REPLACING STEEL TOWERS WITH WOODEN POLES ON ESB NETWORKS 110KV LINES

Brian Gallagher
ESB International – Ireland
brian.gallagher@esbi.ie

Peter Ennis
ESB International – Ireland
peter.ennis@esbi.ie

Anthony Walsh
ESB Networks - Ireland
anthony.walsh@esb.ie

Andy Hanson
ESB Networks - Ireland
andy.hanson@esb.ie

Peadar de hÓra
ESB Networks - Ireland
peadar.dehora@esb.ie

Enda Feeley
EirGrid - Ireland
enda.feeley@eirgrid.com

ABSTRACT

Utilities in all countries are finding it increasingly difficult to establish new HV circuit routes, particularly in areas of outstanding natural beauty, where steel towers may tend to stand out against the landscape.

This issue arose during a joint review by an ESB Networks and EirGrid High Voltage (HV) Line Design Improvement Group and subsequently ESBI was requested to develop and test a Braced Poleset to replace towers on single circuit 110kV transmission lines. This paper describes some of the technical issues with the development of the new structure.

BACKGROUND

ESB Networks has traditionally used steel towers at strain positions on single circuit 110kV transmission lines, normally at line deviations, with a double pole or 'portal' arrangement at intermediate suspension positions (polesets). ESB Networks (TAO) and EirGrid (TSO) regularly set up joint review groups to assess the scope for improvement in the design and construction of transmission lines and stations, as challenging well established existing policies can provide rich scope for improvement.

During one such exercise on 110kV single circuit line design it was noticed that at 38kV a Braced Poleset was used instead of a tower for light angles, whereas for 110kV transmission lines, angle towers were invariably used, even for very small angles.

On investigation it was found that the reasons for the variation in approach related to higher security requirements in the design approach to 110kV lines, as towers provide greater resilience to the line in cases of broken wire and cascade failure. Therefore an examination into the effect on line security of using braced polesets on 110kV lines was prompted.

