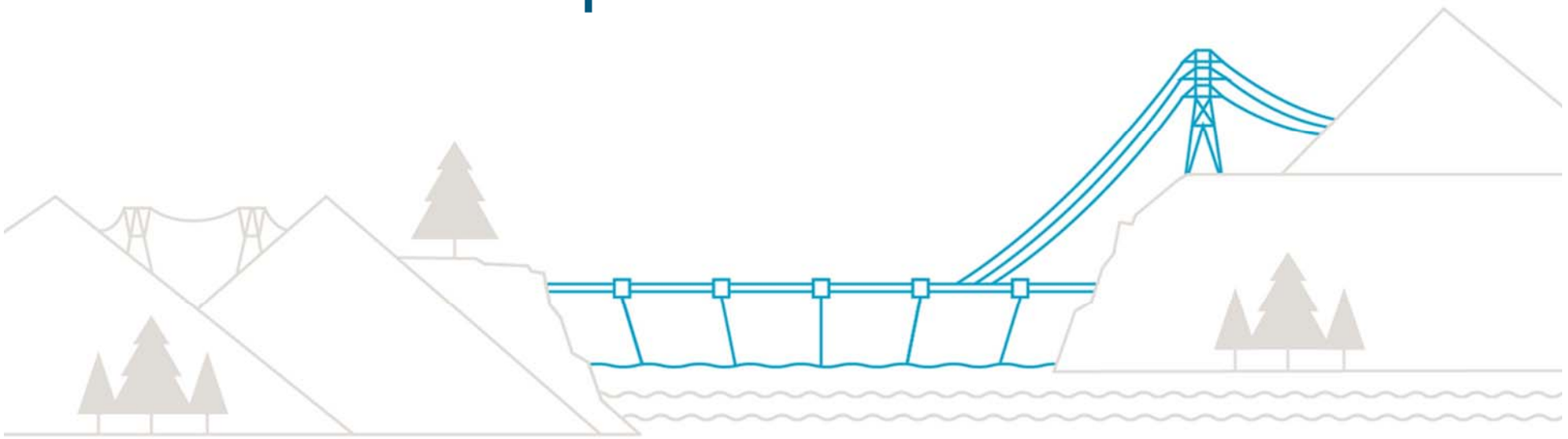
Full-scale testing of 230kV FRP poles



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Content

- Purpose
- FRP poles applications at BC Hydro
- Collaboration
- Testing facility
- FRP pole assembly & installation
- H-frame load cases & pole deflections
- H-frame hardware failure investigation
- H-frame pole failure
- Dead-end load case & pole deflection
- Conclusions

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Purpose

Compare full-scale FRP pole testing results with PLS-POLE™ simulation

- 230kV suspension structure: H-frame
- 230kV 90 degree dead-end Pole: Representing Guyed pole from 3 pole dead-end

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FRP Poles Applications

BC Hydro (BCH) uses FRP structures for the following applications on 69kV and above:

- Environmental sensitive areas (e.g. watersheds, and wetlands)
- Wildlife damage (e.g. woodpecker damage)

Reference: Intelli-pole®'s web page.

Collaboration

Funding for full scale testing: BC Hydro

FRP pole fabricator: RS poles www.rspoles.com

Testing facility: ABEINSA (subsidiary of ABENGOA) is located in Seville, Spain

Testing facility: Eucomsa

Company profile.

- Tower testing subsidiary: **Eucomsa**
- Abengoa: www.abengoa.com
- Abengoa is a Spanish multinational corporation, which includes companies in the domains of energy (solar panels), telecommunications, transportation, and the environment.
- Founded: 1941
- Headquarters: **Seville, Spain**
- 7,151M€ sales, 24,306 employees
- Eucomsa: Design, testing & fabrication of towers

Reference: Abengoa's web page.

