NEW 275 kV OVERHEAD LINE SUPPORT SERIES

(RESEARCH AND DEVELOPMENT)

STAGE 3
FINAL REPORT

90SS545-REP-003

.

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PREFACE

A research and development (R&D) project has been completed, relating to the development of a new 275 kV overhead line (OHL) support series. The R&D project has been undertaken by Scottish Hydro Electric Transmission PLC, with funding awarded as part of the Energy Networks Association's (ENA) Network Innovation Allowance (NIA) scheme (project reference NIA_SHET_0010). The project was managed by Scottish and Southern Energy Power Distribution (SSEPD), with R&D assistance provided by Energyline (EL).

Initially, a wide range of OHL support forms were assessed and a shortlist was selected for more detailed development and assessment. The findings of the early stage of the project were reported in 90SS545-REP-002, *New 275kv Overhead Line Support Series (Research and Development), Stage 3, Interim Report* (herein referred to as REP-02).

This report, REP-03, presents the findings of the completed R&D project, which now includes details of the assessments that were performed on the shortlisted supports, recommendations regarding further development of support form(s), and the findings of associated informative studies.

EXECUTIVE SUMMARY

Thirty six overhead line (OHL) support forms were identified for assessment in the early stages of the project; of these, 8 were shortlisted for detailed assessment, and two of these were chosen as 'winners'. The winning Forms were Series 510, a mono-pole with six, horizontal vee insulated crossarms, and Series 540, a mono-pole with two tubular crossarms supporting two phase conductors on the lower arm and one on the upper arm.

The assessment of the shortlisted forms was facilitated by the use of a purpose made spreadsheet application, the Support Assessment Matrix (SAM). The SAM considers seven Main Design Aspects (MDA): Electrical, Supports and Foundations, Mechanical, Construction, Maintenance, Operational Safety, and Environmental. Each MDA is subdivided into various Design Aspects. The SAM is presented in document 90SS545-95-03 Issue 5, which includes several snapshots corresponding to alternative design weightings, but for ease of reference, a snapshot, corresponding to EL Stage 3 weightings, is included in Appendix A. The snapshot supports selection of the Series 510 and Series 540 as the winning Forms.

In accordance with the Project Execution Plan (PEP) the L8RD specification, lattice steel tower series of supports was used as the benchmark against which the shortlisted Forms were assessed.

All of the Forms that were assessed were 275 kV, double circuit OHL supports with twin earthwires. The double earthwire provision was included to allow the majority of maintenance activities to be undertaken in single circuit outage conditions and to fulfil the requirement to carry communications.

The geometry of the winning Forms was based on an operating voltage of 275 kV, but conversion of the Forms to suit an operating voltage of 132 kV has also been considered. The conversion would be a relatively simple design process, which could result in reduced support heights and reduced support top geometry. Foundation sizes could similarly be reduced.

The stage 3 studies have been based on the use of 1x700 mm^2 AAAC Araucaria conductor operating at 75°C, corresponding to 640MVA (summer pre fault). The winning Forms would be suitable for the support of smaller conductors. Conductor bundles could also be supported, subject to minor adjustments of support top geometry and review of structural member capacities. High temperature low sag conductors (HTLS) could be supported by the winning Forms; these could allow reductions in support heights to be achieved.

From an environmental perspective, the two winning Forms offered improved aesthetics, reduced footprints, and reduced impact on birds.

Both of the winning forms have reduced numbers of elements and connections compared to traditional lattice steel towers (LSTs); the reduced complexity offers advantages in terms of construction and design.

Global costing studies indicate that the winning Forms, the 510 Series and the 540 Series, could achieve cost savings, compared to the benchmark, traditional LSTs, the identified savings being 13% and 3% respectively.

The EMF studies found that EMF acceptance criteria would be met by all of the shortlisted Forms, including the winning Forms. Similarly, audible noise and other electrical design aspects were not found to be critical drivers.

The National Grid T-Pylon project has been in progress throughout the Project. Publicly available information has been reviewed and learning points have been incorporated in the development of the Forms. The T-Pylon supports are mono-pole supports and they rely on an assembly of both tension and compression composite insulators; both features are shared with the 510 Series support.

The modern methods of construction that would be used in the fabrication and erection of the winning Forms offer reduced construction times and, consequently, reduced construction costs.

Both of the winning Forms are mono-poles, this form of construction offers reduced maintenance liabilities, including less onerous painting demands.

The studies have been based primarily on the use of steel as the main structural material, due to its inherent suitability to the scale and geometry of the Forms, however, the use of fibre reinforced plastic (FRP) components has not been precluded. FRP could be used, instead of steel, for secondary structural components and perhaps also for the main poles, subject to development of manufacturing capability.

1 NETWORK APPLICATION REQUIREMENTS

The key network application requirements of SSE by the new overhead line supports included:

- Capability to support double circuit configuration
- An operating voltage of 275 kV
- A maximum rating of 800 MVA
- Suitability for supporting optical circuits
- A range of support types (suspension and light angle, heavy angle and terminal)

By default new supports would be expected to comply with existing SSE policies, procedures, security requirements, and safety rules, but where short falls were identified alternative means of achieving the original objectives would be expected.

2 METHODOLOGY

2.1 *The long list*

Initially a broad range of existing support forms were identified from an extensive review of publically available data sources, in order to gain a broad understanding and appreciation of international practice and ideas. Categories of OHL supports were identified, and a brochure of photographs and illustrations was compiled to capture the range of OHL support types in service internationally. A full range of concept designs were considered and grouped, based on the principal characteristics. The support groups that were identified were:

- Lattice steel towers
- Single poles
- Multiple poles (two or more)
- Moment frame supports
- A-frame supports
- Gantry structures
- No-crossarm supports (such as catenary supports)
- Guyed supports

A longlist of potential candidates was selected from the brochure; these being the ones considered to show promise in one aspect or other by a panel of experts. The panel representatives from SSE and EL, and it included persons with experience in the main design aspects of OHL design, including but not limited to electrical engineering, structural & foundation engineering, mechanical engineering, construction maintenance, and planning & environmental aspects.

Each Form of long list candidate was then developed to meet the network application requirements in terms of at tower clearances, in-span clearances, phase-to-phase separation, and earthwire-to-phase separation. The longlisted forms were drawn to scale to assist with assessments.

A list of 32 design aspects (DA) was developed for the purposes of assessing the longlisted candidates, with the intention of selecting for development only those candidates that showed exceptional promise. The design aspects were grouped in terms of the main design considerations and the experts in each field assessed each of the longlisted forms. There were 10 electrical aspects, 5 structural and foundations aspects, 3 mechanical & electrical aspects, 6 construction & maintenance aspects, 6 environmental aspects, and two others. Further details of the design aspects that were used for the assessment of longlisted candidates are given in REP-02. The results of the assessments of the longlisted candidates informed the selection of a short list of 6, by a joint panel of SSE and EL representatives. After further consideration eight candidates were selected on 9th April 2015 by SSEPD for further development and assessment, this eight being ‘the shortlist’.

2.2 *The shortlist*

At the end of the initial assessment and selection process eight candidates were selected for further development and assessment with the intention of selecting a winner: the support Form that showed most promise in terms of the design aspects. The eight shortlisted candidates are illustrated in Figure 1.

Each of the shortlisted suspension supports were modelled using PLS Tower or PLS Pole software, depending on the structural form. The models were analysed under standard loadcases, and principal elements sized to meet strength requirements. The weights of the supports were then calculated and used in the assessment process. The modelling process also facilitated the determination of surface areas and foundation reactions.

Foundation reactions were used to inform initial design of foundations. On the assumption of typical ground conditions and of caisson foundations to all pole supports, the volumes of excavation, concrete and fill required for each support was determined to inform the assessment process. The volumes associated with foundations to the L8RD specification benchmark support were determined for typical spread foundations, the details being taken from current foundation detail drawings.

In the assessment of the shortlisted candidates the number of design aspects considered increased to 81, and these were grouped into 8 main design aspects: electrical, supports & foundations, mechanical & electrical, construction, maintenance, operational safety, environmental and other. The assessment of all of the design aspects were refined and where appropriate quantified. The proposal was to use the findings of the background studies to inform an allocation of merit score to each design aspect, and then to use the sum of the merit scores to inform the selection of candidates with high merit scores.

For each of the design aspects, summaries of the background studies and the scoring rationale are given in section 2.3.

2.3 *Design Aspects*

2.3.1 Electrical design aspects

Eight options of support structure were modelled with 2D software for the purposes of comparison of electric and magnetic fields on centreline and 100m to either side, and to compare the conductor surface voltage gradient (CSVG or simply E) which is the principal driver for overhead lines generating radio interference, corona and audible noise.

Audible noise

For assessing the electric (E) fields and magnetic (B) fields, the software Electro V9.3 and Magneto 9.2 respectively were utilised. The software yields values of CSVG (see E_i below) which are then utilised in the equation for audible noise, taken from the reference Overhead Power Lines, Planning, Design Construction which is;

Audible Noise = $NP_A = 10\log\{\sum_{i=1}^{n} exp[0.23(NP_{Ai} - 11.4\log D_{Li} - 5.8)]\}$

Where n is the number of subconductors and D_{Li} the distance (in m) between conductor i and the reference point (measuring point). NP_{Ai} is the noise potential of every conductor.

For the purposes of comparison, all calculations were taken at minimum height above ground (7.1m) and assuming that the earthwire sag would be the same as the sag of the phase conductors.

The principal driver for whether or not audible noise is likely to be a problem is the conductor surface voltage gradient (CSVG). In order to compare and score the eight candidates, the highest value of CSVG for each configuration was used to derive relative scores.

Magnetic Fields (External)

The calculated values of magnetic field strength in microteslas generated by the MAGNETO 2D modelling software (V9.3) were used to calculate relative scores for the eight candidates.

The software can produce field profiles over any range. A range of +/- 100m from centreline was selected, for the studies. A minimum height clearance between the bottom phase conductor and ground of 7.1 m was adopted, to give worst case representations of EMFs, for comparison purposes, rather than the average values that are often quoted.

Electric Fields (External)

Values of electric field strength in kV/m were calculated at +/- 100m from the centreline on the support using the ELECTRO 2D modelling software (V9.3), and these were used to calculate relative scores for each of the shortlisted candidates.

Radio Interference

For assessing the electric (E) fields and magnetic (B) fields, the software Electro V9.3 and Magneto 9.2 respectively were utilised. The software yields values of CSVG (see E_i below) which are then utilised in the equation for radio interference, taken from the reference *Overhead Power Lines, Planning, Design Construction* which is;

Radio Interference = $NP_{Ii} = 3.5E_i + 12r_i - 33\log(D_{Li}/20) - 30$

Where E_i is the voltage gradient of the conductor and r_i the radius of the conductor or subconductor in cm.

The principal driver for whether or not radio interference is likely to be a problem is the conductor surface voltage gradient (CSVG). In order to compare and score the eight candidates, the highest value of CSVG for each configuration was used to derive relative scores.

Earthing Performance

The list of shortlisted candidates included lattice steel supports, or steel pole supports, with twin earthwires. It was assumed that all steel supports would be earthed to ground through the foundations. The surge impedance of a lattice steel tower would depend upon the volume of steel, its connected components and the number of interconnected paths. The earthing performance of interconnected twin pole supports and lattice steel supports were considered to be better than independent single poles, with the performance of the lattice steel supports being slightly worse than that of the interconnected two pole supports.

The relative scoring of supports in terms of earthing performance was largely qualitative, based on engineering experience. The weighting of the earthing performance design aspect scoring was set low, because all of the shortlisted supports would be earthed and as such would have adequate earthing performance.

Lightning Performance

In the assessment of lightning performance the principal factor was taken to be shield angle. Relative scores were based on the subtended angle between the vertical plane through the earthwire and the plane passing through the earthwire and the upper conductor, at the line support. In addition a subjective adjustment of score was made for supports with heights greater than 30m. Lightning performance was not considered to be significant as a differentiator, and correspondingly the weighting for lightning performance was set low.

Insulation Coordination

Insulation coordination is affected by many factors, including factors that are not dependent on the characteristics of supports. Representative system details could not be established to allow meaningful insulation coordination studies to be undertaken on a generic basis, and consequently the scoring of this design aspect was neutralised by awarding equal scores to all candidates.

For project specific assessments of supports, where system details would be known, the assessment of insulation coordination would be relevant and possibly influential.

Surge Impedance Loading (SIL)

Generally as conductor separations are reduced (in compact designs for example), there is an increase in capacitance that tends to reduce the surge impedance, which in turn increases the SIL. Compact conductor configurations have better SIL than more spaced out configurations. Conductor separations are determined by the shape of the conductor configuration and the phase separation, so a low height support supporting a tri-form arrangement of conductors would perform better in terms of SIL than a tall support supporting a linear arrangement of conductors. For the purposes of the studies, the geometric mean phase separation was taken as the key factor, and relative scoring between the candidates was based on this factor.

Electric Fields Within Support

For the purposes of assessing non-outage access conditions, the maximum values of electric field strength at the centre of the crossarms were calculated. The calculated values were found to be well below the recommended limits for workers (ICNIRP guidelines 1998 46kV/m), for all of the supports considered, and as such were not considered to be a significant factor for differentiating between candidates, and correspondingly this design aspect has been allocated a low weighting.

Notwithstanding the low weighting given to the in-support electric field strength design aspect, supports with compact conductor configurations were given a low relative score, based on the calculated values of field strength (kV/m).

Magnetic Fields Within/ Near Support

For the purposes of assessing non-outage access conditions, the maximum values of magnetic field strength at the centre of the crossarms were calculated. The calculated values were found to be well below the recommended limits for workers (ICNIRP guidelines 1998, 1800 µT), for all of the supports considered, and as such were not considered to be a significant factor for differentiating between candidates, and correspondingly this design aspect has been allocated a low weighting.

Notwithstanding the low weighting given to the in-support magnetic field strength design aspect, supports with compact conductor configurations were given a low relative score, based on the calculated values of field strength (microtesla).

2.3.2 Supports and foundations

Number of elements

Taking into account the risks associated with each member of a structure, arising from design, manufacture and construction etc., the number of elements in a structure was taken as an indicator of the reliability of the full structure. Structures with fewer numbers of members were considered to have an inherent design advantage over structures with greater numbers of members.
The 'number of elements' design aspect score for any particular Form was calculated by comparing the corresponding number of elements in the Form to the individual totals for the other 7 shortlisted Forms. Forms with numbers of elements greater than 50 were given minimum score 1.

Number of joints

Taking into account the risks associated with each joint within a structure, arising from design, manufacture and construction etc., the number of joints in a structure were taken as an indicator of the reliability of the full structure. Structures with fewer numbers of joints were considered to have an inherent design advantage over structures with greater numbers of joints. The 'number of joints' design aspect score for any particular Form was calculated by comparing the corresponding number of joints in the Form to the individual totals for the other 7 shortlisted Forms.

Side slope – added complexity

Supports that have a wide foot print were considered to be more difficult to construct in hilly terrain, due to the ground level differences. The difference in ground level across a support was taken as an indicator of the additional measures that may be required in the design and the construction of the support. Transverse ground gradients also impact on ground to phase clearance and correspondingly there would be an impact on support heights. For the purposes of the study two dimensions were noted for each Form: the maximum difference in ground level across the Form arising from a transverse slope of 30°; and the reduction in clearance to bottom phase conductors arising from the same gradient, compared to the clearance in level ground. The sum of these two 'hilly ground dimensions', the hilly terrain index, was taken as an indicator of the implications of construction in hilly terrain. The 'hilly terrain' design aspect score for any particular Form was calculated by comparing the hilly terrain index for the Form to the hilly terrain indices of the other 7 shortlisted Forms.

Weight of support – per km

The overall weight of a support impacts on construction, manufacture, embodied energy and resource consumption, and as such it is considered to be a key indicator of good design. The weight of supports per km were calculated for each Form, in order to take into account differences in standard spans. The 'weight of structure' design aspect score for any particular Form was calculated by comparing the weight/km for the Form to the weight/km values of the other 7 shortlisted Forms.

Suitability of alternative materials

For the purposes of the study the construction material was limited to steel. However, for each Form a subjective assessment was made of the practicality of incorporating alternative materials into the Form, such as fibre reinforced plastic tubes, glulam timber poles and crossarms, and concrete poles. Typically, alternative materials were not considered to be suitable for lattice forms of construction, whereas alternative materials were considered to be potentially suitable for use in pole based Forms, especially if simple connection designs were to be developed. The 'alternative materials' design aspect score for any particular Form was allocated on a subjective basis taking into account strength and manufacturing considerations.

Single circuit implications

When 2 circuits are supported circuit 1 tends to balance circuit 2; when only one circuit is supported an out of balance moment is the result. In order to quantify this out of balance effect, the moment arising from dead load in the 2-circuit balanced condition was compared to the moment arising from the 1-circuit out of balance condition. The change in gravity load, overturning moment arising from the change from double circuit to single circuit configuration was taken to be an indicator of suitability for single circuit use. The 'single circuit' design aspect score for any particular Form has been calculated by comparing the increase in overturning moment for the Form to the increases in overturning moment for the other 7 shortlisted Forms.

Ice accretion performance

OHL supports are subject to ice accretion. The weight of the ice that forms on the supports, and also the wind load that is collected by the ice-augmented projected area of the support, have to be resisted by the support. Clearly, the less ice that a support attracts the better. The surface area of the supports was taken as an indicator of proneness to icing effects. The 'ice accretion' design aspect score for any particular Form has been calculated by comparing the surface area of the Form to the surface areas of the other 7 shortlisted Forms.

Surface treatment

Structural steel requires protection against corrosion. The cost of both initial corrosion protection measures, and maintenance of corrosion protection is determined to a large extent by the surface area to be protected. The 'surface protection' design aspect score for any particular Form was calculated by comparing the surface area of the Form to the surface areas of the other 7 shortlisted Forms.

Height extensions

The heights of supports are typically increased from the standard height where spans exceed the standard span, this being to achieve in-span clearances to ground. The heights of supports with vertical tube legs can be easily increased by adding tube extensions, with very little increase in footprint area. The heights of typical tower supports can be increased in height by adding combinations of body and/or leg extensions; the increase in footprint area is greater than the corresponding increase in area associated with tube extensions, and the visual impact of extensions is also greater. Correspondingly lattice steel supports were given lower scores than tube supports. In the case of the series 570 support (x-pylon), extensions would also not match the aesthetics of the standard height support thus attracting a further reduction in score. The 'height extension' design aspect score for any particular Form were allocated subjectively.

Load path

The loads collected by the conductors and earthwire pass through the support structures to ground. The length of load-path is a structural indicator; short, direct load paths are considered to be beneficial. For the purposes of the study, main load paths were identified by inspection and the maximum load path lengths for 6 conductors and 2 earthwires for each suspension Form were summed. The 'load-path' design aspect score for any particular Form has been calculated by comparing the corresponding load-path total to the individual totals for the other 7 shortlisted Forms.

Familiarity of form

'Familiarity of form' is considered to be advantageous to design reliability, in that testing data and historical records (relating to actual performance in service), back up the design principles and methods that were used to design those familiar forms. The 'familiarity of form' design aspect score for any particular Form was allocated subjectively.

Foundation design

Foundations to traditional lattice steel towers are typically simple in concept in that they resist essentially compression and/or uplift loading; overturning moments are relatively small, these arising from residual shears at ground level. Pole supports are such that significant overturning moments are generated at ground level; foundations to poles are therefore required to resist moments as well as vertical loads, and as such the design of foundations to poles require greater design effort. For the purposes of the study, supports requiring only simple uplift/compression foundations were scored 8; supports requiring moment resisting foundations to a standalone pole a score of 4; and supports that require moment resisting foundation to two or more closely spaced poles (shared foundation) a score of 2.

Foundation volume – per km

The volume of concrete in foundations to supports impacts on construction, manufacture, embodied energy and resource consumption, and as such it is considered to be a key indicator of good design. The volume of concrete required to construct foundations was calculated on a unit line length basis to take into account differences in standard spans. The 'concrete volume' design aspect score for any particular Form was calculated by comparing the volume/km for the Form to the volume/km values of the other 7 shortlisted Forms.

Foundation – excavation per km

The volume of excavation required to construct foundations to supports impacts on construction, manufacture, and embodied energy, and as such it is considered to be an indicator of good design. Supports that require smaller excavations for construction of foundations were considered to offer an advantage over those that required more extensive excavations. The volume of excavation required to construct foundations has been calculated on a unit line length basis to take into account differences in standard spans. The 'excavation volume' design aspect score for any particular Form has been calculated by comparing the volume/km for the Form to the volume/km values of the other 7 shortlisted Forms.

Double earthwire

Three scores were allocated on a subjective basis: 9 for two pole supports that require only nominal modification for support of earthwires, 2 for mono-pole supports and 2-pole supports that require modification for support of earthwires, and 1 for lattice towers.

2.3.3 Mechanical & Electrical

Mechanical reliability

'I' String insulators (typical suspension insulators) have a single point of attachment to the support, any mechanical failure in the components of the insulator would compromise the support of the conductor. V-string insulator assemblies, however have two points of attachment; the second insulator provides a level of back-up, whereby the results of failure in one insulator would be mitigated by the action of the other insulator, providing of course that the second insulator has sufficient residual strength. This applies to both the V-string arrangement and the less common horizontal vee arrangement.

In the assessment of mechanical reliability, support Forms that have single insulator arrangements were given low scores, and those that included >1 insulator were given high scores.

Insulation materials

I-String suspension insulators can be traditional cap and pin assemblies, manufactured from glass or ceramic, or long rod insulators from ceramic or composite. Likewise, V-strings can be made up of the same materials and assembly as I-strings. Horizontal vee assemblies comprise a tension insulator and a compression insulator; the compression insulator is necessarily of composite construction, and the tension insulator is usually composite also. The limitation on materials that are used in horizontal vee assemblies was considered to be a disadvantage and consequently the Forms that included horizontal vees were given low scores.

Number of insulators

The number of insulators per phase has an effect on the complexity, number of components required, disposal, and recycling. Also, an increased number of insulators increases the probability of component failure. I-strings were correspondingly marked high, and V-string and horizontal vee insulators were marked low.

Galloping

Conductor galloping is a poorly understood phenomena that causes resonant oscillation of iced conductors, at some locations, under certain wind conditions. Aerodynamic lift effects of wind flowing past ice covered conductors results in non-synchronised resonant oscillation of conductors, which can result in onerous dynamic loading, and also clashing (flashover) of conductors.

The susceptibility of a conductor configuration to adverse galloping effects can be studied by drawing ellipses around each conductor, to signify the positions in space that a conductor may be found during wind excited motion. There are a number of methods in use for determination of ellipse geometry, one of which is presented in CIGRE publication 322. For the purposes of the study the area of overlap between ellipses has been taken as an indicator of susceptibility to adverse galloping effects. The 'galloping' design aspect score for any particular Form has been calculated by comparing the area of ellipse overlap for the Form to the area of ellipse overlap values of the other 7 shortlisted Forms.

Jumpers

Jumpers are typically catenaries of conductor, spanning between the live ends of tension insulators, in a vertical plane between two points of attachment. Where pole positions would obstruct simple jumpers, conductors are spaced away from the pole using intermediate post insulators, to maintain at-support clearances. Low scores were awarded to Forms that relied on any other jumper configuration than a simple 'flag-to-flag', vertical plane configuration. However, this design aspect was not considered to be significant and therefore the weighting value applied was low.

Angle support insulation

Typically, two tension insulators are required to attach a conductor to a tension support, but some of the support Forms required additional insulators. Maximum scores were awarded where two insulators were required per phase; reducing scores were awarded as the number of insulators required at each tension support increased.

Type testing requirements

On the basis that type testing of horizontal vee insulators would be more complex than for I-strings or V-strings, support forms that relied upon horizontal vee insulators were given low scores.

Insulated crossarms

A qualitative assessment has been made of the suitability of each support Form to the use of insulated crossarms. High scores were awarded to the forms that relied on the use of horizontal vee insulators, or other insulated crossarms; low scores were awarded to support Forms that were only suited to conventional 'I' or 'V' strings.

Familiarity of insulator arrangement

Familiarity with the application of insulators was considered to be an advantage in terms of design, construction, and maintenance; correspondingly, the support Forms that had conventional insulator arrangements were scored more highly than those with unconventional insulator arrangements, such as the horizontal vee arrangement. However, this was not considered to be a significant design aspect, and therefore the weighting was set to a low value.

2.3.4 Construction

General

The construction assessments were based on current, 'conventional' activities and procedures for continuous tension stringing; they were also based predominantly on existing OHL construction techniques. Development of full working details for in-built access facilities and attachment points were not included in the studies, but concept studies were undertaken, and the assessments of construction design aspects were based on the details arising from those preliminary studies.

Supply chain – supports

The supply of lattice steel towers for overhead line support is well established; contractors in the UK have well established relationships with steel fabricators, that are familiar with the requirements of the commonly used standards, and that are typically prequalified. Notwithstanding the recent proliferation of wind turbines, and the recent development of the T-Pylon, the supply chain for large, tapered steel tubes in the context of the electricity transmission and distribution is not well established, compared to the supply of lattice steel towers. Development of the supply chain for large diameter steel tubes would be required; and the need for this development is considered to be a negative aspect. Correspondingly, support Forms that included steel tubes were scored lower than those that relied on lattice steel construction. Furthermore, support forms included stayed crossarms received a further reduction in score.

Supply chain – insulators

The application of new insulator technology and / or arrangements, for UK application, may require development of the supply chain, prequalification of new suppliers, and testing. Support Forms where traditional glass or ceramic insulators could be used were awarded higher scores than those that were only suited to the use of composite insulators. However, this design aspect was considered to have low significance and correspondingly given a low weighting.

Support type testing

New OHL supports are type tested prior to project use. Procedures for testing of some innovative support Forms may require more development, and may be more problematic, compared to procedures that are used in the testing of traditional lattice steel towers. Testing of support Forms that rely on moment resisting foundations, and testing of support Forms that have integrated insulated crossarms (vertical vees) may in particular require special consideration. For the purposes of the studies, lattice steel towers and support Forms that have typically have spread foundations were scored highly, compared to support Forms that have moment resisting foundations. Also, Support Forms that incorporated insulated crossarms were given lower scores than those that incorporated standard insulators. However, this design aspect was considered to have low significance, and was correspondingly given a low weighting.

Check erection

For the purposes of the studies, support Forms that comprised few components were given higher scores than those that had a high number of components; correspondingly, lattice steel tower Forms were given lower scores than were pole based Forms. The complexity of form was also taken into account in the scoring. Scoring of the ‘check erection’ design aspect was subjective, and based on experience.

Fabrication – complexity

The fabrication of some support Forms is more difficult than the fabrication of others. Complicating factors include, but are not limited to, the number of elements, the tolerances required for good fit, the ease of manufacture of components, and the number and sophistication of the fabrication processes. Lattice steel towers are constructed using many elements, but each element is fabricated by simple rolling, drilling and in some cases bending process. Steel tube support Forms have fewer numbers of elements, but each element requires non-planar cutting, jigging, and welding. The scoring of support Forms in terms of fabrication complexity could justifiably have been based on subjective judgements, however for the purposes of the studies, the complexity was assessed simply in terms of the number of components.

Foundation – footprint

The plan area of foundations was considered to be an influential factor; support Forms with small plan areas were considered to be preferable to Forms that required greater plan areas for foundations. The advantages would be realised in terms of reductions in disturbed ground and in terms of reduced area required for construction. The scores awarded against the foundation footprint design aspect were based on the plan areas of generic foundations, sized for normal ground conditions, spread foundations for lattice steel towers, and caisson foundations for pole based support Forms.

Assembly area

Typical current practice in the construction of lattice steel towers requires large areas for storage of components and assembly of tower sections; whereas tubular support Forms require less area for storage and assembly. In hilly areas, where ground surface gradients may be unsuitable for assembly, it was reasoned that assembly areas would be even more at a premium. Also, a more linear approach to provision of assembly areas was considered likely for mono-pole support Forms. So, for the purposes of the studies, a subjective score was awarded to each of the candidates, high scores being awarded to pole based support Forms.

Transport & storage

Typically, for lattice steel towers, transportation and storage involves delivery of steelwork to a central storage area, then, after inspection and bundling of components, onward transport to tower sites, for assembly and erection. It was reasoned that the support Forms with few elements, the tube based Forms, would not require delivery to a central site for inspection but instead would be delivered directly to the support sites. However, it was also noted that the transportation of large components could require special transport provisions. On the basis that the components of tube based support Forms would be engineered to avoid large indivisible items, higher scores were awarded to forms with fewer elements. Correspondingly, lattice steel towers were awarded low scores.

Assembly and erection

Lattice steel supports generally require more time and resource for assembly and erection than supports that are comprised of steel tubes. Also, typically during erection, temporary works are used to stabilise lattice steel towers, whereas tube based supports do not generally require temporary works. Correspondingly, lattice steel tower support Forms were awarded lower scores for the assembly and erection design aspect than tube based support Forms.

Access – egress – rescue

During tower climbing on lattice steel towers, climbers can easily attach themselves to the structure by a two tail attachment system, either to lattice steel members or to step bolts, thereby ensuring permanent attachment at all times. Attachment to large diameter pole based supports requires special provisions for climbing. Similarly, for temporary rigging arrangements, such as those employed for during rescue scenarios, are more easily set up on a lattice steel tower than a tube based support, unless suitable attachments have been fitted. Correspondingly, lattice steel tower support Forms were awarded lower scores for the assembly and erection design aspect than tube based support Forms. Subjective differentiations were also made between the pole based support Forms.

Temporary works – insulators

The shortlisted support Forms included three configurations of suspension insulator configurations: the traditional I-string, the V-String, comprising two insulators per phase, and the horizontal vee configuration. The first two configurations have a stable equilibrium position that corresponds to vertical; the horizontal vee configuration is less stable, due to the included effective axis of support. Initial studies indicated that the horizontal vee insulators may require temporary works in order to ensure correct positioning during erection, and therefore support Forms that included HV insulators were scored lower than those that did not.

Conductor installation

In the assessment of the conductor installation design aspect, consideration was given to both traditional land based methods of conductor stringing and to the modern methods, which rely on helicopters; but more weight was given to modern methods. The installation of conductors in some configurations was considered to be more difficult than others; for the purposes of assessment, vertical arrangements of phase conductors were considered to be more advantageous than delta configurations, which were considered to be more advantageous than horizontal configurations. Also, the support legs of some support Forms were considered to pose an obstruction to conductor stringing. Taking into account modern methods of stringing, conductor configurations and obstructions, support Forms with vertical conductors configurations were given higher scores than support Forms with delta conductor configurations or horizontal configurations; and support Forms that 'enclosed' conductors were awarded further reductions in score.

Conductor Attachment point details

Typically, access to conductor attachment points can be gained directly from climbable crossarms where single suspension insulators and vertical vee insulators are used, however for horizontal vee insulators access to the attachment points has to be either via the insulator assembly or via temporary access provisions. Correspondingly, support Forms that included single suspension insulators or vertical vee insulators were awarded high scores. However, tubular crossarms were considered to be more difficult to gain access to than lattice crossarms, and correspondingly lattice steel towers were awarded higher scores than these with tubular crossarms.

Refurbishment

Looking to the future, the refurbishment activities that were considered requiring single circuit outages on double circuit systems were:

- Refurbishment of circuit only
- Refurbishment of circuit and earthwire

- Replacement of earthwire
- Replacement of damaged conductor(s)
- Installation of temporary masts

Separation between circuits was considered to be the key factor. Support Forms with a reduced distance between circuits were scored less favourably than those with greater separations.

Dismantling

Four aspects of dismantling were considered: removal of conductors, removal of insulators and fittings, removal of supports, and removal of foundations, but, were awarded on a subjective basis to reflect the four aspects. Removal of conductors from horizontal vee insulators was considered to be marginally more problematic than from I and V strings. Removal of horizontal vee insulators was again considered to be more problematic than other insulator arrangements. Dismantling of supports was considered to be a reversal of the erection process, so lattice supports were awarded low scores compared to tube based supports. For the purposes of the studies, it was assumed that the foundations to lattice steel supports would be relatively shallow spread foundations, whereas the foundations to pole base support Forms would be deeper, moment resisting foundations, such as mono-piles. Removal of mono-piles and other forms of foundation may not be feasible, and therefore assessments have been based on the assumption that deep foundations would remain in the ground.

Tension supports

Continuous tension stringing procedures were considered to be applicable for each of the shortlisted support series, however landing and sagging of conductors requires access and temporary rigging. Tension support Forms that were considered to have better provisions for access and attachment of temporary rigging, such as lattice steel towers, were awarded higher scores than others.

The studies focused on suspension support Forms, however, notional tension support Forms were drafted for each of the shortlisted support series. Traditional tension insulators were envisaged for all of the support series, but alternative tension insulator configurations were also considered for the series that relied upon horizontal vee insulators at suspension sites; this being to avoid the default option of using traditional supports at tension sites. Insulated crossarms for tension sites were considered to have patent disadvantages, and correspondingly support series that included tension insulated crossarms were awarded lower scores.

2.3.5 Maintenance

General

Access for pole type supports is likely to require the addition of permanent attachment points and/or ladders, to enable climbing and in addition suitable facilities to allow rigging for raising and lowering equipment (for example the provision of a lifting jib).
It has been assumed at this stage that all pole type supports can be designed with these attachment points and that the poles would be manufactured from steel.
In considering the various aspects of the Maintenance elements of the SAM one of the main considerations has been how these items affect Health and Safety as well as System safety and security.

Ancillary equipment

Ancillary equipment in the form of dishes and antennas is commonly fitted to lattice steel towers, by direct attachment to angle members such as leg members, or by fitting cross-members between tower members onto which ancillary equipment is fixed. Fitting of Ancillary equipment to poles would require either bespoke fittings to poles, or circumferential strap fittings. Attachment of ancillary equipment to lattice steel supports was considered to be less problematic than to poles, especially as a post-construction exercise, and therefore high scores were awarded to lattice steel supports and low scores to all pole based supports.

Main component replacement

Main components were considered to be insulators and insulator fittings, and conductor fittings. Forms which included I-strings were given high scores, those with V-strings were given middle range scores, and those with horizontal vee insulator assemblies were given low scores. The Forms with V-strings were further differentiated, the ones with a vertical conductor configuration were given higher scores than those with tri-form conductor configurations.

Operational activities

Scoring of the operational activities design aspect focused on electrical isolation and cross-jumpering at tension supports. Forms that were based on tri-form conductor configurations were given low scores; forms with vertical conductor configurations were given high scores.

Component replacement – earthwires

The 'Main Component Replacement to Earthwires' Design Aspect was assessed in terms of tasks on earthwire fittings, but not including lowering, raising, or adjustment of tensions. The tasks that were considered included work on earthwire saddles and fittings, work on earth bonds, work on dampers, and work on fibre optic systems.

Phase conductor systems repairs

Scoring of the Phase conductor systems repairs Design Aspect was based on the standard techniques that are used to lower and raise phase conductors at tension and suspension supports, with one circuit live; for example, carrying out of repairs to damaged conductors or removal of foreign objects. The primary assessment criteria was considered to be safety from the adjacent live circuit; forms with large circuit to circuit separation were given high scores.

Earthwire system repairs

Scoring of the 'Earthwire systems repairs' Design Aspect was based on the standard techniques that are used to lower and raise earthwires at tension supports, with one or both circuits live; for example, carrying out of repairs to damaged earthwires, removal of foreign objects, or repairs to fibre optic systems. The primary assessment criteria was considered to be safety from adjacent live circuits; forms with large earthwire to circuit separations were given high scores.

Surface preparation and treatment

In the assessment of the 'Surface Preparation and Treatment' Design Aspect, surface area, ease of access, outage requirements, and non-outage working have been taken into account. Typically lattice steel Forms have higher scores than pole based Forms.

Remote Condition Assessment

Some support forms are more suited to remote assessment, from the ground or by aerial methods, than others, and consequently are less reliant on full climbing inspections. Support Forms that were considered to be well suited to remote inspections, i.e. the pole based Forms, were given higher scores than lattice steel based Forms. The condition assessment tasks that were considered included inspection of conductors, inspection of insulators and fittings, and identification of high resistance joints.

Condition assessment – climbing

In the scoring of the 'Intrusive Condition Assessment' Design Aspect, the suitability of the Form to inspection of the full support, conductors, and insulators and fittings, from the support body has been taken into account.

2.3.6 Operational safety

General

The safe access and egress to the supports for maintenance and/or repair work is vital to the support design. In considering the various aspects of the Operation elements of the SAM one of the main considerations has been how these items affect Health and Safety as well as System safety and security.

Access – egress – rescue

The assessment of Forms in terms of access, egress and rescue has taken into account ergonomic access to the support, the suitability for attachment of fall arrest systems, provision of adequate clearances to live circuits, and hindrances to personnel rescue. Forms with extended crossarms were given low scores, lattice steel Forms tended to score well.

Live line working

None of the supports were considered to be well suited to live line working and consequently they were all given a neutral score. The 'Live Line Working' Design Aspect was retained in the SAM, however, to facilitate the future scoring of other support forms for which live line working procedures may be developed.

Management of induced voltages – earthing

The issue of applying earthing systems / procedures for the management of induced voltages/ currents was considered to be similar for all supports, as all of the support Forms were based on steel as the principal construction material. Neutral scores were given to each of the Forms.

The 'Management of Induced Voltages' Design Aspect was retained in the SAM, however, to facilitate the future scoring of other support forms, such as those constructed of non-ferrous materials.

Circuit demarcation

Clear circuit demarcation was considered to be problematic on mono-pole Forms, and consequently mono-pole supports were awarded low scores. Support Forms would need to meet current industry standards for circuit demarcation.

2.3.7 Environmental aspects

Height

Tall supports may have a more negative visual impact than shorter ones. Shorter supports can be more easily hidden in the landscape using Holford's routing guidelines. "The use of low height towers has been successful in reducing the visual impact of towers" (Turnbull, 2004, p.69)
"increased height will generally also mean visibility which (possibly) creates impact over a large area" (Bishop, 1985, p.198). Consequently, tall support Forms have been given low scores compared to short support Forms.

Site frequency

The Site Frequency is the number of supports per kilometre. In the assessment of support Forms, the variation in standard span was considered; short standard spans corresponding to higher site frequency, and hence an increase in the lateral density of the route. Reduced scores were given to support Forms that were considered to be best suited reduced standard spans.

Visual impact – insulators

Insulators are often the most visible feature of a support.

> *"because of their shape, insulator strings always present a convex surface towards the viewer…the effect of this... is often to make the insulators visible even when the towers to which they are attached are not easily seen." (Turnbull & McAulay, 2004, p.60)*

Reducing the number of insulators used on each support can help reduce the visual impact, and therefore high scores have been given to supports that rely on single suspension insulators. Also, Horizontal Vee insulators have scored lower than V-strings, to reflect the increased thickness of the lower, post-insulator.

Transparency

Some supports such as lattice steel towers can appear almost transparent against certain back cloths and therefore have scored highly.

> *"The ratio of solid steelwork to the overall profile area in less than 1:10…making the tower take on the colour and texture of its visual background" (Turnbull & McAulay, 2004, p.27)*

> *"Generic steel pole designs were examined by two landscape architects and were judged to be more obtrusive in Irish rural landscapes (generally rolling) than lattice steel towers which were seen to have a capacity for diffusion." (Doyle et. al., 2010, p.2)*

Solid supports do not benefit from this characteristic and have therefore been awarded lower scores. Further, the transparency of the poles has been quantified by calculating the total projected area of each element; large projected areas were awarded low scores.

Conductor configuration

Compacted conductors may be more visible in the landscape than widely distributed formations.

> "Bundles of conductors are generally more visible than equivalent single conductors." (Turnbull & McAulay, 2004, p. 55)

Correspondingly, support Forms with tri-form conductor configurations were given lower scores than those with vertical configurations. Also, conductor spacing can be reduced as spans reduce, which has an adverse visual effect, so scores were modified to take into account standard span lengths.

Shape distribution

The literature indicates that 'top heavy' supports can be perceived as ‘unstable’, but supports with a tapered top have the opposite affect and so look lighter overall. Top heavy support Forms have correspondingly been awarded low scores.

> *"making a tower too thin, especially when top loaded…would afford the viewer a sense that the tower was unstable and unsafe (JJB, 2008, p.4)*

Crossarm configuration

The literature indicates that upturned crossarms are perceived as having a more positive visual effect than down turned crossarms.

"The characteristic upturned cross arms are intended to give the tower a lighter appearance." According to Crowe, "a fault in the then current transmission tower design was that the drooping arms led the eye down instead of skywards.” (Turnbull & McAulay, 2004)

Correspondingly, supports with upswept crossarms and components have been given higher scores than those with a horizontal or down swept appearance.

Design Aesthetics

Planning policy states that good design must be considered. Design aesthetics were ranked subjectively based on criteria such as elegance and sophistication. The scoring also represents what was felt would reflect public opinion.

> *"Applying 'good design' to energy projects should produce sustainable infrastructure sensitive to place" (DECC, 2011)*

Corridor width

The right of way considers the corridor width required for the whole route i.e. the conductor width (not including sag/swing). A large right of way could potentially be more difficult to get planning permission for, and cause problems in terms of loss of habitat.

The corridor width Design Aspect has been quantified, support Forms with a narrow corridor width have been awarded high scores relative to those with wider corridor widths.

Footprint (land take)

Land take refers specifically to the foot print of the tower. It has been assumed that a smaller land take would be preferred by the land owner, and that in assessment of planning applications, support Forms with small footprint areas would be preferred.

> *"Cable stays dramatically increase the footprint of the tower relative to a lattice steel tower and present an obstacle for farm machinery" (JJB, 200b, p.5)*

The footprint area has been quantified, and support Forms with small footprint areas have been awarded higher scores than those with larger footprint areas.

Birds

The risk of birds (in particular larger birds such as raptors, geese and swans) colliding with overhead lines may increase with the height of the support. Shorter supports can be more suitably routed, such as behind buildings, trees etc.

> *"Constructions shall obstruct only a minimum of air space in vertical direction" (Hass, 2005, p.26)*

> *The earth wire tends to be 'the highest, thinnest and most problematic component' (Eirgrid, 2012, p.31)*

Earthwires are often less visible than the conductors, 'in certain situations appear almost invisible because of the background or lighting conditions' (Scottish Gov.) and therefore many of the collisions take place when birds increase the height of their flight path to avoid the conductors and consequently fly into the earth wire. It is suggested that the closer the earth wire is to the rest of the conductors, the better it is for birds.

> *"Even more favourable are those...which use no neutral cable at all" (Hass, 2005, p.16)*

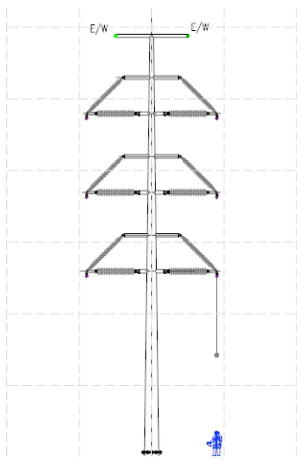
The conductor arrangement of a support can have the most dramatic impact on bird safety. Multi-level conductor arrangements have scored low as they are considered more difficult for birds to avoid than single level arrangements.

> *"Highest risks are posed by those power lines, where the conductors are arranged at different heights" (Hass, 2005, p.16)*

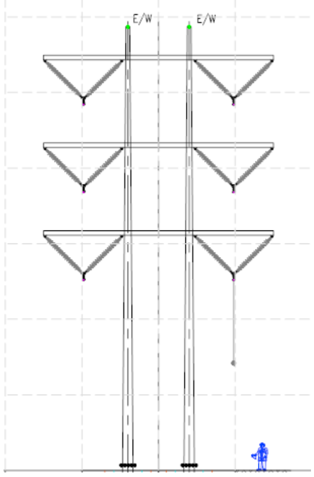
The scores for each of the above three aspects were quantified, combined, and weighted, with the conductor arrangement being the most important aspect.

Suite continuity

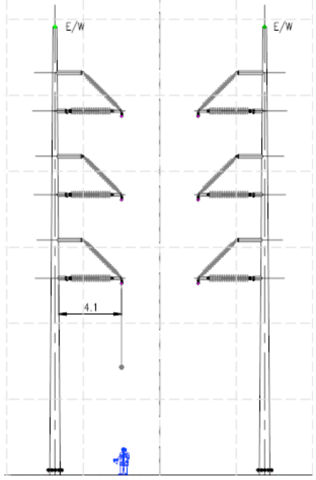
Tension support designs were assessed in relation to 'continuity' with the rest of the route, i.e. how well they resembled the corresponding suspension support. Overall scores were applied to a number of different aspects that were recognised as being 'similar' or 'different' from the corresponding suspension tower. The identified modifications included aspects such as change in tower height, width, & pole thickness, etc. These individual aspects were calculated and averaged to gain a relative score.



