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METHODS FOR EXPERIMENTAL COMPARISON OF TWO- AND THREE-DIMENSIONAL SEISMIC TEST SEVERITY

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ABSTRACT

As seismic shake table testing equipment has evolved, we have been able to more realistically simulate seismic inputs and more reliably qualify equipment. Most qualification in the past 10 years has been performed on independent biaxial tables because 1) these were the best available and 2) it was felt that they provided a sufficiently valid test input. The issue of the adequacy of a biaxial test in simulating a triaxial event was a mute point until independent triaxial tables became available (circa 1980).

Recent exploratory studies using ANCO's independent triaxial table to simulate both triaxial and biaxial inputs have shown that, for two classes of equipment, the standard biaxial testing procedure produces an adequate (conservative) test when compared to actual triaxial events. (The two classes of equipment studied were electrical relays and pressure relief valves, both of which had vibration sensitivities. The project also revealed significant statistical variation in fragility between tests of "identical" components.) These preliminary results indicate that while three-dimensional tables simplify testing and reduce test costs and are consequently desirable, there is reason to believe that past biaxial tests are probably adequate. Based on these initial studies, certain recommendations are made for a detailed exploration of this basic question.

INTRODUCTION

The purpose of this project is to develop methods to experimentally evaluate the comparative severity and adequacy of different shake table testing methods. Methods were developed for two- versus three-dimensional testing and applied to two classes of equipment (four different electric relays and two models of pressure relief valves). This work was carried out as a joint research project of ANCO Engineers (by the author and Peter Rentz) and Bechtel Power Company (Asadour Hadjian, Bruce Linderman, Dick Lin, and Bill Biehl). The incentive for this work was to help determine if that vast majority of equipment in nuclear power plants was adequately tested when placed on two-dimensional (rather than three-dimensional) tables.

Typical seismic testing procedures, representing the "state-of-the-art" from the early 1970's to the present, involve independent biaxial tables (vertical plus horizontal) capable of random (earthquake-like) input. The missing third direction (normally the second horizontal) has been accounted for in two ways. First, the required response spectra from both horizontal directions are enveloped, and the result set as the goal for the single table horizontal direction. Second, the equipment is tested at two orthogonal directions (i.e., rotated 90 degrees between tests) so as to expose all the equipment's axis to input (although not simultaneously). Such testing is made further conservative by two other factors. First, to account for possible errors in containment modeling, the spectra are broadened (typically by ±15%). This greatly increases their energy content. Second, floor motions are most often predicted as time histories. Response spectra are then calculated and generally smoothed (and broadened) before being transmitted to the test laboratory. The lab must now find a time history that matches this (highly artificial) spectra and generally results in a much more severe earthquake than the originally calculated floor motion.

Because of these considerations and conservatisms, it is anticipated that the biaxial tests are adequate in spite of the missing third axis. This study was undertaken in an attempt to quantify this anticipation. It must be emphasized that the decision of what to compare to what is not trivial. One could, for example, compare enveloped and broadened biaxial to enveloped and broadened triaxial. This would not, however, tell how "safe" or "conservative" biaxial testing was compared to a real event. Hence, for most of the tests described herein, the biaxial tests were compared to actual triaxial floor time histories (no enveloping or passage through spectra calculation).

This procedure is illustrated in an eight-step procedure in Figure 1. Note that two sets of free-field earthquakes were used (NRC Artificial and Taft Historical) and two different containment building models. In other studies, the effect of shifting spectra without broadening and adjusting the orientation angle of the equipment on the table were investigated.

In all cases, the equipment being tested had (and indeed was chosen to have) an easily identified "fragility." In the case of relays, the fragility was taken as a chatter of 2 ms or greater. In the case of the pressure relief valve, the fragility was taken as a trigger of the relief function. The fundamental data of the project was the relative severity of earthquake predicted as the fragility of the equipment, as predicted by biaxial versus triaxial testing (ratio of response spectra over frequency range of interest). These fragilities were typically in the 2 to 5 g ZPA range.

Figure 2 presents typical results for two pressure relief valves (nominal set of 60 and 15 psi) and for two orientations of the valve (X and Y discharge). The data show how the fragility level drops as the applied line pressure nears the set pressure. It also shows little difference between biaxial and triaxial tests.

