OTERANGA BAY TO HAYWARDS A LINE (CHURTON PARK SECTION) RECONDUCTORING

ATTACHMENT A: CONDITION ASSESSMENT REPORT

Transpower New Zealand Limited
Keeping the energy flowing

TRANSPOWER

Table of Contents

1 Executive Summary

The Oteranga Bay – Haywards A (OTB-HAY A) transmission line is presently strung with duplex conductor called Moa. This report discusses the condition of the Churton Park section (25 spans) of this transmission line.

The Churton Park section of the OTA-HAY A line is 9.5km long and was constructed in 1991-1992 to deviate the existing OTB-HAY A line around the Churton Park residential area. The conductor was new when installed, giving a service life to date of 26-27 years (in 2018). The life of this conductor would typically be much longer, but manufacturing defects in the conductor has meant the conductor has deteriorated faster.

This section of line is in a severe, corrosive, environment, due to significant airborne salt deposition from the coast nearby. The remainder of this line has already had the conductor replaced between 2008 and 2012 due to condition.

Conductor condition assessment has shown the conductor on this section of the line requires replacement within the next three years. Corrosion defects have been identified on this section of line through testing and aerial surveys which are now beyond replacement criteria.

Until the Moa conductor is completely replaced, on-going inspections and maintenance will be required to ensure the risk of a conductor failure is appropriately managed. This is likely to be in the form of regular close aerial inspections and conductor repairs, as required. The difficulty with detecting defects on this conductor type, combined with the public safety implications and critical role of the HVDC in the network, is such that continuing to manage issues with inspection and corrective maintenance will be expensive. It will not adequately address the risk of conductor failure in the medium- to long-term.

2 Introduction

This document is the Condition Assessment report for the Churton Park section of the OTA-HAY A line reconductoring listed project application.

2.1 Purpose

The purpose of this report is to outline condition assessment information which has led to the need to replace the Churton Park section of conductor on the OTA-HAY A line.

2.2 Document Structure

This report forms part of the OTA-HAY A line reconductoring listed project application.

3 Why does the conductor need to be replaced?

Replacement of the degraded conductors on this line section in RCP2 is prudent considering:

- corrosion defects have been identified on this section of line through Cormon testing and close aerial surveys, with recent surveys now detecting defects beyond replacement criteria
- the condition and high rate of deterioration observed to date
- the lower steel to aluminium ratio. As 70% of the strength of this conductor is in the aluminium, galvanic corrosion lowers the strength of the conductor
- the critical role of the HVDC assets in the electricity market
- high circuit loads and HVDC current distribution
- public safety considerations – this line crosses other infrastructure including State Highway 1, the main trunk railway line (including high volume commuter train routes), other high voltage power lines, and two city roads
- the uncertainty associated with condition assessment, and the difficulties visually detecting corrosion defects in the large Moa ACSR/AC conductor.

4 Background

The OTA-HAY A line is strung with Moa ACSR/AC conductor (with aluminium-clad steel core wires) for the full length of the line. The line section (the Churton Park section) between Tower 45A and Tower 68, which requires replacement, was commissioned in 1991-1992 as part of the newly constructed Churton Park Deviation. The conductor was new when installed, giving a service life to date of 26-27 years (in 2018).

The rest of the OTA-HAY A line (excluding the newer Churton Park Deviation) was replaced between 2008 and 2012. The most coastal section of the line (Oteranga Bay to T10) had already been replaced due to condition in the 1980s.

The Churton Park section of the OTA-HAY A line (Tower 45A – Tower 68) is in a severe corrosive environment, due to significant airborne salt deposition from the coast nearby.

4.1 ACSR conductor

ACSR cable is a specific type of high-capacity, high-strength stranded conductor. The outer 71 outer strands are aluminium, chosen for its excellent conductivity, low weight, and low cost. The central core consists of seven steel strands for the strength required to support the weight without stretching the aluminium due to its ductility and higher thermal expansion. This gives the cable an overall high tensile strength.

