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IMPLEMENTATION OF A SEISMIC TESTING TECHNIQUE FOR NUCLEAR POWER PLANT ELECTRICAL EQUIPMENT

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SUMMARY

The conservative assumption for nuclear power plant electrical equipment seismic tests is that the earthquake occurs during the equipment's operating life. Therefore, specimens should be subjected to accelerated aging before seismic testing. This aging process is time consuming and expensive, especially if it must be repeated because design changes are indicated by the test results.

Traditionally, a complete electrical panel is tested as a unit. The new procedure runs the unit with dummy components on a medium acceleration capacity shaking table to determine the earthquake induced stress levels. Using these levels, small actual components are tested with a high acceleration capacity shaking table.

INTRODUCTION

Specific electrotechnical equipment used in nuclear power generating stations, especially the equipment belonging to safety systems, must perform its functional requirements throughout its installed life. This quality of the equipment must be established and guaranteed by generation and maintenance of evidence that ensures the equipment will meet its requirements.

Particular standards, specifications (Ref. 1-8) and experience in the field show that the best demonstration of qualified life for tens of years is type testing. During the life duration, earthquake events of small probability because of large magnitude as design basis events may occur.

Seismic qualification testing of electrotechnical equipment that must functionally perform during such events is often very complex, time consuming, and expensive. A methodology for reducing this complexity, testing duration, and expense is presented herein.

TESTING PROCEDURE DEVELOPMENT

It has been noted that type testing is the reliable way of qualifying equipment for nuclear power generation systems. Since electrotechnical components are sensitive to aging phenomena, specimens to be seismic tested by shaking table should be aged before the test. This condition may be achieved by accelerated procedures such as thermal aging, radiation aging, vibration aging, operational aging, etc. These accelerated aging conditions should be applied in a chosen sequence specific to the requirements.

This aging requirement changes the technical characteristics and the value of the test specimens. From the technical point of view, the electrotechnical materials are "fragilized" (for example, the insulation is made more brittle) and fatigued or mechanically aged by the many cycles of the operating and vibration environment. From the economic point of view, the accelerated agings with large periods of exposure to the different phenomena with the complex facilities required - temperature ovens, vibration exciters, humidity chambers, radiation sources, etc. have a significant cost.

PROCEDURAL OPTIONS

Upon proper aging completion of the electrotechnical components, an electrotechnical subsystem may be seismically qualified on a shaking table by one of two conventional methods.

a) Testing of the Complete Assembly. The subsystem, for example, an electrical panel, completely equipped with prior individually aged components is subjected to the required acceleration induced stresses while monitoring its electrical functions and/or its mechanical behavior. This method is useful if the results of the test are positive. If one or more components fail, then another panel with new aged components must be tested to determine if the fault is caused by a common mode failure or by a random failure. This procedure makes analysis for redesign very difficult and time consuming. However, it is the only option with a medium-sized shaking table with traditional acceleration capability.

b) Testing Individual Components. Fragility curves for each of the individual components are developed by testing and analysis. These represent the limits of accelerations related to the number of times at which the components still met their functional requirements. These characteristics are compared with the level of location acceleration during the seismic simulation test. If the value is below the fragility curve, then the panel which uses the components is considered seismically qualified.

The disadvantage of this mode of testing is the experimental determination of the fragility curves for each component is again very time consuming and expensive for properly aged components. This is especially true for a typical electrical subsystem with many different components. A shaking table with high performance is required because of acceleration amplification from building and panel structural response.

SEQUENTIAL TESTING

A more efficient and economical technique is to combine tests with the complete assembly and tests with the individual aged components. The electric panel or total subsystem equipped with unaged components (or dummies with equivalent weights located properly in the panel) is tested. The mounting location accelerations are monitored carefully. Afterwards, the properly aged valuable components are tested individually to the measured level on a smaller higher performance shaking table. If the components meet the functional requirements, they are qualified. If not, the redesign and subsequent testing is more straightforward and less expensive. This procedure is especially valuable for systems with multiple identical components located at different locations in the panel.

Figure 1 shows the different procedural options. Note that shaking table facilities traditionally designed for seismic testing of heavy products at small accelerations are not adequate for either the individual component or sequential testing modes. The recommended technique requires an additional facility for subjecting specimens of average or small weights to a higher accelerations, velocities, and displacements. An integrated facility with a large and small shaking table for sequential testing of electrotechnical equipment gives large technical and economic advantages.

