Scottish & Southern Electricity Networks

SHE Transmission

New Suite of Transmission Structures: NeSTS (SSEN003)

Trial Overhead Line Energisation

January 2022

Contents and Overview

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Overview of NeSTS

Scottish Hydro Electric Transmission plc (SHE Transmission) is developing a New Suite of Transmission Structures (NeSTS), which are planned to be deployed on the transmission network.

Overhead lines (OHLs) built using transmission structures are the most visible element of the transmission network. The impact OHLs have on the environment can cause stakeholders concern.

The only available alternative to the steel lattice structures traditionally used in OHL construction is the T-Pylon. Developed by National Grid Electricity Transmission, the T-Pylon reduces the visual impact of OHLs but may be unsuited to areas with challenging terrain and propensity for severe weather events.

Establishing new infrastructure in these areas is essential to connect renewable generation, so there is a need for a new type of structure to address stakeholder concern.

The NeSTS project has developed innovative designs for OHL structures based on new technologies and techniques and driven by stakeholder engagement.

A trial OHL comprised of the new suite of structures has been deployed and energised on the transmission network.

The NeSTS Project seeks to prove the following benefits:

- Improved OHL environmental performance by lowering visual and construction impacts; and
- Lower OHL whole life asset costs via reduced land, construction, maintenance, and outage requirements.

The NeSTS trial OHL will now be assessed by stakeholders to assess to what extent these benefits can be realised.

Introduction

The Project has constructed and energised a trial OHL using the NeSTS 132kV Double Circuit suite of structures to repair the Quoich - Broadford OHL at Loch Quoich where it was damaged by landslide.

This required repeating the design and validation work the Project had already completed for the NeSTS 132kV Single Circuit suite for deployment on the Aberarder windfarm connection OHL project which has been delayed by the developer.

It also involved a change in scope, as it necessitated the Project procuring and managing the trial OHL construction.

These changes were agreed with Ofgem as pragmatic alternatives to delaying the trial OHL by several years to accommodate the modified connection applications for the Aberarder wind farm, and have been discussed in the 2020 and 2021 Project Progress Reports submitted to Ofgem and available on the Project website (www.NeSTSproject.com).

This report details the outputs and learning from the exercise, and compares the NeSTS construction, commissioning, and energisation with that of a typical lattice steel tower project. This evidence fulfils the requirements for the Project’s seventh Successful Delivery Reward Criterion (SDRC), 11.7 Energisation of NeSTS Overhead Lines.

Figure 1: 3d visualisation of the planned NeSTS trial OHL at the Quoich landslide

Summary

The NeSTS trial OHL was constructed between February and July, and energised in October 2021. It has successfully positioned the Quoich – Broadford line's new assets outside the area at risk of further landslide from the failed rock bluff above the site.

The work is being compared to elements of the Dalchork – Loch Buidhe OHL which is currently in construction, supports the same conductors, provides the same insulation level, and uses L7c lattice steel supports.

The scale and method of access works are similar on the projects. The NeSTS trial OHL's access works are being retained for use by the Skye project and have therefore had a higher quality of finish applied. The size of working platforms, gradient constraints, and track constructions are similar.

Rock movement on the failed bluff above the NeSTS trial OHL site during construction and the risk of imminent further mass landslide was a constant backdrop to the project, and influenced the amount of risk taken in its foundation design.

Accordingly, the NeSTS trial OHL foundation works used similar materials and methods to comparable sites on the Dalchork – Loch Buidhe OHL , but the NeSTS construction used much more reinforced concrete, between 2.5 and 5 times the quantity per support.

Opportunities for foundation innovation are being explored by the Aberarder windfarm connection project and may address this difference.

The support erection works realised some of the forecast benefits in reduced on-site structure assembly labour, and have provided insight for further improvements in efficiency of lifting processes, and NeSTS support design and surface finish. The need for larger capacity cranes for NeSTS will persist however, as the top section lifts are heavier than for L7c supports (c11 vs c5t).