The tensile capacity of ACSR conductor is calculated by combining the relative strengths of the aluminium strands and the steel core wires. In the case of Moa ASCR/AC conductor the aluminium strands contribute approximately 70% of the strength (~0.9% per strand) and the steel the remaining 30%.

Predicting the end-of-life of ACSR conductors is very difficult as they are prone to accelerated aluminium corrosion near end-of-life – particularly in corrosive environments. Galvanic cells (due to dissimilar metals – steel and aluminium) are formed where the aluminium coating on the steel core wires has been depleted or perforated. Once the aluminium coating of the steel core wires has corroded or abraded, the aluminium strands ‘sacrifice’ themselves to protect the steel – increasing the rate of aluminium corrosion and loss of strength. Galvanic corrosion between aluminium and steel results in much higher corrosion rates than atmospheric corrosion.

The primary loss of strength in Moa ACSR/AC occurs from loss of the aluminium section – noted by visible aluminium oxide build-up and, in the worst cases, bulging of the conductor. From previous conductor bulge analysis on ACSR conductor we can estimate the loss of aluminium section from the bulge diameter. Bulges are more difficult to detect on the large Moa ACSR/AC conductor. Under high mechanical loading, the loss of strength through corrosion can result in tensile failure of the conductor.

Another failure mode exists where reduced conductive area increases the temperature in the steel core causing overheating. Significant corrosion of the aluminium strands leads to a loss of the conductive cross-sectional area as well as pitting of the steel core wires. Under electrical load this leads to an increase in temperature in the steel core wire causing overheating, annealing and ultimately complete tensile failure (known as ‘burn down’).

The likelihood of ‘burn down’, once area loss is advanced, is also greater for this line compared to lines in equivalent condition with lower electrical loads. This greater likelihood is due to higher electrical loads and HVDC current being distributed more evenly across all conductor strands (rather than predominantly in the outermost layers as occurs in HVAC conductors due to the ‘skin effect’). Both factors increase the likelihood of ‘burn down’, once area loss is advanced.

The higher electrical loads on the OTA-HAY A line mean corrosion rates are likely to be greater. Higher electrical loads and higher operating temperatures can cause greater corrosion rates – corrosion rates double for every 10°C increase in temperature. In some environments, this may be partially offset by a reduced time of wetness if conductors dry out faster (an electrolyte is required for corrosion). This line section is in a relatively moist environment so the conductor may not remain dry for long.

Degradation of conductor condition depends primarily on the corrosiveness of the local atmosphere, but also on vibration, the conductor construction (such as greasing) and the conductor material.

The expected life of ACSR/AC conductors has been influenced by manufacturing deficiencies known as “Grease Holidays” where grease has not been applied, or missed, during the manufacturing process”. The expected life of Grease Holiday conductors in salt-laden environments as used in the 1990s is approximately 55 years, but our experience of some conductors is they do not last anywhere near this long. The following extracts from the conductor fleet strategy TP.FL 01.00 give more detail on these corrosion mechanisms.

> **Grease holiday corrosion:** Grease applied to the core wire during manufacture provides a barrier to galvanic corrosion and can significantly extend conductor life. However, if it is applied poorly it is of little or even negative benefit. Experience has shown that grease application was poorly managed for conductors on many lines throughout the country, resulting in sections of core wire where no grease was applied at all (‘grease holidays’). Grease holidays expose small localised areas of the core wire to the environment that results in higher than normal corrosion rates. In 2005, a span on the BPE-HAY A line failed due to corrosion after only 25 years in service.

However, modern manufacturing techniques and monitored grease application have helped address concerns over grease holidays in modern conductors.

4.2 Replacement Criteria

The replacement criteria for ACSR conductors applies to the OTB-HAY-A line. The applicable Transpower replacement criteria is 20% loss of tensile strength or 15% section loss.

