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Multidirectional breakaway connection for catenary poles

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Abstract

Additional passenger fatalities and injuries can occur during railcar collisions and derailments due to interaction with wayside structures, such as catenary poles that support overhead line equipment (OLE) over rail tracks. The Federal Railroad Administration of the United States Department of Transportation funded Protection Engineering Consultants (PEC) to develop an alternative base connection for steel catenary poles that can disengage under dynamic impact loads from derailed railcars. PEC devised a friction-based connection with multi-directional breakaway capability, that can be used instead of a typical fixed baseplate connection. This breakaway connection acts as “fusible link” between the catenary pole and the foundation. When the fusible link is overloaded with force of an impact from a derailed railcar, the base of the catenary pole is released from the foundation thereby mitigating the consequences to the railcar and to its passengers. The resistance of the connection under impact loads can be tuned by adjusting the clamping load at the slip surfaces, while appropriately chosen friction materials ensure a reliable and predictable behaviour. Following the initial concept development as informed from analytical and detailed numerical simulations, initial testing on a full-scale breakaway connection prototype was performed under static and dynamic impact loads. These initial tests highlighted the importance of the frictional resistance of the materials used at all the contact surfaces. Various friction material combinations were tested with a custom test apparatus to determine material pairs that provide reliable and predictable frictional resistance for the relatively high contact pressures of the breakaway

connection. These friction tests clearly indicated that stainless steel (SS) over bronze (BR) provide steady and predictable frictional resistance. Subsequently, the breakaway connection prototype specimen was upgraded with these new friction materials. Thin sheets of SS and BR were attached to the contact interfaces of the specimen that was subsequently tested under a new series of static and dynamic impact tests. The tests demonstrated the improved performance of the connection prototype and its ability to disengage when impacted with loads above a certain threshold, while remaining fully engaged under design-basis operational loads such as gravity and wind. The test results were used to inform detailed numerical models, which were proven to capture the connection response with high accuracy.

Keywords: breakaway connection, catenary pole, derailment, impact.

1 Introduction

Additional passenger fatalities and injuries can occur during railcar collisions and derailments due to interaction with wayside structures, such as catenary poles that support overhead line equipment (OLE) over rail tracks. The Federal Railroad Administration (FRA) of the United States Department of Transportation (USDOT) funded Protection Engineering Consultants (PEC) to develop an alternative base connection for steel catenary poles that can disengage under dynamic impact loads from derailed railcars. PEC devised a friction-based connection with multi-directional breakaway capability that can be used instead of a typical fixed baseplate connection. This breakaway connection acts as “fusible link” between the catenary pole and the foundation. When the fusible link is overloaded with force of an impact from a derailed railcar, the base of the catenary pole is released from the foundation thereby mitigating the consequences to the railcar and to its passengers.

A view of the breakaway connection can be seen in Figure 1. The basis of the disengagement mechanism relies on the presence of the v-notches at the cap-plates that are attached to the catenary pole and its base. When the catenary pole is overloaded with lateral impact loads, the v-notches allow the bolts to slide through them and at increasing relative slip they completely disengage, thereby releasing the catenary pole from its base. The resistance of the connection under impact loads can be tuned by adjusting the number and pre-tension level of the bolts at the slip interface, while appropriately chosen friction materials ensure a reliable and predictable behaviour.

