CANA
HIGH VOLTAGE

AESO Engineering Studies

Impact of Section 502.2 Meteorological Loads On Wood Pole Transmission Design

Final Report

Prepared By:	Brad Murphy, E.I.T Owen Perry, P. Eng.	OWEN C. PERRY SEPT. 9/2015
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1 Executive Summary

A need has been identified to determine if the current meteorological loadings specified in the ISO Rules, Division 502, Section 502.2 Bulk Transmission Technical Requirements (502.2 Technical Requirements) are driving the 138 kV and 240 kV transmission costs to a situation where wood pole options may not be viable. A study was conducted to identify the differences in structural requirements between the existing Section 502.2 loadings, reduced AESO 502.2 loadings, and CSA deterministic loadings.

Focus of the investigation was to evaluate the impact of the 502.2 Technical Requirements on pole size for various common transmission line configurations in Alberta relative to previously existing CSA and AEUC requirements. As well, the study was to investigate the possible cost benefit of:

- Reducing the current single circuit 240 kV return period loadings from 75 yr. to 50 yr.
- Reducing the specified 138 kV return period loadings from 50 yr. to 35 yr.

An analysis of a typical 138 kV wood pole H-frame design for a ruling span of 220 meters, and a similar 240 kV design was conducted for an assumed line location near Medicine Hat, Alberta (AESO Zone C). The 138 kV H-frame design was examined with one conductor size. The 240 kV H-frame was studied with a single and a two bundle conductor alternative.

Following committee review of the initial draft report, additional scenarios for single pole 138 kV design was added to the scope of this study. These structures were analyzed for average span lengths of 120 and 150m.

For H-frame structures, the investigation determined for areas designated as CSA Heavy Loading, the 502.2 Technical Requirements did not contribute to incremental pole costs; the pole requirements of existing criteria were as stringent as the newer, 502.2 requirements. In areas designated as CSA Medium A Loading, however, the 502.2 Technical requirements required increases of one to two pole classes. Findings were similar for the single pole structure types.

Pole pricing was obtained from a supplier to estimate the cost impact of pole class upgrades. While pole materials influence the overall line cost, the differences seen were found to be small relative to typical transmission line construction costs.

Reducing return period loadings from 75 to 50 years, and 50 to 35 years for the 240kV and 138kV designs, respectively, had no significant cost benefit. The differences between these return period loadings were small.

There are other provisions in the 502.2 Technical requirements (other than meteorological loadings) which may affect the viability of wood pole construction. These were not considered in this report.

2 Background

The Alberta Electric System Operator (AESO) requested CANA High Voltage Ltd. (CHV) perform a loading cost comparison between the Section 502.2 loadings and the CSA[1] specified loadings for both 138 kV and 240 kV.

The study included investigating design limitations and estimated cost differences between the AESO and CSA loadings using the following 3 cases as bookends:

1) CSA minimum deterministic loadings
2) AESO 35 year return loadings for 138 kV and AESO 50 year return loadings for single circuit 240 kV
3) Existing Section 502.2 rules

The study looked at typical H-frame wood pole configurations with the goal of determining whether or not a specific bookend load case was responsible for driving the required wood pole class to a size where a large scale project would not be viable due to lack of available poles in this category. The study was limited to AESO Zone C, with only one conductor type originally being considered per voltage. As the study progressed, a second conductor type, a twin bundled scenario, was added into consideration for the H-frame 240 kV structure.

Due to the prevalence of single-pole 138 kV structures along road allowance, that configuration was later added for consideration, as well, with two commonly used conductor types.

3 Analysis Procedure

For each voltage class, a wood pole model was constructed in PLS-POLE having dimensions representative of a typical three phase configuration for that voltage. The structure model was input into a PLS-CADD LITE line model for structural analysis.

- For H-frame models, a ruling span of 220 meters was chosen as the target design span. Ground clearance for the ruling span was used to obtain the average pole height assuming level terrain.
- For single pole models, multiple ruling span lengths ranging from 120m to 150m were analyzed. Similarly, pole height was determined using ruling span – not maximum span.

The Medicine Hat area was chosen as a representation of Zone C due to the availability of reliable, long term return period wind loading data at its location. It is noted that this region represents the higher range of loadings for Zone C, but this was considered reasonable for the purposes of this report. If the most extreme return period loadings did not result in appreciable impact to cost, then the reduced loads of other Zone C areas would have even lesser impact.

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[1] CSA C22.3 No. 1-10, “Overhead Systems”, Canadian Standards Association, July, 2010.