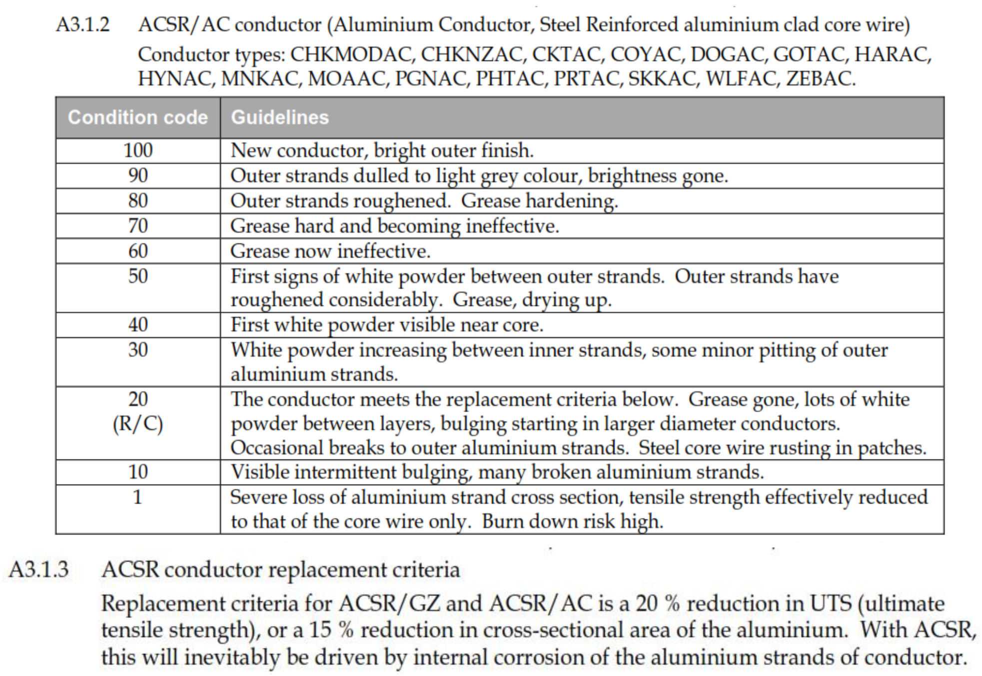
When assessing the condition of in-service conductors all assessment is undertaken in accordance with the condition assessment service specification TP.SS 02.17 - Part C[1]. This service specification ensures that all conductors throughout the country are assessed against a common standard giving comparable and repeatable results. Figure 1 shows the coding system used for ACSR/AC conductor.

The replacement criteria for tensile strength is chosen to ensure there is sufficient residual strength in the conductor to meet the maximum allowable design loads. The Transpower loading code TP.DL 12.01[2] gives the maximum allowable design loads for the conductor. The actual maximum utilisation of a span of conductor is highly dependent on many factors such as span length, elevation and location and as such this is also considered when determining the appropriate time to replace conductor.

---

[1] TP.SS 02.17 Transmission line condition assessment, Part C: Insulators and conductors

[2] TP.DL 12.01 Transmission line loadings code



A3.1.2 ACSR/AC conductor (Aluminium Conductor, Steel Reinforced aluminium clad core wire)

Conductor types: CHKMODAC, CHKNZAC, CKTAC, COYAC, DOGAC, GOTAC, HARAC, HYNAC, MNKAC, MOAAC, PGNAC, PHTAC, PRTAC, SKKAC, WLFAC, ZEBAC.

Condition code	Guidelines
100	New conductor, bright outer finish.
90	Outer strands dulled to light grey colour, brightness gone.
80	Outer strands roughened. Grease hardening.
70	Grease hard and becoming ineffective.
60	Grease now ineffective.
50	First signs of white powder between outer strands. Outer strands have roughened considerably. Grease, drying up.
40	First white powder visible near core.
30	White powder increasing between inner strands, some minor pitting of outer aluminium strands.
20 (R/C)	The conductor meets the replacement criteria below. Grease gone, lots of white powder between layers, bulging starting in larger diameter conductors. Occasional breaks to outer aluminium strands. Steel core wire rusting in patches.
10	Visible intermittent bulging, many broken aluminium strands.
1	Severe loss of aluminium strand cross section, tensile strength effectively reduced to that of the core wire only. Burn down risk high.

A3.1.3 ACSR conductor replacement criteria

Replacement criteria for ACSR/GZ and ACSR/AC is a 20 % reduction in UTS (ultimate tensile strength), or a 15 % reduction in cross-sectional area of the aluminium. With ACSR, this will inevitably be driven by internal corrosion of the aluminium strands of conductor.

