Mechanical Design and Testing of a High Strength Composite Insulated Cross Arm

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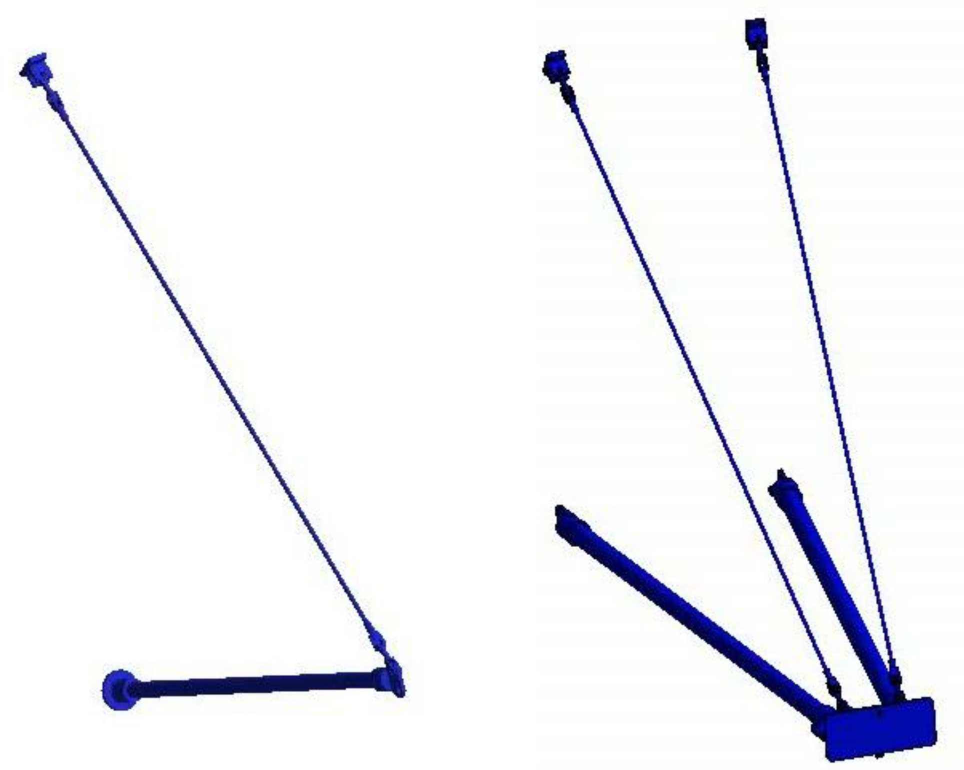
Three Dimensional High Strength Insulated Cross-arms

- Traditional BLP (pivoting and non-pivoting) are recognized solutions for line compaction
- Non-pivoting BLP have limited longitudinal load withstand capabilities which can hinder application
- Wind stability considerations are critical for pivoting type BLP
- Three dimensional high strength insulated cross-arm can overcome these limitations and resist high (longitudinal) loads



Stress and deformation in BLP and Double Vee Composite Insulated Cross-arm under the same load set

