Independent Three-Dimensional Shake Table Excitation and Its Future in Nuclear Power Qualification Programs

John C. Stoessel, Associate Member ASCE*
and Paul Ibáñez, R. Steve Keowen, Peter E. Rentz

Originally, shake table testing was limited to single-direction excitation. A test specimen was rotated many times to cover all possible excitation directions. Later came both vector biaxial and independent biaxial shake testing, reducing both the number of test specimen rotations and the total number of tests the specimen was subjected to, thereby eliminating the costly risk of overtesting damage. Parallel to these improvements were the improvements in drive signal from sine-to-sine beat to actual earthquake motion. These improvements also increased the similarity of the test to the real multiaxis event. ANCO Engineers has developed one of the first functional three-dimensional independent shake tables. Motion is independent in three orthogonal directions, with the capability of testing in one, two, or three dimensions. High-level input (up to 8 g) is possible, and the table capacity is in excess of one ton.

A fully three-dimensional table has several advantages, such as shortened test times, less tests to subject a specimen to, and accurate real-event input. Other features of the system include a 500-ton concrete seismic floor in order to isolate the table from ground disturbance and a computerized data acquisition system to obtain and reduce data.

Shake Table Testing

In order to observe the effects of base or attachment point dynamic excitation on equipment, shake tables were developed and continue to be heavily relied upon to give needed information to engineers and designers. Relating to the nuclear power area, shake table testing is used to study the dynamic characteristics of machinery, cable trays, piping systems, and numerous other components.

Typically, a required response spectra is generated defining the seismic capacity a test specimen must exhibit. This spectra is normally broadened, and a time history is generated to give this reponse spectra. This time history is electronically input to the shake table, and the test specimen is subjected to numerous tests in order to determine whether or not the specimen can withstand the required seismic input.

Originally, shake tables were single-degree-of-freedom exciters (usually with sinusoidal motion) and, as such, required much more work (rotating specimens and increasing spectra to account for single motion) to carry out seismic testing. Large conservatisms were required to

*ANCO Engineers, Inc., 9937 Jefferson Blvd., Culver City, CA 90230.

justify such tests. A step up brought two-dimensional shake tables into play, greatly reducing both the number of tests and the uncertainty of representing a three-dimensional random event by something less than three dimensions.

Currently, much thought is going into three-dimensional shake table testing. Several systems are in operation.

Example of an Independent Three-Dimensional Shake Table

Figure 1 is an illustration of a three-dimensional shake table currently in use. Table dimensions are a 5-ft (1.52-m) diameter base with a maximum specimen weight of 4,000 lb (900 N). Figure 2 describes the performance characteristics of this table. The table is of an unusual design. Three actuators are arranged in a tripod configuration, allowing independent three-dimensional motion of the tripod apex (table center point) to be specified by applying the appropriate input signals to the actuator servo-valves. The pitching or overturning motion of the table is limited by a stabilizer mechanism consisting of pin-jointed linkage arms and self-reacting torque-tubes supported upon roller bearing pillow blocks and arranged in a triangular configuration. The dead weight of the table test fixture and test item is independently supported by a flexible pneumatic isolator unit with adjustable air pressure. The table is anchored to a 500-ton reinforced concrete seismic mass foundation. The hydraulic system consists of a pump and accumulator bank that produces oil flow for short-duration high-demand events such as typical seismic events.

