Testing of THERMOLIGN® Suspension Assembly

For

795-kcmil 3M Brand Composite Conductor

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Scope

This report will cover the description and results of laboratory testing of PLP's THERMOLIGN® Suspension and 795-kcmil 3M Brand Composite Conductor (also called ACCR – Aluminum Conductor Composite Reinforced) manufactured by 3M™.

The specific tests included in this report are:

- Aeolian Vibration Test
- Galloping Test
- Unbalanced Load Test
- Turning Angle Test
- Sustained Heat Test
- High Voltage (Corona) Test
- Field Vibration Test

The results for each test are reported separately.

Aeolian Vibration Test

The purpose of this testing is to demonstrate that the Suspension Assembly will protect the ACCR conductor when it is subjected to the dynamic, wind induced bending stress that are associated with aeolian vibration. It is well understood in the industry that conductors strung under tension will vibrate in standing waves when subjected to laminar wind flows in the range of 2 to 12 miles per hour. Within the span itself, this vibration activity has little or no influence on the conductor. However, at the structures where the conductors are supported, this vibration activity produces bending stresses. The peak-to-peak amplitude of the vibration is generally less than the diameter of the conductor itself, but over a number of years, if not properly protected, the conductor can experience fatigue failures. The field failure experience with various suspension assemblies on ACSR (Aluminum Conductor Steel Reinforced) conductors is well documented (e.g. Aeolian vibration of overhead transmission line cables: endurance limits Braga, G.E.; Nakamura, R.; Furtado, T.A.;Transmission and Distribution Conference and Exposition: Latin America, 2004 IEEE/PES, 8-11 Nov. 2004 Page(s):487 – 492). Laboratory aeolian vibration testing at higher levels of activity is commonly used to demonstrate the effectiveness of suspension assemblies under controlled and accelerated conditions.

There is no published industry test specification for aeolian vibration testing of conductors in the laboratory. However, a laboratory specification has been established by the IEEE for the vibration testing of Optical Ground Wire (OPGW). This specification is IEEE 1138. The testing of the ACCR conductor will be in accordance with this specification.

The laboratory test arrangement consisted of a 30 meter span of 795 ACCR conductor, terminated at each end with a PLP Dead-End Assembly (Figure 1). The Suspension Assembly was installed on the span at the mid-point, and secured to a laboratory tower. The Suspension Assembly was elevated to simulate a sag angle consistent with standard field spans. During the test, the tension was maintained at 25% RBS (7,783#) using a tension beam/weight basket assembly. A vibration shaker was used to initiate and maintain a vibration at a frequency of 28 hertz, with an amplitude of 0.37" peak-to-peak, for a period of 100 million cycles (35 days). Visual observations were made daily of the conductor and Suspension Assembly.

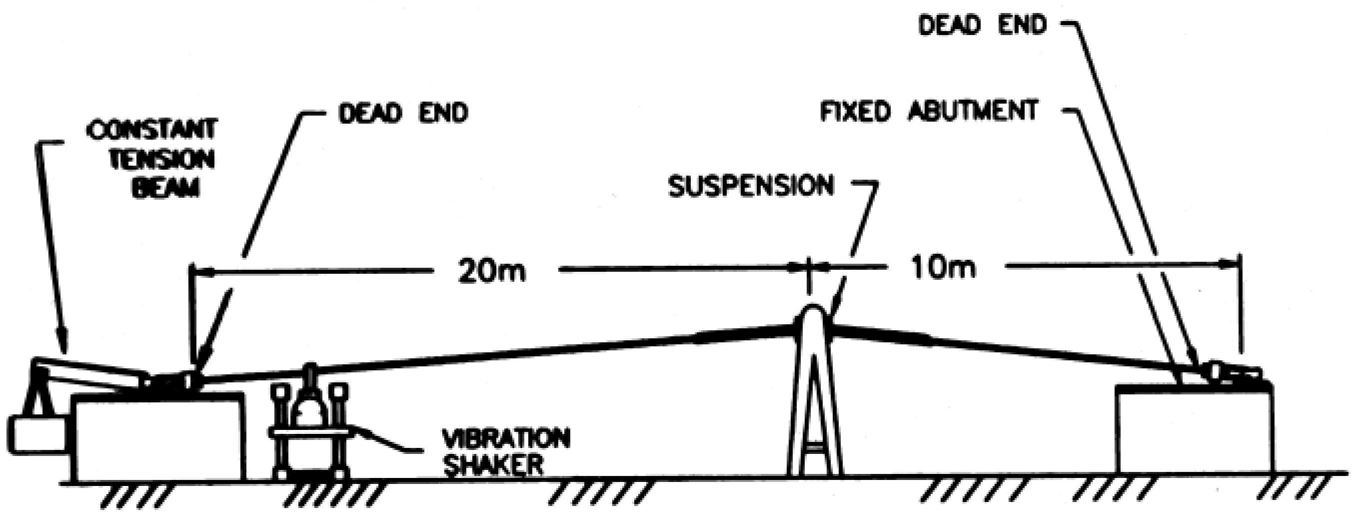


Figure 1 – Aeolian Vibration Test Arrangement

At the completion of the test period the Suspension Assembly was removed and carefully inspected for wear or other damage. The section of the conductor within the Suspension Assembly was cut out of the span and dissected to determine the condition of the Al-Zr strands, the aluminum tape and the composite core.

After 100 million cycles of severe aeolian vibration activity there was no wear or damage observed on the components of the Suspension Assembly or on the components of the ACCR conductor.

Simulated Galloping Test

The purpose of this testing is to demonstrate that the Suspension assembly will protect the ACCR conductor when it is subjected to the potentially high bending stresses associated with conductor galloping. Conductor galloping is generally associated with a coating of ice or wet snow on the conductor. This coating usually forms on the windward side of the conductor surface, creating an aerodynamically unstable profile. Moderate to high winds blowing across the iced conductor can cause the conductor to lift. As the conductor lifts, it rotates slightly, changing the aerodynamic profile, allowing the conductor to fall. This lift/fall action generally "locks" into the fundamental (single loop) natural frequency of the span or into one of the first few natural frequencies (double or triple loop). The resulting motion can be at very large amplitudes, which can produce damaging bending stresses at the conductor support locations.