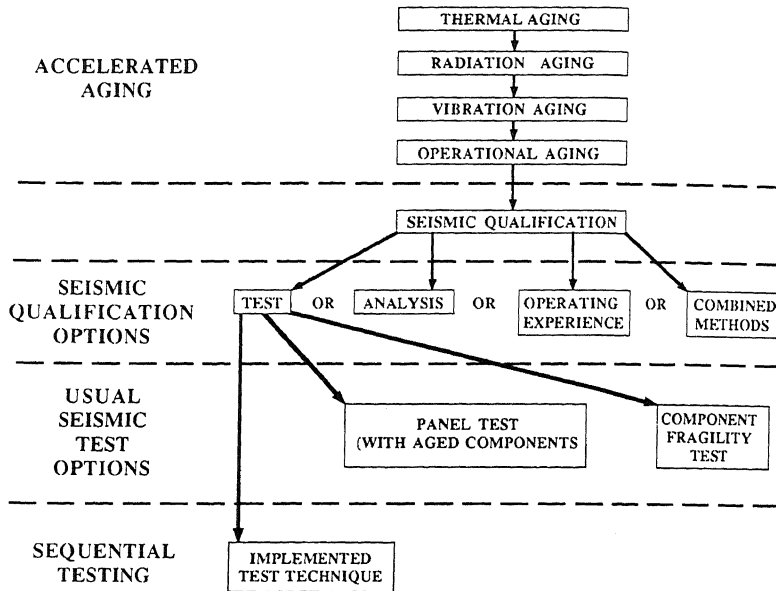


Figure 1. Qualifying Techniques Block Diagram

SHAKING TABLE PERFORMANCE REQUIREMENTS

What should be the shaking table kinematic performances to achieve this sequential testing methodology? Analysis begins with the fact that earthquakes produce random ground horizontal and vertical motions with accelerations in the range of fractions of 1 "g". Electrical equipment in the base of structures such as intervention generator-motor groups and big transformers are subjected to this level of excitation.

Other equipment like electrical switch gear, control, and signal systems are mounted at various elevated levels from the ground base of the structure envelope and auxiliary buildings. At these elevations, there is acceleration amplification with respect to the ground from the structure's dynamic response. There are electrical panels, motors, transducers, etc., products of average size and weights, that must perform their functional requirements under this amplified excitation.

Finally, smaller components like commutation devices (relays), indicators, connection assemblies, electronic modules, control transducers, and instruments are subjected to yet higher levels of acceleration, in the range of +60% with respect to the building floor elevations because of the dynamic structural response of the assemblies they are mounted in.

A testing facility solution to these circumstances was a system consisting of two shaking tables of different sizes. The larger table is designed to perform the testing of assemblies of 3 ton maximum weight, with an acceleration of 5 g and 5 kNm overturning moment capacity on 500 kg specimens, and the smaller table is designed to test components of 100 kg maximum weight with an acceleration of 8 g and 240 Nm overturning moment capacity on 60 kg specimens. Both tables have response in the seismic frequency range of 0.2 - 33 Hz. Figure 2 shows the relationship between the physical dynamic amplification and the shaking tables of the facility. These specifications required some innovative design concepts to implement the sequential testing methodology.

