Investment Decision Pack
A9.09A – Overhead Line (OHL) Towers and Foundations
December 2019

As a part of the NGET Business Plan Submission

nationalgrid

Engineering Justification Paper; Non-Load Related Overhead Lines: Non-lead Assets (Towers and Foundations)			
Asset Family	Overhead Line (OHL) Towers and Foundations		
Primary Investment Driver	Asset Health (Towers – Non-Lead Assets)		
Reference	A9.09		
Output Asset Types	Non-Lead asset work • Tower Steelwork • Tower Painting • Tower Foundations (Condition monitoring, condition assessment, plant status work & maintenance are not covered in this report)		
Cost (T2 Outputs)	£199.7m		
Delivery Year(s)	2021 – 2026		
Reporting Table	C2.2A		
Outputs included in RIIO-T1 Business Plan	Yes		
Spend Apportionment (T2 schemes proposal)	**T1**	**T2**	**T3**
	£2.304m	£194.640m	£2.778m
Completion of RIIO-T1 schemes		£1.282m	
Development of schemes to deliver output beyond T2		£1.011m	
Total	£2.304m	£196.934m	£2.778m

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EXECUTIVE SUMMARY

This report justifies the RIIO-T2 asset intervention plan for Overhead Lines (OHL) non-lead assets (Towers and Foundations) at a total cost of £199.7m over a 5-year period. This plan is based on the output of a condition-based approach for OHL towers and foundations. This report proposes an optimal delivery plan for RIIO-T2 to manage safety risks to staff; without this investment, towers could become unsafe to work on when planned and unplanned work needs to be performed.

During RIIO-T1 we have developed new technologies and systems that give us a better understanding of the condition of our OHL portfolio. In addition, we have achieved enhanced rates of steelwork recovery through application of an enhanced coating system. Consequently, higher cost steelwork replacement rates are 23% of allowances. Our painting volumes are in line with RIIO-T1 forecasts, reflecting increased activity to meet our target of painting 1/18th of the tower population per year.

We did not have specific RIIO-T1 allowances for interventions relating to tower foundations. Nevertheless, we are making significant interventions to address age-related issues which have been identified during RIIO-T1. Our enhanced understanding of these issues forms the basis for a risk-based plan for RIIO-T2 interventions.

Stakeholders have told us a safe and reliable network. The proposed investment will manage the safety risk to staff working on OHL and provide value for money by cost-effectively maintaining the OHL population in serviceable condition.

Our steelwork painting programme of [redacted] per annum is equivalent to 1/18th of the network, based on a whole-life cost study to determine optimum painting interval. This painting programme manages the corrosion of structural tower steelwork and is shown by CBA to demonstrate value compared to replacement of steelwork members. Our RIIO-T2 steelwork painting programme will continue to address 1/18th of the network annually. We will use our condition assessment and our corrosion severity model (aligned to ISO9223) to prioritise routes for protective coating renewal.

Some steelwork cannot be recovered or treated by painting. It must be replaced to maintain the structural integrity of the OHL towers, keep lead assets in service and maintain public safety. Our steelwork replacement interventions over the remainder of RIIO-T1 will target the routes in the worst condition (Grades 5 and 6), and some routes will be addressed as part of planned RIIO-T2 conductor replacement projects. Our RIIO-T2 plan is to address the remainder of the routes in poor quality (equivalent to [redacted] tonnes).

Most of the current OHL tower population was built during the 1960s with limited inspection and maintenance on foundations for much of their early life. Issues with OHL tower foundations across the RIIO-T1 period have triggered a review of the OHL tower foundation asset management policy. We have identified foundation volumes based on exposure to geological hazards. On this basis we have identified [redacted] towers across the network as high risk which we will assess for intervention in RIIO-T2. A proportion of these towers will likely require foundation upgrades, repairs, and potentially full tower replacements depending on condition.

Our painting unit costs for RIIO-T2 are in line with those observed for the latter part of RIIO-T1 [redacted]. Cost estimates for steelworks are based on RIIO-T1 returned tenders for projects that are similar in scope and length to RIIO-T2 interventions. Foundation intervention cost estimates are based on projects currently in delivery, combined with our initial assessment of work required on towers identified as requiring interventions during RIIO-T2.

Overall, we are forecasting a 15% increase in average annual spend during the RIIO-T2 period. This is driven by an increase in foundations interventions to address condition-based issues identified during RIIO-T1. The continuation of our painting programme drives a reduction in steelwork interventions in RIIO-T2, which reduces costs across the two categories as painting is a more cost-effective means of maintaining asset health.

Table 1: Costs and volumes, RIIO-T1 and RIIO-T2

		RIIO-T1				RIIO-T2	RIIO-T1	RIIO-T2
		T1 Allowances	**T1 Actuals**	**T1 Forecast**	**T1 (all years)**	**T2 forecast**	**Annual average**	**Annual average**
Steelwork	**Total cost (£m)**	236	78	52	130	53	16	11
	Total volume (tonnes)	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
	Cost per unit volume	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Painting	**Total cost (£m)**	125	90	36	126	92	16	18
	Total volume (m^2)	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
	Cost per unit volume (£)	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Foundation	**Total cost (£m)**	N/A	0	12	12	52	2	10
	Total volume (towers)	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
	Cost per unit volume (£)	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

BACKGROUND AND INTRODUCTION

Overhead lines (OHL) comprise of lattice steel towers which holding high voltage electrical conductors at a safe height above the ground. The lattice towers sit on a reinforced concrete foundation to provide adequate support for structure, weather and fault loadings. The interface between the legs of the tower and foundation are grouted to provide protection.

The principal consequences of failure for overhead line towers are:

- Dropped conductors which will either fall on the ground or infringe safety clearances and hence present falling object and electrical safety risk to staff and the public. Dropped conductors almost always cause an overhead line trip and will lead to an outage on the network through the short term (typically two days) loss of the OHL circuit.
- Components (e.g. damper weights) falling off OHL routes which present a safety risk to staff and the public.
- Unsafe towers, which present safety risks to staff if they are unsafe to work on and require repair to ensure planned and unplanned work can be performed.
- Full or partial tower collapse leading to any or all of the above consequences coupled with further damage to adjacent towers in the route.

In the case of OHL, the majority of failures do not occur randomly under benign, everyday conditions. In the event of a wind, ice or lightning storm, defects that have not been addressed could become widespread failures within a matter of hours at a time when reliability is most needed. Healthy steelwork and foundations have an important role to play in avoiding these risks.

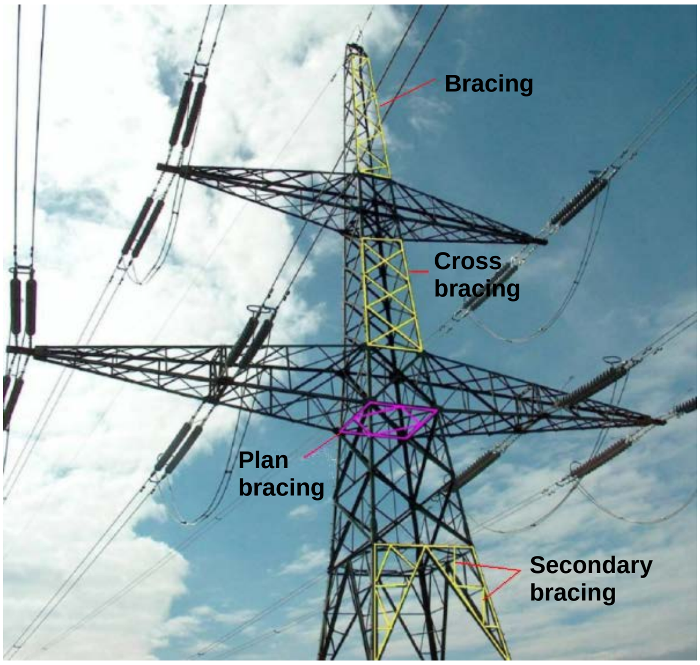
The paper is divided into sections for Steelwork & Painting (Part A) and Foundations (Part B). This reflects the different drivers for investment in each and provides clarity for the reader. Part C describes assumptions and risks and conclusions.

