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Extreme earthquake response of nuclear power plants isolated using sliding bearings

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HIGHLIGHTS

- Response-history analysis of a nuclear power plant (NPP) isolated using sliding bearings.
- Two models of the NPP, five friction models and four seismic hazard levels considered.
- Isolation system displacement can be obtained using a macro NPP model subjected to only horizontal ground motions.
- Temperature dependence of friction should be considered in isolation-system displacement calculations.
- The effect of friction model on floor spectral ordinates is rather small, especially near the basemat.

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ABSTRACT

Horizontal seismic isolation is a viable approach to mitigate risk to structures, systems and components (SSCs) in nuclear power plants (NPPs) under extreme ground shaking. This paper presents a study on an NPP seismically isolated using single concave Friction Pendulum™ (FP) bearings subjected to ground motions representing seismic hazard at two US sites: Diablo Canyon and Vogtle. Two models of the NPP, five models to describe friction at the sliding surface of the FP bearings, and four levels of ground shaking are considered for response-history analysis, which provide insight into the influence of 1) the required level of detail of an NPP model, 2) the vertical component of ground motion on response of isolated NPPs, and 3) the pressure-, temperature- and/or velocity-dependencies of the coefficient of friction, on the response of an isolated NPP. The isolation-system displacement of an NPP can be estimated using a macro model subjected to only the two orthogonal horizontal components of ground motion. The variation of the coefficient of friction with temperature at the sliding surface during earthquake shaking should be accounted for in the calculation of isolation-system displacements, particularly when the shaking intensity is high; pressure and velocity dependencies are not important. In-structure floor spectra should be computed using a detailed three-dimensional model of an isolated NPP subjected to all three components of ground motion.

1. Introduction

Nuclear power plants (NPPs) are designed for severe internal and external natural and man-made hazards, including earthquakes. Extreme earthquakes can challenge new and existing NPPs, with large forces expected in internal structures, systems and components (SSCs) under design basis shaking. Base isolation is a viable strategy to seismically protect SSCs in NPPs, since it effectively filters a significant fraction of the high-frequency horizontal earthquake shaking, and facilitates standardization of plant designs (e.g., Huang et al., 2007; Huang et al., 2010, 2011a,b; Kumar et al., 2017). Sliding isolators, here single concave Friction Pendulum™ (FP) bearings, are one type of hardware that could be used in the United States for safety-related nuclear structures, including NPPs (see Kammerer et al., forthcoming).

This paper presents the results of response-history analyses of an NPP seismically isolated using FP bearings. The sample NPP includes three major structures: auxiliary and shield building (ASB), containment internal structure (CIS) and steel containment vessel (SCV). The ASB considered herein is a 140,000-ton concrete structure with a footprint of 97 m × 60 m, and a total height of 89 m (Roche, 2013). The CIS weighs 41,000 tons with a total height of 33 m (Short et al., 2007). The SCV weighs 3,700 tons and is