Galloping is a very random occurrence in the field, and therefore must be simulated in the laboratory. However, as with aeolian vibration, there have been no industry test specifications established for conductors. The IEEE has however, established a laboratory galloping test for Optical Ground Wire (OPGW) as part of IEEE 1138, which will be used for the ACCR.

The laboratory test arrangement consisted of a 30 meter span of 795 ACCR conductor, terminated at each end with a PLP Dead-End Assembly. The Suspension Assembly was installed on the span near the 1/3rd-point, and secured to a laboratory tower. The Suspension Assembly was elevated to simulate a sag angle consistent with standard field spans. During the test, the tension was maintained at 8% RBS (2,524#) using a tension beam/weight basket. An offset crank mechanism was attached to the conductor to drive the longer span into its fundamental (single loop) natural frequency (1.8 hertz, in this case). A peak-to-peak amplitude of 39" was maintained for a period of 100,000 cycles (15.4 hours).

At the completion of the test period the Suspension Assembly and the section of the conductor within the Suspension Assembly were dissected to determine their condition. After 100,000 cycles of galloping activity there was no wear or damage to the components of the Suspension Assembly or to the components of the ACCR conductor.

Unbalanced Load Test

The purpose of this testing is to demonstrate that the Suspension Assembly will protect the ACCR conductor at a support location which is subjected to unbalanced tension loading. By using roller type stringing blocks, the horizontal tension component of the conductor on both sides of a suspension tower are equal when the Suspension Assembly is installed. However, if ice or wet snow builds-up on the conductors and falls off of one span before the other, a substantial unbalance of the tensions on either side of the suspension can occur. The Suspension Assembly will rotate from its vertical position towards the higher tension. A similar condition will exist at the suspension towers adjacent (in both directions) to a broken conductor.

To simulate the effects of unbalanced loading in the laboratory, a 30 ft. span of 795 ACCR was terminated at one end with a PLP Dead-End Assembly and attached to the hydraulic ram of the 55K Tensile Equipment. The Suspension Assembly was installed near the far end of the span in an inverted position, and secured to a short tower on the tensile equipment test frame (see Figure 2).

The unbalanced load is applied to the conductor in increments of 5% of the RBS (1,557#), until a continuous slip at the Suspension assembly occurs. Each load increment is held for 5 minutes. As the unbalanced load increases, the angle of rotation of the Suspension Assembly on the attachment plate also increases. Specifically, the tilt angle was 14 degrees for a 5% load, 18 degrees for a 10% load, 22 degrees for a 15% load and 28 degrees for a 20% load.

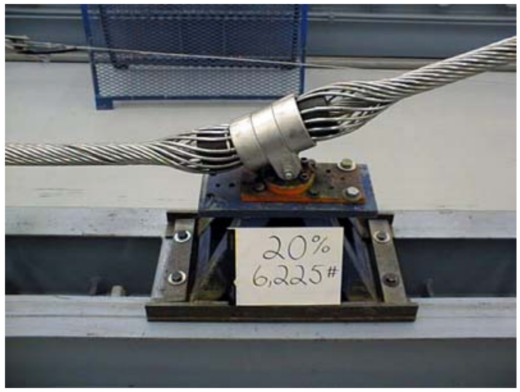


Figure 2 – Unbalanced Load Test Arrangement

Two tests were conducted. For the first test, the Suspension Assembly that was subjected to 240° C for 168 hours was used. The second test utilized a new Suspension Assembly.

For both tests, continuous slipping of the conductor relative to the Suspension Assembly occurred at 20% RBS (6,225#). Afterward, the conductor and Suspension Assembly were dissected, and no damage was observed on any of the conductor or Suspension Assembly components.

Turning Angle Test

It is common practice in the industry to utilize Suspension Assemblies on non-tangent applications for line angles up to and including 30 degrees. For these applications, the supporting structures are configured to allow the insulator string to rotate off of the vertical towards the inside of the angle in the line. The transverse center line of the supporting structure is positioned so that the line angle is split into equal amounts on either side. This produces a balanced turning angle on the Suspension Assembly (15 degrees on each side).

In the laboratory, the turning angle is simulated in the 55K Tensile Equipment. The Suspension Assembly is attached to a tall tower, which is secured to the tensile equipment test frame (see Figure 3).

Figure 3 – Turning Angle Test

For the laboratory turning angle test on the 795 Suspension Assembly for the ACCR conductor, the sample was subjected to a balanced turning angle of 32°, at a conductor tension of 12,460# (40% RBS). The load and angle was held for 5 minutes.

At the completion of the test, the Suspension Assembly and the conductor were dissected, and no damage or distortion was observed on any of the components.

Sustained Heat Test

The purpose of this test is to demonstrate that the performance of the Suspension Assembly will not be affected by continuous operation at an elevated temperature. Specifically, after being exposed to 240C for a period of 168 hours.

The test span consisted of a 65 ft length of 795 ACCR conductor, terminated at both ends with a PLP Dead-End Assembly. A tension of 15% RBS (4,670#) was maintained throughout the test using a tension beam/weight basket arrangement. The conductor was heated by applying approximately 1,500 Amps of AC current, supplied by a pair of heavy duty power supplies.

Thermo-couples were mounted to the conductor and to locations on and within the Suspension Assembly. The maximum temperatures recorded during the 168 hour test period are shown in Table 1.

Location	Max Temperature
Conductor	246C
Elastomer Insert	54C
Outer Rods	78C
Ear of Housing	38C

Table 1

The maximum temperatures shown in Table 1 are well below the maximum rated temperatures of the individual components of the Suspension Assembly. Furthermore, there was no observed deformation or damage to any of the Suspension Assembly components as a result of the sustained heat exposure.

To further demonstrate the performance of the Suspension Assembly after the sustained heat exposure, this sample was used in the unbalanced load test, described earlier in this report.

High Voltage (Corona) Test

The purpose of this testing is to verify that the 795 ACCR conductor Suspension Assembly from PLP will have acceptable performance when subjected to typical transmission line voltages.