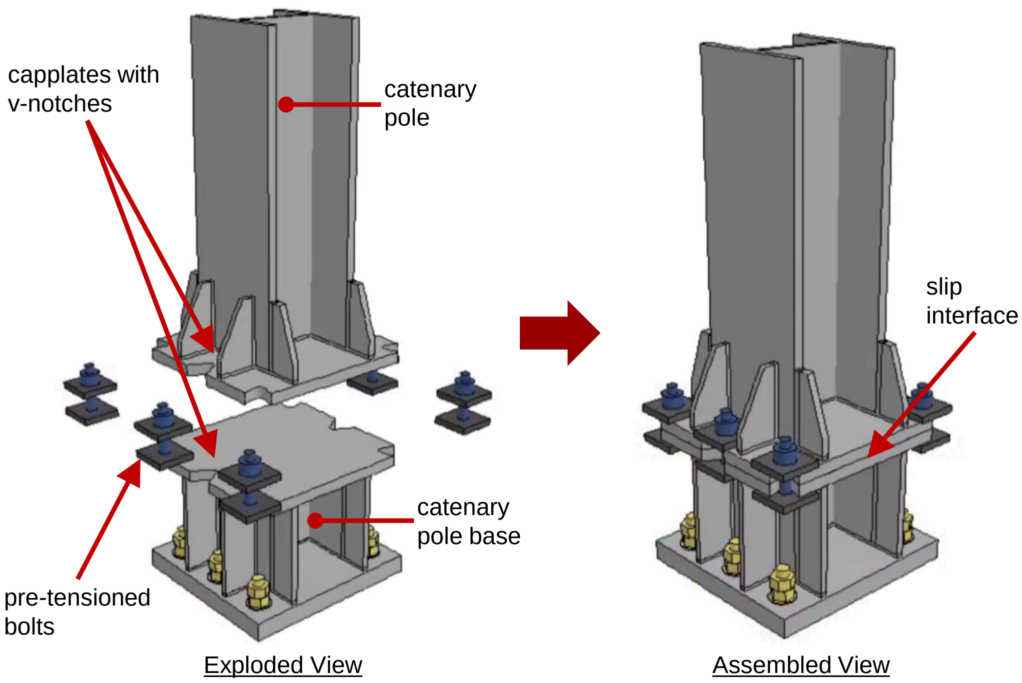


Figure 1: Conceptual View of the Breakaway Connection.

2 Methods

Initial concepts of the breakaway connection were numerically evaluated with detailed numerical simulations using the explicit code LS-DYNA [1]. Realistic impact simulations were performed using a validated finite element model, representative of a 25-ton (55000-lbs) railcar, on catenary poles with a typical baseplate connection and with the breakaway connection. A comparison of the response when the railcar moves sideways and impacts a catenary pole are shown in Figure 2. These simulations demonstrated significantly lower damage to the railcar when impacting a catenary pole with a breakaway connection.

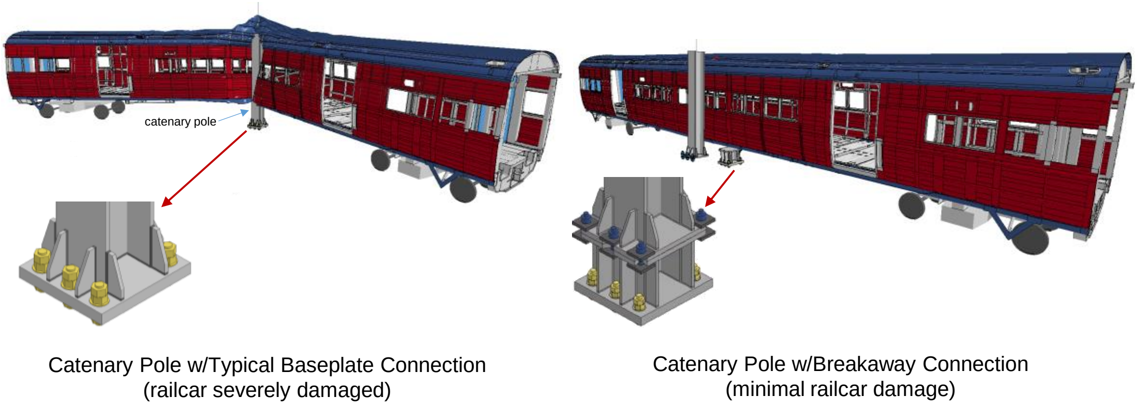


Figure 2: Railcar Impact with Catenary Pole.

Following the initial numerical evaluation stage, full-scale quasi-static and dynamic impact tests were performed on a prototype specimen of the breakaway connection. A view of the test apparatuses used to test the connection are shown in Figure 3. These tests were performed to confirm functionality of the connection and for evaluating the ability of detailed numerical models to compute the connection response during disengagement. For the quasi-static tests, the specimen was fastened to a non-reacting structure and lateral load was applied with a hydraulic actuator at different heights on the column until full disengagement was observed at its base. These tests allowed close monitoring of the connection behaviour during disengagement and to identify areas for improvement. For the pendulum tests, the specimen was fastened to a fixed reaction frame and was impacted at different heights and with different velocities with a 1.8-ton (4000-lbs) pendulum. These tests were designed to evaluate the connection response under dynamic impact loads of magnitude similar to what will be delivered to the connection during an actual impact event with a railcar (or train consist). Two rounds of static and dynamic tests were performed. Following completion of the first round of testing and prior to the second round, refinements were performed to the original design using better friction materials and details that ease assembly of the connection. The improvements were evaluated during the second round of static and dynamic tests. In addition to the full-scale tests, friction tests were performed on a custom test apparatus that were used to inform the choice of friction materials for the relatively high contact pressures at the contact interfaces of the breakaway connection.