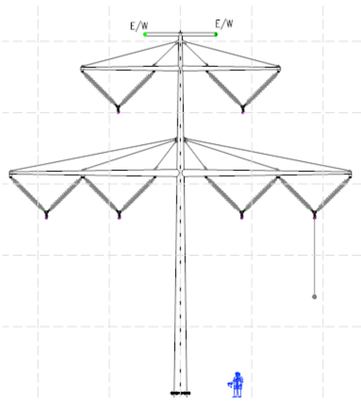
510 Series



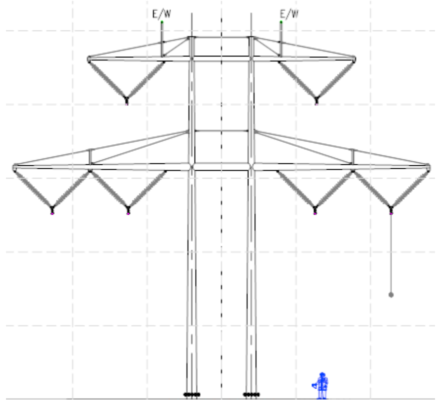
520 Series



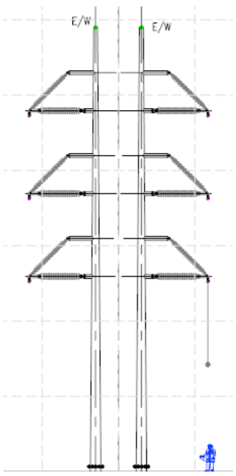
530 Series



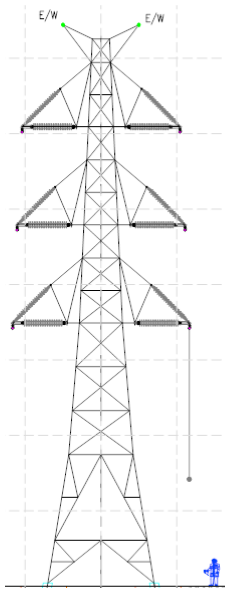
540 Series



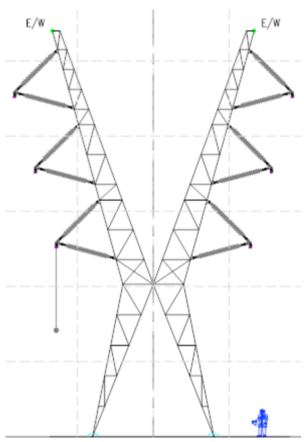
560 Series



550 Series



570 Series



580 Series

Figure 1 – Shortlisted Supports

Table 1 – Design Aspects

Electrical	E.1	Audible Noise
	E.2	Magnetic Fields (external)
	E.3	Electric Fields (external)
	E.4	Radio Interference
	E.5	Earthing Performance
	E.6	Lightning Performance
	E.7	Insulation Coordination
	E.8	Surge Impedance Loading (SIL)
	E.9	Electric Fields within/near structure
	E.10	Magnetic Fields within/near structure

Supports & Foundations	S.1	Number of elements
	S.2	Number of joints
	S.3	Side slope added complexity
	S.4	Weight of structure (per km)
	S.5	Suitability to use of alternative materials
	S.6	Reduction in reliability in single circuit configuration (i.e. strung one side)
	S.7	Ice accretion performance
	S.8	Area for painting
	S.9	Implications of addition of extensions
	S.10	Length of load path
	S.11	Familiarity with Form (familiar forms score high)
	S.12	Foundation complexity
	S.13	Foundations (Volume of concrete per km)
	S.14	Foundations (Volume of excavation per km)
	S.15	Suitability for application of two earthwires

Mechanical & Electrical	M.1	Insulation Mechanical Reliability
	M.2	Insulation Material Limitation
	M.3	Number of Insulators
	M.4	Galloping (susceptibility to conductor clashing)
	M.5	Formation of Jumpers at Angle Supports
	M.6	Angle Support Insulation
	M.7	Type Testing Requirements
	M.8	Suitability for ICA adaption
	M.9	Familiarity with Attachment Arrangement

Construction	C.1	Support Supply Chain Familiarity
	C.2	Insulation Supply Chain Familiarity (Composite)
	C.3	Support Type testing
	C.4	Support check erect
	C.5	Complexity of support (Fabrication)
	C.6	Foundation Construction (footprint)
	C.7	Support Footprint & Assembly Area
	C.8	Support Transport & Storage
	C.9	Ease of support assembly / erection

	C.10	Support access/ egress/ rescue
	C.11	Need for insulator temporary restraint
	C.12	Conductor Installation Process
	C.13	Insulator Conductor Attachment Point
	C.14	Refurbishment inc. e/w- 1 cct live proximity
	C.15	Route Dismantling
	C.16	Tension Support (Conductor Installation)

Maintenance	R.1	Ancillary equipment (including third party)
	R.2	Main Component Replacement
	R.3	Suitability for operational activities (e.g. isolation)
	R.4	Main Component Replacement to Earthwires
	R.5	Phase Conductor System Repairs - 1 cct live proximity
	R.6	Earthwire Conductor System Repairs - 1cct live proximity
	R.7	Surface Preparation & Treatment/ Deterioration Protection
	R.8	Condition Assessment Remote (Ground/ Aerial)
	R.9	Condition Assessment Intrusive (Climbing)

Operational Safety	O.1	Access/ Egress/ Rescue
	O.2	Live line working
	O.3	Management of Induced voltages / currents / Application of additional earthing
	O.4	Circuit Demarcation

Environmental	P.1	Height
	P.2	Supports per km
	P.3	Insulator Visual Impact
	P.4	Transparency (Back clothing)
	P.5	Conductor Arrangement (Compact/ Open)
	P.6	Support shape (eiffelised/ top heavy etc.)
	P.7	Cross arms
	P.8	Design aesthetics
	P.9	Corridor Width
	P.10	Footprint
	P.11	Effect on Birds
	P.12	Tension Support Continuity

2.3.8 Support Assessment Matrix

The Support Assessment Matrix (SAM) is an MS Excel, spreadsheet application that was developed as a decision making tool for use in the compilation, consolidation and visualisation of the strengths and weaknesses of overhead line supports. The SAM allows the user to:

- confirm that all of the key Design Aspects (DA) have been taken into account in the assessment,
- see the significance that has been attributed to each DA, and
- see the performance of each Support Form, not only on a DA-by-DA basis, but also globally.

The SAM allows the weighting of all DAs within a MDA to be adjusted together or individually. One user may wish to see the effects of increasing the weighting of all of the Environmental DAs, this can be done by increasing the Environmental MDA weighting relative to the other MDA's; another user may wish to see the effects of promoting the significance of Operational Safety.

The DA weightings within the MDA's, can also be adjusted individually, in column I of the spreadsheet. The numerical values for DA adjustments within each MDA group is not restricted and so they do not need to be consistent between MDAs. It is the relative DA adjustment values that are processed by the SAM to give DA weightings.

The overall DA weighting for any particular DA is the product of the MDA weighting and the sub-DA. The overall DA weighting values are clearly stated in column L of the application and the relative values are indicated by scaled bars in the cells of that column. The relative importance of DAs within a MDA group can be compared directly by comparing the overall DA weighting values stated in column L.

For each DA, Support Forms have been assessed and allocated scores. The scores range from 1-9. The overall SAM score for a Support Form is then the sum of the products of DA scores and DA weightings, expressed as a percentage. The overall SAM scores for the short listed Support Forms are presented in row 25. Conditional formatting highlights high SAM scores as green and poor SAM scores as red.

The rationale behind the scoring for each DA is stated on a tab within the SAM application, and for ease of reference hovering over cells in column C also shows notes on the rationale for that DA.

The SAM is presented with an initial set of MDA weightings, sub-DA weightings, and Support Form scores. But, the intention is for users of the SAM to copy the main SAM tab and to make adjustments to match their own opinions. Adjustment of the MDA weightings would be good place to start, followed by adjustment of sub-DA weightings, and then perhaps adjustment of Support Form scores. Personalised SAM's can then be used to inform debate and correspondingly to facilitate a consensus of opinion.

The SAM was developed specifically for the project, but the principles could easily be adapted to suit other decision making processes.

2.4 *Informative Studies*

In addition to the studies that were undertaken to inform scoring of the shortlist candidates against the design aspects, background studies were undertaken in areas associated with innovations in the design of overhead line supports. A range of studies were carried out including consideration of alternative materials for supports, access to support forms other than lattice steel towers, the stability aspects of horizontal vee insulator assemblies, assessment of the carbon footprints of overhead lines, and global cost assessments of overhead lines. The findings of the informative studies are reported in section 4.

3 SHORTLIST ASSESSMENT FINDINGS

3.1 *General*

The 'Winners' of the support assessment have been captured by the studies carried out in conjunction with the SAM, these scores have been presented below – Section 3.2. The full SAM spreadsheet can be seen in Appendix A. Consideration and evaluation of these outputs has been provided in terms of the advantages and limitations of each support per MDA in sections 3.3- 3.10.

3.2 *SAM Results*

The SAM results are very dependent on the weighting assigned to each Design Aspect (DA) and Main Design Aspect (MDA), a ranked list of each design aspect can be seen in Appendix B.

3.2.1 MDA Weightings

The weightings that have been considered are presented in Table 2 below with an indication of the reasoning behind the weightings adopted. These weightings are subjective depending upon who is making the assessment and in which aspects they hold in highest regard.

Table 2 – SAM Weightings

Main Design Aspect (MDA)	Weighting	Comments
Electrical	0.05	The electrical MDA has been given a low rating as the impact of the electrical DA's is very low.
Supports & Foundations	0.30	Supports and foundations were considered to have a large importance as these DAs also impact other elements of the design.
Mechanical & Electrical	0.10	Mechanical and electrical aspects are mainly concerned with insulation technology, this is an important aspect but does not outweigh other items.
Construction	0.10	Whilst these MDA's are separate their cumulative weighting is a significant portion of the design and share many similarities associated with working on or around the support.
Maintenance	0.05	
Operational Safety	0.10	
Environmental	0.30	Environmental impact and associated consenting was identified as a main driver of the project and therefore has a large weighting in the assessment considerations.
Other	0.00	The 'Other' MDA is a place holder for other design aspects which potentially do not categorise in the other aspects.

Figure 2 below is a snip taken from the SAM to demonstrate how the weightings can be controlled.

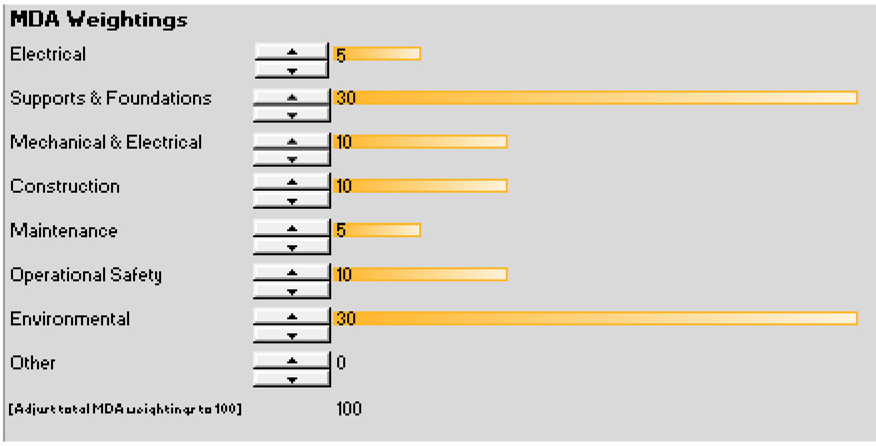


Figure 2 – MDA Weightings

3.2.3 Scores

Based on the weightings presented above the scores in Table 3 are the scores of the 8 supports considered. Other combinations of MDA weightings were reviewed which increased either the construction or environmental weightings, these showed that the 510 was consistently high performing.

Table 3 – Support Scores

Support Series	Score
L8RD	56.83
510	55.21
520	53.54
530	46.97
540	54.86
550	49.14
560	49.9
570	48.19
580	42.28

3.3 *510 Series*

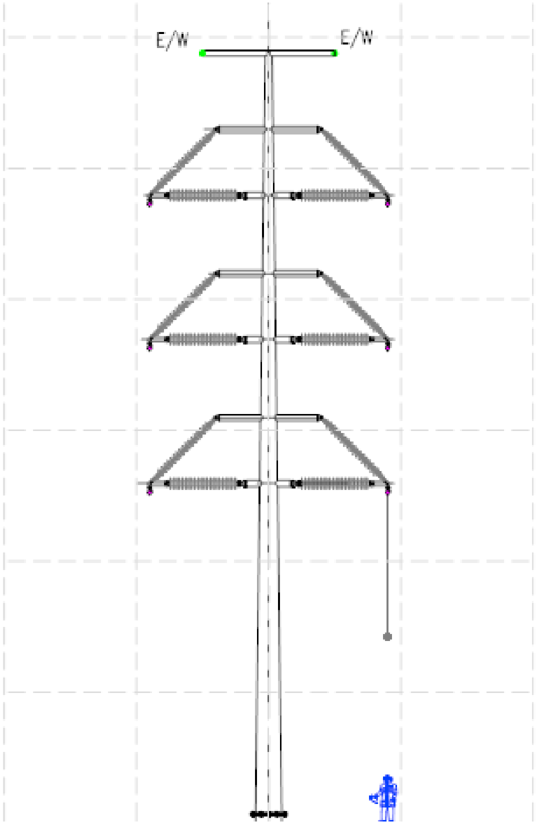


Figure 3 – 510 Series

Weight (kg)	**Approximate Height (m)**	**Span (m)**
9300	29	200

3.3.1 Description

The 510 Series support comprises a single, tapered, steel tube, mono-pole with short tubular stubs for support of insulators, and a top tubular earthwire support crossarm. The main pole has a diameter of 1000 mm at ground level and 250 mm at the top; tubular stubs and crossarms are 250 mm in diameter.

A bolted flange-plate connection is indicated between the support and the foundation.

The conductor configuration is two vertically configured circuits of three phases, with twin earthwires. The conductors of each circuit are indicated as vertically in-line however offsetting to facilitate C&M considerations, and to mitigate against the consequences of galloping is envisaged.

Two insulators support each phase conductor; these being in a 'horizontal vee' configuration, with a raking pivot angle.

A nominal standard span of 200 m indicates an overall height of support of 30 m, and an overall horizontal spacing between outer conductors of 9 m.

3.3.2 Electrical

Overall the electrical performance of the 510 series was in the mid-range of scores. Based on the geometry and phase separations, it scored relatively well for Lightning and SIL and averagely for other aspects.

Electrical studies confirmed that the values varied very little between the different forms in many of the aspects and that all forms would be compliant with statutory and utility limits. As a result, the electrical MDA has a low weighting in the SAM. Section 4.2 provides a more detailed comparison of the electrical characteristics of the L8RD, 510 and 540 Series.

3.3.3 Supports & Foundations

Internal corrosion

Corrosion protection of tube elements would be achieved by galvanising of all surfaces, plus painting of external surfaces (t-coat primer, long life, easy maintenance paint). The sizes of components would be restricted to suit commercially available galvanising bath sizes. It would not be possible to inspect all internal surfaces, and therefore there would be a risk associated with corrosion of hidden surface, albeit a small one. Detailing of components would require careful detailing in order to suit galvanising. Careful detailing of drainage provisions would also be required to safeguard against retention of water within tubes.

Reliance on welded connections

The intention is for this Form to rely on welding as a primary means of connecting elements together. Although welded structures are used in many sectors that demand high standards in terms of reliability and performance welded structures are not commonly used for OHL supports in the UK. The existing, well-developed, non-destructive testing methods and procedures that have been developed by other sectors should be easily adapted to suit the OHL support fabrication industry.

Development on site connection details

No connections are indicate on the general arrangement drawings of connections within the vertical pole lengths. The intention is for the poles to incorporate at least two sleeve joints, not flange plate connections. Flange plate connections are either external or internal; for the size of poles that are envisaged internal flange plates would not be practical, noting that access for tightening of bolts would be required. External flange plates are not preferred due to poor aesthetics, however they do have benefits in terms of ease of construction. The detailing of construction connections would require development.

Earthwire support

The support of the two earthwires for this Form is achieved via a horizontal tube crossarm at the top of the pole. Feedback from environmental assessment indicates that the appearance could be improved by upsweeping the arms and tapering the sections. Construction and maintenance feedback also indicates reservations regarding attachment of earthwires and the use of earth wire support arms for C&M procedures. The design of the earthwire support arms therefore requires further development to suit the various assessment preferences and requirements.

Spans

The assessment of this Form has been based on a standard span of 200m (maximum span 300m). Typically lattice steel tower supports have standard spans in the range 300m - 350m in the UK. The reduced standard span allows some advantages to be realised including, but limited to:

- reduced height, reduced climatic loading effects,
- reduced foundation sizes,
- reduced susceptibility to galloping effects, and
- reduced construction requirements.

The adoption of a reduced standard span, however, has a detrimental effect in terms of weight and cost of supports and foundations per kilometre of line, and in terms of the number of sites in a line. It is hoped that assessment of the Form, configured to suit the 200m standard span, has facilitated due consideration of the benefits of reduced spans, however, assessment of the Form in a 300m standard span configuration may be required if direct comparisons to existing steel lattice tower supports is required or if there is a requirement for 'common practice' OHL support spacing at 275kV to be matched.

3.3.4 Mechanical & Electrical

The Mechanical & Electrical performance of the supports is primarily driven by the insulator arrangement adopted. The 510 series performs relatively poorly in this regard as horizontal-vee insulators increase the number of insulator strings required (2 instead of 1 ‘I’ string in a conventional tower), potentially increasing the incidence of insulator failure on a route. Horizontal-vees also limit the material choice of the insulators for the designer. The benefits that result from the application of horizontal-vees are considered in the other main design aspects when considering factors such as support geometry.

If development of Horizontal-Vees proves to be too problematic, then the 510 series could be modified to suit the use of vertical-Vs or even I-strings, by the extension of the tube crossarms, but this would fundamentally change the appearance and function of the Form, and as such would be difficult to justify without reconsideration of the other forms that were not included in the short-list.

Another aspect considered is the galloping performance which for the 510 scores low due to the vertical conductor configuration and reduced spacing between phases. The extent of overlap between adjacent galloping ellipses could be reduced by offsetting the middle crossarm, and/or by increasing the vertical spacing between phase conductors.

Consideration has also been given to angle support insulation, at present the angle supports are initial concepts only so this is somewhat of a misleading assessment, however the indication of a four leg insulated crossarm for light angles increases the complexity of the insulator design.

3.3.5 Construction

In terms of the initial construction of the support and foundations the 510 series performs the best as significant savings in resource and programme could be achieved with the monopole installation process.

The majority of the benefit comes from the simplicity of the support, it will greatly reduce construction times due to the reduction in elements and the way in which the support will be erected (likely a modular approach). There are also advantages in terms of the footprint for construction, especially in terms of foundations which will be greatly reduced.

Support access systems and procedures would require development for the monopole / 510 series.

3.3.6 Maintenance

Maintenance aspects are difficult to quantify at this stage as the procedures and equipment required have not yet been fully considered, the assessment being made relates to how well the form may lend itself to maintenance operations. Noting that there is likely a workable solution for all the support designs.

The 510 does not perform as well as the 520 in terms of conductor maintenance / refurbishment operations. This is a result of the close proximity of the circuits and the insulator arrangement which adds complexity for working over the standard I or V string.

The 510 series performed poorly in maintenance aspects overall, one of the largest contributing factors to this outcome is the consideration of how main components will be replaced if damaged / deteriorated. This principally relates to working on horizontal vee insulators; the methods and procedures are somewhat unknown and are anticipated to be more complex than conventional arrangements. This also includes access to the conductor attachment point.

3.3.7 Operational Safety

Access, egress and rescue has been deemed to be the most important aspect of operational safety and the 510 series would require significant development in this regard. It performs fairly poorly in its current form, however, none of the designs considered are unworkable with the necessary developments. Some of the key considerations for this form are as follows:

- Access/ egress and rescue procedures will need careful development. There are currently no access methods proposed i.e. ladder, step bolts etc. The single pole restricts movement around the structure to some extent i.e. for rescue there may need to be two access routes to be able to rescue from above.
- Proximity to live circuits due to the compactness of the design and difficulty of demarcation shall require the development of procedures and/ or physical constraints on the structure to satisfy Safety Rules and encroachment towards live apparatus.

3.3.8 Environmental

This support ranked second best in the environmental design aspect. The support demonstrates a reduced visual impact due to its narrow form, lower height and tapered shape. However, due to its solid steel configuration it cannot benefit from the any potential transparency effects of back clothing. The main risk to birds would be the multi-level conductor arrangement. The design is simple, and familiar, it may be obvious in the landscape, but not intrusive and could be improved visually by removing or adjusting the earth wire cross bar.

3.4 *520 Series*

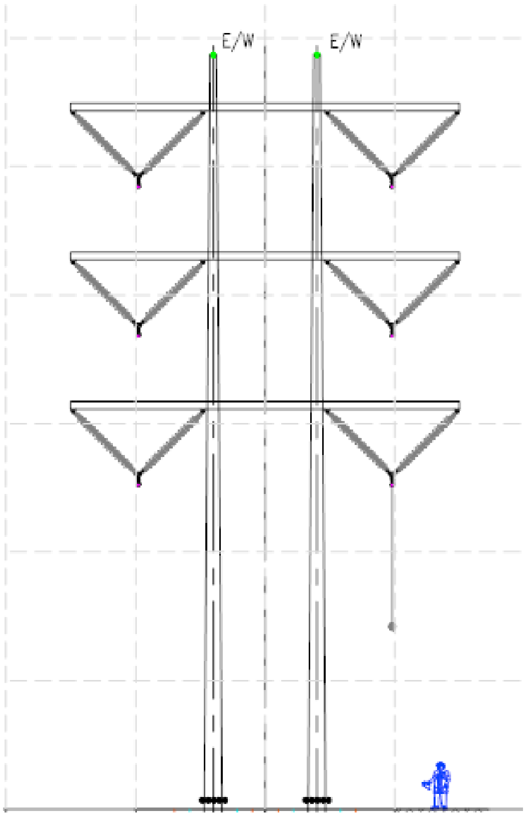


Figure 4 – 520 Series

Weight (kg)	**Approximate Height (m)**	**Span (m)**
17500	29	200

3.4.1 Description

The 520 Series support comprises twin, tapered, steel tube, poles with three vertically spaced rolled steel channel crossarms. The poles have 700 mm diameter at ground level and 250 mm at the top. Crossarm channels are 300 mm in depth. Earthwires are indicated as being attached to the tops of each pole, but nominal stubs may be required for C&M purposes; these would be 150 mm.

A bolted flange-plate connection is indicated between the support and the foundation. Depending on the type of foundation selected at each site, there may be a shared foundation or separate foundations to each leg.

The conductor configuration is two vertically configured circuits of three phases, with twin earthwires. The conductors of each circuit are indicated as vertically in-line however offsetting to facilitate C&M considerations, and to mitigate against the consequences of galloping is envisaged.

Two insulators support each phase conductor; these being in a 'vertical vee' configuration.

A nominal standard span of 200 m indicates an overall height of support of 29 m, and an overall horizontal spacing between outer conductors of 10 m.

3.4.2 Electrical

The electrical performance of the 520 series was roughly central in the spread compared to the other supports. It has a slightly larger phase separation than some of the other supports with the vertical conductor configuration leading to a relatively better score for audible noise than the 510 but only by a very marginal amount.

Electrical studies confirmed that the values varied very little between the different forms in many of the aspects and that all forms would be compliant with statutory and utility limits. As a result, the electrical MDA has a low weighting in the SAM. Section 4.2 provides a more detailed comparison of the electrical characteristics of the L8RD, 510 and 540 Series.

3.4.3 Supports & Foundations

Internal corrosion

Corrosion protection of tube elements would be achieved by galvanising of all surfaces, plus painting of external surfaces (t-coat primer, long life, easy maintenance paint). The sizes of components would be restricted to suit commercially available galvanising bath sizes. It would not be possible to inspect all internal surfaces, and therefore there would be a risk associated with corrosion of hidden surface, albeit a small one. Detailing of components would require careful detailing in order to suit galvanising. Careful detailing of drainage provisions would also be required to safeguard against retention of water within tubes.

Development on site connection details

No connections are indicate on the general arrangement drawings of connections within the vertical pole lengths. The intention is for the poles to incorporate at least two sleeve joints, not flange plate connections. Flange plate connections are either external or internal; for the size of poles that are envisaged internal flange plates would not be practical, noting that access for tightening of bolts would be required. External flange plates are not preferred due to poor aesthetics, however they do have benefits in terms of ease of construction. The detailing of construction connections would require development.

Earthwire support

The proposed support of the two earthwires for this Form is achieved via two short horizontal tube davit arms at the top of the poles. Construction and maintenance feedback indicates reservations regarding attachment of earthwires and the use of earth wire support arms for C&M procedures. The design of the earthwires therefore requires further development to suit the various assessment preferences and requirements.

Spans

The assessment of this Form has been based on a standard span of 200m (maximum span 300m). Typically lattice steel tower supports have standard spans in the range 300m - 350m in the UK. The reduced standard span allows some advantages to be realised including, but limited to:

- reduced height, reduced climatic loading effects,
- reduced foundation sizes,
- reduced susceptibility to galloping effects, and
- reduced construction requirements.

The adoption of a reduced standard span, however, has a detrimental effect in terms of weight and cost of supports and foundations per kilometre of line, and in terms of the number of sites in a line. It is hoped that assessment of the Form, configured to suit the 200m standard span, has facilitated due consideration of the benefits of reduced spans, however, assessment of the Form in a 300m standard span configuration may be required if direct comparisons to existing steel lattice tower supports is required or if there is a requirement for 'common practice' OHL support spacing at 275kV to be matched.

The proposed rolled steel section crossarms are already heavy for the 200m standard span configuration; an increase in the standard span may result in this form of construction being considered impractical.

Phase to leg clearance

The phase to leg clearance for this Form is less than all of the other Forms in the short-list. Feedback from construction and maintenance assessments indicate that a reduced clearance could not be accommodated, consequently extension of the crossarms to achieve the climbing leg clearance of 4.0m may be required. If this were to be the case then the increase in weight of structure and the impact on the environmental assessment of the Form would probably rule it out as a candidate for development.

3.4.4 Mechanical & Electrical

The 520 series ranked third for the mechanical and electrical MDA, the only two supports to perform better also incorporate V strings. The benefits in terms of reliability benefits of having two strings rather than one are similar to that of a horizontal vee but additionally there are less restrictions in terms of material choice for the designer.

The 520 series angle supports were drafted with a very conventional insulator arrangement which is thought to be the most simple and minimises the number of insulators required in comparison with some other designs.

In terms of galloping performance the 520 performs similarly to the other vertical conductor configurations.

3.4.5 Construction

The 520 series performs slightly worse than the 510 due to the increased number of elements in the structure which in turn increases the footprint and timescales for assembly and erection of the support yet the operations around the conductor system are anticipated to be simplified.

3.4.6 Maintenance

The 520 series performed the best out of the 8 shortlisted designs in the maintenance category. The V string insulation with a crossarm above is thought to be simpler to work on/ with than the horizontal vee insulator arrangements. However, there would still be a need to consider the aspects of maintenance in more depth.

3.4.7 Operational Safety

This design performed particularly well in terms of operational safety as it provides easy demarcation of the circuits and there is a larger width of support body to allow for distance to live circuits. Additionally rescue procedures would be envisaged to be simple as access could be provided up each leg.

Whilst this is the best performing support of the 8 considered for maintenance there has been a common assessment made that painting and getting around pole type supports will be more difficult than lattice steel supports. However, there is a reduction in surface area and ease of surface preparation which must be taken into account.

3.4.8 Environmental

This double pole support has a robust, symmetrical structure, but the collection of solid lines may make it highly visible in the landscape. The main risk to birds would be the multi-level conductor arrangement. This support ranked in the mid-range of the support forms assessed for environmental design factors.

3.5 *530 Series*

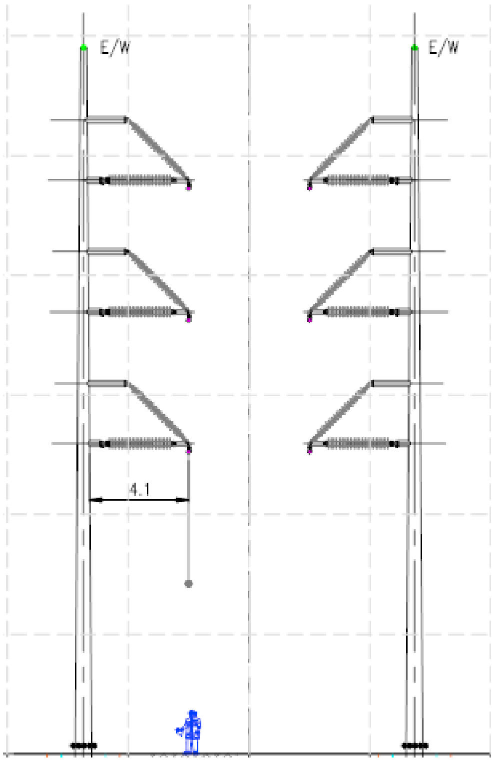


Figure 5 – 530 Series

Weight (kg)	Approximate Height (m)	Span (m)
15800	29	200

3.5.1 Description

The 530 Series support comprises two, free standing single, tapered, steel tube, mono-poles with short tubular stubs for support of insulators. The main pole has a diameter of 700 mm at ground level and 250 mm at the top; tubular stubs are 250 mm in diameter. Earthwires are indicated as being attached to the tops of each pole, but nominal stubs may be required for C&M purposes; these would be 150 mm.

A bolted flange-plate connection is indicated between the poles and the foundations. Two separate foundations are required at each site.

The conductor configuration is two vertically configured circuits of three phases, with one earthwire to each circuit. The conductors of each circuit are indicated as vertically in-line however offsetting to facilitate C&M considerations, and to mitigate against the consequences of galloping is envisaged. The conductors are located between the posts.

Two insulators support each phase conductor; these being in a 'horizontal vee' configuration, with a raking pivot angle.

A nominal standard span of 200 m indicates an overall height of support of 30 m, and an overall horizontal spacing between outer conductors of 5 m.

3.5.2 Electrical

Audible noise has been attributed the most weighting of the electrical design aspects, as a result the 530 series performs the worst due to the close proximity of the circuits. This does not mean the design will necessarily be noisy it is just the worst of the selection and the differences in relative scores is quite small.

Electrical studies confirmed that the values varied very little between the different forms in many of the aspects and that all forms would be compliant with statutory and utility limits. As a result, the electrical MDA has a low weighting in the SAM. Section 4.2 provides a more detailed comparison of the electrical characteristics of the L8RD, 510 and 540 Series.

3.5.3 Supports & Foundations

Internal corrosion

Corrosion protection of tube elements would be achieved by galvanising of all surfaces, plus painting of external surfaces (t-coat primer, long life, easy maintenance paint). The sizes of components would be restricted to suit commercially available galvanising bath sizes. It would not be possible to inspect all internal surfaces, and therefore there would be a risk associated with corrosion of hidden surface, albeit a small one. Detailing of components would require careful detailing in order to suit galvanising. Careful detailing of drainage provisions would also be required to safeguard against retention of water within tubes.

Reliance on welded connections,

The intention is for this Form to rely on welding as a primary means of connecting elements together. Although welded structures are used in many sectors that demand high standards in terms of reliability and performance welded structures are not commonly used for OHL supports in the UK. The existing, well-developed, non-destructive testing methods and procedures that have been developed by other sectors should be easily adapted to suit the OHL support fabrication industry.

Development on site connection details

No connections are indicate on the general arrangement drawings of connections within the vertical pole lengths. The intention is for the poles to incorporate at least two sleeve joints, not flange plate connections. Flange plate connections are either external or internal; for the size of poles that are envisaged internal flange plates would not be practical, noting that access for tightening of bolts would be required. External flange plates are not preferred due to poor aesthetics, however they do have benefits in terms of ease of construction. The detailing of construction connections would require development.

Earthwire support

The proposed support of the two earthwires for this Form is achieved via two short horizontal tube davit arms at the top of the poles. Construction and maintenance feedback indicates reservations regarding attachment of earthwires and the use of earth wire support arms for C&M procedures. The design of the earthwires therefore requires further development to suit the various assessment preferences and requirements.

Spans

The assessment of this Form has been based on a standard span of 200m (maximum span 300m). Typically lattice steel tower supports have standard spans in the range 300m - 350m in the UK. The reduced standard span allows some advantages to be realised including, but limited to:

- reduced height, reduced climatic loading effects,
- reduced foundation sizes,
- reduced susceptibility to galloping effects, and
- reduced construction requirements.

The adoption of a reduced standard span, however, has a detrimental effect in terms of weight and cost of supports and foundations per kilometre of line, and in terms of the number of sites in a line. It is hoped that assessment of the Form, configured to suit the 200m standard span, has facilitated due consideration of the benefits of reduced spans, however, assessment of the Form in a 300m standard span configuration may be required if direct comparisons to existing steel lattice tower supports is required or if there is a requirement for 'common practice' OHL support spacing at 275kV to be matched.

Alternative configurations

The inclusion of this Form in the short list was heavily influenced by a non-UK precedent on the understanding that electrical performance would score highly. It was also considered to have some aesthetic benefits. However, the electrical studies have not found any significant improvement in electrical performance. Shorter variants of this form could be investigated as shown, as these offer improved performance in terms several design aspects, including:

- height,
- weight,
- foundation size,
- susceptibility to the effects of galloping

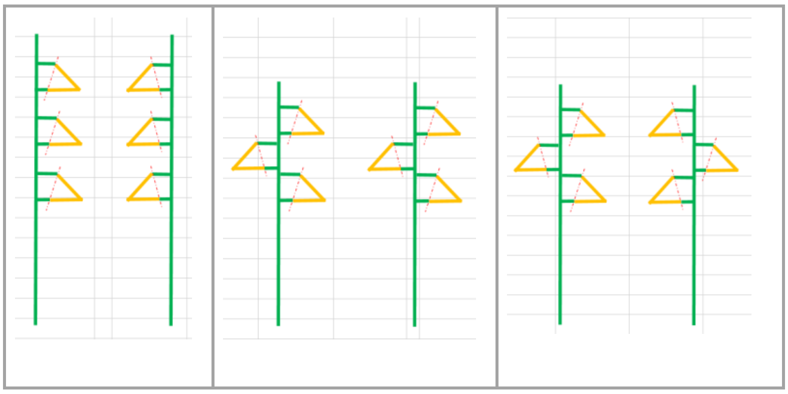


Figure 6 – 530 Series Alternative Configurations

3.5.4 Mechanical & Electrical

Many of the mechanical and electrical design aspects of the 510 series are considered to be identical to the 510 series support, however the angle support insulation which has been considered is considered to be simpler and therefore the 530 performs marginally better than the 510.

The angle support which has been considered uses tension sets direct to the pole body and then pilot post(s) to support the jumper around the support. This is an additional complexity over the conventional tension arrangements but simpler than utilising a 4 leg insulated crossarm.

3.5.5 Construction

In terms of construction, the 530 series performed fairly well, it has many similar benefits to those of the other pole type support in terms of ease of construction, especially in comparison with lattice steel. However, the separation of the poles would essentially require the installation of two separate foundations rather than the singular foundation of the monopole designs which is less favourable.

3.5.6 Maintenance

The 530 series came out as the worst performing support for maintenance aspects. The principal concern for this type of support is the proximity of the circuits during phase conductor system repairs with 1 cct live. The proximity could be controlled or the distances increased to mitigate this problem. In relation to the other supports it is the least preferred conductor configuration.

Conversely however, in terms of repairs to the earthwire this was the best performing support as it would allow for complete separation and a physical barrier provided by the phase conductors.

3.5.7 Operational Safety

This design performed relatively well in terms of operational safety, it provides easy demarcation as it is essentially two separate supports. However, access egress and rescue arrangements are not considered to be considerably better than a single pole due to the challenges presented by the tubular structure.

3.5.8 Environmental

This support scored fairly well as from a visual impact perspective, this simple design would potentially perform well in the landscape due to its narrow, tapered poles. However, the wide spacing between the two poles may create a sense of multiple lines when viewed along a route rather than a singular line supported by one structure. The main risk to birds would be the multi-level conductor.

3.6 *540 Series*

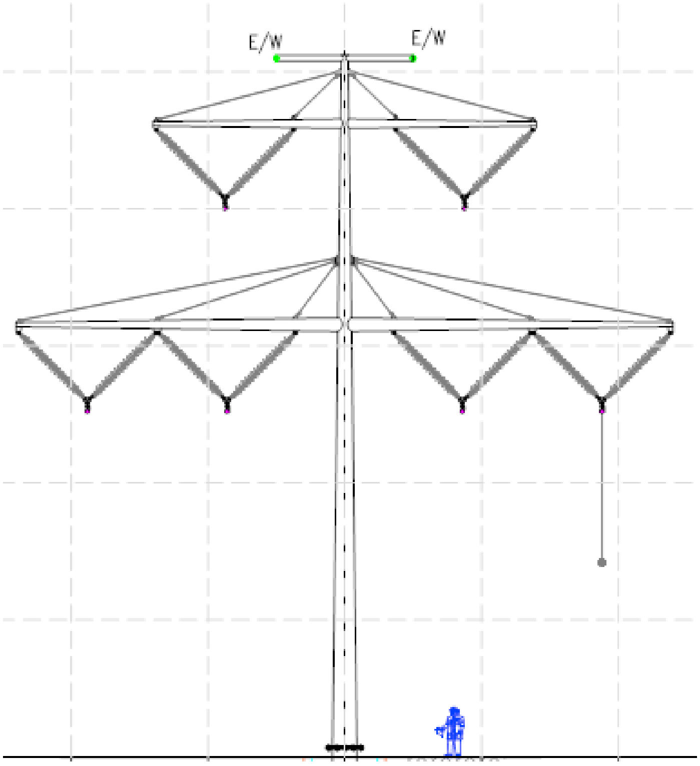


Figure 7 – 540 Series

Weight (kg)	Approximate Height (m)	Span (m)
11900	25	200

3.6.1 Description

The 540 Series support comprises a single, tapered, steel tube, mono-pole with two, cable-stayed, tubular crossarms. The main pole has a diameter of 900 mm at ground level and 250 mm at the top, which corresponds to a two-circuit configuration, however the pole size increase for single circuit configuration. Earthwires are supported by tubular post extensions from the top crossarms.

A bolted flange-plate connection is indicated between the support and the foundation.

The conductor configuration is two delta arrangements of three phases; the top crossarms support one phase conductor and the bottom crossarms support two phase conductors. There are two earthwires, one to each circuit.

Two insulators support each phase conductor; these being in a 'vertical vee' configuration.

A nominal standard span of 200 m indicates an overall height of support of 26 m, and an overall horizontal spacing between outer conductors of 19 m.

3.6.2 Electrical

The 540 series was one the best performing designs electrically overall due to its Danube configuration of conductors and spacing between circuits, this provides good AN** and EMF performance in relation to the other designs, albeit with small differences in some categories.

**The formula used to determine a relative score for AN is a general equation principally driven by CSVG and the 540 produces lower CSVG than the 510. Fully detailed noise studies would need to be undertaken to assess impacts such as proximity of closest conductor to the observer. With the 540 (and 560), the outer phases are closer than the vertical Forms to an observer just off-line and if there is a noise issue (which is not expected), the reduced CSVG of the 540 could be offset by the distance.

Electrical studies confirmed that the values varied very little between the different forms in many of the aspects and that all forms would be compliant with statutory and utility limits. As a result, the electrical MDA has a low weighting in the SAM. Section 4.2 provides a more detailed comparison of the electrical characteristics of the L8RD, 510 and 540 Series.

3.6.3 Supports & Foundations

Internal corrosion

Corrosion protection of tube elements would be achieved by galvanising of all surfaces, plus painting of external surfaces (t-coat primer, long life, easy maintenance paint). The sizes of components would be restricted to suit commercially available galvanising bath sizes. It would not be possible to inspect all internal surfaces, and therefore there would be a risk associated with corrosion of hidden surface, albeit a small one. Detailing of components would require careful detailing in order to suit galvanising. Careful detailing of drainage provisions would also be required to safeguard against retention of water within tubes.

Reliance on welded connections

The intention is for this Form to rely on welding as a primary means of connecting elements together. Although welded structures are used in many sectors that demand high standards in terms of reliability and performance welded structures are not commonly used for OHL supports in the UK. The existing, well-developed, non-destructive testing methods and procedures that have been developed by other sectors should be easily adapted to suit the OHL support fabrication industry.

Development of site connection details

Few connections are indicate on the general arrangement drawings of connections within the vertical pole lengths. The intention is for the poles to incorporate at least two sleeve joints, not flange plate connections. Flange plate connections are either external or internal; for the size of poles that are envisaged internal flange plates would not be practical, noting that access for tightening of bolts would be required. External flange plates are not preferred due to poor aesthetics, however they do have benefits in terms of ease of construction. The detailing of construction connections would require development.

Earthwire support

The support of the two earthwires for this Form is achieved via a horizontal tube crossarm at the top of the pole. Feedback from environmental assessment indicates that the appearance could be improved by upsweeping the arms and tapering the sections. Construction and maintenance feedback also indicates reservations regarding attachment of earthwires and the use of earth wire support arms for C&M procedures. The design of the earthwire support arms therefore requires further development to suit the various assessment preferences and requirements.

Consideration has also been given to supporting the earthwires via two post from the top crossarm, this alternative may offer aesthetic benefits however, construction and maintenance considerations may favour the earthwire crossarm.

Spans

The assessment of this Form has been based on a standard span of 200m (maximum span 300m). Typically lattice steel tower supports have standard spans in the range 300m - 350m in the UK. The reduced standard span allows some advantages to be realised including, but limited to:

- reduced height, reduced climatic loading effects,
- reduced foundation sizes,
- reduced susceptibility to galloping effects, and

- reduced construction requirements.

The adoption of a reduced standard span, however, has a detrimental effect in terms of weight and cost of supports and foundations per kilometre of line, and in terms of the number of sites in a line. It is hoped that assessment of the Form, configured to suit the 200m standard span, has facilitated due consideration of the benefits of reduced spans, however, assessment of the Form in a 300m standard span configuration may be required if direct comparisons to existing steel lattice tower supports is required or if there is a requirement for 'common practice' OHL support spacing at 275kV to be matched.

Alternative crossarm configurations

Initially, leading up to the short-list selection event, this form comprised lattice crossarms supported by a principal post. After the selection event, the lattice crossarms were changed to cable stayed, horizontal tubes, this being primarily to improvement of appearance, but also to work around the limitations of available finite element design software. Feedback from C&M assessments indicate that access onto the crossarms would be complicated by the change from lattice to stayed tubes and therefore confirmation is required that safe C&M procedures are achievable.

Both the lattice crossarms and the stayed tube crossarms adopted horizontal bottom edges to the crossarms, however, feedback on environmental assessments indicate that significant improvement in appearance could be realised by up-sweeping the crossarms. Fabrication would be made slightly more complex by including upswept bottom edges but this modification is recommended to achieve the environmental benefits.

3.6.4 Mechanical & Electrical

The 540 series performed joint best with the 560 for the mechanical and electrical considerations. The main disadvantages compared to the L8RD identified were the increased number of insulators which potentially increase the incidence of insulator failure, and the lack of the ability to adapt the design to include insulated crossarms in the future.

The 540 and 560 performed better than the other V string design (520 series) because of the conductor configuration which is better for reducing the probability of conductor clashing during galloping.

3.6.5 Construction

The 540 series performed reasonably in comparison with the other supports for construction activities. Whilst it has many of the benefits associated with a monopole i.e. reduced foundation footprint and construction area, it is more complicated than some of the other designs, in-particular the tensioning of the crossarm stays to the appropriate level would be considered an added complexity.

