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SEISMIC QUALIFICATION OF MULTIPLE INTERCONNECTED SAFETY-RELATED CABINETS IN A HIGH SEISMIC ZONE

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1. INTRODUCTION

Certain safety-related multiple, interconnected electrical cabinets and the devices contained therein are required to perform their intended safety functions during and after a design basis seismic event. In general, seismic testing is performed to ensure the structural integrity of the cabinets and the functionality of their associated devices. Constrained by the shake table capacity, seismic testing is usually performed only for a limited number of interconnected cabinets. Also, original shake table tests performed usually did not provide detailed response information at various locations inside the cabinets. For operational and maintenance purposes, doors and panels of some cabinets may need to be opened while the adjacent cabinets are required to remain functional. In addition, in-cabinet response spectra need to be generated for the seismic qualification of new devices and the replacement parts. Consequently, seismic analysis of safety-related multiple, interconnected cabinets is frequently required for configurations which are different from the original tested conditions. This paper presents results of seismic tests of three interconnected safety-related cabinets and finite element analyses performed to compare the analytical results with those obtained from the cabinet seismic tests. Parametric analyses are performed to determine how many panels and doors can be opened while the adjacent cabinets still remain functional.

2. QUALIFICATION OF ELECTRICAL CABINETS

Major nuclear power plant safety related electrical cabinets include motor control centers, control panels and benchboards, relay panels, switchgear cabinets and other cabinets. These cabinets generally consist of large flexible panels which can have relatively high amplification during an earthquake. For example, switchgear cabinets are typically about 24" wide, 72" deep and 78" high weighing approximately 2500 lbs. In the field installation, the switchgear assembly may contain a large number of cabinets placed side by side. Many lineups contain more than 20 units (Ref. 1). In general, the electrical cabinets are qualified by seismic shake table test (Ref. 2), by static or dynamic analysis (Refs. 3 and 4), or by a combination of analysis and test (Refs. 5, 6, 7, and 8). For some operating plants located at a lower seismic zone, if applicable, seismic qualification by experience can be used (Refs. 9 and 10).

3. SEISMIC TESTING OF CABINETS

Constrained by the shake table capacity, seismic testing of only three interconnected safety-related cabinets was performed using bi-axial multi-frequency input. During the first few seismic tests, the top and/or side panels are bolted to and the doors are latched to the cabinet frame. Functional operability of various relays and control devices were monitored and in-cabinet response at some critical locations were recorded. Some chatter or change of state in the relay contacts in its original commercial configuration was observed due to door rattling and its associated high-frequency loading. The cabinets were modified by adding stiffener plates in the side to side direction at the bottom and mid-section of the cabinet, and by stiffening and bolting the door panels to the cabinet to make them effective in resisting seismic loads. The seismic tests were then repeated and the modified cabinets meet the design basis seismic requirements.

4. METHOD OF ANALYSIS

The as-built configuration was first obtained for the construction of a detailed three-cabinet finite element model. This model consists of beam elements which model the edge members and bent-up section of the plate. The membrane elements model the skins and rear doors. The plate elements model the front doors and panels mounted with devices. The spring elements model the door-to-cabinet connections and base connections. The base springs are located at each welded base connections and they were adjusted to match the cabinet test frequencies in the side-to-side and front-to-back directions (Figure 1). The critical damping values used were validated by comparing the in-cabinet response spectra obtained from the time-history analysis and seismic testing. The required response spectra at the device locations can be obtained using the detailed three-cabinet finite element model. This detailed model was also used to study the effect of opened doors and panels on the seismic qualification of the cabinets which reflect the conditions during operation or maintenance.

Based on the detailed three-cabinet model, a simplified three-cabinet model was constructed to match the overall dimensions, total weight, base connections and dynamic characteristics of the detailed model. This model consists of beam and spring elements. Assuming that all the interconnected cabinets are similar, this model is then expanded to represent the actual nine to eleven-unit equipment (Figure 2). These models were used to study the effect of the number of cabinets and different base connections on the dynamic response of the multiple-unit equipment. These models can be easily modified to evaluate future design changes efficiently.

5. RESULTS OF ANALYSIS

The cabinet critical damping was estimated by comparing the amplification factors of the test in-cabinet spectra and those of the analytical spectra generated at a similar location. Comparing the 5% damping test SSE spectra at the top of cabinet with that of the shake table control motion, it was determined that the maximum amplification factor is approximately 3.0. Three time-history analyses of the model using 7%, 10% and 15% cabinet damping ratios were performed. The 5% damping spectra generated at the top of the cabinet provide amplification factors of 6.0, 4.8 and 3.5 for the above cabinet damping ratios, respectively. Therefore, it was concluded that at the SSE level, the cabinet critical damping ratio is close to 15%. However, a 7% critical damping ratio is conservatively used in studying the adequacy of the cabinet under various operating and maintenance conditions.

