

CENTRAL PARK – WILTON B CONDUCTOR RELACEMENT

Attachment A CONDITION ASSESSMENT

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1 | Executive Summary

The Central Park – Wilton B (CPK-WIL B) line is presently strung with duplex Zebra conductor for all but the final 5 spans into the Central Park substation which is strung with a simplex Chukar conductor. This line is in a highly corrosive environment with a lot of air borne salts due to the close proximity to the coast.

Conductor condition assessment has shown that the Zebra section of the line has reached replacement criteria and requires replacement. The Chukar section of the line has also been assessed, but due to the different structure of this conductor, it has performed better than the Zebra in the corrosive environment. It is estimated that the Chukar has 10 years remaining life and should be scheduled for replacement in the later stage of RCP3.

Experience from previous testing and inspections has established that a Zebra ACSR/GZ conductor of this era has an estimated life of 40 years in a highly corrosive environment. The CPK-WIL B line was commissioned in 1978 and therefore the conductor has performed as expected based on previous experience.

Until the Zebra conductor is completely replaced, on-going repairs and inspections will be required to ensure the risk of a conductor failure is appropriately managed. This is likely to be in the form of isolated conductor defect removal and close aerial inspections.

2| Introduction

This document is a Condition Assessment report for the Central Park – Wilton B line conductor replacement listed project application.

2.1 Purpose

The purpose of this document is to outline condition assessment information which has led to the need to replace the conductor on the Central Park – Wilton B line.

2.2 Document Structure

This report forms part of the Central Park – Wilton B line conductor replacement listed project application.

3 | Condition Assessment

3.1 Why does the conductor need to be replaced?

The main reasons for this conductor reaching end of life are as follows:

1. Widespread corrosion of the steel core wire and aluminium strands due to 'grease holidays'; (sections that did not receive grease during manufacture); and
2. Dog bone spacer damage due to the design of some original conductor spacers

3.2 Background

The Central Park – Wilton B line is a 110kV double circuit line and was first commissioned in 1978 and is presently strung with a duplex Zebra ACSR/GZ conductor for the majority with several spans at the Central Park end strung with a simplex Chukar ACSR/GZ conductor. Due to corrosion caused by the severe coastal climatic conditions the Zebra ACSR/GZ conductor has now reached end of life and needs replacement. The Chukar section of the line is excluded from the scope of replacement. We have undertaken testing and investigation on this section which has shown it has performed better in the corrosive environment due to the different conductor structure and has an estimated remaining life of 10 years.

The length of the Zebra section planned for replacement is 26 spans totalling approximately 11.7km.



3.3 ACSR conductor

Aluminum conductor steel-reinforced cable (ACSR) is a specific type of high-capacity, high-strength stranded type of conductor. The outer strands are aluminium, chosen for its excellent conductivity, low weight and low cost. The centre strand is of steel for the strength required to support the weight without stretching the aluminium due to its ductility. 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 wire. In the case of Zebra ACSR conductor, with 54 aluminium strands and 7 steel strands, the aluminium strands contribute approximately 50% of the strength (~1% per strand) and the steel the remaining 50%. Extensive study has now found that ACSR/GZ conductors are prone to accelerated corrosion in salt laden areas as the galvanic cells are formed due to the dissimilar metals (steel, zinc and aluminium). The addition of grease between the zinc and aluminium creates a protective barrier against this.

Once the galvanised coating of the steel core has galvanically corroded it is found that the steel core wire does not corrode appreciably because the aluminium strands “sacrifice” themselves to protect the steel. Loss of strength therefore occurs from loss of aluminium section – noted by visible aluminium oxide build up, and in the worst case, bulging of the conductor. From previous conductor bulge analysis on ACSR conductor we can get an indicative estimate of the loss of aluminium section from the bulge diameter.

Significant corrosion of the aluminium strands leads to a loss of the conductive cross sectional area as well as pitting of the steel core wire. Under electrical load the reduced area leads to an increase in temperature of the aluminium, which in turn accelerates the corrosion process. Conductor failure is typically caused by the steel core wire overheating and effectively burning down, or when exposed to high load conditions that exceed the remaining strength of the conductor.