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FRP Pole Assembly & Installation

Very similar to steel pole assembly & installation

- FRP poles are fabricated in modules
- Modules can be easily nested, transported and assembled
- Installation kit consists of hydraulic jacks
- Installation kit is designed, fabricated & supplied by the FRP pole fabricator (RS Poles)

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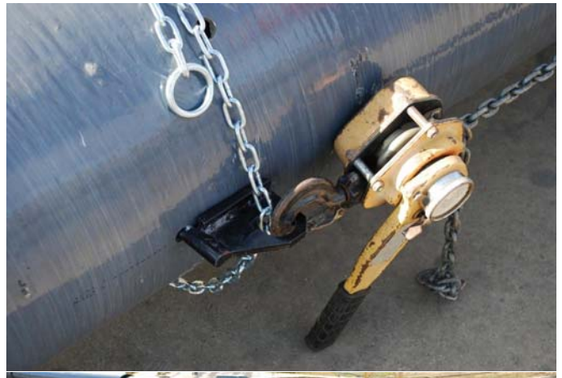
FRP Pole Assembly & Installation Continued



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H-frame Assembly

- Structure was framed on the ground
- Hardware supplied by BCH
- Hardware was adapted from existing wood pole hardware (BCH Standard 41I)
- Hardware fitting issues
- ABENGOA fabricated hardware for the FRP structures on site
- FRP pole testing schedule delays
- BCH hardware failed during H-frame testing
- Soil was not properly compacted in canisters

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H-frame Assembly Continued

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H-frame Load Cases (Loading Tree)

Load Case	Joint Label	Vertical load (N)	Transverse load (N)	Longitudinal load (N)	Maximum expected Pole Tip Deflection (cm)
LC1. Everyday Loads (Wind 95.76 Pa) (Tangent/Angle Str.),I NA+	Left	6785	2473	0	16.2
	Centre	6785	2473	0	
	Right	6785	2473	0	
	Pole-L:Wind1	0	120	0	
	Pole-L:Wind2	0	264	0	
	Pole-L:Wind3	0	1055	0	
	Pole-R:Wind1	0	120	0	
	Pole-R:Wind2	0	264	0	
	Pole-R:Wind3	0	1055	0	

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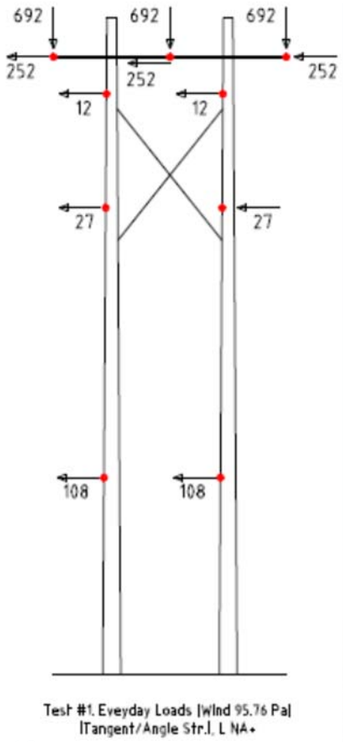
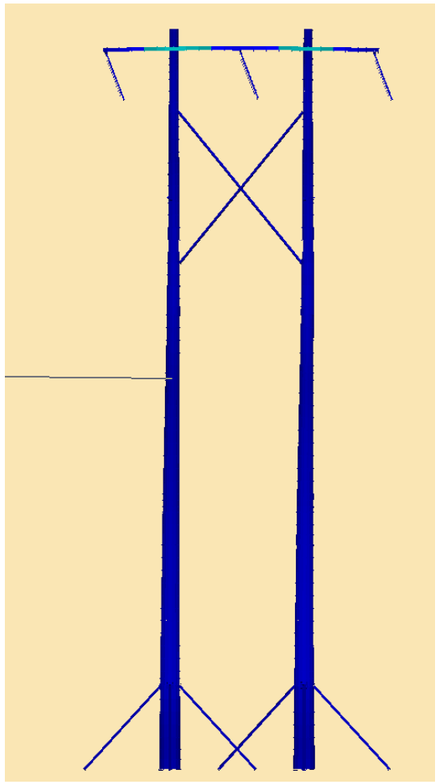
H-frame Test #1: Everyday loads





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H-frame Load Cases (Loading Tree)

Load Case	Joint Label	Vertical load (N)	Transverse load (N)	Longitudinal load (N)	Maximum expected Pole Tip Deflection (cm)
LC2. CSA Wind for ROW (Wind 230Pa) (Tangent/Angle Str.),I NA+	Left	6785	4357	0	29.7
	Centre	6785	4357	0	
	Right	6785	4357	0	
	Pole-L:Wind1	0	289	0	
	Pole-L:Wind2	0	633	0	
	Pole-L:Wind3	0	2535	0	
	Pole-R:Wind1	0	289	0	
	Pole-R:Wind2	0	633	0	
	Pole-R:Wind3	0	2535	0	