In-service High Strength Composite Insulated Cross-arms

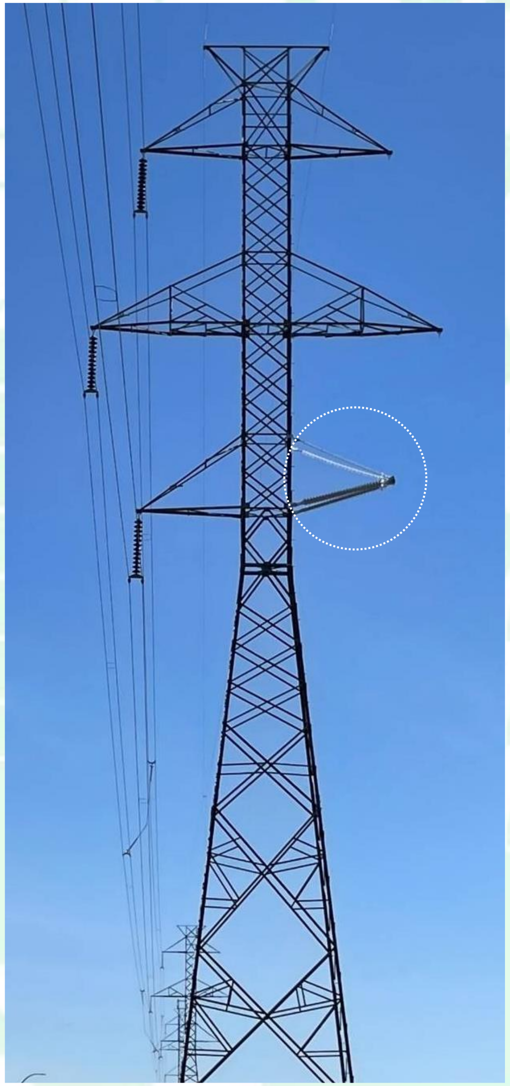
750 kV EHV AC

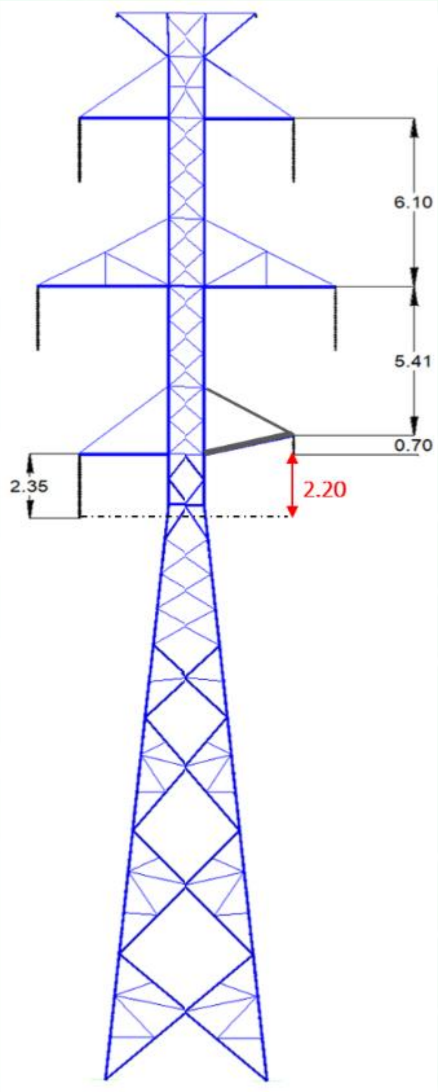
±800 kV UHV DC

1000 kV UHV AC

Application Details

- Retrofitting of existing 230 kV tower with insulated cross-arm for ground clearance mitigation
- Increase in ground clearance by 2.2 m without elevating the tower
- Cost effective, less disruptive and easier to implement compared to other alternatives
- Minimal modification of the existing tower and hardware
- Other uses: use with monopoles that require more capacity than typical BLP, overcoming RoW constrictions and thermal uprating



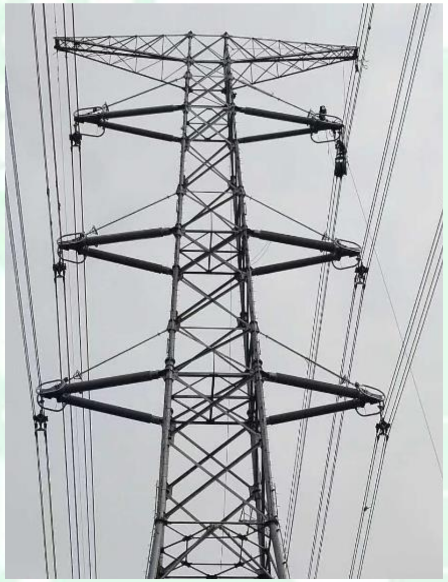


Ground clearance or allowable sag increase with insulated cross-arm retrofit

Mechanical Design Requirements – Cross Arm Configuration

- Three common configurations of spatial insulated cross-arms
- Selection of optimal configuration considers withstand loads, cost, weight and design of tower structure
- Double Vee configuration chosen to keep tower and hardware modifications at a minimum and retain the same reaction force pattern

Tetrahedron



Tripod

Double Vee

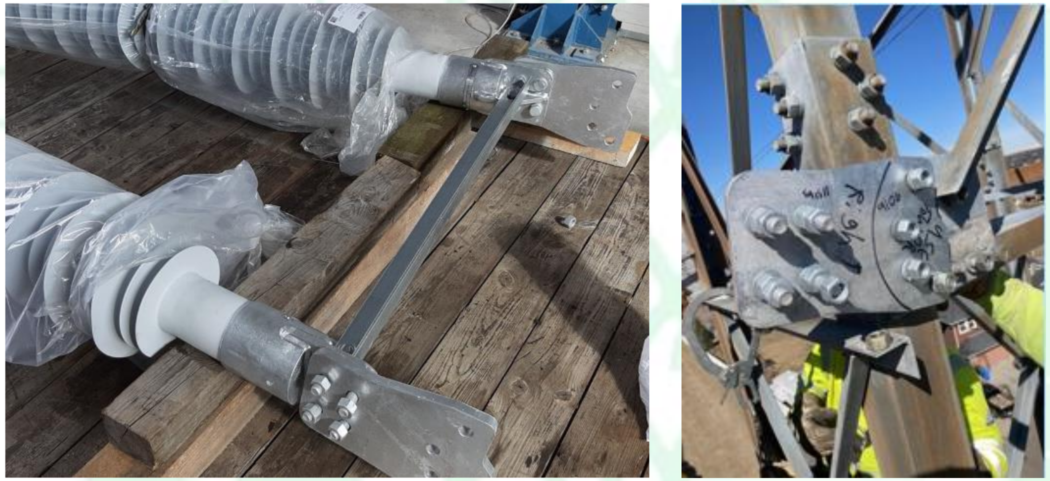
Design Requirements – Connection & Suspension Hardware

