Maintenance of Buried Corrugated Steel bridges in Regional Victorian Railway

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Abstract
This paper presents the maintenance strategy of Buried Corrugated steel bridges and culverts (ARMCO pipes) on V/Line railway network, focussing on their maintenance. Inspection, assessment, durability evaluation and mitigation of defective ones are the main maintenance aspect these buries pipes conspiring heavy railway axle loads.

There are more than 379 buried corrugated steel bridges and culverts (ARMCO pipes) within V/Line network which their diameters vary from 5.5 meters to 600 mm. This type of structure is a much less expensive option compared to other forms of structures and they have been used to replace the old timber bridges over creeks and rivers within the Victorian railway network in 1960’s and 70’s.

Having a thin metal wall that encounters water and saturated soil, vulnerable and sacrificial thin galvanization layer, and means that it has corrosion potential which can significantly reduce a structure’s design life. Based on the inspection photos, we estimated the effective lifetime of these buried structures. Severe Corrosion and section loss, excessive deformation, invert damages observed recently in several locations which show their effective lifetime is now about to finish. To manage the operation risks and increase the reliability of the structural integrity, a comprehensive plan for these assets has been considered. This maintenance program consists of (i) more frequent detailed inspection (ii) improve the inspection quality (iii) mitigation options including full lining and invert lining. Also, the effect of full lining and invert lining on the performance of these flexible pipes have been investigated and deformation and flexural moments have been assessed before and after lining.

1: Introduction:
There are about 5000 culverts and 1200 bridges on the Victorian regional rail network (V/Line network). Among these assets, 379 Buried Corrugated Metal Structures (BCMS or Armco pipes) have been used in 129 locations (assets). These Armco pipes were a cost-effective solution for the railway back in the 70s and 80s to replace timber bridges and culverts.

However, in spite of the use of galvanised steel plates, after about 60 years, they are considered to be nearing or past their expected/effective life – nominally between 30 to 50 years depending on environmental conditions. The diameter of these buried pipes is up to 5.5 m, and their thickness varies from 3 to 5 mm. Almost all of them have developed severe corrosion and section loss, particularly in their inverts due to the deteriorating protection layer, which naturally reduces over time. Major
maintenance works have been done to extend the serviceable life. However, after about 60 years, their useful lifetime is passed, and they are coming for renewal. In figure 3, a typical end of life Armco pipe asset has been shown.

![Image of Armco pipe asset](image)

Figure 1: Invert corrosion and zinc loss – pipe Diameter – 4 pipes, 1.8 m dia.- Gippsland line kp 167

Regarding their overall poor condition, in 2010, V/Line as the assets maintainer, started a comprehensive program to replace/line the defective ones. Since then, about 14,000 of Armco pipes have been replaced/lined, which is about 30% of all Armco pipes area which was initially 42,000 m². Table 1 lists the Armco pipes status within the V/Line network. Of those Armco pipes currently listed as unlined, 21 are reported to be either programmed for lining in the current year or to be under consideration for the lining.

<table>
<thead>
<tr>
<th>Description</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Armco assets</td>
<td>129 assets</td>
</tr>
<tr>
<td>Number of pipes</td>
<td>379 pipes</td>
</tr>
<tr>
<td>Max. diameter</td>
<td>5.5 m</td>
</tr>
<tr>
<td>Min. diameter</td>
<td>0.6 m</td>
</tr>
<tr>
<td>Total exposed area of the pipes</td>
<td>42000 m²</td>
</tr>
<tr>
<td>Number of assets have been lined/replaced</td>
<td>16</td>
</tr>
<tr>
<td>Number of assets with half lining/invert lining</td>
<td>8</td>
</tr>
<tr>
<td>Total fixed/replaced area</td>
<td>14,000</td>
</tr>
<tr>
<td>The remaining area</td>
<td>28,000 m²</td>
</tr>
<tr>
<td>Number of assets to be fixed in 3 years</td>
<td>56 assets</td>
</tr>
</tbody>
</table>

Table 1: Condition and status of Armco within the V/Line Network
2: Assessment and evaluation of the pipes:

According to V/Line’s standard, general inspection of pipes required every year and a detailed inspection is required every three years. The traditional approach for the general inspection is visual inspection combined with the overall assessment of the pipe geometry/shape. However, since there is no corrosion protection on the invert of most of the pipes and section loss has been started, non-destructive ultrasonic testing techniques are now being used widely during detailed inspection to make measurements of residual thickness.

![Figure 2: (left) Ultrasonic testing of thickness – (Right) Testing of thickness when the pipe is almost/fully submerged Armco pipe- Bald Hill swamp -2015 – Gippsland](image)

3: Australian standard approach to Armco pipes

AS 1762 “Helical lock-seam corrugated steel pipes - Design and installation” and AS/NZS 2041 “Buried corrugated metal structures Design methods” are the relevant Australian standards for design of Armco that contain recommendations for the use of suitable coatings and concrete invert lining to protect the internal and external surfaces. These standards nominate rates of corrosion for galvanised coatings and steel that are used to predict the design-life of Armco pipes.