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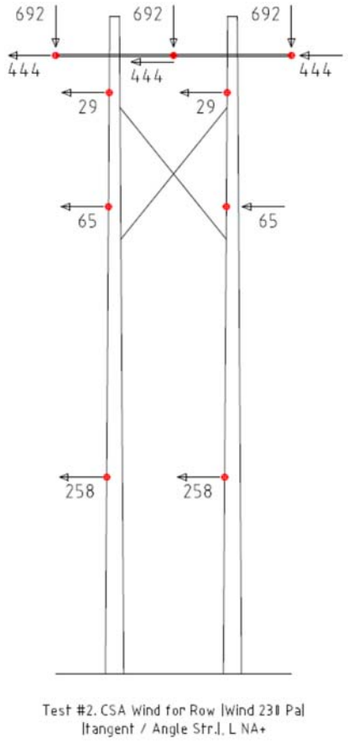
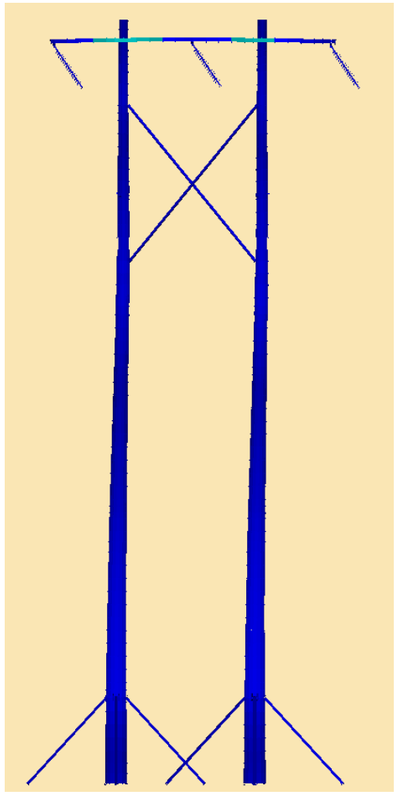
H-frame Test #2: CSA Wind for ROW



Test #2. CSA Wind for Row |Wind 23ll Pal
|tangent / Angle Str.|. L NA+



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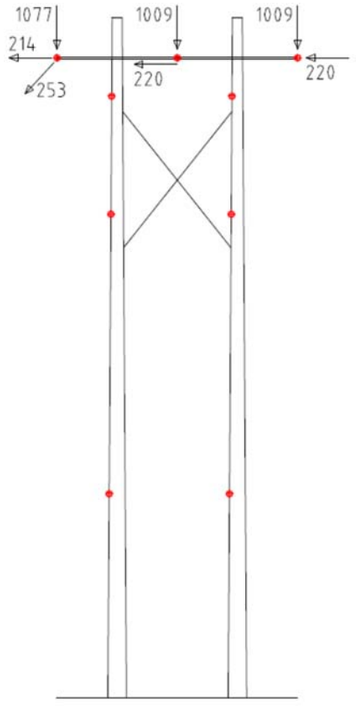
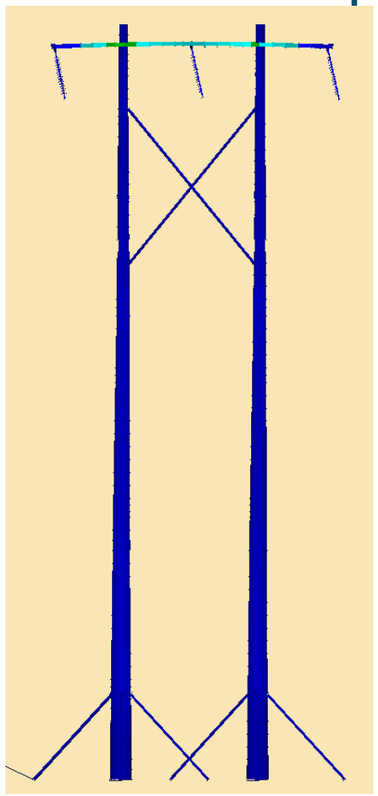
H-frame Load Cases (Loading Tree)