The wiring works demonstrated that the NeSTS supports can be wired without the need for back-staying. This required increased sagging analyses however, and therefore may provide limited benefit. Otherwise, the wiring works, and the conductor system component costs are similar.

The commissioning and energisation works were similar to those of an equivalent lattice steel OHL (these have not been completed on the Dalchork – Loch Buidhe project yet).

A key difference between the OHLs is their average span. In response to stakeholder request, NeSTS 132kV DC supports enable higher average spans of 400m between overhead line supports, more than the 268m spans achieved on the Dalchork – Loch Buide OHL using the equivalent lattice steel supports. Stakeholders intend this to reduce the visual and construction impacts of OHLs.

This is one of the reasons NeSTS supports are more expensive than lattice supports. Others are that they are not as structurally efficient in the use of steel, that more of their assembly and finishing is performed in the factory, and that the designs and supply chain are immature.

Evolution of the NeSTS designs to enable procurement without significant design input from the manufacturer will help to address the high cost of the NeSTS supports, as will increased volume of use.

However, NeSTS support procurement risk remains the primary adoption barrier for main contractors and OHL construction projects. Construction of the Aberarder windfarm connection OHL should help to mitigate this.

To what extent the reduced access works, lower number of foundations, supports, and insulators and the associated programme reductions offered by the higher spans compensate for the increased support and foundation costs is unclear, and likely to be variable depending on project scope and geography. Further analysis will be reported, although uncertainty is likely to remain until several deployments of NeSTS have been completed.

Stakeholder response to the trial OHL, compared to the Dalchork – Loch Buidhe OHL, will inform SHE Transmission's response to the remaining risks of NeSTS adoption and will be reported in the Project's final SDRC in 2022.

Summary

Figure 2: Photographs of the energised NeSTS trial OHL at the Quoich landslide

Trial OHL Design

Specification

The requirements for the trial OHL were to;

- Permanently repair the Quoich – Broadford OHL (QB1), replacing the temporary wood pole repair effected following the landslide.
- Provide resilience to further landslide from the failing rock bluff above the site.
- Mitigate associated risks to construction and maintenance operatives.
- Support double circuit Araucaria, and an optical ground wire (OPGW) when the Skye project is constructed.
- Support a single circuit Araucaria, and an optical ground wire until the Skye project is constructed, and tie into QB1 without need for refurbishment of existing structures.
- Retain access for Skye project construction.

New NeSTS support   Lattice steel support retained   Lattice steel support removed   Wood pole support removed

New/retained 132kV OHL   132kV OHL removed   33kV OHL replaced with cable   33kV OHL retained

Figure 3: Quoich Repair Plan

Trial OHL Design

NeSTS Supports

A suite of NeSTS 132kV Double Circuit supports were designed using the LT91 Skye project specification.

The suite was based on the single circuit suite which had been designed for the Aberarder OHL and type tested at full scale, and embodied learning from its use designing the Aberarder OHL. This learning will be detailed in the Project's final SDRC in 2022.

Drawings of the T1E2 and T2E6 variants used to construct the trial OHL and their assembly instructions are available in Appendix 1. A photograph of a constructed T2E6 support is shown in Figure 4, where the wood poles in the background are supporting the temporary repair effected following the landslide.