- Vertically aligned blade end fitting of the line post connected to plate attached to the tower body

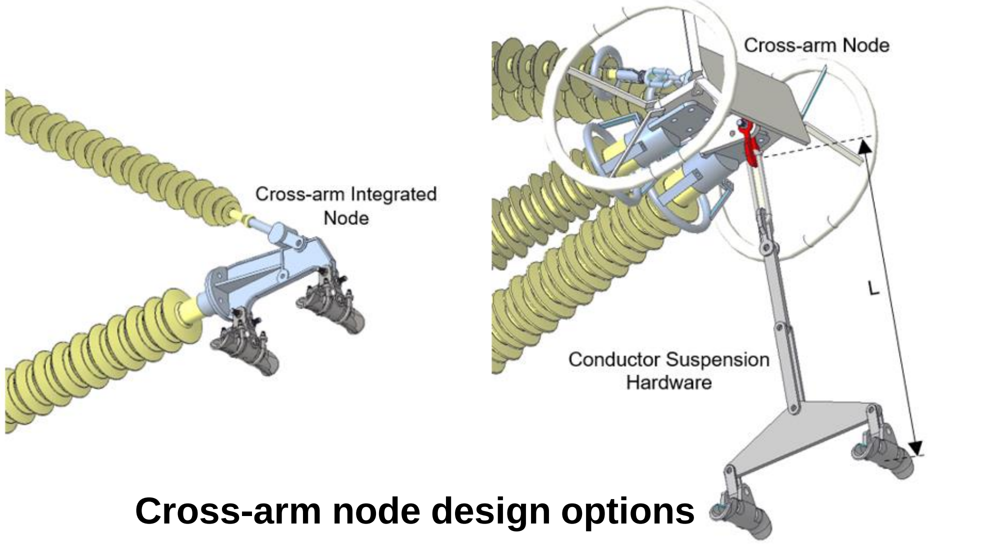
- Conductor bundle suspended through a freely swinging hardware assembly of 700 mm to provide longitudinal load alleviation:

LONGITUDINAL LOAD

Suspension Hardware Length (mm)	**Unsymmetrical Ice Condition** (N)
1800	2617
900	5642
700	7400
450	12260



Connection of insulated cross-arm with tower



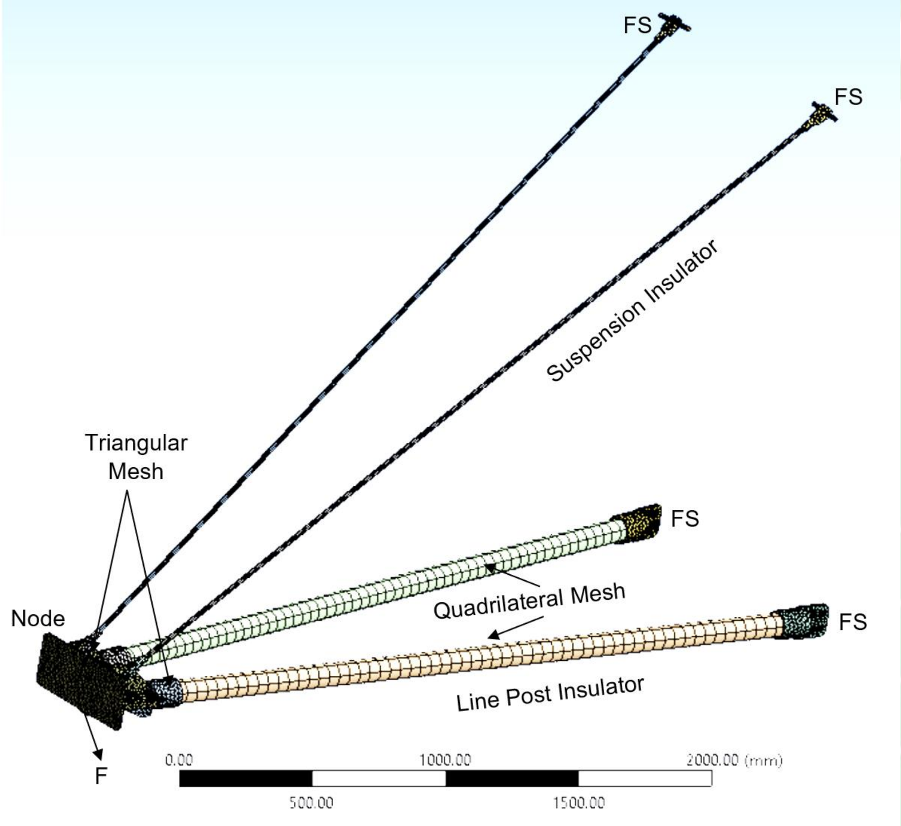
Cross-arm node design options

FEA Simulations – Model Setup

- Some 3D model simplifications are made to make analysis more efficient

- Use of bonded interface between FRP and end fittings, representative degrees of rotational freedom of hardware fittings and bolts modelled as beam elements