Load Case	Joint Label	Vertical load (N)	Transverse load (N)	Longitudinal load (N)	Maximum expected Pole Tip Deflection (cm)
LC3. Construction Tie Down Load at Left Phase,I NA+	Left	10564	2098	2478	52.7
	Centre	9903	2163	0	
	Right	9903	2163	0	
LC4. Construction Tie Down Load at All Phases,I NA+	Left	10564	2098	2478	135.4
	Centre	10564	2098	2478	
	Right	10564	2098	2478	
LC5. 3/4" Ice Only,L NA+	Left	13850	2133	0	10.5
	Centre	13850	2133	0	
	Right	13850	2133	0	

H-frame Test #3: Construction 1 ph only



Test #3, Construction Tie Down at Left Phase, L NA+



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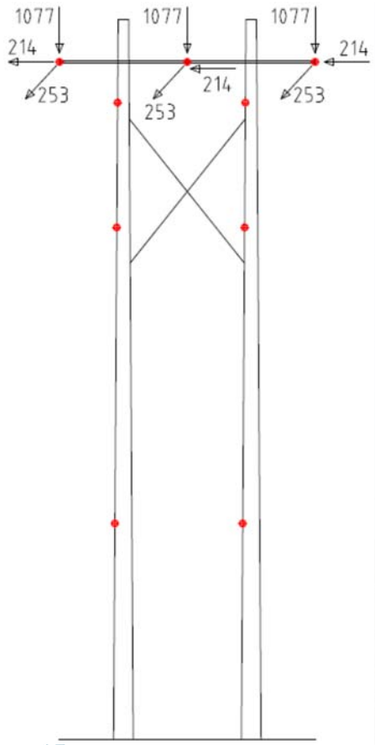
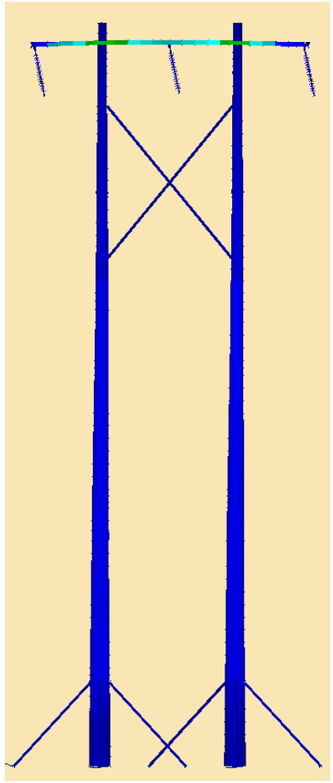
H-frame Test #4: Construction all phases





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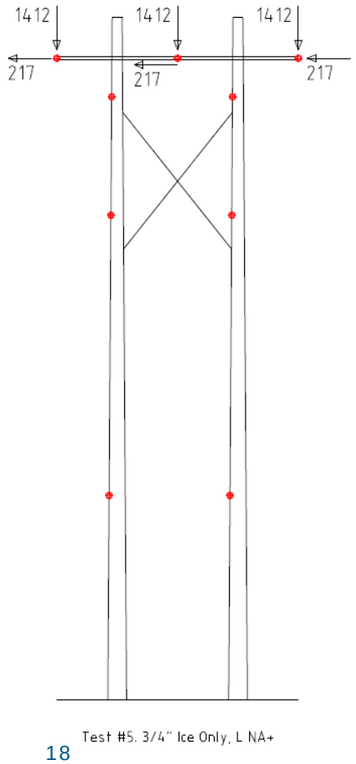
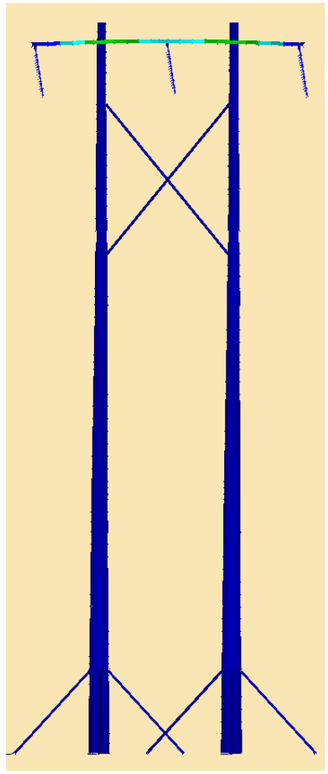
H-frame Test #5: ¾” Ice