Today’s modern equivalent conductor is greased ACSR/AC – an ACSR conductor with an aluminium clad core wire. The advantage of an aluminium clad core is that it removes the galvanic cell between the previously used galvanised core (zinc) and the dissimilar aluminium strands. In addition, in areas of high corrosion Transpower now specifies a Type 2 greasing to IEC 61089 (greasing to the outer layer of the conductor). The figure¹ below shows the expected conductor life for the different conductors and corrosion zones in New Zealand.

Type	Benign	Low	Moderate	Severe	Very Severe	Extreme
ACSR-GZ Greased*	157	126	99	73	54	38
ACSR-GZ Grease Holiday	121	96	74	53	38	26
ACSR-GZ Ungreased	114	90	70	50	35	24
ACSR-AC Greased*	180	143	113	91	70	47
ACSR-AC Grease Holiday	126	113	88	71	54	35
AAAC Greased	160	139	120	103	87	70
Copper	117	104	90	77	65	54
SC/GZ	80	63	49	35	25	17
SC/AC & SC/CC	96	75	59	48	36	23

Figure 1 - Expected conductor life for different conductors in different corrosion zones

3.4 Failure modes

As seen in the figure above, the expected life of ACSR/GZ Grease Holiday (GZ meaning galvanised core) conductors in salt-laden environments as used in the 1980s is approximately 40 years. The points of failure being identified today are predominantly where grease has not been applied, or missed, during the manufacturing process, known as ‘grease holidays’ or at

points known as dog bone spacer damage. The following extracts from the conductor fleet strategy TP.FL 01.00ⁱ give more detail on these corrosion mechanisms.

Grease holiday corrosion: As discussed in subsection 2.1.3 above, 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.

Dog bone spacer corrosion: A number of lines in the network with twin bundled conductors have external corrosion damage from early 'dog bone' spacers. This corrosion occurred through the late 1980s to early 1990s as a result of incompatible rubber in contact with the conductor. The majority of damage is confined to the outer layer of the conductor. Preform rods have been applied as a permanent repair. Sampling and metallurgical assessment suggest the corrosion mechanism is relatively benign now that the incompatible rubber has been removed. Some lines in more coastal areas require implosive repair sleeves to be fitted, as damage is beyond the repair capabilities of the pre-form rods.

Examples of these two types of failure mechanisms are shown below in Fig 1 and Fig 2.



Figure 2 - Conductor bulge due to grease holidays (CPK-WIL B Span 14-15)



Figure 3 - Example of dog done spacer damage as seen on the BPE-WIL A line

Recent conductor failures on other lines strung with similar conductor has greatly improved the knowledge and awareness of these failure mechanisms. The main cause is identified as corrosion of the aluminium strands and steel core wire, with the steel strands yielding under electrical load (burn-down). As noted, bulging occurs when galvanising on the steel core wire is depleted and the aluminium strands corrode, forming white aluminium oxide which expands within the conductor.

Experience has shown that once a conductor bulge is first detected there is approximately two years of operation remaining before that section of conductor needs to be repaired or replaced. Once bulging occurs there is also an inherent risk with this timeframe as factors such as location, degradation rate and line load need to be also considered, i.e. the rate of degradation is not typically linear, and can differ for different sections of the same line.

3.4.1 Replacement Criteria

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 Cii. This service specification ensures that all conductors throughout the country are assessed against a common standard giving comparable and repeatable results. Figure 4 shows the coding system that is used for ACSR/GZ conductor. This replacement criteria is also reiterated in the fleet strategy, as shown in Figure 5.

The replacement criteria level chosen ensure there is a correlation between the maximum allowable design loads and the residual strength in the conductor. The Transpower loading code TP.DL 12.01iii gives the maximum allowable design loads for the conductor. The actual maximum utilisation of a span of conductor is highly dependant 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.

A3 Conductor Condition Assessment Guidelines
A3.1 ACSR (GZ) conductor (zinc coated core wire)

Condition code	Guidelines
100	New conductor, with 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	Start of core wire zinc loss.
50	First signs of white powder between strands. Outer strands have roughened. Grease, drying up. Core wire zinc still intact, but getting depleted.
40	Zinc on core wire depleted in isolated spots. No rusting started. First white powder visible near core.
30	White powder increasing between inner strands, some minor pitting of aluminium strands, zinc coating on core wire depleted in patches, specks of rust appearing on wire.
20 (R/C)	Grease gone, lots of white powder between layers, bulging starting in larger diameter conductors, occasional breaks to outer aluminium strands, severe corrosion affecting cross section of some inner strands. Steel core wire rusting in patches but no loss to cross section or UTS of steel core. 20 % loss of conductor UTS.
10	Visible intermittent bulging, many broken aluminium strands, patchy surface rusting on core wire.
0	Severe loss of aluminium strand cross section, tensile strength effectively reduced to that of the core wire only. Burn down risk high.