The danube configuration of conductors is thought to introduce complexity for stringing operations including the raising and lowering of conductors and set up of stringing equipment. The danube configuration has been used in the UK in the L9 and L12 Low height lattice steel towers however, the vertical arrangement of conductors is preferred.

3.6.6 Maintenance

The 540 series was the second worse in terms of maintenance activities. The Conductor configuration being around a monopole and in a danube formation is not preferred.

Whilst working with the outer conductors supported by the lower crossarm and the associated works around this area (i.e. insulator/ component replacement) the V insulators are considered preferential to the horizontal vee arrangements.

3.6.7 Operational Safety

The 540 series performed worst for operational safety as it has two conductors supported by a single crossarm. Access to this point of the structure will be difficult and may require the addition of some type of platform and hand rail to gain access. Additionally, the single pole presents difficulties for circuit demarcation.

Common to all of the pole type supports, a suitable access arrangement will require development.

3.6.8 Environmental

Overall this design performed the best against environmental criteria. The support has a reduced height which should minimise visual impact as well as decrease the risk to birds (particularly when routed in treed areas). Its double level conductor arrangement is also largely beneficial to birds in flight by reducing their chance of collision. However, this Triform conductor formation could make the structures more visible in the landscape. The design demonstrates a good, familiar shape but could benefit visually from slightly uplifted cross arms or less insulators.

3.7 *550 Series*

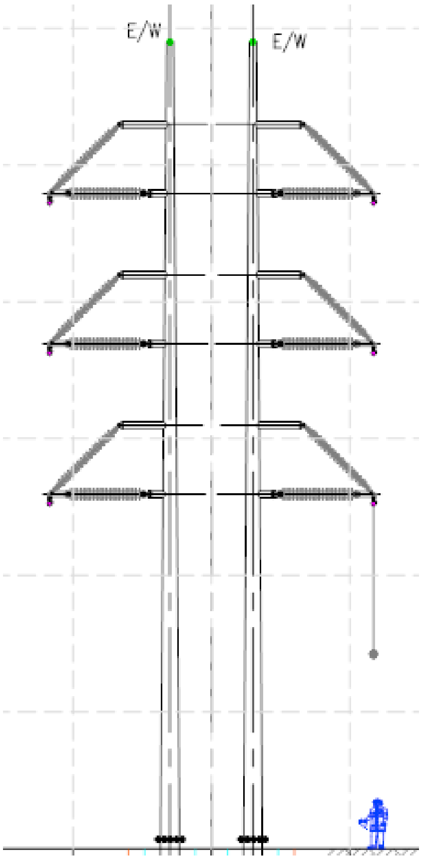


Figure 8 – 550 Series

Weight (kg)	**Approximate Height (m)**	**Span (m)**
15800	29	200

3.7.1 Description

The 550 Series support is the same as the 530 Series support except that the vertical poles are closer together and the conductors are supported externally to the poles rather than between the poles.

The 550 Series support comprises two, free standing single, tapered, steel tube, mono-poles with short tubular stubs for support of insulators. The main pole has a diameter of 700 mm at ground level and 250 mm at the top; tubular stubs are 250 mm in diameter. Earthwires are indicated as being attached to the tops of each pole, but nominal stubs may be required for C&M purposes; these would be 150 mm.

A bolted flange-plate connection is indicated between the poles and the foundations. Two separate foundations are required at each site. Depending on the type of foundation selected at each site, there may be a shared foundation or separate foundations to each leg.

The conductor configuration is two vertically configured circuits of three phases, with one earthwire to each circuit. The conductors of each circuit are indicated as vertically in-line however offsetting to facilitate C&M considerations, and to mitigate against the consequences of galloping is envisaged. The conductors are located externally to the posts.

Two insulators support each phase conductor; these being in a 'horizontal vee' configuration, with a raking pivot angle.

A nominal standard span of 200 m indicates an overall height of support of 30 m, and an overall horizontal spacing between outer conductors of 12 m.

3.7.2 Electrical

The performance of the 550 series was very similar to that of the 510 overall and any comments relating to the 510 series are relevant to the 550.

Electrical studies confirmed that the values varied very little between the different forms in many of the aspects and that all forms would be compliant with statutory and utility limits. As a result, the electrical MDA has a low weighting in the SAM. Section 4.2 provides a more detailed comparison of the electrical characteristics of the L8RD, 510 and 540 Series.

3.7.3 Supports & Foundations

Internal corrosion

Corrosion protection of tube elements would be achieved by galvanising of all surfaces, plus painting of external surfaces (t-coat primer, long life, easy maintenance paint). The sizes of components would be restricted to suit commercially available galvanising bath sizes. It would not be possible to inspect all internal surfaces, and therefore there would be a risk associated with corrosion of hidden surface, albeit a small one. Detailing of components would require careful detailing in order to suit galvanising. Careful detailing of drainage provisions would also be required to safeguard against retention of water within tubes.

Reliance on welded connections,

The intention is for this Form to rely on welding as a primary means of connecting elements together. Although welded structures are used in many sectors that demand high standards in terms of reliability and performance welded structures are not commonly used for OHL supports in the UK. The existing, well-developed, non-destructive testing methods and procedures that have been developed by other sectors should be easily adapted to suit the OHL support fabrication industry.

Development on site connection details

No connections are indicate on the general arrangement drawings of connections within the vertical pole lengths. The intention is for the poles to incorporate at least two sleeve joints, not flange plate connections. Flange plate connections are either external or internal; for the size of poles that are envisaged internal flange plates would not be practical, noting that access for tightening of bolts would be required. External flange plates are not preferred due to poor aesthetics, however they do have benefits in terms of ease of construction. The detailing of construction connections would require development.

Earthwire support

The proposed support of the two earthwires for this Form is achieved via two short horizontal tube davit arms at the top of the poles. Construction and maintenance feedback indicates reservations regarding attachment of earthwires and the use of earth wire support arms for C&M procedures. The design of the earthwires therefore requires further development to suit the various assessment preferences and requirements.

Spans

The assessment of this Form has been based on a standard span of 200m (maximum span 300m). Typically lattice steel tower supports have standard spans in the range 300m - 350m in the UK. The reduced standard span allows some advantages to be realised including, but limited to:

- reduced height, reduced climatic loading effects,
- reduced foundation sizes,
- reduced susceptibility to galloping effects, and

- reduced construction requirements.

The adoption of a reduced standard span, however, has a detrimental effect in terms of weight and cost of supports and foundations per kilometre of line, and in terms of the number of sites in a line. It is hoped that assessment of the Form, configured to suit the 200m standard span, has facilitated due consideration of the benefits of reduced spans, however, assessment of the Form in a 300m standard span configuration may be required if direct comparisons to existing steel lattice tower supports is required or if there is a requirement for 'common practice' OHL support spacing at 275kV to be matched.

3.7.4 Mechanical & Electrical

For the purposes of the mechanical and electrical assessment the 550 and 530 series supports are equivalent as there is no difference in insulator arrangements or phase separation.

3.7.5 Construction

The 550 series performed very well in the construction assessment, and shares similarities with both the 510 and 540 of which it come between in the scoring. It has many of the same attributes of the 530 series as it is essentially two single poles, however, the pole bases are closer together which simplifies the foundation construction activities.

3.7.6 Maintenance

Similarly to the other pole supports there are concerns over main component replacement with the 550 series, i.e. working with horizontal vees, additionally there is concern over main component replacement to earthwires because of the design of the peak, which does not lend itself to being worked upon. Although the development of extended earthwire support arms could alleviate these issues. This being said, in overall terms the 550 performed well due to the physical separation of the poles which will aid in the safe access and egress of the support.

3.7.7 Operational Safety

This support performs very similarly to the 530 series as the structure is very similar with the exception of which side the circuits are on the poles. Either arrangement is not envisaged to make a significant difference to operational safety.

3.7.8 Environmental

This support would perform well in the landscape due to its narrow, tapered poles. This simple design is well balanced, not too intrusive potentially and like the other dual pole designs, it benefits visually by not needing an additional earth wire cross arm. However, there are several noticeable variations between the suspension and tension designs which may affect the overall visual aesthetics in terms of congruence/compatibility. The main risk to birds would be the multi-level conductor arrangement. This design scored a total of 1.33.

3.8 *560 Series*

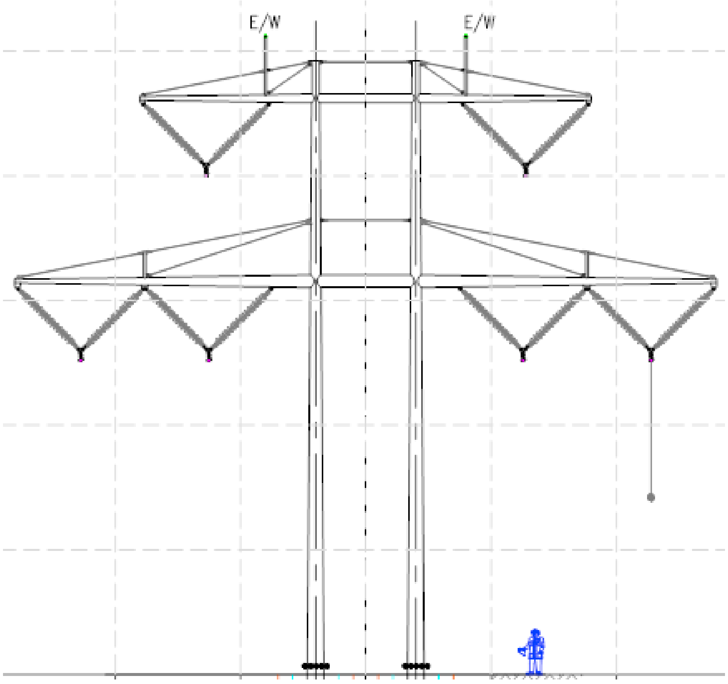


Figure 9 – 560 Series

Weight (kg)	Approximate Height (m)	Span (m)
11700	29	200

3.8.1 Description

The 560 Series support is the same as the 540 Series support except that the mono-pole is replaced by a pair of poles.

The 560 Series support comprises a pair of, tapered, steel tubes with two, cable-stayed, tubular crossarms. The main poles have a diameter of 700 mm at ground level and 250 mm at the top. Earthwires are supported by tubular post extensions from the top crossarms.

A bolted flange-plate connection is indicated between the support and the foundation. Depending on the type of foundation selected at each site, there may be a shared foundation or separate foundations to each leg.

The conductor configuration is two delta arrangements of three phases; the top crossarms support one phase conductor and the bottom crossarms support two phase conductors. There are two earthwires, one to each circuit.

Two insulators support each phase conductor; these being in a 'vertical vee' configuration.

A nominal standard span of 200 m indicates an overall height of support of 26 m, and an overall horizontal spacing between outer conductors of 23 m.

3.8.2 Electrical

The performance of the 560 series was very similar to that of the 540 overall and any comments relating to the 540 series are relevant to the 560.

Electrical studies confirmed that the values varied very little between the different forms in many of the aspects and that all forms would be compliant with statutory and utility limits. As a result, the electrical MDA has a low weighting in the SAM. Section 4.2 provides a more detailed comparison of the electrical characteristics of the L8RD, 510 and 540 Series.

3.8.3 Supports & Foundations

Internal corrosion

Corrosion protection of tube elements would be achieved by galvanising of all surfaces, plus painting of external surfaces (t-coat primer, long life, easy maintenance paint). The sizes of components would be restricted to suit commercially available galvanising bath sizes. It would not be possible to inspect all internal surfaces, and therefore there would be a risk associated with corrosion of hidden surface, albeit a small one. Detailing of components would require careful detailing in order to suit galvanising. Careful detailing of drainage provisions would also be required to safeguard against retention of water within tubes.

Reliance on welded connections

The intention is for this Form to rely on welding as a primary means of connecting elements together. Although welded structures are used in many sectors that demand high standards in terms of reliability and performance welded structures are not commonly used for OHL supports in the UK. The existing, well-developed, non-destructive testing methods and procedures that have been developed by other sectors should be easily adapted to suit the OHL support fabrication industry.

Development of site connection details

Few connections are indicate on the general arrangement drawings of connections within the vertical pole lengths. The intention is for the poles to incorporate at least two sleeve joints, not flange plate connections. Flange plate connections are either external or internal; for the size of poles that are envisaged internal flange plates would not be practical, noting that access for tightening of bolts would be required. External flange plates are not preferred due to poor aesthetics, however they do have benefits in terms of ease of construction. The detailing of construction connections would require development.

Earthwire support

The support of the two earthwires for this Form is achieved via a horizontal tube crossarm at the top of the pole. Feedback from environmental assessment indicates that the appearance could be improved by upsweeping the arms and tapering the sections. Construction and maintenance feedback also indicates reservations regarding attachment of earthwires and the use of earth wire support arms for C&M procedures. The design of the earthwire support arms therefore requires further development to suit the various assessment preferences and requirements.

Consideration has also been given to supporting the earthwires via two post from the top crossarm, this alternative may offer aesthetic benefits, and however, construction and maintenance considerations may favour the earthwire crossarm.

Spans

The assessment of this Form has been based on a standard span of 200m (maximum span 300m). Typically lattice steel tower supports have standard spans in the range 300m - 350m in the UK. The reduced standard span allows some advantages to be realised including, but limited to:

- reduced height, reduced climatic loading effects,
- reduced foundation sizes,
- reduced susceptibility to galloping effects, and
- reduced construction requirements.

The adoption of a reduced standard span, however, has a detrimental effect in terms of weight and cost of supports and foundations per kilometre of line, and in terms of the number of sites in a line. It is hoped that assessment of the Form, configured to suit the 200m standard span, has facilitated due consideration of the benefits of reduced spans, however, assessment of the Form in a 300m standard span configuration may be required if direct comparisons to existing steel lattice tower supports is required or if there is a requirement for 'common practice' OHL support spacing at 275kV to be matched.

Two pole vs single pole

This Form is similar to the Series 540 Form, except that it has two poles. Difference in weight and width have been measured by the DA assessments, but complexity of analysis is not picked up by the DAs. Of the shortlisted Forms, only Series 560 includes rigidly connected enclosed frames comprising horizontal and vertical elements. This form of structure has associated with it complications in analysis due to its indeterminate nature; the interaction between jointed members due to their relative stiffness's is not intuitive, and not immediately apparent without the use of finite element analysis. It would be beneficial to avoid indeterminate rigidly jointed frames.

Alternative pole materials

Principal vertical steel poles could be replaced by poles of an alternative material, such as:

- fibre reinforced plastic (FRP),
- laminated timber, or
- concrete.

One of the advantages of steel poles is the availability of welding to form connections; if alternative materials were to be adopted then careful design of steel/alternative connections would be required. Connections between steel crossarms and poles of other materials would probably require steel sleeves or similar, which may have an adverse effect on appearance and other assessment considerations.

Alternative crossarm configurations

Initially, leading up to the short-list selection event, this form comprised lattice crossarms supported by a principal post. After the selection event, the lattice crossarms were changed to cable stayed, horizontal tubes, this being primarily to improvement of appearance, but also to work around the limitations of available finite element design software. Feedback from C&M assessments indicate that access onto the crossarms would be complicated by the change from lattice to stayed tubes and therefore confirmation is required that safe C&M procedures are achievable.

Both the lattice crossarms and the stayed tube crossarms adopted horizontal bottom edges to the crossarms, however, feedback on environmental assessments indicate that significant improvement in appearance could be realised by up-sweeping the crossarms. Fabrication would be made slightly more complex by including upswept bottom edges but this modification is recommended to achieve the environmental benefits.

3.8.4 Mechanical & Electrical

The 560 series performs identically to the 540 for the mechanical and electrical design aspects, the addition of the extra pole and therefore increased spacing between circuits has no bearing on its relative performance to the 540 series.

3.8.5 Construction

The 560 series performed fairly poorly in comparison with the other supports for construction activities. It has many of the same issues as the 540 series with the additional complexity of both the support and foundations.

3.8.6 Maintenance

Unlike some of the other main design aspects which find great benefit in the monopole for maintenance activities the converse is generally true. The added separation between circuits makes working on the conductor system and the clearances associated less constricted. This is true of the 560 series which is a preferable solution to the 540, although there are still aspects such as isolation and main component replacement which this type of support does not lend itself to.

3.8.7 Operational Safety

This support performs poorly for similar reasons to the 540 with the similar conductor arrangement, however circuit demarcation is considered to be improved with the addition of the second pole.

3.8.8 Environmental

This support is similar to 540. It has a reduced height but is very wide. Whilst the use of stays may help to reduce the visual impact, the design has the potential to appear complex and cluttered when viewed laterally along the line. This support is, however likely to reduce the potential of bird collision due to its double level conductor arrangement and therefore received ranks well in comparison to the other supports.

3.9 *570 Series*

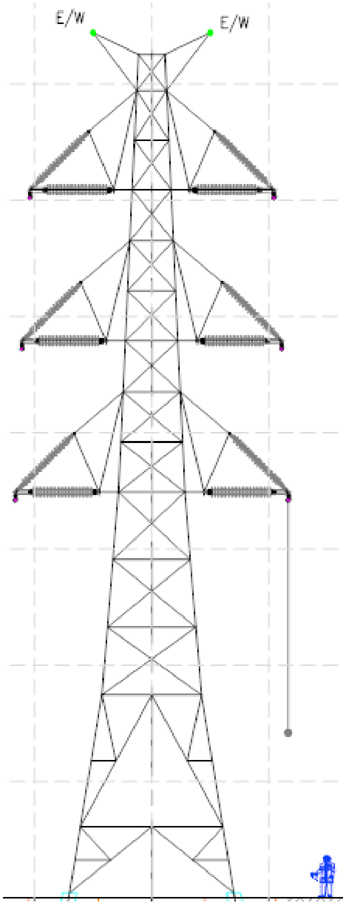


Figure 10 – 570 Series

Weight (kg)	Approximate Height (m)	Span (m)
9100	37	300

3.9.1 Description

The 570 Series support is a traditional lattice steel tower, but modified to support twin earthwires and horizontal vee insulators.

The foundations to the 570 Series support would typically be traditional spread foundations, but other forms of foundations would be considered on a site specific bases where ground conditions do not suit spread foundations.

The conductor configuration is two vertically configured circuits of three phases, with twin earthwires. The conductors of each circuit are indicated as vertically in-line however offsetting to facilitate C&M considerations, and to mitigate against the consequences of galloping is envisaged.

Two insulators support each phase conductor; these being in a 'horizontal vee' configuration, with a raking pivot angle.

A nominal standard span of 300 m indicates an overall height of support of 37 m, and an overall horizontal spacing between outer conductors of 12 m.

3.9.2 Electrical

The 570 series was the best performing of the vertically disposed conductor configurations in some of the key aspects, mainly due to the increased spacing of the phases.

Electrical studies confirmed that the values varied very little between the different forms in many of the aspects and that all forms would be compliant with statutory and utility limits. As a result, the electrical MDA has a low weighting in the SAM. Section 4.2 provides a more detailed comparison of the electrical characteristics of the L8RD, 510 and 540 Series.

3.9.3 Supports & Foundations

Spans

The assessment of this Form has been based on a standard span of 300m (maximum span 450m). Typically lattice steel tower supports have standard spans in the range 300m - 350m in the UK, so it is directly comparable to the towers that are in service in the UK. In the assessments of the shortlisted forms, some adjustments have been made to compensate for the difference in standard span between this Form and the other seven, but the difference needs to be kept in mind when studying the SAM data.

This form could be modified to suit a 200m standard span, which would result in a reduced interphase separation, reduced height, and reduced weight etc. This should be done if there is an interest in both the Form and the concept of implementation of shorter standard spans.

Length of crossarms

The length of the crossarms was noted to be greater than those on the other Forms, this was to suit the lattice support to the insulators, however, it may be possible to amend the crossarm steel such that the insulator assemblies hinge from the face of the tower rather than offset from the face of the tower. But, concerns about insulator/leg clashing in broken wire loading conditions would need to be addressed, and clearance to climbing legs would need to be maintained.

Lattice configuration

The lattice configuration that is illustrated in the general arrangements is not fully developed. The configuration is notional only. If this Form were to be selected for development then the bracing configuration would be reassessed from first principles, taking into account all design aspects, including consideration of aesthetic and functional objectives.

3.9.4 Mechanical & Electrical

The 570 series was the worst performing support in the mechanical and electrical category. The horizontal vees present the same challenges as discussed with the 510 series and the tension supports are proposed with 4 leg insulated crossarms which increase the number of insulators significantly.

The assessment of this Form was based on a 300m standard span which resulted in the worst performance for conductor gallop. The low score needs to be reviewed; if the conductor configuration were to be changed to suit a 200m standard span then the performance of this Form would probably match that of similar Forms with vertical conductor configurations, such as the Series 510 Form.

3.9.5 Construction

The two lattice supports of the 8 identified were identified as two of the worst supports in terms of constructability. The 570 series performs better than the 580 because it is closer to that of a conventional lattice steel support.

As with all lattice structures, the number of elements and the time involved in the assembly and erection of the structure make it score low against the monopole structures. Additionally the foundation footprint is very similar for the 570 to conventional foundation layouts which therefore brings no advantages in this area.

3.9.6 Maintenance

The 570 series performed poorly for maintenance aspects, principally as a result of the work associated with the main component replacement (refer to SAM rationale).

3.9.7 Operational Safety

The 570 series performed relatively well in terms of operational safety, it would offer very similar performance to existing lattice steel tower arrangements other than the arrangements for working on the horizontal vee insulators which is yet to be fully considered.

3.9.8 Environmental

This is a very tall support which could make it more visually intrusive. However, it is designed to handle longer spans which would reduce the visual impact laterally along a route, reducing potential ‘stacking effects’ and delivering wayleaving and other consenting benefits e.g. by helping avoid damage to groundwater dependant terrestrial ecosystems. The lattice steel design means that it can benefit from back clothing/skylining effects potentially becoming largely transparent in the landscape. It is a sturdy, tapered design that may also benefit from feeling familiar therefore potentially making the viewer less sensitive to it. Unfortunately due to its tall height, the large distance between the earth wire and top conductor, and the multi-level conductor layout, it could potentially prove to be very dangerous to birds in flight. For the environmental criteria this support has been ranked in the mid-range.

3.10 *580 Series*

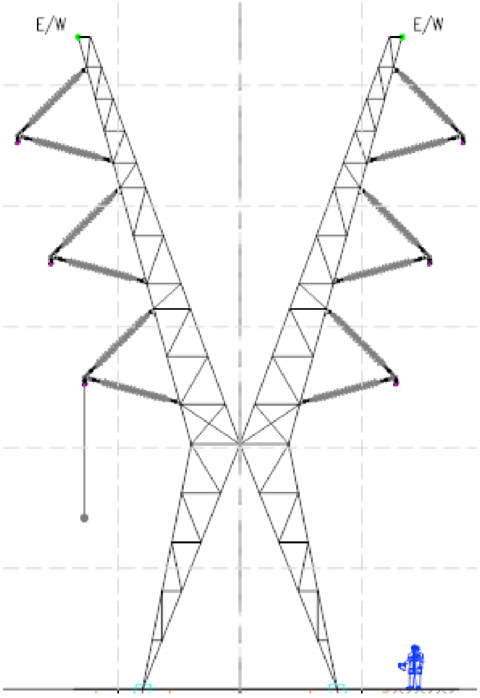


Figure 11 – 580 Series

Weight (kg)	Approximate Height (m)	Span (m)
6300	27	200

3.10.1 Description

The 580 Series support is a non-traditional lattice steel tower, comprising four support legs and two raking support arms. The transition between legs and arms occurs at approximately one third height.

The foundations to the 580 Series support would typically be traditional spread foundations, but other forms of foundations would be considered on a site specific bases where ground conditions do not suit spread foundations.

The conductor configuration is two vertically configured, but progressively offset, circuits of three phases, with one earth wire at the top of each arm.

Two insulators support each phase conductor; these being in a 'horizontal vee' configuration, with a raking pivot angle.

A nominal standard span of 200 m indicates an overall height of support of 27 m, and an overall horizontal spacing between outer conductors of 18 m.

3.10.2 Electrical

The performance of the 580 series was very similar to that of the 510 overall. Owing to the close proximity of the phases the electrical performance, particularly AN and EMF, is not as good as some of the other designs.

Electrical studies confirmed that the values varied very little between the different forms in many of the aspects and that all forms would be compliant with statutory and utility limits. As a result, the electrical MDA has a low weighting in the SAM. Section 4.2 provides a more detailed comparison of the electrical characteristics of the L8RD, 510 and 540 Series.

3.10.3 Supports & Foundations

Spans

The assessment of this Form has been based on a standard span of 200m (maximum span 300m). Typically lattice steel tower supports have standard spans in the range 300m - 350m in the UK. The reduced standard span allows some advantages to be realised including, but limited to:

- reduced height, reduced climatic loading effects,
- reduced foundation sizes,
- reduced susceptibility to galloping effects, and
- reduced construction requirements.

The adoption of a reduced standard span, however, has a detrimental effect in terms of weight and cost of supports and foundations per kilometre of line, and in terms of the number of sites in a line. It is hoped that assessment of the Form, configured to suit the 200m standard span, has facilitated due consideration of the benefits of reduced spans, however, assessment of the Form in a 300m standard span configuration may be required if direct comparisons to existing steel lattice tower supports is required or if there is a requirement for 'common practice' OHL support spacing at 275kV to be matched.

Lattice configuration

The lattice configuration that is illustrated in the general arrangements is not fully developed. The configuration is notional only. If this Form were to be selected for development then the bracing configuration would be reassessed from first principles, taking into account all design aspects, including consideration of aesthetic and functional objectives.

3.10.4 Mechanical & Electrical

The 580 series support performed relatively poorly, and only marginally better than that of the 510 series support. The only aspect for which the support performs better than the 510 is in galloping, this is because of the horizontal offset of the phases.

3.10.5 Construction

This support was the worst performing for constructability, as with all lattice structures, the number of elements and the time involved in the assembly and erection of the structure make it score low against the monopole structures. In addition, the angle of both the lower and upper portions of the structure creates additional fabrication and access to insulator / conductor issues

3.10.6 Maintenance

The maintenance aspect for the 580 series was fair, the horizontal vee arrangement is thought to make main component replacement more challenging. However, the separation of the circuits is considered to be a positive for phase conductor works.

3.10.7 Operational Safety

Whilst the 580 is a lattice steel structure and can be easily demarcated, the presence of the overhang would make working and access difficult on this support.

3.10.8 Environmental

This support ranked the lowest of the eight designs, the reduced height and lattice steel form of this support could potentially result in a relatively low visual impact on the landscape. However, the design itself is less familiar and slightly complicated in appearance, and its sharp angles may appear unsettling, restless and potentially alien in a rural context. The continuity between the supports within the series is also less than ideal, with the tension supports taking on a completely different design. The main risk to birds would be the multi-level conductor arrangement.

4 INFORMATIVE STUDIES - FINDINGS

4.1 *Consideration of Support Suite*

Whilst some consideration of the angle supports has been included in the SAM i.e. continuity of supports, angle support insulation etc. The majority of the assessment has been based on the suspension supports as these typically account for the majority of the supports along an OHL.

The suites of supports, tension and suspension, that comprise each support series are illustrated in Appendix C.

The general arrangement of tension supports for each of the shortlisted support series' have been developed based on electrical clearance requirements and estimated component sizes; but further studies are required to verify the geometry and the sizes of structural elements.

4.2 *Electrical Comparison of L8RD, 510 and 540*

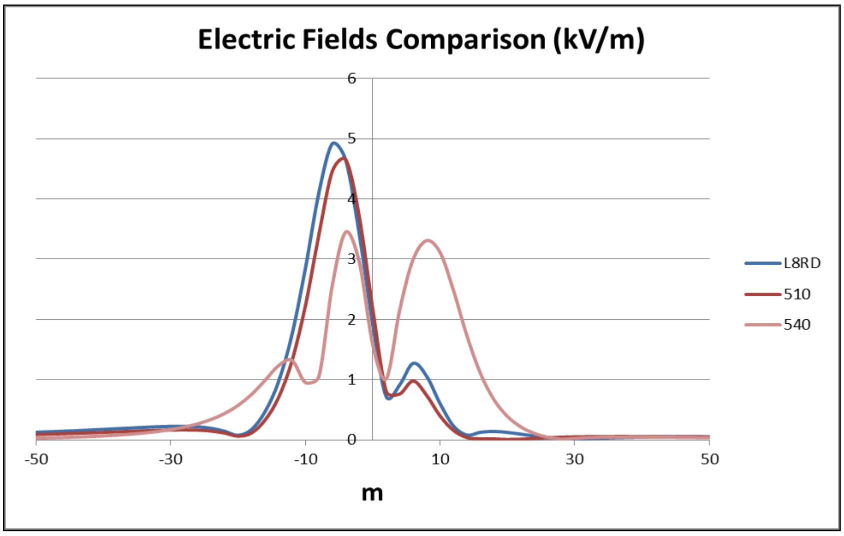
Given the fixed parameters of voltage and rating selected for comparison studies and the fact that neither of the candidates are "compact" designs, the Electrical MDA influence on overall "winner" selection was given a relatively low weighting for the SAM analysis.

For each design the electrical studies are based upon the outline general arrangements and whilst it is understood that outputs such as EMFs, Audible Noise, Corona Loss and Radio Interference are influenced principally by voltage, current and voltage gradients, one particular circuit phasing arrangement was selected for the purposes of providing a comparative score. It is also acknowledged that phasing for the vertical supports (L8RD, 510) is different from the Danube (540) and optimum phasing arrangements would need to be studied in detail in the next phase of development.

Further, studies have been based upon a mid-span minimum clearance to ground in order to provide a comparison of EMF profiles although again the phasing arrangement is known to alter such profiles with clearance.

All calculated EMF figures at or near centreline and outside right of way (ROW) are within statutory limits and the range quoted for 275kV overhead lines on the emfs.info website. Profiles are shown below which demonstrate how similar in profile and values the L8RD and 510 are for the electric fields but the 540 profile is somewhat different. Outside the ROW the values are similar with L8RD in this case being slightly higher.

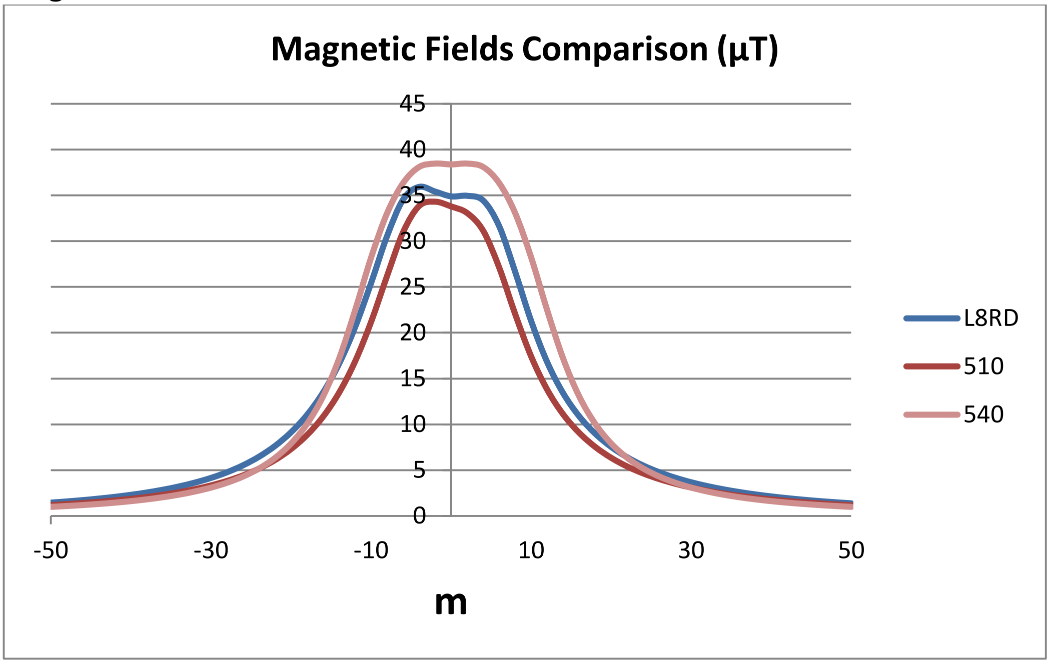
Graph 1 – Electric Fields



Regarding magnetic fields, the configuration plays a major role again and the 540 generates higher fields at the centreline. Again though, at distances greater than 25m or slightly less, the L8RD is the highest again, albeit with relative differences being quite low.

Adjusting the phasing will provide different profiles and exact values and optimum phasing would be the subject of further detailed studies.

Graph 2 –Magnetic Fields



The 510 and 540 do have reduced phase separation distances and as a result generate marginally higher conductor surface voltage gradients (CSVGs) as follows;

Table 4 - CSVG

Type	CSVG (Max)	Increase
L8RD	15.02	Reference
510	15.51	3.2%
540	15.25	1.5%

SSE report that no problems with Audible Noise ensue from single Araucaria installations at 275kV and further detailed studies would be needed to confirm if the marginal increase in CSVG of the 510 Series and 540 Series would have any material influence on this and Radio Interference and Corona Losses.

It should be stressed that any figures quoted above are derived from calculations based on key assumptions i.e. maximum design loading, minimum clearance to ground and one group of circuit phasings.

4.2.1 Earthing Performance

The eight shortlisted candidate forms include steel pole or poles, with twin earthwires or lattice steel towers with twin earthwires. On the assumption that appropriate earthing to ground through footings shall be installed for all options, this design aspect is considered to be a very minor scoring factor in the SAM. The L8RD has 4 leg connections to ground as opposed to the one for the 510 Series and 540 Series, albeit the latter with greater metallic surface area. A detailed assessment of earthing performance has not been undertaken, but further earthing studies are recommended for any of the support series that are selected for development.

4.2.2 Lightning Performance

With the application of twin earth wires, the shielding performance of all eight options will be very good when compared to single earthwire applications. Simply based on height and shielding angle, the L8RD is scored lower than the 510 Series. The 540 Series is scored lower than the 510 Series as the shielding angle is larger on the former, this is a result of the outer phase on the bottom crossarm being further out (although still within the limit).

Back flashover (increase in tower potential leading to increase in voltage across insulators) performance will depend upon the quality and performance of the phase insulation and the tower surge impedance and footing resistance. On the assumption that a 10 ohms footing resistance maximum is achieved and that any final support structure would include insulation to meet appropriate performance standards, the back flashover aspect of lightning performance has been removed from the scoring process.

4.2.3 Surge Impedance Loading (SIL)

Generally as conductor separations are reduced the increase in capacitance tends to reduce the surge impedance which in turn increases the SIL. SAM scoring is based upon the geometric mean of the phase conductor separation values to give a relative notional comparison. Both the 510 Series and 540 Series score well compared to the L8RD in this aspect although its importance to the system designer would need to be discussed once detailed designs are given further consideration as part of development studies.

4.3 *Alternative materials*

Consideration has been given to the use of alternative materials. However, the use of steel as the principal construction material best suits the scale and geometry of the support Forms that have been considered. The operational voltage (275 kV) and the conductor specification (two circuits + two earthwires) dictates the overall scale of the supports.

Fibre reinforced plastic (FRP) and glue laminated timber (Glulam) in particular were considered as alternative materials to steel. In order to illustrate the relative performance of steel, FRP and Glulam, equivalent section sizes were derived by calculation.

Firstly, a comparison was made between the three materials, based on one of the largest FRP sections available from a FRP pole supplier (RS Poles). The relative sizes of the equivalent sections is illustrated by Figure 12. The steel section diameter of 580 mm is significantly less than the structurally equivalent FRP pole diameter of 1050 mm.

It is important to note that the maximum FRP pole size currently available would not have sufficient capacity to suit the shortlisted Forms. In order to source FRP poles for the selected Forms, suppliers would be required to extend the range of pole sizes available, both in terms of tube thickness and overall diameter. The manufacturing capability to increase thickness and diameter may be available but initial enquiries indicates not, in which case significant development work may be needed.

Similarly, initial enquiries indicate that glulam sections of the sizes required to suit the selected Forms are not currently commercially available. Manufacturing processes for deep glulam beams of sizes up to 290x2000 mm is well developed, however manufacturing of sections that are both large and square on plan is less well developed. In order to manufacture large square sections, a number of deep sections of limited width would be joined together, side by side, by a separate process. It is understood that the process of joining large deep sections is not well developed at this time.

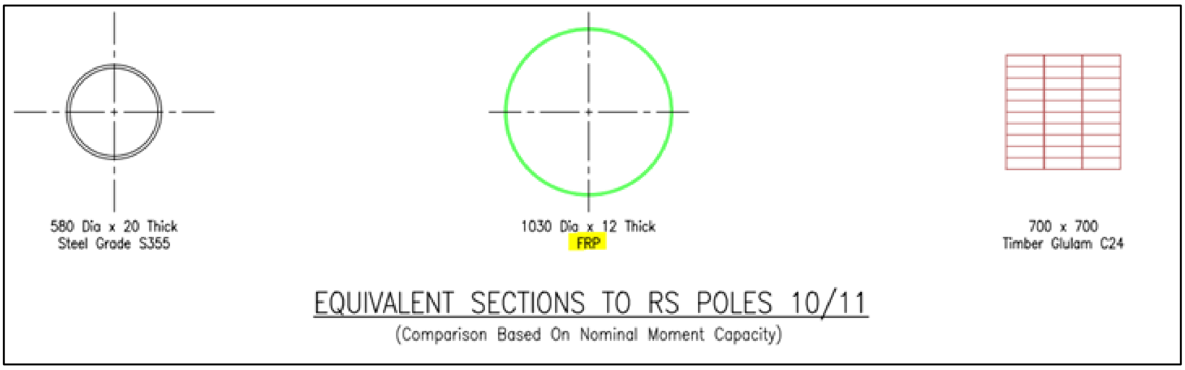


Figure 12 - Relative Section Sizes (based on currently available FRP section)

The second comparison between the three materials was based on the largest steel section required to construct the Series 510 pole (the bottom section). The results are illustrated by Figure 11. Both the FRP section (1950 mm diameter) and the glulam section (1150 mm square) are not currently commercially available.

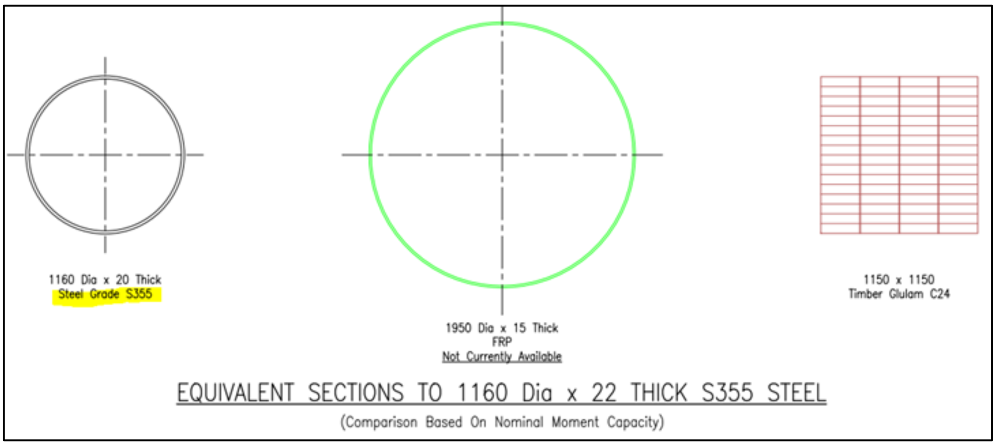
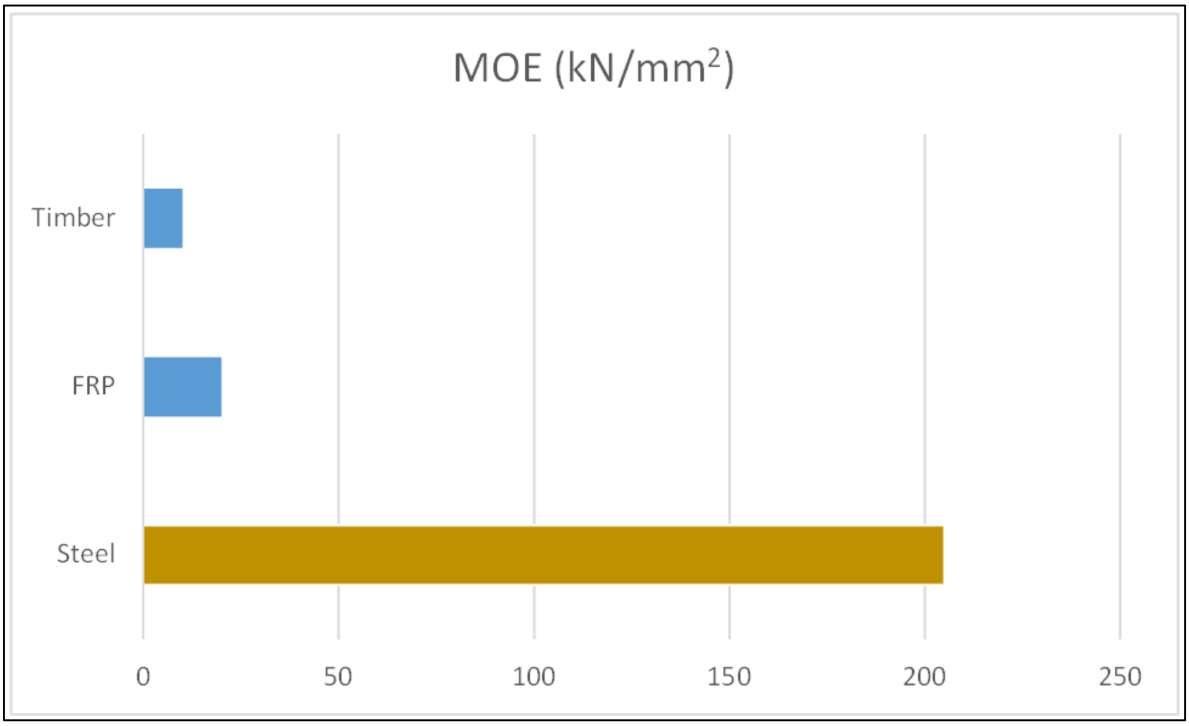


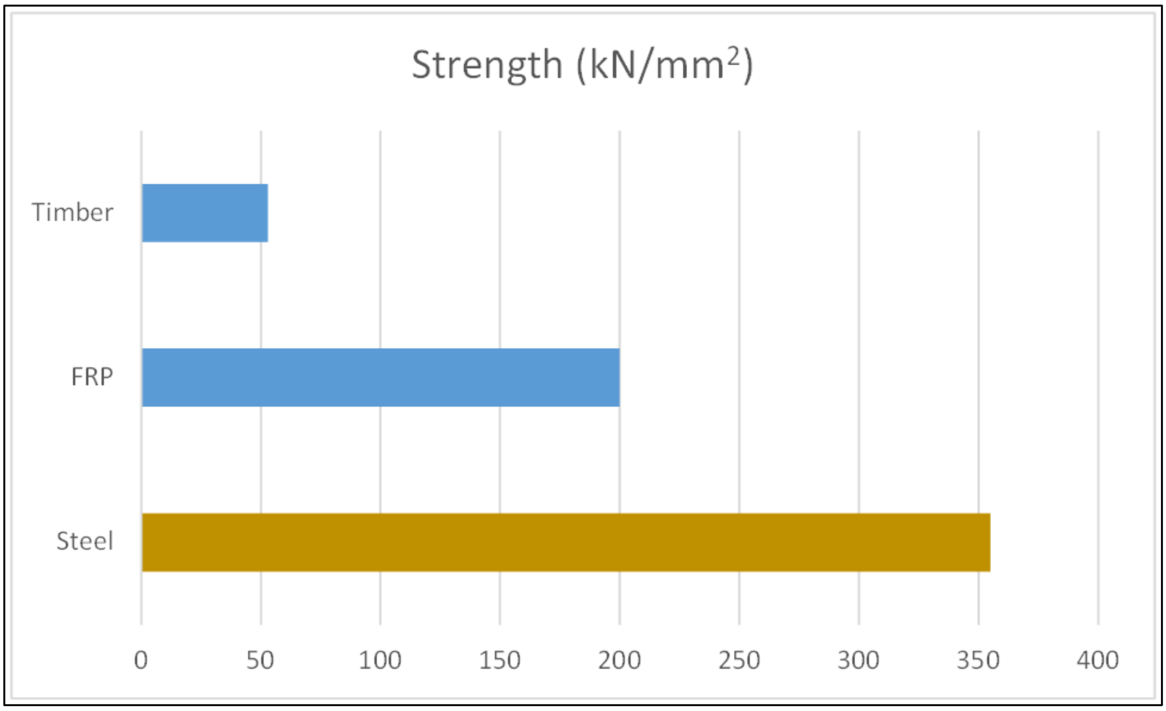
Figure 13 - Relative Section Sizes (based on series 510 bottom pole section)

The essential properties of modulus elasticity (MOE) and strength of steel FRP, and timber are illustrated in Graphs 3 and 4.