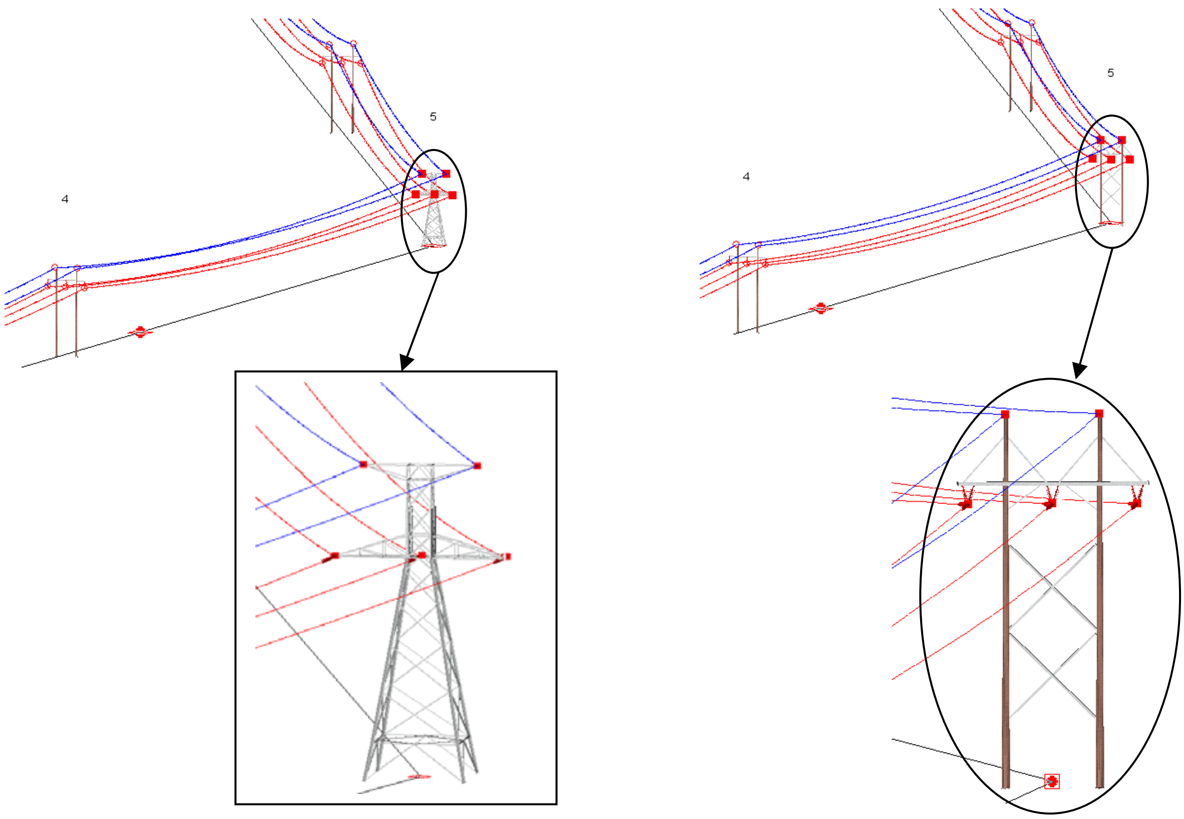

Figure 1 Comparison of a Shieldwire 110kV steel tower with the 110kV braced angle poleset

On analysis of 110kV lines it was clear that up to 35% of towers were used at angles of less than 25°, with 10% in the range 20 - 25°. This meant that if Braced Polesets could be used on new 110kV lines (or on 110kV line diversions) then a much greater proportion of the line could be of wood pole construction.

Wood poles are aesthetically more acceptable than steel towers and so reduce resistance from local communities to new lines. For comparison, a shieldwire 110kV steel tower is shown against a typical 110kV Braced Poleset in a PLS Cadd model in Figure 1 below.

The alternative of staying a normal suspension poleset had been used in the past in a number of locations around the country but these were not popular with landowners as the stays interfered with farming operations.

ESB International, the Engineering Consultancy wing of ESB Group who design ESBN's Transmission Lines were then commissioned to produce a cost effective design where Braced Polesets could be used on single circuit 110kV lines with Bison conductor (430mm² ACSR) – with and without 93mm² ACS shieldwire, for angles up to 25° with a direct initial construction cost less than or equal to the cost of a traditional steel tower.

The Design was then to be built and tested to destruction before deployment on the network.

LOADING

The braced poleset was checked for loading derived from standard ESB weather conditions covering cases of maximum wind, wind and ice and ice only. Typical weight and wind spans found on 110kV single circuit lines were assumed.

For all these conditions, the difference in equivalent span had to be considered as large differences will result in longitudinal loading to which a planar structure such as the Braced Poleset is sensitive.

LINE SECURITY

It was not intended that the braced poleset would add any more security to the line than a standard suspension poleset. Therefore, the impact of replacing towers, which will resist cascade failures, with Braced Polesets, had to be examined.

A study was performed to determine the average length of line sections (distance between strain structures) on lines built in the last ten years, as compared to lines built in the 1950s and 1960s. Due to a build up of one off housing in rural Ireland, the routes of modern lines are more contorted. As a consequence, the average length of line section had reduced to approximately 2.6km. On older ESB lines, section lengths of 5-10km are not uncommon.

Therefore it was determined that as long as a steel tower was installed at intervals of no more than 10km, that the line security would be in line with the original design philosophy. This also reflects what's done in central Europe and France where anti cascade structures are installed every 10km at similar voltages as a minimum [1].

It should be noted that there has been no case of cascade failure on the 110kV system in Ireland.

BRACED POLESET STRUCTURE

Two versions of the Braced Poleset were designed and tested: one for shieldwire lines and the other for non-shieldwire lines.

The structures are a hybrid between a strain and suspension structure. The conductor is connected to the structures using strain insulator chains as they would be to a steel tower. However, the point of connection is the bottom of a hanger which is free to swing longitudinally like a suspension insulator, but not transversely. This allows the structure to relieve out of balance tensions when significant differences in equivalent spans are present.

The main components of the structures are shown in Figure 2 and are discussed in the following sections.

Poles

The tallest wood poles generally used on the ESB Network are 23m. This height was chosen as it allowed enough room for 2 sets of braces with the necessary electrical clearances to the phase jumpers, and sufficient clearance from the ground to the lowest brace to make unaided climbing of the poleset very difficult. The poles are spaced as they are for the standard suspension poleset; 5m apart.

The heaviest pole was specified in order to help resist the longitudinal loads (510mm minimum ground-line diameter). The pole species is Douglas Fir.

Crossarms

The crossarms primarily consist of two steel channels connected on either side of the poles. Various plates and channels span the gap between the crossarm channels to (a) ensure they work together and (b) to provide connection points for the hangers and braces. Some flexibility had to be allowed in the connection details to allow for the variation in pole diameters that are inevitable in a natural product.

The crossarms are longer than the crossarms used on standard polesets in order to (a) provide room for the connection of the hangers and (b) to allow sufficient clearance for jumpers.