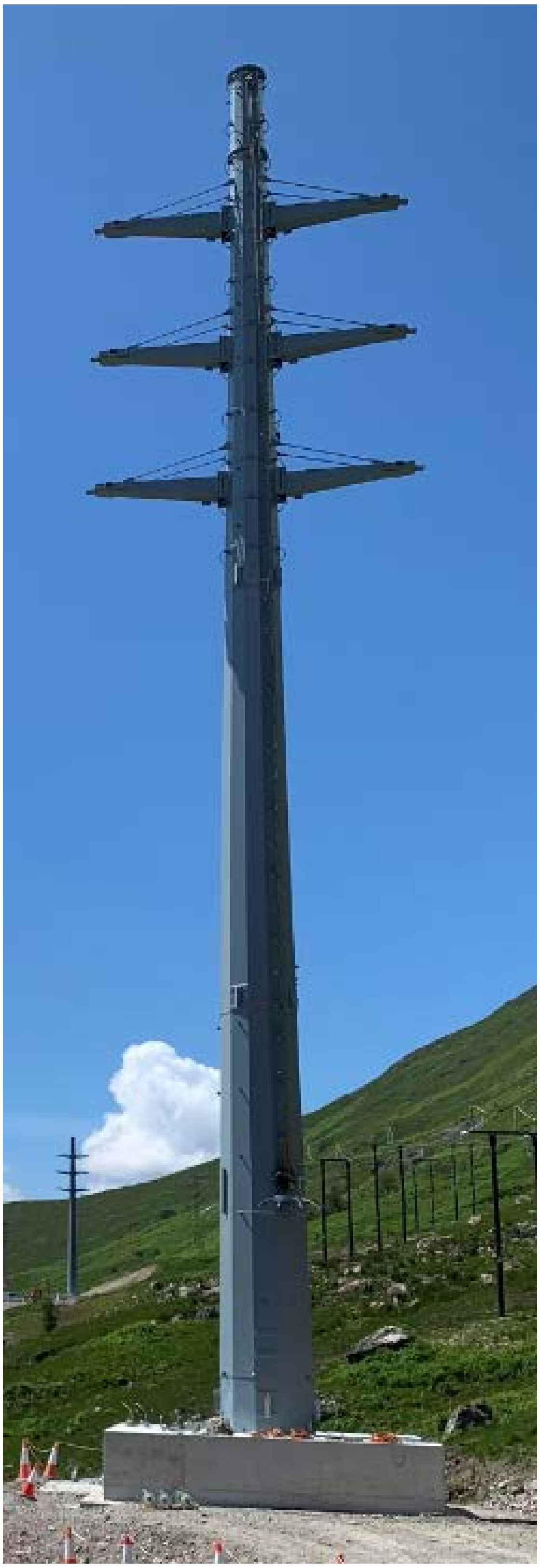

Figure 4: NeSTS 132kV DC T2E6 Structure at QB279R

Foundations

Foundation design was constrained by the proximity to the failed rock bluff responsible for the landslide, which has a large, partially detached body of rock which poses an imminent risk of further significant landslide.

Innovative techniques employing pyrotechnic rock breaking and / or large diameter augering plant were discounted due to vibration risk. The Project wants to trial these techniques as they offer potential to directly embed pole bases as an alternative to use of reinforced concrete, and to provide a solution to compete with the relatively efficient foundations commonly used for lattice steel OHL supports. These techniques are being investigated by the Aberarder windfarm project.

Foundations were designed using mini piles, and concrete pile caps.

The spigot foundation connection, which the Project tested and reported in SDRC 11.6 Outputs of Type Testing, was used in order to explore its constructability and performance. Further details on learning regarding spigot design will be included in the Projects final SDRC in 2022.

Foundation and spigot drawings, and the piling specification are available in Appendix 3. A finished pile cap and spigot are shown in the photograph in Figure 4.

Trial OHL Design

Access

The Quoich – Broadford OHL was built in the 1970s on steep side slopes several hundred metres from the only road in the area.

The Project and its main contractor Norpower considered duties under the Construction Design and Management regulations and decided to construct the permanent repair closer to the road to enable lower impact access arrangements and activity.

However, even closer to the road, the side slopes at the site are substantial as shown in the access drawings which are available in Appendix 4, and by the excerpt in Figure 5.

The photograph shown in Figure 6 illustrates the access challenge, and provides a view of the failed rock bluff and QB280 which was subsequently dismantled.