PART A – OHL TOWER STEELWORK AND PAINTING

A.1. INTRODUCTION AND BACKGROUND

OHL towers are designed and constructed using a lattice steel arrangement. Steelwork is segregated into primary and secondary classifications. Components such as leg sections, main crossarm pieces and large plan bracings are identified as primary members. Secondary members are bars such as wind bracings and small tie bars.

Figure 1: Photo of OHL lattice tower steelwork bracing



Transmission tower steelwork is manufactured from mild and high-tensile steel sections which have been hot-dip galvanised to form an anti-corrosion zinc coating. We expect our towers to last in excess of 100 years (typically two conductor lifetimes, depending on environmental factors), so to prevent this zinc coating wearing away over time the steelwork is further protected with paint as part of an ongoing asset management regime to preserve the life of the towers as far as is practicable.

Tower painting and the need to replace tower steelwork are closely linked, as maintaining a suitable painting regime will prevent the need to replace the majority of tower steelwork before it degrades to an unrecoverable level.

We inspect on a 6-year frequency and utilise a visual steelwork grading classification to categorise the health of the steelwork, identifying where degradation of the paint occurs. This approach is supplemented by thickness measurements of the bars to confirm visual grade classifications – especially if replacement is signalled. This allows tower steelwork interventions to be based on a uniform, accurate and objective classification method (described below).

Although the aim is to paint steelwork on a frequency that prevents further corrosion this is not always possible to achieve. Rates of corrosion of paint and steel vary across a route and even vertically within a tower. Coupled with this, much of a tower requires network outages to paint (e.g. crossarms) and therefore must be planned appropriately. Repainting a tower involves cleaning and preparing the existing surface to ensure adherence of the new coating and is a very labour-intensive job. As the painting surface is never going to be as perfect as a newly constructed tower, inevitably imperfections are introduced over time. Ultimately this means that, despite aiming to ensure all towers are painted as required, some degradation and corrosion of tower steelwork does occur and needs to be remedied.

The optimum time to paint an asset is typically every 18 years in a range of 12 to 24 years, based on the corrosion exposure of the immediate environment at each tower. Some towers (<2% of the National Grid population) in very highly polluted areas (C5) will require coating at intervals less than every 12 years. Table 2 shows how the external environment (Corrosion category) impacts on painting frequency. This is based on ISO 9223 (an international standard).

Table 2. Corrosion Classifications – A study of National Grid's ACSR routes in 2018 modelled zinc corrosion rates between 23 and 94 microns per annum.

Corrosion Category (ISO 9223)	Corrosion Level – Zinc loss rates	Approximate Paint Frequencies
C2	Low – 1.3 to 25 microns of zinc per annum	24
C3	Medium – 25 to 50 microns of zinc per annum	18
C4	High – 50 to 80 microns of zinc per annum	12
C5	Very High – 80 to 200 microns of zinc per annum	<12

The majority of our towers are in a C2 or C3 environment hence an average painting programme of 18 years.

Visual inspections of tower steelwork are carried out every six years and the tower steelwork is classified into grades as defined in Table 3 below. This details the 6 grades of steelwork classification, with visual examples, and the intervention typically taken on each grade. These grades (coupled with some other factors) are used to determine asset health scores for each "tower side" (each half of a tower). We have asset health scores (and resulting asset health indices (AHIs)) for both the coating and the underlying steel itself. These are explored later in the document.

Table 3: Overview of steelwork grading

Grade	1	2	3	4	5	6
Grade description	Fully painted – overcoat and undercoat intact Fully galvanised – coating intact 	Paint coating on all surface, but some overcoat may not be intact. Galvanising intact except for small areas of corrosion 	Very light surface corrosion, majority of coating intact 	Light pitting, with loss of coating and zinc layers. Bar thickness is still equal to its specification 	Significant pitting - loss of section clearly visible Bar thickness is smaller than its specification 	Perforated element with severe physical damage 
Intervention	No action required	No action required. Part of the long-term painting plan (10-15 years)	Optimal time to paint. Plan painting within 5 years – steelwork then reclassified as Grade 1	Recover steelwork via enhanced treatment – steelwork then reclassified as Grade 1	Steelwork measured to identify thickness loss and structurally assessed, then treated to prevent further degradation if required. Replacement of critical steelwork members.	Replacement of steelwork required

Figure 2 shows how painted steel typically moves through the grades and the interaction with intervention strategies. This is explored in more detail later in the document.

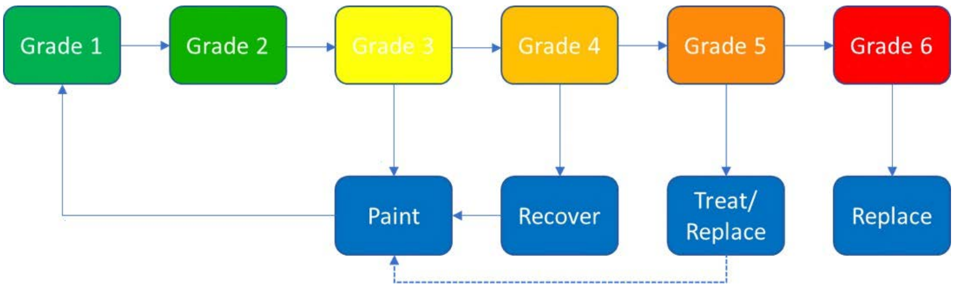


Figure 2. Tower steelwork grade progression

RIIO-T1 PERFORMANCE

A.2.1. How RIIO-T1 allowances are set

In RIIO-T1, there is an allowance for the majority of our tower painting. Some tower painting is embedded into the scope of conductor replacement projects.

Conductor replacement projects also included an amount of steelwork replacement, some of which was condition-driven and some of which was associated with strengthening towers for the replacement conductor systems. For this reason, it is more difficult to fully extract the RIIO-T1 allowances for these steelwork activities from Ofgem's Final Proposals, which stated allowances at a higher, category level. However, there were also subsets of schemes which were identified as being steelwork replacement only.

For the purposes of this paper and any other reporting/estimating standard conversion rates are used to simplify analysis.

Table 4. Standard tower values for estimating

Item	Average tower
Mass	[redacted]
Area	[redacted]

The values in table 4 allow for a conversion rate between steel replacement and painting. There is variance between tower weights, e.g. up to 88 tonnes for a larger terminal tower, with the average being [redacted] tonnes.

A.2.2. Volumes and costs overview

In RIIO-T1, we were allowed £236m to replace a total of [redacted] tonnes of steelwork and £125m for tower painting. Table 5 summarises the interventions carried out in RIIO-T1 by displaying the total volumes delivered (forecast until the end of RIIO-T1) and the total cost for each steelwork replacement and tower painting and compares them to the RIIO-T1 allowance.