The testing was conducted at the NEETRAC indoor high voltage laboratory.

The 795 Suspension Assembly was installed on a single 20’ length of 1.125” tubing for one test. On the second test two Suspension Assemblies were tested, each attached to a 20’ length of 1.125” tubing, spaced 18” apart (See Figure 4). For both tests the Suspension assemblies were positioned 12 feet above the ground plane.

Corona onset (based on visual and RIV measurements) occurred at 289 KV (phase-to-phase) for the single conductor configuration, and at 510 KV (phase-to-phase) for the twin configuration.

For a single conductor configuration, it may be possible to use a 795 conductor on lines operating at voltages up to 230 KV. The twin 795 configuration would commonly be used on 345 KV lines (400 KV internationally). The results of these tests clearly show that the Suspension Assembly will meet these electrical performance requirements.

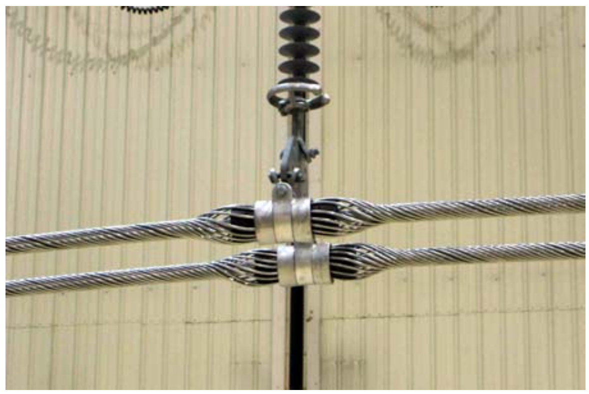


Figure 4 – Corona Test Arrangement

Field Vibration Test

The purpose of this study is to determine, in the field, the effectiveness of the PLP Suspension Assemblies and the Alcoa Vibration Dampers in controlling the bending stresses on the ACCR conductor, when it is subjected to aeolian vibration.

The 1 mile test line in Fargo for the 795 ACCR conductor was specifically chosen because this region is known to have the environmental conditions and flat terrain which can produce severe levels of vibration. A January (2003) study period was chosen because the conductor tensions would be the highest, due to extremely low ambient temperatures. It is well understood that conductor tension plays a major role in anticipated vibration levels. Generally speaking, the higher the tension, the more severe the vibration levels can become.

Over the years, the industry has done considerable work on determining “acceptable” tension levels for conductors to avoid serious vibration. One guideline that has been used is to limit the unloaded tension (without ice or wind) in cold weather (0° F, for example) to a percentage of the conductor’s rated breaking strength (RBS). One limit that has been widely used, and confirmed by field experience and vibration studies, is 20% of the RBS. The existing 954 Kcmil54/7 ACSR (Cardinal) on the WAPA line in Fargo has a published unloaded tension level of 5787#

(17% RBS) at 0° F. The 795 ACCR conductor in the test section was installed to match the sag of the 954 ACSR. This resulted in an unloaded tension at 0° F of about 4500# (14.5% RBS).

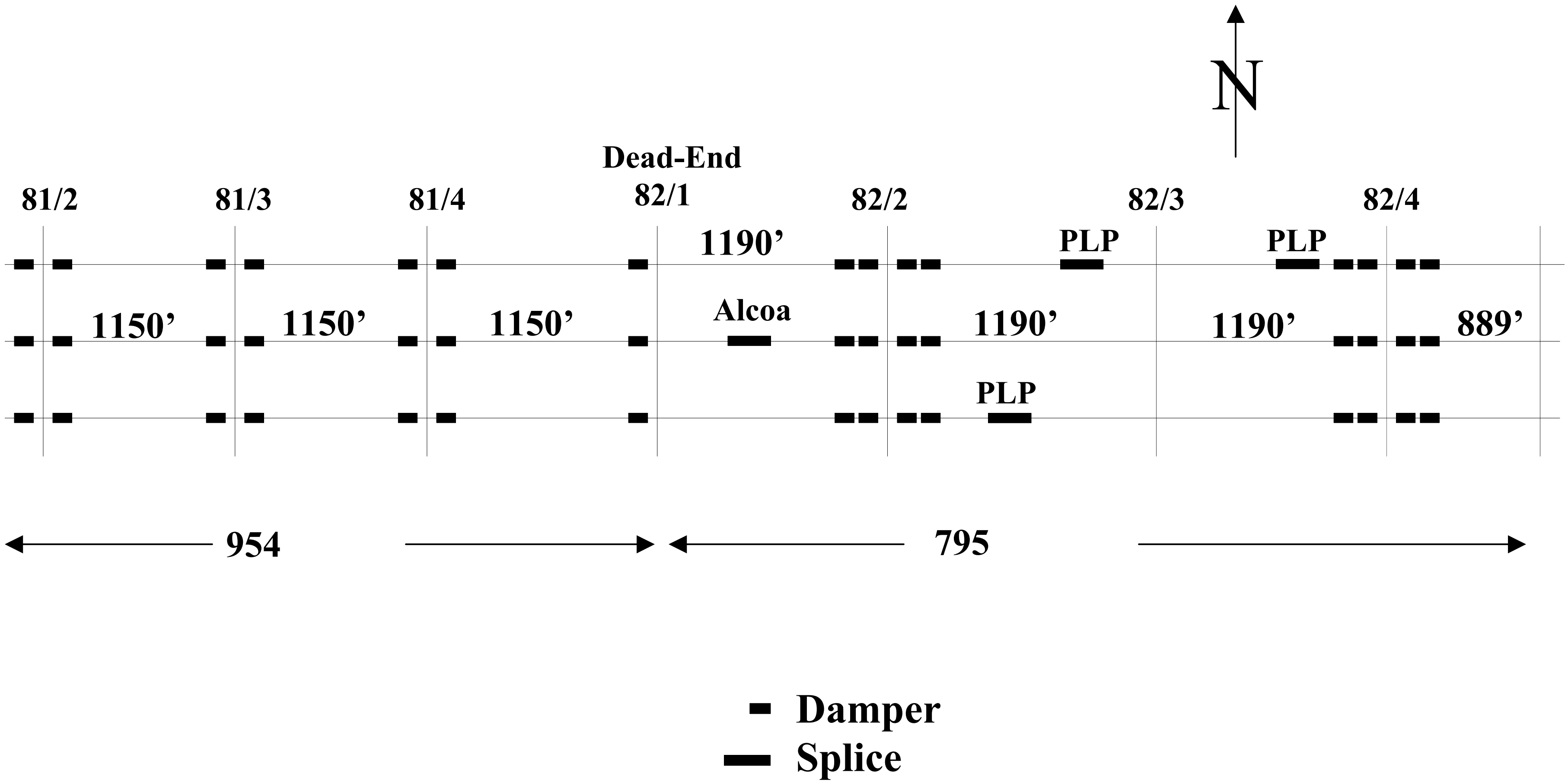
To compare the levels of vibration on the 954 ACSR and the 795 ACCR, both with and without vibration dampers, a total of six vibration recorders were used for the study. The diagram on Page 8 shows the study area beforehand. The configuration of the study area during the vibration study is detailed on Page 9.