All poles, for the sake of this analysis, were assumed to be set to the standard utility depth of 10% plus 600mm (2 ft).

3.1 138 kV Structures

For 138 kV H-frame analysis the conductor was set as a single 477 kcmil ACSR Hawk, tensioned in PLS-CADD LITE according to the conductor tension limits prescribed in existing Section 502.2. The minimum pole height required for the structure was found using the minimum agricultural clearance from AEUC 2013 of 6.7 meters for 138 kV, with an additional 600mm design buffer added to the projected sag for the 220m ruling span.

The later addition of the single pole 138kV structure similarly used 477 kcmil Hawk, but also was analyzed using 266.8 kcmil Partridge conductor to reflect common usage in road allowance applications. A range of ruling spans from 120m to 150m were analyzed, ground clearances were determined in the same manner as for the H-frame configuration.

3.1.1 138kV Wood Pole H-frame Model

The structure chosen for the 138 kV analysis was an H-frame having the dimensions shown in Figure 3.1.

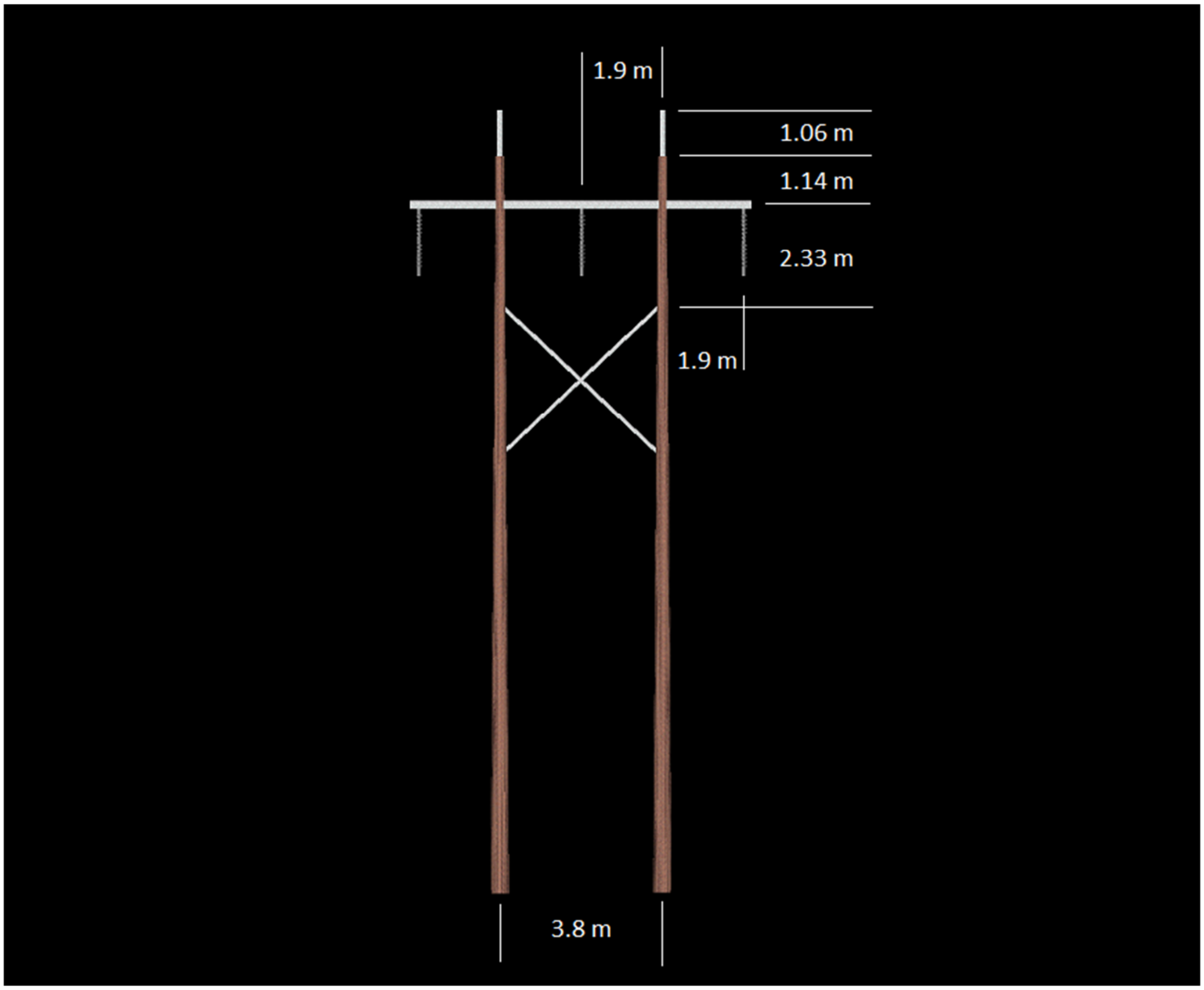

Figure 3.1: Typical 138 kV Wood Pole H-Frame Structure

H-frame structures were equipped with two 3/8” Grade 220 overhead shield wires. The crossarm was an 8 meter long 152.4x152.4x6.35mm HSS section. The cross bracing was composed of two 5 meter long 88.9x88.9x4.78mm HSS sections.

