Abstract Transactions, SMiRT-22
San Francisco, California, August 18-23, 2013

Vertical and 3D Isolation Systems: A Review with Emphasis on Their Use in Nuclear Structures

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Introduction

Although the horizontal component of earthquake response can be significantly reduced through the use of conventional seismic isolators, the vertical component of excitation is still transmitted directly into the structure. Records from instrumented structures, and some recent tests and analyses have actually seen increases in vertical response in base isolated structures under the combined effects of horizontal and vertical ground motions. This issue becomes of great concern to facilities such as a Nuclear Power Plant (NPP), with specialized equipment and machinery that is not only expensive, but critical to safe operation. As such, there is considerable interest worldwide in vertical and 3D isolation systems. For example, the European Fast Breeder Reactor (EFR) project (IAEA, 2002) and the Fast Breeder Reactor (FBR) project of Japan (Inoue et al, 2004) have considered using vertical isolation and done several studies about it. This paper examines several vertical and 3D isolation systems that have been proposed and their potential application to modern nuclear facilities. In particular, a series of case study analyses of a modern PWR NPP model are performed to examine the benefits and challenges associated with 3D isolation compared to horizontal isolation.

Various Vertical and 3D Isolation Systems

Vertical isolation systems provide flexible supports in the vertical direction usually by means a combination of metallic or air springs and supplemental damping devices. For example, the EFR project considers isolating the reactor vault from the horizontally isolated base mat by vertical springs. A vertical isolation system, consisting of a series of coned disk springs that surround a central vertical guide that maintains the shape, was explored for the FBR project of Japan.

The early effort to develop 3D isolation systems was by modifying the design parameters of laminated rubber bearings. A 2-story RC acoustic laboratory demonstration building was built using this approach by Kajima in Japan, 1986 (Kelly, 1988). 3D isolation systems using laminated rubber bearings was also explored for the United States nuclear industry (Aiken et al, 1989). A type of laminated thick rubber bearing was adopted for seismic isolation design of Japan Sodium-Cooled Fast Reactor (JSFR) recently (Okamura et al, 2011).The GERB System, consists of helical springs that are flexible horizontally and vertically, was developed and has been implemented in two residential buildings in California. These buildings were shaken strongly in the 1994 Northridge Earthquake (Makris et al, 1996). Three promising ideas for 3D isolation were examined by the FBR project of Japan, i.e., “Rolling Seal Type Air Spring”, “Hydraulic 3D Isolation System”, and “Cable Reinforced Air Spring”. Among these systems,

Inoue et al. 2004 indicates that the Rolling Seal Air Spring in combination with the rocking suppression system was the most promising system. Kozo Keikaku Engineering, Inc. in conjunction with Shimizu Corporation has extended the basic ideas from these 3D isolation projects and applied it to an actual three-story reinforced concrete apartment building in Tokyo (Suhara et al, 2008; Takahashi et al, 2008). The isolator assembly consists of a single isolator supported on three vertical air springs.

Case study Analyses

A representative but simplified "stick" lumped mass model is introduced to represent a standard modern PWR NPP in the case study analyses. Analyses of the model are used to examine the effect of 3D isolation compared to horizontal isolation in reducing peak instructure vertical accelerations, and reducing the floor response spectra in the vertical direction. P-Delta effects are considered in these analyses to account for the possible stability issues of the bearing.

Conclusions

Two approaches to isolate vertical ground motion can be selected for consideration for the next generation nuclear power plant. One is where the entire building utilizes 3D base isolation technology, and the other is where vertical isolation is provided for key components within a horizontally isolated building. While no NPP has been constructed using vertical or 3D isolation systems, there have been many efforts to develop them. The case study of a NPP model performed in this paper confirms the effectiveness of vertical isolation.

References

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