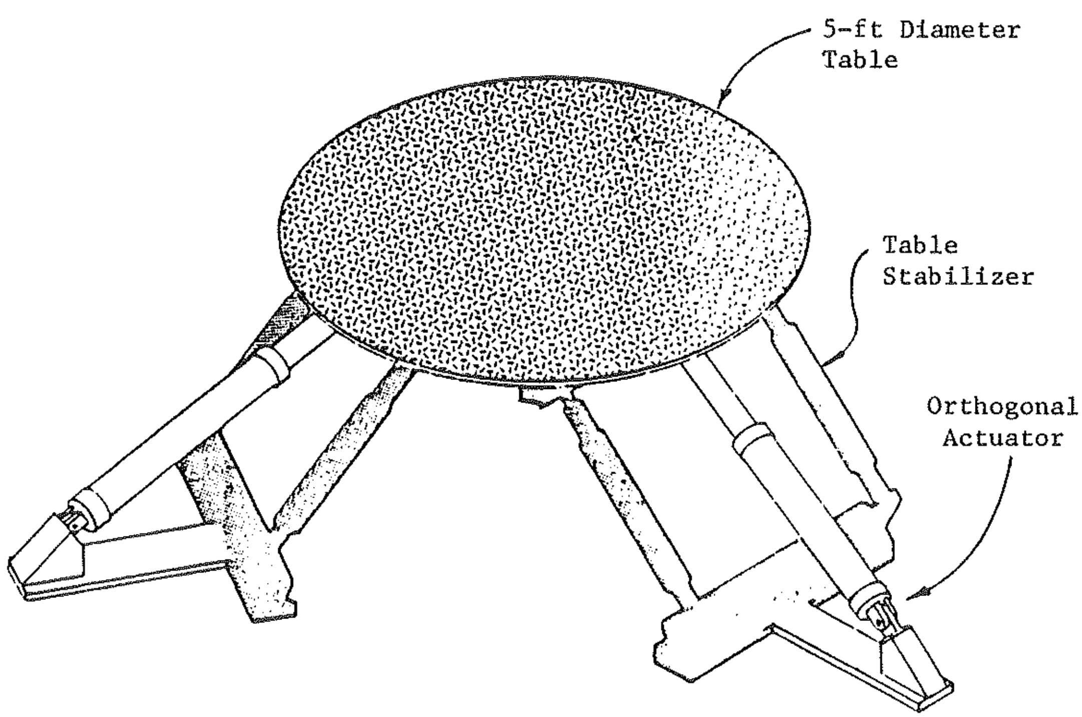

Figure 1

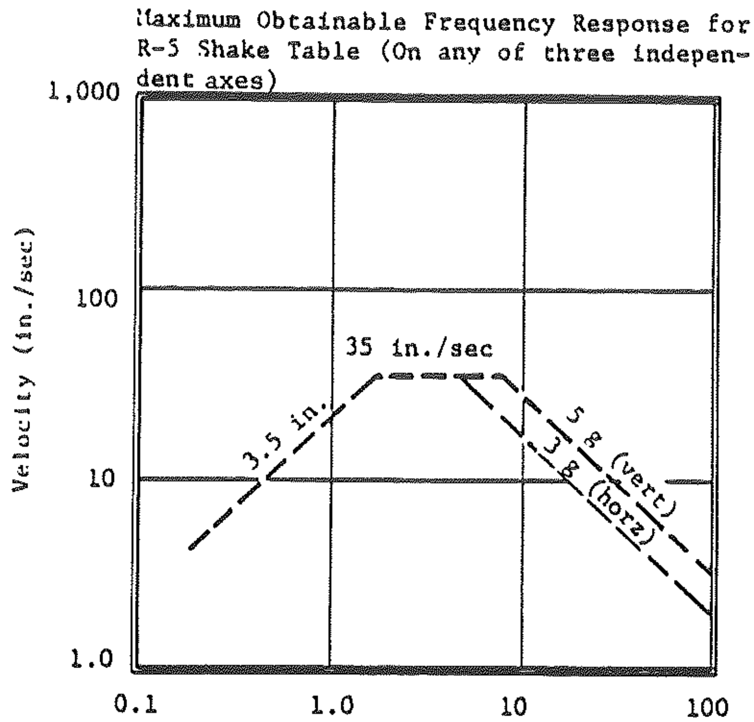

Figure 2

Table performance has been researched, and the crucial area of cross-axis sensitivity studied. It has been determined that, for seismic-related research, cross-axis response (i.e., coupling of independent motions) is only a second-order effect and is less than 10% up to 20 Hz.

Economical Considerations in the Nuclear Industry

The qualification of nuclear power plant equipment, by any means, is a serious safety and economic issue. Over the last 15 years, billions of dollars of equipment have been qualified in hundreds of nuclear power plants at the cost of hundreds of millions of dollars. Should past methods (e.g., biaxial) be called into serious question, retesting could cost even more--as replacement equipment might have to be found and plants temporarily shut down.

More than likely, past methods have been conservative (due to safety factors, spectral broadening, and typical overtesting). Establishment of this is currently the concern of many organizations, including the USNRC, EPRI, and architect/engineers who are funding research in this area. Fortunately, the availability of fully triaxial tables allows research programs to be carried out to compare two-dimensional and three-dimensional methods. Hopefully, such tests will indicate that three-dimensional testing is less severe to equipment and less costly, but not required.

Benefits of Independent Three-Dimensional Testing

Several important benefits of three-dimensional shake testing warrant discussion. First, and most obvious, is that *independent* three-dimensional excitation represents the real-time event and, as such, is the best representation of what a test specimen may be subjected to in situ. As such, many of the uncertainties associated with classical two-dimensional testing (e.g., the requirement to envelope two horizontal response spectra simultaneously) are not necessary.

Another benefit is reduced testing effort. Classical methods require test specimens to be rotated in order to produce all the required excitation directions. For large structures, this can amount to a significant manpower effort and considerably increase the costs associated with shake testing. However, given the real-event situation of independent three-dimensional testing, rotations of specimens are not necessary.

A second feature of reduced testing is lessening the probability of equipment failure due to cumulative tests. In order to perform a two-dimensional test, equipment may be subjected to many more seismic events than its seismic life would approximate. The probability of fatigue failure is greater, and equipment failure in a test program can increase costs tremendously (not to mention the political aspect). A method to reduce the number of tests on a specimen can produce a higher margin of safety against equipment damage, and three-dimensional testing can do this.

A third benefit is currently being studied and is as yet unquantified. Two-dimensional testing, with all its conservatism, may be more severe than the real event. While this may give added margins of safety for equipment certified by two-dimensional test methods, it may not be the most efficient engineering method. Efforts are proceeding to compare the two approaches, and the results may shed new light on shake table testing in the future.*

Conclusion

Shake testing has been used quite successfully, and its role in the nuclear power field is expected to grow. Therefore, new ideas are necessary to keep abreast with increased technology, greater emphasis on economy, and a stronger public awareness and demand for margins of confidence. Independent three-dimensional shake testing fills these requirements. Practical operating systems, such as that discussed, are in use and performing satisfactorily. The benefits afforded appeal to both engineering economics, technological advances, and the realism necessary to quiet the social questions.

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*Bechtel Power Corporation/ANCO Engineers, Inc., research effort.