Figure 4 - Extract from TP.SS 02.17 Part C

Conductor replacement criteria

Conductor condition is assessed based on a combination of loss of section and loss of tensile strength. AAAC conductors are deemed to have reached replacement criteria at 15% loss of strength or section loss and at 10% for copper. For ACSR conductors, the replacement criteria is set at 20% loss of tensile strength and 15% section loss. These values are generally in line with those used by other international utilities.

Figure 5 - Extract from Fleet Strategy

3.5 CPK-WIL B Conductor Condition

For the CPK-WIL B line, conductor condition assessment 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

Table 1 - Summary of conductor testing and inspection

	Test 1	Test 2	Test 3	Test 4
Cormon Eddy Current Testing¹	March 2010 – 10 spans	December 2012 – 3 spans	March 2014	
Close Aerial Survey	2005 – Full Line	2011 – Full Line	2012 – Full Line	2013 – Full Line
Metalurgical Testing²	2007 – 1 sample	2009 – 2 samples		

¹Only the results for the Zebra conductor section are reported on in this report.

²In addition to the testing specifically undertaken on the CPK-WIL B line, 3 samples were also taken from the BPE-WIL A line, which has the same conductor, to investigate Dog Bone spacer damage. This line is in the same relative location as the CPK-WIL B line and as such these results are relevant to this line.

3.5.1 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 wire of ACSR conductors. 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. Some 1,200 sub conductor spans had been tested by February 2013. Although some catch-up was required initially, the programme is now at a stage where it can follow a prioritised listing of assets based on their predicted end of life. Our strategy is to begin Cormon testing some 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 approach¹.

The output of the Cormon analysis is a classification of the conductor into 5 categories for conductor condition as shown in Table 2 below. An example of the results from one span are shown in Figure 6.

Table 2 - Cormon testing categories

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

Condition Over Distance:

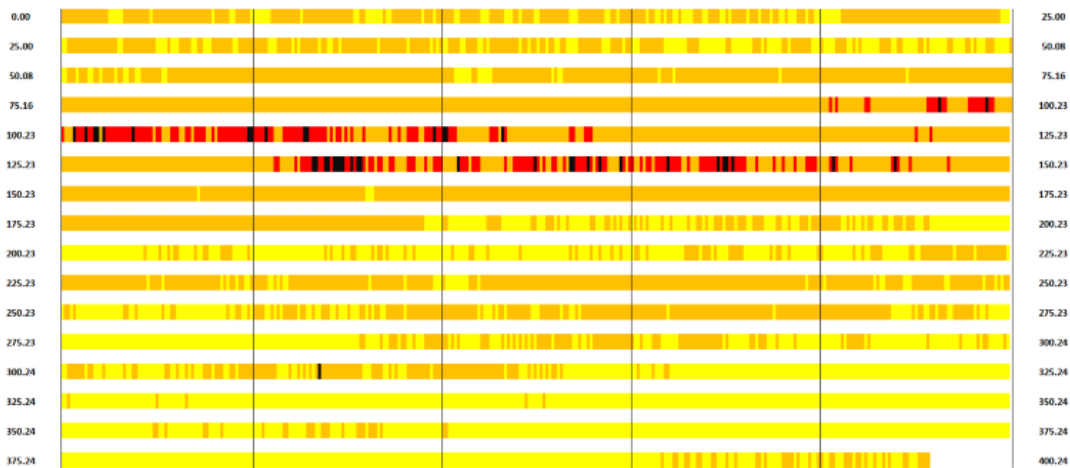


Figure 6 - Example of Cormon results for a single span of conductor (CPK-WIL B span 5-6)

Figure 4 shows that majority of this span is showing moderate to severe loss of its galvanising on the steel core wire, with some isolated sections reporting no remaining galvanising. These areas with no galvanising remaining are where the Aluminium conductor strands will begin to sacrifice themselves and cross sectional loss will be occurring.

Overall a total of 36 spans of Zebra conductor have been Cormon tested. This represents approximately 12% of the line which is considered a representative sample size for this line section. A summary of these results are given below in Table 3 along with an extrapolation for the entire line.