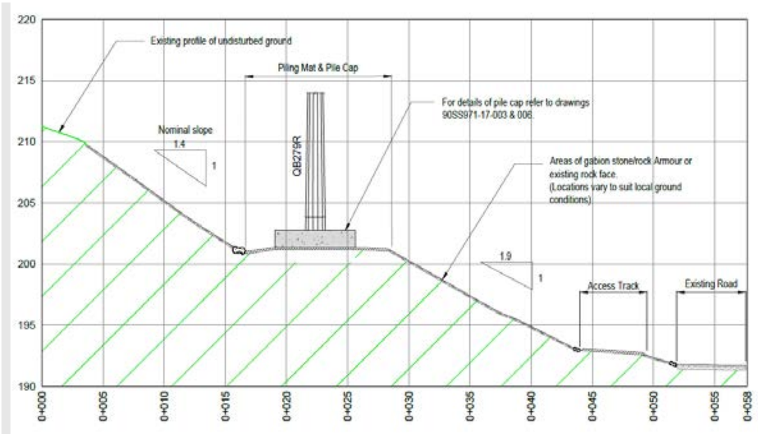

Figure 5: Side slope profile at QB279R

Figure 6: Photograph of QB279R during pole erection from road

Trial OHL Design

OHL Design

The NeSTS 132kV DC supports have been designed to enable higher spans between overhead line supports than are achievable using the equivalent lattice steel supports.

This is in response to stakeholder input that this would result in lower visual and construction impacts as the Project reported in its SDRC 11.3 Outputs of Stakeholder Engagement.

The design toolset is similar to that used for lattice steel OHL design with the exception that PLS Pole is used instead of PLS Tower for structure modelling and analysis. Figure 7 shows the PLS CADD line profile for the trial OHL.

The line was designed around an average span of 400m, which suited the purpose of spanning the area at risk of further landslide, and provides a comparison to the 268m average span being constructed on the Dalchork – Loch Buidhe OHL.

The photographs in Figure 8 broadly illustrate the difference in line appearance, however, the assessment of relative visual impact performance will involve higher quality photographic evidence and detailed assessment of any differing light, weather conditions, viewing angles and field of view, and supervision by landscape architects.

