Final Project Summary— PEER Lifelines Program

Project Title—**ID Number**	*Seismic Qualification and Fragility Testing of 500 kV Disconnect Switches*—**411**		
Start/End Dates	8/1/02 – 6/30/04	Budget/ Funding Source	$210,012 / PG&E/CEC
Project Leader (boldface) and Other Team Members	**Fenves (UCB)**		

1. Project goals and objectives

The objective of the study is to conduct seismic qualification and fragility testing of a single pole of 550-kV porcelain disconnect switch shown in Fig.1. Due clearance limitations above the shaking table the switch with the main blade in open position could not be tested in a typical field installation; therefore, several switch configurations were developed for testing. The 550-kV disconnect switch is tested in three configurations: mounted on typical 14 ft tall supports, mounted on a short 4-in spacer to simulate flexibility of the top plates of the supports, and rigidly fixed to the earthquake simulation platform. In the two latter configurations the switch is tested with the main blade in open and closed positions, and these configurations are used for seismic qualification testing of the open-blade switch (shown in Fig. 2) and in the experimental study for amplification factor estimation.

Fig. 1 550-kV switch in the closed position mounted on supports

Fig. 2 550-kV switch in the open position mounted without the tall supports.

Tri-axial tests of a single pole of the porcelain disconnect switch mounted on elevated supports are conducted by means of IEEE-compatible time history to determine its dynamic properties and to qualify the switch to the high Performance Level. A feasibility of seismic qualification testing of tall electrical equipment with supports removed by introduction of an amplification factor due to the supports is also studied experimentally. Tri-axial time history tests of a single pole of porcelain disconnect switch mounted without the tall supports on the simulator platform is conducted to determine the dynamic properties of the pole and to evaluate its seismic response. A seismic qualification test for the switch in open blade position on the earthquake simulator platform (mounted without the tall supports) by means of use the amplification factor is performed.

In addition, the main objective of the study includes static and dynamic testing of switch components (the tall supporting legs and the insulator posts) and a study of feasibility to replace the blade with an equivalent shorter

blade or a concentrated mass for seismic qualification testing of tall electrical equipment that cannot accommodate clearance above the table. The component testing also includes static cantilever tests on insulator posts to determine failure modes and equivalent cantilever loads in failure for the ceramic insulators used in the switch.

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.

The seismic qualification testing of the 550-kV disconnect switch assessed its vulnerability and demonstrated its adequate performance during strong earthquakes.

3. Brief description of the accomplishments of the project

The disconnect switch preserved its major functions up to the highest levels of PL testing conducted in this project, without any major damage. Some anomalies occurred during the test were insignificant and minor. The restoration work did not involve any installation of new parts: the parts impacted out from their original positions were simply repositioned back in place. Therefore, the disconnect switch complied with seismic qualification criteria for PL testing, up to the level conducted in the project. Although the TRS achieved in the test program technically does not satisfy the new recommended specification for IEEE 693 (developed in a companion theoretical study: Task408) for qualification to the High Seismic PL, the deficiencies in the TRS are limited to frequency ranges not close to the important modal frequencies of the equipment. Although the TRS came close to satisfying the new recommended input motion specifications for IEEE 693, the rigid insulator post in the PL test was loaded to a level 37% beyond the rated cantilever strength assigned to this model of insulator by the manufacturer. Fracture of the porcelain insulator post did not occur during the PL test because the actual strength of the installed insulator exceeded the rated cantilever strength by over 40%. This outcome highlights the conservatism associated with insulator cantilever strength ratings.

The disconnect switch mounted on 4-in spacer with main blade in the open position and grounding blade in closed position preserved its major functions after the 1.17g target pga testing without major damage. Therefore, the disconnect switch complies with IEEE 693 criteria for PL seismic qualification testing at the Moderate Seismic Qualification Level, using the new recommended input motion specifications for IEEE 693 (developed in the companion theoretical study: Task408). In order to qualify the switch to the High Seismic Qualification Level, allowable stresses in critical elements are reviewed. Demand to capacity ratios for porcelain insulators were found to exceed allowable values by about 60%, assuming that a 1.83 amplification factor is used.

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

Since the disconnect switch tested represents a very common design of the 500-kV switch used by utilities, the results of qualification testing are very important for assessing the vulnerability of a electrical power transmission system during strong earthquakes.

5. Methodology employed

The seismic qualification testing and associated experimental study of the 550-kV switch was conducted by means of earthquake simulator. The experimental study on the switch components was consisted of low-level pull-back, free-vibration, and cantilever strength tests. The latter testing was conducted for porcelain posts only.

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

The qualification testing used a strong motion time history for the IEEE 693 that was developed in a companion theoretical study entitled ‘Ground Motions for Earthquake Simulator Qualification of Electrical Substation Equipment’ by Shakhzod M. Takhirov, Gregory L. Fenves, Eric Fujisaki, Don Clyde.

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

Both numerical and experimental studies should be conducted to develop a reliable procedure for estimation of the amplification factor. Such procedures or guidelines are needed in order to streamline the qualification procedure, particularly for large equipment that cannot be practically tested on their supports, and also for equipment that may be supported on several different types of support structures. In addition, the consideration of alternative methods of testing, possibly using substitute support structures which are intended to provide the same equipment response as a full-scale structure, would be valuable.

Further material studies on porcelain insulator acceptance criteria are needed. IEEE 693 acceptance criteria for qualification require a factor of safety of 2.0 and 1.0 against the "ultimate strength" of the insulator, respectively for the RRS and PL. The current practice of most utilities, manufacturers or consulting engineers is to use the rated cantilever strength as the ultimate strength of the insulator. As highlighted in the tests conducted in this project, the rated cantilever strengths of insulators are frequently set at levels representing a guaranteed minimum breaking strength. Alternative definitions of ultimate strength should be explored for use when designing for extreme events such as a large earthquake.

Differences between the stiffness of porcelain insulators in tension and compression should be investigated further. Investigations should include further tests on multiple-section insulators, porcelain material studies and tests, and collaboration with insulator manufacturers. The differences observed in this project may be significant enough to influence the outcome of qualification tests.

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

Shakhzod M. Takhirov, Gregory L. Fenves, Eric Fujisaki. 'Seismic Qualification and Fragility Testing of Line Break 550 kV Disconnect Switches' 08/20/2004.