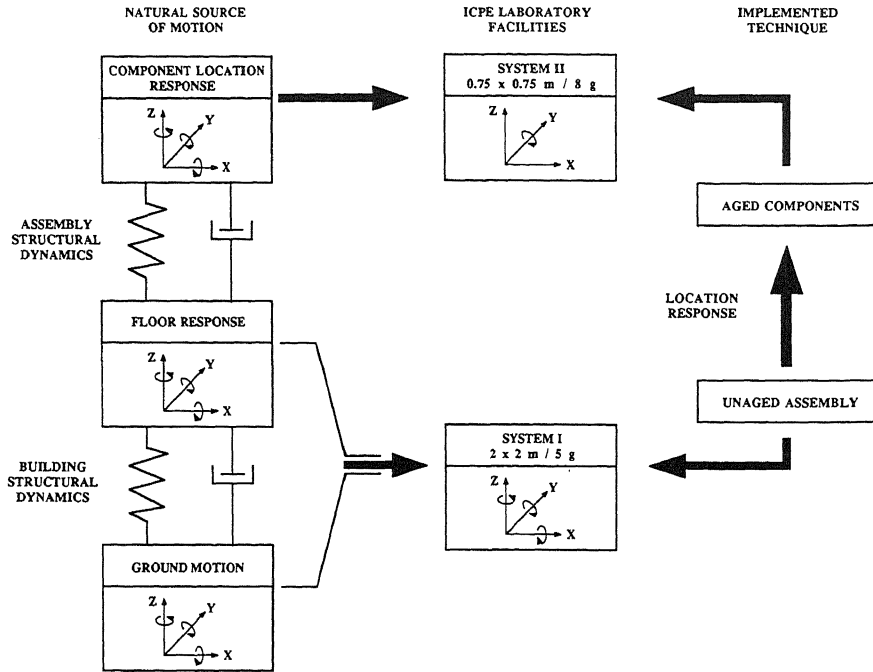


Figure 2. Implemented Technique Block Diagram

RESULTING LABORATORY IMPLEMENTATION

The facility at ICPE for realizing the technique explained above features a table of $2\text{ m} \times 2\text{ m}$ and a table of $0.75\text{ m} \times 0.75\text{ m}$. The acceleration performance of the two tables as a function of frequency is shown in Figure 3. These performance specifications were developed by considering the envelopes of the floor and equipment assembly location response spectra.

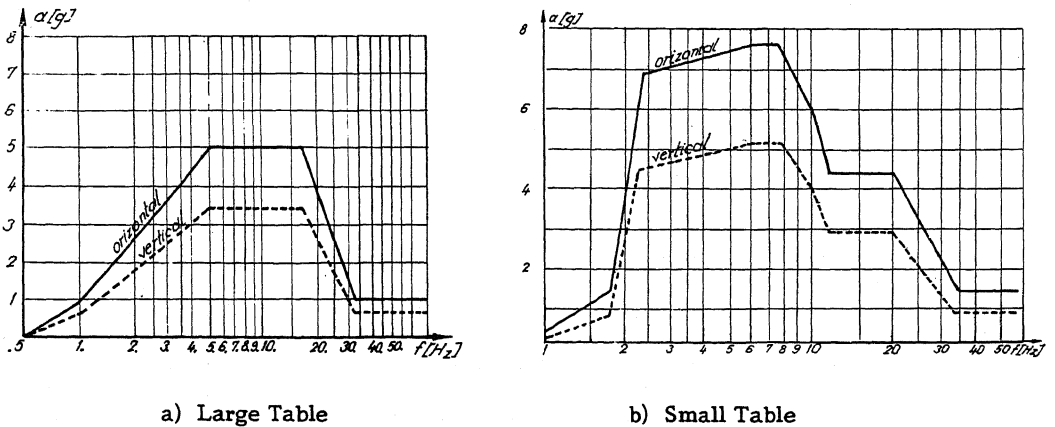


Figure 3. Continuous Sinusoidal Acceleration Performance

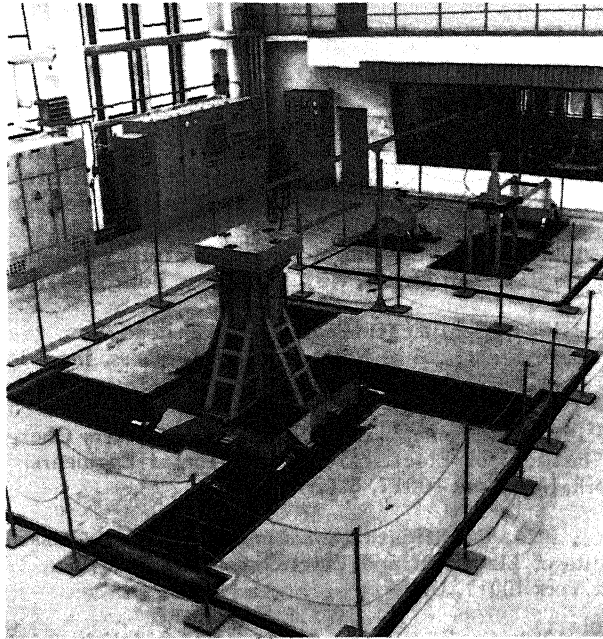


Photo 1: ICPE Seismic Qualification Laboratory

The large table is actuated by eight servohydraulic actuators arranged with four vertical and four horizontal in a "pin wheel" configuration because of the large stroke required and to dynamically balance the system with symmetry. All six degrees of motion are possible. The small table was designed by borrowing kinematic technology from high performance road simulation equipment. Four vertical actuators work through bellcranks with torque boxes to provide four degrees of motion, three translation and one rotational. Photo 1 is a picture of the overall laboratory showing the two tables with checkout specimens.

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