The effect of opened doors and panels during routine maintenance were analyzed by removing the membrane and plate elements representing these doors and panels. The door mass was added to the door jamb. The response spectra at the top of the cabinet were generated using the models representing various operating and maintenance conditions. The two conditions which deviated from the normal operating condition are:

a. The front and rear doors and top panels of two adjacent units of the three-unit equipment are opened. The heavy breakers located in the lower compartment of these two units are also removed.

b. The front and rear doors of one unit is opened. However, all the heavy breakers remain in place.

The comparison of the horizontal spectra is shown in Figures 3 and 4. The cabinets are vertically rigid. The floor spectra are also shown in these figures for reference. As shown in Figure 4, only minor changes were found in the front-to-back spectra. However, some shifts in frequency was observed in the side-to-side spectra (Figure 3). Since the TRS exceeds the RRS with a large margin, the change in spectra due to various operating and maintenance conditions is acceptable.

The effect of the number of cabinets in a multiple-unit equipment was evaluated by comparing the spectra at the top of cabinet generated using the three-cabinet and eleven-cabinet simplified models. Comparison of the spectra generated at the same location using different models indicates that the spectra generated using the simplified models are higher than that generated using the detailed model. Therefore, using the simplified models is conservative. The spectra generated using the three-cabinet and eleven-cabinet simplified model show negligible differences.

6. SUMMARY AND CONCLUSIONS

The study indicates that for cabinets located in a high seismic zone, the critical damping of the cabinet is significantly higher than 5% to 7% typically used in qualifying electrical equipment. For devices mounted on the cabinet doors to performed their intended safety function, it requires stiffening of doors and that these doors be properly bolted to the cabinet frame. It also shows that even though doors and panels bolted to the cabinet frame are the primary seismic resistant element of the cabinet, opening of a limited number of them will not impair the structural integrity of the multiple interconnected cabinets or significantly affect the required response spectra of the devices mounted inside these cabinets.

7. REFERENCES

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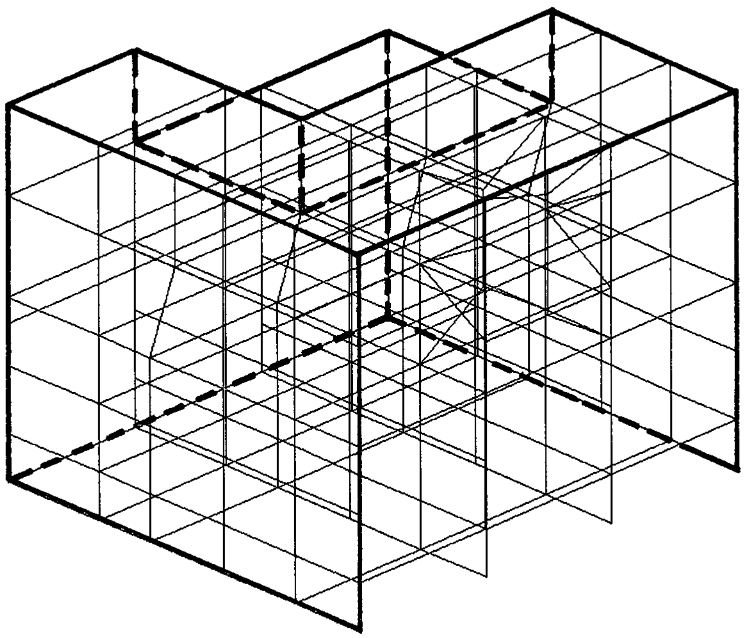