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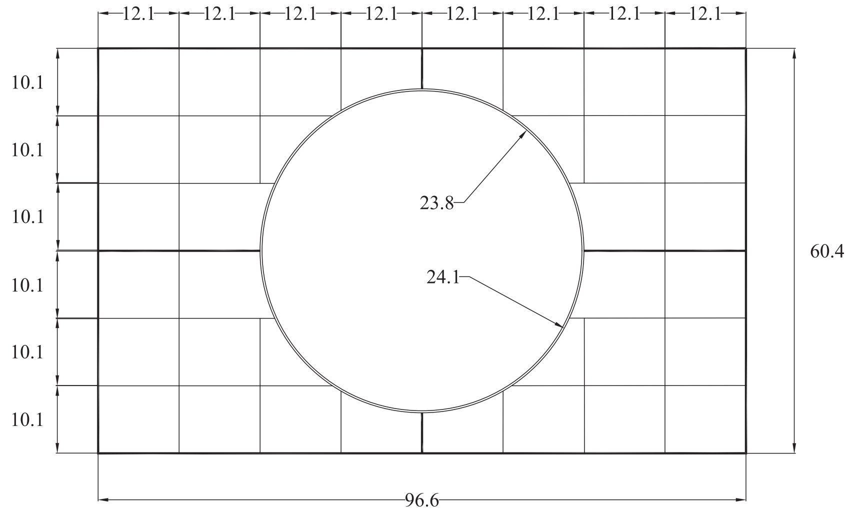
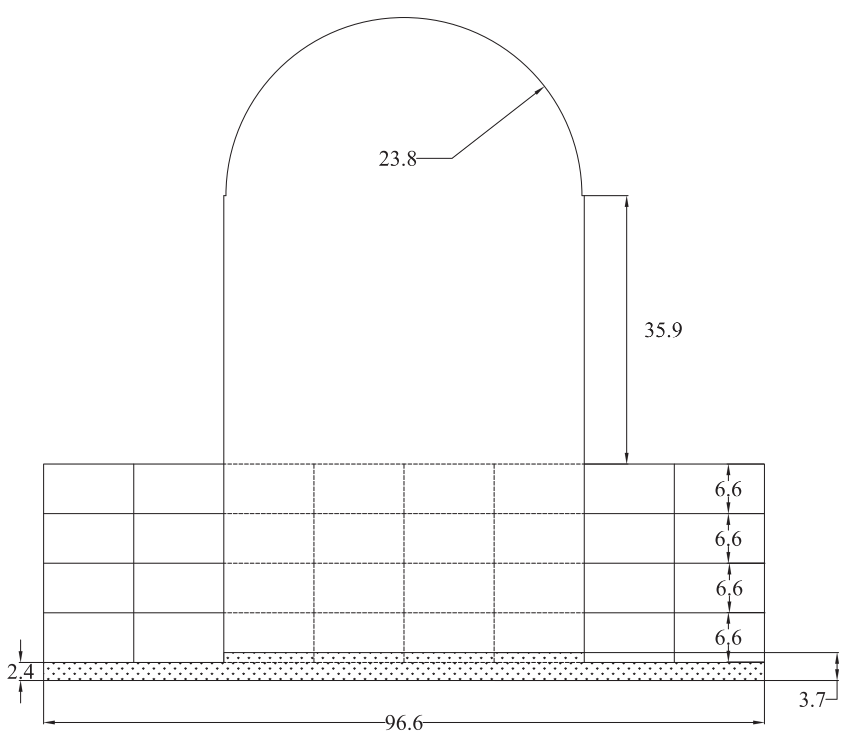


- Dimensions are in meters.
- Exterior walls and the walls along the central lines are 0.9 m (3 ft) thick.
- Interior walls are 0.6 m (2 ft) thick.
- The circle of radius 24.1 m (80 ft) indicates the 1.2 m (4 ft) thick cylindrical wall.
- The circle of radius 23.8 m (79 ft) indicates the 0.9 m (3 ft) thick hemispherical dome.

Fig. 1. Plan view of auxiliary and shield building (adapted from Roche (2013)).

ignored in this study due to its relatively small mass (see Short et al., 2007). Two models of the sample NPP are developed. The first model of the NPP is the ASB and CIS supported on a common isolation system comprising single-concave FP bearings. The second model of the NPP involves a macro (single) FP bearing with aggregated properties of the Model 1 isolation system. Friction at the sliding surface is described by the five models proposed by Kumar et al. (2015a), which update, time step by time step, the coefficient of friction at the sliding surface of a bearing as a function of the axial pressure on the bearing, horizontal velocity of the slider relative to the sliding surface, and/or temperature at the sliding surface.



- Dimensions are in meters.
- Floors and roof are 0.6 m (2 ft) thick.
- Thickness of cylindrical wall is 1.2 m (4 ft).
- Thickness of hemispherical dome is 0.9 m (3 ft).

Fig. 2. Elevation view of auxiliary and shield building (adapted from Roche (2013)).