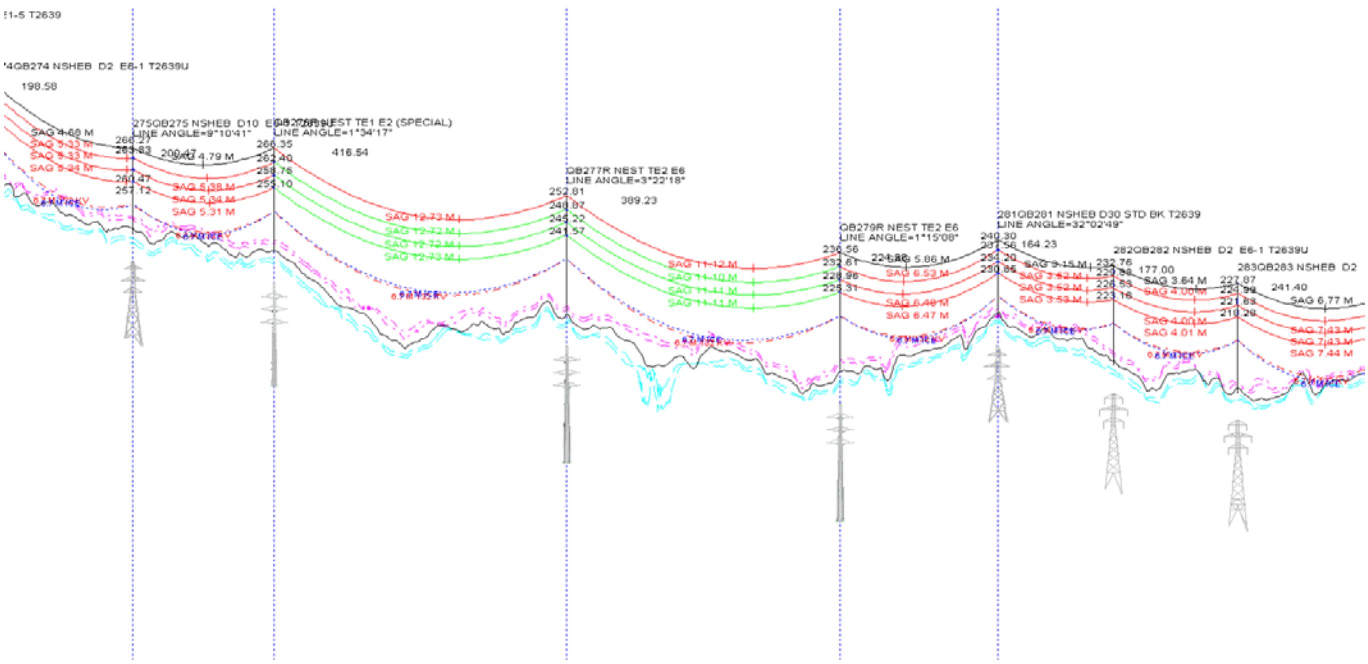

Figure 7: PLS CADD Line Profile for the NeSTS trial OHL and tie in to QB1

Figure 8: Photographs of erected structures from the NeSTS trial and the Dalchork - Loch Buidhe OHL projects

Trial Overhead Line Construction and Energistion

Access Construction

The scale of access works was dictated by the platforms required for piling and for crane positioning for lifting structures. The access works represented about a third of the construction cost, excluding support and conductor system costs, and half the construction programme.

Access works are being retained for use during the Skype project construction. This necessitated removal of spoil from site for storage, and stabilisation of cut faces using gabion stone and hydro-seeding which would otherwise not have been required.

Foundation Construction

The foundations represented around a third of the construction costs (excluding supports and conductor system). The work was completed on budget and within programme, and constructed the foundations detailed in Appendix 2 without issue, excepting 3 failed pile placements which were repeated.

Learning from the foundation construction is regarding spigot connections. The benefits of these are:

- Removal of support base flange costs and failure point;
- Removal of anchor bolt cage, levelling nuts, and any grouting required; and
- Increased robustness and tamper proofing of support base.

Initial concerns regarding the lack of ability to adjust position post construction were overcome by placement and checking processes developed by Norpower and their sub-contractor Grid Line Foundations. However, the following costs need to be considered alongside the benefits for future deployments:

- The programme and cost implications of the separate concrete pours required; and
- The increased volume of concrete required and its environmental footprint.

Ideally, spigot connections in the future will be provided by direct embedment of support bases to avoid these costs.

Support Erection

The gradient constraints for crane access informed a decision to site crane platforms separately to the piling platforms at QB276R and QB279R. This necessitated contract lifts from up to 8 meters under the receiving structure, resulting in a top section lift of 8.5t to up to 52m and up to 21m radius.

A 130t crane was therefore required, although a 150t crane was used without full ballast to suit available plant.

The decision to use 2 cranes for lifting—one used to lift the tails of NeSTS support pole sections off the ground before lifting the tops into vertical position—sized crane platforms at 20 x 25m.

Learning from the process is that tail lifting involved rigging and de-rigging work whose risks outweigh the benefit provided in control of the tails. The contract lift provider recommends that in future, tail lifting could be replaced by skids and controlling access to the lift area.

This would enable a substantial reduction in crane platform size and therefore access costs and programme, and reductions in contract lifting costs and programme.

Trial Overhead Line Construction and Energistion

Wiring

The supports were wired similarly to lattice steel OHL supports, except that they were not back stayed during or after wiring.

This was foreseen as a benefit, but it is counterbalanced by the need to perform more complex sagging analyses to account for movement of the attachment points during the process.

The costs of this process should be considered against the costs of back staying in future, and the main contractor advise that they will back stay in future for standard builds.

Commissioning and Energisation

The commissioning and energisation processes were similar to those used on lattice steel OHL projects.

Figure 9: Middle conductor pulling on NeSTS trial OHL

Comparison to L7c Lattice Steel OHL Construction

The NeSTS trial OHL is being compared to elements of the Dalchork – Loch Buidhe OHL (DLB) which is currently in construction, supports the same conductors, provides the same insulation level, and uses L7c lattice steel supports.

This reflects the comparison made to inform the Project's SDRC 11.4 Stage Gate – Decision to Proceed which was also based on the Dalchork – Loch Buidhe OHL, which estimated that NeSTS OHL costs would be comparable to lattice steel OHL construction.

