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Testing and Validation of Implosive Splices for Passing Through Stringing Travelers

A Case Study of SCE's TRTP Project

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***Abstract*—Transmission line construction with traditional splice technology is environmentally invasive. Traditional splices require temporary grips to pull conductor, and then access to the grip location for permanent splice installation with hydraulic tooling. Installing a permanent implosive splice that can be pulled through stringing travelers eliminates the need to access temporary grip locations. However, allowing splices to go over stringing travelers raises concerns related to connection integrity, namely: bending of the connector, and conductor stress concentrations at the mouth of the rigid splice. These factors are incorporated in so-called stringing charts, which provide the parameters for safely pulling a specific implosive splice through stringing travelers. To determine their effectiveness, a unique test program was developed to validate the stringing charts for splice connections under various tensions and angles. Results of the testing revealed that no strength or electrical degradations occur when stringing conditions were within the parameters of the stringing charts.**

***Index Terms*—construction, electrical products, materials testing, power transmission, transmission lines, implosive connection, stringing traveler.**

I. INTRODUCTION

Many transmission line projects encounter strict environmental regulations. SCE's Tehachapi Renewable Transmission Project (TRTP), a $2 billion project to bring wind-generated energy to the Los Angeles basin, is one such project, which served as the case study providing background to the test development program described herein. The routing of the TRTP line takes it across the San Gabriel Mountains, and through the environmentally sensitive Angeles National Forest, located north of Los Angeles. As a result, new methods are needed to help reduce the construction footprint, allowing the project to go through to completion, yet minimizing the disturbance to the natural environment. Implosive splice technology is one way SCE is looking to minimize environmental impact.

Traditional, hydraulic-tool installed splice connections require temporary grips to pull the conductor into place through the stringing travelers. Then, access roads (or aerial work in the remotest locations) are needed to get equipment and crews to the temporary grip locations to install the permanent splice connections with hydraulic tooling.

Implosive splice technology was originally designed to be pulled through stringing travelers. This functionality allows the permanent splice to be installed at the tensioner equipment, where an area has already been cleared for construction. Then, pulling that splice through the stringing travelers eliminates any further egress into remote locations to replace temporary pulling grips.

Pulling a splice connector through a stringing traveler, however, raises concerns for the final connection integrity. Further, in the case of TRTP, the mountainous terrain would require conductor pulls over long spans with steep vertical variations. This would subject the splices to high tensions and large vertical angles which could potentially place high stresses on the splice/conductor interface.

With these known application parameters, a series of unique tests were developed in an attempt to validate connector-specific stringing charts that were developed for safely pulling the associated implosive splice through stringing travelers.

II. TESTING PHILOSOPHY

Stringing charts, as shown in Fig. 1, are created based on splice connector design characteristics and application parameters. These charts are specific to a single connector design and cannot be applied across a product family, or across the industry. Given the implosive splice design is set, thus generating the tailored stringing chart, the test program was developed around performance of the splice after being subjected to conditioning according to stringing chart extremes.

By testing data points at the upper limit, if the test results met or exceeded the minimum pass/fail criteria, the stringing charts would be validated. In turn, the implosive splices would be able to be used with confidence, provided specific tension and vertical angle combinations fall within the stringing chart recommendations.

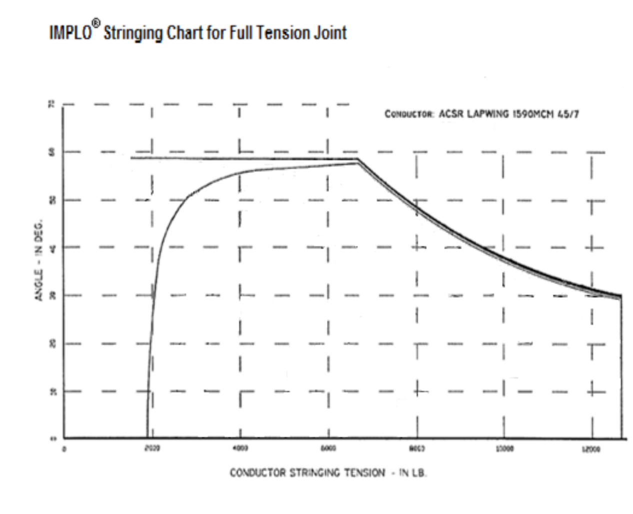

Figure 1. IMPLO splice stringing chart - 1590 ACSR Lapwing.