- Boundary conditions: Force (F) and Fixed Support (FS)

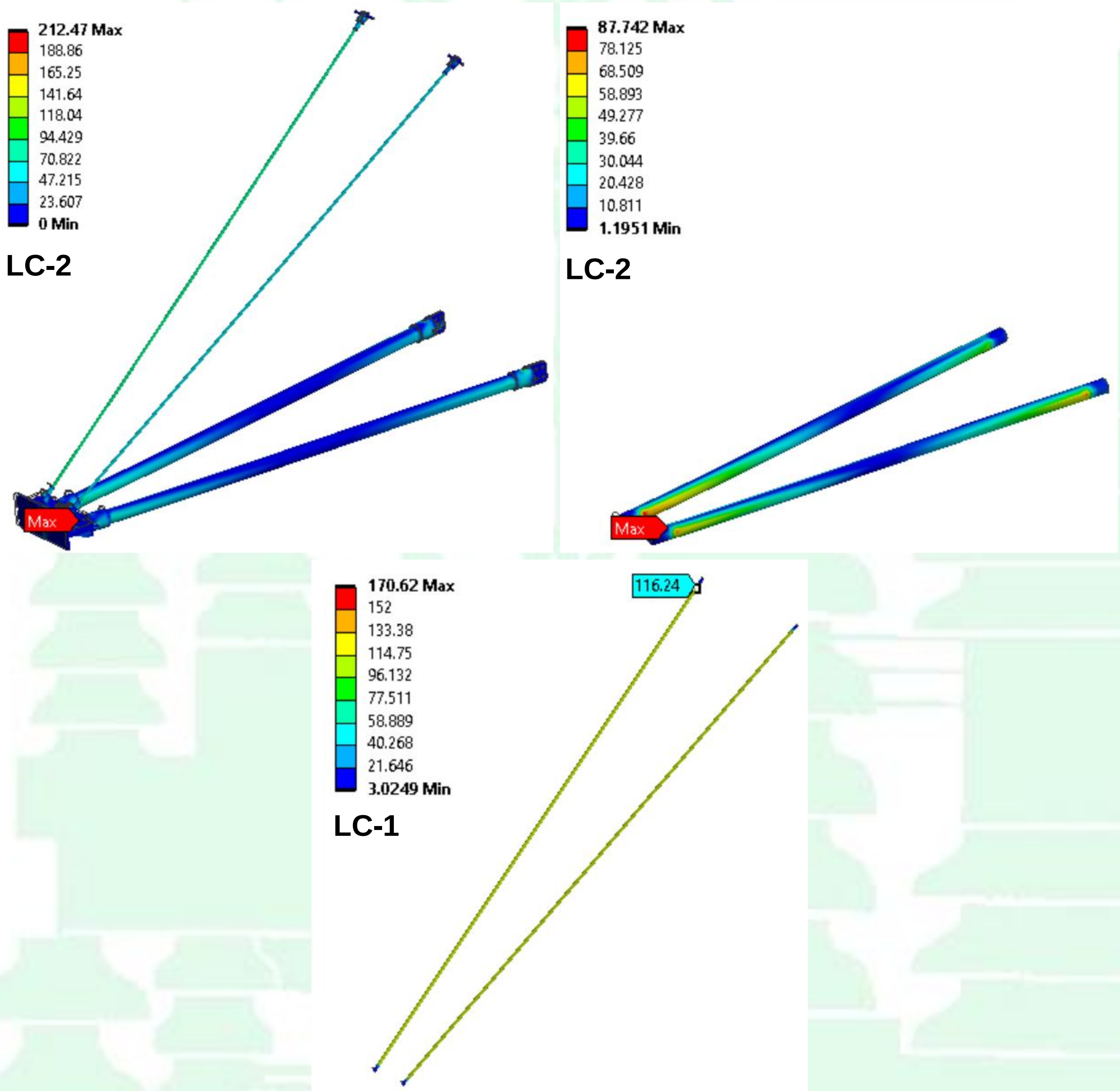


DESIGN LOAD CASES (divided into Repeatable and Security cases)

Load Case	Condition	Vertical (kN)	Transverse (kN)	Longitudinal (kN)	Overload Factor	Strength Factor
LC-1	Ice	22.3	0	0	1.66	0.5
LC-2	Ice & Unbalanced Tension	22.3	0	17.8	1.0	1.0
LC-3	Wind	9.2	10.8	0	1.66	0.5
LC-4	Wind & Un-balanced Tension	9.2	10.8	17.8	1.0	1.0
LC-5	Ice & Wind	29.0	16.1	0	1.3, 1.25	0.5