Table 3 - Summary of the Cormon Results for the Zebra conductor on the CPK-WIL B line

Section WIL-26 (Zebra)		Predicted Zinc Loss (No. of defects)					
No of conductor spans		Total spans with corrosion defects	Class 1 0-5%	Class 2 5-20%	Class 3 20-50%	Class 4 50-80%	Class 5 80-100%
Tested Spans	36	24	0	3	9	8	16
Extrapolated results (whole line)	312	208	0	26	78	69	139
Percentage of entire line		67%	0%	8%	25%	22%	44%
Margin of error		13%	0%	8%	12%	11%	14%

These cormon results indicate the overall condition of the conductor on this line is very poor with approximately 44% of the spans showing signs of complete galvanising loss on the steel core wire. These spans can all be expected to show visible signs of bugling and loss of aluminium cross section in the next few years as the aluminium strands begin to sacrifice now that the galvanising is all gone from the steel core wire. The conductor should be replaced prior to this widespread corrosion and breakdown being evident, more on this is discussed in section 3.5.2 below.

Due to the limited sample size there is a relatively high margin of error for these extrapolated results. Based on the sample size of 36 and a 90% confidence interval ($z^* = 1.645$) the approximate margin of error for each extrapolation is given in Table 3 above. Due to the nature of condition assessment where a small population spans are randomly selected it is unlikely that we have assessed the worst span on the asset, conversely it is also unlikely we have assessed the best span.

3.5.2 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 in 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 discoloration but no visible bulging occurring yet. These markers can be re evaluated during subsequent inspections and are generally good indicators of imminent conductor bulging.

To date, 2 close aerial surveys have been undertaken on the CPK-WIL B line in 2011 and 2013. The summary results of this are shown below:

2005 Result:

The first bulge on this line was discovered in span 1-2.

2011 Result:

- Spans 0001 – 0030 were flown.
- 2 defects less than code 20 found.

2012 Result:

As part of the handover to the new maintenance contractor this line was reflowed in 2012. These survey re-evaluated the code 18 defect (from 2011) to code 21 and the other defect could not be seen. The results of aerial surveys are highly dependant on the light and weather conditions on the day, and as such it can be very difficult to locate some of the smaller bulges.

2013 Result:

- Spans 0001 – 0030 were flown.
- 110 markers in the range CA21-25
- 1 code 20 defect found.
- 19 defects less than code 20 found.

The increase in the number of defects found, and more importantly markers, clearly demonstrates that the conductor on this line is reaching end of life. Given the relatively severe environment of this line, once a conductor bulge is evident during aerial survey that section of conductor has 2-3 years of service life remaining.

3.5.3 Destructive metallurgical testing

2005 Test – 3 Samples:

Three samples were removed from the BPE-WIL A line to investigate the effects of dog bone spacer damage. This line is strung with the same conductor from the same era and environment as they CPK-WIL B line so these results should be applicable to the line in question.

This report found that the 3 samples tested all met or exceeded Transpowers replacement criteria for loss of aluminium cross section. The recommendation from this report was that the useful life of these conductors could be extended by approximately 15 years providing the appropriate repair method is used. Further detail on these repairs is given below in section 3.5.4.

2007 Test – 1 Sample:

Sample selected at random and had no visible corrosion or localised defects. Overall loss of Aluminium was estimated at 1.93% and estimated remaining life of approximately 20 years.

2009 Test – 2 Samples:

Two samples were removed as part of localised corrosion repairs where there were signs of visible bulging. Loss of Aluminium cross section was estimated as 17.1% and 31.2% respectively which both exceed replacement criteria of 15% loss of Aluminium.

The sample with 32.1% loss of section was estimated to have reached the 15% replacement criteria approximately 7 years earlier.

Figures 5 and 6 below show the condition of the on the samples at differing stages of the examination.

