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Performance validation of a twin spacer damper system for AAC 49 mm conductors

P. VAN DYKE[1], D. BÉLANGER[2], M.H. TREMBLAY[2], É. DESJARDINS[2], P. MESSIER[2]
[1]Institut de recherche d'Hydro-Québec [2]Hydro-Québec
Canada

SUMMARY

The use of a 48.69 mm AAC conductor in a twin bundle is planned for a new 320 kV DC transmission line at Hydro-Québec TransEnergie. It will be the largest bundle conductor ever used on its transmission network and one of the largest in North America. Since this conductor is 35% larger than the conductor usually used in our twin bundles, the distance between the bundle conductors has been increased by the same percentage, from 406 to 560 mm to minimize the aerodynamic interaction between the conductors and prevent subspan oscillation problems. In addition, as the conductor is larger, the aeolian vibrations are expected to be more severe since the energy imparted by the wind is proportional to the diameter of the conductor with a fourth exponent [EPRI, 2009]. Therefore, in order to validate the effectiveness of the spacer damper system for controlling aeolian vibrations and subspan oscillations on a 48.69 mm AAC twin bundle, field tests were conducted on the IREQ's full scale test line, which consists of three suspension spans and two dead-end spans for a total length of 1.6 km. Two tests were carried out at a mechanical tension of the conductors of 59 kN since subspan oscillations are more severe at a lower mechanical tension because the resonant frequencies of the subspans are lower and at 76 kN since aeolian vibrations are more severe at a higher mechanical tension because the self-damping of the conductor decreases as the tension increases.
Regarding the aeolian vibrations, a maximum fY_{max} (frequency multiplied by the antinode amplitude) of 106 mm/s and Y_b (bending amplitude) of 288 μm p-p were obtained during the tests, which is lower than the endurance limit of the conductor in a metal-to-metal clamp. Moreover, the conductors are suspended in an elastomeric suspension (ES) clamp which has a higher endurance limit. Therefore, no conductor fatigue is expected.
For the subspan oscillations, the maximum displacement was 55 mm peak-to-peak, which is well below the allowable amplitude of 300 mm and no clashing is expected on the bundle. The maximum fY_{rms} was 4.9 mm/s rms which is also well below the allowable amplitude of 90 mm/s and no damage to the conductor or spacer damper articulations is therefore expected.
This study on 48.69 mm AAC conductors with ES suspension clamps validated the performance of the spacer damper system with 560 mm spacing to protect the twin bundle against aeolian vibrations and subspan oscillations before building the line and investing considerable sums of money.

KEYWORDS

AAC conductor, twin bundle, spacer damper, aeolian vibrations, subspan oscillations
VanDyke.Pierre@ireq.ca

Introduction

The use of a 48.69 mm AAC conductor in a twin bundle is planned for a new 320 kV DC transmission line at Hydro-Québec TransEnergie. It will be the largest bundle conductor ever used on its transmission network and one of the largest in North America. Since this conductor is 35% larger than the conductor usually used in our twin bundles, the distance between the bundle conductors has been increased by the same percentage, from 406 to 560 mm to minimize the aerodynamic interaction between the conductors and prevent subspan oscillation problems. In addition, as the conductor is larger, the aeolian vibrations are expected to be more severe since the energy imparted by the wind is proportional to the conductor diameter with a fourth exponent [EPRI, 2009]. Therefore, the aim of this project was to validate the efficiency of the spacer damper system to control aeolian vibrations and subspan oscillations on a 48.69 mm AAC twin bundle on a full-scale test line. Failure to do so might lead to conductor fatigue and/or damage due to conductor clashing as well as premature aging of the spacer damper articulations.

Description of the conductor and bundle

An economical study showed that 320 kV DC was the optimum voltage for this new line as a lower voltage would lead to higher electrical losses and a higher voltage would be more expansive in terms of line and conversion equipment (AC to DC). A triple bundle with smaller conductors could have been used but the ice and wind loads would have been higher and the visual impact would have been greater. Moreover, on a twin bundle, the same conductor can be used for the poles and the return cable. Table 1 provides the characteristics of the conductor and bundle and Figure 1 shows a section of the conductor.