FEA Simulations – Results and Sizing

- LC-2 resulted in the highest stress and compression load (85 kN) on the post insulator
- LC-1produced the highest tension load (33 kN) on the brace insulator
- Bending stresses on the post insulator are low and it’s sizing is controlled by the required SCoL (170 kN)
- Brace insulators are articulated at either ends with suitable fittings to provide two rotational degrees of freedom, their sizing involves the selection of the suitable SML



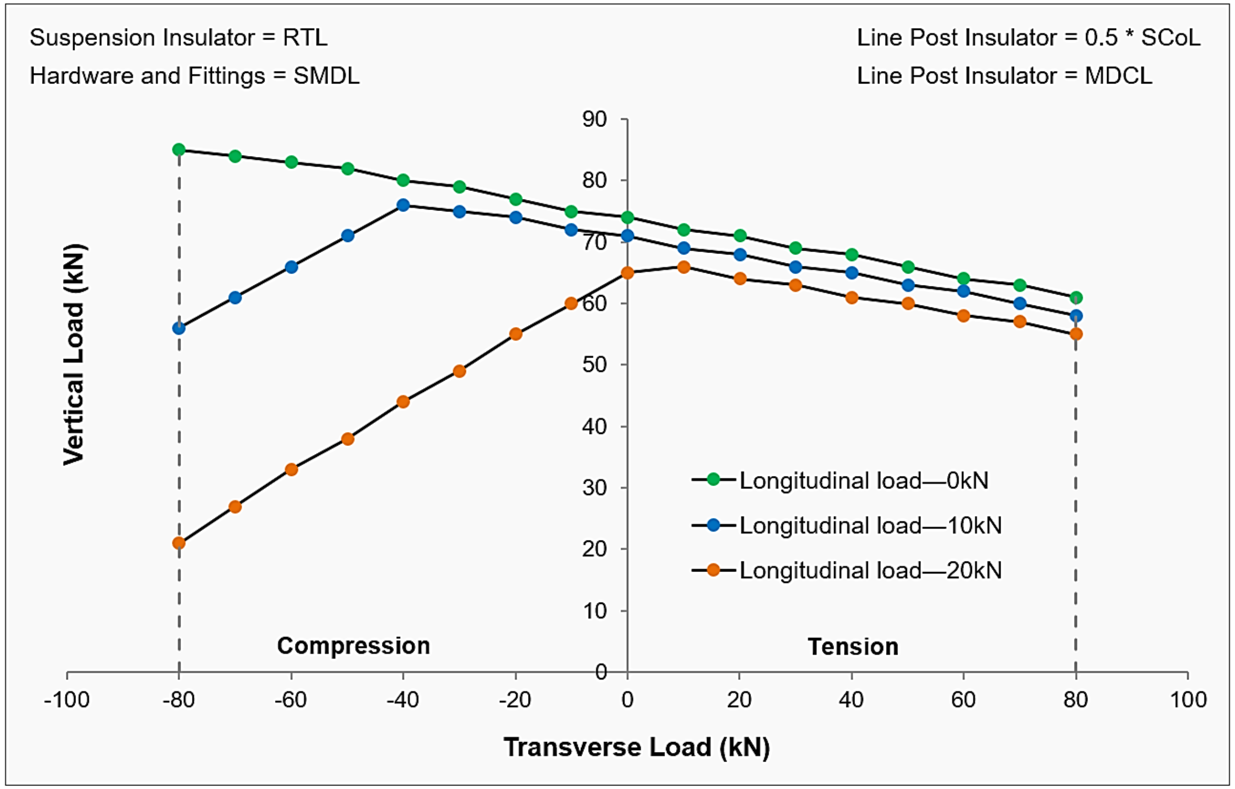
Stress distribution of crossarm (units: MPa)

LC-1 Ice
LC-2 Ice & Unbalanced Tension

FEA Simulations – Combined Load Curves

- The cross-arm is mechanically rated as 'system'
- Derivation of working load curves of 3-dimensional cross-arms is more complicated than BLP
- Formulation of curves considers capabilities and strength of the following:

- Stresses in the insulator FRP cores (SCL & SML)
- Buckling stability of line post insulator (SCoL)
- Strength of bolted connections (Shear etc.)
- Rating of hardware fittings (SMDL)



Combined 'working' load interaction diagram of double Vee composite insulated cross-arm