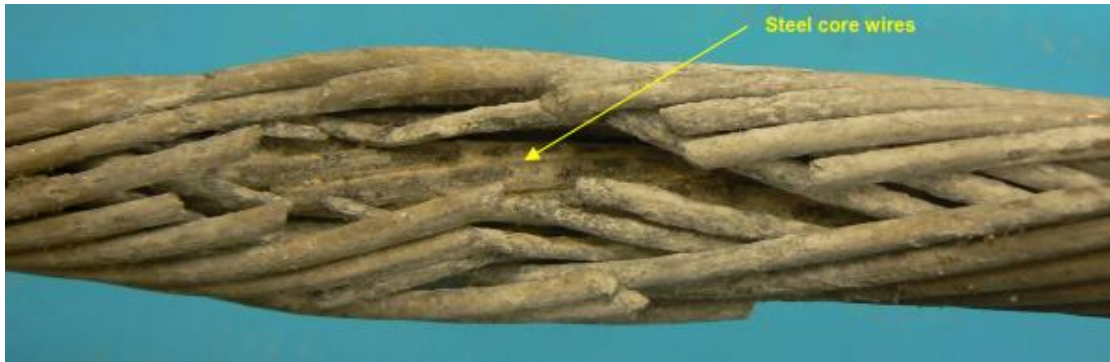


Figure 7 - Condition of one sample with the outer layer of Aluminium removed



Figure 8 - Steel core wires as identified in Figure 5, note the dried grease and corrosion product on the wires.

3.5.4 Dog Bone Spacer Repairs

Repair work has previously been completed in 2008/09 to install repair rods and implosive repair fittings on all areas of identified dog bone spacer damage. In total 405 individual repairs have been made on this conductor to negate the effects of this dog bone spacer damage. A summary of this information is given in Table 4 below:

Table 4 - Summary of Dog bone spacer damage repairs

Extent of Damage	Circuit 2	Circuit 3	Total	Repair Method
Up to 6 broken strands	177	215	392	Preform fitting
7-18 broken strands	8	5	13	Implosive Repair sleeve
Totals	185	220	405	

The repair method utilised was based on the premise that the full tensile strength of the conductor would be restored. What is unknown and reasonably untested is the combination effect of grease holidays (conductor bulges) and dog bone spacer damage.

Dog bone spacer damage is evident by broken strands on the outside of the conductor, while grease holidays generally exhibit broken strands on the inner layers of the conductor. Should these two mechanism occur at the same location the effect of this is likely to be a greater than expected loss is tensile strength.

3.6 Conductor Management Options

To help manage the condition of the conductor on this asset, localised repairs have been, and will continue to be completed on some of these defects to help ensure the condition of the entire conductor is degraded to the point where it justifies complete replacement. The cost of this localised repairs on this asset are far higher than might be seen on other lines due to the line location and configuration. Depending on the location within the span and the particular span requiring repair, crane access may not be possible and the cost to cut out these defects and add in a new section of conductor is expected to be \$100K-\$200K per repair. It is therefore not considered a long term solution to manage the numerous number of defects that are now present on this line.

Further close aerial survey is also planned to ensure all known defects and markers are monitored and addressed as needed to ensure the risk of a conductor drop is minimised until the conductor is replaced.

Something else to consider is when replacing the conductor on this asset, the preferred construction method is to use the existing conductor as a “pull wire” to string the new conductor. To utilise this method it is also imperative that the old conductor has sufficient strength to complete this task. If the conductor is left to the point where it cannot be used as a pull wire then more complex and costly construction methods would need to be utilised.

4| Conclusions

The Zebra conductor between Wilton and Tower 26 (11.7km) on the CPK-WIL B line meets or exceeds replacement criteria and is recommended for complete replacement by June 2019. By the time of replacement this conductor will be approximately 40 years old which is the expected service life for a Zebra ACSR conductor in this high corrosion environment.

The Chukar conductor (Tower 26 to Central Park) has an estimated remaining life of 10 years. Further testing will be undertaken on this section of the line to provide more certainty on this timing but this replacement should be scheduled to occur in the later stages of RCP3

Conductor monitoring and repair programmes have extended the life of the conductor but a visual survey in June 2013 has shown there are incidences of further bulging occurring. Condition assessment is not an exact science; however, experience with both Cormon testing and visual inspection has led to greater certainty on remaining conductor life. Our requirement to replace the conductor by June 2019 ensures the prudent operation of core grid assets.

Repair work is likely to continue in the interim, but due to the location and configuration of this line it is an expensive and complex task. In some instances it is not feasible to repair conductor defects, as crane access will be impossible.

ⁱ TP.FL 01.00 TL Conductors and Insulators Fleet Strategy (Issue 1 2013)

ⁱⁱ TP.SS 02.17 Transmission line condition assessment, Part C: Insulators and conductors

ⁱⁱⁱ TP.DL 12.01 Transmission line loadings code