Table 1 AAC 1400 A1 conductor characteristics

Outside diameter	48.69 mm
Aluminium strands	61 x 5.41 mm
Section	1402.21 mm^2
Weight per unit length	38 N/m
Rated tensile strength	224.354 kN
Twin bundle spacing	560 mm

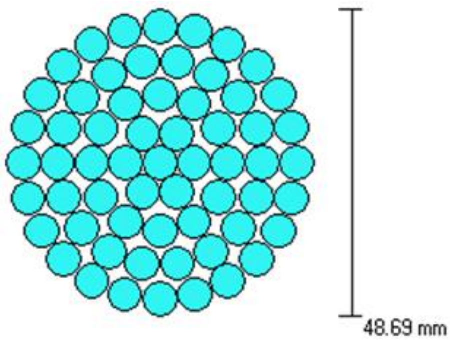

Figure 1 Section of the conductor

In the area where the new line will be built, the averaged temperature of the coldest and hottest month is -30 and 20°C respectively. The initial tension of the conductor at these temperatures is as follows:

- Initial tension at -30°C : 76,39 kN, 34% RTS or H/w = 2010 m
- Initial tension at 20°C : 59,77 kN, 27% RTS or H/w = 1572 m

Knowing that the severity of the aeolian vibration increases with the tension and that the subspan oscillation severity is more severe at lower tensions, it was decided to validate the spacer damper system at both tensions.

Description of the spacer damper

The ratio of the spacing (a) between conductors in the same bundle to the diameter of the conductors (d) greatly influences the aerodynamic interaction that there will be between the conductors and the severity of the subspan oscillations. A low a/d ratio will favor more severe subspan oscillations.
The a/d ratios obtained in a CIGRE survey varied between 10 and 25 for different Transmission System Operators (TSO) [CIGRE TB 277, 2005]. The a/d ratio usually used on the twin bundles on Hydro-Québec transmission lines is 11.4 and 11.6 for Bersfort and Bersimis conductors spaced 406 mm apart.
As the diameter of the AAC 1400 A1 conductor is much larger, in order to properly control the subspan oscillations, the frame of the Hydro-Québec spacer damper has been lengthened to have a spacing of 560 mm (Figure 2) to obtain an a/d ratio of 11.5, which is similar to the current a/d.
The arms of the spacer damper have not been modified nor their angle to the horizontal. It is a standard practice at Hydro-Québec to use spacer dampers with helical rod attachment as they are more

tolerant to vibration and avoid problems such as wear and abrasion of the conductor that may occur with bolted clamps that are not torqued properly [CIGRE TB 708, 2017].

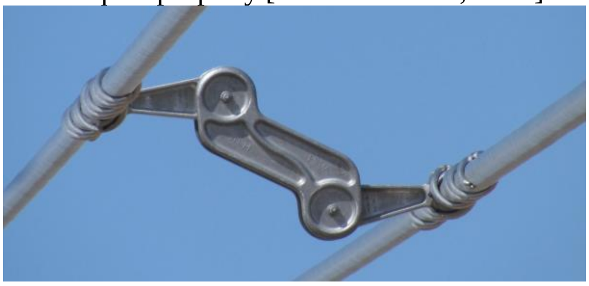

Figure 2 560 mm spacer damper for twin bundle

Description of the Elastomer suspension (ES) clamp

ES suspension clamps (Figure 3) are the standard clamp systematically installed on Hydro-Québec transmission lines. The ES clamp has a metal section in the middle to meet the criteria for conductor slippage in the clamp and has a tapered elastomer insert at each end (Figure 4) to gradually reduce the holding stiffness where the conductor exits the clamp and thereby greatly reduce the conductor bending severity at this point [Paradis and Van Dyke, 2020].

Figure 3 Elastomer suspension (ES) clamp and relative displacement transducers (CDR)

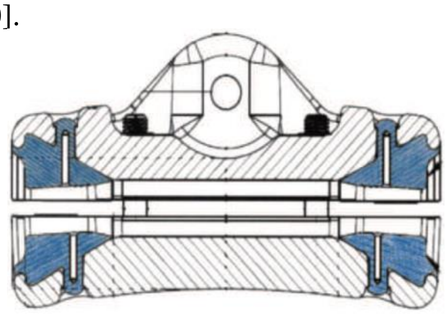

Figure 4 Cross-section of the ES clamp (Elastomer inserts shown in blue)