The data were obtained using the ANCO R-4 independent triaxial table, which could be run in either independent triaxial or independent biaxial modes.

SUMMARY

The major finding of this program is that for the equipment tested, broadened and enveloped biaxial tests are as severe or more severe than realistic triaxial events. (This is illustrated in, for example, Figure 2.) We did find significant (factor of 2) variations in fragility between "identical" components and about 20% to 30% variation on test repeat. A number of other factors affect fragility (rotation, up- and down-shift of spectra, no broadening of biaxial inputs) but appeared to be of secondary importance.

RECOMMENDATIONS

These studies have developed and verified techniques to compare the severity of various types of testing and have tentatively shown that for at least two classes of equipment, biaxial tests are conservative. It is recommended that other classes of equipment be similarly investigated (a possible 10 to 20 classes in all) and that conservatisms of other past test types (e.g., sinusoidal, vector biaxial) be investigated. Such studies can then be extended, using judgement, to validate and screen testing of all equipment. It is anticipated that most previous testing was adequate.

REFERENCES

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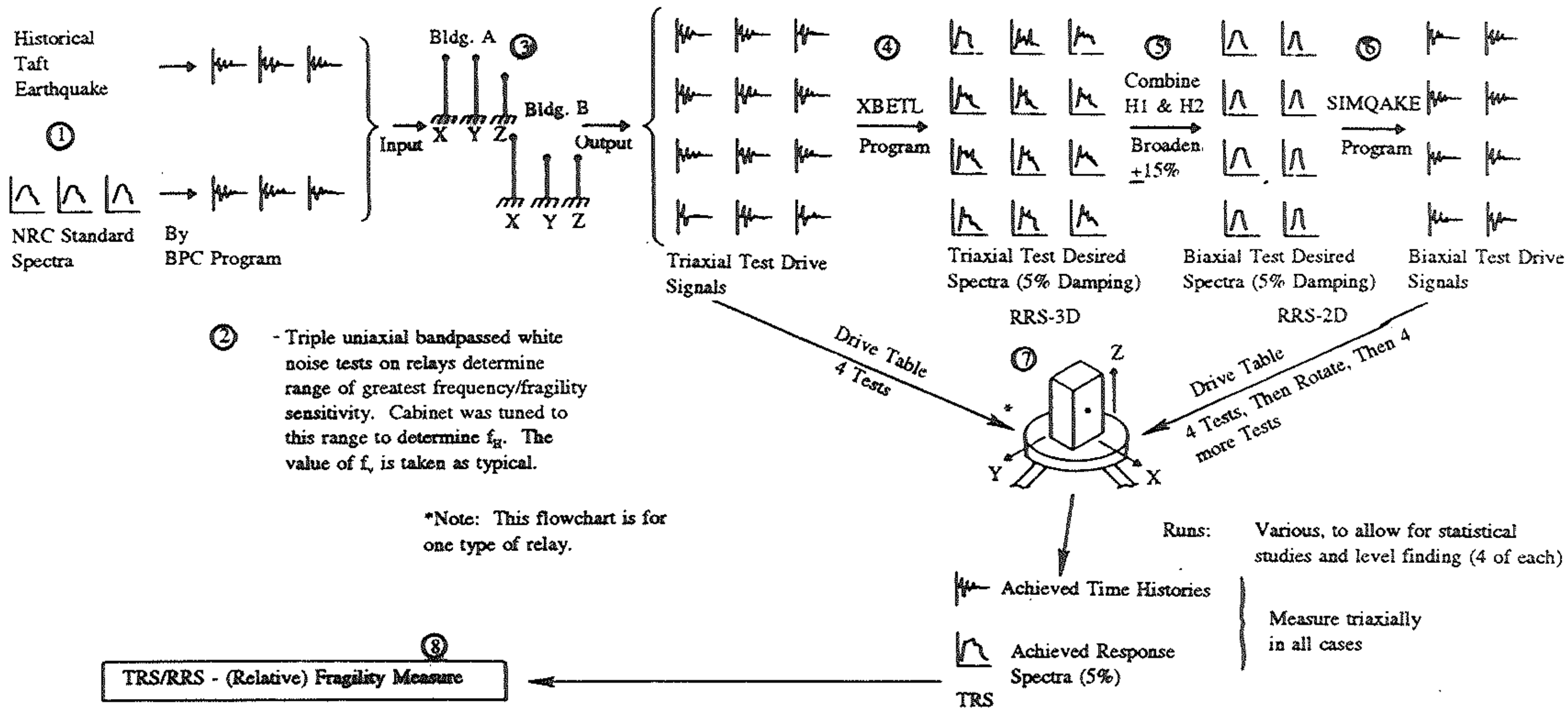

Fig. 1. Program overview.