The vibration dampers were removed on the North and Center phases of the 954 ACSR conductor for the three spans west of the dead-end tower (82/1) to monitor the un-damped vibration activity. Similarly, the vibration dampers were removed from the Center phase of the suspension towers (82/2 & 82/4) in the 795 ACCR section.

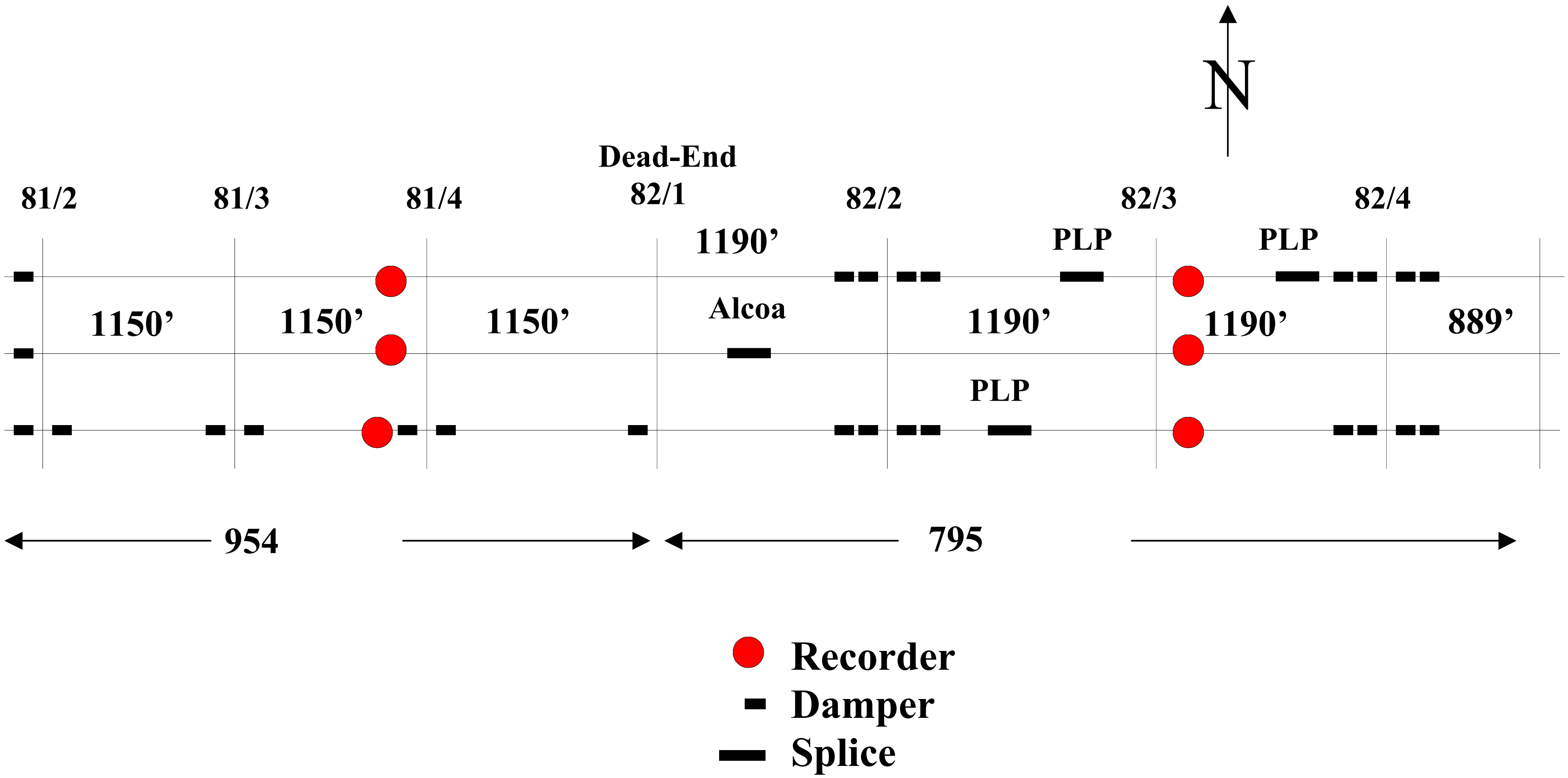
The existing attachment hardware on Tower 81/4 consisted of different suspension clamps on each phase, applied over "wrench-formed" armor rods. To provide a consistent attachment for the vibration recorders, the "wrench-formed" armor rods were removed and replaced with PLP Armor Rods, and new suspension clamps were installed.

The vibration recorders would be mounted to monitor the vibration on all phases on the span between towers #81/3 and #81/4 in the 954 ACSR section, and between towers #82/3 and #82/4 on the 795 ACCR section.

Test Area Prior to Vibration Study



Test Area During Vibration Study



The vibration study was conducted in accordance with IEEE Committee Report, "Standardization of Conductor Vibration Measurements," IEEE Transactions, Vol. PAS-85, 1966, pp. 10-20.