Four (4) splice/conductor samples were made for each of 1590 ACSR Lapwing and 2156 ACSR Bluebird conductors. The samples consisted of 12.2 m (40 ft) lengths of conductor with the implosive splice at the center of the sample and compression deadend fittings at each end. Three (3) of each of the 1590 and 2156 samples were run through a series of two tests. In the first test, the splices would be pulled through a stringing traveler at various vertical line angles and tensions. The test combinations of vertical line angles and tensions would be at the envelope of the stringing chart curves. In the second test, the splice/conductor sample would be pulled in a tensile test to failure. The fourth 1590 and 2156 sample was not pulled through the traveler and was subjected to only the tensile test to failure. This fourth sample would serve as a control to compare an untested splice/conductor sample to the Rated Tensile Strength (RTS) of the conductor. By comparing the results of the tensile tests with the RTS of the conductor, there would be an indication as to the strength degradation (if any) the splice/conductor has by being pulled through the traveler.

Subsequent to the mechanical testing, dissections of the tested splices were made to determine the quality of the implosive splices.

III. TEST PROCEDURE

The testing procedure consisted of two sequential tests.

In the first test (conditioning sequence), the implosive splice was pulled through a traveler at specified combinations of vertical line angles and tensions corresponding to desired stringing chart curve values. The test setup is shown in Fig. 2. In the second test the conductor and splice were subjected to tensile loading to failure (as shown in Fig. 3).

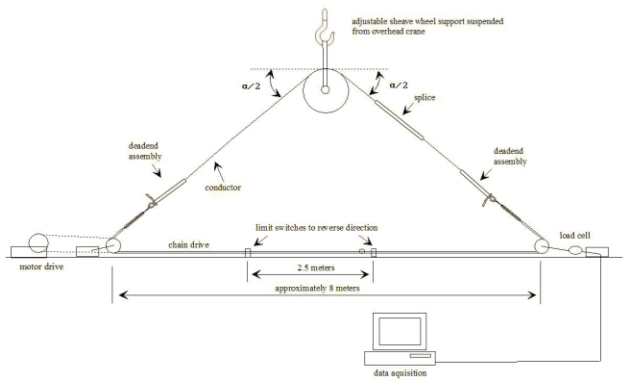

Figure 2. Schematic of tension vs. angle testing

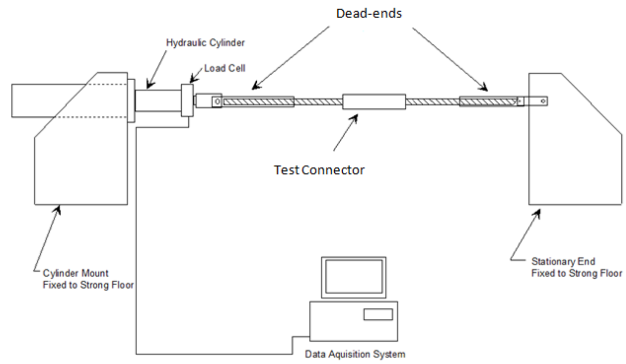

Figure 3. Schematic of tensile testing of implosive splice..

IV. Test Pass/Fail Criteria

Three (3) pass/fail criteria were developed to provide an objective means to determine if the results of the tests were successful. The pass/fail criteria for the tests were defined as follows:

1) No bending of the implosive splices
2) No damage of the conductors at the mouth of the splice after the tension vertical angle testing
3) The tensile strength as tested in accordance with ANSI C119.4, clause 7.3.4 shall be equal to or greater than 95% of the rated strength of the conductor.

V. Test Results

Table 1 summarizes the results of the testing performed on the implosive splices.

Criteria 1: No bending of the implosive splice

As a splice passes over the traveler, there is a point when the conductor will apply a downward force from each end of the splice. The combination of forces acting on the splice will attempt to bend or break the splice.

Result: No bending was seen or measured on any of the tested implosive splices within this test group.