Safe design tension and endurance limit of the conductor

CIGRE TB 273 [2005] gives the maximum safe design tension for horizontal twin bundles with spacer dampers that apply to AAC conductors. The safe design tension depends on the type of terrain where the transmission line is located. According to the TB, this configuration is safe for $H/w < 2200$ m on terrain 2: open, flat no obstruction, no snow terrains such as farmland without any obstruction, Summer time. Of course, this would also work on terrains 3 and 4 where there are more obstacles. For terrain 1, open, flat, no trees, no obstruction, with snow cover, or near/across large bodies of water, flat desert, the maximum safe design tension H/w is 1900 m which is below the H/w of 2010 m of the bundle under study. However, it is mentioned in the TB that use of supporting devices such as cushioned clamps may justify higher design tensions. As the tests were carried out during the winter period, the test line was category 1 terrain and the tests will validate the performance of the spacer damper system under such conditions.

EPRI [2009] provides and endurance limit fY_{max} = 128 mm/s peak for AAC conductors in a metal-to-metal clamp.

There is no Y_b endurance limit available in the literature for the AAC conductor in a metal-to-metal clamp and even if there were, this limit would not be adequate for the ES clamp. Indeed, the flexibility of the elastomer insert which reduces the severity of the bending of the conductor at the exit of the suspension clamp allows a vertical displacement of the conductor, the relative displacements are therefore greater than for a metal-to-metal clamp, although the damage due to conductor fatigue is reduced.

Fatigue test [IEC 62568, 1998] were carried out on an ACSR Crow conductor in a semi-rigid clamp and the endurance limit was set at fY_{max} = 220 mm/s peak [Paradis and Van Dyke, 2020] and Y_b = 680 microns peak-to-peak.

Regarding the fY_{max} endurance limit, both fY_{max} values of 128 and 220 mm/s peak will be shown on the graphs but it is believed that the endurance limit of the AAC conductor in an ES clamp is

equivalent to the endurance limit of an ACSR conductor in an ES clamp since both conductors have the same type of external aluminium strands and it has been shown that the ES clamp increases greatly the endurance limit of a conductor [Paradis and Van Dyke, 2020]. Moreover, the endurance limit fY_{max} of an AAC conductor in a metal-to-metal clamp is slightly higher than an ACSR conductor in a metal-to-metal clamp.
The endurance limit at the spacer damper attachment should be higher than at the ES clamp because the combination of the helical rod attachment and the elastomer pad is more flexible than the ES clamp. In addition, it will be seen later in this paper that the vibration amplitude was also much lower at this location.

Description of the test line
Both field tests were carried out on IREQ's full-scale test line which consists of three suspension spans and two dead-end spans for a total length of 1.6 km (Figure 5 and Figure 6). When the test line was built, its orientation was chosen perpendicular to the predominant direction of the wind. There are no obstacles in the direction perpendicular to the line, which minimizes wind turbulence and maximizes the severity of conductor vibration.