Test #5. 3/4" Ice Only, L NA+



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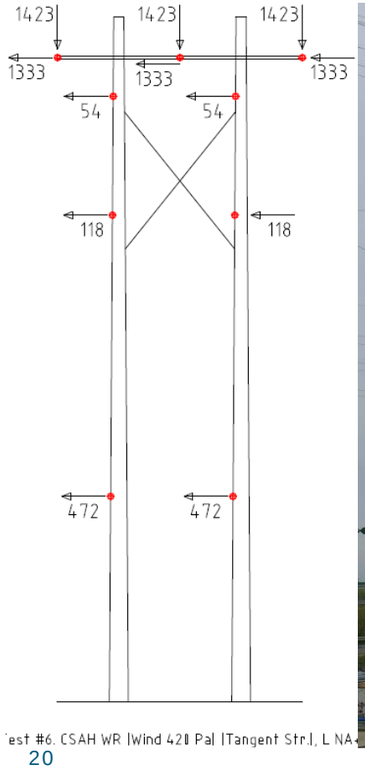
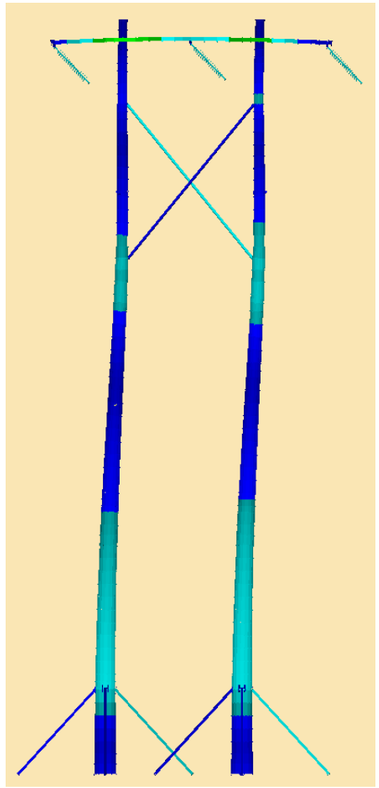
H-frame Load Cases (Loading Tree)

Load Case	Joint Label	Vertical load (N)	Transverse load (N)	Longitudinal load (N)	Maximum expected Pole Tip Deflection (cm)
LC6. CSAH WR (Wind 420Pa) (Tangent Str.),L NA+	Left	13955	13079	0	72.0
	Centre	13955	13079	0	
	Right	13955	13079	0	
	Pole-L:Wind1	0	528	0	
	Pole-L:Wind2	0	1156	0	
	Pole-L:Wind3	0	4628	0	
	Pole-R:Wind1	0	528	0	
	Pole-R:Wind2	0	1156	0	
	Pole-R:Wind3	0	4628	0	
LC7. Unbalanced Ice-12.7mm/Bare Ice at -20 Deg C,No Wind(Tangent st.)-Left phase	Left	6251	2109	10098	193.3
	Centre	8210	2373	0	
	Right	8210	2373	0	

H-frame Test #6: 420 Pa wind



est #6. CSAH WR |Wind 420 Pa| |Tangent Str.|, L NA



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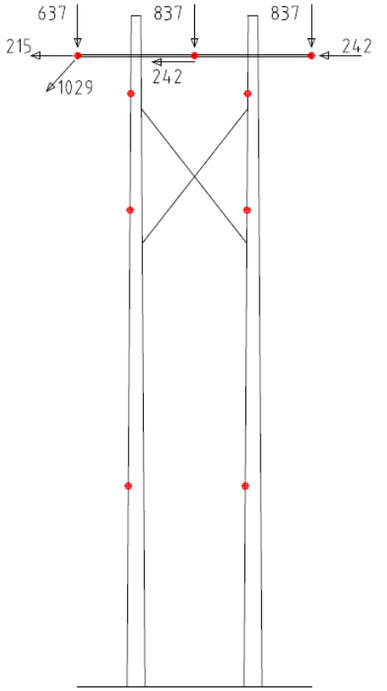
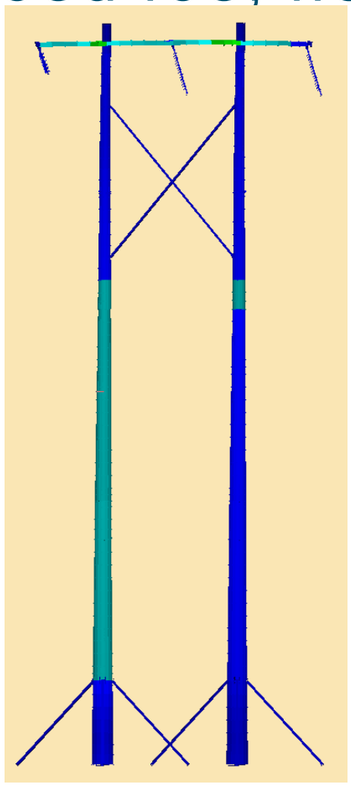
H-frame Test #7: Unbalanced ice, no wind