Figure 1: Extract from TP.SS 02.17 Part C

4.2.1 Condition Assessment Types

We carry out regular condition assessments on transmission lines. Conductor condition is assessed based on a combination of loss of section and loss of tensile strength. The assessments produce a condition assessment (CA) score for various components on a scale from 100 (new) to 20 (replacement or decommissioning criteria).

Line assets are generally assessed every eight years and pole lines every six years.

When the CA score of any component is less than 50, the assessment frequency is generally increased. The aim is to ensure no component can deteriorate by more than 50% between assessments (such as from CA score 60 to 30). Sites with very high degradation rates or criticality may be assessed more frequently.

Ground-based and structure-based visual assessments yield valuable results for steel earthwire because any rusting can be more readily observed. For ACSR and AAAC conductors, such assessments are of very limited use in predicting end-of-life. This is because degradation (corrosion, fatigue, fretting) generally begins on the inside of the conductor, so is invisible until well advanced. Even detecting white corrosion product or small bulges is extremely difficult from the ground when looking up into the sky.

The condiction assessment (CA) approach for conductors is based on the assessed and forecast condition. Due to the limitations of ground-based and structure-based CA, we use more intensive inspection methods as the condition of the conductor gets closer to the replacement criteria. These inspection methods include close visual inspection from a helicopter, and the use of a line-crawling robot (Cormon testing) that provides a reliable assessment of the condition of the coating on the inner steel core wires. Samples may be also taken for analysis.

4.3 Condition of the OTB-HAY A line (T45A – T68) Conductor

4.3.1 Conductor CA undertaken

For the OTB-HAY A line Churton Park section, conductor CA has been undertaken using several different methods, these are summarised in Table 1 below with a further summary of results given below:

- Cormon (Eddy Current) Testing
- Close Aerial Surveys
- Destructive metallurgical testing
- Accelerated corrosion tests.

Table 1: Summary of conductor testing and inspection

	Pre 2011	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**
Cormon Eddy Current Testing		14 tests	10 tests			***12 tests***		
Close Aerial Survey			Yes	***Yes***	***Yes***	***Yes***		***Yes***
Accelerated corrosion tests				***Yes***				
Destructive metallurgical testing	Yes		Yes					

Results and analysis associated with the reports shown in **bold to the right were not available for the RCP2 submission.*

At the time of submitting the RCP2 proposal, there was an indication that the condition of the conductor on this section was going to potentially require conductor replacement during the RCP2 period. At that time, no defects identified had reached Transpower's replacement criteria, but observed evidence of accelerating degradation compared to earlier testing suggested replacement criteria was likely to be reached during RCP2.

Subsequent CA undertaken since the submission of the RCP2 proposal has verified the need for replacement due to condition deterioration before the end of the RCP2 period. Conductor bulging has since been identified in a number of areas along the line. Bulging indicates that replacement criteria has been exceeded – it also implies that the likelihood of bulging in other areas is likely to soon follow. Close aerial surveys have identified a number of areas showing obvious signs of corrosion and the number of detectable bulges increased in the 2017 inspection.

4.3.1.1 Cormon Testing Summary

The Cormon detector is a non-destructive test device that uses eddy current technology to estimate the remaining thickness of zinc or aluminium coating on the steel core wires of ACSR conductors. The condition of the coating on the inner steel core wires contributes to knowledge of conductor condition and gives prior warning of where conductor budging will occur.

The Cormon detector is placed on the conductor by linemen span-by-span. The device then self-propels to the other end of the span, taking measurements every 5mm to 10mm. Results from this device have proven to be remarkably accurate, providing an excellent indication of conductor condition without the need for destructive sample testing.

We have carried out a Cormon test programme annually since 2006. Approximately 1,900 sub-conductor spans have been tested to date. Our RCP2 strategy was to begin Cormon testing 10 years before predicted end-of-life, and then establish appropriate times for repeat inspections to ensure end-of-life predictions are refined as they approach. Our new strategy will be to start this detailed inspection earlier, to provide a sufficient forward lookahead and to meet current planning timeframes.