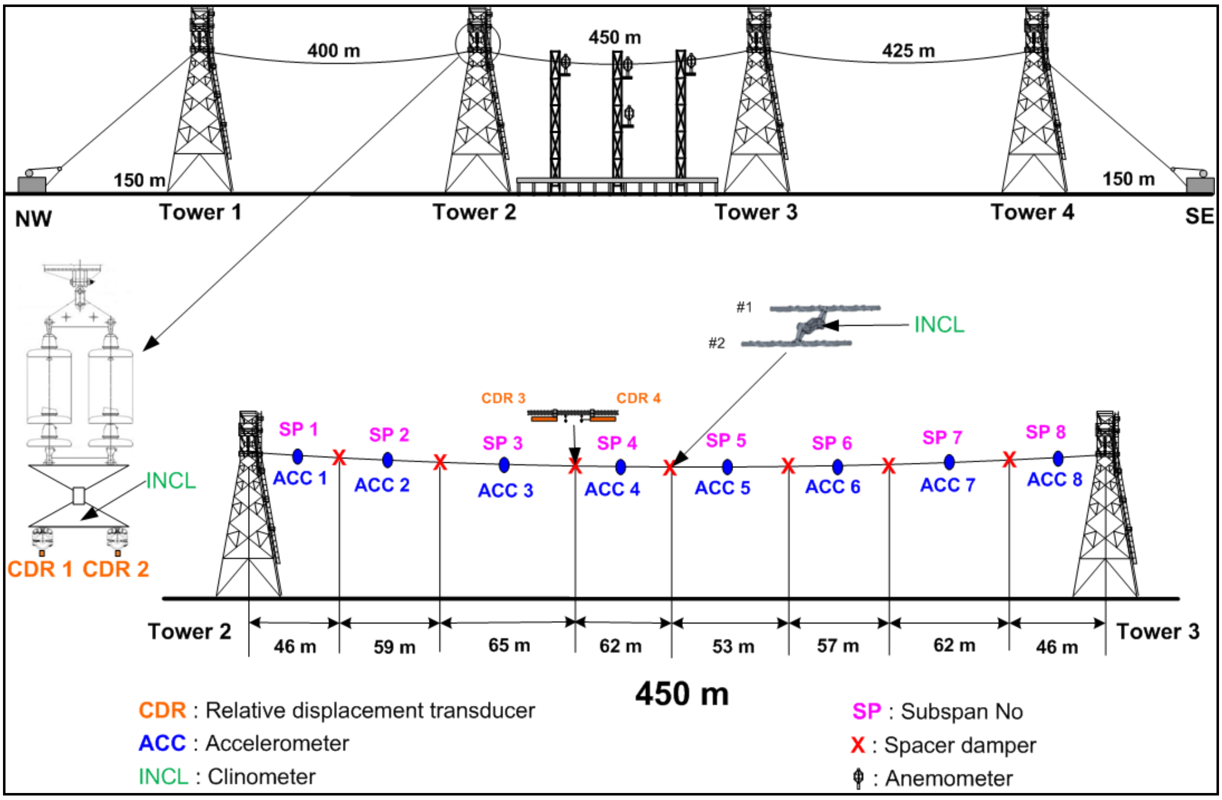

Figure 5 Test line schematic and instrumentation

Instrumentation
Transducers are installed in the 450-m span to monitor both aeolian vibrations and subspan oscillations and the location of most transducers is shown in Figure 5.
Three ultrasonic anemometers were installed at the height of the conductor along the span and a fourth one at a height of 10 m in the middle of the span to measure the wind speed, azimuth, elevation and turbulence level.
Strain-gaged cantilever beams were fixed on the ES suspension clamps at tower 2 to measure the relative displacement Y_b at 89 mm from the last point of contact of the conductor with the elastomer in the 450-m span (Figure 3).
Since the spacer dampers had helical rod attachments, the inverse bending amplitude was also recorded on each side of one clamp of the third spacer damper starting from tower 2 located between

the longest subspans in the 450 m-span. The inverse bending amplitude was converted to bending amplitude [Hardy and Brunelle, 1991].
Aeolian vibrations were also measured with vertical accelerometers located at 1 m from the last point of contact of the conductor with the elastomer in the 450-m span (Figure 7). Those measurements allowed to calculate the fY_{max}.
Subspan oscillations were measured with horizontal accelerometer located in the middle of each subspan on the North-East subconductor. Since the moderate and high wind speed is mostly from the opposite direction, this subconductor is usually on the leeward side of the bundle.

Figure 6 IREQ’s test line

Figure 7 Accelerometers near tower 2 to measure aeolian vibrations

Data acquisition and processing
The 59.77 kN test was performed intermittently from December, 18 2020 to March 17, 2021 during which 4444 acquistions were collected. The 76.39 kN test was performed intermittently from March 17 to May 4, 2021 during which 4760 acquistions were collected.
Data acquisition was resumed every ten minutes and the data acquisition rate and duration are provided in Table 2.

Table 2 Data acquisition rate and duration

Type of transducer	Acquisition rate (points/s)	Duration (s)
Anemometers	10	300
Subspan oscillations transducers	32	145
Aeolian vibrations transducers	420	83.3

Wind exposure
Each box in Figure 8 and Figure 9 represents the number of acquisitions obtained for a combination of mean wind speed and azimuth measured at the height of the bundle for each test. Exposure to light winds conducive to severe aeolian vibrations was excellent for both tests. Winds of up to 70 and 50 km/h with a direction near perpendicular to the line conducive to subspan oscillations were measured for 59.77 and 76.39 kN tests respectively. Since the second test was primarily for aeolian vibrations, it was not extended to obtain higher wind speeds.