The vibration recorders used in this study are the Ontario Hydro Mechanical Recorder (see Figure 5). These recorders were used because of their ruggedness and overall reliability. The newer electronic vibration recorders (Scolar, Vibrec) are very sensitive to extreme temperatures.

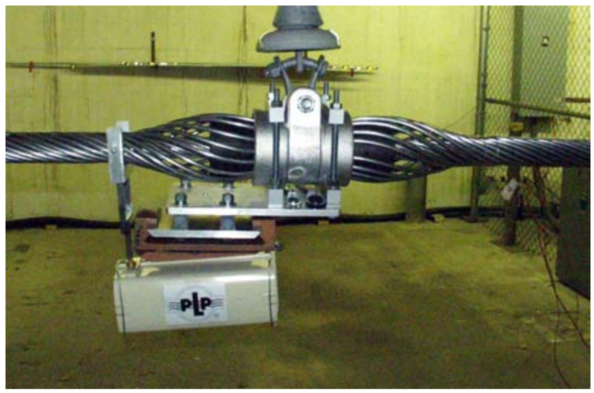


Figure 5 – Ontario Hydro Vibration Recorder
Mounted to Suspension Assembly in Lab

All vibration recorders, including the Ontario Hydro, record one second of vibration activity every 15 minutes, or 96 records each day. The measurements recorded are the amplitude (in mils) of the relative displacement between the suspension assembly and the conductor and the frequency (in Hertz) of the vibration motion. The IEEE adopted 3-1/2" as the standard distance between the attachment fork of the vibration recorder (see Figure 5), and the last point of contact between the conductor and the keeper component of the suspension clamp (the point of maximum bending stress on the conductor). The standard 3-1/2" distance was used on the 954 ACSR conductor during this study, however, for the 795 ACCR conductor a longer distance had to be used, due to the design of the PLP Suspension Assembly. With the cushioned PLP Suspension Assembly the maximum bending stress on the conductor occurs in the center of the suspension. This has been verified in the past with strain gauge measurements made in the laboratory on PLP ARMOR-GRIP® Suspensions. The result of using a longer fork distance is an increase in the measured amplitude, when compared to the 3-1/2" distance. In the final analysis, the difference in the fork distance is factored into the standard IEEE report curves.

In the case of the Ontario Hydro recorders, the vibration activity is "scratched" onto a plastic film, which is advanced by a motor for one second every 15 minutes. After the completion of the vibration study (usually two weeks), the film is loaded into a calibrated microfilm reader, and a technician records the amplitude and frequency of each record.

The six recorders were successfully installed on Thursday January 16th, and left in place until February 5th. At that time, the recorders were removed and the vibration dampers were re-installed in the test area (see page 8).

The temperatures and wind velocities (highs and lows) for the Fargo area during the two week period beginning January 16th are shown in Table 2.

	Temperature, F		Wind, MPH	
Date	High	Low	High	Low
01/16	13	-5	15	3
01/17	23	-10	30	3
01/18	15	-2	29	7
01/19	15	1	16	calm
01/20	4	-7	16	calm
01/21	4	-9	13	6
01/22	-2	-15	14	3
01/23	-3	-21	9	calm
01/24	12	-3	16	8
01/25	4	-6	18	9
01/26	1	-16	17	calm
01/27	29	3	35	calm
01/28	30	14	22	3
01/29	29	-11	18	calm
01/30	33	16	18	5

Table 2

Each record from the vibration recorder with an amplitude above some minimum value (3mils for the 954 suspension clamps and 10 mils for the 795 ACCR Suspension Assemblies) is accumulated on a graph of amplitude vs frequency. The minimum recorded value for the Suspension Assembly is higher because of the longer fork distance required (discussed earlier). The records with amplitudes below the minimum are not recorded because they represent insignificant amount of bending on the conductor at the suspension point.

The amplitude/frequency graphs for the undamped Center phases of both the 954 ACSR and the 795 ACCR conductors are shown in Figures 6 and 7. The graphs for the phases with dampers are not included because nearly all of the records fell below the minimum amplitude level.

