Final Project Summary — PEER Lifelines Program

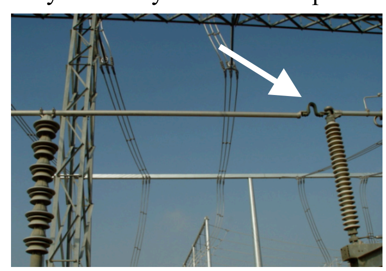
Project Title—**ID Number**	*Substation Equip. Interaction-Experimental Models of Rigid Bus Connectors*—**402**		
Start/End Dates	4/1/02 – 3/31/03	Budget/ Funding Source	$100,000 / PG&E/CEC
Project Leader (boldface) and Other Team Members	**Filiatrault (UCSD)**		

1. Project goals and objectives

The main objective of this project is to experimentally investigate the interaction between components of substation equipment connected by re-designed (or improved) rigid bus connectors through quasi-static and shake table testing. The purpose was to generate data that would provide guidance in the design of conductor assemblies with the improved connectors.

2. Benefits of the results of this project to develop technologies and protocols to mitigate the vulnerability of electric systems and other lifelines to damage directly and indirectly caused by earthquakes. Also, benefits to develop assessment techniques to evaluate damage to electric systems caused by earthquakes and to assess fiscal impacts due to the loss of electric service to the community.

Earthquakes in recent years have demonstrated that electrical substations display a certain level of vulnerability to seismic loading. Because substation equipment items were designed in the 1950s and 1960s, consequences from seismic events were not always taken into consideration. Certain equipment components were designed solely to supply electricity and have shown to perform poorly in seismic events. In response to these vulnerabilities, in recent years, the IEEE 693 standard was developed to address the performance of substation equipment under seismic loading. However, this standard does not address the influence of interconnection on the equipment performance. Due to the complexity of the connectors, the seismic response of interconnected system may become complicated and unpredictable. Currently, according to the IEEE 693 standard, the equipments are qualified in a "stand-alone" condition. One type of connection that is particularly complicated is the rigid bus connection (see Figure). Typically, rigid buses utilize relatively flexible end connectors that account for thermal expansion. Depending on the flexibility and damping characteristics of these connectors, some of the seismic energy may be absorbed in the connectors before being transferred to the equipment components. Connectors in current systems, however, have shown not to provide a sufficient amount of flexibility nor dissipate a large amount of energy, thereby transferring forces to the equipment, resulting in damage. In 1999 as part of the Task 2C project of the PEER-PG&E program, several types of rigid bus connectors currently installed in electrical substations underwent quasi-static and shake table testing. Three types of flexible strap connectors, which dissipate energy through yielding of and friction between flexible straps, were tested. Additionally, a second type of connector, the bus slider connector, was tested. This bus slider dissipates energy through friction and exhibits a higher damping capacity. While the results of these tests showed a relatively good energy dissipation capacity, these connectors were relatively stiff and could transmit significant forces to the equipment. Consequently, these results led to the realization that connectors with lower stiffness should be examined as possible replacements for the current connectors. This project is the continuation of the investigation on substation equipment interaction performed in Task 2C of the PEER-PG&E program. Two new specimens were recently fabricated to improve the connector performance through lower stiffness and higher damping capabilities.



3. Brief description of the accomplishments of the project

Based on the results of the quasi-static tests performed on the improved rigid bus connectors, the following main conclusions can be drawn:

- The new S-shape Flexible Strapped Connector (S-FSC) specimen tested exhibited large and stable hysteresis loops with good energy dissipation capabilities.
- The equivalent damping ratios of all FSC specimens increase with displacement amplitude, indicating higher dissipation capacity at large inelastic displacements.

- The new S-FSC specimen exhibited higher damping than all the original FSC specimens.
- Both the old and new bus sliders exhibited a behavior that is typical of a Coulomb-type friction system coupled with an elastic restoring force mechanism.
- The improved bus slider had a lower post-slip stiffness about half of that of the original bus slider.

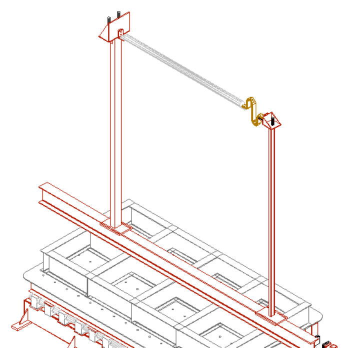
Based on the results of the shake table tests performed on five different pairs of generic equipment connected by three different types of rigid bus connectors, the following main conclusions can be drawn:

- The natural frequencies measured on the generic equipment specimens interconnected by the bus assemblies were always between the natural frequencies obtained for the uncoupled equipment specimens.
- The natural frequencies measured on the generic equipment specimens interconnected by the SEFCOR connector were nearly the same as the frequencies obtained from the uncoupled equipment specimens.
- The bus slider specimen exhibited the highest damping capabilities of the three specimens.
- The new bus slider specimen performed well except when subjected to the high amplitude Tabas record, when the plunger extended to the point where the stoppers hit the inside of the tube, and high impact forces were transmitted to the equipment items. More stroke may be needed to prevent this impact phenomenon.
- The response of the equipment items connected with the SEFCOR connector was similar to the response with the S-FSC specimen. The size of the loops from the SEFCOR specimen is believed to be great enough such that the connector will not become taut under severe ground motions.
- Among the three connectors investigated, the new bus slider consistently reduced the response at the top of both equipment specimens.

4. Describe any instances where you are aware that your results have been used in industry

The results generated in this study are being considered by the IEEE-693 Committee for future editions of their standard.

5. Methodology employed



In the first part of the project, quasi-static tests performed on improved S-shaped Flexible Strap Connectors (S-FSC) and on an improved bus slider connector. These tests were performed in the longitudinal direction of the connectors under a prescribed displacement history. The main objective of these tests was to obtain the mechanical properties of each specimen and compare them with the mechanical properties of the connectors tested previously in the Task 2C study. In the second part of the project, shake table tests were performed on five pairs of generic substation equipment connected with the three different rigid bus assemblies considered in this study (see Figure). Simulated horizontal ground motions were applied in the longitudinal direction of the bus assemblies by the uniaxial earthquake simulation facility at UC-San Diego. The variables considered in the tests were: the dynamic characteristics of the generic equipment, the types of rigid bus assemblies, the simulated ground motions, and the intensities of the simulated ground motions.

6. Other related work conducted within and/or outside PEER

This project was conducted in close collaboration with an analytical project on the same topic conducted at the University at California, Berkeley.

7. Recommendations for the future work: what do you think should be done next?

Enter text here.

8. <u>Author(s), Title, and Date</u> for the final report for this project

Filiatrault, A., and Stearns, C., Electrical Substation Equipment Interaction–Experimental Rigid Conductor Studies, March 2004.