It is important to note that the Cormon test programme is a sample-based programme, with only a small proportion of wires and spans typically tested with this equipment.

The output of the Cormon analysis is a classification of the conductor into 5 categories for conductor condition as shown in Table 2 below. A new conductor would be expected to have 0% coating loss (indicated Green) and the condition of conductors deteriorate from that point over time toward 100% (Black).

Table 2: Cormon testing categories

Class	Coating loss	Colour Code
1	0-5%	Green
2	5-20%	Yellow
3	20-50%	Orange
4	50-80%	Red
5	80-100%	Black

An example of the results from two spans are shown in Figure 2 and Figure 3.

Figure 2: Example of Cormon results for a single wire span of conductor from OTB-HAY A (T45A-T45B)

The Cormon results for this line show deterioration of the aluminium coating on the steel strands, with many localised defects where advanced or complete coating loss is detected. Deterioration of the aluminium coating exposes the steel, resulting in galvanic corrosion between the steel and aluminium strands, which leads to decreased strength, reduced conductive area, and potential overheating should enough aluminium cross section be lost. Figure 2 and Figure 3 show numerous localised sections reporting advanced loss of aluminium coating on the steel core wires (Class 4 & Class 5). These areas of advanced coating loss are likely to have some exposed steel, and are where the aluminium conductor strands will begin to sacrifice themselves and accelerated loss of cross-sectional will be occurring.

Figure 2 and Figure 3 also illustrate that that these areas of coating loss can vary in length and are distributed along the wire, which can make localised repairs difficult, ineffective and expensive.

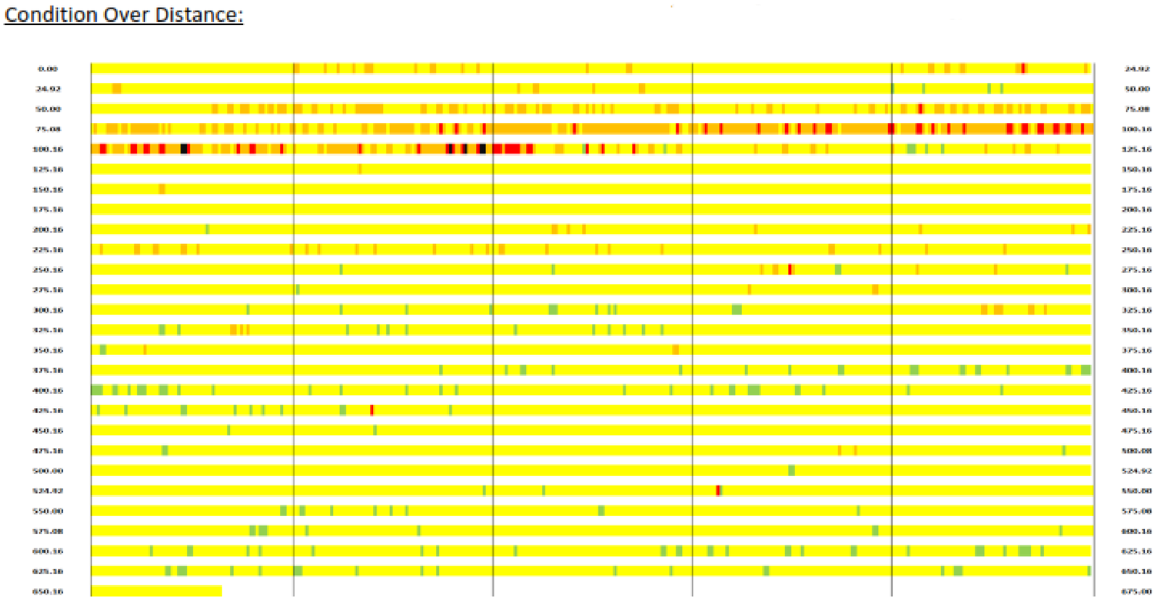


Figure 3: Cormon results for a single wire span of conductor from OTB-HAY A (T67A-T68)

Based on the Cormon results we can reasonably expect undetected internal corrosion is occurring within the conductor, which cannot be seen in close aerial surveys at this time.