Figure 6

Amplitude vs Frequency, Number of Records

954 ACSR Conductor

Tower 81/4 Center Phase – No Dampers

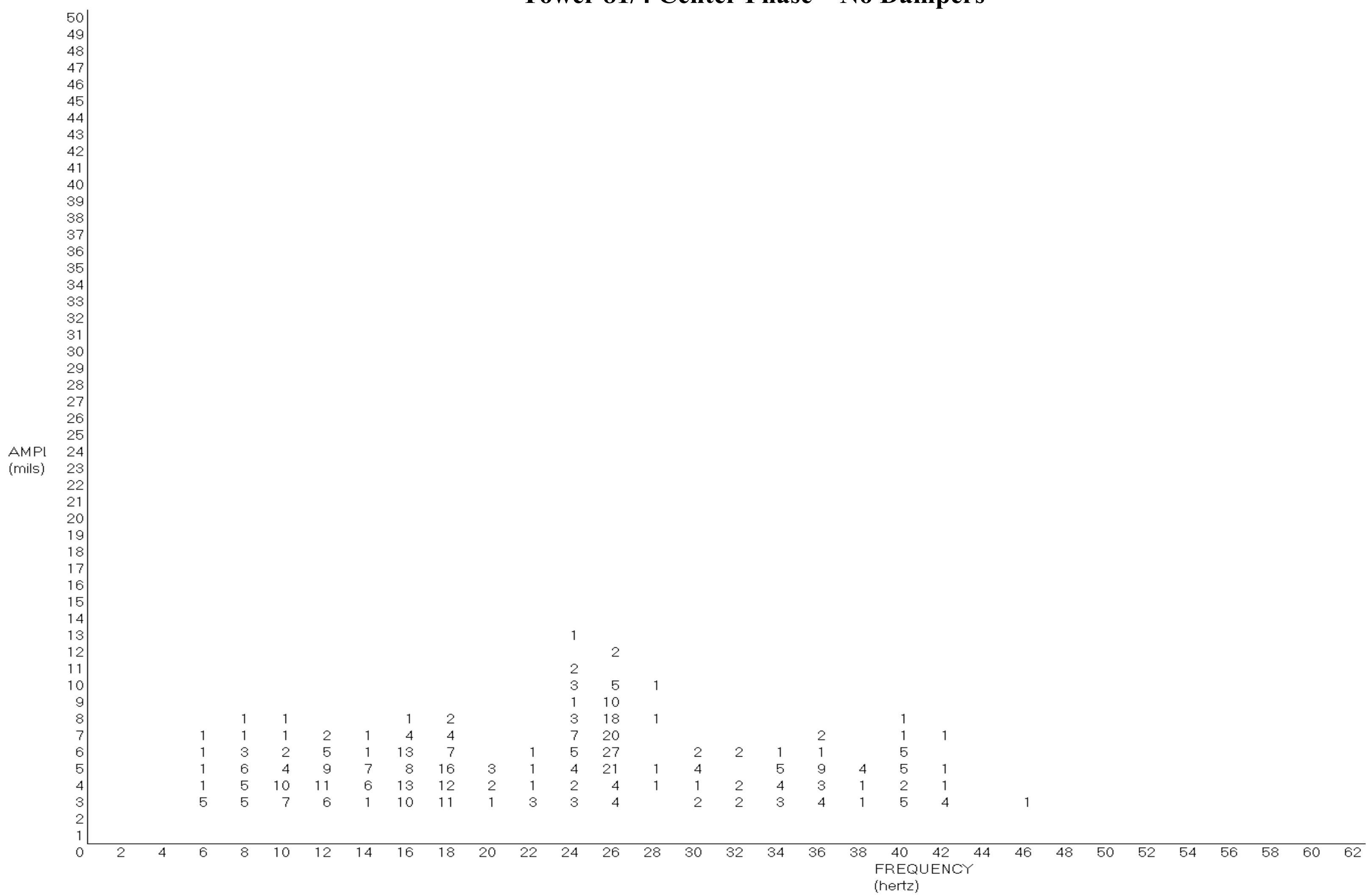
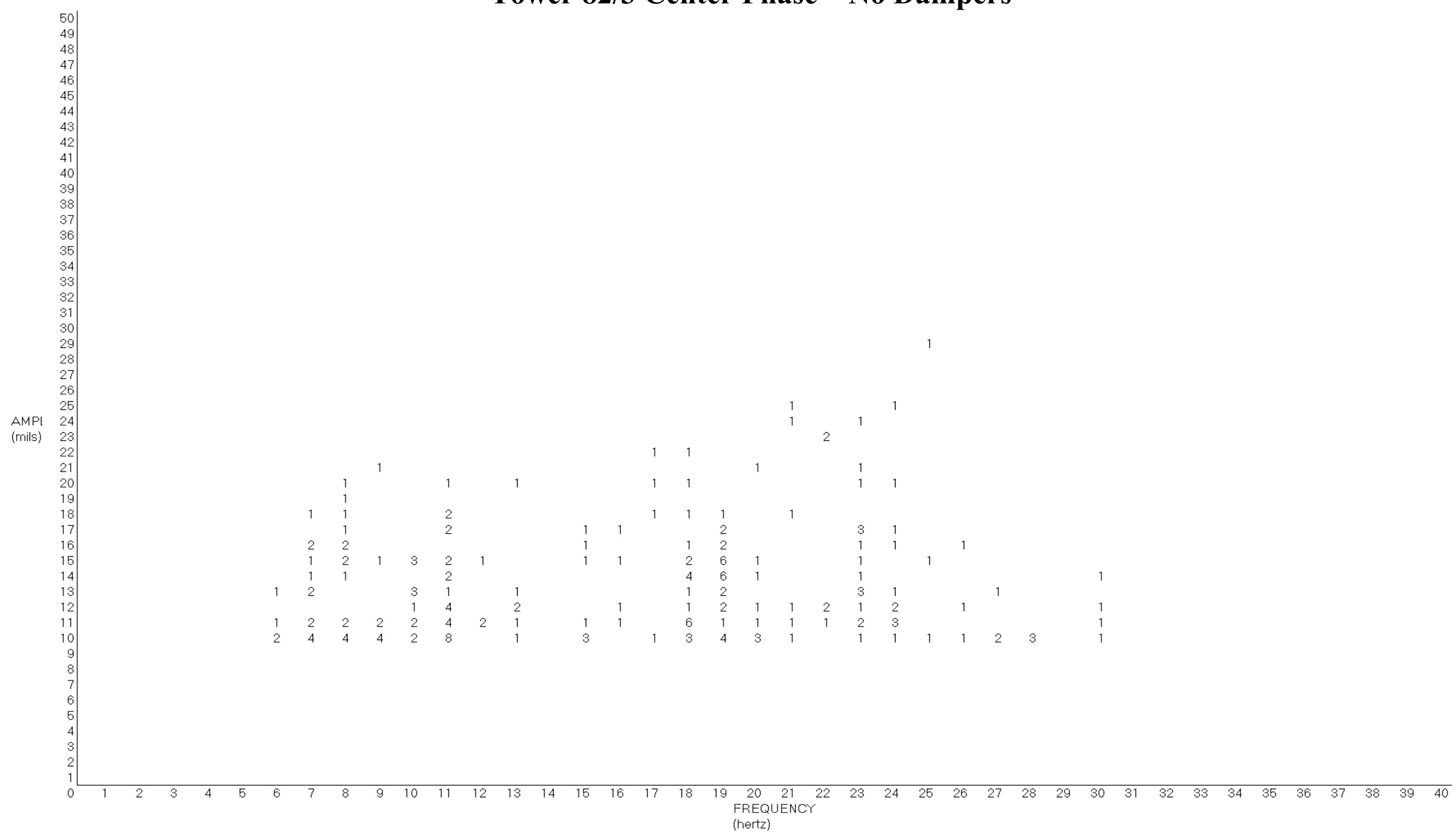


Figure 7

Amplitude vs Frequency, Number of Records
795 ACCR Conductor
Tower 82/3 Center Phase – No Dampers



The IEEE has established a standard method for the presentation of results for field vibration studies. This standard is a graph of mega-cycles per day (MC/Day) accumulated on the y-axis, and micro-strain on the x-axis. The mega-cycles per day is calculated from the total number of records at a specific amplitude. An assumption is made that the vibration activity that is recorded for the one second interval remains the same over the entire 15 minute period (until the next record is taken). Each record is multiplied by the frequency and than by 900 (seconds in 15 minutes) to get the total number of vibration cycles in the 15 minute period. All the records (multiplied by frequency than 900) for each amplitude level are accumulated and divided by 1,000,000 to get the MC/Day value. This is repeated for each amplitude level.