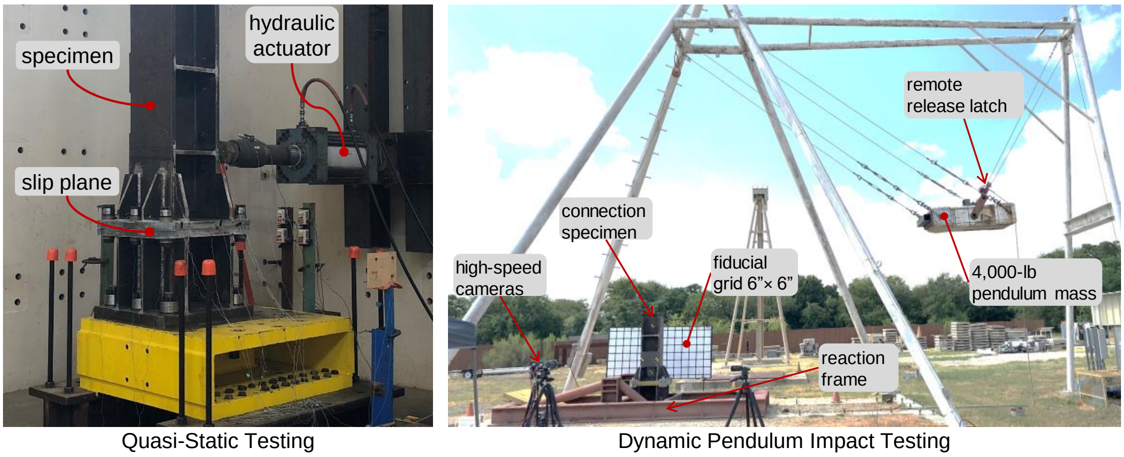
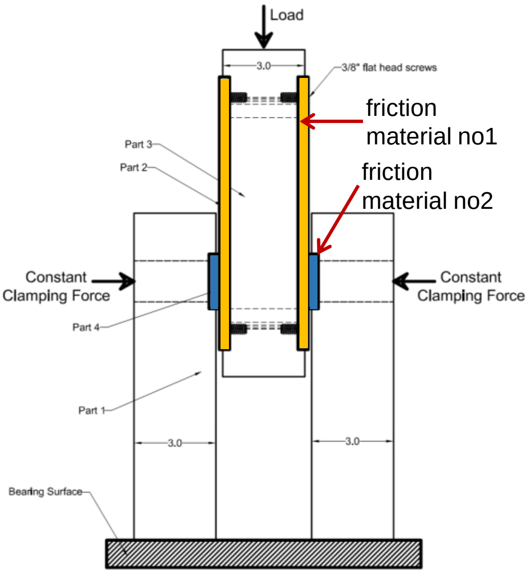


Figure 3: Full-Scale Testing Apparatuses.

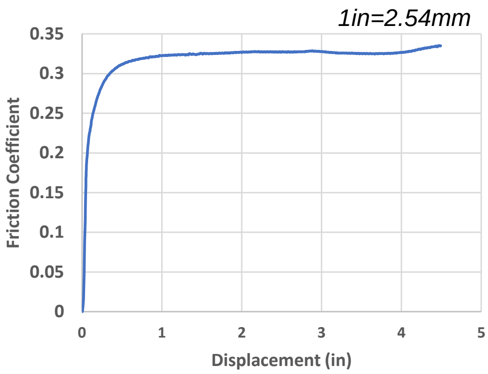
3 Results

Early test results on the connection demonstrated the importance of having reliable and consistent frictional behaviour at the connection’s slip interfaces. Combinations of similar and dissimilar friction materials were tested with a custom test apparatus, shown in Figure 4 (left), that allowed the application of relatively high clamping loads, consistent with the applied loads on the breakaway connection cap-plate. Among the material combinations tested, excellent frictional behaviour was observed when 510 bronze (510BR) was used in conjunction with 440C stainless steel (440SS), which is consistent with earlier test results by Grigorian and Popov [2]. Figure 4 (right) shows the measured coefficient of friction (COF) when this combination was tested. It can be seen that over the 110-mm (4.5-in) sliding distance the COF was fairly stable and close to 0.32.

All the contact interfaces of the breakaway connection specimen were "coated" with thin sheets of 510-BR and 440C-SS that were waterjet cut to the shape of the cap-plates (Figure 1) and welded to them. The static and dynamic impact test results (Figure 3) demonstrated consistent and predictable slip behaviour. A comparison of the test and computed response for one of the static lateral load tests is shown in Figure 5. In this test, the load was applied 450-mm (17.75-in) above the slip plane. As can be seen in the plot of Figure 5, the profile of the lateral resistance compares fairly well between the test and the LS-DYNA simulation. The computed peak lateral resistance was 630-kN (142-kips) which is only 15% higher than the measured value of 534-kN (120-kips). The post-test condition after several testing cycles of the 440C-SS and 510-BR friction plates is shown in Figure 6. Both metals remained in excellent condition without abrading and grooves which is another indication of the very good tribological interaction between these two metals.