However, the current Armco pipes within the V/Line network have been placed before these standards and according to site inspection reports, the actual rates of corrosion significantly exceed these nominated values. Predictions of design-life based on actual rates of corrosion yield design-lives that fall short of the current requirement 100 years. This implies that when estimating design-life, the highest recommended rates of corrosion must be used.

4: Corrosion rate of zinc layer and steel

Based on the available inspection data, we estimated the zinc layer loss rate and bare steel corrosion rate. These values are being used to give us some indication of the effective lifetime of the Armco pipes.
zinc coating loss
Based on the V/Line Armco pipes inspection data, 25 to 30 years after installation, corrosion appears on the invert which means zinc coating loss is about 3-5 microns/year considering the 85-micron thickness of zinc layer. Regarding water and sediment exposure based on AS 2041, “the invert of the structure below the usual waterline may, under certain conditions, be subject to abrasion and corrosion.” However, no specific data has been provided. This invert corrosion depends on several unknown conditions like the corrosiveness of water and sediment and abrasion of sediment particle. In addition to this type of corrosion, Armco pipes like other buried metal structures are subject to two other different exposure conditions as per below:

(i) Atmospheric exposure of the exposed area on the internal face of the pipe
(ii) Backfill exposure the soil-side surface of the pipe

Regarding Atmospheric exposure, based on AS/NZS 4680, requirements for a coating thickness of hot-dip galvanised plates when the thickness is between 3 mm to 5 mm category C3 environment of outdoor, is 75 to 85 micron. Estimated coating life at corrosion rate of 1.5 μm/year is about 50 years.

The corrosion rate for zinc on the soil-side of a BCMS is difficult to quantify as the soil-side surface cannot be easily inspected, and it is not possible to make direct assessments. According to AS 2041, the corrosion rate of zinc depends on the soil PH, drainage and the zinc section loss is between 2-4 microns per year.

![Figure 3: typical example f Zin layer loss- no section loss](image)

Corrosion of exposed Steel
Based on the rates we measured in the V/Line assets, the corrosion of bare unprotected steel without any protection is about 40-50 micron per year including delamination because of corrosion. The minimum steady-state rate for loss of steel thickness at active hotspots is likely to exceed 30μm per year when based on the loss rates for wet soil given in Table C3 of AS/NZS 2041. This means 15 years for a 3 mm plate to lose 25% of its thickness or 25 years when the thickness is 5 mm. This means
after about 50 years, 25 percent of the section is gone. Based on this value, we developed the following table regarding the zinc layer loss and corrosion rate.

<table>
<thead>
<tr>
<th>Original thickness</th>
<th>Corrosion later thickness</th>
<th>Zinc layer loss</th>
<th>Expected life of the zinc layer</th>
<th>Corrosion rate of bare steel</th>
<th>Expected time to loose 25% of the section</th>
<th>Estimated Total effective lifetime</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 mm</td>
<td>85 micron</td>
<td>3 - 5 micron</td>
<td>25-30 years</td>
<td>40-50 micron</td>
<td>12-15 years</td>
<td>35-45 years</td>
</tr>
<tr>
<td>5 mm</td>
<td>85 micron</td>
<td>3 - 5 micron</td>
<td>25-30 years</td>
<td>40-50 micron</td>
<td>25-35 years</td>
<td>50-65 years</td>
</tr>
</tbody>
</table>

Table 2: the estimated lifetime of 3 and 5 mm pipe

5 : Critical thickness/section loss: Case study- Morwell River

Armco pipes are flexible pipes that rely on soil-structure interaction to carry loads. Both the soil and steel pipes play a vital role in the structural design and performance of Armco pipes including installation method. This flexible design and non-uniform loads mean that there are axial loads as well as bending moment in the Armco pipes. Therefore, the thickness of the pipe and also its geometry is essential. The primary question after any detailed inspection of Armco pipes is what is the critical thickness of the pipe and when it is not safe to run heavy high-speed passenger and freight train on the corroded pipe. (axle load varies from 23 ton to 30-ton axle load). The relevant case study here is Morwell River bridge which includes 30 Armco pipes, 3.6 m each. The middle four pipes are located lower than other pipes, and there were more exposed to water and sediment corrosion. In October 2014, severe deformation of the pipes reported, and Gippsland line closed suddenly for a couple of weeks. The original thickness was 4 mm, however. The site investigation showed that due to severe corrosion, the section loss is 2.5 mm and 1 mm.