Criteria 2: No damage of the conductors at the mouth of the splice after tension vertical angle testing.

Conductor strands at the mouth of the splice are at the interface between the very stiff splice and the flexible conductor. Thus, that area sees the highest stress concentrations and represents the area most likely to see conductor damage during a stringing operation.

During the testing process, inspections of the splices and the conductor strands at the mouth of the splices were made at the end of each pass through the sheave for a given tension and vertical angle. The purpose of the inspections was to determine the extent of damage, if any, to the conductor strands.

Result: No conductor strand damage was observed in all of the tests through the various vertical angle tests. However, localized flattening of the outermost strands was observed to varying degrees depending on the tension and vertical angle of the tests. For the tests performed at the 30 deg vertical angle, little or no flattening was observed. For the tests performed at the 40 deg vertical angle, minor localized flattening was observed. For the tests performed at the 50 deg vertical angle, localized flattening of the conductor strands was observed, as seen in Fig. 4.

LAPWING						**BLUEBIRD**					
Sample No.	Vert Angle (deg)	Initial Tension (lbs)	No. of Passes over sheave	Peak Tension (lbs)	RTS	Sample No.	Vert Angle (deg)	Initial Tension (lbs)	No. of Passes over sheave	Peak Tension (lbs)	RTS
		5,000	2F 2B	6,319 6,551				5,000	2F 2B	6,720 7,115	
1	29.0	7,000	2F 2B	8,371 8,685	39,630 93.9%	1	30.2	6,500	2F 2B	8,202 8,624	63,173 104.8%
		8,000	1F 1B	9,369 9,787				7,500	1F 1B	9,096 9,876	
		5,000	2F 2B	7,138 7,617				4,800	2F 2B	7,492 8,246	
2	39.9	6,200	1F 1B	8,375 9,006	38,145 90.4%	2	40.7	6,200	2F 2B	8,796 9,496	61,012 101.2%
		6,800	1F 1B	8,948 9,623							
		2,500	1F 1B	- -				3,000	1F 1B	6,746 7,249	
3	50.0	3,500	1F 1B	6,703 6,999	39,480 93.6%	3	50.0	4,500	1F 1B	8,241 9,011	54,537 90.4%
		3,700	1F 1B	6,698 7,400							
4					42,841 101.5%	4					63,557 105.4%

TABLE I. RESULTS OF IMPLOSIVE SPLICE TESTING

Criteria 3: The tensile strength as tested in accordance with ANSI C119.4, clause 7.3.4 shall be equal to or greater than 95% of the rated strength of the conductor.

A test to determine the integrity of splice connections that have been passed through a stringing traveler has never been developed. Once the splices were subjected to the conditioning of passing through a traveler, it was necessary to determine the mechanical integrity of the samples. The ANSI C119.4 tensile strength criteria was selected as the baseline.

Result: Referencing the results in Table 1, it is that as the splice contacts and then passes over the traveler, there is a jump in the conductor tension. The highest tension at the jump was considered the maximum tension of the tests.

In reviewing the results of the tensile tests in Table 1, it is noted that the conductor samples failed in the range of 90.4% to 104.8% RTS. Four of the six samples failed below the 95% RTS criteria. After reviewing the data, it was noted that the sample size was extremely small, and more samples would need to be tested to provide an accurate statistical measure against the 95% RTS criteria.

Figure 4. Localized conductor strand flatenning at 50 degree tensile test. (1590 ACSR Lapwing splice)

In addition, the current design code allowable design conditions of a transmission line were also examined. Per the NESC code the maximum design tension of a conductor should not exceed 50% RTS. Thus, while 95% RTS was established as the test criteria, realistically the maximum tension which a conductor will see over its life would never exceed 50% RTS and would most probably be much lower than 50% RTS. As such, a reduction of approximately 5% from the 95% criteria would not represent a significant reduction in strength when compared to the maximum design tension of a transmission line.

It is also noted that the rigid configuration of the lab set up for performing this testing did not completely correspond to an actual stringing operation. Without the play in the conductor that would normally be present in the field, the lab test was more stressful at particular points, thus increasing the margin of safety between the results obtained and application.

As such, this criterion was also passed.