Test #7. Unbalanced Ice-12.7 mm/Bare Ice at -20 Deg. C, No Wind (Tangent Str.)- Right Phase, L NA+



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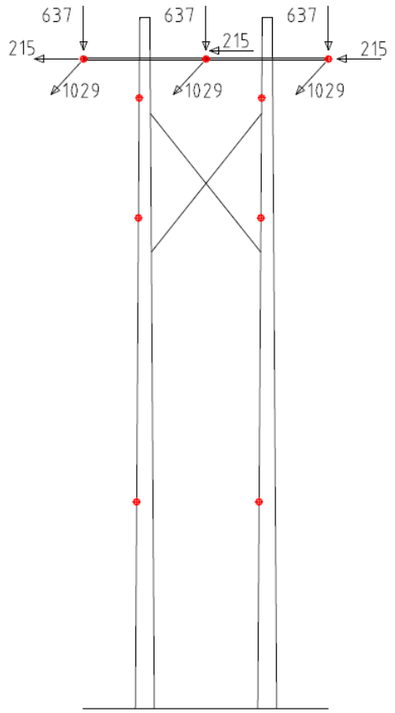
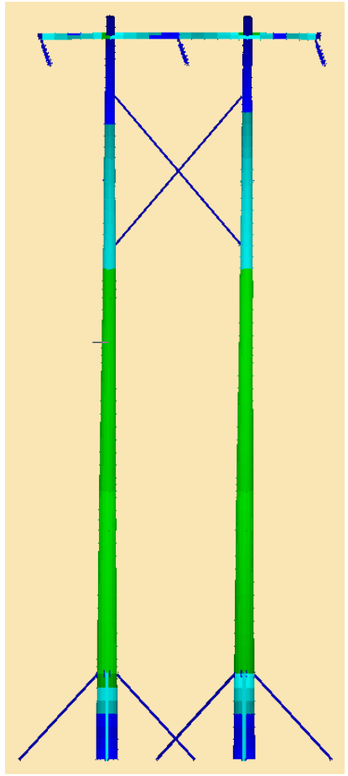
H-frame Load Cases (Loading Tree)

Load Case	Joint Label	Vertical load (N)	Transverse load (N)	Longitudinal load (N)	Maximum expected Pole Tip Deflection (cm)
LC8. Unbalanced Ice-12.7mm/Bare Ice at -20 Deg C,No Wind(Tangent st.)-All Phases,I NA+	Left	6251	2109	10098	472.9
	Centre	6251	2109	10098	
	Right	6251	2109	10098	
LC9. HIGH WIND (1320 Pa) With Point Load WR(Tangent Str.),L NA+ (**After maximum loading has been achieved, each transverse load will be incremented by 2200N until destruction)	Left	7409	20763	0	125.8
	Centre	7409	20763	0	
	Right	7409	20763	0	
	Pole-L:Wind1	0	1660	0	
	Pole-L:Wind2	0	3633	0	
	Pole-L:Wind3	0	14552	0	
	Pole-R:Wind1	0	1660	0	
	Pole-R:Wind2	0	3633	0	
	Pole-R:Wind3	0	14552	0	

H-frame Test #8: Unbalanced ice & -20C



Test #8. Unbalanced Ice-12.7 mm/Bare Ice at -20 Deg. C, No Wind |Tangent Str.|- All Phases, L NA+