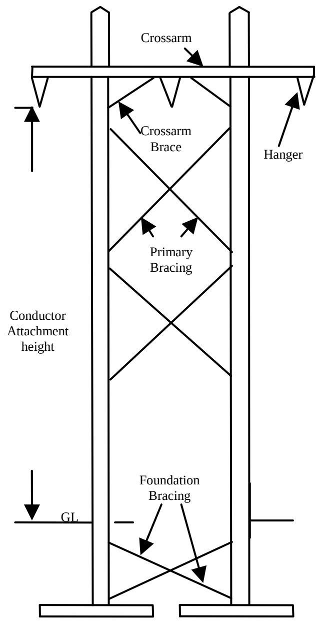

Figure 2 Arrangement of Non-Shieldwire Braced Poleset

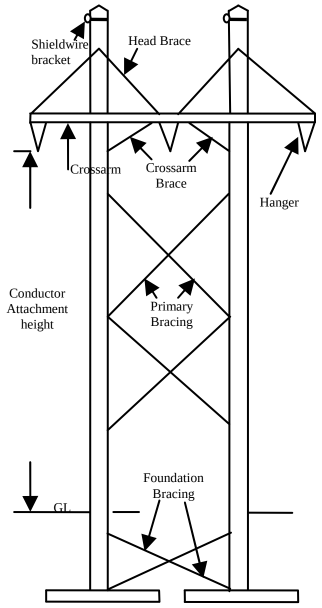

Figure 3 Arrangement of Shieldwire Braced Poleset

Braces

The primary, crossarm and head braces were all made from rectangular hollow section. RHS was chosen for the primary braces after a study showed that it was more efficient than using angles and allowed simpler connections than if circular hollow sections were used. RHS sections were then selected for other braces to avoid material variation and so help reduce costs.

All the braces were designed with pin connections using a single bolt. As the forces were large, the pin had to be 36mm in diameter and the ends of the members had to be reinforced to reduce bearing stresses on the steel.

Primary Braces

The primary braces are used to reduce the moment in the poles when the structure is subjected to transverse loads. They are connected to brackets bolted to the poles. The positions of the connections of the braces to the pole were optimized by trial and error. Note that the optimum position of the connection points relative to each other differs between the shieldwire and non-shieldwire versions.

The braces are clamped together at their intersection point to aid resistance to out of plane buckling.

Crossarm Braces

Crossarm braces were added to further reduce the bending in that portion of the pole between the crossarm and the start of the primary bracing.

Head Braces

For the shieldwire version of the structure, braces were added to help improve the security of the crossarm but also to reduce the bending moments in the pole above the crossarm.

Hangers

As stated above, hangers allow the attachment point of the phase conductors to move longitudinally, so relieving out of balance tensions. As this item is hinged it is most susceptible to wear. Therefore it was designed with steel resistant to steel (grade C40).

Although not designed for broken wire, if it should occur, the hanger will help relieve the broken wire load.

Shieldwire brackets

For the shieldwire version of the Braced Poleset, the brackets were purchased from a supplier's catalogue and consist of an eye pole bolt and an adjustable band which fits around the pole. These allow no relief of out of balance tensions resulting in significant additional loads on the shieldwire version of the structure.

ANALYSIS AND DESIGN

Structure

Analysis of the structure models was performed using Powerline systems software PLS Pole and loading files were created using PLS Cadd as per the weather conditions discussed above. In generating the loads, PLS Cadd could be manipulated to take account of the relieving effect of the swing of the hanger. However, conservatively, no allowance was made for the fact that the structural deflection would further relieve the out of balance tensions.

A non-linear analysis was performed on the structure using these loads and the utilisations of each component assessed. Not all elements could be designed in PLS Pole and so detailed design of individual steel components and connections were designed manually using Eurocodes 3 (steel design) and 5 (to determine bearing capacity of wood).

Utilisations of steel elements and their connections were kept below 80% to allow for the effects of unmodelled offsets. The utilisations of poles was limited to 60% to reduce the risk of deflection due to creep of wood fibres under constant load [2].

Foundations

As soil conditions can vary, the scope of the foundation design was to devise a foundation suitable for the soil conditions found at the proposed test location.

The standard practice of directly embedding poles would not alone provide sufficient strength to resist the large transverse foundation moments generated from the Braced Poleset. Braces were designed to span between the poles below ground to make the two poles work together and convert the moment resistance into vertical forces - uplift and compression. The "foundation" braces are also RHS sections and use the same design approach as the primary braces.