Table 4: summary of volumes and costs of OHL non-lead asset sub-categories in RIIO-T1

		RIIO-T1				
		T1 allowance	**T1 Actuals**	**T1 Forecast**	**T1 (all years)**	**Annual average**
Steelwork	**Total cost (£m)**	236	78	52	130	16
	Total volume (tonnes)*	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
	Cost per unit volume	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Tower Painting	**Total cost (£m)**	125	90	36	126	16
	Total volume (m^2)	N/A	[redacted]	[redacted]	[redacted]	[redacted]
	Cost per unit volume (£)	N/A	[redacted]	[redacted]	[redacted]	[redacted]

**Does not include steelwork recovery*

A.2.3. Volume Performance

Steelwork

Steelwork replacement volumes are significantly below allowances. The drivers for this are provided in this section.

During RIIO-T1 we have introduced new technologies and systems that have improved our understanding of the condition of our OHL assets. We have transitioned away from predominantly using climbing assessments for initial (Level 1) surveys to using helicopter-based inspections. We now use climbing assessments for Level 1 surveys only where aerial surveys cannot be used due to location (e.g. next to motorways where helicopters are not allowed to hover) and focus this resource-intensive activity on Level 2 assessment activities, particularly for steelwork, where a greater level of detail is required. Assessment types are summarised in Table 6 below.

Table 6: Assessment approaches

Assessment type	Description
L1 (‘Zonal Survey’)	Visual Assessment; typically conducted by a review of helicopter high-definition camera imagery.
L2(‘Bar-by-Bar Survey’)	Intrusive Assessment carried out by climbing the tower to inspect issues highlighted by L1 survey, including taking measurements and recording which individual bars require treatment or replacement.

Using data from Level 2 steelwork surveys, we have been able to derive a standard that better defines when a corroded steelwork member must be replaced. This method requires accurate measurements of the remaining cross-section of a corroded steel member to be taken. Using that data, we can compare against the design standards for the tower and use computational analysis to determine whether the member meets its design specification. This is used on the primary members of a tower that are very difficult to replace economically; where analysis results are favourable, this could mean avoiding replacement of a tower crossarm or even an entire tower, resulting in significant savings.

Being able to avoid replacement of corroded members is dependent on us being able to recover the bars and re-coat them to prevent further loss of section. This has become possible for Grade 4 steelwork as a result of a successful innovation project (see box below).

Case Study: Grade 4 Steelwork Recovery

At the time of our RIIO-T1 submission, we were part-way through an innovation project into an enhanced coating system that would allow the recovery of Grade 4 steelwork. Our RIIO-T1 submission assumed that we would be able to recover 60% of Grade 4 steelwork, with the remaining 40% of Grade 4 together with all Grade 5 and 6 steelwork being replaced. This innovation project has subsequently been implemented, and we are now forecasting to recover 100% of Grade 4 steelwork.

Recovered Grade 4 steelwork is reclassified as Grade 1, and by maintaining our planned painting regime, should not go beyond Grade 3 in the future.

The recovery project has resulted in a forecast of [redacted] tonnes of additional (total of [redacted] tonnes) Grade 4 steelwork recovered through the enhanced paint coating system at a cost of £3m instead of £148m of replacement in RIIO-T1 period; the net saving will be shared with customers via the Totex Incentive Mechanism.

Figure 3. Comparison photos showing Grade 4 recovery preparation

Figure 4 summarises the RIIO-T1 split between steelwork recovery and replacement. This emphasises that even though replacement volumes are significantly lower than allowances, recovery is allowing us to manage risks relating to OHL towers steelwork.

[redacted]

Figure 4. Forecast tower steelwork for T1

A.3. Tower painting

We are forecasting to paint an average of [redacted] m^2 per year compared to policy of a nominal [redacted] m^2. This is in line with our RIIO-T1 submission forecast, which reflected a ramp up in painting activities to achieve the 1/18th network target.

A.3.1. Cost Performance

Steelwork

Table 5 shows that costs per unit for steelwork replacement is running above RIIO-T1 allowances (£[redacted]k/tonne versus £[redacted]k/tonne).

Of the steelwork that did require replacement in RIIO-T1, a higher proportion than expected was of critical primary members on tower crossarms. These sections require replacement under circuit outage, which significantly increases project set-up costs and programme, increasing the overall unit cost. Several whole towers were also discovered that required full replacement due to targeted steelwork replacement being uneconomic.

This is offset by the innovation in steelwork recovery. This offers large savings, as indicated by the above case study where we substituted £148m of steelwork replacement for £3m of steel recovery.

Tower Painting

Our RIIO-T1 submission contained £125m for tower painting. We are forecasting to deliver in line with this allowance, painting [redacted] m^2 of steelwork towers over the eight years – a cost of £[redacted] per m^2 for the first 6 years, and £[redacted] per m^2 for the last 2 years.

A.4. DEFINING RIIO-T2 INTERVENTION VOLUMES

This section shows how we have defined volumes for steelwork and tower painting in RIIO-T2. It provides information on:

- High level drivers for investment
- How we define asset health for steelwork and painting
- How we have identified routes for intervention at RIIO-T2 based on our asset health assessment
- How we are using innovation to drive efficiency in condition assessment and monitoring in RIIO-T1 and going forward.

A.4.1. Investment drivers

Our stakeholders have said they want us to maintain a safe and reliable network. By ensuring that tower steelwork is maintained we ensure that not only are the structures safe to work on for our staff (and thus interventions on items like conductors and fittings can be carried out) but also ensure that risk to the public is minimised.

Stakeholders want us to provide value for money. We therefore aim to identify interventions that allow us to manage risk in the most cost-effective way possible.

The majority of the OHL towers population (57%) shows that the majority were installed in the 1960s (see Figure 5 below). Our RIIO-T2 activities aim to maintain the condition of OHL steelworks to allow them to fulfil their expected 100-year lifetime.

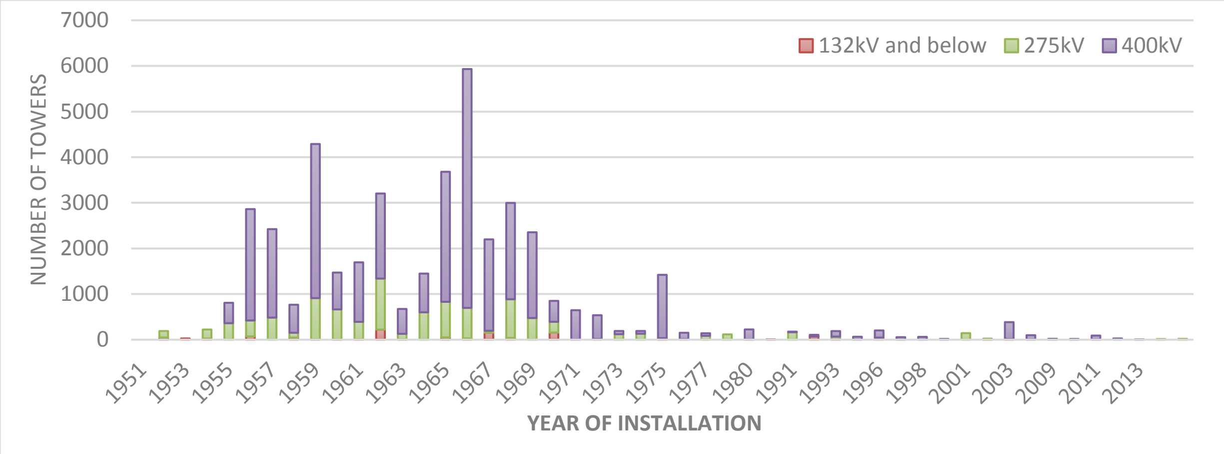


Figure 5: Age profile of overhead line towers

A.4.2. Our approach to defining RIIO-T2 volumes

RIIO-T2 volumes for OHL tower steelwork and painting have been identified from condition information gathered from climbing assessments, high-resolution aerial helicopter surveys, and intrusive inspections. In this section we show how we have used this information to define RIIO-T2 intervention volumes. We do this separately for steelwork and painting.