Development of Test Plan

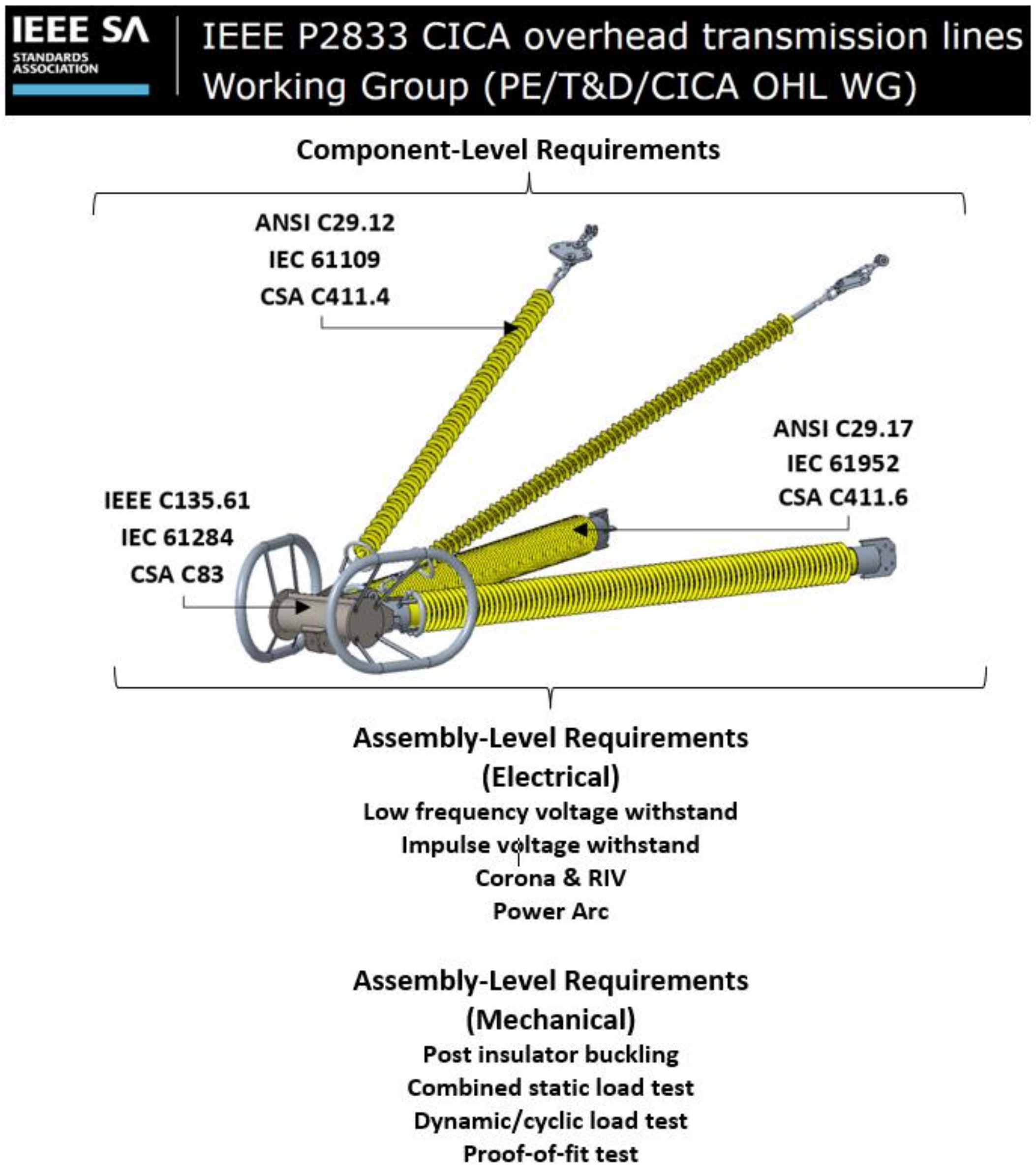
- Currently, no international standards or guides cover mechanical testing of insulated crossarms (incl. BLP)

- Objectives of mechanical testing:

- Confirm buckling capacity of post insulator
- Subject the crossarm assembly to the most critical LC
- Confirm the integrity of insulator end fittings under cyclic loading conditions

- The following tests were selected:

- Static Load Test 1: Post insulator ultimate capacity test
- Static Load Test 2: Assembly combined load test
- Cyclic Load Test 1: Post insulator 2 Hz high cycle test
- Cyclic Load Test 2: Assembly 0.03 Hz low cycle test