The Plaxis FEM back analysis showed that because of severe section loss, the factor of safety dropped from 1.9 to 1.3 (thickness 2.5 in the lower half) and 0.7 (if the section thickness became 1 mm). In other cased like Parwan Creek, same analysis gave us an idea that the critical section loss is 25 percent section loss in a large area which has an almost linear relationship with section loss. To answer this question, it needs to note that Armco pipes have been designed using the allowable stress design ASD design method. Based on these two recent case studies, when section loss is more than 25%, it is not safe to run Railway traffic on the corroded pipes.

<table>
<thead>
<tr>
<th>Thickness</th>
<th>Buckling load (kn)</th>
<th>Factor of safety</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 mm</td>
<td>800</td>
<td>2.5</td>
</tr>
<tr>
<td>2.5 – lower part</td>
<td>500</td>
<td>1.6</td>
</tr>
<tr>
<td>1 mm lower part</td>
<td>210</td>
<td>0.7</td>
</tr>
</tbody>
</table>

Table 3: factor of safety calculation of the pipes in 21.8 t axle load – non factored loads
When the thickness of the pipe is reduced due to corrosion, the moment of inertia and the cross-sectional area of the wall are decreased with a resulting reduction in pipe strength in dead and live loads. In addition, this will increase the deformation of the pipe and soil under the sleeper. The back analysis of the pipe strength shows that the possibility of pipe failure remains unaffected until about 40 years of service life, then it gradually changes as time increases and after 50 years, the probability of failure rises drastically. The risk associated with the corroded and old Armco pipe is unacceptable and to be mitigated. Regarding the possible risks, as a result of this severe corrosion, two primary failure modes are expected:

**Failure mode 1: Severely deformed and weak pipe:**

This happened in Morwell Armco pipes: Due to severe corrosion, the flexural capacity of the pipe and its axial capacity reduced. As a result, the reliability of the asset in live load decreased drastically. Track geometry issue is the instant result of this mode. This mode can develop to the major failure of the corroded pipe.

**Failure mode 2: major crushing**

Over time, corrosion of pipe will result in the reduction of wall thickness, formation of pipe perforations (holes), and the eventual collapse of the Armco. Both modes are not acceptable and pose an unacceptable level of risk to passenger and freight trains considering the axle load and dynamic nature of the pipe. As a result, before losing 25 percent of the thickness, remedial actions to be considered:

![Figure 4: Corrosion and section loss of the pipe – Morwell river bridge](image)

From asset management perspective, the likelihoods of buried pipe failure due to corrosion induced excessive deflection increased drastically. This will reduce the asset reliability and poses a considerable risk to the railway operation.

**6: Remediation and replacement of corrosion-damaged BCMS**

Based on the recent experience on the asset management of Armco pipes, there are several methods to strengthen corroded Armco pipe as per below
Temporary solution | Mid Term - Corrosion protection strengthening | Long term solution
---|---|---
Props – toms- protection rings | Lining with plastic liner | Structural lining (Full lining Slide RCP pipes)
Speed restriction | Fold and forms | Replacement with precast units
Load restriction | Plastic sleeves | • Half lining
| | | • Invert lining

Replacement is considered when the Armco small and diameter is less than 2.5 m. Concrete lining with reinforcement is by far the most frequently used method since it relatively low cost and no occupation required. Among these methods, full lining with reinforcement shotcrete is the prefered option.

Figure 5: Left: corroded Armco pipe – Right: the Armco pipe after reinforced shotcrete lining

Figure 6: Invert lining of corroded invert
7: Conclusion:
This paper presents the maintenance strategy of Buried Corrugated steel bridges and culverts (ARMCO pipes) on the V/Line railway network, focussing on maintenance and asset management and risk management. Also, based on the remaining thickness of the corrosion pipes, we assessed the factor of safety of these pipes.

Based on the inspection findings, we estimated the effective lifetime of these buried structures and developed an asset management plan to manage to manage the operational risks and increase the reliability of the structural integrity. This maintenance program consists of (i) more frequents detailed inspection (ii) improve the inspection quality (iii) mitigation options including full lining and invert lining.

Based on the presented case study, the Armco pipe is not reliable after 40-50 years because of three various sources of exposure as the source of corrosion. Also, the back analysis of the pipe capacity revealed that only maximum 25% section loss on the large area of the pipe could be tolerated and beyond that this asset is not reliable for railway loads and to be fixed.

8: References:

1: Guidelines for Design, Construction, Monitoring and Rehabilitation of Buried Corrugated Metal Structures, AUSTROADS technical report, 2011
2: AS5100, bridge design standard, 2017


5: CSPI- Handbook of Steel Drainage & Highway Construction Products, corrugated pipe institute, 2010

5: Independent engineering assessment: Morwell River bridge, Reference: 244199, Aurecon

Revision: 1, 20 October 2014

6: AS/NZS 4680: Hot-dip galvanized (zinc) coatings on fabricated ferrous articles

7: AS 1762, Helical lock-seam corrugated steel pipes - Design and installation

8: AS/NZS 2041, Buried corrugated metal structures Design methods