Steelwork

For tower steelwork, corrosion is the life-limiting process for towers. The end of life (EoL) of a tower is the point at which so many bars require changing that it is more economic to replace the whole tower. Alternatively, EoL may be the point at which it is no longer safe to work on the tower due to critical members compromising the structural integrity. However, our policies aim to avoid whole tower replacement and hence we intervene at a bar-by-bar level to economically manage the population. Assessment of the high-definition images obtained from helicopter surveys combined with the results of climbing condition surveys determine the proportion of critical steelwork in each particular grade for each tower assessed.

Asset health scores have been derived based on Level 1 condition assessments of the steelwork. Each tower is split into approximately 30 zones (15 per tower side) encompassing the base, body, cross arm, and peak sections. These zones are photographed with a high-resolution camera from a helicopter and visually assessed by trained technicians. Each tower side is then assigned a Grade of 1-6, which is used to dictate the next course of action, as demonstrated by the flowchart in Figure 6.

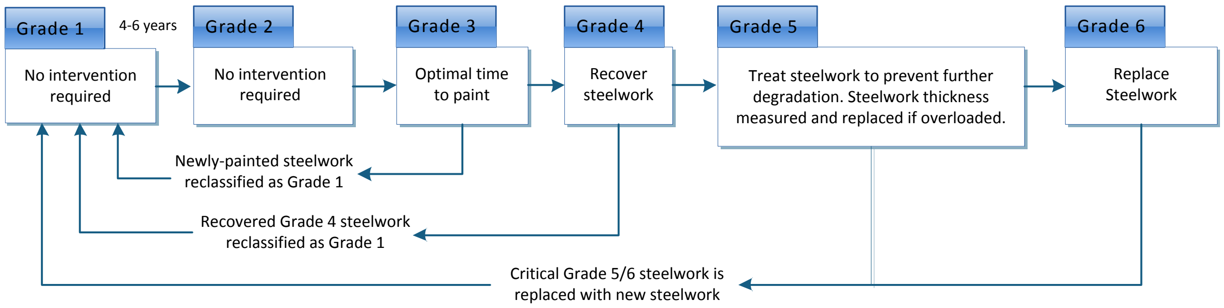


Figure 6. Steel grade and intervention flowchart

The flowchart above shows the typical degradation process of tower steelwork and the interventions taken. For a typical environment, tower steelwork increases in grade every 4-6 years, which is also used to derive the painting schedule of every 18 years on average. This timespan seeks to prevent tower steelwork exceeding Grade 3 before the metal itself begins to corrode, but this is not always possible. Steelwork can degrade to Grade 4 and above if painting cannot be carried out due to outage or access constraints, or if extreme weather or pollution events accelerate corrosion.

Table 7 below shows how asset health scores map to steel grade and to AHI. This is used to determine the AHI of each tower side.

Table 5: Mapping of steel grade to asset health score to AHI

Condition Assessment Score	Asset Health Score	Coating Asset Health Index	Asset Health Description	
			Zinc Galvanising	Steel (Including Step Bolts)
Grade 1	0	4	Fully intact	Assumed no corrosion, fully protected by zinc and paint coatings
	10		Fully intact	No corrosion
	20		Partial or full corrosion (in this latter instance an extra undercoat has replaced zinc coating)	Partial surface corrosion
Grade 2	30	3	Galvanising exposed and corroded up to full loss where paint coating is lost	Surface corrosion where paint and galvanising is lost
Grade 3	40	2	Galvanising exposed and corroded up to full loss where paint coating is lost	Surface corrosion where paint and galvanising is lost
	50			Grade 3 extends to Primary steel bars
Grade 4	60	1	Near full loss in areas with no paint	Light pitting and edge roughening in distinct, non-uniform patches. Cleaning of corroded surfaces will dominate Bar thickness is still greater than or equal to its specification (minimum tolerance)
	70			Corrosion extends to bolt heads, back to backs and in angles that are difficult to prepare. May require replacement if cannot be cleaned to base metal
Grade 5	80		Full loss in areas with no paint	Significant pitting, section loss visible Bar thickness is smaller than specification
	90			Grade 5 extends to Primary steel bars
Grade 6	100			Perforated element, severe physical

Figure 8 shows a summary of the steelwork grades across the network.

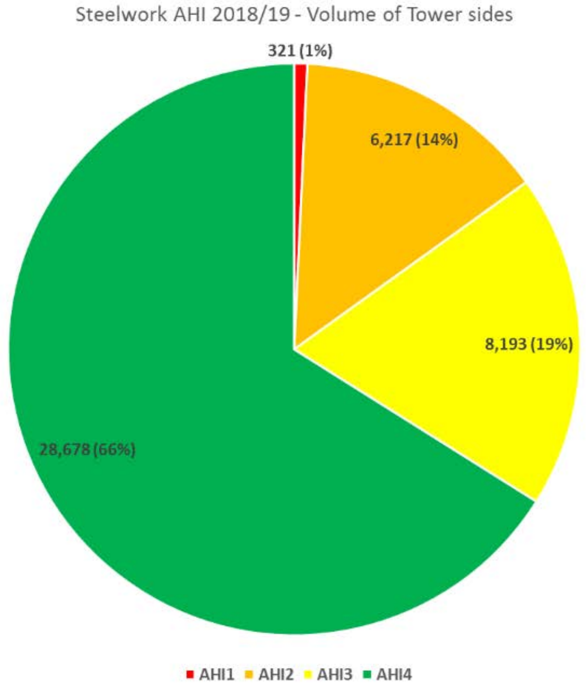


Figure 7. Asset Health Index volume of tower sides.

Of the [redacted] tower sides identified as an asset health index (AHI) of 1 (Grades 5 and 6), the majority will be addressed during the remainder of the RIIO-T1 period. Tower steelwork integrity will also be addressed as part of the conductor replacement projects planned for RIIO-T2 and is included in the cost estimates for those specific schemes. However, several routes that are not subject to a fittings or conductor replacement scheme in RIIO-T2 have been identified as having steelwork in poor condition- interventions on these routes are justified in this paper.

To provide an allowance to address the steelwork on these stand-alone routes, a cost estimate has been calculated based on the percentage of critical steelwork surveyed for the identified routes. Converting the number of remaining tower sides with an AHI of 1 to the total tonnage of steelwork required to manage tower integrity is calculated to be [redacted] tonnes.

The benefit of the tower painting programme delivered in RIIO-T1, along with the assumption that 100% of Grade 4 steelwork can be recovered, is that the volume of tower steelwork replacement required is forecast to be significantly lower than in RIIO-T1 (an annual average of [redacted] tonnes in RIIO-T2 versus [redacted] tonnes in RIIO-T1).