Static Load Tests – Post Ultimate Compression Capacity

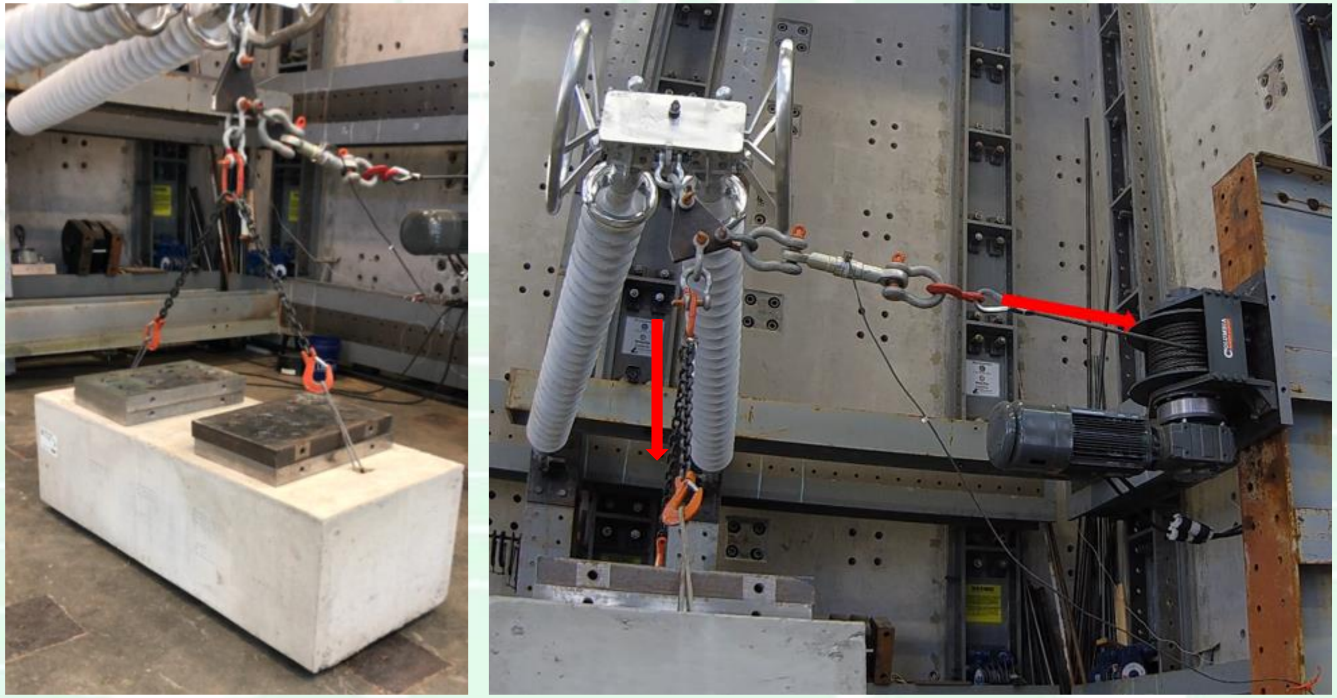
- Simulated end conditions: fixed-pinned
- Three samples tested to confirm the SCoL of 170 kN
- Predicted UlCoL equal to 250 kN based on Euler equation and FRP core diameter of 90 mm
- Test results:

- Iteration 1: 59.4 kip (266 kN) = 157% of target
- Iteration 2: 56.9 kip (255 kN) = 150% of target
- Iteration 3: 66.6 kip (299kN) = 176% of target

Post insulator ultimate compression capacity test

Static Load Tests – Assembly Combined Load Test

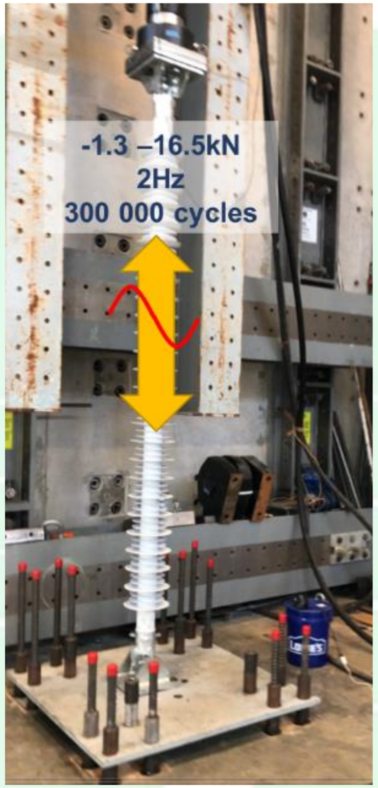
- FEA simulations showed LC-2 as the most demanding condition
- Vertical applied with free hanging weight and longitudinal load with a hydraulic winch
- Test results:
- Failure at 49.9 kN longitudinal load (175%)
- Shear failure of bolts connecting the post insulator to the node