The micro-strain is the dynamic bending strain (inches/inch) on the outer strands of the conductor itself. The micro-strain is calculated from the measured amplitude and a "strain conversion factor" that had been developed in the 1950s' by J. Poffenberger and R. Swart of PLP. The strain conversion factor was developed from extensive strain gauge measurements of conductors in the laboratory. Since the ACCR conductor is a unique design, a conservative strain conversion factor based on the theoretical properties of the conductor was used. Future laboratory testing using strain gauges would be needed to confirm this value.

The graph in Figure 8 shows the results for all three phases of the 795 ACCR conductor at Tower #82/3. The two dots near the bottom of the y-axis are the phases with the vibration dampers. Figure 9 shows the activity of the 954 ACSR conductor at Tower #81/4. The South phase with the dampers had no recorded amplitudes above the minimum value.

The graph in Figure 10 is a summary of all the study results on the same graph. It is clear from this graph that the bending strain (micro-strain) on the 795 ACCR conductor is, for the worst case, 40% to 50% below that of the 954 ACSR for the same study period. This is mainly due to the protection provided by the PLP Suspension Assembly. The inner and outer rods of the PLP Suspension Assembly take a large percentage of the bending stress, thus reducing the stress on the conductor by 40% or more.

The amount of bending strain on the 95
4 ACSR conductor, without dampers, is in the moderate range (280 micro-strain). This value is somewhat below the fatigue endurance limit for ACSR conductors. The fatigue endurance limit is a value (micro-strain) at which the conductor can handle, regardless of the accumulated number of cycles. Above the endurance limit, there is a finite number of cycles, after which the conductor will begin to experience fatigue failures in the outer strands. ACSR conductors in the field that have been subjected to micro-strain levels above 400 have been known to experience fatigue breaks in as little as one or two years.

It is also clear from the results shown in Figures 8-10 that the vibration dampers are effective in reducing the levels of vibration on both the ACSR and ACCR conductors.

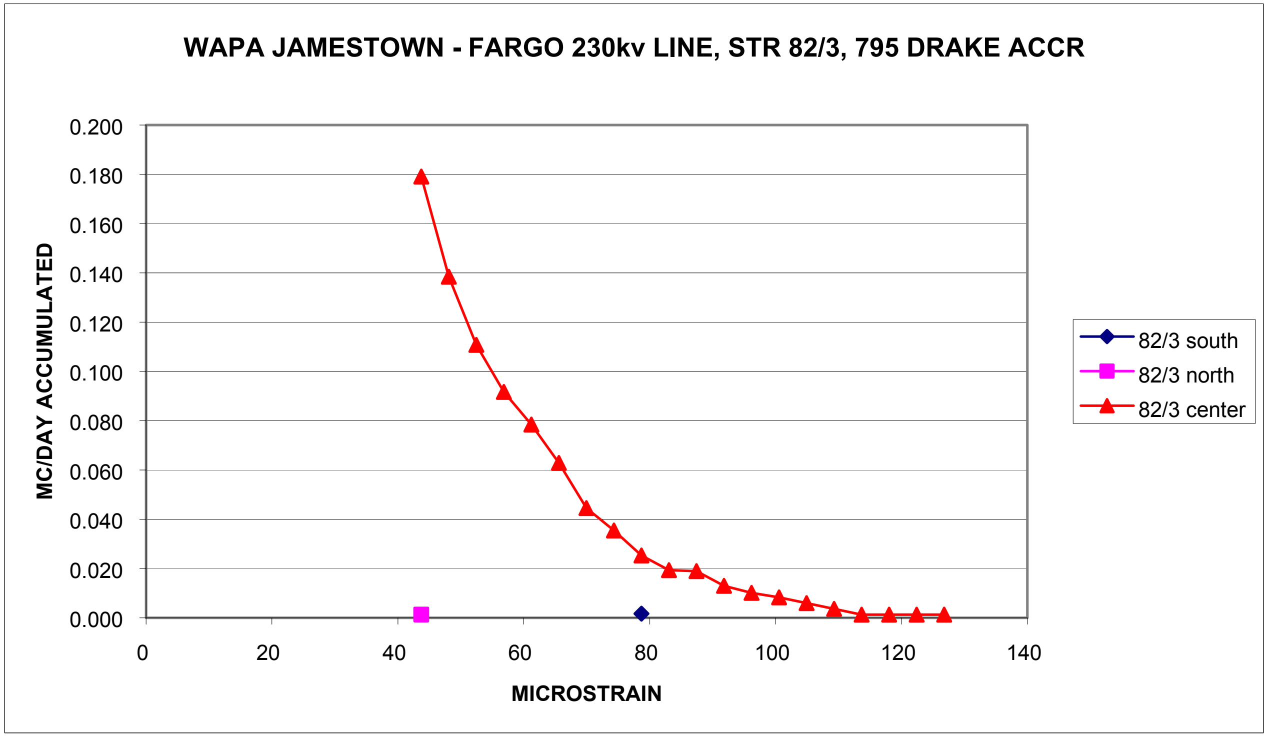


Figure 8. Plot of mega-cycles per day (MC/Day) vs. micro-strain for all three phases of the 795 ACCR conductor at Tower #82/3