Graph 3 - Comparison of modulus of elasticity



Graph 4 - Comparison of strengths



It can be seen that the strength of steel (grade S355) is 1.77 times the strength of the average FRP pole material (data taken from RS Poles data sheets), and it is 6.7 times the strength of scots pine timber (Pinus sylvestris). Steel is also stiffer than both FRP and timber; the modulus of elasticity of steel is 10times greater than that of FRP, and 20 times that of timber.

4.4 *Foundations*

4.4.1 General

Foundation studies were undertaken corresponding to the 8 shortlisted forms. Both spread foundations and caisson foundations were considered for each Form. Foundation loads were derived using PLS CADD PLS Tower and PLS Pole software, and corresponding to the generic design criteria. A limited range of ground conditions were considered, namely, typical clayey ground (cohesion Cu 35 kN/m², unit weight 16 kN/m³) and typical sandy ground (angle of internal friction 30°, unit weight 16 kN/m³). The geotechnical parameters corresponding to these soil types were taken from ENA TS 43-125, Table 12.D.1 and Table 12.D.2. No submerged conditions were considered.

Of the eight shortlisted Forms 6 were pole based and 2 were lattice steel towers with 4 legs. The most efficient foundations to lattice towers in typical ground conditions are spread foundations with advantage taken of the weight of soil in the frustum cone to resist uplift.

For pole based Forms, foundations are required to resist overturning moments as well as vertical and shear loading. In this regard the requirements of foundations for mono-pole OHL supports are similar to those for wind turbines. Raft foundations and piled foundations are typically used to support wind turbines, and these foundation forms can be used to support mono-pole OHL supports, but caissons could also be used, and these promise cost savings.

4.4.2 Caisson foundations

The foundations studies for caisson foundations were undertaken using PLS Caisson software.

> *CAISSON is a Microsoft Windows program for the design of moment resisting concrete pier foundations for pole structures, using the ultimate strength design concept. It can also be used for the design of direct embedded poles. In such cases the diameter of the pier is that of the pole and the concrete/reinforcing properties are irrelevant. The theoretical basis of the program is the paper Analysis and Design of Laterally Loaded Piles and Caissons in a Layered Soil System, T R Naik & A H Peyrot*.

An additional factor of safety of 2 was applied in the studies.

The caisson studies identified the nominal sizes of caissons required to support/resist the concurrent calculated vertical loads, shear loads and overturning moments associated with each support Form. Some summary details are given in the Table 5.

There has been no extensive use of caisson foundations for support of OHL's in the UK to date however this form of foundation is used in other countries, and it offers some advantages in terms of design and construction. Further studies will however be required to prove compliance with current UK/European design standards for foundations.

The equipment and construction methods used for the construction caisson foundations will be chosen to suit the ground conditions on a site specific basis. The use of large diameter drilling buckets is envisaged for many sites but other methods of construction are available including caisson shaft sinking systems.

Caisson foundations can also be used for support of lattice steel legs, however the forces imposed on foundations by lattice steel towers are primarily vertical, with limited shear and overturning moments, and therefore caisson would not typically be the most efficient foundation solution for lattice steel towers.

Table 5 - Caisson Dimensions

Support Series/ Span (m)	Soil Type	Diameter (m)	Depth (m)
Series 510/200	Sand	3.00	5.90
Series 510/200	Sand	2.00	6.72
Series 510/200	Clay	3.00	6.05
Series 510/200	Clay	2.00	7.33
Series 520/200	Sand	3.00	4.98
Series 520/200	Sand	2.00	5.66
Series 520/200	Clay	3.00	4.68
Series 520/200	Clay	2.00	5.66
Series 530/200	Sand	3.00	4.98
Series 530/200	Sand	2.00	5.66
Series 530/200	Clay	3.00	4.68
Series 530/200	Clay	2.00	5.66
Series 540/200	Sand	3.00	5.44
Series 540/200	Sand	2.00	6.27
Series 540/200	Clay	3.00	5.44
Series 540/200	Clay	2.00	6.57
Series 560/200	Sand	3.00	3.91
Series 560/200	Sand	2.00	4.44
Series 560/200	Clay	3.00	5.59
Series 560/200	Clay	2.00	6.42
Series 570/300	Sand	3.00	3.15
Series 570/300	Sand	2.00	3.83
Series 580/205	Sand	3.00	3.61
Series 580/205	Sand	2.00	4.29

4.4.3 Raft foundations

Raft foundations could be used to support mono-pole OHL supports. Resistance to overturning would primarily be resisted by the dead weight of the raft and the soil on top of it. Notional designs of raft foundations were prepared with typical depths to formation of 4 m and raft plan dimensions of 7 m or so, depending on Form. The depths of rafts also varied depending on support Form, the range was 450-850mm.

Whereas volumes of excavation are large for raft foundations, the bulk of the excavation material can be replaced in the ground, once the raft has been constructed; this is an advantage over caisson foundations, where all of the excavation spoil is a disposal liability. A disadvantage of raft foundations over caisson foundations is that the rafts tend to be heavily reinforced.

4.5 *Modelling of PLS CADD routes*

To test the concept designs structurally, PLS Pole and Tower models were created, and PLS CADD routes created to assess whether the designs are strong enough, and whether there are any modelling issues that may occur. When creating the PLS CADD routes, various terrains were considered to assess the designs under different loading scenarios. This led to the following terrain models being created:

- Dounreay Mybster Route C (90SS364)- High wind and Ice conditions
- Beauly Denny Section FT1a-43- High altitude and rough terrain.
- Chickerell East route (90SS540) Low wind, ice, and altitude, flat terrain

4.6 *Modelling Horizontal Vees*

Some of the shortlisted supports include horizontal vee (HV) insulator assemblies for support of phase conductors. The advantages afforded by the use of HV assemblies are discussed elsewhere in the report, but some characteristics of HV's are discussed here, together with particular design considerations.

A horizontal vee (HV), is made up of three parts

- A stay (the tension insulator at the top)
- A strut (the compression insulator at the bottom), and
- Hardware to join the insulators together, to support the conductors and to connect the assembly to the support

The main components are illustrated in Figure 14:

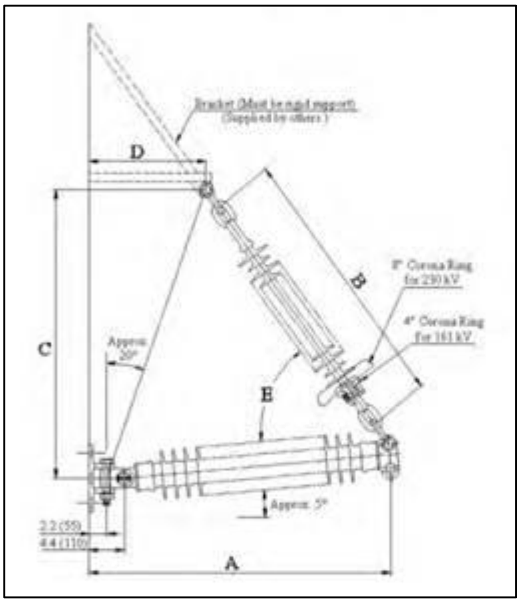


Figure 14 – Horizontal Vee (NGK Locke)

The geometry of the assembly can be adjusted to suit the various design considerations, the main variables are

- Stay angle
- Strut angle
- Hinge angle (this is the angle between vertical and a line drawn between the pin connections at the start of the stay and strut insulators)
- Insulator length

In order for a HV to move longitudinally at a suspension support, slack is pulled out of one span into the adjacent span; in a line section, these transfers of 'slack' can be cumulative. When the available cumulative slack at a HV reaches a critical level instability occurs, this critical level is referred to as the wind loading instability limit (WLSL). The WLSL performance of a line can be modelled using FE software, taking into account a range of factors, including:

- Section lengths
- line geometry
- assembly geometry
- climatic loading

The need for these WLSL studies is an additional design task to the usual line design procedures. The details of suitable WLSL design procedures requires development.

The concept of cumulative displacement is illustrated in Figure 15.

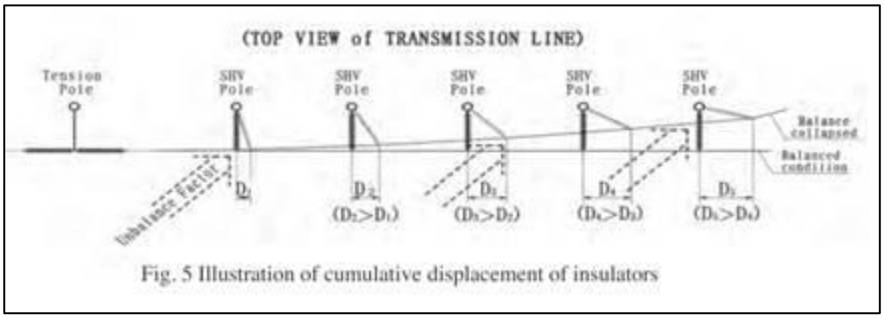


Figure 15 – Cumulative Displacement (PLS CADD Manual)

The WLSL for a line can be improved by:

- increasing the hinge angle
- increasing vertical load
- increasing conductor tension
- reducing span length
- limiting the number of spans in a section between tension supports

The preliminary WLSL studies that have been carried out indicate that the WLSL for a line with a standard span of 200m would be approximately 2.0 km. In this case, tension supports would then be required at nominally 2.0 km maximum intervals along a line that supported by HV's. Alternatively fixed insulator assemblies (comprising 1-stay and 2-struts) could be used to restrain cumulative slack transfer between spans, such as the configuration illustrated in Figure 16. A variant of this form has not been developed for the 510 Series as part of this study, but it could be included in future studies, as it would be a useful addition.

Figure 16 – Fixed insulator Assembly (K Papailou)

The development of suitable design procedures for lines that incorporate horizontal vees would be essential for success in developing a support specification to 'project ready' status.

4.7 *Consideration of Access/ Ancillary equipment*

Whilst the implications of the differing support forms has been considered for construction, maintenance and operational activities, the details and design of the access/ ancillary equipment requirements has not been developed in detail.

The development of the supports will involve the development of access facilities, associated equipment, working and safety procedures.

Figure 17 below has been drafted as an indicative sketch of the kinds of features and the associated equipment which could be fabricated onto the 510 series support.

Additionally the tubular form at the base of the support provides added security to unauthorised access.

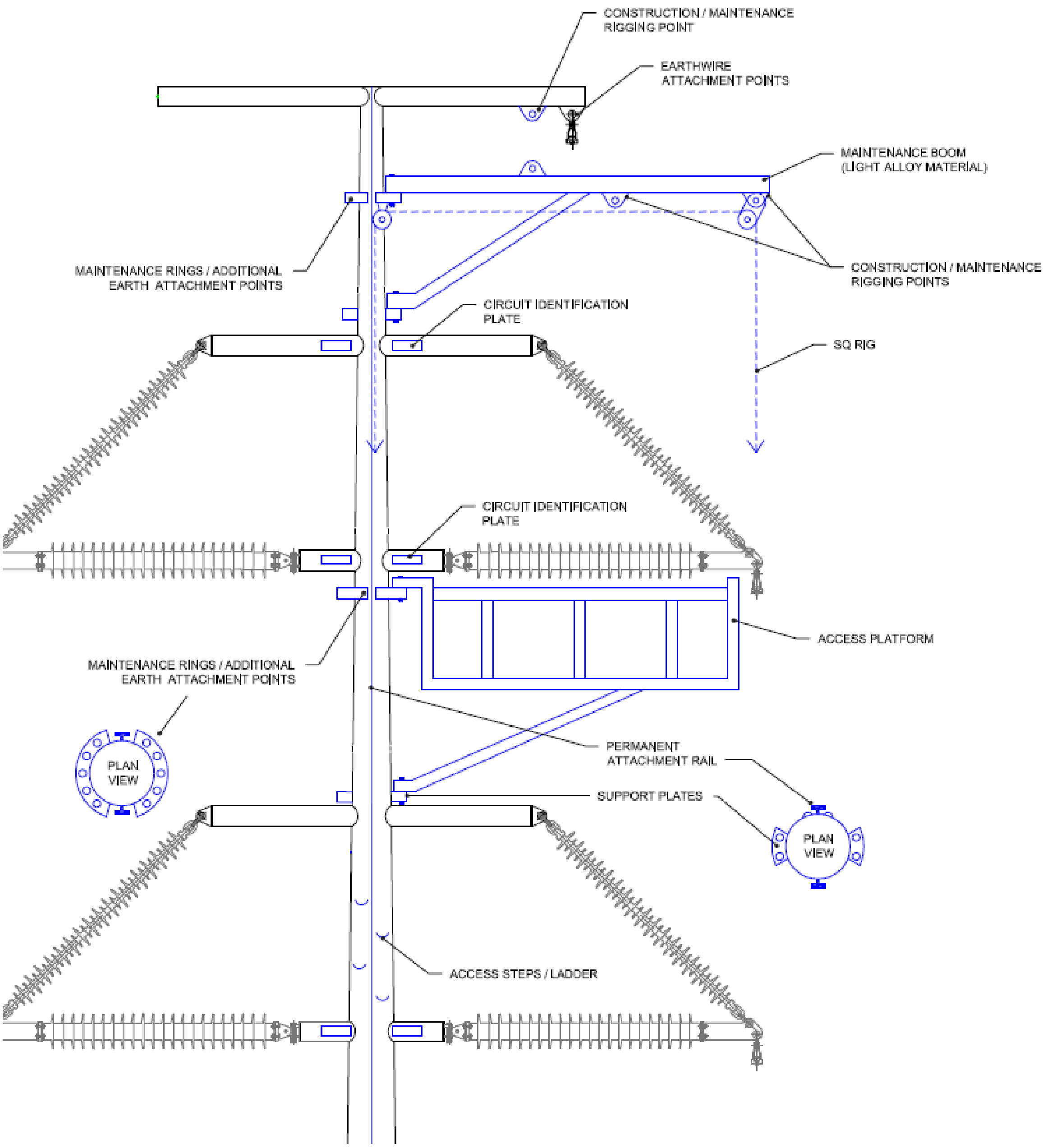


Figure 17 – 510 Series Access/ Ancillary Equipment

4.8 *Environmental Development Considerations*

This section of the report considers limitations of the work undertaken and areas of uncertainty with regard to environmental concerns as well as matters which require further attention.

4.8.1 Visualisation

Photomontages have been prepared for all the designs to provide a representation of their likely appearance – see Appendix D. However, only the Scottish Upland landscape has been considered. It would be beneficial to produce photomontages in other landscapes such as semi-urban so that a more rounded assessment can be made of the supports.

4.8.2 Protecting Birds from Collisions

Earth wire

The position of the earth wire can be crucial in terms of minimising bird collisions; therefore a key recommendation would be to keep the distance between the earth wire and the highest conductor to a minimum in the development/selection of any preferred design solution. Even better would be the removal of the earth wire all together.

Bird diverters

There are a number of mitigation measures currently in use to help prevent bird collisions such as bird diverters that attach to conductors. However, bird diverters can appear as an afterthought, can undermine the design 'integrity' of projects and can cause a negative visual impact. Their use should only really be considered/justified in relation to important bird areas and migration paths on a case-by-case basis.

4.8.1 Improving Visual Appearance/Reducing Impact

Earth wire

Removal of the earth wire could be very visually beneficial, especially with regards to the candidate monopole supports that include earth wire cross arms as part of their design.

Colour

Many studies have been carried out that look at the effect that different colours/materials can have on current lattice steel supports in the landscape. However, the general conclusion/rule of thumb is that for current supports in the UK, unpainted galvanised steel performs best. Grey is considered a good compromise colour in reducing the visibility of towers against a range of landscapes as well as across a range of weather and lighting conditions. Choice of Insulator material/colour should also be a careful consideration. When judging what is currently in use, clear glass or grey ceramic appear to perform the best on lattice steel supports, whilst green glass and dark ceramics should be avoided.

Cross arms

A minor, universal design recommendation would be to adapt any horizontal features such as cross arms or insulators by giving a slight 'uplift'. According to the literature (and industry orthodoxy), this subtle design feature can significantly improve the aesthetics of a support, making it more visually pleasing to the viewer.

Insulators

Keeping the number of insulators to a minimum may also give rise to a general visual benefit in the appearance of supports. For instance, using individual I-string insulators instead of vertical-V arrangements could help towards reducing the visibility of supports.

4.8.2 Other considerations

Terrain

Each design has the potential to perform differently in a variety of landscapes. Lattice steel supports, for example, may benefit from the potential effects of back-clothing which is demonstrated best in rural situations with a mixture of terrain types/textures and natural environmental features such as woodland. Solid steel supports on the other hand, may perform better in urban locations where other similar structures tend to be found such as lighting columns, traffic sign supports, certain telecom mast designs etc. This said, pole-shaped features, both natural (trees) and man-made (wind turbines, wooden phone and lower voltage overhead electric line poles) are also common in some rural areas.

Familiarity

'Familiarity' was not considered as a design aspect during the scoring stage of the environmental assessment. However, it is worth noting that this concept can play an important part in public perception/acceptance. People may have a natural draw towards supports that they have previous association with or structures that resemble other familiar objects which they already know and are comfortable with.

Other equipment

The potential visual impact of additional ancillary equipment such as telecoms should also be considered/assessed prior to installation. Like bird diverters, such apparatus may appear as an afterthought and undermine the design coherence/composition/concept and integrity of the support with detrimental visual effects.

Tension Supports

Tension and termination supports were provided as draft outlines only, to be used as a comparison alongside the suspension designs. However, these have not been fully modelled and therefore cannot be accurately considered. (A low weighting has been used in the assessment for the appropriate criterion to reflect this point.)

Continuity of Form

It is also worth noting the relevance of continuity with other forms in the landscape. Pole structures for example may be better received in environments that currently host other similar tubular forms (see 3.8.4.2 above). Similarly, in a landscape where a traditional lattice steel overhead line already exists, it may be more appropriate to replicate this form.

4.9 *Cost Assessment*

Costs have been considered comparatively against the L8RD to assess the potential for savings in the 510 and 540 support series'. As well as the capital costs, the ongoing lifetime costs of maintenance have been considered in 5.11.3.

4.9.1 Foundation Costs

One of the biggest expenditures in the cost of a new build route is foundation construction, Table 6 below compares the details of the 510 foundations against the L8RD. It should be noted that not all routes will have the same foundation requirements and therefore these comparisons may not equate in all ground conditions.

Table 6 – Foundation Costs

Cost Aspect	L8 RD	510 Series	Relative Value	Comment/ Basis
RC Volume	33m^3	30m^3	0.91	
Excavation volume	166.6m^3	30m^3	0.18	
Spoil	33m^3	30m^3	0.91	
Installation Time (Effort)	2 weeks	1 week	0.5	Lattice steel could be up to 3 weeks on a side slope
Construction Impact/Working Area	1225m^2 (35m x 35m)	200m^2	0.16	Environmental surveys and mitigation, land damage, reinstatement of site, drainage repairs and crop loss
Land sterilisation (footprint at ground level)	49m^2 (7m x7m)	1.8m^2	0.04	Wayleave/ Servitude/ Easement costs for consent and future use
Land needed for design	331.2m^2 (18.2mx18.2m)	87m^2	0.26	Initial micro siting, impact on third party apparatus and operations and future impacts.

Further to the discussions and responses provided at the first Expert Panel ,the basis to the anticipated cost savings relating to the foundation design aspect of the concept designs has been considered in respect of;

- **Direct construction** related costs including site/drainage reinstatement and corresponding crop losses.
- **Scheme costs** that are generally as a result of routing and micrositing of consenting e.g. agreements with third parties, landowners.

In order to derive an overall value of cost saving the assessment has used a current contract value of £48k for the supply and install cost of an equivalent lattice steel tower foundation. The cost proportions used i.e. 50/50 for the Direct and Scheme costs respectively are considered to be a sensible basis noting that where land use and value is at a premium scheme costs can be significant.

A review of construction cost proportions including comments from a main contractor has determined that a material/labour and plant proportion of 30/70 would be suitable when taking into consideration the wide range of factors and applications.

Given the range of support types, ground conditions and overall land/third party issues (values) it is not possible to derive a simplified rule for comparison. However, the table below illustrates the basis to the proposed savings by comparing the 510 series concept design support with an 'equivalent' L8RD lattice steel tower.

For a given route the costs, and therefore comparisons, would vary significantly therefore associated benefits such as described below are likely to provide further cost efficiencies.

- **Direct construction**-larger land take area differentials (in favour of monopoles) for taller supports, environmental surveys and mitigation, wider competition in foundation installation supplier base, opportunities for refinement/optimisation of designs.

- **Scheme costs** – the need to divert third party apparatus away from the area of influence required for foundation design and or restricting third party operations.

Using the information from table 6, a potential cost saving of 35% has been derived from:

Direct costs/ scheme costs [A]	50:50
Material costs/ Other construction costs [B]	30:70
Relative value of cost aspect	NeSTS value/ L8RD value

Notes:

1. 'Other construction costs' Include: formwork, plant & equipment, site costs etc.
2. The 'Relative value' values are based primarily on volume of concrete for 'Direct costs (materials)', and on areas for 'Direct costs (other)' and 'Scheme costs'.

Direct costs (materials)	[A]x[B]x[C]	0.5 x 0.3 x 0.9	0.14
Direct costs (other)	[A]x[B]x[C]	0.5 x 0.7 x 0.5	0.18
Scheme costs	[A]x[C]	0.5 x 0.2	0.10
Relative cost NeSTS/L8RD			0.42

A cost reduction of 58% is demonstrated in the table above, therefore a potential cost reduction of 50% has been considered. Whilst it is acknowledged that the scheme related costs savings could be accounted for under different headings, the benefits all equate to the foundation design.

4.9.2 New Build Cost Comparison

Costs have been considered in reference to a recent new build route of the L8RD tower series. Extrapolations of steelwork weight and foundation volumes to account for the full suite and angle supports has been used to complete the assessment. Therefore the values below are likely to change once there is more certainty over the full suite and range of designs.

Table 7 below shows that the 510 series could realise savings of up to 13% over an equivalent L8RD route, and the 540 series at 3% cost reduction.

Table 7 – Support Cost Comparison

Support Series	L8RD		510		540	
	Relative Cost	Cost (£k)	Relative Cost	Cost (£k)	Relative Cost	Cost (£k)
Support Supply - Steel Raw Material	100%	693.67	100%	912.27	100%	1065.71
Support Supply - Fabrication	100%	693.67	50%	456.13	50%	532.86
Support Supply - Galvanizing	100%	693.67	80%	729.81	80%	852.57
Support Supply - Total	100%	2080.80	101%	2098.01	118%	2450.90
Support Erection	100%	809.00	33%	266.97	66%	533.94
Foundations	100%	1360.00	50%	680.00	60%	816.00
Conductor System	100%	2699.12	110%	2969.04	110%	2969.04
Total	Ref	6948.92	-13%	6014.02	-3%	6769.88
Per kilometre (£k/km)		475.95		411.92		463.69

4.9.3 Maintenance Cost Comparison

Corrosion protection (Painting) of existing lattice steel towers has a significant impact on the lifetime maintenance costs of an overhead line. The comparison of costs for painting the NeSTS supports can be estimated in terms of the surface area and the reduction in effort anticipated.

The relative effort cannot easily be quantified at this stage, however, a reduction factor of 0.5 is considered to be a reasonable, conservative estimate. The unobstructed, single-plane, curved surfaces of the monopoles would avoid the difficulties of lattice steel which has angular elements with many arises, corners, and internal angles.

The estimated cost reduction factor for painting would be as presented in table 8 below.

Table 8 – Maintenance Cost Comparison

Value	L8RD M4.9	510 Series	540 Series
Surface Area per kilometre (m^2/km)	1.09 (A)	0.43 (B)	0.79 (B)
Surface Area Reduction Factor (C)=B/A	1	0.39	0.72
Effort Reduction Factor (X)	1	0.5	0.5
Cost Reduction Factor = C*X	1	0.20	0.36

Maintenance costs are also influenced by the materials used for construction. Steel is used exclusively in the manufacture of lattice steel towers, and therefore, the need for painting cannot reasonably be avoided during the service life. The material of choice for the NeSTS is also steel, however, the use of FRP for the principal pole elements has not been ruled out. Maintenance costs associated with FRP poles would be significantly lower than for steel, and therefore there is a potential saving to be realised on maintenance costs associated with material selection.

The shortlisted 8 support forms utilise a double earthwire arrangement as opposed to the singular earthwire of typical lattice steel towers. This arrangement provides greater operational flexibility with regard to negating the need for double circuit outages as a result of earthwire works. Hence, system operation and constraint costs would be reduced significantly. Noting that modifications to existing designs can be made to add a double earthwire peak.

4.10 *Carbon footprint assessment*

The carbon footprint assessment has been carried out using the Environment Agency's Carbon Calculator 2014. The basis of the study is a 20km route which equates to 67 L8RD supports, and 100 supports each for the 510 & 540 Series'. As part of the optimisations of the standard span lengths the carbon footprint can also be taken into account.

The values used in Table 9 are conservative and are potentially more onerous than would be expected in reality. There are multiple factors which have not been included as this stage such as the reduction in plant and personnel travel as a result of reduced construction times for example.

As more data is collected the calculations for CO_2 emissions will become more accurate.

Table 9 - Construction Carbon Emissions

Source	L8RD (Tonnes CO_2e)	510 Series (Tonnes CO_2e)	540 Series (Tonnes CO_2e)
Concrete, Mortars and Cement (Foundations)	1,720	3,299	2,991
Metals (Support Steel)	1,033	1,540	1,972
Material Transport	147	374	403
Total	**2,900**	**5,212**	**5,365**

5 CONCLUSIONS

1 Of the eight shortlisted support forms, the 510 Series and the 540 Series scored most highly, in terms of the Design Aspects considered by the study, and the weightings that were assigned to the Design Aspects. The details of the assessments are presented in the Support Assessment Matrix.

2 The multi-aspect assessment of supports forms that have been undertaken indicates that mono-pole supports offer equivalent overall advantage to lattice steel towers, when a full range of design aspects are considered.

3 The lattice steel tower support that was included in the multi-aspect assessment studies, the L8RD, scored highly overall, but poorly in terms of environmental design aspects and in terms of construction aspects. For new overhead lines where environmental aspects (including aesthetics) are not considered to be critical, lattice steel towers offer an effective solution.

4 The EMF studies that were undertaken found that EMF acceptance criteria would be met by all of the support Forms that were considered. Similarly, audible noise and other electrical design aspects were not found to be design limiting factors.

5 Both of the winning forms, the 510 Series and the 540 Series, have reduced numbers of elements and connections compared to traditional lattice steel towers; the reduced complexity is considered to be a significant advantage in terms of appearance, construction and design.

6 The modern methods of construction that are suited to the winning Forms promise reduced construction times and consequently, reduced construction costs. Foundation times and costs are also expected to be significantly less than for equivalent lattice steel tower supports.

7 From an environmental perspective, the two winning Forms offer improved aesthetics, reduced footprints, and reduced impact on birds, in comparison to equivalent lattice steel tower supports.

8 Global costing studies indicated that the 510 Series and 540 Series supports would be less expensive to construct than the benchmark L8RD lattice steel tower support, the indicative savings being 13% and 3% respectively.

9 The geometry of the winning Forms has been based on an operating voltage of 275 kV, but conversion of the Forms to suit an operating voltage of 132 kV has also been considered. The conversion would be a relatively simple design process, and would result in correspondingly shorter supports and reduced support top geometry. Foundation sizes would similarly be reduced.

10 The two ‘winning’ supports are of a similar style and could conceivably both be used to form a ‘family’ of supports which allow the designer to select the most appropriate suspension support on a site specific or section specific basis. The 540 Series suspension support could be developed as a low height addition to the 510 Series suite.

11 The studies have been based primarily on the use of steel as the main structural material, due to its inherent suitability to the scale and geometry of the Forms, however, the use of fibre reinforced plastic components is considered to be feasible, especially for secondary structural components and perhaps also for main poles, subject to availability. Currently FRP tubes with sufficient capacity to replace the principal steel poles are not commercially available.

6 LIMITATIONS

1. Assessments for access, attachment, and other construction and maintenance related design aspects were based on preliminary studies. Further studies would be required to confirm the suitability of the preliminary details and provisions. Pole type supports in particular would require further design effort to develop 'in built' access facilities and rigging attachment points etc.
2. The assessments of Construction, Maintenance and Operational safety aspects were based primarily on conventional working practices.
3. The assessments of Design Aspects have been based on concept designs. Within each suite of supports the design development for suspension supports was greater than that of tension supports. In particular, tension supports have not been analysed.
4. Assessments of support Forms have been based on assumed optimum standard spans: typically, lattice steel tower supports 300 m, pole based supports 200 m. Where appropriate adjustments have been made in the assessment of Design Aspects, e.g. by measuring weight per linear length of route, however, advantages in height and width resulting from a reduced standard span length have been taken through to the SAM. This may be viewed as a bias towards pole based supports, but it allows the benefits of reduced standard spans to be taken into account.
5. The flexibility of the support for use with different conductor systems has not been investigated, the rating requirement has been based around the utilisation of 1 x 700mm^2 AAAC Araucaria. The implications of different conductor systems i.e. bundled conductor, larger diameter etc. on support strength requirements and geometry has not been investigated.
6. The study has been based on the use of conventional all aluminium alloy conductors; it has not investigated in any detail the potential benefits of using high temperature low sag conductors which would allow support heights and corridor widths to be reduced.
7. The foundation design studies have considered only a limited range of typical ground conditions and foundation solutions.

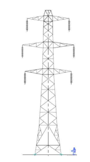
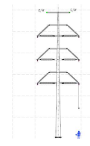
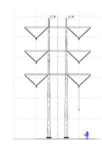
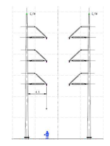
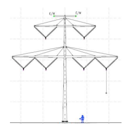
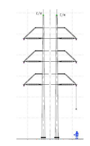
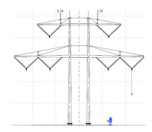
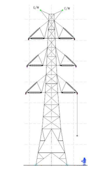
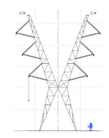
APPENDIX A – SUPPORT ASSESSMENT MATRIX (SAM)

90SS545-95-03-Issue 5 – (Snapshot - EL Stage 3 weightings 20160304)

90SS545 - New 275kV Support Series

ASSESSMENT MATRIX

	L8RD M4.9	510 SERIES	520 SERIES	530 SERIES	540 SERIES	550 SERIES	560 SERIES	570 SERIES	580 SERIES
	(BENCHMARK)	OGA-202	OGA-204	OGA-206	OGA-223	OGA-224	OGA-225	OGA-110	OGA-112
Support Type	L8RD M4..9	Single Pole ICA 3-Xarm	2 Pole 3-Xarm	2 Single Pole 3-ICA, internal	Single pole, 2-lattice xarm	2 Single Pole 3-ICA, Ext	2-pole, 2-lattice xarm	ICA 3-Xarm	MISC, X lattice
Conductor configuration	Vertical	Vertical	Vertical	Vertical	Tri-form	Vertical	Tri-form	Vertical	Vertical
Nominal standard span (m)	305	200	200	200	200	200	200	300	200

MDA Weightings

Electrical	5	0.05
Supports & Foundations	30	0.30
Mechanical & Electrical	10	0.10
Construction	10	0.10
Maintenance	5	0.05
Operational Safety	10	0.10
Environmental	30	0.30
Other	0	0.00
[Adjust total MDA weightings to 100]	100	

Main Design Aspect (MDA)		Design Aspect (DA)	Quant/ Qual	MDA weighting	Sub DA adjust't	Sub DA weighting	Overall weighting (%)	L8RD M4.9	Weighted score	510	Weighted score	520	Weighted score	530	Weighted score	540	Weighted score	550	Weighted score	560	Weighted score	570	Weighted score	580	Weighted score
Totals							1.00		56.83 %		55.21		53.54		46.97		54.86		49.14		49.90		48.19		42.28
Electrical	E.1	Audible Noise	Quant've	0.05	2.5	0.37	1.8%	9	0.17	5	0.09	6	0.11	1	0.02	7	0.13	5	0.09	8	0.15	8	0.15	5	0.09
Electrical	E.2	Magnetic Fields (external)	Quant've	0.05	1.2	0.18	0.9%	1	0.01	5	0.04	4	0.04	5	0.04	9	0.08	5	0.04	9	0.08	1	0.01	5	0.04
Electrical	E.3	Electric Fields (external)	Quant've	0.05	1.1	0.16	0.8%	1	0.01	3	0.02	3	0.02	4	0.03	9	0.07	3	0.02	6	0.05	2	0.02	2	0.02
Electrical	E.4	Radio Interference	Quant've	0.05	1	0.15	0.7%	9	0.07	5	0.04	6	0.04	1	0.01	7	0.05	5	0.04	8	0.06	8	0.06	5	0.04
Electrical	E.5	Earthing Performance	Qual	0.05	0.001	0.00	0.0%	7	0.00	3	0.00	9	0.00	1	0.00	3	0.00	2	0.00	8	0.00	7	0.00	6	0.00
Electrical	E.6	Lightning Performance	Quant've	0.05	0.001	0.00	0.0%	1	0.00	9	0.00	5	0.00	7	0.00	6	0.00	3	0.00	5	0.00	6	0.00	5	0.00
Electrical	E.7	Insulation Coordination	Quant've	0.05	0.8	0.12	0.6%	5	0.03	5	0.03	5	0.03	5	0.03	5	0.03	5	0.03	5	0.03	5	0.03	5	0.03
Electrical	E.8	Surge Impedance Loading (SIL)	Quant've	0.05	0.001	0.00	0.0%	1	0.00	7	0.00	5	0.00	7	0.00	7	0.00	7	0.00	7	0.00	1	0.00	9	0.00
Electrical	E.9	Electric Fields within/near structure	Quant've	0.05	0.1	0.01	0.1%	2	0.00	3	0.00	3	0.00	5	0.00	9	0.01	2	0.00	5	0.00	1	0.00	3	0.00
Electrical	E.10	Magnetic Fields within/near structure	Quant've	0.05	0.1	0.01	0.1%	4	0.00	6	0.00	5	0.00	7	0.01	1	0.00	7	0.01	1	0.00	4	0.00	9	0.01
					6.803	1.00	0.050		0.28		0.23		0.25		0.14		0.37		0.23		0.37		0.26		0.23
Supports & Foundations	S.1	Number of elements	Quant've	0.30	10	0.11	3.3%	1	0.03	8	0.26	9	0.30	7	0.23	8	0.26	7	0.23	5	0.16	1	0.03	1	0.03
Supports & Foundations	S.2	Number of joints	Quant've	0.30	10	0.11	3.3%	1	0.03	5	0.16	9	0.30	4	0.13	2	0.07	4	0.13	1	0.03	1	0.03	1	0.03
Supports & Foundations	S.3	Side slope added complexity	Quant've	0.30	5	0.05	1.6%	6	0.10	9	0.15	7	0.12	1	0.02	9	0.15	7	0.12	7	0.12	5	0.08	5	0.08
Supports & Foundations	S.4	Weight of structure (per km)	Quant've	0.30	20	0.22	6.6%	9	0.57	7	0.46	1	0.07	2	0.15	5	0.33	2	0.15	5	0.33	9	0.59	9	0.58
Supports & Foundations	S.5	Suitability to use of alternative materials	Qual	0.30	7	0.08	2.3%	2	0.05	7	0.16	9	0.21	8	0.18	5	0.12	8	0.18	5	0.12	2	0.05	1	0.02
Supports & Foundations	S.6	Reduction in reliability in single circuit configuration (i.e. strung one side)	Quant've	0.30	3	0.03	1.0%	4	0.04	4	0.04	4	0.04	9	0.09	3	0.03	9	0.09	1	0.01	4	0.03	1	0.01
Supports & Foundations	S.7	Ice accretion performance	Quant've	0.30	1	0.01	0.3%	1	0.00	9	0.03	9	0.03	7	0.02	5	0.02	7	0.02	5	0.02	3	0.01	1	0.00
Supports & Foundations	S.8	Area for painting	Quant've	0.30	3	0.03	1.0%	1	0.01	9	0.09	9	0.09	7	0.07	5	0.05	7	0.07	5	0.05	3	0.03	1	0.01
Supports & Foundations	S.9	Implications of addition of extensions	Quant've	0.30	1	0.01	0.3%	5	0.02	9	0.03	8	0.03	8	0.03	9	0.03	8	0.03	8	0.03	5	0.02	1	0.00
Supports & Foundations	S.10	Length of load path	Quant've	0.30	1	0.01	0.3%	6	0.02	8	0.03	2	0.01	8	0.03	4	0.01	8	0.03	1	0.00	4	0.01	9	0.03
Supports & Foundations	S.11	Familiarity with Form (familiar forms score high)	Qual	0.30	10	0.11	3.3%	9	0.30	5	0.16	6	0.20	5	0.16	4	0.13	5	0.16	4	0.13	8	0.26	3	0.10
Supports & Foundations	S.12	Foundation complexity	Qual	0.30	4	0.04	1.3%	8	0.11	4	0.05	2	0.03	4	0.05	4	0.05	2	0.03	2	0.03	8	0.11	8	0.11
Supports & Foundations	S.13	Foundations (Volume of concrete per km)	Quant've	0.30	10	0.11	3.3%	6	0.20	8	0.26	1	0.03	3	0.10	9	0.30	5	0.16	5	0.15	6	0.21	5	0.16
Supports & Foundations	S.14	Foundations (Volume of excavation per km)	Quant've	0.30	5	0.05	1.6%	8	0.12	7	0.12	3	0.04	1	0.02	9	0.14	7	0.12	9	0.15	8	0.12	3	0.06
Supports & Foundations	S.15	Suitability for application of two earthwires	Qual	0.30	1	0.01	0.3%	1	0.00	2	0.01	9	0.03	9	0.03	2	0.01	2	0.01	2	0.01	1	0.00	9	0.03
					91	1.00	0.300		1.60		2.02		1.50		1.31		1.69		1.53		1.34		1.61		1.27
Mechanical & Electrical	M.1	Insulation Mechanical Reliability	Qual	0.10	1	0.05	0.5%	1	0.01	9	0.05	9	0.05	9	0.05	9	0.05	9	0.05	9	0.05	9	0.05	9	0.05
Mechanical & Electrical	M.2	Insulation Material Limitaton	Qual	0.10	1	0.05	0.5%	9	0.05	1	0.01	9	0.05	1	0.01	9	0.05	1	0.01	9	0.05	1	0.01	1	0.01
Mechanical & Electrical	M.3	Number of Insulators	Qual	0.10	5	0.26	2.6%	9	0.24	1	0.03	1	0.03	1	0.03	1	0.03	1	0.03	1	0.03	1	0.03	1	0.03
Mechanical & Electrical	M.4	Galloping (susceptibility to conductor clashing)	Qual	0.10	5	0.26	2.6%	7	0.18	5	0.13	5	0.13	5	0.13	9	0.24	5	0.13	9	0.24	1	0.03	6	0.16
Mechanical & Electrical	M.5	Formation of Jumpers at Angle Supports	Qual	0.10	1	0.05	0.5%	9	0.05	9	0.05	9	0.05	9	0.05	9	0.05	9	0.05	9	0.05	9	0.05	9	0.05
Mechanical & Electrical	M.6	Angle Support Insulation	Qual	0.10	5	0.26	2.6%	9	0.24	1	0.03	9	0.24	5	0.13	9	0.24	5	0.13	9	0.24	1	0.03	1	0.03
Mechanical & Electrical	M.7	Type Testing Requirements	Qual	0.10	0.5	0.03	0.3%	9	0.02	7	0.02	9	0.02	7	0.02	9	0.02	7	0.02	9	0.02	7	0.02	7	0.02
Mechanical & Electrical	M.8	Suitability for ICA adaption	Qual	0.10	0.5	0.03	0.3%	5	0.01	9	0.02	3	0.01	9	0.02	1	0.00	9	0.02	1	0.00	9	0.02	9	0.02
Mechanical & Electrical	M.9	Familiarity with Attachment Arrangement	Qual	0.10	0.001	0.00	0.0%	9	0.00	1	0.00	9	0.00	1	0.00	9	0.00	1	0.00	9	0.00	1	0.00	1	0.00
					19.001	1.00	0.100		0.79		0.33		0.57		0.43		0.67		0.43		0.67		0.22		0.35
Construction	C.1	Support Supply Chain Familiarity	Qual	0.10	1	0.02	0.2%	9	0.02	5	0.01	5	0.01	5	0.01	4	0.01	5	0.01	4	0.01	9	0.02	9	0.02
Construction	C.2	Insulation Supply Chain Familiarity (Composite)	Qual	0.10	1	0.02	0.2%	5	0.01	5	0.01	5	0.01	5	0.01	5	0.01	5	0.01	5	0.01	5	0.01	5	0.01
Construction	C.3	Support Type testing	Qual	0.10	2	0.03	0.3%	5	0.02	5	0.02	5	0.02	5	0.02	5	0.02	5	0.02	5	0.02	5	0.02	5	0.02
Construction	C.4	Support check erect	Qual	0.10	2	0.03	0.3%	3	0.01	9	0.03	7	0.02	8	0.03	7	0.02	8	0.03	7	0.02	3	0.01	3	0.01