Tower Painting

Undertaking tower painting helps to maximise the asset life, striking a balance between the costs of ongoing maintenance to prolong the asset life and capital expenditure to replace tower steelwork. Based on modelling using the APT-Maintenance tool (which models asset degradation under varying maintenance intervals) our policy is to paint our [redacted] towers once every 18 years in a range of 15 to 20 years, depending on operating environment and hence speed of paint degradation.

Table 8 shows how steel grade maps to asset health score and AHI. This is coupled with additional data such as the last painting date to form the overall AHI for the coating on the route (scored from 1-4).

Table 8: Mapping of steel grade to asset health score to coating AHI

Condition Assessment Score	Asset Health Score	Coating Asset Health Index	Steelwork Asset Health Index	Asset Health Description Coating
Grade 1	0	4	4	Overcoat and undercoat fully intact Unpainted
	10			
	20			Overcoat and undercoat fully intact, enhanced preparation of steel may have been applied at last painting Overcoat may not be intact and very small patches (≤1% of surface area) of undercoat paint flaked/eroded away
Grade 2	30	3		
Grade 3	40	2	3	Majority of over and undercoating remains Ideal time at which to paint
	50			
Grade 4	60	1	2	<75% of over and undercoating intact. Paint coatings no longer effective as breaking down and exposing zinc/steel in increasing areas at a non-uniform rate
	70			
Grade 5	80		1	
	90			
Grade 6	100			

Figure 10 shows how the tower sides on our network are distributed by AHI score:

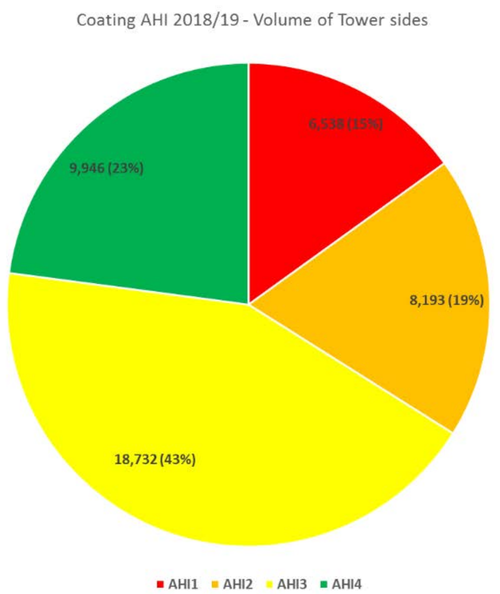


Figure 8. Coating Asset Health Index (Individual Tower Sides)

The target run rate for the renewal of coatings is 1/18th of the system every year. This equates to [redacted] sides per year.

Based on the current view of system coating health, this run rate appears to be more than enough to manage the system in the short term. However, there is a large volume of towers at AHI3 (Grade 2) that will deteriorate to Grade 3 within the next ten years. A tower steel grade is expected to deteriorate to the next grade approximately every 4-6 years.

Table 6: Tower side volumes by AHI and equivalent tower steel grade

AHI	Equivalent Tower Steel Grade	Intervention Priority	Volume	Time Required to Neutralise volume of AHI at 2412 sides per year (1/18th of the system)
1	4,5,6	0-5 years	[redacted]	[redacted]
2	3	5-10 years	[redacted]	[redacted]
3	2	10-15 years	[redacted]	[redacted]
4	1	16+ years	[redacted]	[redacted]

We plan to maintain the target painting run rate of 1/18th of the system each year, using our condition assessment and our model of corrosion severity in England and Wales aligned to ISO9223 to prioritise routes for protective coating renewal. We are in the in process of extending the installation of steel coupons across our network to improve our understanding of the rate of corrosion within the C1-C5, ISO classifications noted above in Table 2.

Our RIIO-T2 submission is based on achieving a policy painting interval of once every 18 years, which equates to [redacted] m^2 per annum (equivalent to [redacted] towers). As part of the painting process, any Grade 4 steelwork will be recovered, and Grade 5 may be treated to prevent further degradation if deemed economic. The routes for painting will be identified using the latest condition information coupled with bundling efficiencies with existing planned outages wherever possible.

Our plan assumes a flat spend profile, with a similar volume of tower painting planned for each year of RIIO-T2.

A.4.3. Inspection Regime and Innovation

In this section, we set out how we are improving our condition assessment and monitoring processes over RIIO-T1. These improvements are embedded into our RIIO-T2 plan:

- **Tower steelwork:** Developments in tower steelwork condition assessment and an enhanced coating system have allowed for more recovery of steelwork categorised as Grade 4 than originally identified. RIIO-T1 replacement volumes are therefore lower than originally forecast. Adopting this approach for future work has enabled a significant reduction in RIIO-T2 steelwork replacement, equivalent to £124m of avoided cost.
- **Tower painting:** Improved asset management practices and innovative technologies continue to be developed for OHL assets. Enhanced airborne camera technologies are being developed to complement helicopter surveys and replace the need for some climbing inspections. Other techniques such as wind energy and corrosion mapping are also being developed to understand which OHL routes are located in harsh operating environments. This would enable us to target OHL routes which require more frequent assessment and painting, thereby extending the life of the assets.

A.5. OPTIONEERING

In this chapter, we set out how we have identified the optimal way of delivering the interventions identified in Chapter 4 to address stakeholder priorities and provide value for money for stakeholders.

As stated previously, our tower painting policy is based on modelling using the APT-Maintenance tool. To supplement this, we have carried out Cost Benefit Analysis (CBA) to confirm our approach to steelwork recovery. The options considered for tower body interventions are based around finding the optimal ratio between painting and steelwork replacement.

Table 10 summarises the long list of identified options, and which have been taken forward for quantitative CBA.

Table 7: Intervention options, steelworks and tower painting

Option	Description	Taken forward for CBA?
Baseline- no intervention	This option equates to zero spend on OHL tower bodies by either painting or steelwork recovery, treatment, or replacement. The 'Do nothing' option will always involve the lowest initial capital expenditure, but without intervention tower steelwork will degrade until it poses an unacceptable health and safety risk to our workers and the general public, and potentially reduced resilience to storms	No
1. Tower painting, Grade 4 recovery, no intervention for Grades 5-6	This option would continue with the maintenance painting programme as per National Grid's Policy, including the treatment of Grade 4 steelwork in order to recover the condition back to a lower grade. No intervention would be taken on Grades 5 and 6. Under this option, the risk of failure of critical steelwork members assessed as Grade 5-6 is increased, leading to an increased likelihood of emergency interventions beyond RIIO-T2.	Yes
2. Tower painting, with replacement of Grades 4-6	This option would continue the maintenance painting programme but stop use of the enhanced coating system, and instead replace steelwork bars identified as Grade 4 as well as Grades 5 and 6.	Yes
3. Tower painting, Grade 4 recovery, and replacement of Grades 5-6	This option would continue with the maintenance painting programme as per National Grid's Policy, including the treatment of Grade 4 steelwork in order to recover the condition back to a lower grade. Steel Grades 5 and 6 cannot be recovered and this option would see these steelwork members replaced with new members.	Yes
4. Tower painting, with no recovery or steelwork replacement	This option would continue with the maintenance painting programme but stop use of the enhanced coating system, and undertake no intervention on Grades 4, 5, or 6. Under this option, the risk of failure of critical steelwork members assessed as Grade 5-6 is increased, leading to an increased likelihood of emergency interventions beyond RIIO-T2.	Yes

The outcome from our detailed CBA analysis is summarised in Table 11 below.