3.1.2 Single Pole 138 kV Model

The structure chosen for the 138 kV analysis was a V-braced wooden spar configuration having the dimensions shown in Figure 3.2. Similar to the H-frame models, the objective was to evaluate the pole capacity, not the arm capacity. This made specification of HSS steel arms irrelevant for this study.

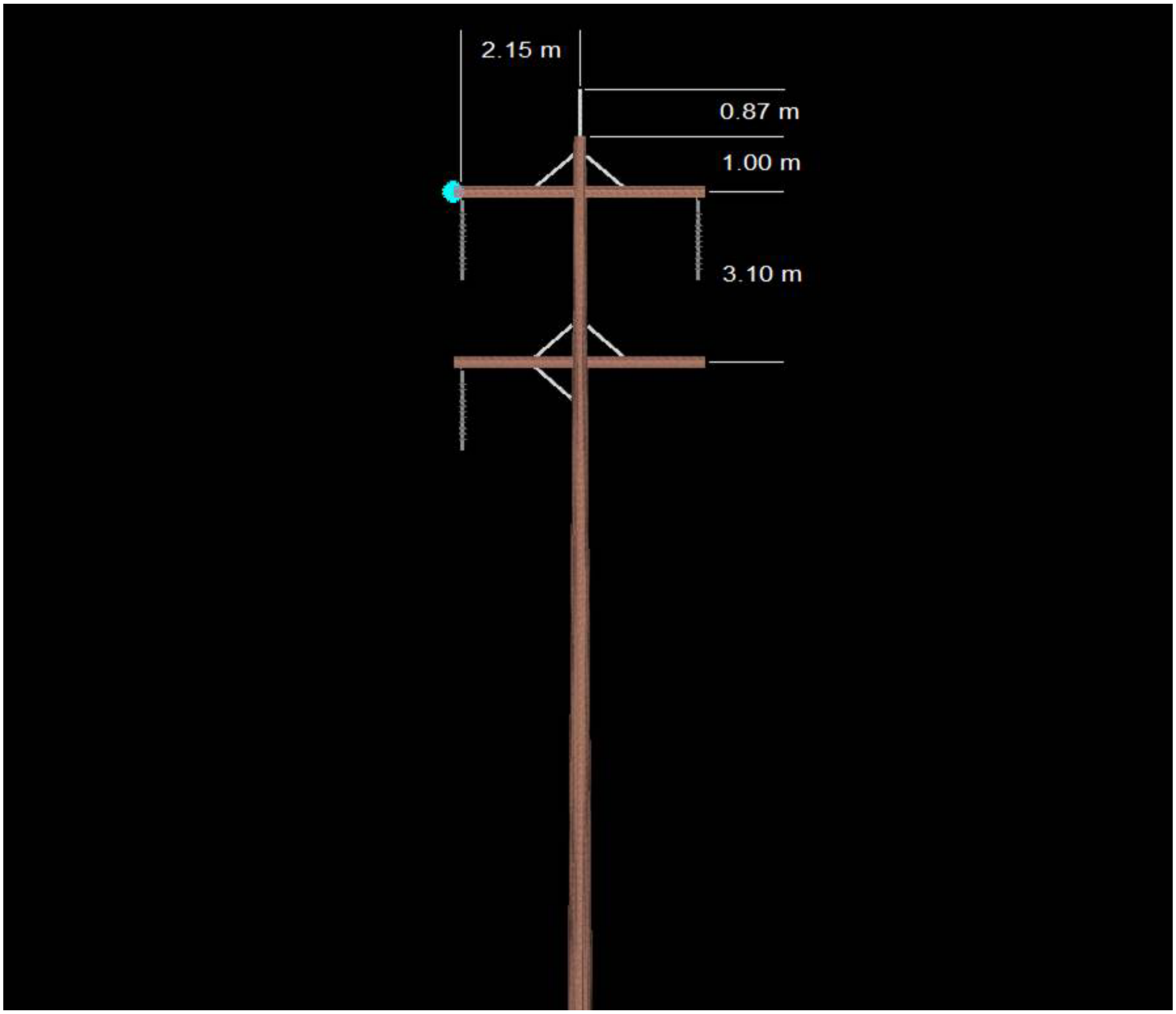

Figure 3.2: Standard 138 kV Single Pole Wooden Structure

The 138kV single pole structure was equipped with a 5/16" Grade 220 shield wire for analysis.