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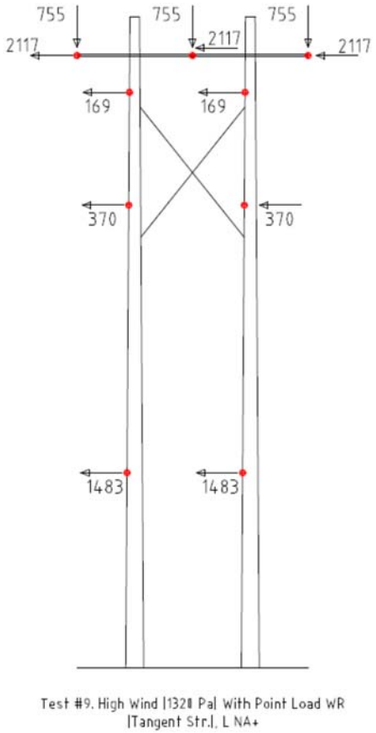
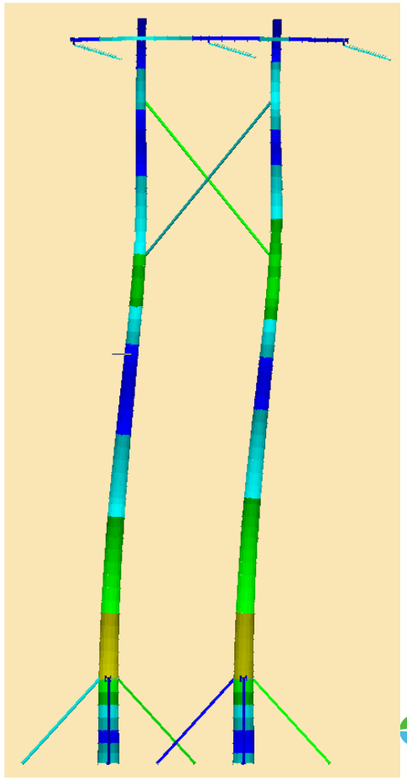
H-frame Test #9: 1320 Pa wind



Test #9. High Wind (1320 Pa) With Point Load WR
(Tangent Str.), L NA+



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H-frame Test #9: 1320 Pa wind

H-frame FRP pole failure video

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H-frame Measured vs Calculated Pole Deflections

Test #	Load Case	PLS-POLE™ Structure Usage (%)	Maximum Measured pole deflection (cm)		PLS-POLE™ pole deflection (cm)	
			Left	Right	Left	Right
1	Everyday loads	10.7	7	6	16	16
2	CSA Wind for ROW	19.3	12	24	29.7	29.7
3	Construction 1 ph only	9.3	14	15	52.7	40.5
4	Construction all phases	21.6	24	22	135.4	134.3
5	¾” Ice	6.73	9	9	10.5	10.5
6	420 Pa wind	42.6	34	63	71	72
7	Unbalanced ice, no wind	28.3	64	22	193	144.6
8	Unbalanced ice & -20C	67	-	-	472	469
9	High wind (failed @ 95%)	87	97	107	137	138

Bolt failure investigation

BC Hydro's subsidiary Powertech Labs. conducted failure investigation

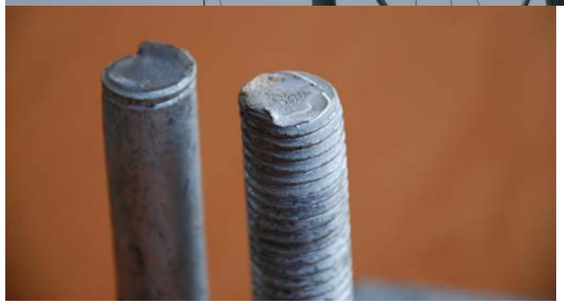
Specification:

- 3/4-inch diameter, 8-inch long bolt specified to IEEE Standard C135.1.

Scope:

- Visual examination
- Shear strength testing of the failed bolt and exemplar bolts
- Fractographic and microscope examination

H-frame Test : Bolt failure



Bolt failure video

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Bolt failure investigation

Conclusion:

- The bolt failed due to overload, based on evidence from fractographic examination and shear strength testing.

Figure 2. Composite image of the bolt fracture surfaces on: (a) the threaded portion, (b) the un-threaded portion. A shear lip on both surfaces, likely the location of final fracture, is indicated with an arrow.