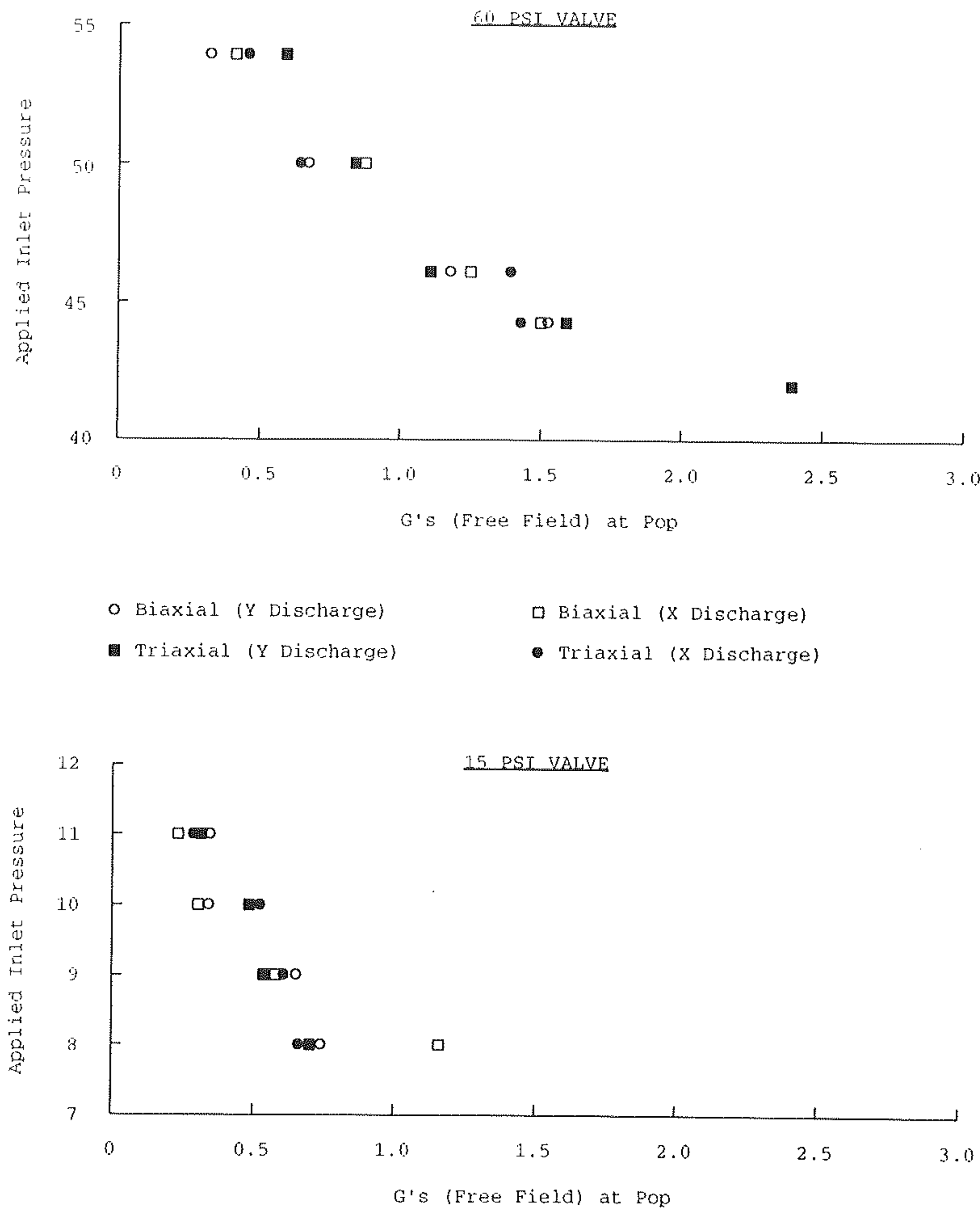

Fig. 2. Seismic Fragilities.