3.1.3 138 kV Weather Cases

The weather cases used for determining the minimum wood pole classes for a typical 138 kV construction were as shown in Table 3.1. The wind pressures for the Section 502.2 wind loading cases were adjusted for the average wire height over the maximum span length. The 35 year return period loadings were obtained by extrapolating from the known 50 and 100 year return period winds for Medicine Hat, Alberta assuming a Gumbel extreme value distribution.

LOAD CASE	WEATHER CASE	ICE THICKNESS	WIND PRESSURE	NOTES
1	CSA Heavy	12.5 mm	400 Pa	Overload factors applied according to CSA C22-3 No 1-10
	CSA Medium A	6.5 mm	400 Pa	
2	AESO 35 Year Wind	0 mm	970 Pa	Option considered for 138/144kV. Wood Pole Strength factor of 0.75 applied
	AESO 35 Year Wet Snow	NOT REQURED (SEE NOTE)		Section 502.2 specifies that 138 kV construction need not be designed for a wet snow and wind case.
3	AESO 50 Year Wind	0 mm	1030 Pa	Required for 138/144kV. Wood Pole Strength factor of 0.75 applied
	AESO 50 Year Wet Snow	NOT REQURED (SEE NOTE)		Section 502.2 specifies that 138 kV construction need not be designed for a wet snow and wind case.

Table 3.1: Weather Loadings For 138 kV Structural Analysis

As the scope of this study was limited to examining the impact on pole classification, the Section 502.2 provision for heavy vertical load on the arms was not considered as it does not govern pole design.

3.2 240 kV Structures

For 240 kV analysis two separate conductor cases were considered. The first was a single 1033 kcmil ACSR Curlew, the second was bundled 477 kcmil ACSR Hawk. The conductor was sagged in PLS-CADD LITE according to the tension limits set forth in existing Section 502.2.

The minimum pole height required for the structure was found using the minimum agricultural clearance from AEUC 2013, 7.3 meters for 240 kV, with a 0.6 m additional safety factor for the ruling span of 220 meters.

As with the 138kV H-frame, the structure was equipped with two 3/8” Grade 220 overhead shield wires for analysis of pole capacity.

3.2.1 240kV H-Frame Wood Pole Model

The structure chosen for the 240 kV analysis was an H-frame having the dimensions shown in Figure 3.3.