A key difference between the OHLs, that was not factored in the previous analysis is their average span. In response to stakeholder request, NeSTS 132kV DC supports have been designed to enable higher average spans of 400m between overhead line supports than the 268m spans achieved on the Dalchork – Loch Buide OHL using the equivalent lattice steel supports.

The different scale and stage of the construction projects obviate a whole cost comparison, and a quantities and component cost based assessment has been used.

Supports

The 3 NeSTS supports used to construct the NeSTS trial OHL line were several times more expensive than the equivalent 5 lattice steel supports used on DLB. Part of this results from design and supply chain immaturity, however, in the longer term NeSTS supports will remain more expensive than the equivalent lattice steel supports because of their increased use of steel and factory manufacturing content.

It is unlikely that this difference will be recouped by the faster support installation process alone.

Conductor System

The conductor systems are similar except for a stronger variant of the Keziah OPGW which is used on the NeSTS trial OHL in order to achieve higher span. The incremental costs of the OPGW and its fittings are likely to balance savings made on insulators and fittings associated with the difference in span.

Access

The scale and method of access construction was similar on the OHL projects. Working platforms vary in size and shape to suit ground conditions and gradients. The average size of the NeSTS platforms (excluding pulling platforms) shown in Appendix 3 is 1245m^2.

Access platform drawings are not available for DLB. Site survey estimates an average size of 1093m^2. Photographs of sample working platforms from 2 DLB sites are shown in Figure 10.

The range of platform sizes is large on both projects, and the difference between these averages is not significant.

The track construction is similar. Comparison of average length Is moot because the DLB project has no adjacent road like the NeSTS trial OHL.

For the purposes of this exercise, the conclusion is that the per support access platform costs are similar.

Access platform costs will therefore be lower for NeSTS deployments utilising the higher span on offer.

Spur access track costs should also reduce in proportion to the numbers of supports.

Whether proportional savings in main access track costs can be realised will depend on how many existing access roads or tracks can be utilised on a project.

Comparison to L7c Lattice Steel OHL Construction

Figure 10: Working platforms at DLB 13 and DLB 47

Comparison to L7c Lattice Steel OHL Construction

Foundations

Piled foundations were used on the NeSTS trial OHL in order to avoid vibration/landslide and delay risks involved in the innovative directly embedded designs which the Project expects to be more efficient and compete with lattice steel OHL foundations. These foundation techniques are being investigated by the Aberarder windfarm connection project.

The NeSTS foundations detailed in Appendix 2 have been compared with equivalent DLB foundations detailed in Appendix 4. The piling techniques used were similar, except for the cylindrical hollow sections added to piles on the NeSTS foundations. These have been neglected for this exercise.

The QB276R comparator, DLB44, uses 5x less reinforced concrete.

The QB279R comparator, DLB39, uses 3.4x less reinforced concrete.

QB277R would produce a similar comparison to a piled foundation, and therefore NeSTS used c150m^3 more reinforced concrete than the DLB equivalent.

However, piled foundations are not the preferred option for lattice steel supports, and are only deployed when ground conditions necessitate. The preferred option is the pyramid and chimney design shown in the drawing for DLB47, which has been compared to QB277R to illustrate the challenge for the NeSTS foundation innovation being investigated by the Aberarder windfarm connection project.

The results follow in Figure 11.

Support number	Number of 220mm Piles	Reinforced concrete (m^3)
QB276R	12	58.4 + 6.4
DLB44	12	13
QB279R	16	60.6 + 12.9
DLB39	16	21.7
QB277R	12	47.7 + 12.9
DLB47	0	32.9

Figure 11: Foundation Quantities Comparison

Programme Savings

The differences in scale, and impacts of the COVID 19 pandemic on the projects invalidate comparison of their programmes.

The implications of higher span, resulting in 33% fewer access spurs, platforms, foundations, supports, and insulators to programme related costs have not been estimated, but may be significant.

SSEN003 NeSTS: Construction and Energisation of Trial OHL Rev 1.0 – January 2022