Figure 1 Detailed Three-Cabinet Model

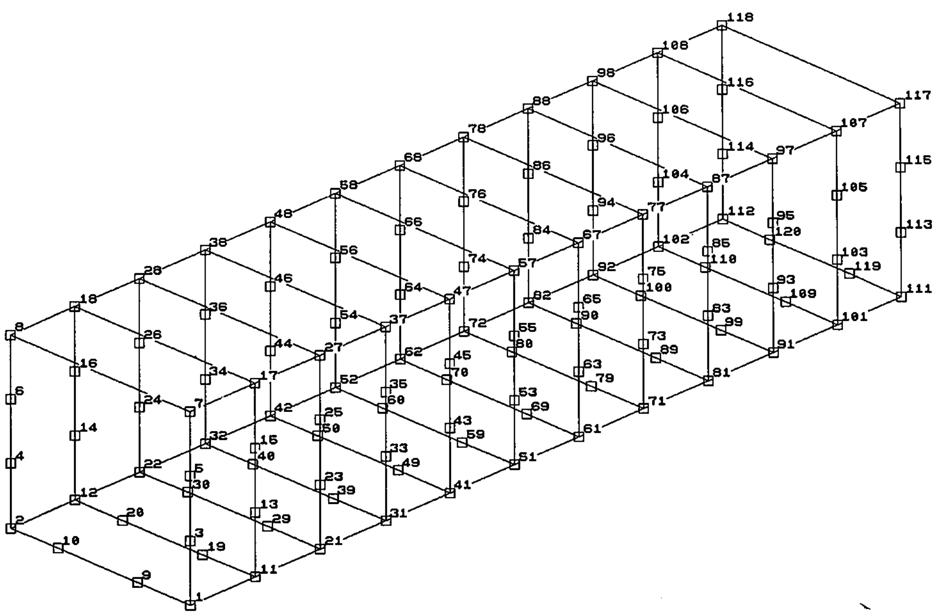

Figure 2 Simplified Eleven-Cabinet Model

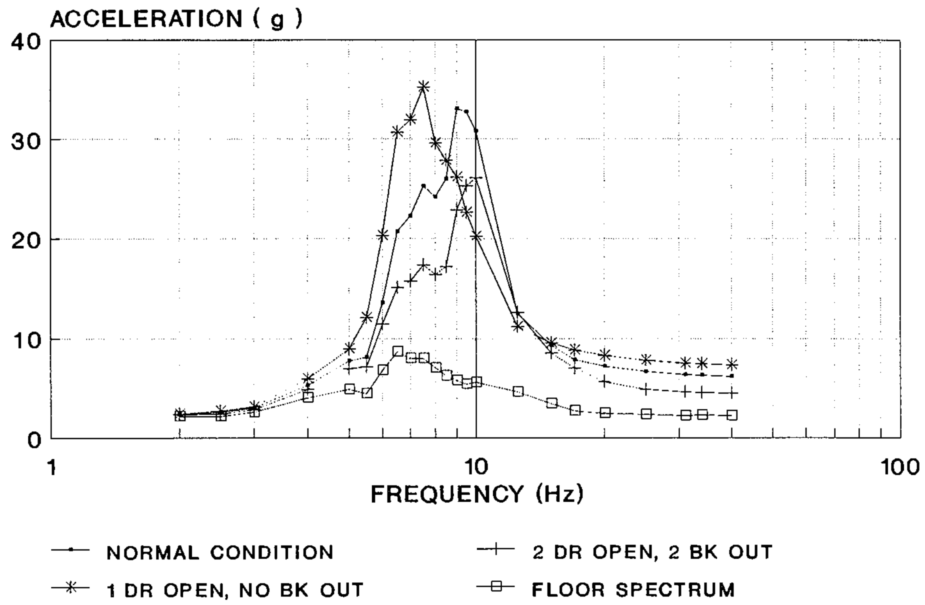

Figure 3 Side-to-Side Spectra at Top of Cabinet (5% Damping)

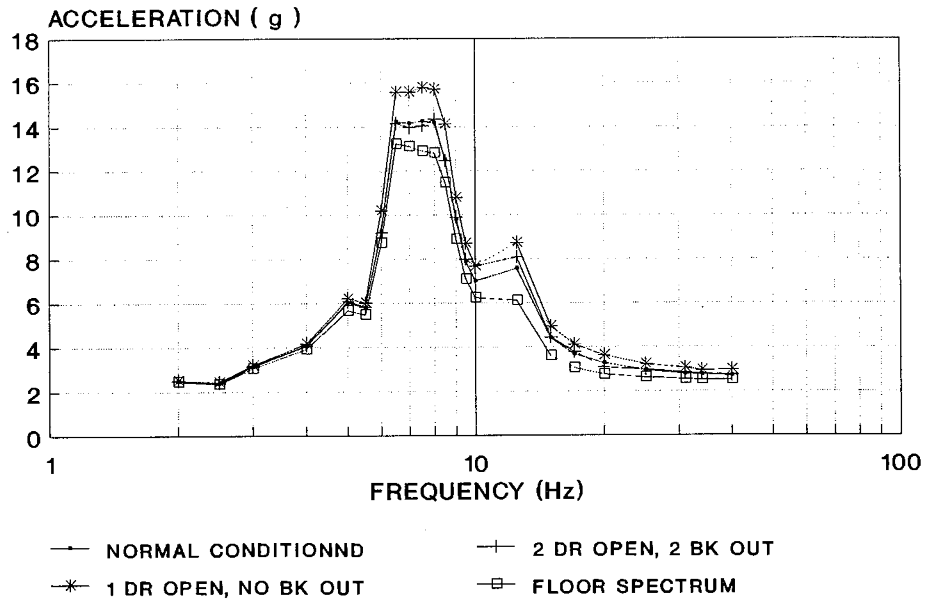

Figure 4 Front-to-Back Spectra at Top of Cabinet (5% Damping)