Main Design Aspect (MDA)		Design Aspect (DA)	Quant/ Qual	MDA weighting	Sub DA adjust't	Sub DA weighting	Overall weighting (%)	L8RD M4.9	Weighted score	510	Weighted score	520	Weighted score	530	Weighted score	540	Weighted score	550	Weighted score	560	Weighted score	570	Weighted score	580	Weighted score
Construction	C.5	Complexity of support (Fabrication)	Qual	0.10	5	0.09	0.9%	3	0.03	9	0.08	7	0.06	8	0.07	6	0.05	8	0.07	6	0.05	3	0.03	1	0.01
Construction	C.6	Foundation Construction (footprint)	Qual	0.10	2.5	0.04	0.4%	2	0.01	9	0.04	4	0.02	3	0.01	9	0.04	5	0.02	4	0.02	2	0.01	2	0.01
Construction	C.7	Support Footprint & Assembly Area	Qual	0.10	4	0.07	0.7%	2	0.01	9	0.06	7	0.05	6	0.04	6	0.04	8	0.06	5	0.03	2	0.01	2	0.01
Construction	C.8	Support Transport & Storage	Qual	0.10	5	0.09	0.9%	1	0.01	9	0.08	6	0.05	7	0.06	6	0.05	7	0.06	5	0.04	1	0.01	1	0.01
Construction	C.9	Ease of support assembly / erection	Qual	0.10	4	0.07	0.7%	2	0.01	9	0.06	7	0.05	8	0.06	7	0.05	8	0.06	6	0.04	2	0.01	1	0.01
Construction	C.10	Support access/ egress/ rescue	Qual	0.10	9	0.16	1.6%	9	0.14	5	0.08	7	0.11	5	0.08	1	0.02	5	0.08	1	0.02	7	0.11	4	0.06
Construction	C.11	Need for insulator temporary restraint	Qual	0.10	1.5	0.03	0.3%	9	0.02	1	0.00	9	0.02	1	0.00	9	0.02	1	0.00	9	0.02	1	0.00	1	0.00
Construction	C.12	Conductor Installation Process	Qual	0.10	4	0.07	0.7%	9	0.06	9	0.06	9	0.06	9	0.06	3	0.02	9	0.06	3	0.02	9	0.06	5	0.03
Construction	C.13	Insulator Conductor Attachment Point	Qual	0.10	1	0.02	0.2%	9	0.02	5	0.01	8	0.01	5	0.01	4	0.01	5	0.01	4	0.01	5	0.01	4	0.01
Construction	C.14	Refurbishment inc. e/w- 1 cct live proximity	Qual	0.10	4	0.07	0.7%	1	0.01	7	0.05	9	0.06	3	0.02	7	0.05	9	0.06	8	0.06	9	0.06	9	0.06
Construction	C.15	Route Dismantling	Qual	0.10	4	0.07	0.7%	7	0.05	5	0.03	3	0.02	4	0.03	4	0.03	4	0.03	3	0.02	7	0.05	7	0.05
Construction	C.16	Tension Support (Conductor Installation)	Qual	0.10	8	0.14	1.4%	9	0.12	6	0.08	9	0.12	6	0.08	4	0.06	6	0.08	4	0.06	4	0.06	4	0.06
					58	1.00	0.100		0.54		0.70		0.70		0.58		0.49		0.65		0.44		0.47		0.37
Maintenance	R.1	Ancillary equipment (including third party)	Qual	0.05	1	0.04	0.2%	9	0.02	1	0.00	1	0.00	1	0.00	1	0.00	1	0.00	1	0.00	9	0.02	9	0.02
Maintenance	R.2	Main Component Replacement	Qual	0.05	7	0.25	1.3%	9	0.11	1	0.01	6	0.08	1	0.01	3	0.04	1	0.01	3	0.04	1	0.01	1	0.01
Maintenance	R.3	Suitability for operational activities (e.g. isolation)	Qual	0.05	2	0.07	0.4%	9	0.03	9	0.03	9	0.03	9	0.03	1	0.00	9	0.03	1	0.00	9	0.03	9	0.03
Maintenance	R.4	Main Component Replacement to Earthwires	Qual	0.05	2	0.07	0.4%	9	0.03	9	0.03	4	0.01	4	0.01	9	0.03	4	0.01	4	0.01	9	0.03	9	0.03
Maintenance	R.5	Phase Conductor System Repairs - 1 cct live proximity	Qual	0.05	4	0.15	0.7%	6	0.04	5	0.04	6	0.04	1	0.01	5	0.04	8	0.06	9	0.07	6	0.04	9	0.07
Maintenance	R.6	Earthwire Conductor System Repairs - 1cct live proximity	Qual	0.05	4	0.15	0.7%	2	0.01	5	0.04	8	0.06	9	0.07	6	0.04	8	0.06	8	0.06	3	0.02	2	0.01
Maintenance	R.7	Surface Preparation & Treatment/ Deterioration Protection	Qual	0.05	2.5	0.09	0.5%	6	0.03	3	0.01	3	0.01	5	0.02	3	0.01	5	0.02	3	0.01	6	0.03	5	0.02
Maintenance	R.8	Condition Assessment Remote (Ground/ Aerial)	Qual	0.05	4	0.15	0.7%	5	0.04	8	0.06	7	0.05	8	0.06	7	0.05	8	0.06	7	0.05	5	0.04	5	0.04
Maintenance	R.9	Condition Assessment Intrusive (Climbing)	Qual	0.05	1	0.04	0.2%	8	0.01	7	0.01	8	0.01	8	0.01	7	0.01	8	0.01	7	0.01	8	0.01	7	0.01
					27.5	1.00	0.050		0.33		0.24		0.31		0.23		0.23		0.27		0.26		0.24		0.25
Operational Safety	O.1	Access/ Egress/ Rescue	Qual	0.10	7	0.40	4.0%	9	0.36	5	0.20	7	0.28	5	0.20	1	0.04	5	0.20	1	0.04	7	0.28	4	0.16
Operational Safety	O.2	Live line working	Qual	0.10	4	0.23	2.3%	1	0.02	1	0.02	1	0.02	1	0.02	1	0.02	1	0.02	1	0.02	1	0.02	1	0.02
Operational Safety	O.3	Management of Induced voltages / currents / Application of additional earthing	Qual	0.10	4	0.23	2.3%	6	0.14	5	0.11	6	0.14	5	0.11	6	0.14	5	0.11	6	0.14	5	0.11	6	0.14
Operational Safety	O.4	Circuit Demarcation	Qual	0.10	2.5	0.14	1.4%	9	0.13	1	0.01	9	0.13	9	0.13	1	0.01	9	0.13	9	0.13	9	0.13	9	0.13
					17.5	1.00	0.100		0.65		0.35		0.57		0.47		0.21		0.47		0.33		0.55		0.45
Environmental	P.1	Height	Quant've	0.30	9	0.17	5.2%	1	0.05	6	0.31	6	0.31	6	0.31	9	0.47	6	0.31	9	0.47	1	0.05	8	0.42
Environmental	P.2	Supports per km	Quant've	0.30	6	0.12	3.5%	9	0.31	1	0.03	1	0.03	1	0.03	1	0.03	1	0.03	1	0.03	9	0.31	1	0.03
Environmental	P.3	Insulator Visual Impact	Qual	0.30	5	0.10	2.9%	9	0.26	1	0.03	3	0.09	1	0.03	3	0.09	1	0.03	3	0.09	1	0.03	1	0.03
Environmental	P.4	Transparency (Back clothing)	Qual	0.30	4	0.08	2.3%	9	0.21	5	0.12	1	0.02	3	0.07	4	0.09	3	0.07	3	0.07	9	0.21	9	0.21
Environmental	P.5	Conductor Arrangement (Compact/ Open)	Qual	0.30	1	0.02	0.6%	9	0.05	7	0.04	7	0.04	7	0.04	1	0.01	7	0.04	1	0.01	9	0.05	7	0.04
Environmental	P.6	Support shape (eiffelised/ top heavy etc.)	Qual	0.30	1	0.02	0.6%	8	0.05	9	0.05	8	0.05	9	0.05	8	0.05	9	0.05	8	0.05	7	0.04	5	0.03
Environmental	P.7	Cross arms	Qual	0.30	1	0.02	0.6%	8	0.05	4	0.02	5	0.03	4	0.02	5	0.03	4	0.02	5	0.03	3	0.02	7	0.04
Environmental	P.8	Design aesthetics	Qual	0.30	5	0.10	2.9%	4	0.12	9	0.26	5	0.14	8	0.23	8	0.23	7	0.20	6	0.17	4	0.12	5	0.14
Environmental	P.9	Corridor Width	Quant've	0.30	5	0.10	2.9%	6	0.17	7	0.20	7	0.20	9	0.26	3	0.09	6	0.17	1	0.03	6	0.17	3	0.09
Environmental	P.10	Footprint	Quant've	0.30	3	0.06	1.7%	2	0.03	9	0.16	8	0.14	8	0.14	9	0.16	8	0.14	8	0.14	3	0.05	1	0.02
Environmental	P.11	Effect on Birds	Semi-quant	0.30	7	0.13	4.0%	1	0.04	5	0.20	5	0.20	5	0.20	9	0.36	5	0.20	9	0.36	4	0.16	6	0.24
Environmental	P.12	Tension Support Continuity	Qual	0.30	5	0.10	2.9%	5	0.14	8	0.23	7	0.20	5	0.14	8	0.23	2	0.06	5	0.14	9	0.26	1	0.03
					52	1.00	0.300		1.48		1.66		1.46		1.53		1.83		1.33		1.59		1.47		1.32

APPENDIX B – RANKED LIST OF DESIGN ASPECTS

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RANKING OF DESIGN ASPECTS

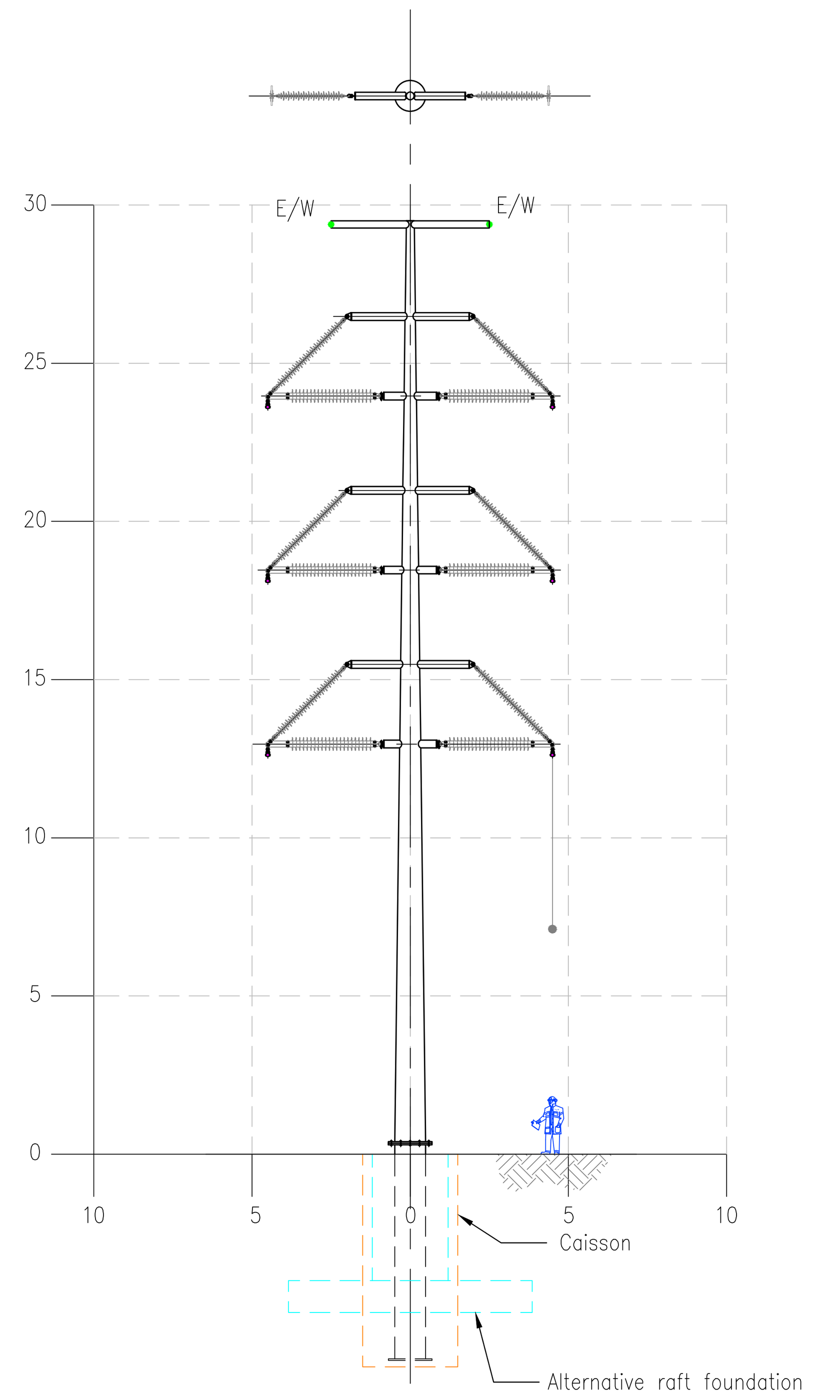
Design aspect ranking reset

	DA ref	Main Design Aspect (MDA)	Design aspect (DA)	MDA weighting	DA weighting	O/A weighting
1	S.4	Supports & Foundations	Weight of structure (per km)	0.30	0.22	0.066
2	P.1	Environmental	Height	0.30	0.17	0.052
3	P.11	Environmental	Effect on Birds	0.30	0.13	0.040
4	O.1	Operational Safety	Access/ Egress/ Rescue	0.10	0.40	0.040
5	P.2	Environmental	Supports per km	0.30	0.12	0.035
6	S.1	Supports & Foundations	Number of elements	0.30	0.11	0.033
7	S.2	Supports & Foundations	Number of joints	0.30	0.11	0.033
8	S.11	Supports & Foundations	Familiarity with Form (familiar forms score high)	0.30	0.11	0.033
9	S.13	Supports & Foundations	Foundations (Volume of concrete per km)	0.30	0.11	0.033
10	P.3	Environmental	Insulator Visual Impact	0.30	0.10	0.029
11	P.8	Environmental	Design aesthetics	0.30	0.10	0.029
12	P.9	Environmental	Corridor Width	0.30	0.10	0.029
13	P.12	Environmental	Tension Support Continuity	0.30	0.10	0.029
14	M.3	Mechanical & Electrical	Number of Insulators	0.10	0.26	0.026
15	M.4	Mechanical & Electrical	Galloping (susceptibility to conductor clashing)	0.10	0.26	0.026
16	M.6	Mechanical & Electrical	Angle Support Insulation	0.10	0.26	0.026
17	P.4	Environmental	Transparency (Back clothing)	0.30	0.08	0.023
18	S.5	Supports & Foundations	Suitability to use of alternative materials	0.30	0.08	0.023
19	O.2	Operational Safety	Live line working	0.10	0.23	0.023
20	O.3	Operational Safety	Management of Induced voltages / currents / Application	0.10	0.23	0.023
21	E.1	Electrical	Audible Noise	0.05	0.37	0.018
22	P.10	Environmental	Footprint	0.30	0.06	0.017
23	S.3	Supports & Foundations	Side slope added complexity	0.30	0.05	0.016
24	S.14	Supports & Foundations	Foundations (Volume of excavation per km)	0.30	0.05	0.016
25	C.10	Construction	Support access/ egress/ rescue	0.10	0.16	0.016
26	O.4	Operational Safety	Circuit Demarcation	0.10	0.14	0.014
27	C.16	Construction	Tension Support (Conductor Installation)	0.10	0.14	0.014
28	S.12	Supports & Foundations	Foundation complexity	0.30	0.04	0.013
29	R.2	Maintenance	Main Component Replacement	0.05	0.25	0.013
30	S.6	Supports & Foundations	Reduction in reliability in single circuit configuration (i.e. s	0.30	0.03	0.010
31	S.8	Supports & Foundations	Area for painting	0.30	0.03	0.010
32	E.2	Electrical	Magnetic Fields (external)	0.05	0.18	0.009
33	C.5	Construction	Complexity of support (Fabrication)	0.10	0.09	0.009
34	C.8	Construction	Support Transport & Storage	0.10	0.09	0.009
35	E.3	Electrical	Electric Fields (external)	0.05	0.16	0.008
36	E.4	Electrical	Radio Interference	0.05	0.15	0.007
37	R.5	Maintenance	Phase Conductor System Repairs - 1 cct live proximity	0.05	0.15	0.007
38	R.6	Maintenance	Earthwire Conductor System Repairs - 1cct live proximity	0.05	0.15	0.007
39	R.8	Maintenance	Condition Assessment Remote (Ground/ Aerial)	0.05	0.15	0.007
40	C.7	Construction	Support Footprint & Assembly Area	0.10	0.07	0.007
41	C.9	Construction	Ease of support assembly / erection	0.10	0.07	0.007
42	C.12	Construction	Conductor Installation Process	0.10	0.07	0.007
43	C.14	Construction	Refurbishment inc. e/w- 1 cct live proximity	0.10	0.07	0.007
44	C.15	Construction	Route Dismantling	0.10	0.07	0.007
45	E.7	Electrical	Insulation Coordination	0.05	0.12	0.006
46	P.5	Environmental	Conductor Arrangement (Compact/ Open)	0.30	0.02	0.006
47	P.6	Environmental	Support shape (eiffelised/ top heavy etc.)	0.30	0.02	0.006
48	P.7	Environmental	Cross arms	0.30	0.02	0.006
49	M.1	Mechanical & Electrical	Insulation Mechanical Reliability	0.10	0.05	0.005
50	M.2	Mechanical & Electrical	Insulation Material Limitaton	0.10	0.05	0.005
51	M.5	Mechanical & Electrical	Formation of Jumpers at Angle Supports	0.10	0.05	0.005
52	R.7	Maintenance	Surface Preparation & Treatment/ Deterioration Protectio	0.05	0.09	0.005
53	C.6	Construction	Foundation Construction (footprint)	0.10	0.04	0.004
54	R.3	Maintenance	Suitability for operational activities (e.g. isolation)	0.05	0.07	0.004
55	R.4	Maintenance	Main Component Replacement to Earthwires	0.05	0.07	0.004
56	C.3	Construction	Support Type testing	0.10	0.03	0.003
57	C.4	Construction	Support check erect	0.10	0.03	0.003
58	S.10	Supports & Foundations	Length of load path	0.30	0.01	0.003
59	S.7	Supports & Foundations	Ice accretion performance	0.30	0.01	0.003
60	S.9	Supports & Foundations	Implications of addition of extensions	0.30	0.01	0.003
61	S.15	Supports & Foundations	Suitability for application of two earthwires	0.30	0.01	0.003
62	M.7	Mechanical & Electrical	Type Testing Requirements	0.10	0.03	0.003
63	M.8	Mechanical & Electrical	Suitability for ICA adaption	0.10	0.03	0.003
64	C.11	Construction	Need for insulator temporary restraint	0.10	0.03	0.003
65	R.1	Maintenance	Ancillary equipment (including third party)	0.05	0.04	0.002
66	R.9	Maintenance	Condition Assessment Intrusive (Climbing)	0.05	0.04	0.002
67	C.1	Construction	Support Supply Chain Familiarity	0.10	0.02	0.002
68	C.2	Construction	Insulation Supply Chain Familiarity (Composite)	0.10	0.02	0.002
69	C.13	Construction	Insulator Conductor Attachment Point	0.10	0.02	0.002
70	E.9	Electrical	Electric Fields within/near structure	0.05	0.01	0.001
71	E.10	Electrical	Magnetic Fields within/near structure	0.05	0.01	0.001
72	E.5	Electrical	Earthing Performance	0.05	0.00	0.000
73	E.6	Electrical	Lightning Performance	0.05	0.00	0.000
74	E.8	Electrical	Surge Impedance Loading (SIL)	0.05	0.00	0.000
75	M.9	Mechanical & Electrical	Familiarity with Attachment Arrangement	0.10	0.00	0.000
76	T.5	Other	Cost of supports (per km)	0.00	0.42	0.000
77	T.1	Other	Susceptibility to damage (vandalism/accident)	0.00	0.14	0.000
78	T.2	Other	Resistance of materials to deterioration/attack	0.00	0.14	0.000
79	T.3	Other	Number of supports per km of OHL	0.00	0.03	0.000
80	T.4	Other	Embodied energy (embodied carbon)	0.00	0.00	0.000
81	T.6	Other	Side slope - effect on height	0.00	0.28	0.000

APPENDIX C – OUTLINE GENERAL ARRANGEMENT DRAWINGS

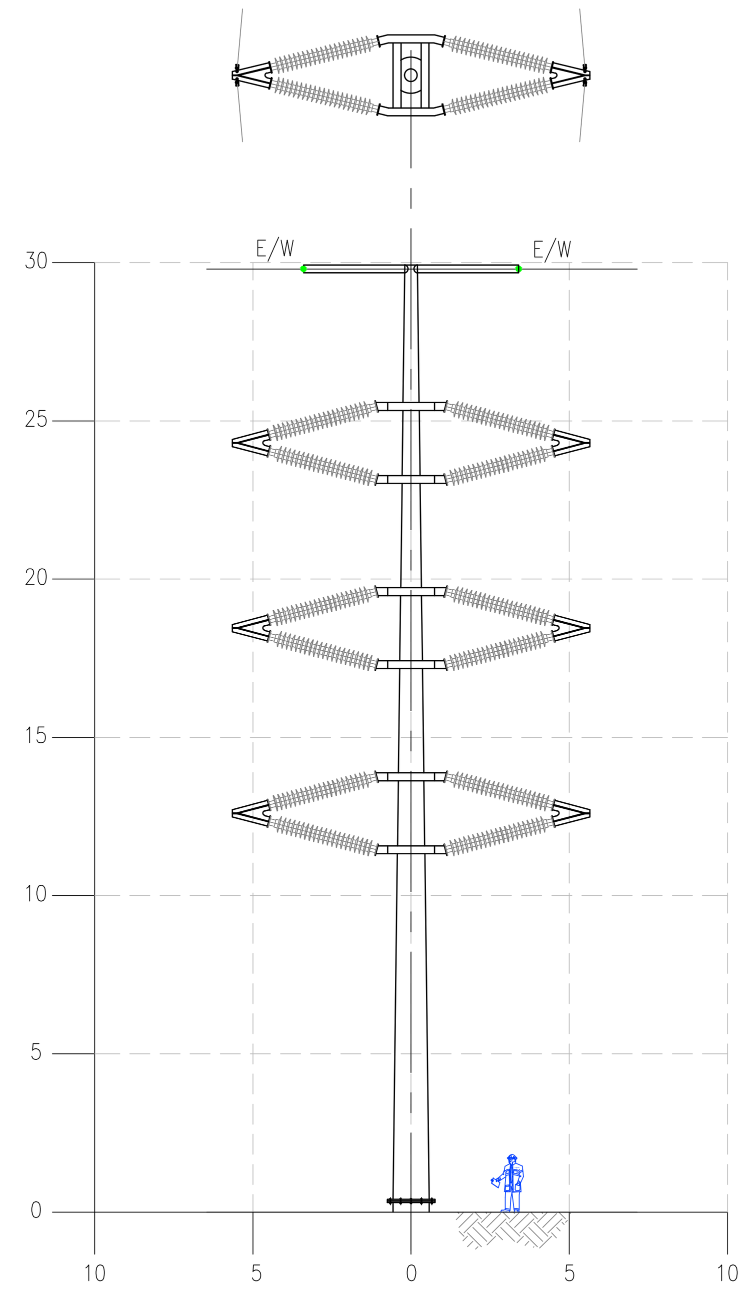
Drawings:

90SS545-OGA-511
90SS545-OGA-521
90SS545-OGA-531
90SS545-OGA-541
90SS545-OGA-551
90SS545-OGA-561
90SS545-OGA-571
90SS545-OGA-581



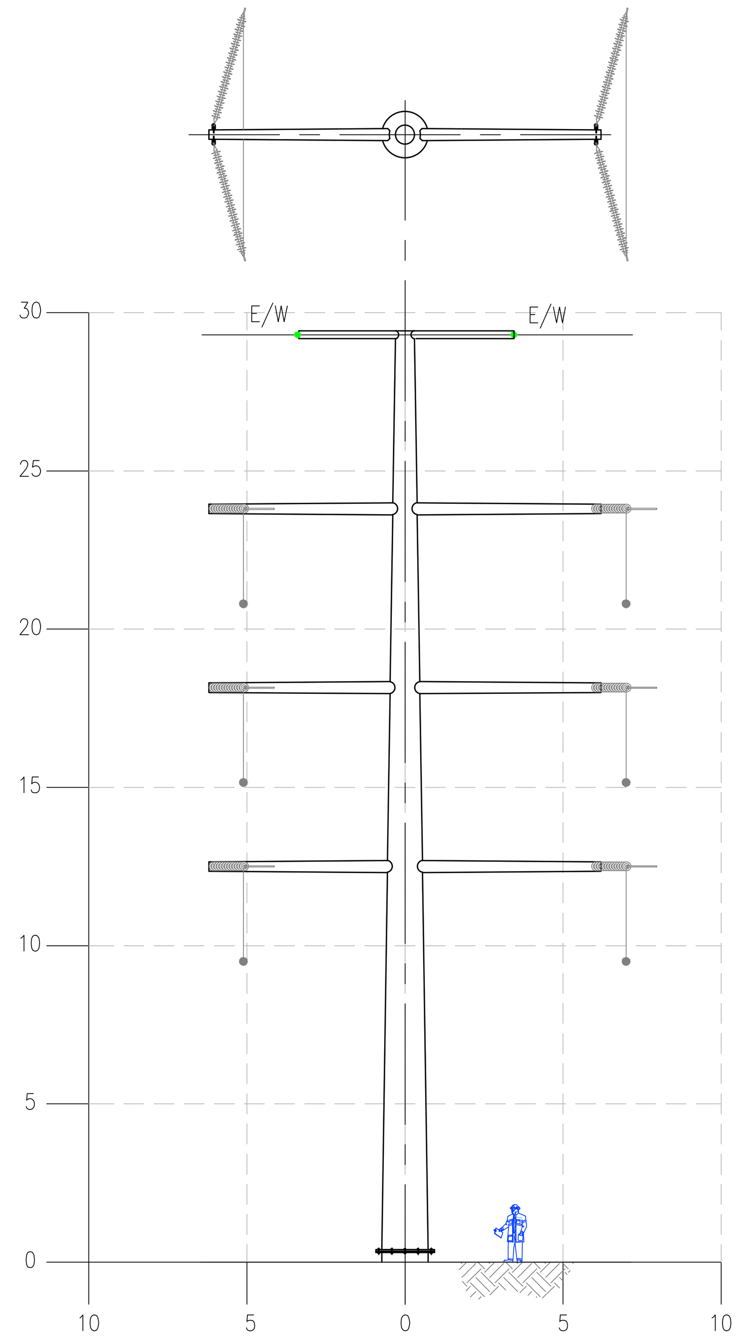
TRANSVERSE ELEVATION

SP-02-D, SINGLE POLE
3 INSULATED CROSSARMS, INTERMEDIATE (D)
90SS545-OGA-512 (200m Nominal Span)



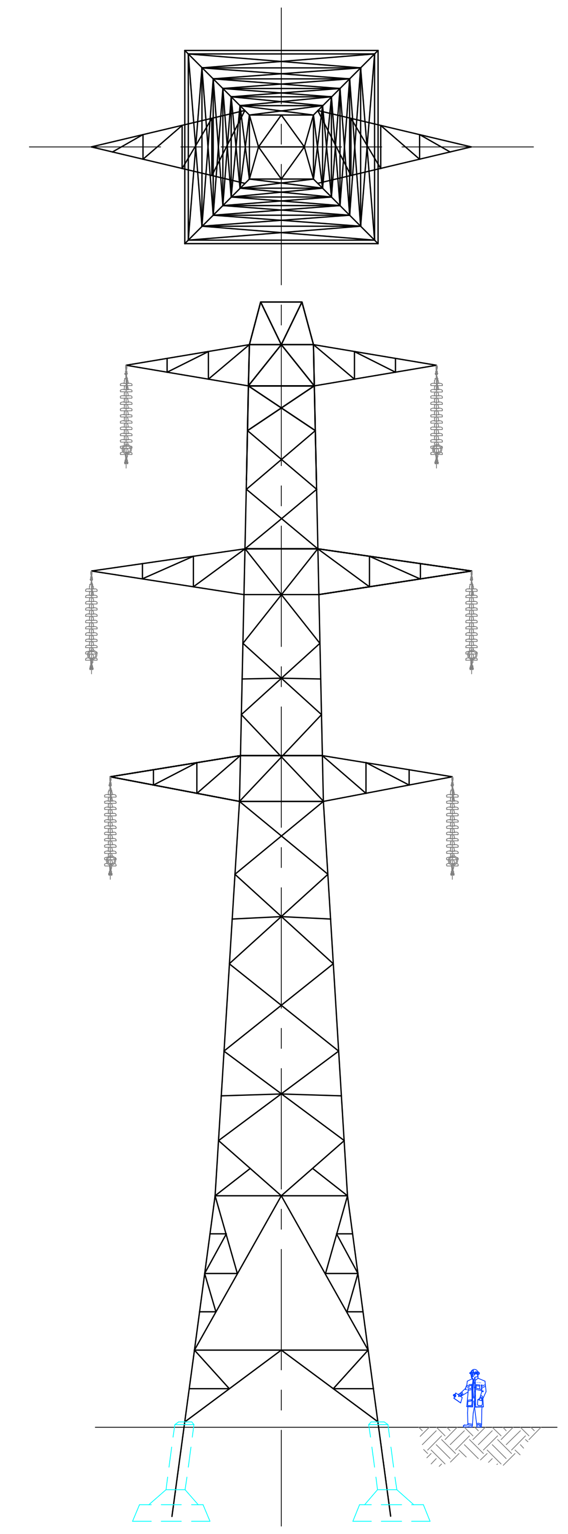
TRANSVERSE ELEVATION

SP-02-D10, SINGLE POLE
3 INSULATED CROSSARMS, TENSION (D10)
90SS545-OGA-513 (200m Nominal Span)



TRANSVERSE ELEVATION

SP-02-D30, SINGLE POLE
3 TUBULAR CROSSARMS, TENSION (D30)
90SS545-OGA-514 (200m Nominal Span)

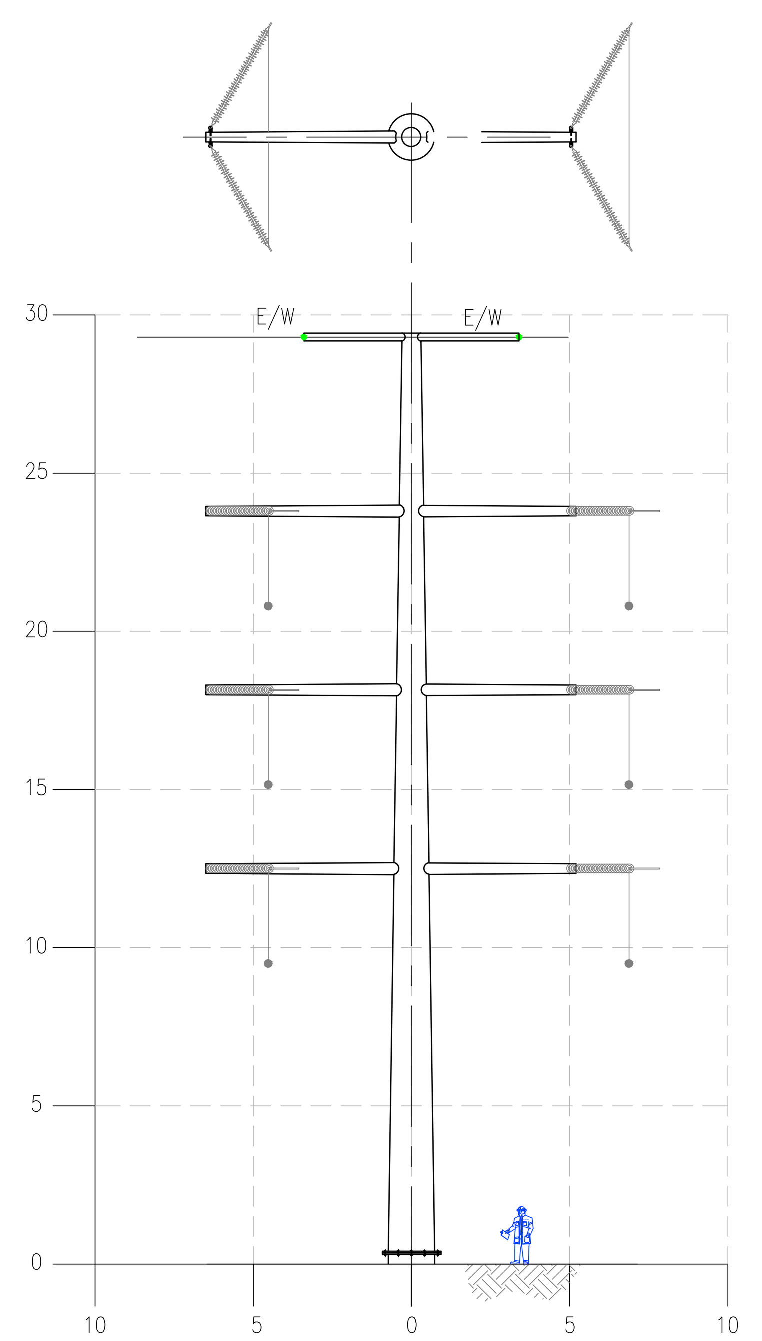


TRANSVERSE ELEVATION

L8C RD M4.9 SUSPENSION TOWER 275kV

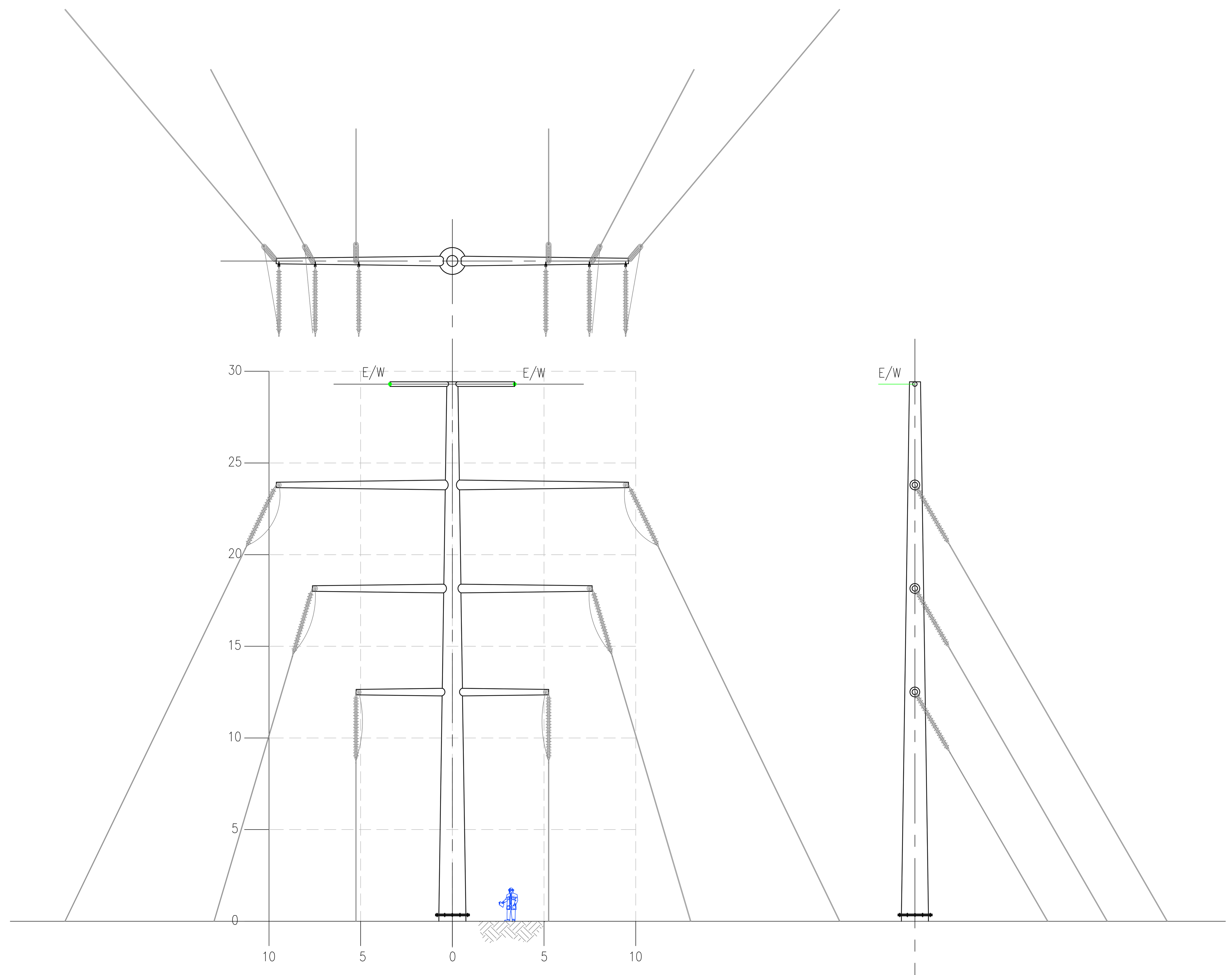
SHOWN FOR COMPARISON ONLY

ISSUED FOR DISCUSSION ONLY



TRANSVERSE ELEVATION

SP-02-D60, SINGLE POLE
3 TUBULAR CROSSARMS, TENSION (D60)
90SS545-OGA-515 (200m Nominal Span)



TRANSVERSE ELEVATION

SP-02-DT, SINGLE POLE
3 TUBULAR CROSSARMS, TERMINAL (DT)
90SS545-OGA-516 (200m Nominal Span)

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1	24:06:15	Issued for discussion	JP	JS	MDL

energyline

YORK HOUSE, 9 YORK PLACE, KNARESBOROUGH HG5 0AD
TEL: 01423-799950

TITLE

SINGLE POLE 3 INSULATED CROSSARMS

ROUTE / CIRCUIT

NEW 275kV SUPPORT PROJECT

ENERGYLINE PROJECT / DRG No.	SHT No.	No. OF SHTS
90SS545-OGA-511	1	1

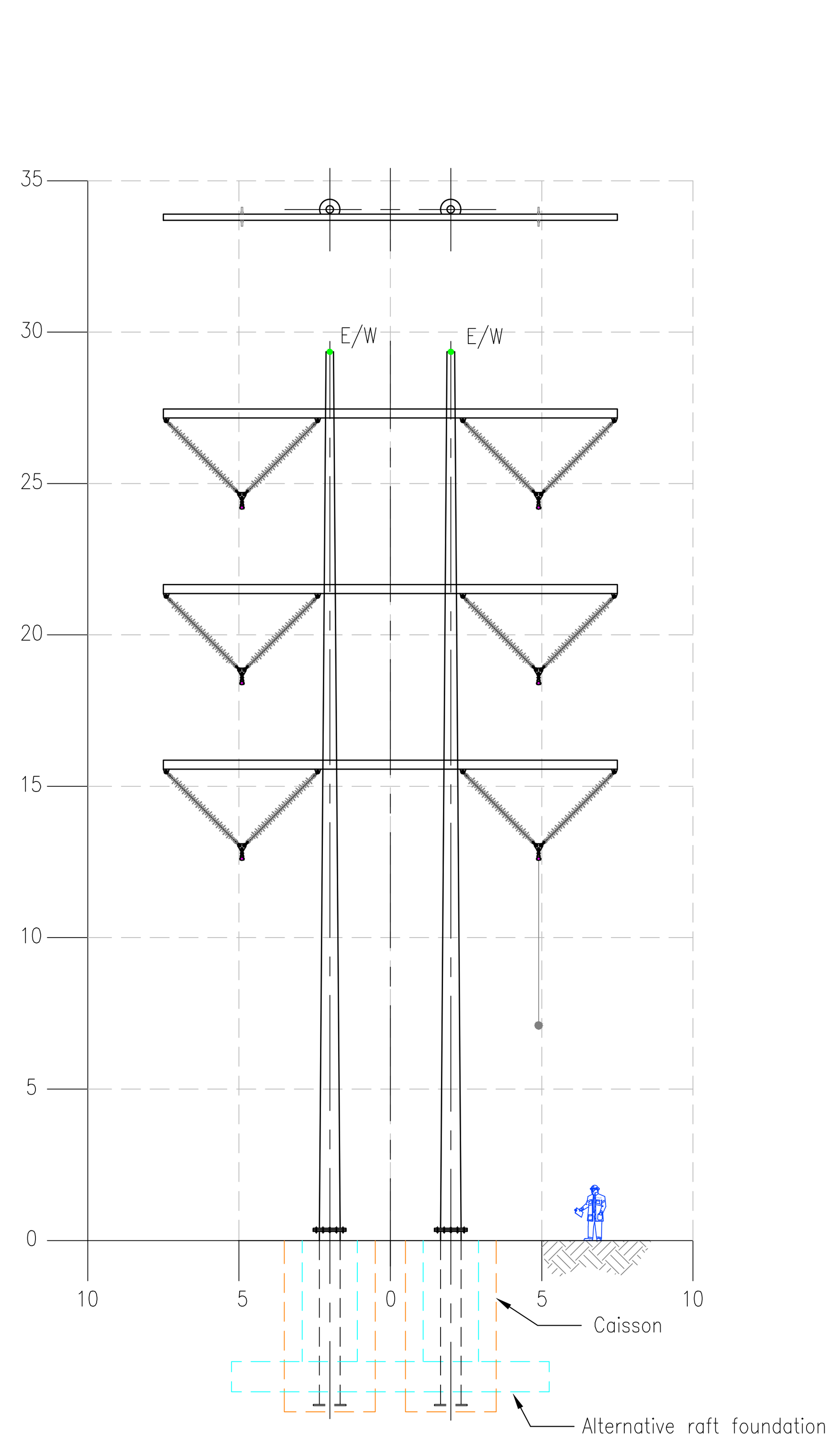
CLIENT: Scottish and Southern Energy Power Distribution

CLIENTS PROJECT REF. *

CLIENTS DRG No. *

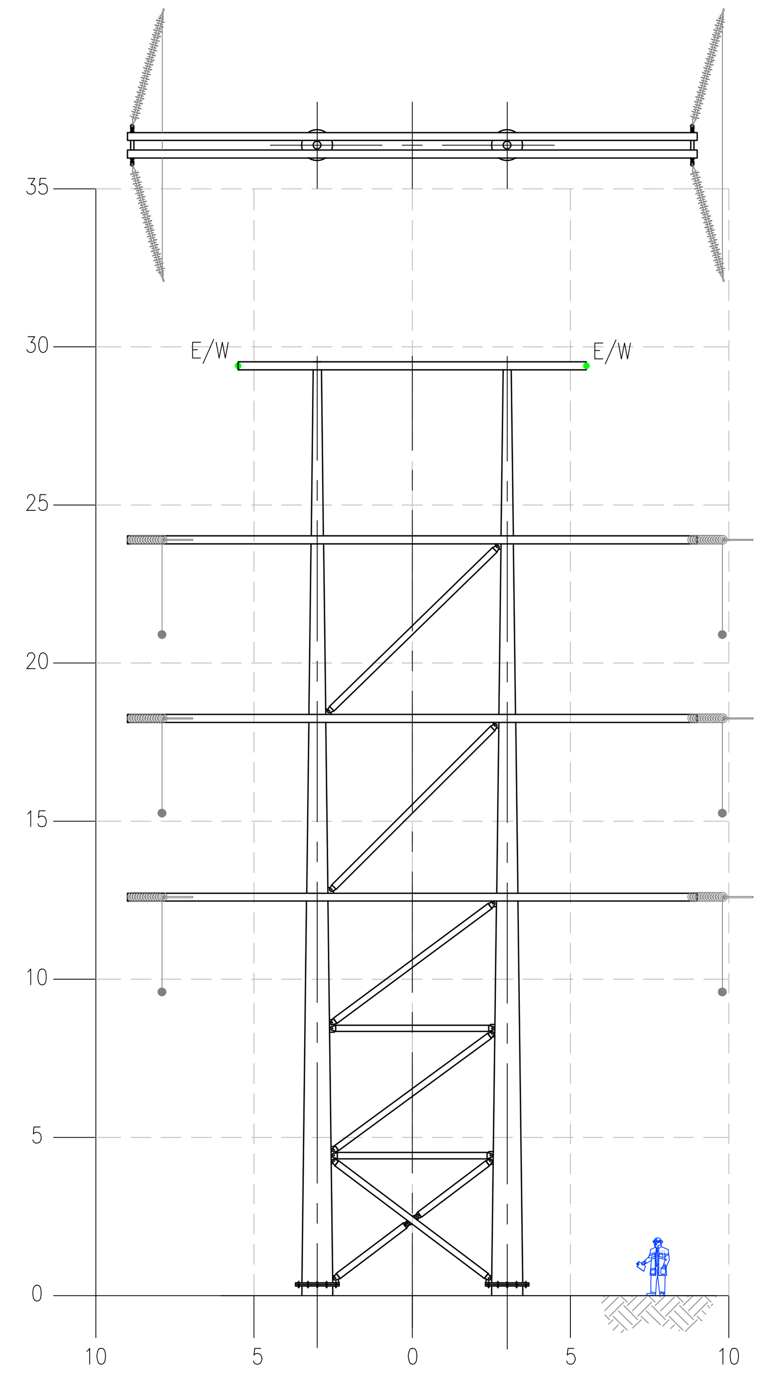
SCALE	NTS
ELEC FORM	DWG
SHT SIZE	A1

1



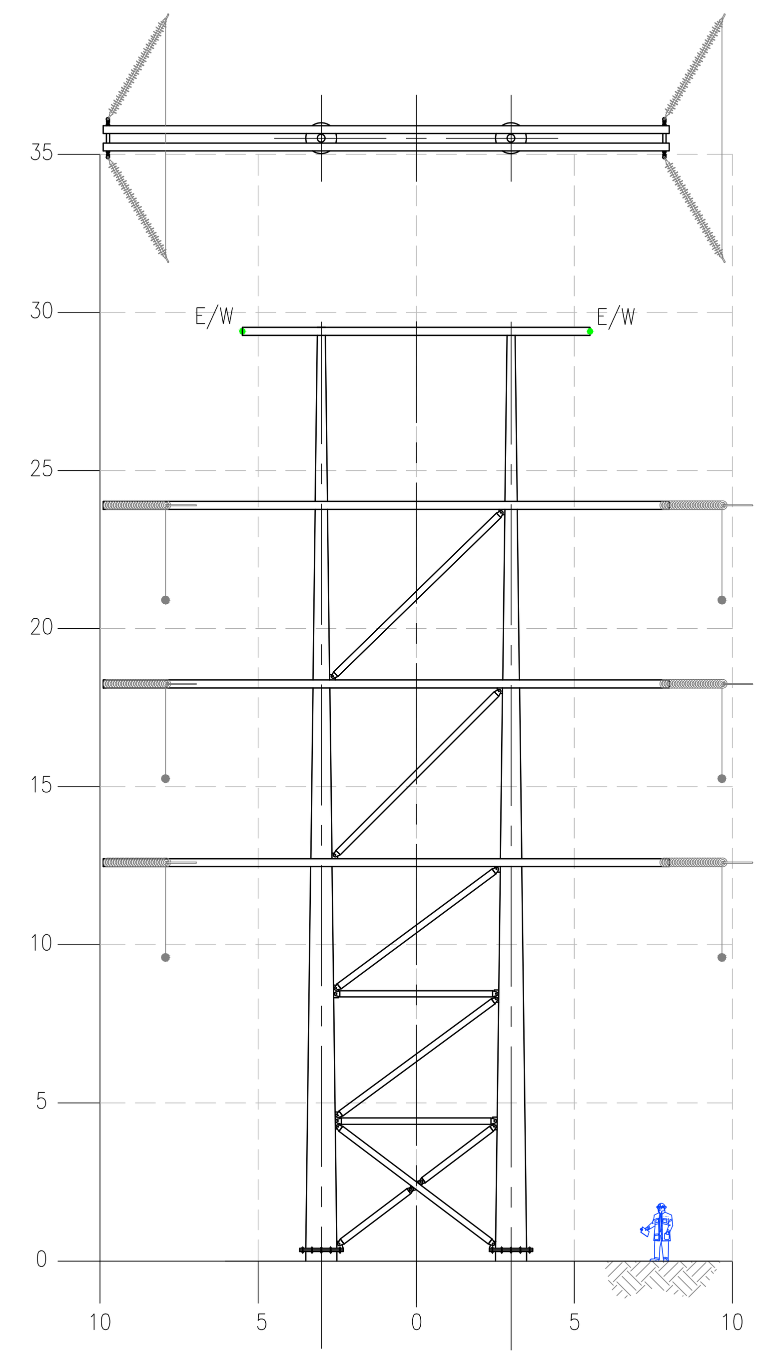
TRANSVERSE ELEVATION

MP-01-D, MULTI-POLE
2 POLES, 3 CROSSARMS, SUSPENSION (D)
90SS545-OGA-522 (200m Nominal Span)