VI. Implosive Splice Dissection

Subsequent to the mechanical testing, the implosive splices were dissected. The dissections would provide an indication as to the quality of the splice connection that is achieved through the implosive process. Figures 5 and 6 detail the results of the dissections.

The results of the dissection analysis show that the implosive splices from this tested sample group provide a uniform and very dense connection with no voids. Figure 5 shows a cross-sectional dissection of the Bluebird implosive splice. The cross-section appears as a uniform solid piece with the splice and conductor being essentially formed into a homogeneous unit. Figure 6 shows a longitudinal dissection of the Bluebird implosive splice. This dissection shows that the homogeneous unit of the splice is consistent throughout the length of the splice.

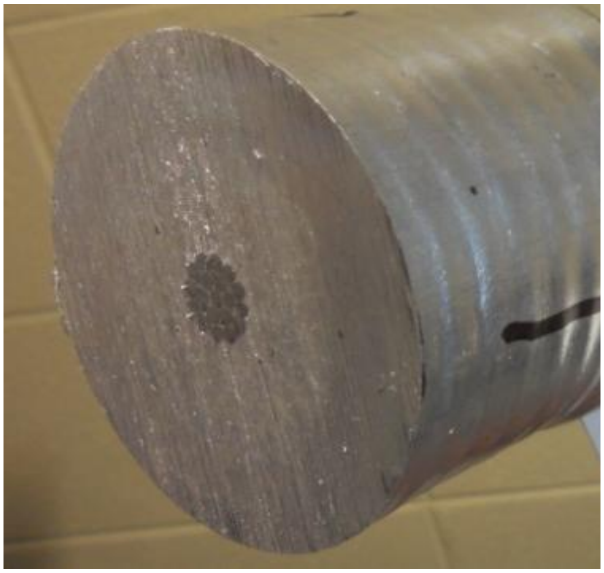

Figure 5. Cross-sectional dissection of Bluebird implosive splice.

VII. Conclusion

Based on results of the mechanical and electrical testing, along with the analysis of the implosive splice dissections, it was determined that the implosive process, as used for this testing, results in a very consistent splice connection. The test results also indicate that there is very little or no reduction in strength of the splice as it is pulled through the travelers. In many instances of the tensile testing, the conductor failed at the deadend connection rather than at the splice. When combined with the analysis of the tests that did exceed 100% RTS, there is indication that the strength of this implosive splice design could be consistently greater than the RTS of the conductor after passing through stringing travelers.

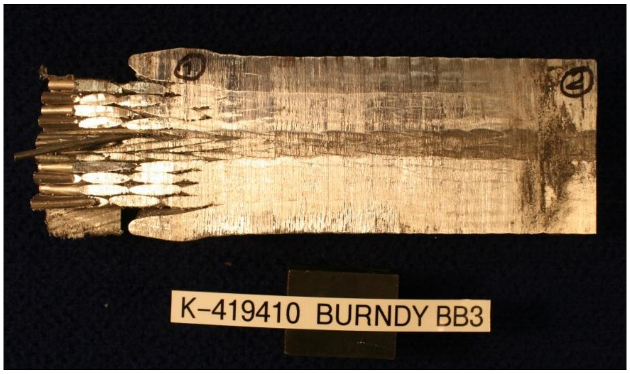

Figure 6. Longitidunal dissection of Bluebird implosive splice.

The results of this testing also validated the stringing charts developed for this specific implosive family of splices. Stringing charts are necessary when considering pulling splice connectors through stringing travelers. By selecting maximum points at the angle/tension limits, this testing showed these curves represent an acceptable application window for the splices tested. To broaden this test program to other splice connection designs, a similar strategy using specific stringing charts would be required to ensure the connections are tested within design capabilities.

Having performed to acceptable levels, these implosive splices for 1590 Lapwing and 2156 Bluebird were specified for use in application on the TRTP for pulling through the travelers subject to the following:

- The tension and vertical line angles of the pull shall be within the maximum allowable envelope as detailed by the stringing charts.
- The diameter of the sheave shall be equal to or greater than the minimum sheave diameter as indicated on each stringing chart.
- The installation of the implosive splices shall follow the manufacturer's recommendations.

Figure 7. Completed section of the TRTP located in the Angeles National Forest.

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