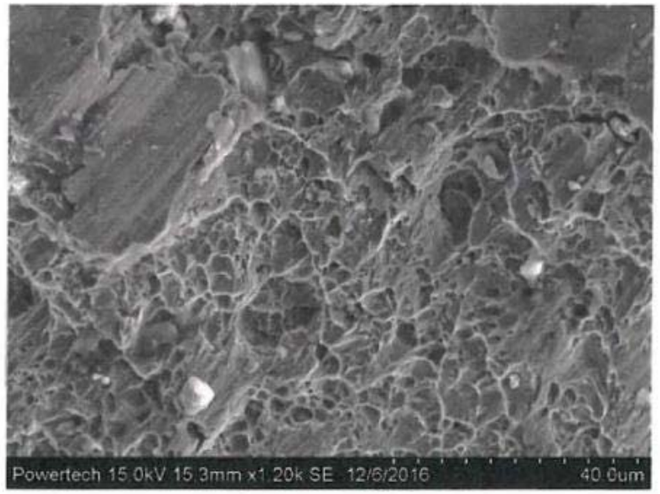

Figure 3. SEM image of the fracture surface, showing dimples, which are consistent with overload. Some smearing due to mechanical damage is also present (top left).

90 Degree Dead End Monopole Load Case

LOAD CASE	JOINT LABEL	VERTICAL LOAD (N)	TRANSVERSE LOAD (N)	LONGITUDINAL LOAD (N)	TRANSVERSE WIND (Pa)	LONGITUDAL WIND (Pa)	EXPECTED DEFLECTION (CM)	EXPECTED MAXIMUM GUY TENSION(KN)
LC1. CONDUCTOR TENSION **AFTER MAXIMUM LOAD CONDITION HAS BEEN REACHED, LONGITUDINAL LOADS WILL BE INCREMENTED BY 2,000N UNTIL DESTRUCTION.	LEFT	10,000	0	59,000	0	0	40	95
	RIGHT	10,000	0	59,000	0	0	40	95

Measured vs Calculated Pole Deflections

Test #	Load Case	PLS-POLE™ Structure Usage (%)	Measured pole deflection @100% (cm)		PLS-POLE™ pole deflection (cm)	
			Long.	Transv.	Long.	Transv.
1	Everyday loads	64	36	45	40	40

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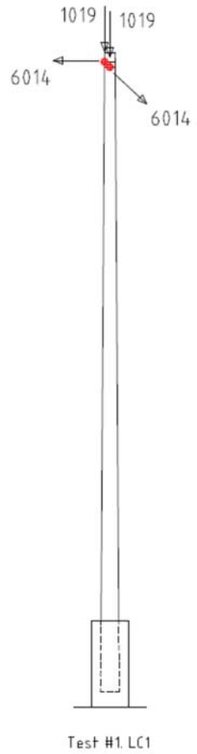
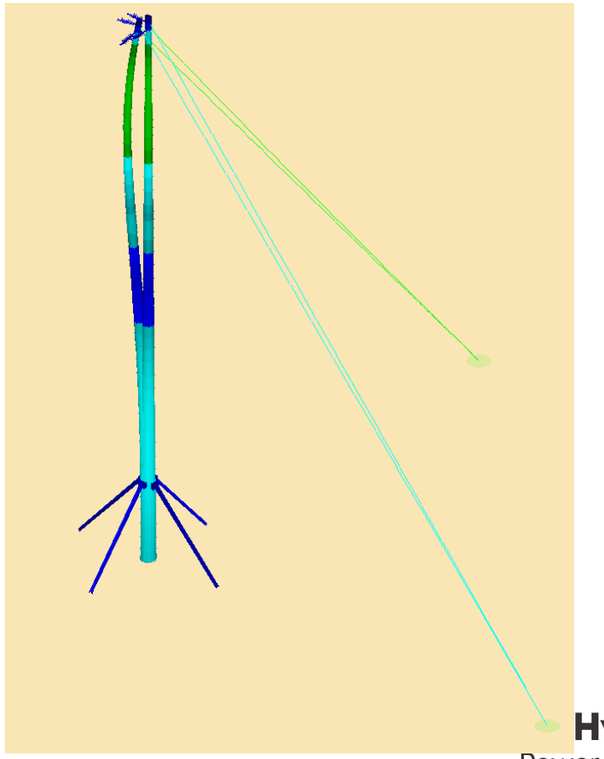
90 Degree Dead End Test:





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Conclusions

- PLS-POLE™ FRP H-frame analysis predicted the following:
  - conservative results for deflection of the H-frame test with loads in all 3 directions
  - consideration of the local pole usage near holes was required to predict the failure point.
  - More accurate results for simple load cases in only 2 directions
- X-brace pin bolt failed because it was overloaded. A larger bolt was required
- PLS-POLE™ FRP analysis accurately predicted the buckling load and deflected shape of the 90 degree dead end monopole.


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