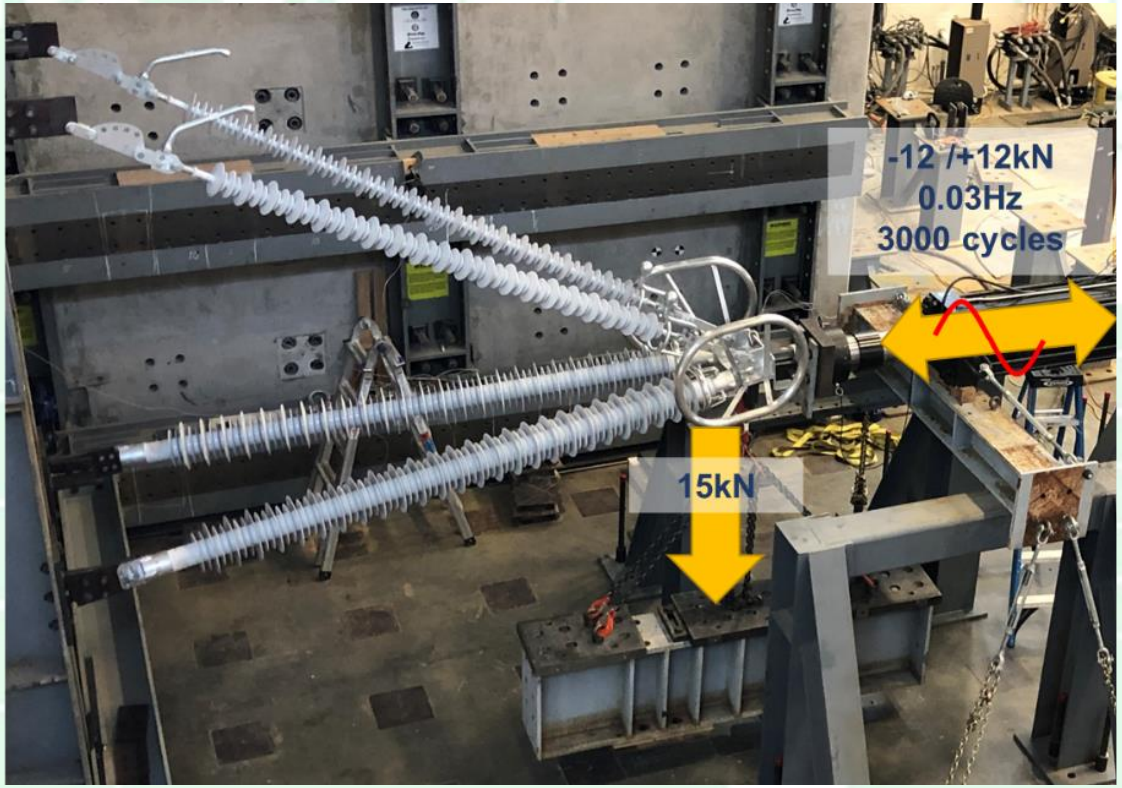


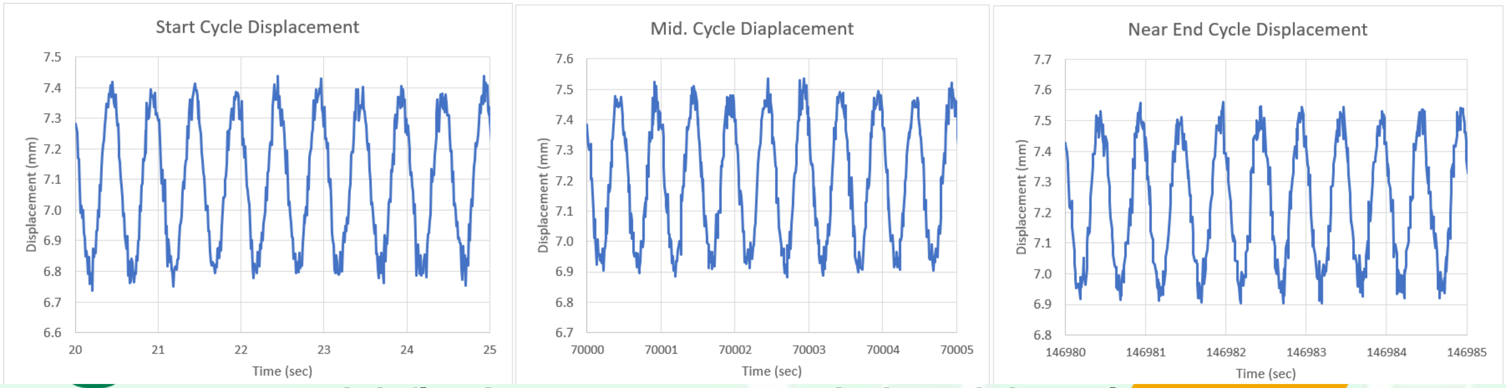
Cross-arm assembly combined static load application

Strength Coordination	**Vertical Load** (kN)	**Transverse Load** (kN)	**Longitudinal Load** (kN)	**% of Ultimate Target**
Damage limit	Not specified			
Ultimate limit hold point	-22.3	0.0	17.8	100%
Ultimate limit	-22.3	0.0	26.7	150%

Cyclic Load Tests – Setup and Post Test Evaluation







End deflection measurements during High Cycle Test

Slippage measurements before and after Cyclic Test

Conclusions

- Insulated cross-arms are a proven solution for modern line compaction and upgrading
- Three-dimensional high strength insulated cross-arm overcome the mechanical load limitations of traditional BLP
- Mechanical design of insulated cross-arm takes into account the damage and ultimate limit considerations of the composite material and relies on FEA simulations
- Testing of multi-component insulation arrangements is an essential part of insulator development where identified weak points and analysis of failure modes lead to improved designs
- Full-scale static and cyclic load tests are vital to provide the necessary validation of mechanical performance of the insulated cross-arm