Aeolian vibrations
The maximum value of fY_{max} measured for each frequency on the twin bundle near tower 2 is given in Figure 10 for the two tests. As expected, on the NE conductor, the vibration severity is higher when the bundle is strung at a higher tension. Surprisingly, on the SW conductor, the vibration amplitude is similar for both tests. The maximum value obtained is 106 mm/s peak which is lower than the two

endurance limits plotted and the spacer damper system protects the twin bundle against aeolian vibrations.

The maximum bending amplitudes measured at the SE clamp and at the spacer damper clamp are shown in Figure 11. The bending amplitude at the spacer damper clamp is very low at both tensions. As expected, the bending amplitude is higher when the bundle is strung at a higher tension. However, in both cases, the bending amplitudes are well below the endurance limit.

The maximum values obtained are given in Table 3.

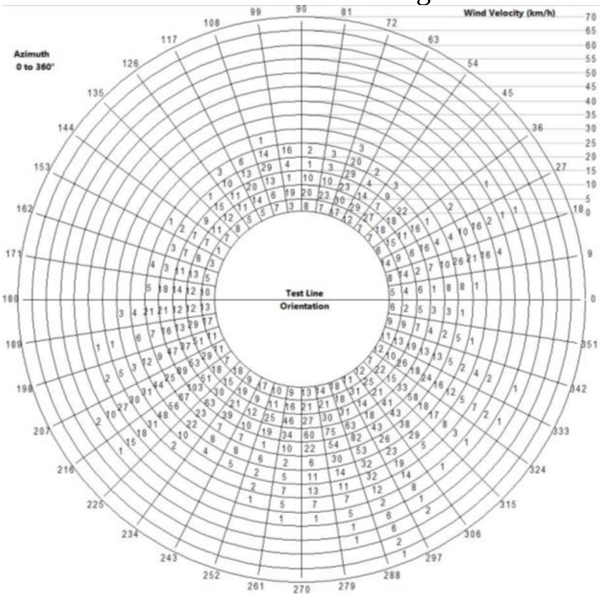

Figure 8 Wind exposure at 59.77 kN

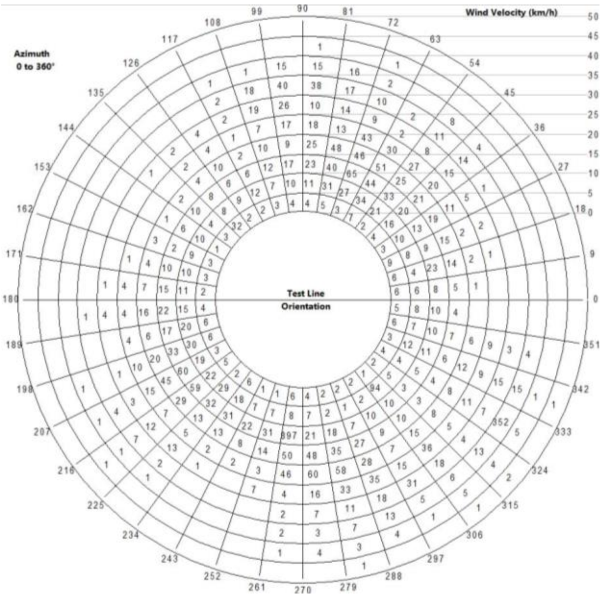

Figure 9 Wind exposure at 76.39 kN

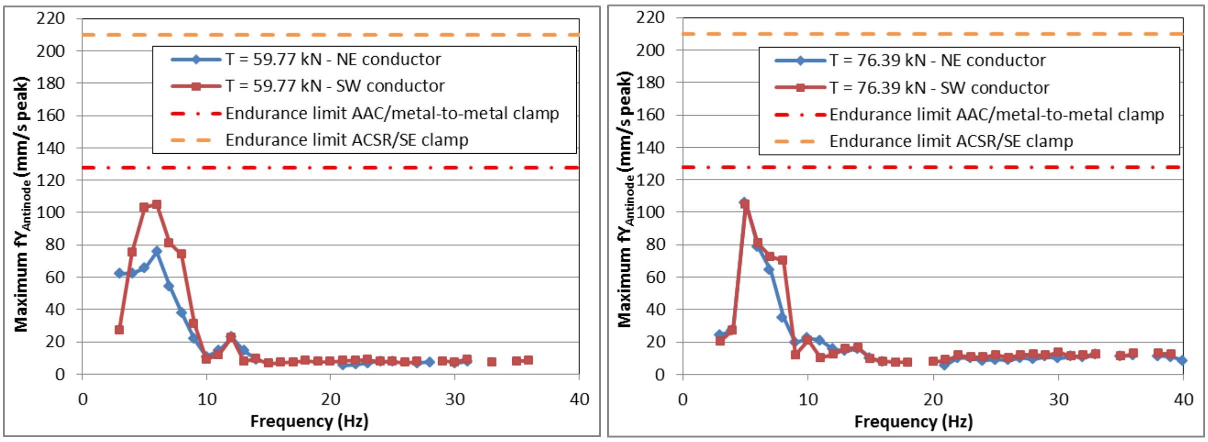

Figure 10 Maximum $fY_{antinode}$

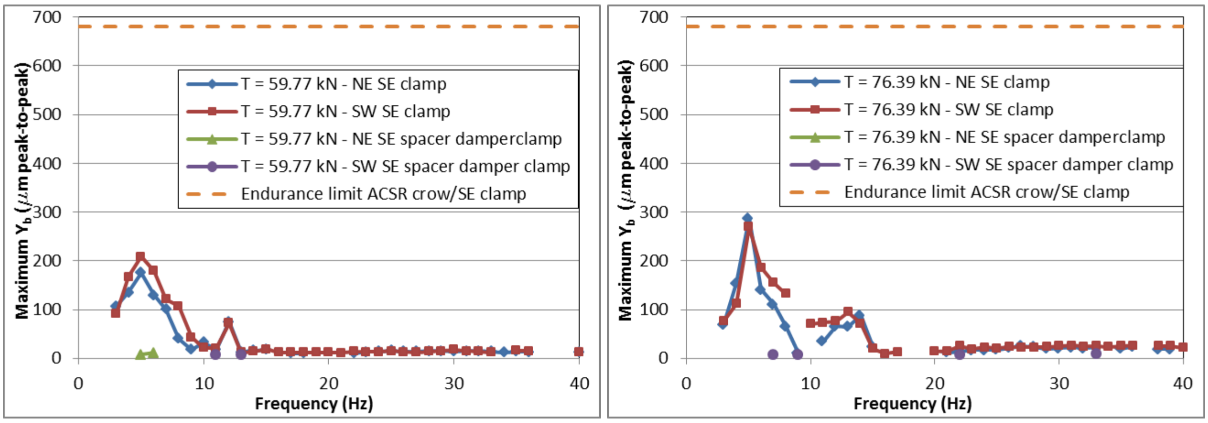

Figure 11 Maximum bending amplitude Y_b

Table 3 Aeolian vibration results

Parameter	Conductor	Results at 59.77 kN	Results at 76.39 kN	Endurance limit