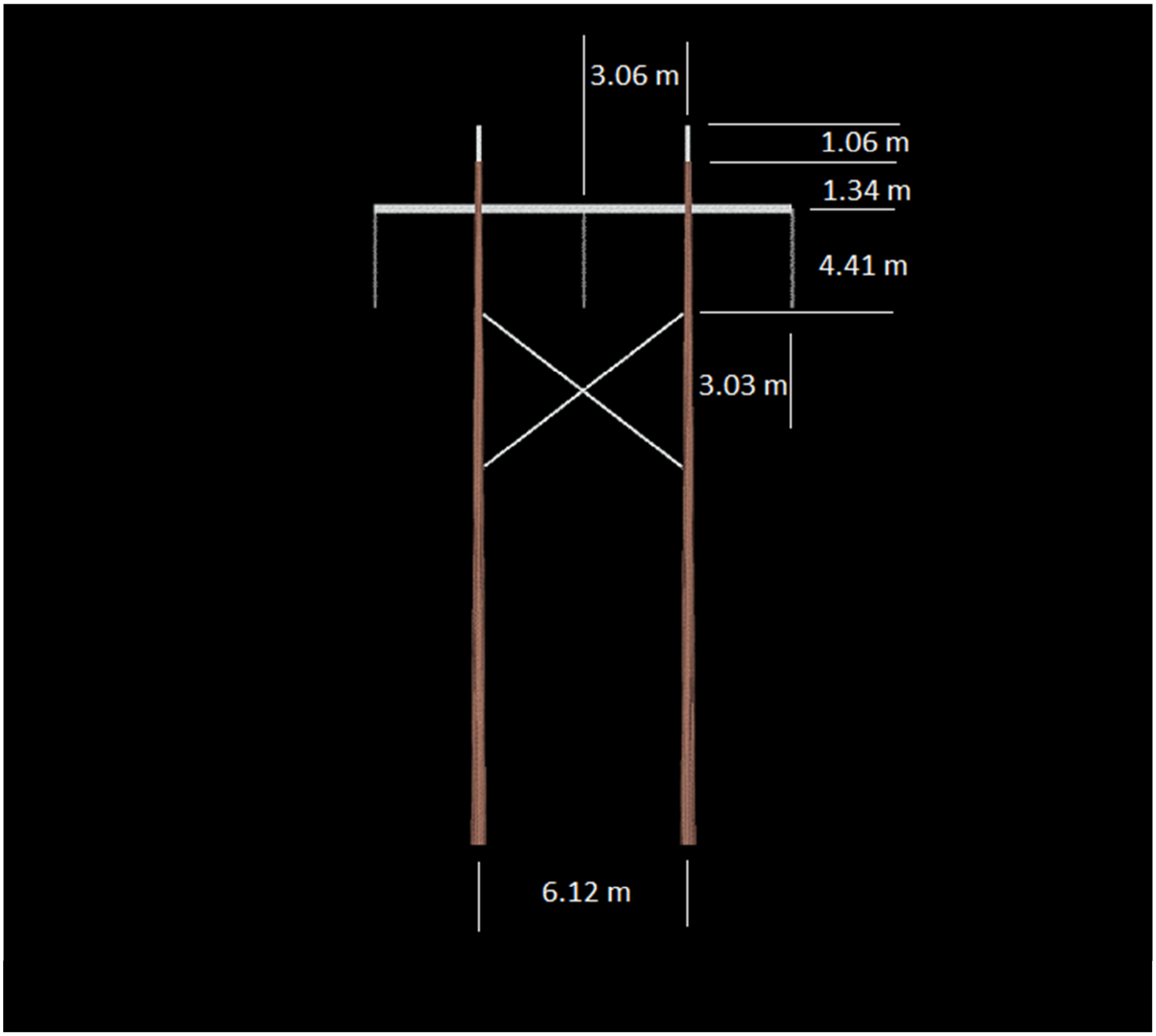

Figure 3.3: 240 kV Standard Wood Pole H-Frame Structure

The crossarm is a 12.18 meter long 203.2x152.4x6.35mm HSS section. The cross bracing is composed of two 7.3 meter long 88.9x88.9x4.78mm HSS sections.

3.2.2 240 kV Weather Cases

The weather cases used for determining the minimum wood pole classes for a typical 240 kV construction can be seen in Table 3.2. The wind pressures for wind loading cases were adjusted for the average wire height over the design span length assuming minimum possible pole height to achieve the required ground clearance.

The impact of lowering the currently specified 75 year return period loadings to a 50 year return was investigated.

LOAD CASE	DESCRIPTION	ICE THICKNESS	WIND PRESSURE	NOTES
1	CSA Heavy	12.5 mm	400 Pa	Overload factors applied according to CSA C22-3 No 1-10
	CSA Medium A	6.5 mm	400 Pa	
2	AESO 50 Year Wind	0 mm	1055 Pa	Current 502.2 requires 75yr with wood pole Strength factor of 0.75 applied to wood components.
	AESO 50 Year Wet Snow	40 mm	185 Pa	
3	AESO 75 Year Wind	0 mm	1130 Pa	
	AESO 75 Year Wet Snow	45 mm	200 Pa	

Table 3.2: Weather Loadings For 240 kV Structural Analysis

4 Findings of Analysis

For the H-frame structures, all results were obtained by running a non-linear structural analysis on the representative wood pole models in PLS CADD for the design average span length of 220 meters. A secondary linear analysis was done for each weather case using manual procedures. The results produced through the linear analysis correlated fairly well with those of the non-linear analysis for H-frame structures.

Results were different for the single pole, 138kV model. In this case, the linear analysis suggested a decrease of one pole class for many of the loadings considered in contrast with the more modern, non-linear analysis techniques.

We are aware that non-linear analysis is the preferred method of analysis in CSA C22.3 No. 1-10, but this standard does not explicitly rule out the use of linear techniques (although this is likely to change with the 2015 version). Neither is non-linear analysis an explicitly stated requirement of the Section 502.2 requirements for return period loads.

In all analyzed cases, the initial failure point was the wood pole at a location located just above the upper brace connection point. No attempt was made to further optimize the X-brace location.

All pole lengths are referenced in imperial units of feet. This is a common industry practice and was used throughout this report.