These spans can be expected to show visible signs of bulging and loss of aluminium cross section in the next few years as the aluminium strands begin to sacrifice now that the aluminium coating on the steel core wires is depleted or perforated. The conductor should be replaced prior to this widespread corrosion and breakdown being evident.

4.3.1.2 Close Aerial Survey Summary

Using a helicopter to undertake a close aerial survey is considered the best method of identifying conductor bulges/defects or areas requiring further monitoring known as "markers". A conductor bulge or defect is characterised by a noticeable bulge or significant corrosion product on the conductor and these correspond to a CA score of 20 or less depending on the diameter of the bulge. A marker is an area of conductor that is showing some discoloration but visible bulging or significant build-up of corrosion product is not occurring yet. These markers can be re-evaluated during subsequent inspections and are generally good indicators of imminent conductor bulging. Since 2012, five close aerial surveys have been undertaken on this line. These surveys have identified obvious signs of corrosion, with the latest survey in 2017 identifying corrosion in 32% of the spans. The number of detectable bulges also increased in the 2017 inspection, requiring further monitoring.

Figure 4 shows the increase in observed bulging on the line section, indicating replacement criteria has been reached or exceeded.

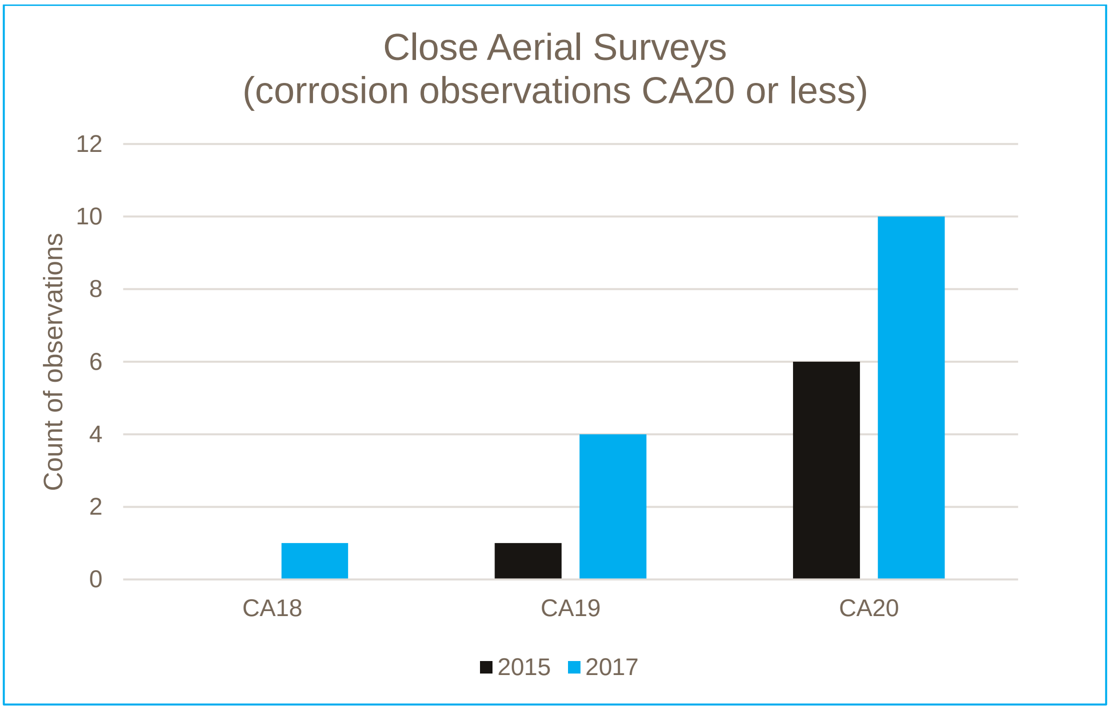


Figure 4: Observations of conductor bulging CA20 or less during close aerial surveys

Conductor bulging is more difficult to assess on this conductor type. Bulging requires the corrosion product to fill all internal voids within the conductor before the outer strands then begin to bulge. Moa conductor has more internal voids due to the additional layer of aluminium strands so more internal corrosion and aluminium loss occurs before bulging can be visibly observed. At 15% aluminium loss (replacement criteria), the expected increase in conductor diameter is less than 1mm for Moa conductor. A change in diameter of this magnitude is not readily detectable though visual inspection so it is difficult to identify when replacement criteria has been met. This factor, combined with the criticality, high electrical loads, and even current distribution on the HVDC circuits, means it is not prudent to use higher area losses and widespread conductor bulging to justify replacement.