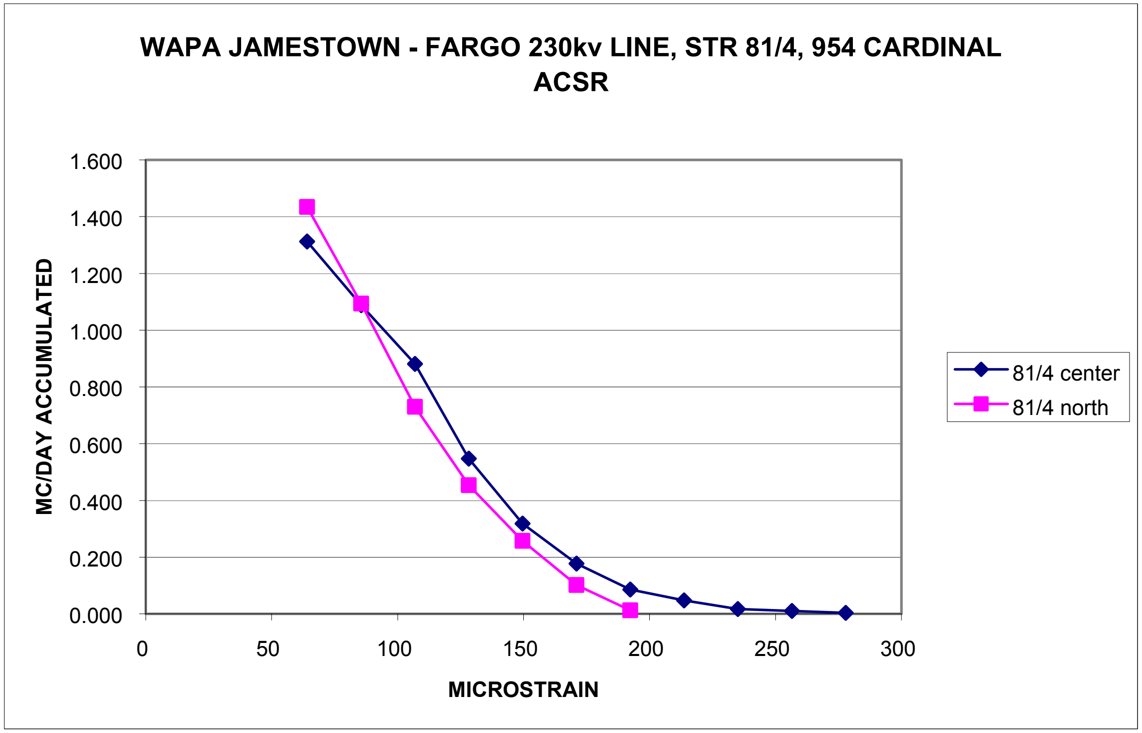


Figure 9. Plot of mega-cycles per day (MC/Day) vs. micro-strain for undamped phases of the 954 ACSR conductor at Tower #81/4

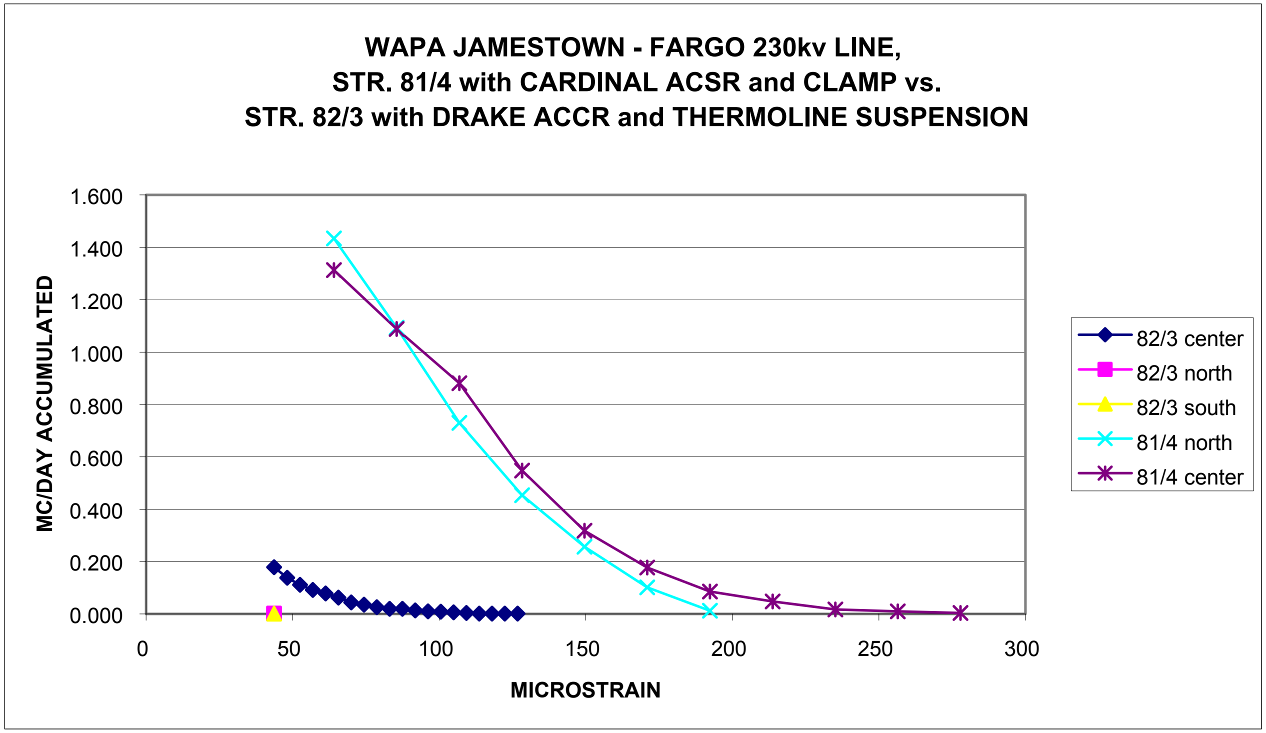


Figure 8. Plot of mega-cycles per day (MC/Day) vs. micro-strain, comparing ACCR (tower 82/3) with ACSR (tower 81/4). The bending micro-strain on the 795 ACCR conductor is, in the worst case, 40% to 50% below that of the 954 ACSR for the same study period. This is mainly due to the protection provided by the PLP Suspension Assembly.

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