$fY_{antinode}$	NE	76 mm/s peak	106 mm/s peak	AAC/metal-metal clamp: 128 mm/s peak
	SW	105 mm/s peak	105 mm/s peak	ACSR Crow /SE clamp: 210 mm/s peak
Relative displacement Y_b	NE	176 µm p-p	288 µm p-p	ACSR Crow /SE clamp: 680 µm peak-to-peak
	SW	209 µm p-p	270 µm p-p	

Subspan oscillations

In order to prevent damage to conductors due to clashing or severe bending stresses at the spacer damper clamp and to prevent wear of the spacer damper elements, the spacer damper systems were expected to control subspan oscillations within the following limits:

- In any individual subspan, the peak to peak amplitude of each subconductor shall never exceed 300 mm which provides a 46% safety factor before conductor clashing may occur.
- In any individual subspan, the RMS value (Yrms) of each oscillation measurement sample shall be such that fYrms < 90 mm/s (f: frequency of the oscillation (Hz) and Yrms: antinode amplitude (mm)) which corresponds to the rounded value of the endurance limit of an AAC conductor in a metal clamp which is more severe than the same limit in an ES clamp.

Figure 12, Figure 13 and Table 4 show that the values resulting from the two tests are much lower than these limits, so the bundle is well protected against subspan oscillations. As expected, the bundle strung at a lower tension experiences higher subspan oscillations.