4.1 138 kV H-Frame

As detailed in section 3.1, the minimum pole length to maintain the AEUC 2013 agricultural clearance over the 220 meter design ruling span was found to be 65 feet. The results of the non-linear structural analysis for 138 kV using the 220 meter design average span are shown in Table 4.1 for the 65 ft. pole.

138kV H-Frame; 477kcmil Hawk; 220m Avg. Span; 65ft Pole			
LOAD CASE	**WEATHER LOAD**	**REQUIRED POLE CLASS (Linear Analysis)**	**REQUIRED POLE CLASS (Non-Linear Analysis)**
1	CSA Heavy	2	2
	CSA Medium A	3	3
2	AESO 35 Year Wind	2	2
3	AESO 50 Year Wind	2	2

Table 4.1: Results of Structural Analysis For 138 kV H-Frame with 220m Span

4.2 138 kV Single Pole Construction

For single pole construction there were additional factors which CHV believed needed consideration. These were:

- Design span lengths are typically longer when in CSA Medium Loading zones than when in CSA Heavy Loading areas;
- Two conductor types are prevalent for this type of construction, 266 kcmil and 477 kcmil;
- Our investigation determined that non-linear analysis had a more significant impact on pole class than with the H-frame structures.

Accordingly, the 138kV single pole configuration was analyzed for two average span lengths and for two conductors. Results were summarized for linear and non-linear analysis.

Using the approach discussed in section 3.2, the minimum pole length to maintain the AEUC 2013 agricultural clearance was computed. For the single pole structures, this was done for two span lengths assuming the use of a 266 kcmil ‘Partridge’ ACSR conductor. Results are summarized in tables 4.2 and 4.3.

Single Pole 138kV; 266kcmil Partridge; 120m Avg Span; 60ft Pole			
LOAD CASE	**WEATHER LOAD**	**REQUIRED POLE CLASS (Linear Analysis)**	**REQUIRED POLE CLASS (Non-Linear Analysis)**
1	CSA Heavy	3	2
	CSA Medium A	4	3
2	AESO 35 Year Wind	3	3
	AESO 50 Year Wind	3	2

Table 4.2: Results of Structural Analysis For 138 kV Single Pole with 120m Span

Single Pole 138kV; 266kcmil Partridge; 150m Avg Span; 65ft Pole			
LOAD CASE	**WEATHER LOAD**	**REQUIRED POLE CLASS (Linear Analysis)**	**REQUIRED POLE CLASS (Non-Linear Analysis)**
1	CSA Heavy	2	1
	CSA Medium A	3	2
2	AESO 35 Year Wind	2	2
	AESO 50 Year Wind	2	1

Table 4.3: Results of Structural Analysis For 138 kV Single Pole with 150m Span

A similar analysis was performed using a 477 kcmil ‘Hawk’ ACSR conductor, and the results summarized in tables 4.4 and 4.5.

Single Pole 138kV; 477kcmil Hawk; 120m Avg Span; 60ft Pole			
LOAD CASE	**WEATHER LOAD**	**REQUIRED POLE CLASS (Linear Analysis)**	**REQUIRED POLE CLASS (Non-Linear Analysis)**
1	CSA Heavy	2	1
	CSA Medium A	4	3
2	AESO 35 Year Wind	2	2
	AESO 50 Year Wind	2	1

Table 4.4: Results of Structural Analysis For 138 kV Single Pole with 120m Span

Single Pole 138kV; 477kcmil Hawk; 150m Avg Span; 65ft Pole			
LOAD CASE	**WEATHER LOAD**	**REQUIRED POLE CLASS (Linear Analysis)**	**REQUIRED POLE CLASS (Non-Linear Analysis)**
1	CSA Heavy	1	H1
	CSA Medium A	3	2
2	AESO 35 Year Wind	1	H1
3	AESO 50 Year Wind	1	H1

Table 4.5: Results of Structural Analysis For 138 kV Single Pole with 150m Span

4.3 240 kV H-Frame Construction

Using the same approach as for the 138kV, the minimum pole length to maintain the AEUC 2013 agricultural clearance over the 220 meter design ruling span was found to be 70 feet for both conductors considered.

The results of the structural analysis for 240 kV Single 'Curlew' ACSR and 2-bundle 'Hawk' ACSR using the 220 meter design average span are shown in Tables 4.6 and 4.7, respectively.