The photographs below show corrosion of the OTA-HAY A line conductor and the ACSR conductor degradation mechanism described above Figures 5 and Figure 6.

Figure 5: Conductor defect on span 54A-55A shows extent of white corrosion product on the underside of the conductor before removal from the line

Figure 6: Exposed steel on aluminium-clad steel core wires (span 67A – 68)

4.3.1.3 Destructive metallurgical testing

Lab tests on conductor samples in 2012 confirmed that galvanic corrosion is occurring in localised areas, with exposed steel and losses of aluminium cross-section of up to 2.5% (observed after only ~26 years in service). The grease is tacky and losing adhesion to the strands in sections resulting in decreased corrosion protection. Pitting depths observed on the aluminium strands also suggest that galvanic corrosion is likely to be common across the section of line. These samples were selected based on Cormon test results and notable build-up of corrosion product, but did not exhibit the conductor bulging now observed in close aerial surveys.

Accelerated corrosion tests on ex-service conductor have shown that the galvanic corrosion rates within the conductor are many factors higher than atmospheric corrosion rates and overall corrosion rates for ‘as new’ conductors.

5 Ongoing maintenance

On-going inspections and maintenance will be required to ensure the risk of a conductor failure is appropriately managed until the Moa conductor is replaced. This is likely to be in the form of regular close aerial inspections, and conductor repairs as required. The difficulty detecting defects on this conductor type, combined with the public safety implications and critical role of the HVDC in the network is such that continuing to manage issues with inspection and corrective maintenance will be expensive and will not adequately address the risk of conductor failure in the medium to long term.

At present, the likelihood of catastrophic failure is low due to the inspection and repair strategy in place, but is increasing due to the localised instances of corrosion beyond or approaching replacement criteria. The consequence of and overall risk associated with an HVDC failure is high.

Outages for repairs are relatively difficult to obtain, and affect the electricity market and the HVDC availability performance measure. This further limits our ability and desire to implement a ‘patch repairs’ approach on this line.

At intervention for replacement or maintenance, the residual tensile capacity of the conductors must also be sufficient, considering construction loads and safety factors.

6 Condition Assessment Conclusion

The Moa ACSR/AC conductor between Tower 45A and Tower 68 (9.5km) on the OTB-HAY A is recommended for replacement by June 2019.

Replacement criteria for ACSR conductors are 15% loss of cross-sectional area, or 20% loss of tensile strength. The increasing instances of conductor bulging confirm that this replacement criteria has been met, and Cormon testing confirms that there is widespread corrosion on this line section that is not yet detectable in close aerial surveys.

In summary, replacement is supported based on the defect observations below:

1. Cormon testing has identified numerous locations of advance aluminium-cladding loss.
2. Conductor sample testing has confirmed that galvanic corrosion is occurring.
3. Accelerated corrosion testing has confirmed that aluminium corrosion rates accelerate significantly once galvanic corrosion is occurring (note, Moa ACSR/AC gets 70% of its structural strength from the Aluminium).
4. Close aerial surveys are starting to detect conductor bulging – an indication of aluminium losses beyond replacement criteria.
5. Extrapolating the Cormon test results, we expect that there are hundreds of instances where galvanic corrosion is occurring within this short line section. A portion of these localised defects are expected to have reached replacement criteria already, but are not yet detectable in close aerial surveys. These corrosion defects are widespread and will continue to degrade.

Additional testing to further quantify degradation is not required as it will not allow a material change in our strategy for maintaining or replacing this particular conductor.