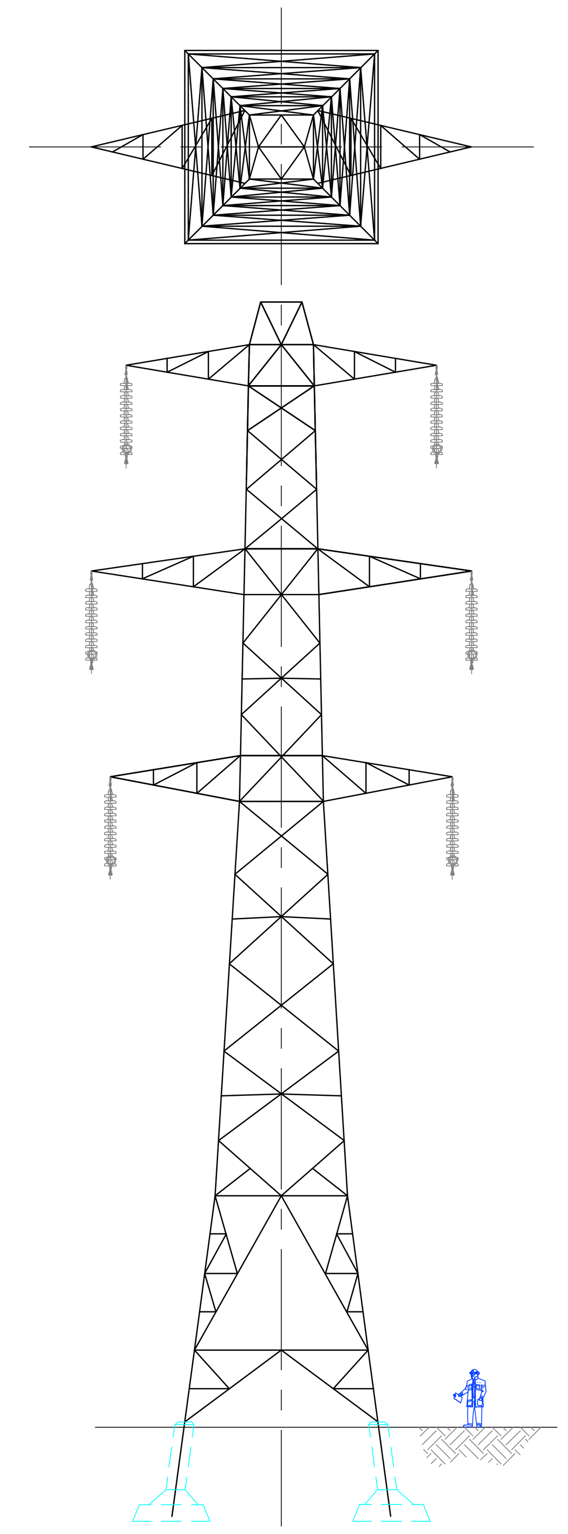
TRANSVERSE ELEVATION

MP-01-D30, MULTI-POLE
2 POLES, 3 CROSSARMS, TENSION (D30)
90SS545-OGA-524 (200m Nominal Span)



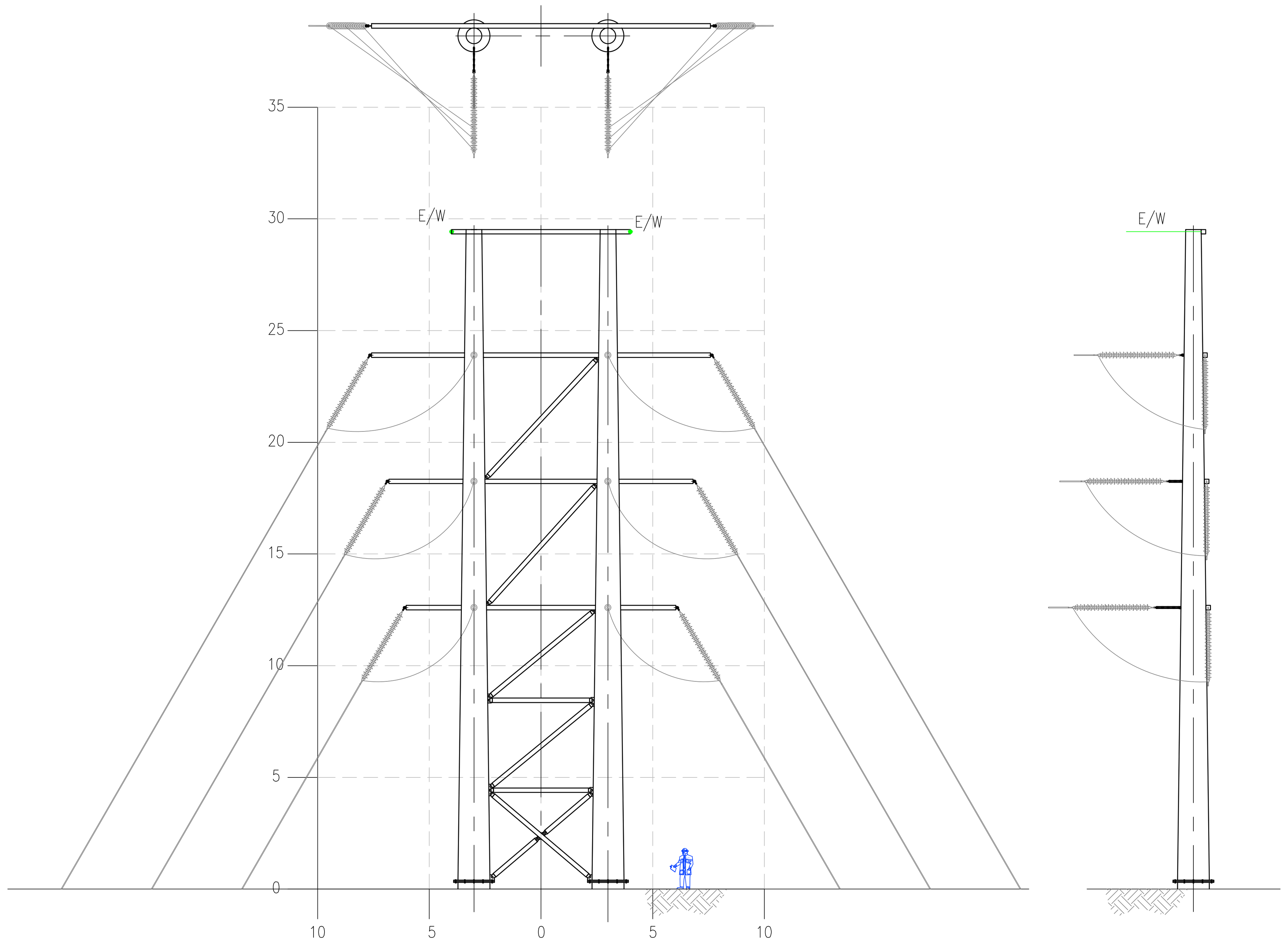
TRANSVERSE ELEVATION

MP-01-D60, MULTI-POLE
2 POLES, 3 CROSSARMS, TENSION (D60)
90SS545-OGA-525 (200m Nominal Span)



TRANSVERSE ELEVATION

L8C RD M4.9 SUSPENSION TOWER
275kV
SHOWN FOR COMPARISON ONLY



TRANSVERSE ELEVATION

MP-01-DT, MULTI-POLE
2 POLES, 3 CROSSARMS, TERMINAL (DT)
90SS545-OGA-526 (200m Nominal Span)

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1	24:06:15	Issued for discussion	JP	JS	MDL

energyline
YORK HOUSE, 9 YORK PLACE, KNARESBOROUGH HG5 0AD
TEL: 01423-799950

TITLE
MULTI-POLE, 2 POLES, 3 CROSSARMS

ROUTE / CIRCUIT
NEW 275kV SUPPORT PROJECT

ENERGYLINE PROJECT / DRG No.	SHT No.	No. OF SHTS
90SS545-OGA-521	1	1

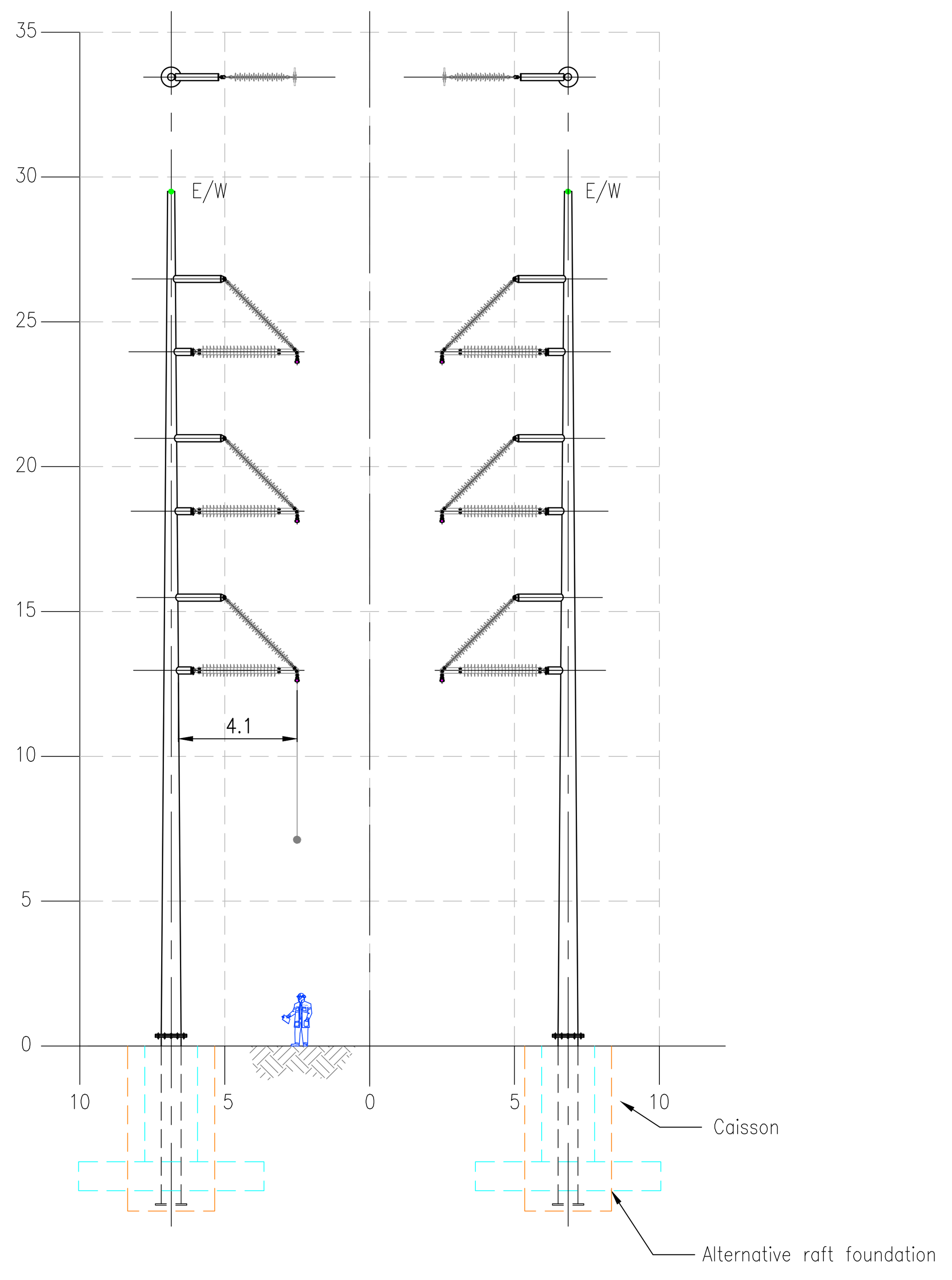
CLIENT
Scottish and Southern Energy
Power Distribution

CLIENTS PROJECT REF.
*

CLIENTS DRG No.
*

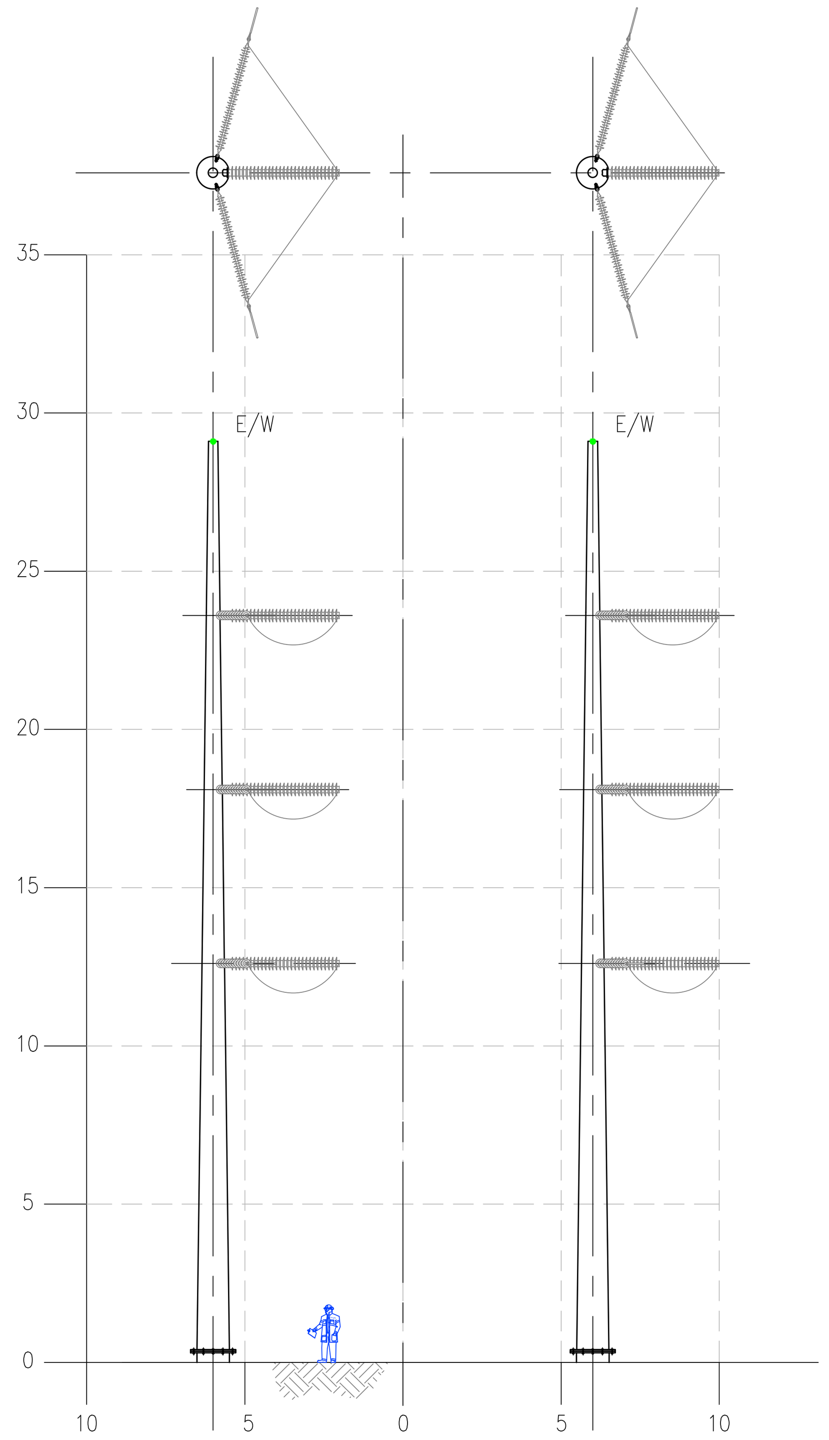
SCALE NTS
ELEC FORM DWG
SHT SIZE A1

1



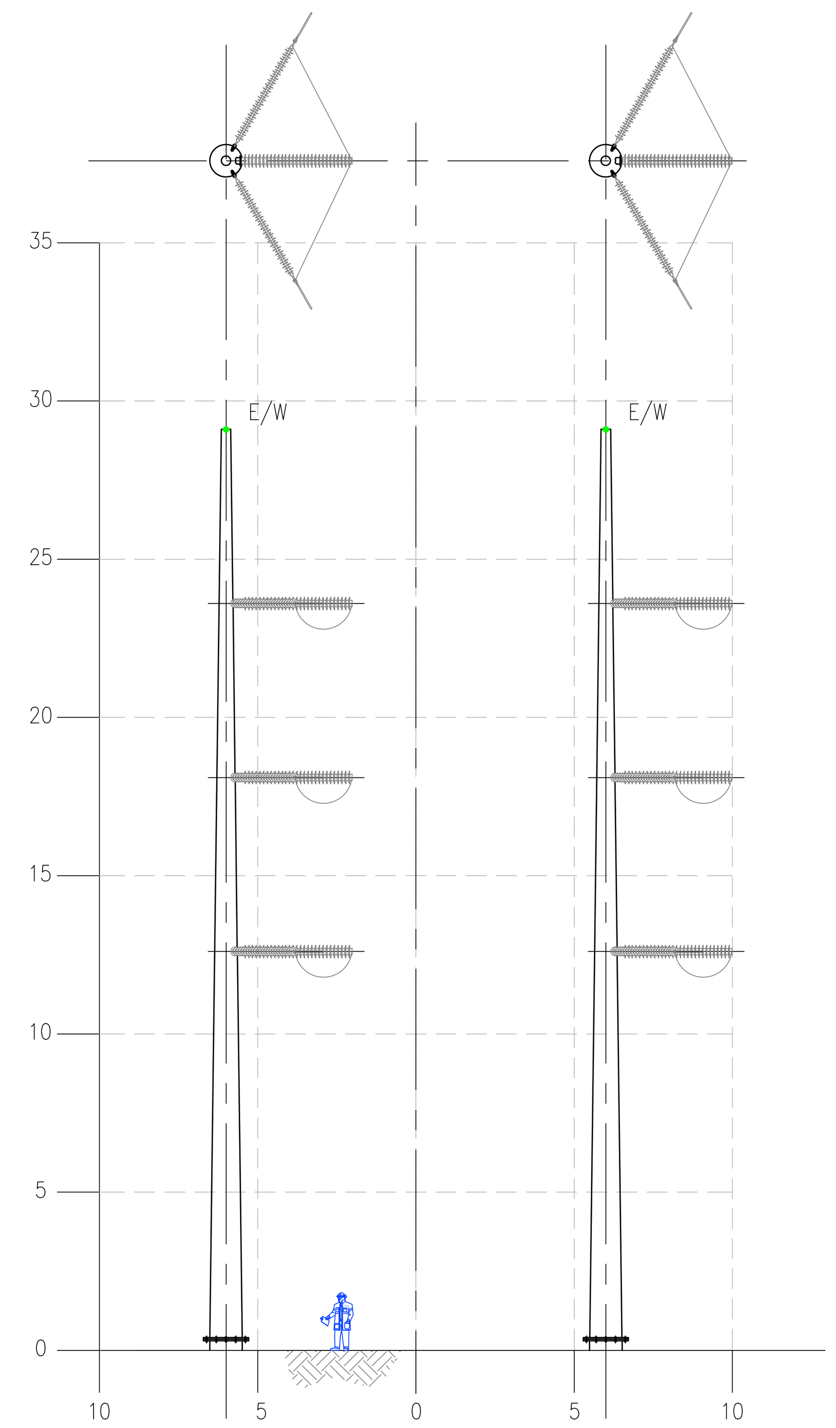
TRANSVERSE ELEVATION

MP–02–D, MULTI–POLE. 2 SINGLE POLES,
3 INSULATED CROSSARMS, INTERMEDIATE (D)
90SS545–OGA–532 (200m Nominal Span)



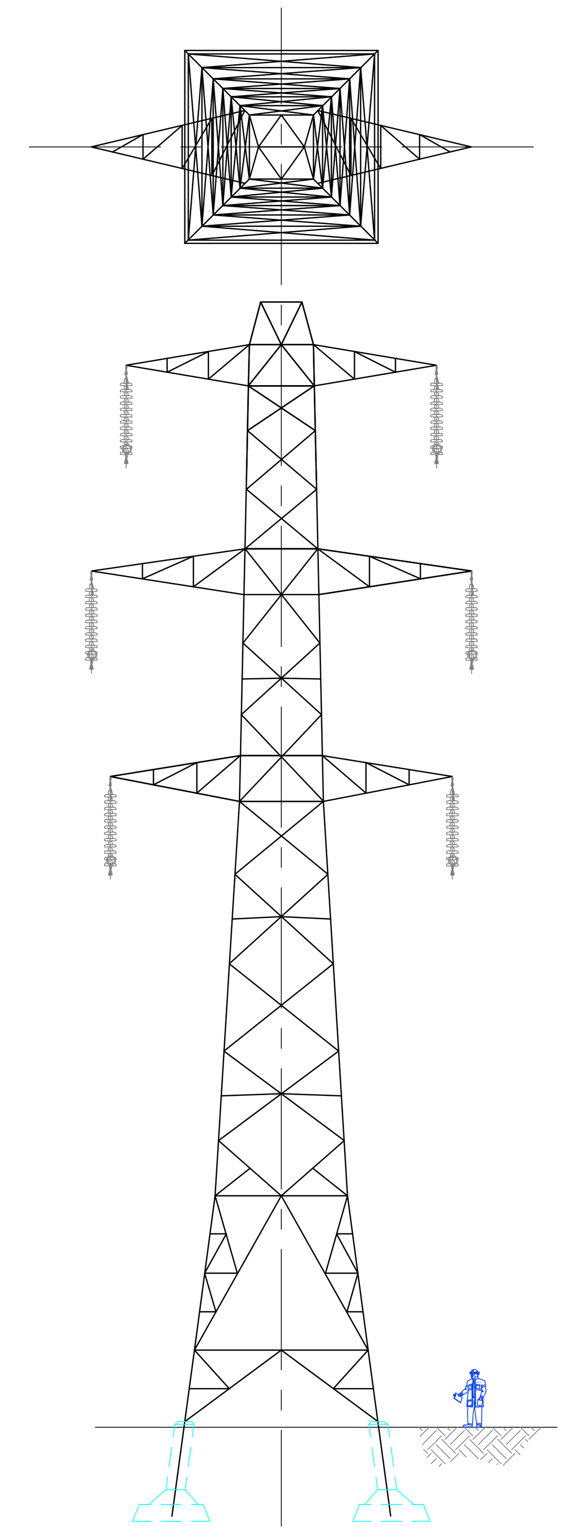
TRANSVERSE ELEVATION

MP–02–D30, MULTI–POLE. 2 SINGLE POLES,
3 INSULATED CROSSARMS, ANGLE (D30)
90SS545–OGA–534 (200m Nominal Span)



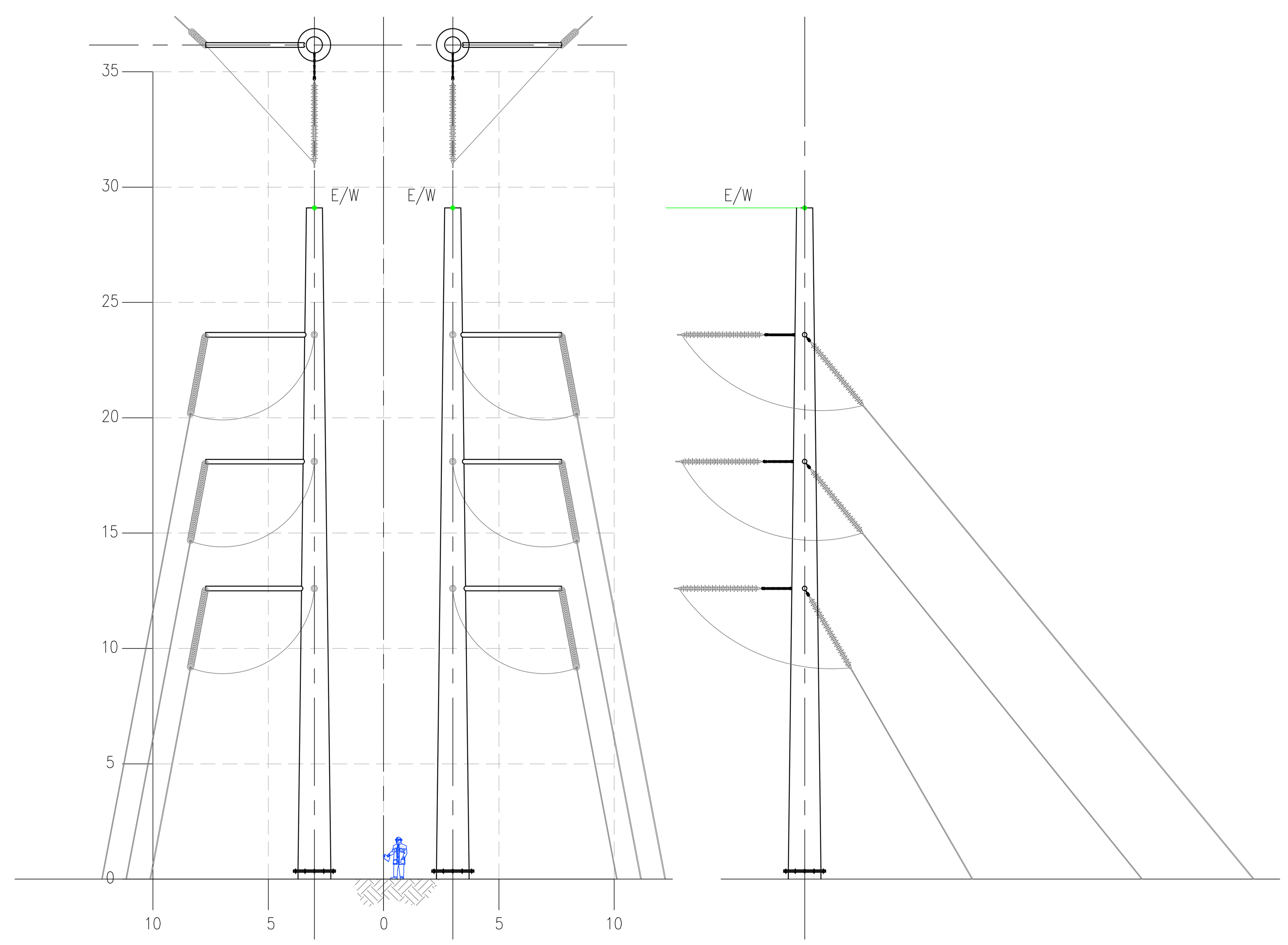
TRANSVERSE ELEVATION

MP–02–D60, MULTI–POLE. 2 SINGLE POLES,
3 INSULATED CROSSARMS, ANGLE (D60)
90SS545–OGA–535 (200m Nominal Span)



TRANSVERSE ELEVATION

L8C RD M4.9 SUSPENSION TOWER
275kV
SHOWN FOR COMPARISON ONLY



TRANSVERSE ELEVATION

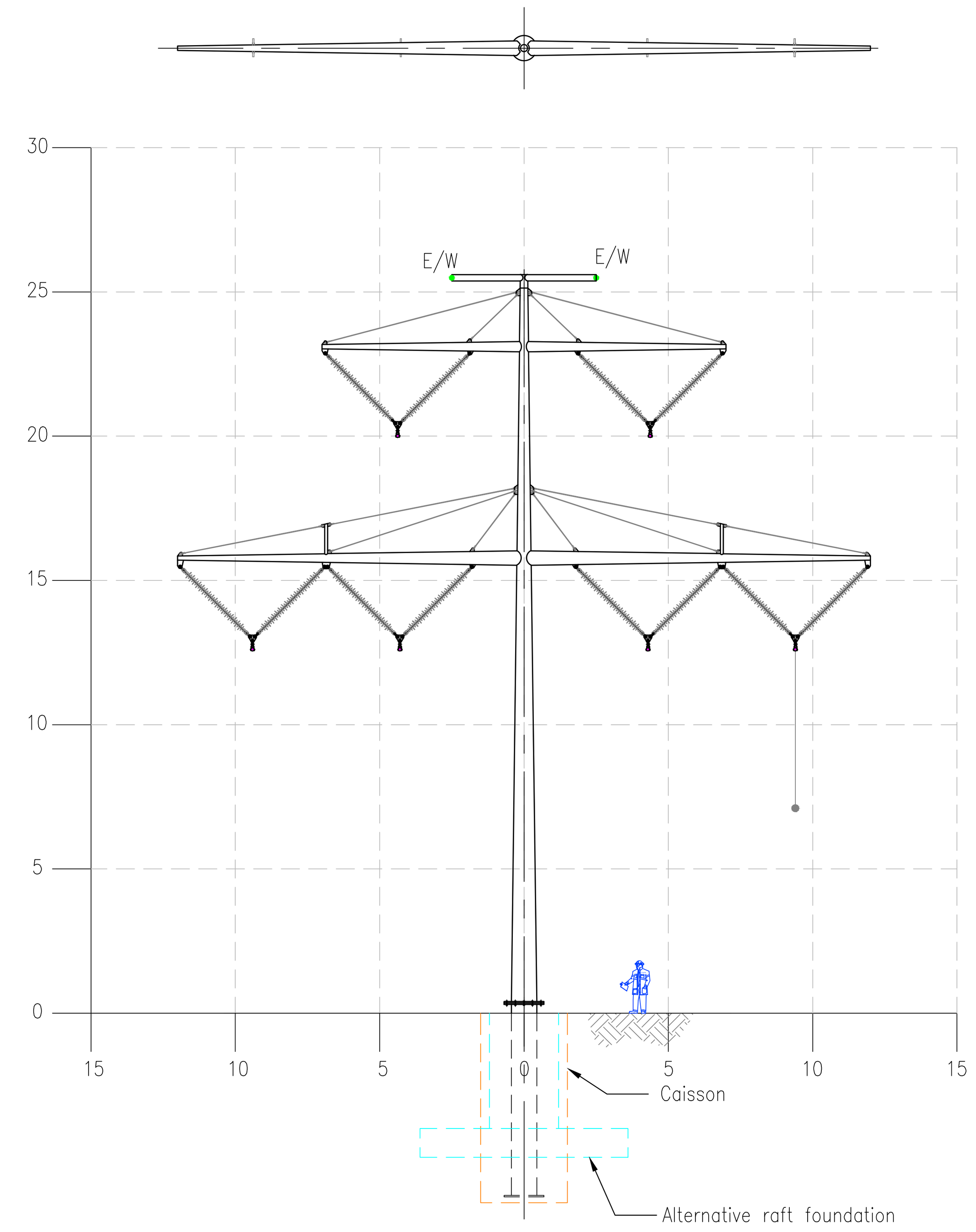
MP–02–DT, MULTI–POLE. 2 SINGLE POLES,
3 TUBULAR CROSSARMS, TERMINAL (DT)
90SS545–OGA–536 (200m Nominal Span)

ISSUE	DATE	REVISION	DRAWN	CHK'D	APP'D
1	24:06:15	Issued for discussion	JP	JS	MDL

energyline
YORK HOUSE, 9 YORK PLACE, KNARESBOROUGH HG5 0AD
TEL: 01423-799950

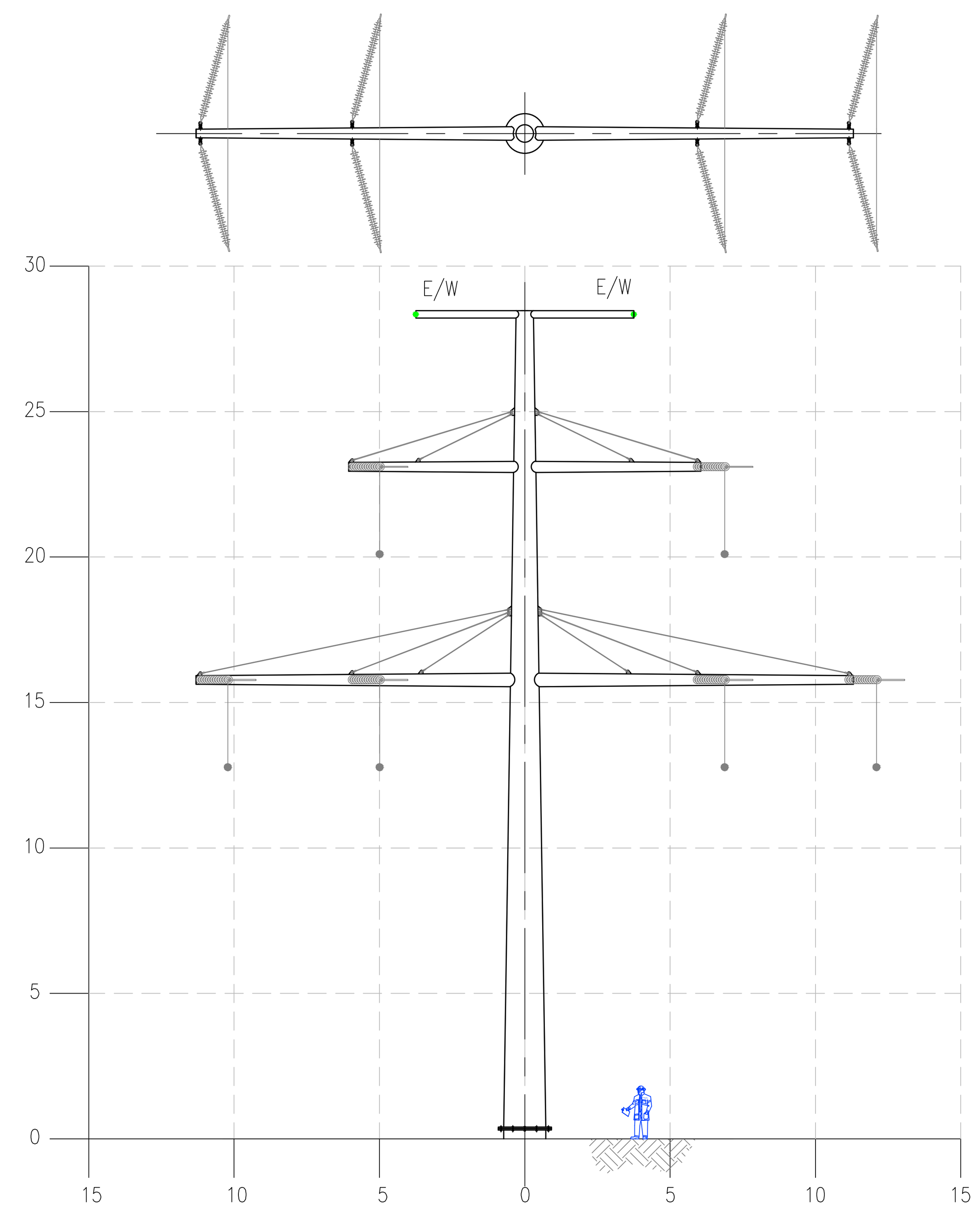
TITLE: MULTI–POLE, 2 SINGLE POLES, 3 CROSSARMS		
ROUTE / CIRCUIT: NEW 275kV SUPPORT PROJECT		
ENERGYLINE PROJECT / DRG No.: 90SS545–OGA–531	SHT No.: 1	No. OF SHTS: 1
CLIENT: Scottish and Southern Energy Power Distribution	CLIENTS PROJECT REF.: *	
CLIENTS DRG No.: *	SCALE: NTS	
	ELEC FORM: DWG	
	SHT SIZE: A1	

1



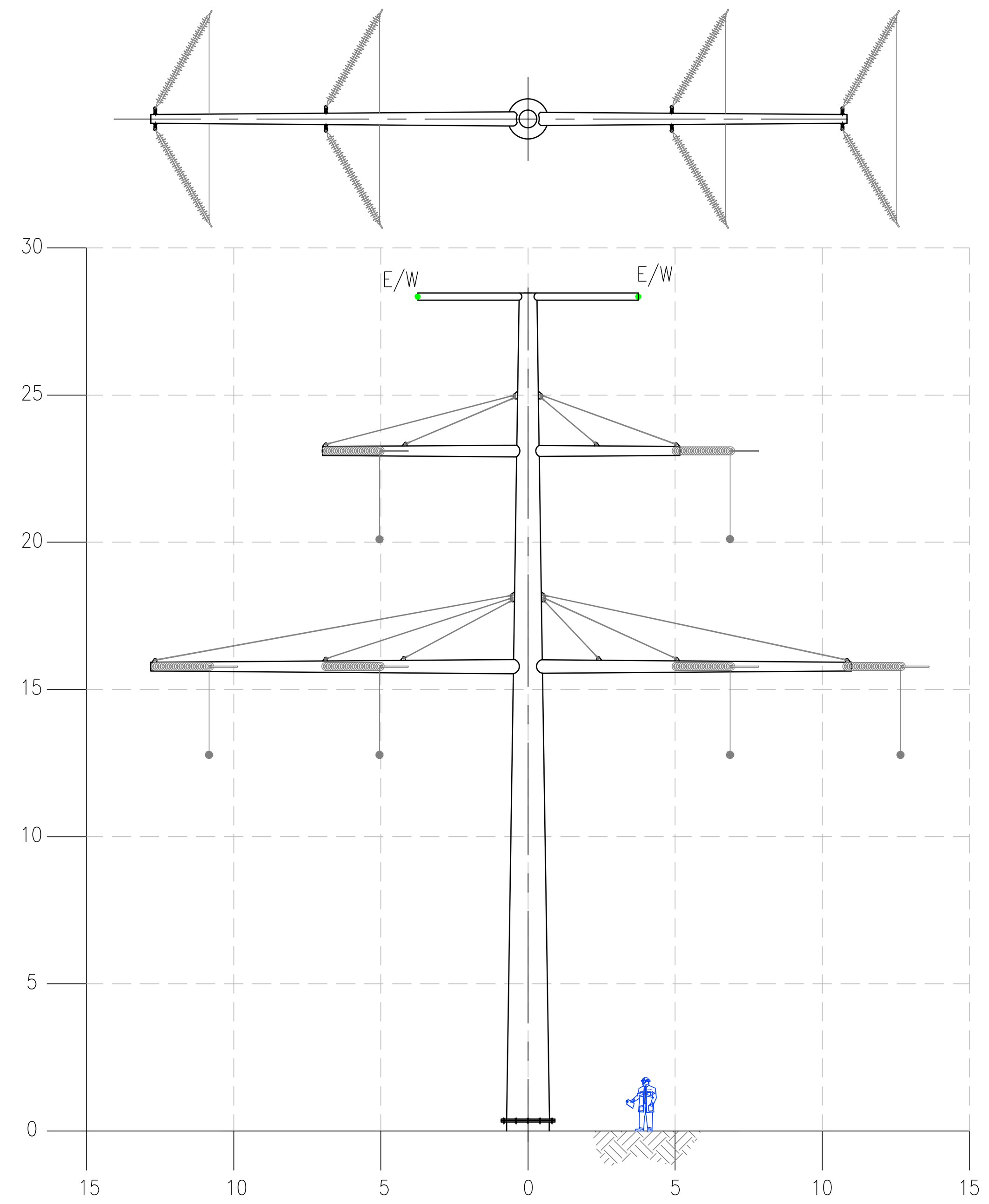
TRANSVERSE ELEVATION

SP-05-D, SINGLE-POLE
2 TUBULAR CROSSARMS, SUSPENSION (D)
90SS545-OGA-542 (200m Nominal Span)



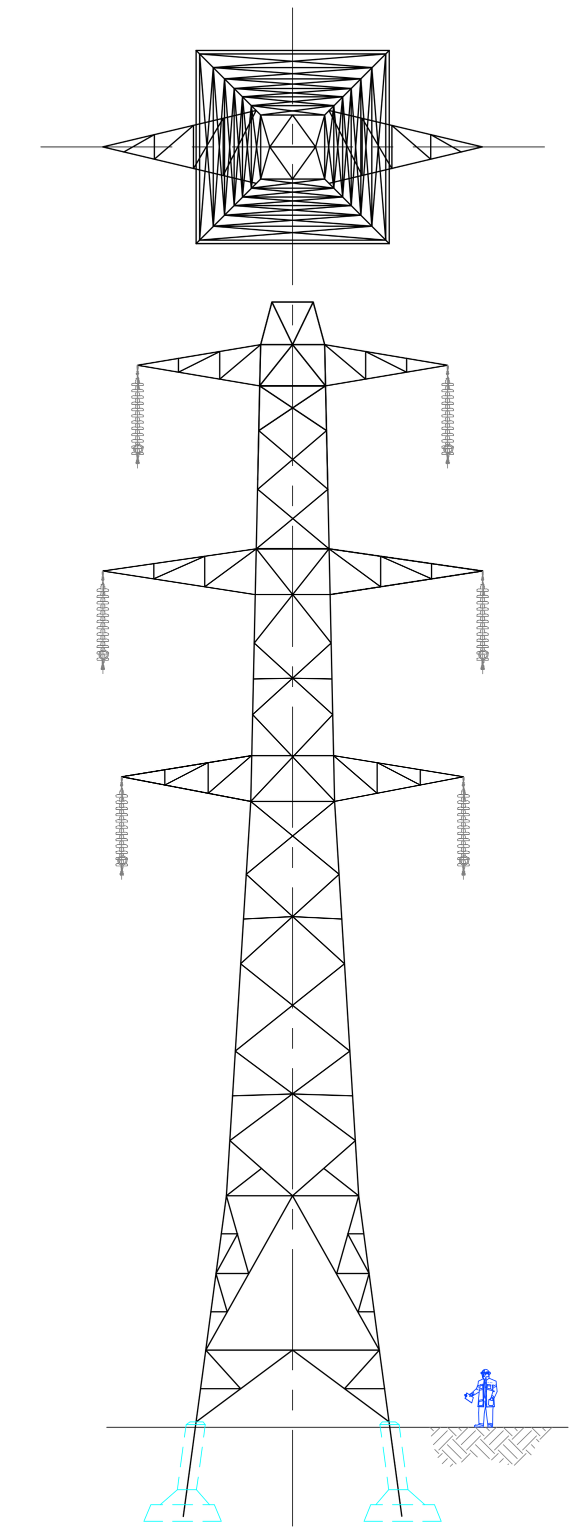
TRANSVERSE ELEVATION

SP-05-D30, SINGLE-POLE
2 TUBULAR CROSSARMS, TENSION (D30)
90SS545-OGA-544 (200m Nominal Span)