240kV H-Frame; 1033kcmil Curlew; 220m Avg Span; 70ft Pole			
LOAD CASE	**WEATHER LOAD**	**REQUIRED POLE CLASS (Linear Analysis)**	**REQUIRED POLE CLASS (Non-Linear Analysis)**
1	CSA Heavy	H1	H1
	CSA Medium A	2	2
2	AESO 50 Year Wind	1	H1
	AESO 50 Year Wet Snow	1	1
3	AESO 75 Year Wind	H1	H1
	AESO 75 Year Wet Snow	1	H1

Table 4.6 Results of Structural Analysis For 240 kV Design – Single Curlew ACSR

240kV H-Frame; 2-477kcmil Hawk; 220m Avg Span; 70ft Pole			
LOAD CASE	**WEATHER LOAD**	**REQUIRED POLE CLASS (Linear Analysis)**	**REQUIRED POLE CLASS (Non-Linear Analysis)**
1	CSA Heavy	H2	H2
	CSA Medium A	1	1
2	AESO 50 Year Wind	H2	H2
	AESO 50 Year Wet Snow	H1	H2
3	AESO 75 Year Wind	H2	H2
	AESO 75 Year Wet Snow	H2	H3

Table 4.7 Results of Structural Analysis For 240 kV Design – 2-Bundle 'Hawk' ACSR

5 Observations and Conclusions

5.1 138 kV H-Frame

Observation of the findings for 138 kV H-Frame structures determined the following:

a) The analysis of the 138 kV H-Frame structure showed, for a single 477 Hawk ACSR conductor, the minimum pole size required is a Class 2 in CSA Heavy Loading areas and is governed by the CSA deterministic load. The 502.2 Technical requirements have no impact on poles size regardless if the requirements are reduced from 50 year to 35 year return periods.

b) In areas where CSA Medium Loading is the maximum deterministic load, the 502.2 Technical Requirements will require poles to be increased from Class 3 to Class 2. This is true regardless of whether the existing return period requirements are reduced to 35 years or not.
c) The difference between a 35 year return and 50 year return wind loading is not large and has minimal effect on pole classification.
d) Manual linear analysis techniques for transverse loading of the 138/144kV H-Frames demonstrated good agreement with the non-linear techniques.

5.2 138 kV Single Pole Structure

Analysis of the 138 kV single pole structure determined the following:

a) Analysis of the single pole structures for 120m and 150m spans resulted in similar observations to the H-frame structures in that, for CSA Heavy Loading areas, no economic impact would result from the requirements of the 502.2 Technical Requirements.
b) In areas where CSA Medium Loading is the maximum deterministic load, the 502.2 Technical Requirements will require poles to be increased by one to two classes. This is true regardless of whether the existing return period requirements are reduced to 35 years or not.
c) Presently, non-linear (P-delta) analysis is not a requirement of the 502.2 Technical Requirements. However, this is a common practice among designers and is the preferred approach of CSA C22.3 No 1-10. Should this become mandatory for single pole structures, it is likely to increase pole requirements by one additional class.

5.3 240 kV H-Frame

Analysis of 240 kV H-Frame structures using a single, 1033kcmil ‘Curlew” ACSR determined the following:

a) The analysis determined a minimum required pole of class 1 under AESO 50 year loadings and H1 under AESO 75 year loadings when the conductor was a single 1033 Curlew ACSR.
b) For CSA deterministic loadings, minimum required pole class of 2 for CSA Medium Loading and H1 for CSA Heavy Loadings were found. The current 502.2 Technical Requirements loadings require a minimum pole size of Class H1. Thus, it would have no economic impact in Heavy Loading areas, but would require a pole upgrade of two classes in a Medium Loading area.
c) Manual linear analysis techniques for transverse loading of the 240 kV H-Frames demonstrated good agreement with the computer, non-linear techniques. Differences in pole classification were due to minor spreads in results falling on either side of the selected pole capacity. In practice, this would be mitigated through selection of marginally shorter spans, with minimal or no cost impact.

When the 240 kV structure was run for a bundled 477 Hawk ACSR, the minimum required pole classes increased, with the following observations:

a) The analysis determined a minimum required pole class of H2 under AESO 50 and 75 year loadings when the conductor was a two bundle Hawk ACSR (marginally H3 for non-linear).
b) For CSA deterministic loadings, minimum required pole class of 1 for CSA Medium Loading and H2 for CSA Heavy Loadings were found. The Section 502.2 loadings would have no economic impact in Heavy Loading areas, but would require a pole upgrade of two classes in a Medium Loading area.
c) As was observed for the single-conductor option linear analysis techniques demonstrated good agreement with non-linear techniques. Regardless of the value in table 4.7 for case 3, it is doubtful that pole classes would be upgraded to H3 for the small differences observed.