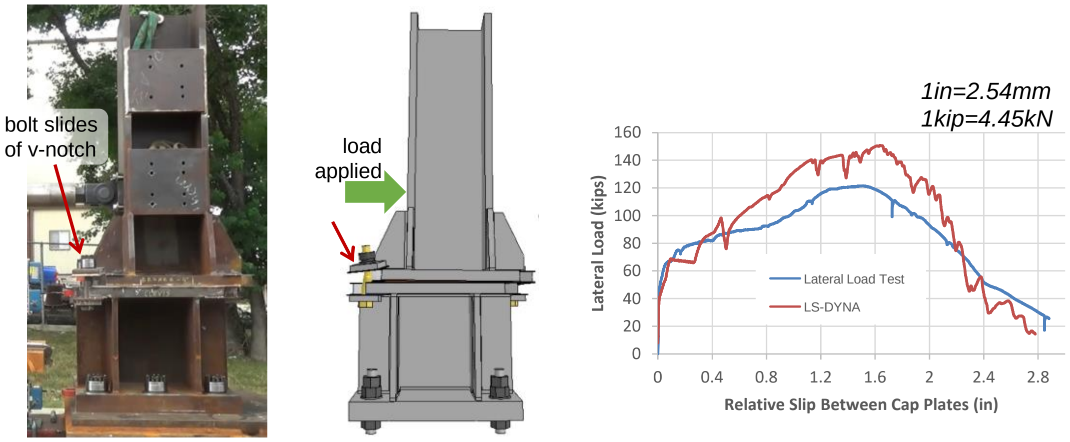


Friction Testing Apparatus



COF Vs Relative Displacement (bronze on stainless steel)

Figure 4: Friction Testing and Results.



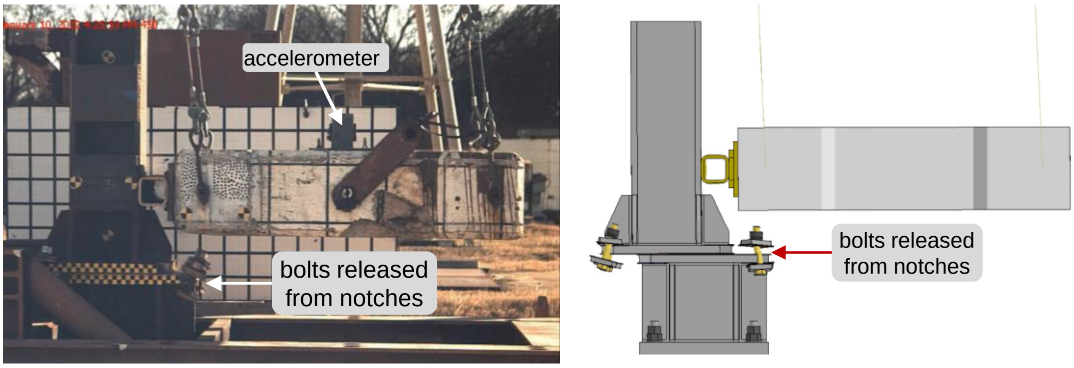
Post-Test Condition LS-DYNA Simulation Lateral Load Resistance - Test Vs Simulation

Figure 5: Connection Response under Quasi-Static Lateral Load.

440C Stainless Steel 510 Bronze

Figure 6: Post-Test Condition of 440C-SS and 510-BR Friction Plates.

Figure 7 shows a comparison of the test against the computed specimen response from one of the pendulum impact tests. For this test, the pendulum impact velocity was 10.95-m/s (24.5-mph) As can be seen in both cases, the top part of the specimen disengaged from it base and the bolts released from their notches.



High-Speed Video Footage LS-DYNA Simulation

Figure 7: Connection Response under Dynamic Impact Load.

4 Conclusions and Contributions

The Federal Railroad Administration of the USDOT funded Protection Engineering Consultants to develop a multi-directional breakaway connection for application with steel catenary poles that support commuter rail overhead line equipment (OLE). This connection can replace existing typical baseplate connections of steel catenary poles supporting OLE to reduce injuries and damages to derailed railcars. PEC devised, numerically evaluated, and tested a friction-based breakaway connection that can disengage under dynamic impact loads. Component-level friction tests were performed to identify friction materials that can provide predictable and reliable frictional behaviour. 440C stainless steel on 510 bronze was found to provide high-performance, reliable frictional resistance which was subsequently incorporated at all the friction interfaces of a prototype specimen of the breakaway connection. Static and dynamic pendulum impact tests were performed on the prototype connection specimen, which demonstrated the ability of the connection to disengage above a certain threshold load. The connection design can be tuned by changing the number and pre-tension level of the bolts at the slip interface. Additionally, detailed numerical models were developed and validated against the test results and were proven to predict the connection behaviour with good accuracy. These numerical models were then used during a subsequent stage of the R&D program to evaluate system-level response of several OLE support frames that incorporate the breakaway connection. We believe the development of the novel breakaway connection design can offer substantial safety enhancements to commuter rail lines, and the authors are now exploring various market delivery strategies.

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