To resist the vertical forces, raft type foundations were designed. Compression forces are distributed across the area of the raft and uplift forces are resisted by the weight of the foundation and the backfill over it.

A concrete raft would not be suitable (given the lime component of the concrete) in environmentally sensitive locations. Therefore a composite raft of wood and steel (steel frame with wooden sleepers) was designed and backfilled with imported graded material (804). To ensure sufficient weight of backfill the raft had to be located at a depth of 3.2m.

A typical arrangement of the braced poleset foundation at installation can be seen in Figure 4.

A key element to the foundation design was the connection of the wood poles to the raft – especially for the resistance of uplift loads. Using wood poles presented several issues in this regard. Firstly, the design had to be flexible enough to accommodate a range of pole diameters. Secondly, the limited bearing capacity of the wood had to be considered. Thirdly, the pole bolts had to be supported on either side of the poles to ensure they stayed straight and did not just bear on the outer edge of the bolt hole.

Due to out of balance tensions, the Braced Poleset must also resist longitudinal moments. The backfill alone would not provide enough resistance to the loading. After several options were examined, it was decided to add a diagonal "longitudinal" brace connecting the pole to the edge of the raft.

Figure 4 Arrangement of Braced Poleset Foundation

RESULTS

It was found that the critical loading elements for the braced polesets were the line angle and the difference in equivalent span. Furthermore, it was found that the presence of the shieldwire reduced the maximum angle that the design could support. The limits on the braced poleset structure are detailed in Figure 5.

	Shieldwire	Non-Shieldwire
Wind Span	250m	250m
Weight Span	250m	250m
Line Angle	20°	25°
Max Attachment ht	14.9m	16.7m
Max Difference in Equivalent Span	50m	50m

Figure 5 Braced Poleset Limits

Contractors were asked to price the installation of the final braced poleset design. This cost, combined with the material cost was found to be less than the installation and material costs of an equivalent steel tower supported on four pad foundations.

TESTING OF THE BRACED POLESET

Both the shieldwire and non-shieldwire structures were submitted to a series of on site tests to verify the design work. The prototype steel was fabricated locally to ESBI drawings, and specialised suppliers designed and supplied the shieldwire brackets and some components of the hanger.

Several load cases were applied to the structure using winches and loading frames and measured using load cells. During testing, the loads were applied in increments and at each increment, deflections of the structure were measured using survey equipment. Surveyors also measured permanent pole deflections after all loads were removed and also monitored the uplift foundation to detect any heave. The loading arrangement is shown in Figure 6.

The structure and the foundations passed all tests without excessive structural deflections.

The final load case tested was the most onerous. After 100% of the load was reached, the load was increased with the aim of determining the point of failure for the structures. Failure occurred at almost twice the design load. The component that failed was the bolt connecting the two members of the hanger together.

After testing, the structure was disassembled and the foundations excavated. Only minor damage was found, mainly in the brackets for connecting the primary braces.

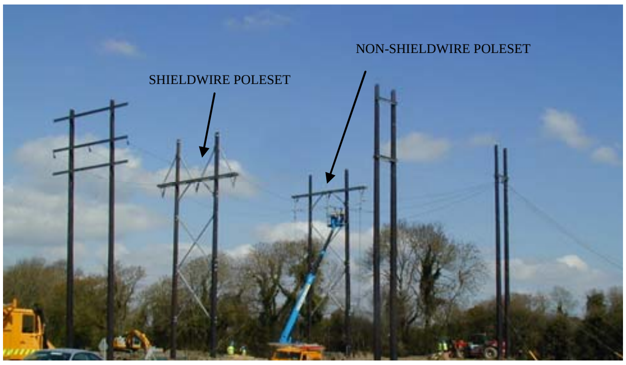

Figure 6 Arrangement of Braced Poleset testing

CONCLUSION

Towers can be replaced by Braced Polesets for line angles less than 25° on non-shieldwire lines and 20° on shieldwire lines and so decrease the visual impact of 110kV single circuit transmission lines while reducing installation costs. However, it is necessary to limit the difference in equivalent span at the structure location. The braced poleset is now in use on the system and is helping to ease the resistance to planning applications for new lines.

ACKNOWLEDGEMENTS

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REFERENCES

For a Conference citation:

[1] Overhead Power Lines by Kiessling, Nefgzer, Nolasco and Kaintzmk published by Springer.

[2] Wood Handbook – Wood as an Engineering Material published by the United Sates Department of Agriculture.