The need for class H2 and H3 poles on the "average" tangent structure implies even higher class poles will be needed at specific locations to deal with local issues. Poles in such high classification categories may not be available; the viability of such construction entirely with wood poles could become difficult. Tubular steel may be a more viable option.

5.4 Costing of Poles

A preliminary quote was obtained from a supplier based in British Columbia for varying lengths and classes of Western Red Cedar poles shipped to Medicine Hat[2]. These quotes were "for estimation purposes".

All pole class and length combinations could not reasonably be priced, so some were extrapolated from given data for the sake of comparison in Table 6.1.

6 Conclusions and Observations

6.1 Conclusions

1. A summary of direct cost impacts of the 502.2 Technical Requirements are summarized in Table 6.1.

2. In CSA Heavy Loading areas there is no cost that can be attributed to the 502.2 Technical Requirements for the wood pole structure types examined in this study.

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[2] Preliminary quote obtained from Stella-Jones Inc. for Western Red Cedar Poles. Prices noted for estimating purposes only. Final prices are subject to order quantity and pole size availability at time of order placement.

Structure	CSA LOADING AREA	REQUIRED POLE UPGRADE	ADDED COST ($/Km)
138kV H-Frame 477 kcmil	CSA Heavy	None	$0
	CSA Medium A	3->2	$3,640
138kV 1-Pole 266 kcmil	CSA Heavy	None	$0
	CSA Medium A	3->2	$2,670
138kV 1-Pole 477 kcmil	CSA Heavy	None	$0
	CSA Medium A	3->1	$5,330
240kV H-Frame 1033 kcmil	CSA Heavy	None	$0
	CSA Medium A	2->H1	$9,450
240kV H-Frame 2-477 kcmil	CSA Heavy	None	$0
	CSA Medium A	1->H2	$11,000
Note: Some costs are extrapolated from costs provided by pole supplier for other pole sizes and classes. Return periods used are 50 yr. for 138kV and 75 yr. for 240kV.			

Table 6.1: Summary of Cost Contributions of 502.2 Technical Requirements by CSA Loading Area

3. Pole material costs, alone, are not likely to be a determining factor in reducing overall transmission line cost. Availability of certain classes may be a greater concern.

    - For example, upgrading from class 3 to class 2 poles is misleading. Class 3 poles are not used for transmission construction in large quantities and the supplier noted that they only maintain limited stock with transmission treatment. Class 2 poles would most probably be substituted – or longer spans would be designed to better utilize pole strength.

    - While H-class poles are currently available in larger quantities, this has not always been the case. Pole availability may have a much more direct impact on project costs than pole price; if structure quantities/km increase due to a lack of higher class poles, then both material and labour costs will increase roughly proportional to the number of structures (excepting conductor).

4. Should supply become an issue, an alternative to H-Class wooden poles could be tubular steel or composite structures. However, the 502.2 Technical Requirements place a failure containment loading criterion on non-wooden poles which can affect their economic viability for an H-frame line. The benefits of this requirement are unclear for direct embedded structures.

5. The scope of this study was limited to use of existing H-frame and single pole configurations which are in widespread use in the province. However, these structures are not fully compliant with the 502.2 technical requirements as they presently exist; the 502.2 insulator swing and air gap requirements would apparently require a fairly extensive modification of these designs which may well increase pole height and class independent of the meteorological loads assumed (see section 6.3 for further discussion).

6.2 Recommendations

The following recommendations are made to the Section 502.2 Working Group based upon the findings of this study:

1. Even if the CSA C22.3 update scheduled for 2015 includes removes linear analysis as an option for transmission structure design, it will take a year or more to incorporate this into the AEUC documents making it mandatory in Alberta. It is recommended that language be added to the Section 502.2 Rules during its current revision which would require the use of non-linear analysis to avoid this delay.

2. It is observed that the 502.2 Technical Requirements effectively penalize pole structures using steel or composite construction by exempting only wood poles from both sequence of failure and failure containment loadings. It is recommended that the language of the Section 502.2 Rules be revised to exempt all direct embedded pole-type structures, rather than just wood pole.

6.3 Other Comments

While investigating the impact of Section 502.2 loads on 138kV wood pole structures, we observed one potential driver of cost escalation. These findings were not within the scope of this report to investigate, but might provide a basis for future study.

The impact of the specified insulator swing and associated air gaps in the 502.2 Technical Requirements and Information Document appear to invalidate previously existing wood pole standards of the Alberta Transmission Facility Owners. These would require extensive modification to meet these swing/clearance criteria. It is unclear as to the need for these changes and what their basis in system reliability could be.