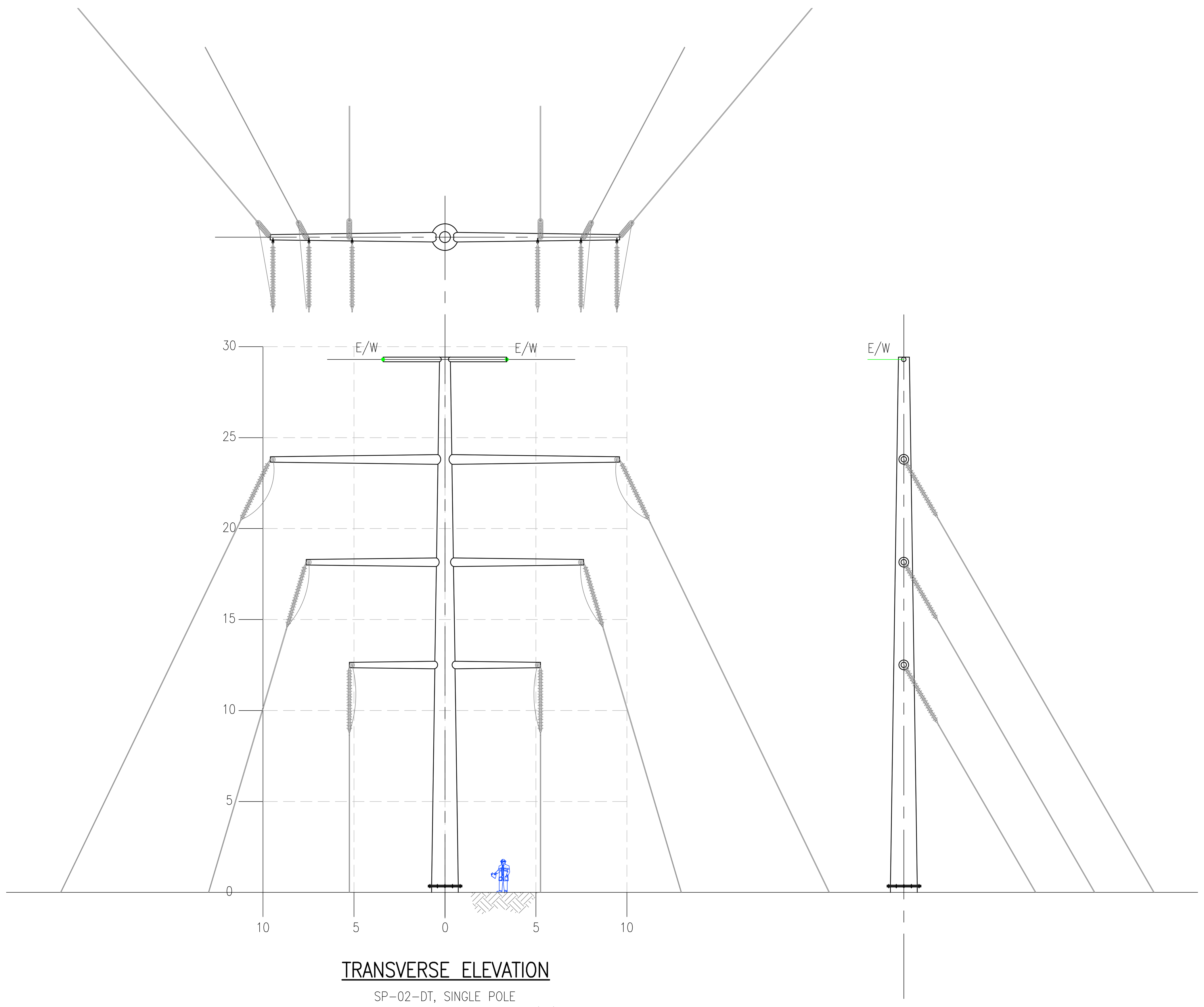
TRANSVERSE ELEVATION

SP-05-D60, SINGLE-POLE
2 TUBULAR CROSSARMS, TENSION (D60)
90SS545-OGA-545 (200m Nominal Span)



TRANSVERSE ELEVATION

L8C RD M4.9 SUSPENSION TOWER
275kV
SHOWN FOR COMPARISON ONLY



TRANSVERSE ELEVATION

SP-02-DT, SINGLE POLE
3 TUBULAR CROSSARMS, TERMINAL (DT)
90SS545-OGA-516 (200m Nominal Span)

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1	24:06:15	Issued for discussion	JP	JS	MDL

energyline
YORK HOUSE, 9 YORK PLACE, KNARESBOROUGH HG5 0AD
TEL: 01423-799950

TITLE
SINGLE POLE 2 TUBULAR CROSSARMS

ROUTE / CIRCUIT
NEW 275kV SUPPORT PROJECT

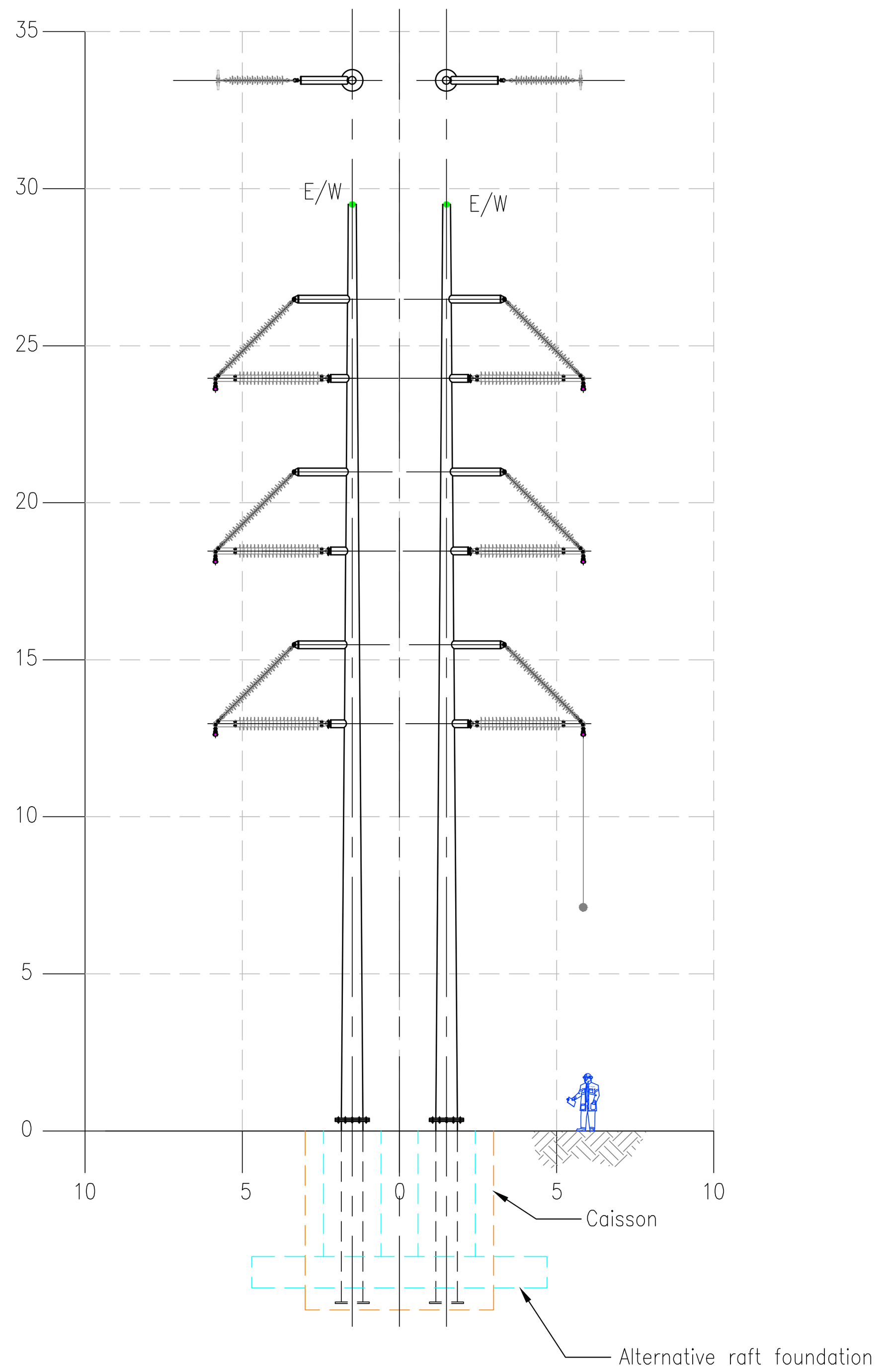
ENERGYLINE PROJECT / DRG No.	SHT No.	No. OF SHTS
90SS545-OGA-541	1	1

CLIENT: Scottish and Southern Energy Power Distribution
CLIENTS PROJECT REF.: *

CLIENTS DRG No.: *

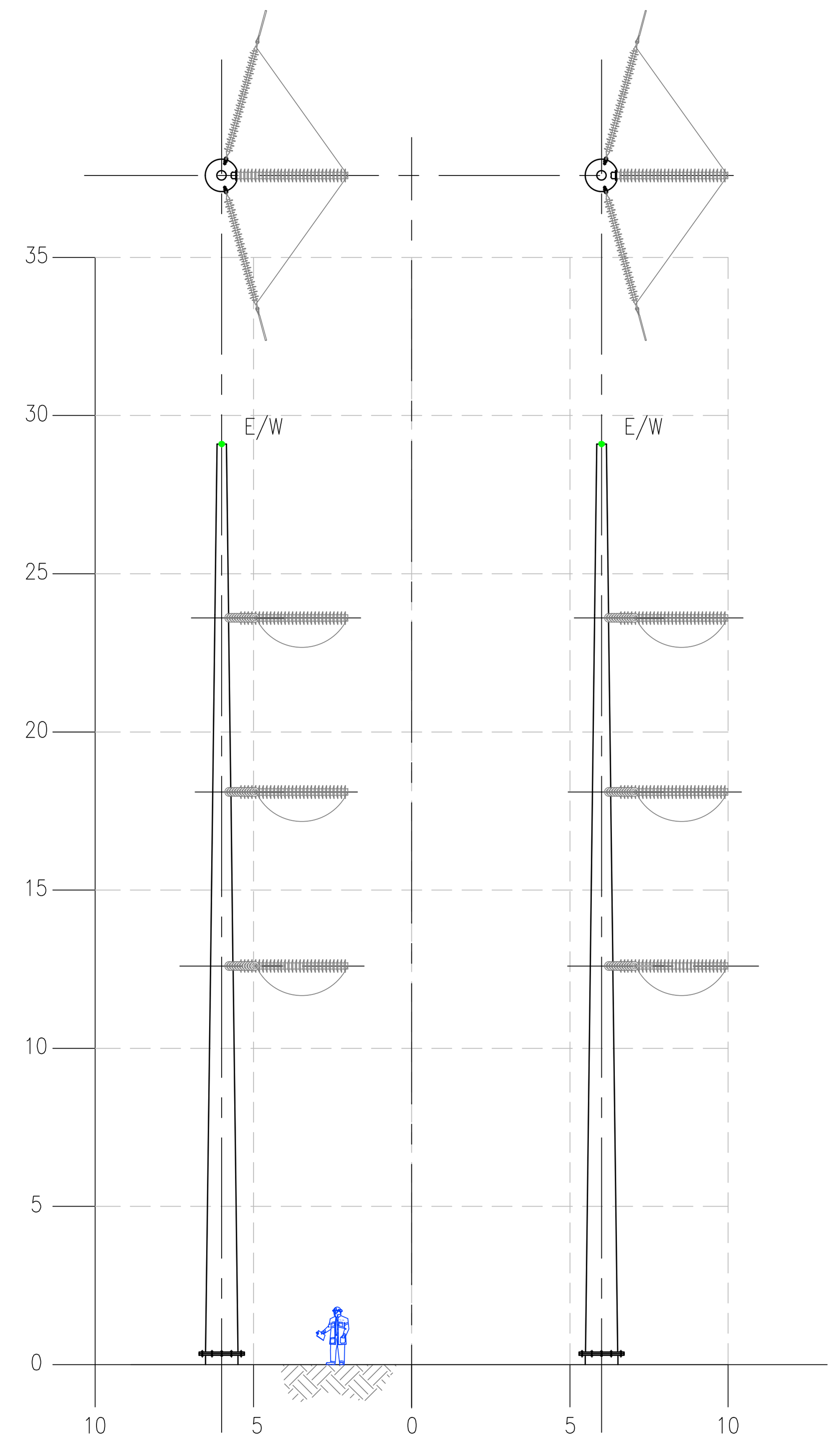
SCALE	NTS
ELEC FORM	DWG
SHT SIZE	A1

1



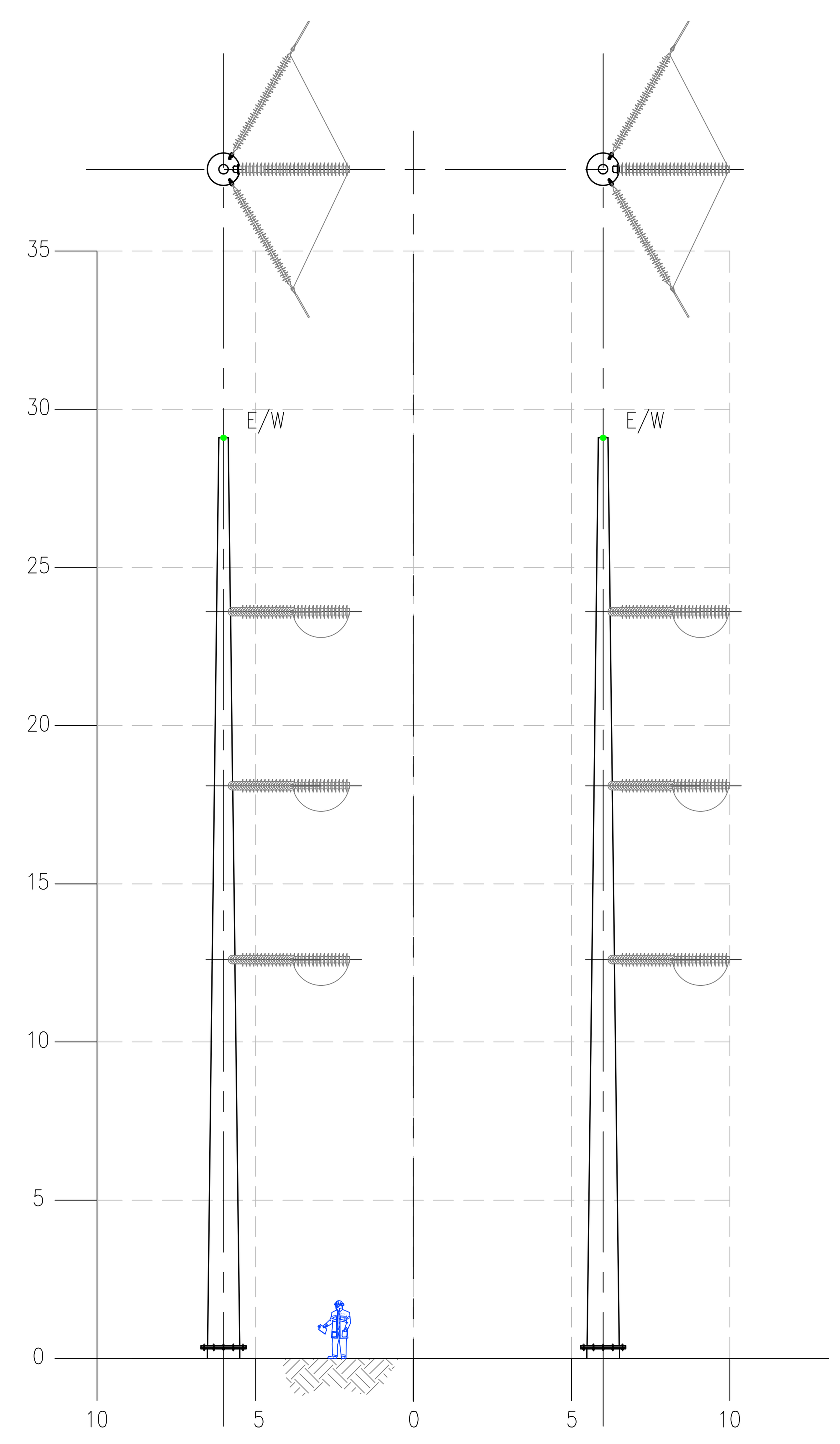
TRANSVERSE ELEVATION

MP-03-D, MULTI-POLE. 2 SINGLE POLES,
3 INSULATED CROSSARMS, EXTERNAL CONFIGURATION SUSPENSION (D)
90SS545-OGA-552 (200m Nominal Span)



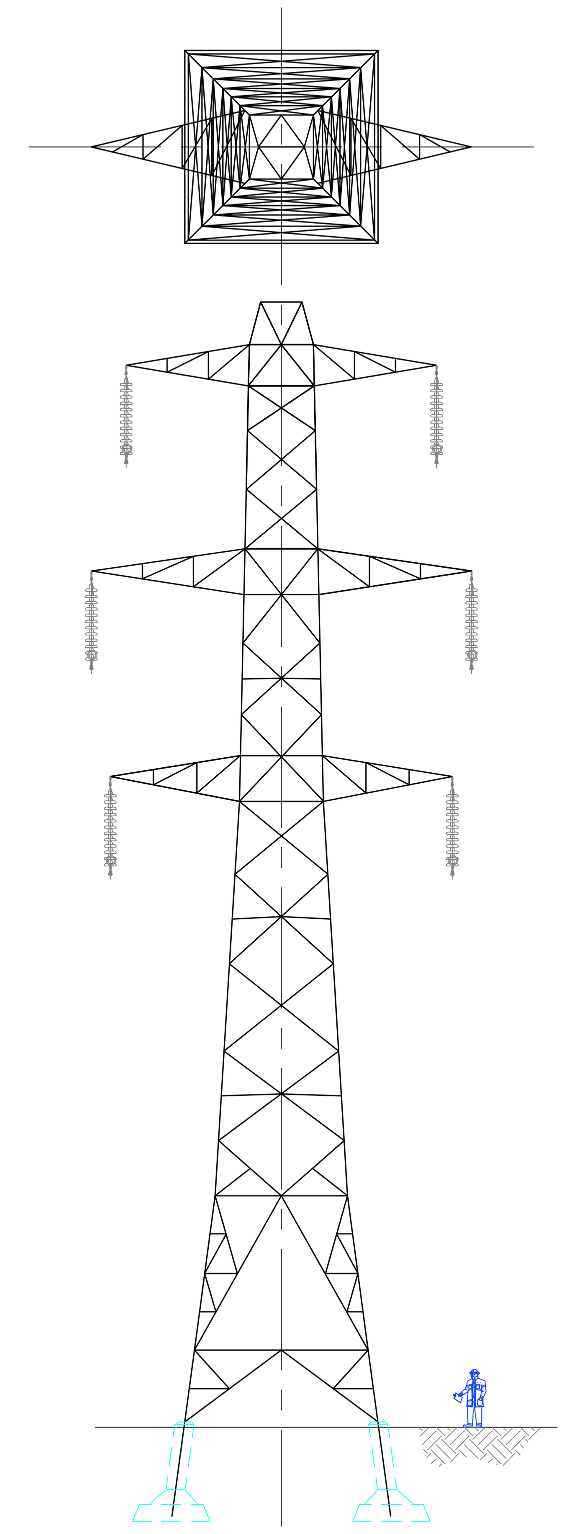
TRANSVERSE ELEVATION

MP-02-D30, MULTI-POLE. 2 SINGLE POLES,
3 INSULATED CROSSARMS, ANGLE (D30)
90SS545-OGA-534 (200m Nominal Span)



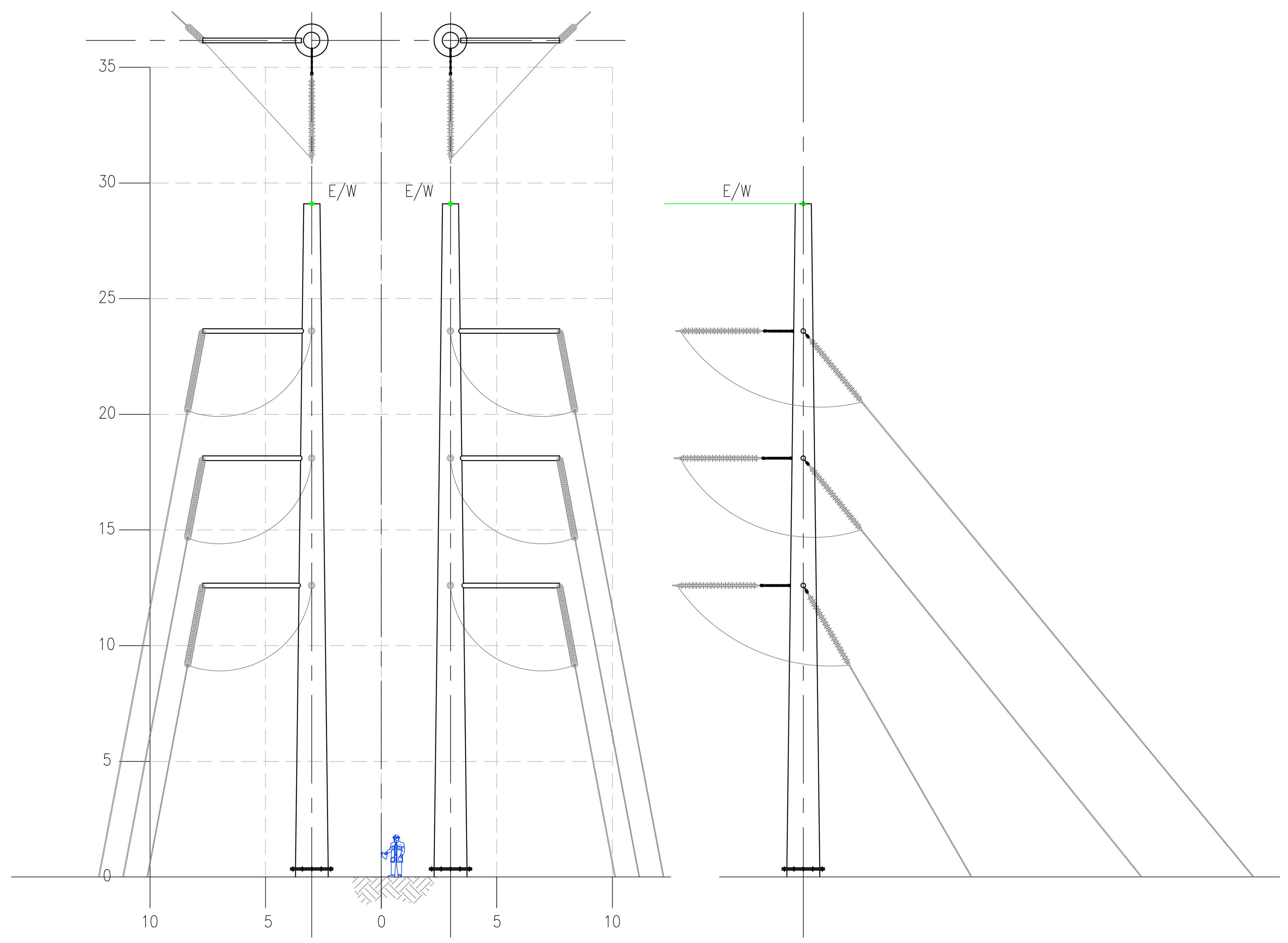
TRANSVERSE ELEVATION

MP-02-D60, MULTI-POLE. 2 SINGLE POLES,
3 INSULATED CROSSARMS, ANGLE (D60)
90SS545-OGA-535 (200m Nominal Span)



TRANSVERSE ELEVATION

L8C RD M4.9 SUSPENSION TOWER
275kV
SHOWN FOR COMPARISON ONLY



TRANSVERSE ELEVATION

MP-02-DT, MULTI-POLE. 2 SINGLE POLES,
3 TUBULAR CROSSARMS, TERMINAL (DT)
90SS545-OGA-536 (200m Nominal Span)

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1	24:06:15	Issued for discussion	JP	JS	MDL

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YORK HOUSE, 9 YORK PLACE, KNARESBOROUGH HG5 0AD
TEL: 01423-799950

TITLE
MULTI-POLE, 2 SINGLE POLES, 3 CROSSARMS

ROUTE / CIRCUIT
NEW 275kV SUPPORT PROJECT

ENERGYLINE PROJECT / DRG No.	SHT No.	No. OF SHTS
90SS545-OGA-551	1	1

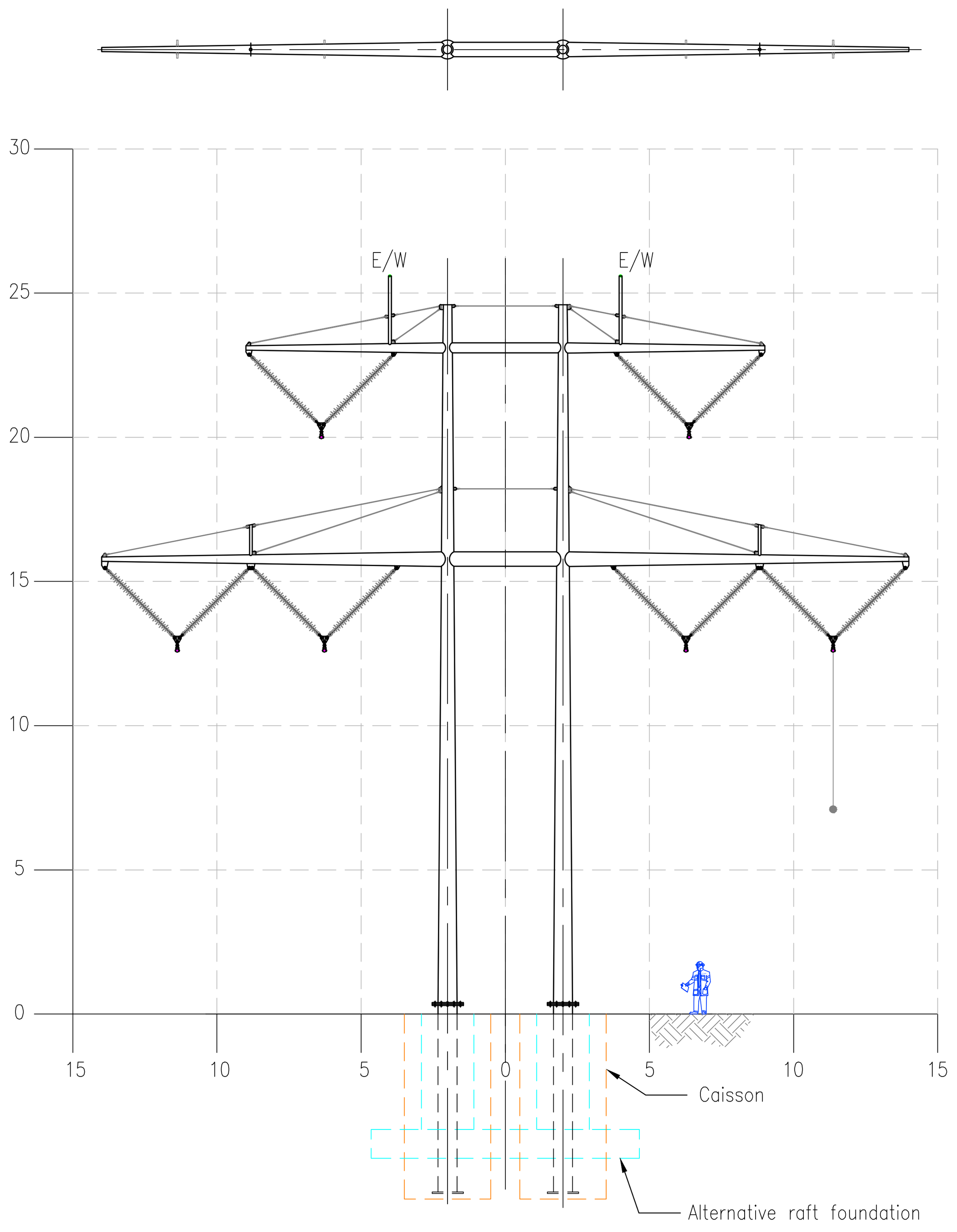
CLIENT
Scottish and Southern Energy
Power Distribution

CLIENTS PROJECT REF.
*

CLIENTS DRG No.
*

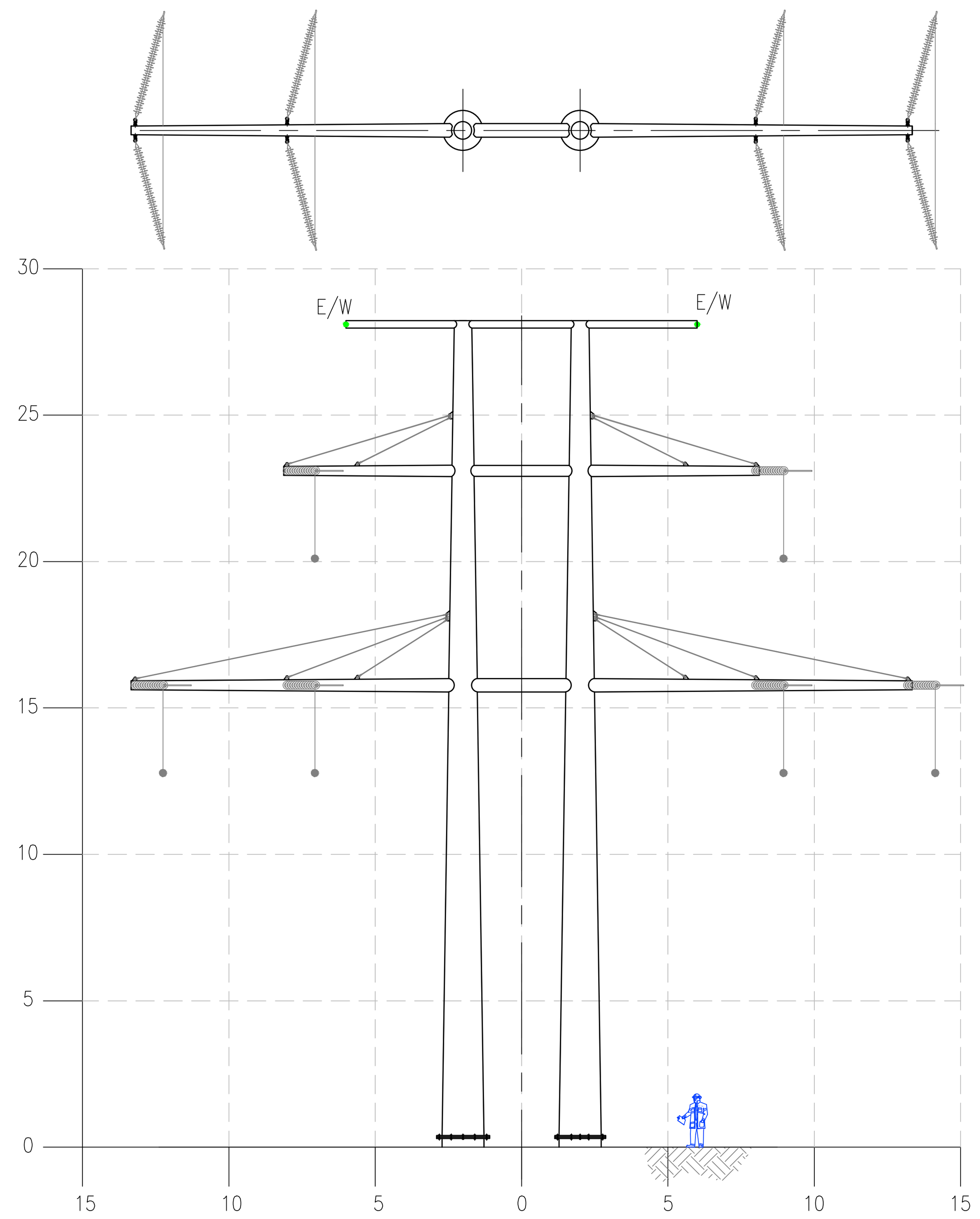
SCALE	NTS
ELEC FORM	DWG
SHT SIZE	A1

1



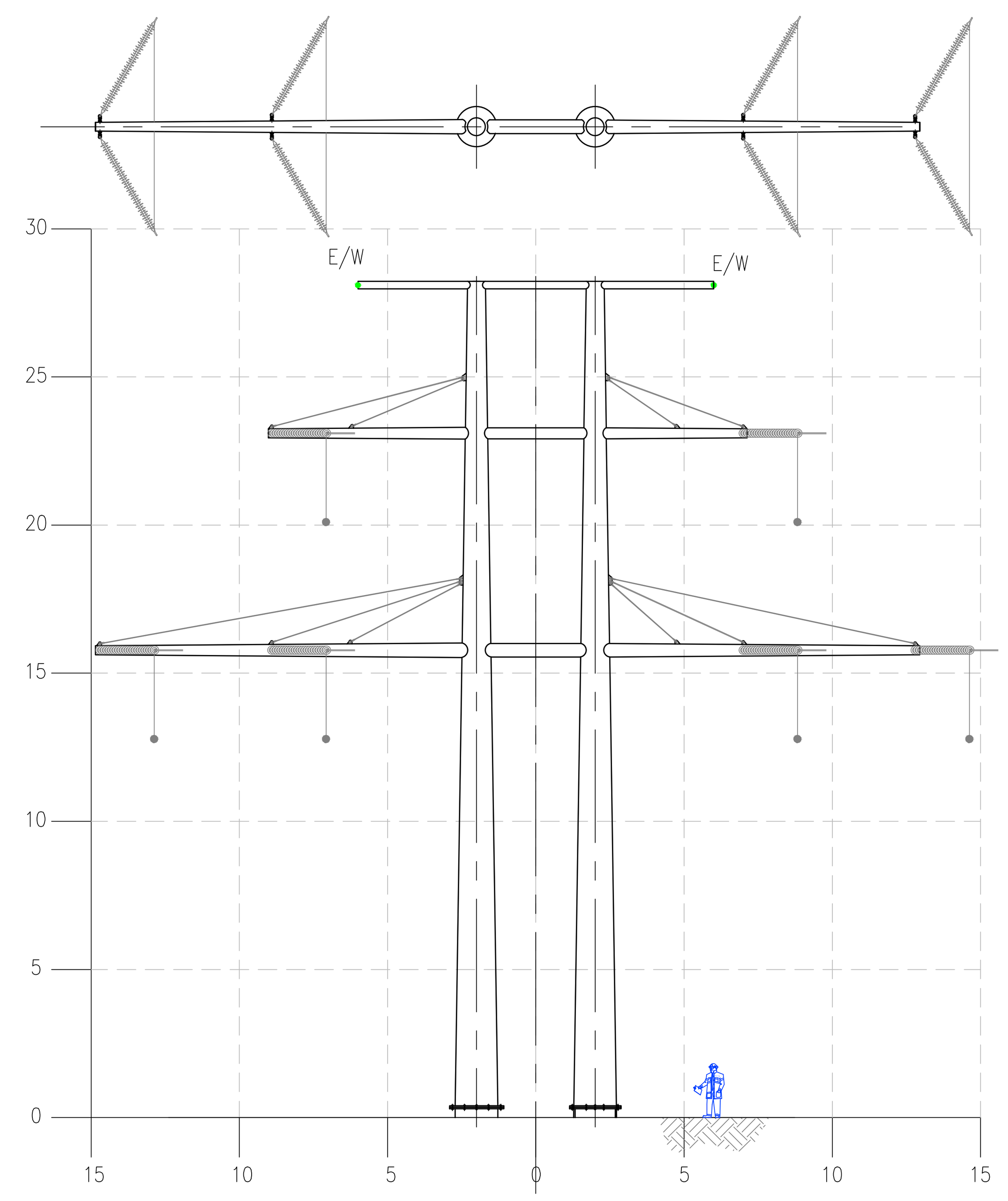
TRANSVERSE ELEVATION

MP-04-D, MULTI-POLE
2 POLES, 2 TUBULAR CROSSARMS, SUSPENSION (D)
90SS545-OGA-562 (200m Nominal Span)



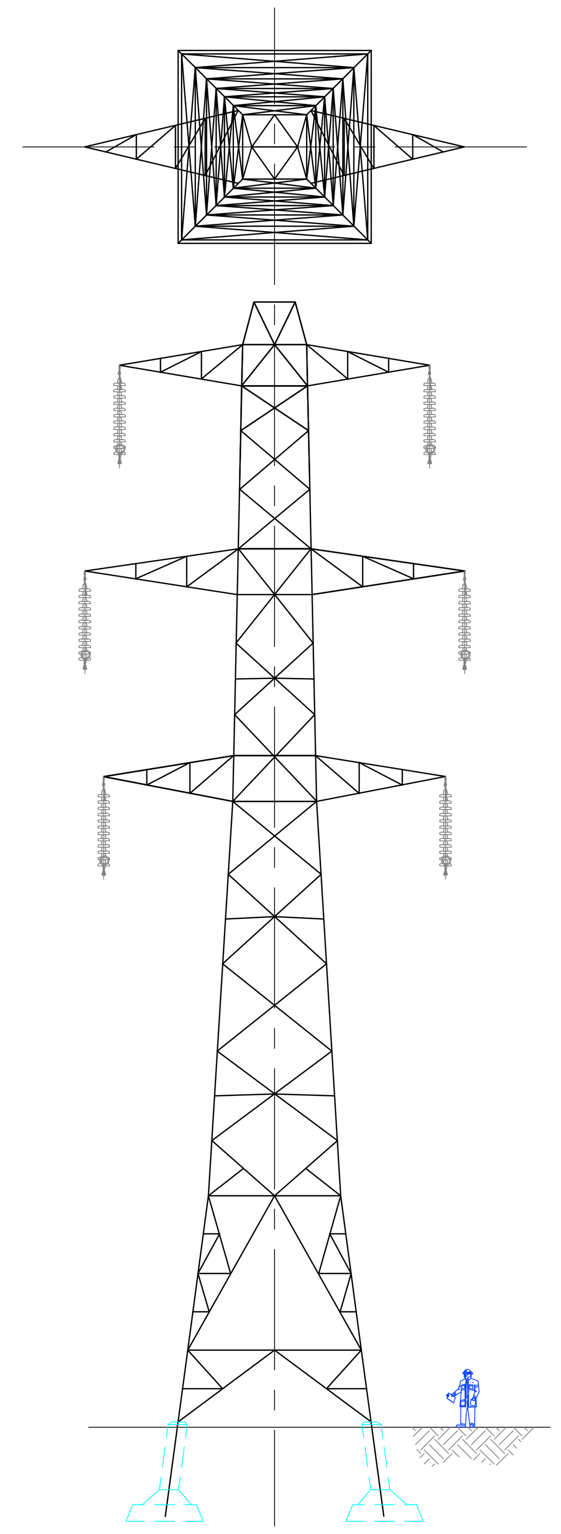
TRANSVERSE ELEVATION

MP-04-D30, MULTI-POLE
2 TUBULAR CROSSARMS, TENSION (D30)
90SS545-OGA-564 (200m Nominal Span)



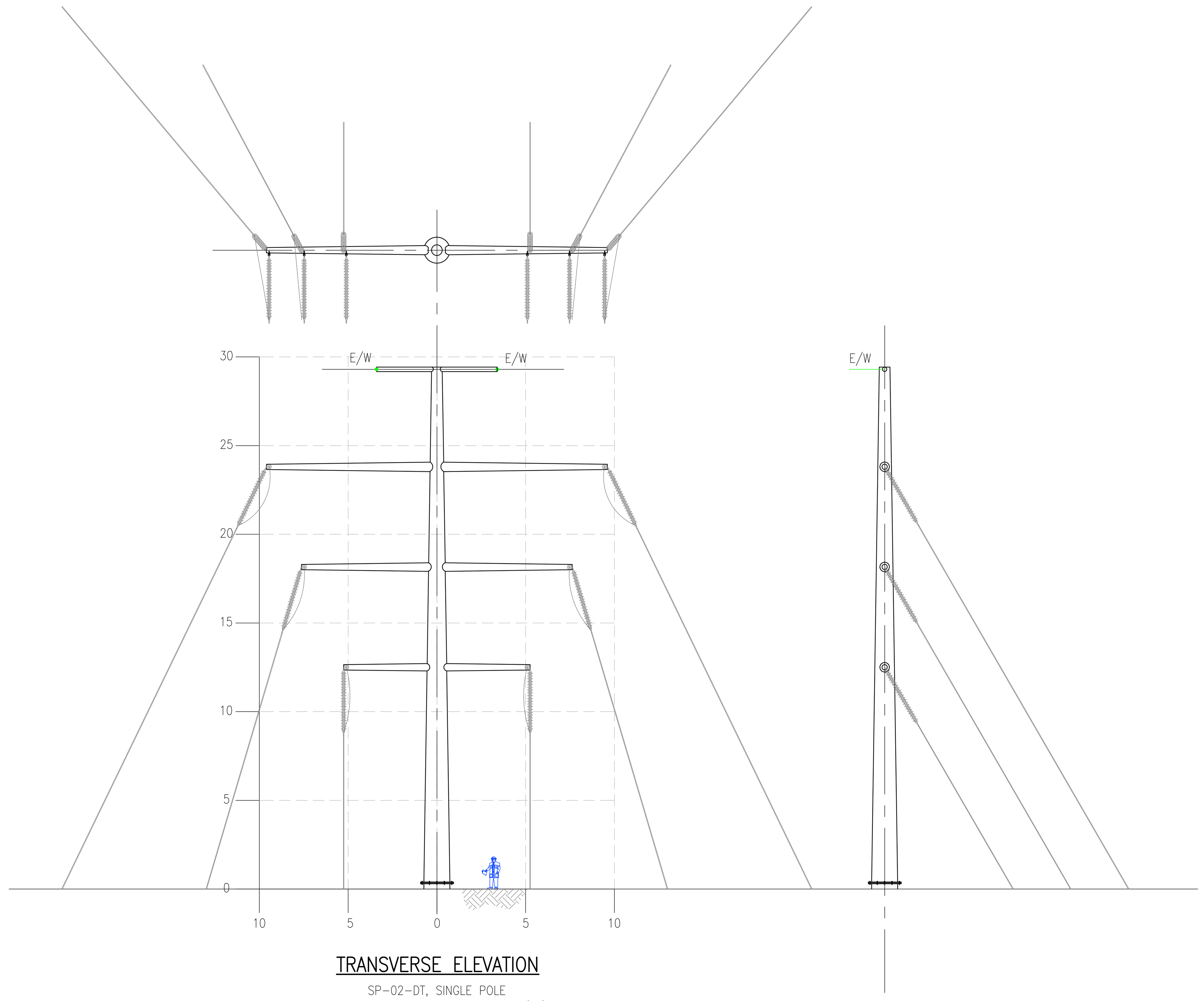
TRANSVERSE ELEVATION

MP-04-D60, MULTI-POLE
2 TUBULAR CROSSARMS, TENSION (D60)
90SS545-OGA-565 (200m Nominal Span)



TRANSVERSE ELEVATION

L8C RD M4.9 SUSPENSION TOWER
275kV
SHOWN FOR COMPARISON ONLY



TRANSVERSE ELEVATION

SP-02-DT, SINGLE POLE
3 TUBULAR CROSSARMS, TERMINAL (DT)
90SS545-OGA-516 (200m Nominal Span)

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1	24:06:15	Issued for discussion	JP	JS	MDL