Table 11: Option comparison

Option	RIIO-T2 investment cost (£m, undiscounted)	Total Investment Cost (£m, undisc)	NPV (£m, disc)	Ranking
Option 1 - Tower painting, Grade 4 recovery, but no intervention of Grades 5-6	90.9	212.6	-150.8	Rejected
Option 2 - Tower painting, with no recovery or steelwork replacement	519.8	523.2	-458.3	Rejected
Option 3 - Tower painting, Grade 4 recovery, and replacement of Grades 5-6	142.8	144.6	-122.5	Recommended
Option 4 - Tower painting, with no intervention of Grades 4-6	68.5	8,728	-2,861	Rejected

The tower steelwork CBA demonstrates that the most effective option is to undertake a comprehensive tower painting programme including Grade 4 steelwork recovery, along with targeted Grade 5 and 6 steelwork replacement. This option balances the level of risk expected by our stakeholders with the efficient spend required to maintain the reliability of the OHL towers, which directly affect their associated lead assets. It avoids the cost of emergency interventions in RIIO-T3 and beyond, which are more likely to occur in the options which have the lowest RIIO-T2 cost (Options 1 and 4). It also ensures our towers continue to operate safely to enable our operational staff and contractors to carry out asset management activities.

A.6. ASSESSMENT OF COST EFFICIENCY

In this chapter, we show how we have derived our unit costs for tower painting and steelwork, and why they are efficient. We do this separately for tower painting and steelworks.

Steelworks

Our forecast for steelwork intervention costs in RIIO-T2 (cost per tonne) has increased significantly in comparison with observed T1 unit cost due to the change in route length mix in our T2 plan[1]. For example, several routes in T1 were long, allowing a large weight of tower body steelwork to be replaced, decreasing the average cost per unit. The steelwork identified for intervention in T2 is based on smaller sections of critical steelwork across a larger number of circuits. Each will require a separate project to be delivered, and most will require outages to be arranged, increasing the unit cost.

Tower painting

Our cost for tower painting at RIIO-T2 will be £[redacted]/m^2. This compares to a RIIO-T1 average of £[redacted]/m^2. RIIO-T2 costs are in line with the cost for the remainder of RIIO-T1 (see Table 5 above).

Tower painting is a specialist skill and requires a seasonal workforce and as such is competitively outsourced.

Recognising the volume of painting that we need to undertake we continue to work closely with the supplier base to ensure the companies undertaking the work remain competitive. Key to this is the tendering of stable workloads so that the supply chain has the confidence to retain staff numbers to deliver our plans.

[1] The long route length allowed for delivery efficiencies such as a single site establishment and project overheads, while the nature of the steelwork allowed for large amounts to be replaced without the need for an outage, which can be done far quicker and cheaper

PART B – Tower Foundations

B.1. BACKGROUND

National Grid Electricity Transmission (NGET) has [redacted] OHL towers (as of 2019) on the transmission network across England and Wales, operating across 132kV, 275kV and 400kV.

Each OHL tower typically has a structural foundation for each tower leg, which is ultimately responsible for transferring load from the conductors, tower structure and the associated environmental effects into the soil strata via a combination of bearing (compression), uplift (tension) and friction (shear). Considering that each tower will have an individual foundation per leg, that equates to an estimated population of at least [redacted] foundations.

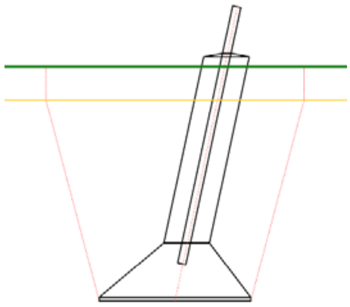


Figure 9: Typical OHL tower concrete spread foundation

The majority of OHL towers use either a concrete spread foundation (as shown in Figure 11) or a piled solution.

Most of the current OHL tower population was built before 1970. For the majority of well-constructed foundations using the appropriate materials and quality controls, age-related deterioration of the concrete is unlikely to be an issue until for at least 80 years. However, workmanship and past design details on older foundation structures (pre-1970) do give rise to potentially serious structural problems (like those found in the case study below) and when considering the combined effect along with environmental impacts (flood and geological risk), worst-case deterioration rate could result in issues as early as 40 years post-installation.

There has been limited inspection and maintenance on the foundations over RIIO-T1 – it is therefore reasonable to expect that a number of the towers will be in poor condition consistent with deterioration mechanisms associated with both steel and reinforced concrete. These could require interventions such as:

- ensuring foundation safety in an emergency scenario where the overall structural system is considered to be compromised
- repairing significant foundation defects to reduce the rate of deterioration and extend the life of the foundation
- upgrading foundations to ensure design compliance with the structural Eurocodes technical suite of documents
- full replacement of the tower foundations (and where required the tower steelwork)

B.2. OVERVIEW OF RIIO-T1 PERFORMANCE

Even though there were no specific allowances for OHL tower foundations in RIIO-T1, there were still significant interventions required.

This section provides details of the issues we have found with OHL tower foundations in RIIO-T1, and how these have driven volumes.

In RIIO-T1, we are forecasting to spend £12m to respond to the recently discovered OHL tower foundations issues where significant interventions are required (and where the work is out of scope of existing projects). Table 12 summarises the interventions planned to be carried out on OHL tower foundation in RIIO-T1 by displaying the total volume delivered (forecast until the end of RIIO-T1) and the total cost during the RIIO-T1 period.

Table 12: summary of volumes and costs of OHL tower foundations interventions in RIIO-T1

		RIIO-T1				
		T1 allowance	T1 Actuals	T1 Forecast	T1 (all years)	Annual average
Foundation	Total cost (£m)	N/A	0	12	12	1.5
	Total volume (towers)	N/A	0	[redacted]	[redacted]	[redacted]
	Cost per unit volume	N/A	N/A	[redacted]	[redacted]	[redacted]

During RIIO-T1 we have been further developing our foundation management strategy. As previously stated, detailed inspection of all tower foundations is impractical and hugely expensive (in the region of £0.5-1bn to inspect all towers). Therefore, we need to develop non-intrusive techniques and classify known parameters that impact on foundation aging in order to shortlist "high risk" towers for intrusive investigation (see box below). More details around the defects we have discovered in RIIO-T1 are provided in Appendix [redacted]. We will build on the information we have gathered during RIIO-T1 to build our RIIO-T2 programme of work (see next section).

Intrusive Investigations

Intrusive Investigations have been carried out as part of RIIO-T1 conductor replacement schemes on a risk-assessed basis. Any issues that can be resolved as part of the existing scheme are managed through existing design procedures, whereas more significant issues (including emergency scenarios) must be addressed separately.

The number of Intrusive Investigations carried out per route are primarily based on the number of towers on the route but also considers tower foundations associated with a critical span (e.g. public transport crossings, canal, 3rd party infrastructure) and towers where local knowledge may indicate heightened environmental risk.

Intrusive investigations involve the excavation of soil surrounding the individual foundation leg, permitting both non-invasive and invasive investigation techniques – including visual assessment of concrete surface conditions, dimensional checks, taking concrete core samples to assess concrete compressive strength and removing the muff/chimney concrete to assess embedded steelwork condition.

Due to the high effort required (site access, excavations, temporary works etc.) intrusive investigations can cost between £[redacted]k to £[redacted]k per tower.