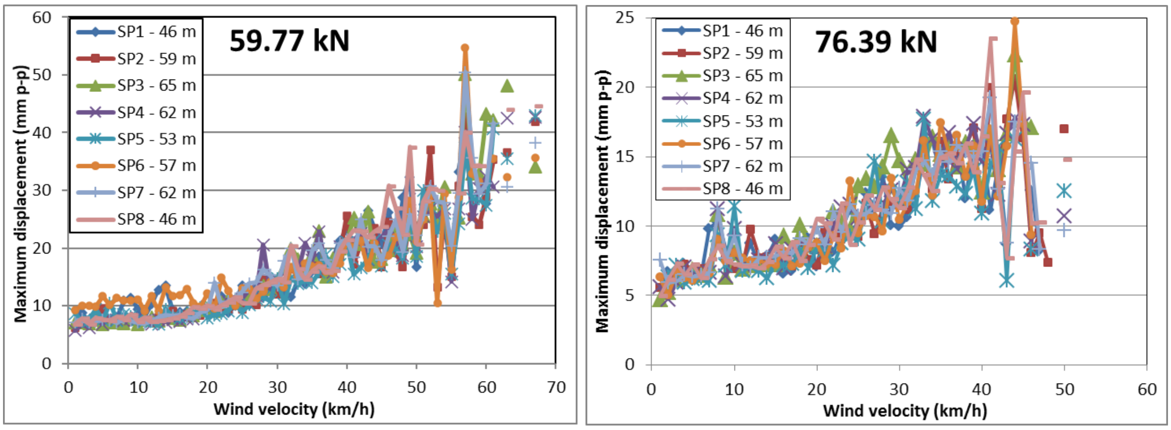

Figure 12 Maximum peak-to-peak displacement in each subspan

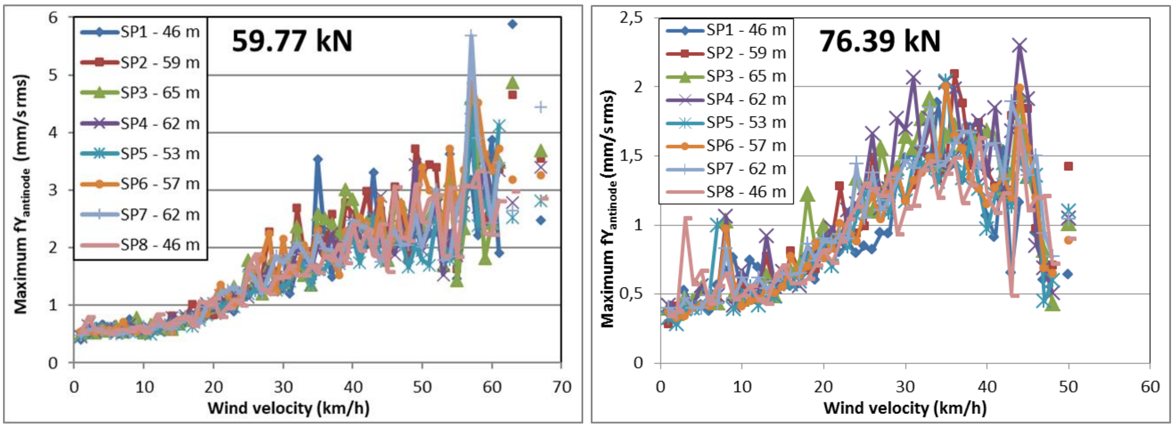

Figure 13 Maxiumum fY_{rms} in each subspan

Table 4 Subspan oscillation results

Subspan	Maximum peak-to-peak displacement (mm peak-to-peak)			Maximum $fY_{antinode}$ (mm/s rms)		
	Results at 59.77 kN	Results at 76.39 kN	Limit	Results at 59.77 kN	Results at 76.39 kN	Limit
1 – 46 m	40	16	300	5.9	1.9	90
2 – 59 m	43	21		4.7	2.1	
3 – 65 m	50	22		4.9	1.9	
4 – 62 m	43	18		4.0	2.3	
5 – 53 m	43	18		4.4	2.0	
6 – 57 m	55	25		4.9	2.0	
7 – 62 m	51	19		5.7	1.9	
8 – 46 m	45	24		3.3	1.7	

Conclusions

This study on 48.69 mm AAC conductors with ES suspension clamps validated the performance of the spacer damper system with 560 mm spacing to protect the twin bundle against aeolian vibrations and subspan oscillations before building the line and investing considerable sums of money.

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