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YORK HOUSE, 9 YORK PLACE, KNARESBOROUGH HG5 0AD
TEL: 01423-799950

TITLE
2 POLES, 2 TUBULAR CROSSARMS

ROUTE / CIRCUIT
NEW 275kV SUPPORT PROJECT

ENERGYLINE PROJECT / DRG No.	SHT No.	No. OF SHTS
90SS545-OGA-561	1	1

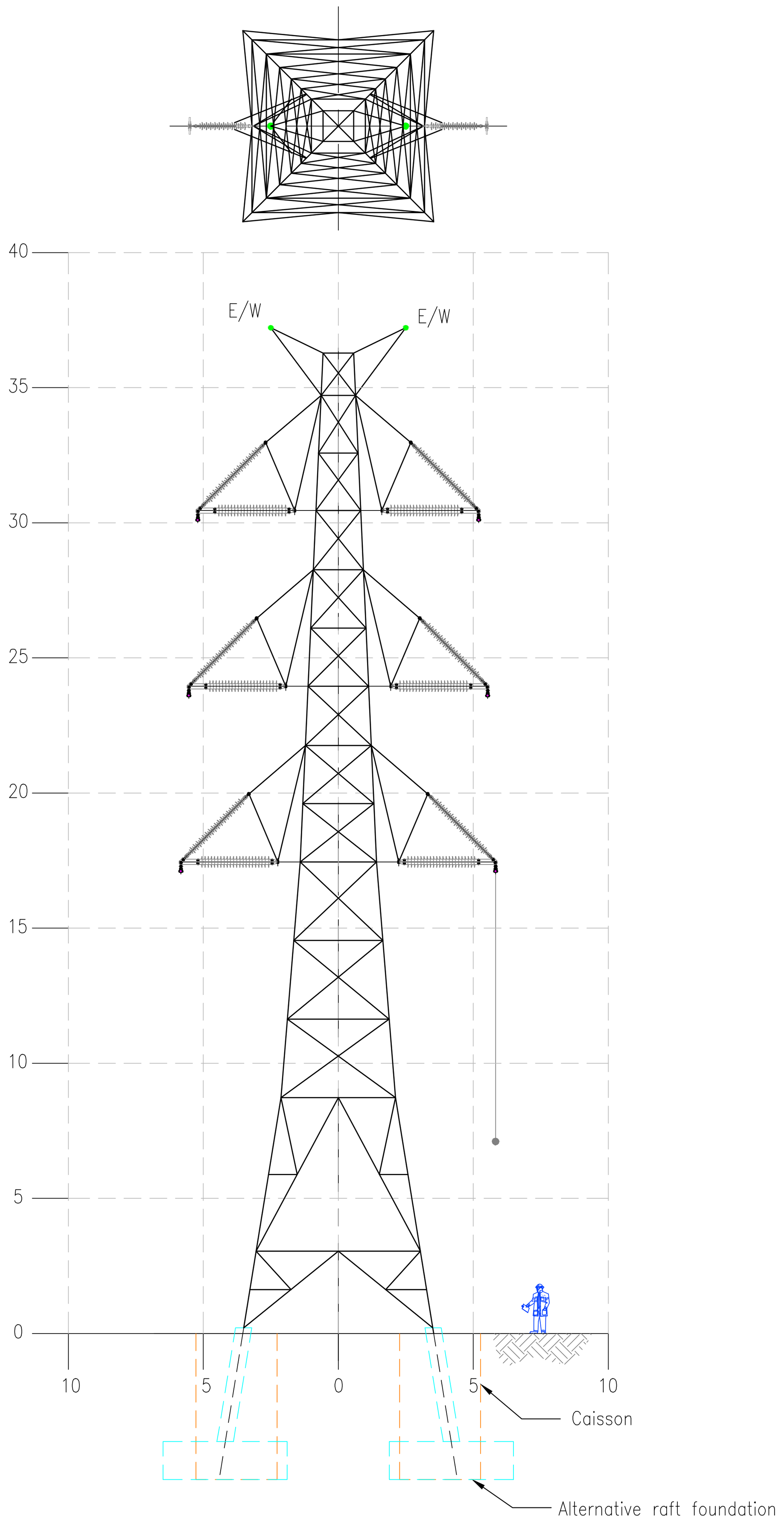
CLIENT: Scottish and Southern Energy Power Distribution

CLIENTS PROJECT REF. *

CLIENTS DRG No. *

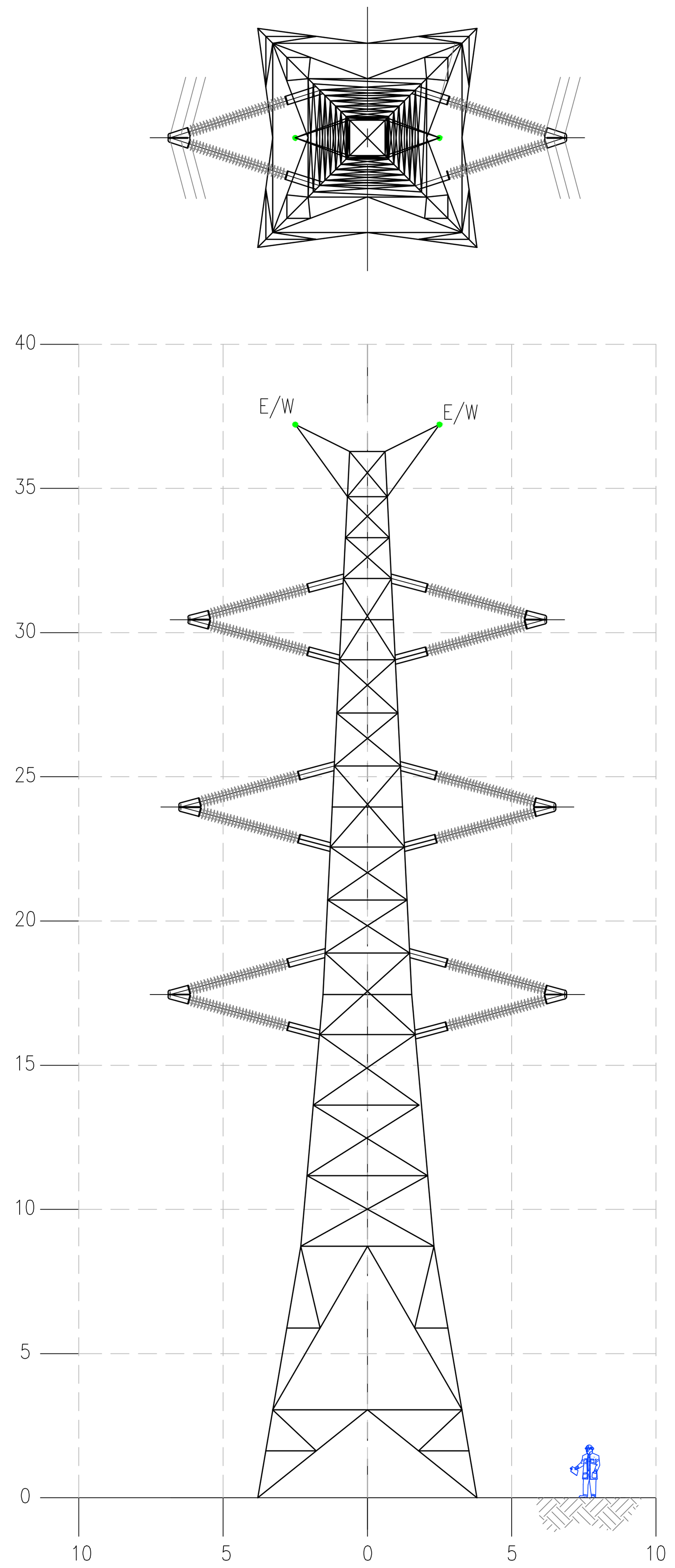
SCALE	NTS
ELEC FORM	DWG
SHT SIZE	A1

1



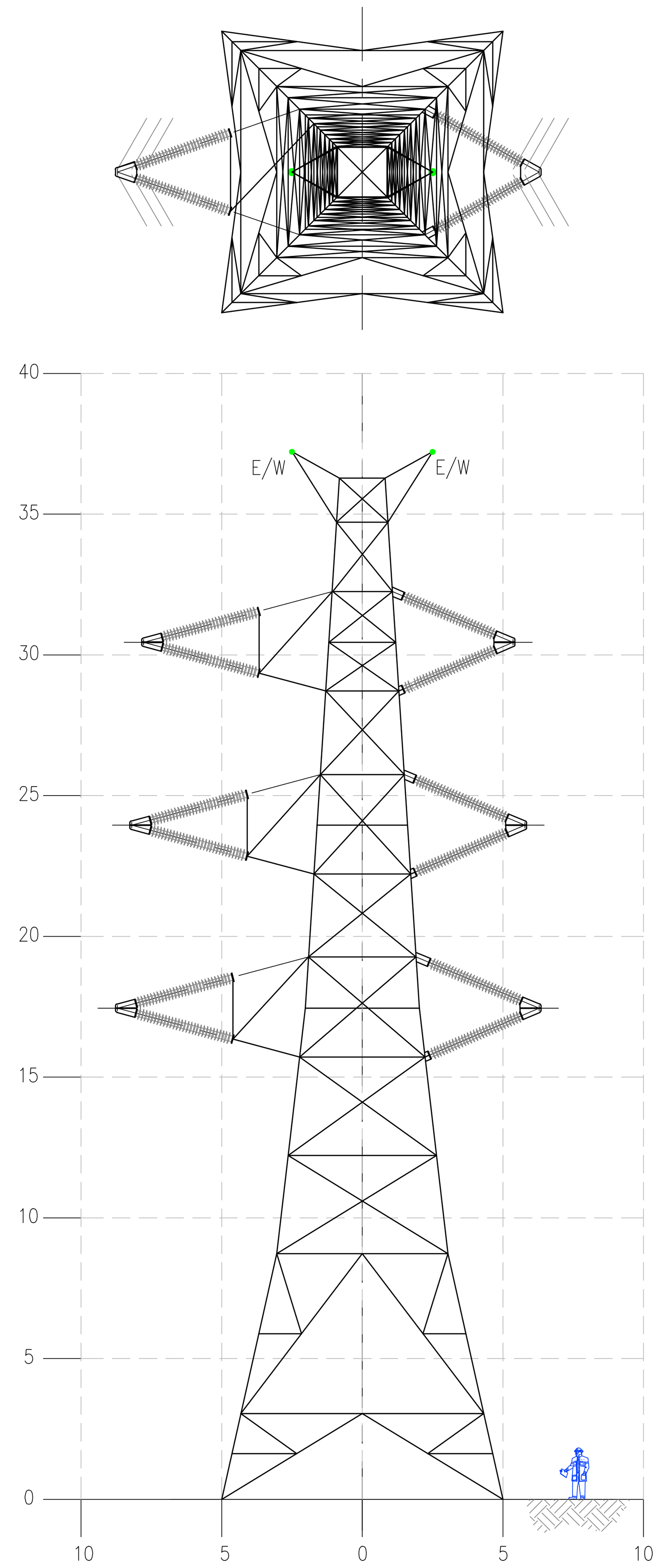
TRANSVERSE ELEVATION

LT-6-D, LATTICE STEEL SUPPORT
3 CROSSARM -ICA, INTERMEDIATE (D)
90SS545-OGA-572 (300m Nominal Span)



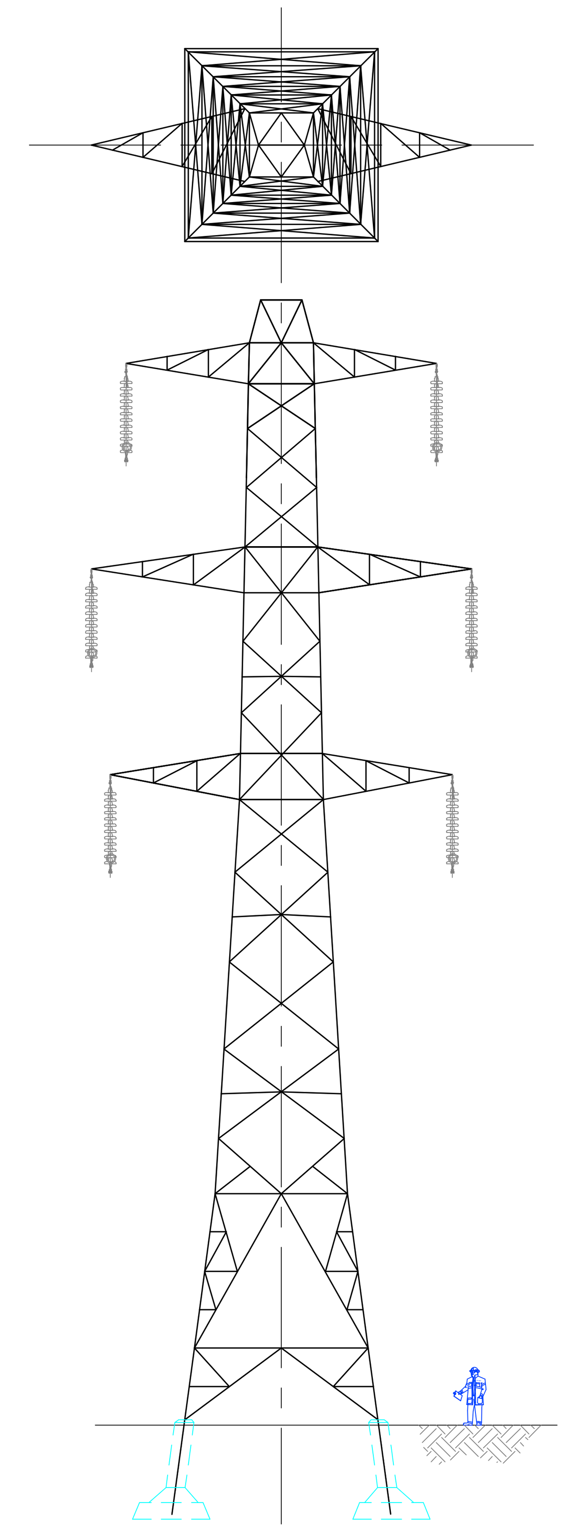
TRANSVERSE ELEVATION

LT-6-D30, LATTICE STEEL SUPPORT
3 CROSSARM - ICA, TENSION D30 (& D10)
90SS545-OGA-574 (300m Nominal Span)



TRANSVERSE ELEVATION

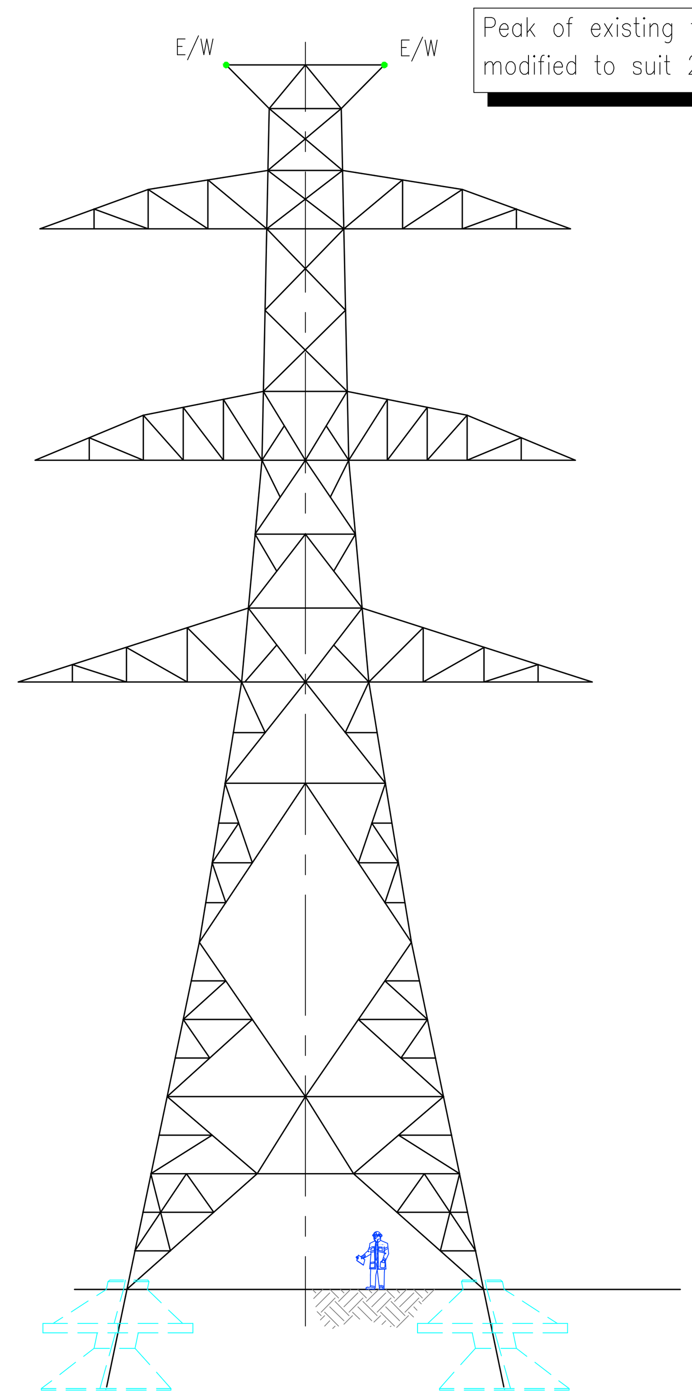
LT-6-D60, LATTICE STEEL SUPPORT
3 CROSSARM -ICA, ANGLE (D60)
90SS545-OGA-575 (300m Nominal Span)



TRANSVERSE ELEVATION

L8C RD M4.9 SUSPENSION TOWER
275kV
SHOWN FOR COMPARISON ONLY

Peak of existing tower design to be modified to suit 2 No earthwires



EXISTING SPCIFICATION FOR TERMINAL TOWERS
TRANSVERSE ELEVATION
(e.g L3C DT STD BK MT1120 TERMINAL TOWER)

ISSUE	DATE	REVISION	DRAWN	CHK'D	APP'D
1	24:06:15	Issued for discussion	JP	JS	MDL

energyline
YORK HOUSE, 9 YORK PLACE, KNARESBOROUGH HG5 0AD
TEL: 01423-799950

TITLE
LATTICE STEEL SUPPORTS 3 CROSSARMS

ROUTE / CIRCUIT
NEW 275kV SUPPORT PROJECT

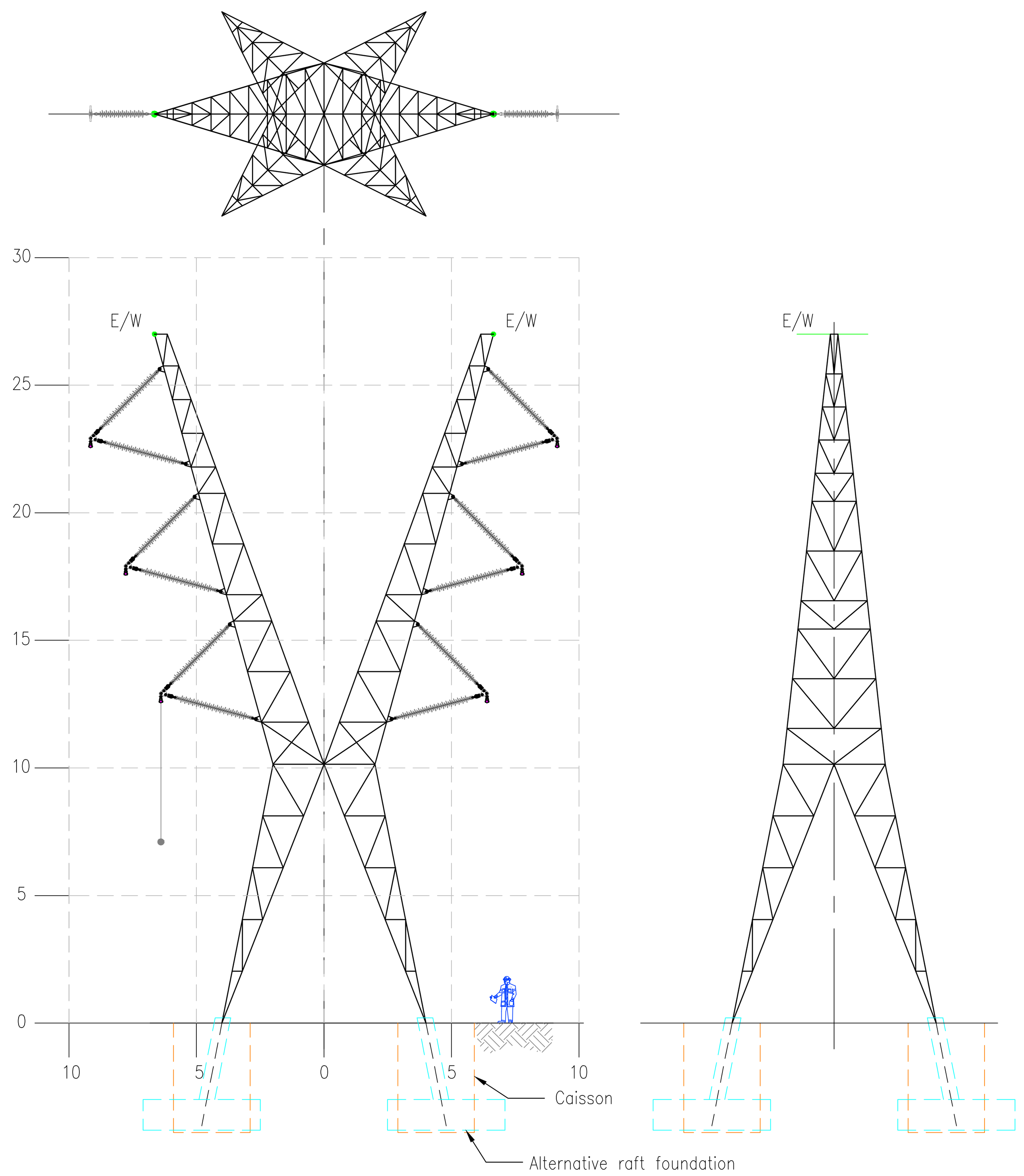
ENERGYLINE PROJECT / DRG No.: 90SS545-OGA-571
SHT No.: 1
No. OF SHTS: 1

CLIENT: Scottish and Southern Energy Power Distribution
CLIENTS PROJECT REF.: *

CLIENTS DRG No.: *

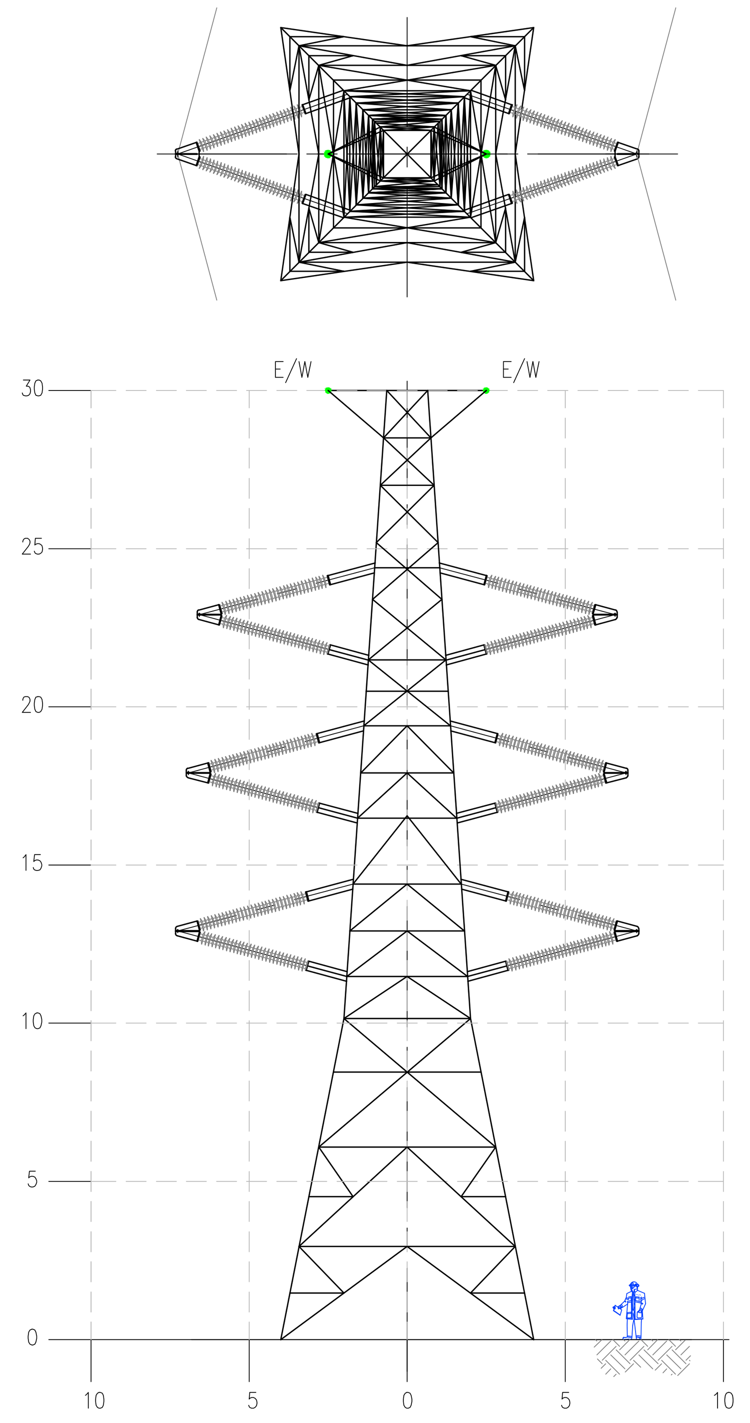
SCALE: NTS
ELEC FORM: DWG
SHT SIZE: A1

1



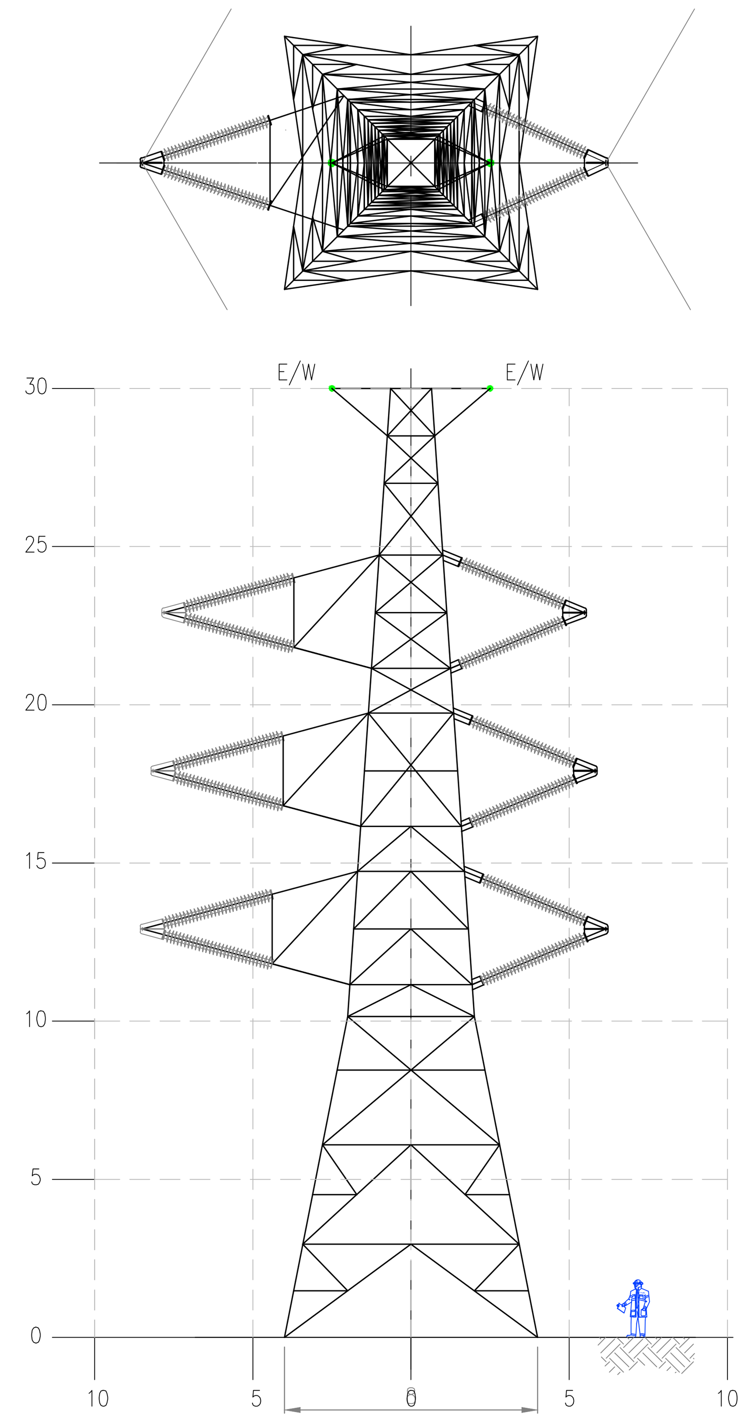
TRANSVERSE ELEVATION

LT-7-D, LATTICE STEEL SUPPORT
2 ARM V – ICA, INTERMEDIATE (D)
90SS545-OGA-582 (200m Nominal Span)



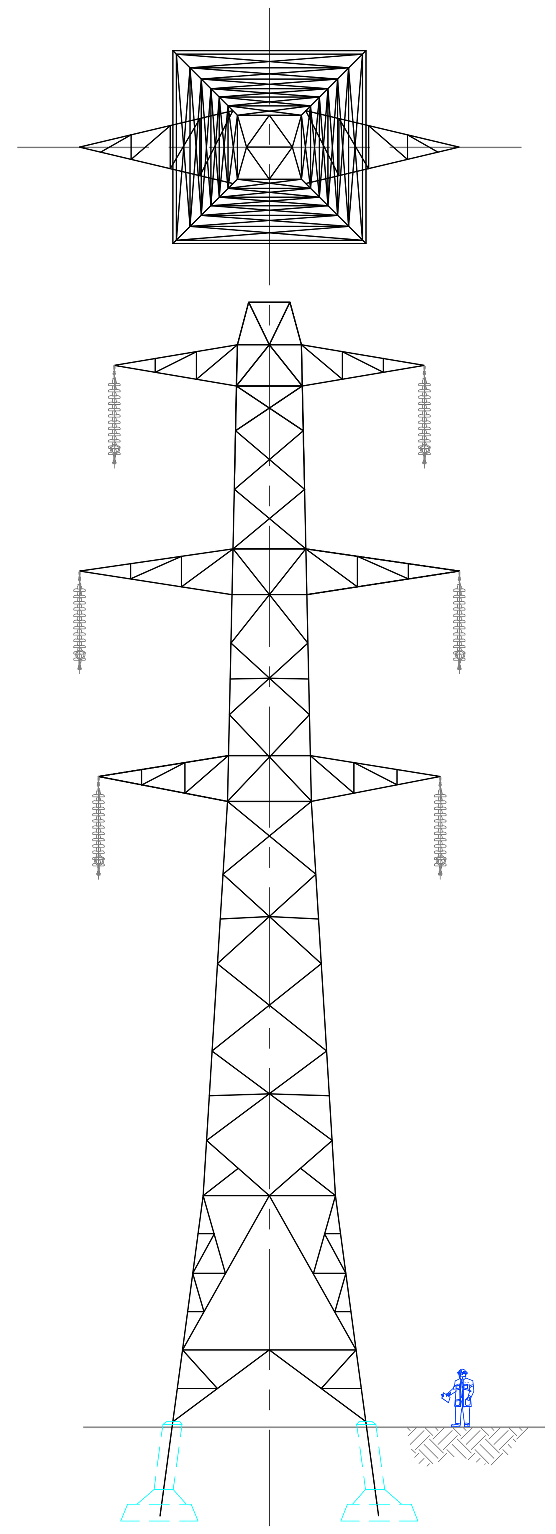
TRANSVERSE ELEVATION

LT-7-D30, LATTICE STEEL SUPPORT
2 ARM V – ICA, INTERMEDIATE D30 (& D10)
90SS545-OGA-584 (200m Nominal Span)



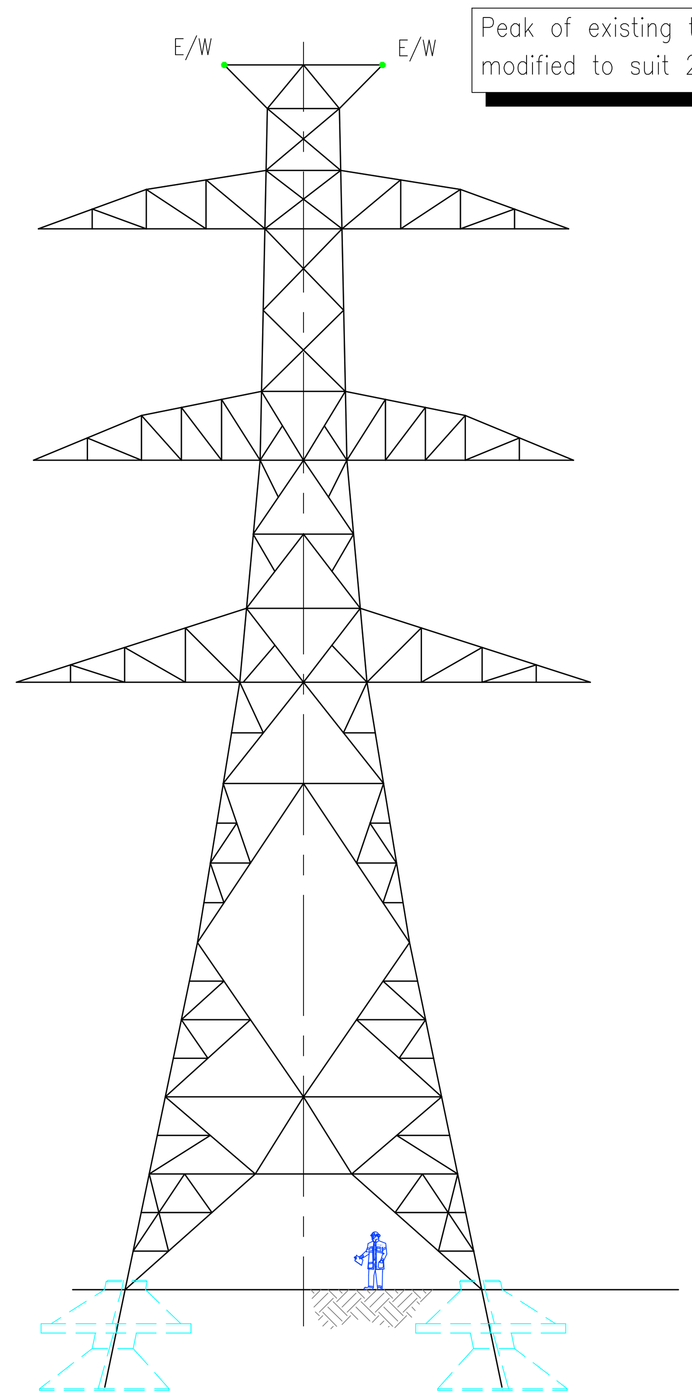
TRANSVERSE ELEVATION

LT-7-D60, LATTICE STEEL SUPPORT
2 ARM V – ICA, INTERMEDIATE D60
90SS545-OGA-585 (200m Nominal Span)



TRANSVERSE ELEVATION

L8C RD M4.9 SUSPENSION TOWER
275kV
SHOWN FOR COMPARISON ONLY



Peak of existing tower design to be modified to suit 2 No earthwires

EXISTING SPCIFICATION FOR TERMINAL TOWERS
TRANSVERSE ELEVATION
(e.g L3C DT STD BK MT1120 TERMINAL TOWER)

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YORK HOUSE, 9 YORK PLACE, KNARESBOROUGH HG5 0AD
TEL: 01423-799950

TITLE
LATTICE STEEL SUPPORT 4 INSULATED CROSSARMS

ROUTE / CIRCUIT
NEW 275kV SUPPORT PROJECT

ENERGYLINE PROJECT / DRG No.	SHT No.	No. OF SHTS
90SS545-OGA-581	1	1

CLIENT	CLIENTS PROJECT REF.
Scottish and Southern Energy Power Distribution	*

CLIENTS DRG No.	
*	SCALE NTS
	ELEC FORM DWG
	SHT SIZE A1

1

APPENDIX D – PHOTOMONTAGES


510 Series
Tower Type D, 200m Span
Single Pole, 3 Insulated Crossarms
Illustrated in Upland landscape (Corriegarth).
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520 Series
Tower Type D, 200m Span
2 Poles, 3 Crossarms
Illustrated in Upland landscape (Corriegarth).
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530 Series
Tower Type D, 200m Span
Multi-pole, 2 Single Poles, 3 Crossarms
Illustrated in Upland landscape (Corriegarth).
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540 Series
Tower Type D, 200m Span
2 Tubular Crossarms
Illustrated in Upland landscape (Corriegarth).
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550 Series
Tower Type D, 200m Span
Multi-pole, 2 Single Poles, 3 Insulated Crossarms
Illustrated in Upland landscape (Corriegarth).
energyline


560 Series
Tower Type D, 200m Span
Multi-pole, 2 Poles, 2 Tubluar Crossarms
Illustrated in Upland landscape (Corriegarth).
energyline


570 Series
Tower Type D, 300m Span
Lattice Steel, 3 Insulated Crossarms
Illustrated in Upland landscape (Corriegarth).
energyline


580 Series
Tower Type D, 200m Span
Lattice Steel, 2 Arm V, Insulated Crossarms
Illustrated in Upland landscape (Corriegarth).
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APPENDIX E – KEY DOCUMENTS

Table E1 – Electrical (E) Key Documents

Title	Code/ Publication
Overhead electrical lines exceeding AC 1 kV. General requirements. Common specifications	BS EN 50341-1:2012
Overhead electrical lines exceeding AC 45 kV. Set of National Normative Aspects	BS EN 50341-3:2001
Insulation co-ordination. Application guide	BS EN 60071-2:1997
Protection against lightning. Risk management	BS EN 62305-2:2012
Application of Clearances to Overhead Lines at LV to 400kV	PR-PS-340
Current Ratings for Overhead Lines	TGN€ 026
Ratings and Requirements for Plant, Equipment and Apparatus	TS 1
Generic Design Principles for a New Overhead Line	TS 2.27
Technical and Operational Characteristics of the Transmission System	CI 01
DESIGN GUIDE AND TECHNICAL SPECIFICATION FOR OVERHEAD LINES ABOVE 45 kV	43-125
Tower top geometry.	Cigre TB 048
Guide to procedures for estimating the lightning performance of transmission lines.	Cigre TB 063
Guidelines for Insulation Coordination in Live Working	Cigre TB 151
Tower Top Geometry and Mid Span Clearances	Cigre TB 348
A Compact 420kV line utilising line surge arresters for areas with low isokeraunic levels	22/33/36-08
Application of Clearances to Overhead Lines at LV to 400kV	PR-PS-340
EMF Guidelines (up to 300GHz) 1998	N/A
J. F. Nolasco, P. Nefzger, U. Kaintzyk, *Overhead Power Lines, Planning, Design Construction*	

Table E2 – Mechanical & Electrical (M) Key Documents

Title	Code/ Publication
Silicone Composite Insulators, Materials, Design, Applications.	ISBN 978-3-642-15319-8
Validation of Composite Cross-Arms for XCN-XCS:132 kV Installation: December 2013	Arago Technology Report 3/3/14, Rev 3.2
Insulator Crossarms for 345-KV EHV Transmission Line	IEEE Transactions on Power Apparatus and Systems, VOL. PAS-90, No.2,
Narrower Transmission Corridors Made Possible with New Compacted Conductor	Cigre WG 22-06
Improved wind model to verify the stability of Wintrack braced post-insulator sets Session 2014.	Cigre B2_110
Examples of Transmission Line Tower Configurations and Solutions such as 765 kV insulated Cross Arms to minimize the Impact of new EHV Lines. 2014	Cigre B2-106
Guide for Braced Insulator Assemblies for Overhead Transmission Lines 60kV and Greater	IEEE
Development of a compact bipole 380kV overhead line. 2010.	Cigre B2_112_2010
Structural advantage of using V-strings	Powline
Overhead Power Lines; Planning, Design, Construction	Kiessling

Title	Code/ Publication
Overhead Electrical Lines Exceeding AC 1kV Part 1: General Requirements – Common Specifications	BS EN 50341-1
Overhead Electrical Lines Exceeding AC 45kV Part 3: Set of National Normative Aspects	BS EN 50341-3-9
Design guide and technical specification for overhead lines above 45kV	ENA-TS-43-125
Generic Design Principles for a new overhead line	TS 2.27
Composite Insulators for Overhead Lines	TS 3.04.18
Insulator Sets for Overhead Lines	TS 3.04.17
Overhead Lines: Cigre Green Book	Cigre 2014

Table E3 – Supports & Foundations (S) Key Documents

Title	Code/ Publication
Design Criteria of Overhead Transmission Lines	IEC 60826
Overhead Electrical Lines Exceeding AC 1kV Part 1: General Requirements – Common Specifications	BS EN 50341-1
Overhead Electrical Lines Exceeding AC 45kV Part 3: Set of National Normative Aspects	BS EN 50341-3-9
Design guide and technical specification for overhead lines above 45kV	ENA-TS-43-125
Generic Design Principles for a new overhead line	TS 2.27
Lattice towers and masts. Code of practice for loading Code of practice for loading	BS 8100-1:1986
Lattice towers and masts. Guide to the background and use of Part 1 'Code of practice for loading'	BS 8100-2:1986
Lattice towers and masts. Code of practice for strength assessment of members of lattice towers and masts	BS 8100-3:1999
Lattice towers and masts. Code of practice for loading of guyed masts	BS 8100-4:1995
Specification for Single Circuit Overhead Lines on Wood Poles for use at 132kV	43-50
Stay strands and stay fittings for overhead lines	43-91
Code of practice for strength assessment of members of lattice towers and masts	DD 133:1986
Design of Latticed Steel Transmission Structures	ASCE 10-97
Recommendations for angles in lattice transmission towers	ECCS 39
Eurocode 7. Geotechnical design	BS EN 1997
Structural timber. Wood poles for overhead lines.	BS EN 14229:2010
Overhead lines. Testing of foundations for structures.	BS EN 61773:1997
Code of practice for foundations	BS 8004
Eurocode 5. Design of timber structures	BS EN 1995
Structural use of timber	BS 5268
Eurocode 3. Design of steel structures.	BS EN 1993
Structural Use of Steelwork in Building	BS 5950
Eurocode 2. Design of concrete structures	BS EN 1992:2004
Structural use of concrete	BS 8110
Electricity Association Technical Report (EATR) 111 - High Voltage Single Circuit Overhead Lines on Wood Poles (1991)	EATR 111

Title	Code/ Publication
Eurocode. Basis of structural design.	BS EN 1990:2002
Innovative Solutions for Overhead Line Supports	Cigre TB 416
Tower Top Geometry and Mid Span Clearances	Cigre TB 348

Table E4 - Construction & Maintenance (CM) Key Documents

Title	Code/ Publication
Approved Procedure for the Fitting and Removal of Additional Earths on 66, 132, 275 & 400kV Overhead Lines	PR-PS 580
Work on or near high voltage overhead lines [NGUK/PM/ETSR/NSI/04/GN Issue 5]	NSI 04
Linesman's Manual For 132, 275 and 400kV Overhead Lines	Linesman's Manual M1
National Grid Safety Rules and Guidance	NGUL/PL/ETSR/GN
Scottish and Southern Energy, Operational Safety Rules (2012)	N/A
Guidelines for Insulation Coordination in Live Working	Cigre TB 151

Table E5 – Environmental (P) Key Documents

Title	Author
Position Statement on Birds and Power lines: on the risk to birds from transmission facilities and how to minimise any such adverse effects.	BirdLife
Visual Simulation and Assessment of Electricity Transmission Towers	Bishop, I. et al.
Discourses of energy infrastructure development: a Q-method study of electricity transmission line siting in the UK	Cotton, M & Devine-Wright, P
Explaining public preferences for high voltages pylon designs: An empirical study	Devine-Wright, P & Batel, S.
National Policy Statement for Electricity Networks Infrastructure (EN-5)	DECC
Overarching National Policy Statement for Energy (EN-1)	DECC
Ecology Guidelines for Electricity Transmission Projects. A standard approach to ecological impact assessment of high voltage transmission projects	Eirgrid
Coming to terms with power lines.	Elliot, P & Wadley, D.
Protecting Birds from power lines	Haas, D et al.
Automated mapping of visual impacts in utility corridors.	Hadrian, D. et al.
Poles & Structures Transmission Structures As Landscape Art Artistic and Structural design are blended to create a visually appealing transmission line	Nieminen, K et al.
High voltage overhead lines. Environmental concerns, procedures, impacts and mitigations	CIGRE Brochure 147
Aesthetics and Public Perception of Transmission Structures	EPRI
Public acceptance for new transmission overhead lines and substations.	Eurelectric
The future of Britain's electricity networks	HMSO
Beauly to Denny Overhead Transmission Line, Assessment of the Stirling Visual Impact Mitigation Scheme	Ironside Farrar Ltd & University of Newcastle
Environmental Impact of Transmission Lines.	Public Service Commission of Wisconsin
Proposed Beauly to Denny 400kV Overhead Transmission Line: Review of Bird Collision & Power Lines	Scottish Government

The backclothing of wind turbines in the Scottish landscape. A report to the Cairngorms National Park Authority	Stanton, C.
Overhead transmission tower study	Turnbull, M & McAulay, I / SSE