Below we provide an example of one of the projects that has been driving RIIO-T1 volumes:

Case Study: Tower Foundation Corrosion in South Wales

During a conductor replacement scheme on the 4YW route in South Wales, the project team discovered that that the structural integrity of at least two towers had been compromised by severe corrosion of the tower leg steelwork within the foundations. Both the towers sit within tidal river flood plains, leading to the conclusion that salt water has contributed to accelerated corrosion of the leg steelwork and that the concrete had degraded sufficiently over time to enable flood water ingress into the leg/muff/foundation interface.

Consequently, emergency works were carried out to make both towers safe using a temporary mass-infilled concrete solution until system availability permits replacement of both towers.

If this issue was discovered sooner and the foundations were repaired before they deteriorated to such a level, it would have avoided the requirement for emergency temporary works and the requirement for a full tower replacement.

Regular flooded conditions the tower was subjected to

Disconnection of the tower leg to the foundation

Significant temporary repairs to make the towers safe

B.3. DEFINING RIIO-T2 INTERVENTION VOLUMES

As indicated in the previous section, inspections at RIIO-T1 have uncovered a number of condition issues with OHL foundations.

Across the wider foundations population, with regards to the rate of deterioration and considering Figure 13 below, it is currently expected that the majority of the tower foundations sit on the normal deterioration curve but there will be a number of towers that sit on the other principal curve – suggesting that the rate of deterioration due to a combination of materiality and environmental factors will be accelerated and the likelihood of defects also increasing.

Over the RIIO-T1 period we have identified significant defects across a wide geographical spread, suggesting a trend between accelerated deterioration and age/environmental factors – and this drives our aspirations and plans for RIIO-T2 to understand the wider risk across the network and plan more effective interventions rather than relying on reactive interventions.

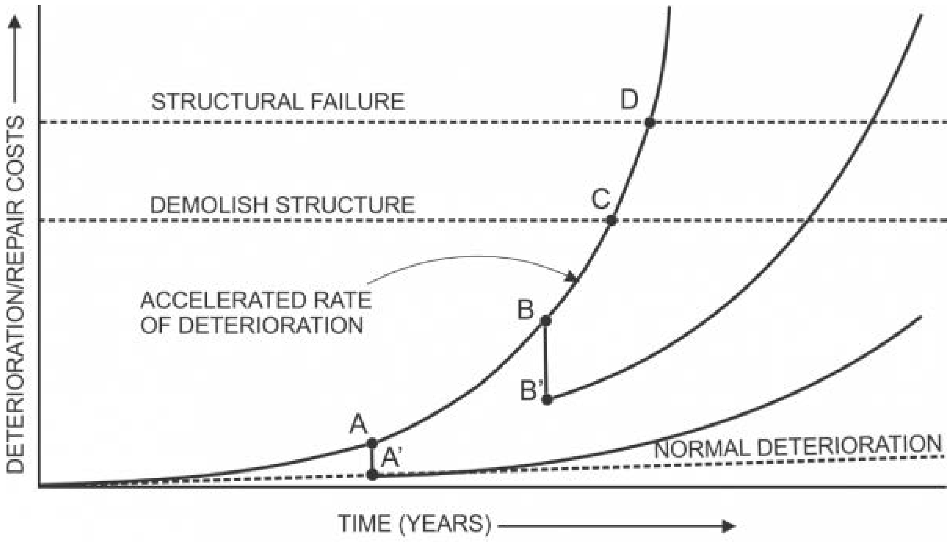


Figure 10. Example of Deterioration Curve aligned with OHL Tower Foundation Performance

Due to the foundation issues that have been observed in RIIO-T1 the intention in RIIO-T2 is to further develop and validate a methodology for a risk based inspection programme.

A purely reactive approach to dealing with tower foundation issues involves higher cost, as for an issue to be discovered it will have manifested itself above ground, usually in the form of tower movement or loss of structural support. This leads to additional work being required (steelwork replacement, new towers etc.). Being able to proactively identify locations that are at greater risk will allow us to undertake repairs and avoid more extensive works.

The most effective way to gather accurate condition data for OHL tower foundations is using a combination of non-intrusive and intrusive investigation methodologies to assist in developing a risk-influenced intervention plan for the OHL tower foundation population.

The proposed strategy for the remainder of RIIO-T1 and looking forward to RIIO-T2 considers age and environmental factors to determine an initial risk profile.

Over the last 6 years National Grid has been working with the British Geological Survey (BGS) to better understand natural hazards relating to our assets. From work that we have done with BGS we have been able to risk assess all of our towers against the following parameters:

- fluvial and coastal flooding[2]
- high ground water
- geological impacts (including compressible ground, soluble ground, landslides etc.)

Using the BGS data, we developed a simple scoring matrix to the exposure of our towers to a range of geological risks. The matrix is summarised in Table 12. We have scored all towers against each hazard. The cumulative scores are grouped into risk bands (see Table 13) to identify the towers that are hypothetically at higher risk.

Table 12: Cumulative scoring matrix used to quantify risks

	BGS Report Banding					
Geological Hazard	**N**	**A**	**B**	**C**	**D**	**E**
Shrink swell	0	0	0	1	2	3
Collapsible ground	0	0	0	1	2	3
Compressible Ground	0	0	0	1	2	3
Running Sand	0	0	0	1	2	3
Soluble Ground	0	0	0	1	2	3
Land slide	0	0	0	1	2	3
Non-Coal Mining	0	0	0	1	2	3
Ground Water	0	0	0	3	-	-
Geological Indication of Flooding (GIF)	**N**	**2 Fluvial**	**1 Fluvial**	**2 Coastal**	**1 Coastal**	
	0	1	1	1	3	
Water Proximity		**>200m**	**>100 - 200m**	**>50 - 100m**	**>25 - 50m**	**0 - 25m**
		0	0	1	2	3
Highest risk banding present				5	5	5

Table 13: Scoring bands

Risk Level	**Scoring Band**
Low Risk	***1-7***
Medium Risk	***8-12***
High Risk	***13-15***
Very High Risk	***15+***

Our RIIO-T2 plan will address [redacted] units, of which [redacted] are classified in the 'High' category and [redacted] in the 'Very High' category. Towers in these categories are likely to need an intervention during RIIO-T2.

[2] The risk relating to flooding is separate to that covered by A10.05 – Extreme Weather. The flooding context with respect to towers in that context relates to the acute risk of scour and debris impacts on towers whereas here we are concerned about the chronic issue of elevated ground water levels and the impact that has on corrosion in the long term.

We will validate these RIIO-T2 volumes through intrusive investigations on these specific towers, along with a sample of other towers deemed a lower-risk, in order to confirm their condition. It is expected that targeted intrusive investigations will identify a need for foundation upgrades, repairs, and potentially full tower replacements. For more detail about what Intrusive Investigations involve, please see Appendix C.

During the RIIO-T2 period we will focus on OHL tower foundations associated with the planned RIIO-T2 conductor replacement schemes to ensure that any interventions required can be actioned by contractors aligned with the schemes – this will ensure quick mobilisation times and ensure the correct resource is available to carry out design and construction work.

Once the model and strategy is validated during the RIIO-T2 period, the intention would be to address all very high and high risk towers across the portfolio during RIIO-T3 – using targeted intrusive investigations and agile contractors that could deliver smaller scale works on an individual tower basis rather than as part of a large refurbishment scheme.

B.4. OPTIONEERING

B.4.1. Options and Assessment

Due to uncertainties around the condition of OHL foundations, the exact intervention type will not be identified until intrusive below-ground surveys have taken place. The recommended course of action may be no intervention, a simple foundation repair or strengthening, but could require a significant upgrade or potential full tower replacement.

