement grout and the use of admixtures should be tailored to the particular task in hand. Factors include crack width, crack moistness etc.

The grout mixture contains cement and water. For larger cracks sand is added to the mixture. Pressure grouting is suitable for cracks greater than 0.15 mm in width.

The repair procedure is similar in principle to epoxy injection. Good access would be required to the damaged area.

C3-7.3 Patch Repairs

Patch repairs are carried out to small areas of otherwise sound masonry. They are generally trowel applied and require little formwork. In some cases it may be practical to remove damaged brickwork and replace with new brickwork.

Patch repairs can be undertaken in areas damaged by spalling and impact. Repairs are generally limited to depth thicknesses not exceeding 100mm. Concrete repairs can be utilised to achieve greater thicknesses.

There is a range of materials/products that are suitable for patch repairing. These include:

- Portland cement mortars
- Latex and polymermodified cementitious mortars
- Epoxy mortars
- Concrete (larger repairs)

C3-7.3.1 Portland cement mortars

Care should be exercised in removing unsound and contaminated brickwork and preparing the area to be patched (clean and prepare edges). Consideration should be given to achieving good bonding. A low slump cement sand mixture is commonly used. Overhead repairs would generally be undertaken in stages in order to limit sagging of the mortar.

Silica fume-modified repair mortars that are specifically engineered to repair load bearing concrete and masonry are also available. Formulations that allow application by spray, pump and trowel methods on vertical, horizontal and overhead surfaces and mortars containing strengthening fibres (e.g. steel) are also available.
C3-7.3.2 **Latex and polymer modified cementitious mortars**

The installation procedure is similar to that for sand-cement mortars. However the working time is relatively short (approx 20 min). Therefore there are limitations on quantity, as the total task including placing, compaction, and finishing needs to be completed within this working time.

C3-7.3.3 **Epoxy mortars**

These types of repairs need to be carried out by experienced personnel. They are generally unsuitable for application at low temperatures, as they take too long to cure. Application of epoxy mortars should be restricted to thin sections (e.g. approx 20mm) and should only be applied to dry surfaces, as they won’t harden properly. Epoxy mortars are difficult to mix without suitable equipment. Working times are relatively short.

C3-7.3.4 **Concrete (larger repairs)**

Suitable for thicker applications. Larger repairs involving recasting with concrete are suitable where there has been more damage than is appropriate for patching. For example, extensive scouring of brick culvert inverts may be best repaired by the addition of a concrete wearing surface. Spalling due to impact damage may be repaired by the use of concrete.

Preference should be given to utilising cementitious products in order to ensure reasonable compatibility with brickwork properties.

Patches seem to perform best if their dimensions are “chunky” rather than forming thin sheets of mortar/concrete. A cementitious mortar or concrete, with or without resin modifiers in the mix, will usually be the best material to use for patch repairs. The mix may also contain plastic or steel fibres to enhance homogeneity, improve its plastic properties, or increase its toughness once hardened. Cementitious materials require curing for several days to ensure best results.

To be fully effective the patch material must be highly durable, bond well to the masonry, be relatively elastic and have minimal shrinkage characteristics. These properties are usually best met by proprietary modified cementitious mortars.

Larger repairs utilising recasting with concrete, often with a light reinforcing mesh, are suitable where there has been extensive scouring of brickwork (e.g. culvert inverts), or spalling (e.g. due to impact damage).

C3-7.4 **Sprayed Concrete**

Sprayed concrete is suitable when it is desirable to treat large areas of defective masonry. Silica fume based concrete is sometimes used, where rapid hardening and high strength and durability are required.

Unsound brickwork needs to be removed before the area to be treated is thoroughly cleaned.

Reinforcement is then placed in position (where applicable) and the sprayed concrete is applied by building up in thin layers and cured.

Sprayed concrete consists of a mixture of cement, aggregate and water forcefully projected onto a surface through a hose and nozzle by means of compressed air. In some applications fibres and admixtures are present.

Sprayed concrete develops excellent bond, is homogeneous and compact and does not sag, even on vertical walls and roof applications. It is therefore suitable for wide-ranging coating and lining applications.

There are two primary application techniques, one involving a dry mix and the other a wet mix process.

Sprayed concrete is specialised work that requires specialist engineering knowledge and requires a skilled experienced operator.

Spraying is most suitable where large areas of thin concrete (30 to 60 mm) repairs are required.
Steel reinforcement mesh is generally included for the thicker end of the range.

Dry mix applications are applicable to thin sections, and care needs to be exercised in ensuring proper curing.

This technique is only suitable for culverts at the upper end of the standard culvert range (e.g., 2000mm dia.) because of the size of the equipment and the application techniques involved. The spraying equipment nozzle needs to be held nearly perpendicular to the surface to be sprayed and at a distance of approximately 0.6m and 1.0m.

This repair type results in a slightly reduced waterway area, and generally a rougher finish than the original brick culvert. Therefore hydraulic efficiency is generally reduced.