All of the options described below (except the No intervention baseline) were analysed via a Cost Benefit Analysis (CBA).

Table 148: Summary of intervention options

Option	Description	Taken forward for CBA?
Baseline- no intervention	Historically, it has been National Grid's policy to undertake non-intrusive foundation checks as part of surveys for OHL reconductoring projects. However, an increasing trend of tower foundation issues has triggered a requirement to take further action. If no further intervention is taken on the rest of the network, there is an increasing likelihood that towers will either fail and require a full emergency replacement or be identified after significant damage has already occurred and require an emergency foundation repair. This would have to be addressed for safety reasons, so in effect there is no zero-cost option to take forward for full CBA analysis.	No
1. Foundation repairs on towers deemed High and Very High risk	Intervene on ‘very high risk’ and ‘high risk’ foundations as identified during the survey conducted in the T1 period.	Yes
2. Tower painting, with replacement of Grades 4-6	Similar to Option 1 but extended to include foundations deemed to be ‘medium’ risk.	Yes

B.4.2. CBA and Decision

The outcome from our detailed CBA analysis is presented in Table 15 below.

Table 15: Option comparison

Option	RIIO-T2 investment cost (£m, undiscounted)	Total Investment Cost (£m, undisc)	NPV (£m)	Ranking
Foundation repairs on towers deemed 'High & Very High' risk	51.80	55.07	-47.59	Recommended
Foundation repairs on towers deemed 'Medium', 'High' & 'Very High' risk	136.14	140.58	-121.14	Rejected

The tower foundations CBA validates that, in order to maintain an acceptable level of risk, intrusive surveys and subsequent repairs and upgrades to tower foundations should take place in RIIO-T2. These should be targeted at the towers defined as High or Very High risk, with a small sample of surveys conducted on Low and Medium risk towers to validate the risk scoring matrix.

B.5. ASSESSMENT OF COST EFFICIENCY

We do not have a benchmark for these works because they are highly site-specific. Any such works will be let competitively to specialist contractors.

Recent interventions in South Wales have provided the basis for estimation of RIIO-T2 unit costs. We have taken into account identified delivery efficiencies which may only relate to the South Wales area. We have combined this with available condition information for the assets we have identified for RIIO-T2 intervention. As explained in Chapter 4 above, we will only fully understand the scope of work involved for each intervention once intrusive investigations have been carried out. This will lead to variances in outturn costs.

PART C- KEY ASSUMPTIONS, RISKS, CONTINGENCIES AND CONCLUSION

C.1. OHL Foundation Assumptions

The ‘High’ and ‘Very High’ Risk OHL towers identified should have an intrusive investigation prior to development, to assist in informing the scope and reduce the impact during delivery.

The ‘Low’ and ‘Medium’ Risk OHL towers should be considered for intrusive investigations based on existing policy - using verticality checks, visual assessments and non-intrusive technology to inform their requirement during the development phase of the project.

The costs associated with the decisions within this Justification Paper align with the National Grid Electricity Transmission cost book. Where an intervention is not listed within the cost book, cost have been based on historic development costs.

C.2. Risks

OHL Tower 4ZC030

Tower 4ZC030 was demolished in 2014 after safety concerns, and a temporary tower erected in its place. That section of the circuit is currently in scope to be removed as part of the VIP Snowdonia project, but if this project is not approved the tower must be replaced in T2 as both its temporary asset life and planning permission will expire by 2025. Costs for this replacement are currently not included in the plan.

Tower Steelwork volume

Several OHL routes with steelwork in poor condition (bars at Grades 5 & 6) have been assessed using helicopter survey data (which will not identify seemingly sound paintwork which is not actually bonded to the steel). In addition, steelwork condition continues to deteriorate at a rate of approximately one Grade every 6 years. Until climbing surveys have been completed immediately prior to the delivery year for each route, there is a risk that the scope may be greater than currently estimated.

Thames Crossing

Until further surveys have been completed and structural assessment work carried out, the extent of the work required on OHL towers ZR10 to ZR13 is not fully understood. This could range from significant piecemeal steelwork replacement to a full tower and river crossing replacement, requiring the full refurbishment planned in T3 to be accelerated.

System Access

Asset failure or faults on the distribution or transmission network may affect the availability of outages. Delays or cancellations may result in under delivery of interventions required to achieve Monetised Risk targets.

C.3. Contingency

No contingency has been applied to any of the CBA calculations.

C.4. CONCLUSION

This report has provided background information on the OHL non-lead assets, including asset descriptions, steelwork grading classification, and an explanation of condition monitoring techniques and asset health methodology.

In developing our proposal, National Grid has sought to balance stakeholder feedback which values maintaining network reliability and safety with ensuring the plan delivers the best value to end consumers.

A summary of interventions taken place in RIIO-T1 was provided, and a comparison of unit costs between T1 and T2 was given, including an explanation of why certain unit costs have increased between price controls.

The interventions planned to be carried out across the T2 period include a planned painting programme, with some steelwork replacement on non-recoverable sections on towers in poor condition. A CBA was undertaken to demonstrate that the economic balance has been met between preventative painting and steelwork replacement.

A developing trend of issues with OHL tower foundations has also been highlighted, and an explanation as to why funding is being sought to address [redacted] towers.

Appendix B - RIIO-T2 Non-Lead Asset Tables - Tower Steelwork interventions

THIS APPENDIX HAS BEEN REDACTED

Appendix C: Tower foundation issues discovered in RIIO-T1

Every OHL route is walked and visually inspected every 12 months, paying particular attention to critical assets associated with the overall OHL system – including above ground aspects of the foundations (for example muff concrete and surface pile caps). The inspections will also use verticality checks where there could be issues with the vertical alignment of the tower in both planes – which can be symptomatic of issues with the foundations (including settlement, embedded steelwork corrosion/displacement, concrete deterioration etc.). When such a defect is identified, it is recorded, validated and reported for further inspection to be undertaken. Some example photos of typically reported defects can be seen in Figure 12 below:

Figure 11. L-R – a) Exposed Foundation, b) Corrosion of Embedded Steelwork, and; c) Significant Cracking through Muff Concrete

Some of the defects identified during RIIO-T1 include:

- Insufficient embedment of stubs into the block and the lack of cleats can result in uplift failures, such that the pyramid block remains in the ground
- Excessive foundation settlement due to local compressible soils, mining subsidence or landslides usually indicated by verticality issues, exposed foundations or buckled tower steelwork.
- Corrosion of the embedded tower steelwork can occur when in contact with oxygen and moisture, this is typically found at the muff/chimney interface where poor construction has left the joint open sufficiently that bare steel is exposed, providing seepage pathways for moisture. The factors that affect the rate at which the corrosion occurs include:
    - Foundation construction quality – continuity of concrete, interface quality, concrete cover, concrete mix design
    - Soil types – clay, alluvial soils are the most onerous due to water retention/soil solubility
    - Soil pH
    - Ground water levels
    - Flood zones - coastal and fluvial

- Concrete defects (spalling, cracking etc.) conducive with expected deterioration mechanisms, including:
    - carbonation - lower alkalinity which is important for preventing corrosion of reinforcement
    - chlorides - high percentage of chlorides within concrete have been shown to induce chemical changes in Portland cement, leading to a loss of strength

- Concrete quality defects – honeycombing, insufficient concrete cover etc.