ANS Meeting

2018 International Congress on Advances in Nuclear Power Plants

Using seismic isolation to simplify and standardize NPP designs

Benjamin Kosbab, Ph.D.
SC Solutions, Atlanta, GA
Chingching Yu, Ph.D. candidate
MCEER/University at Buffalo, NY
Andrew Whittaker, Ph.D., S.E.
MCEER/University at Buffalo, NY

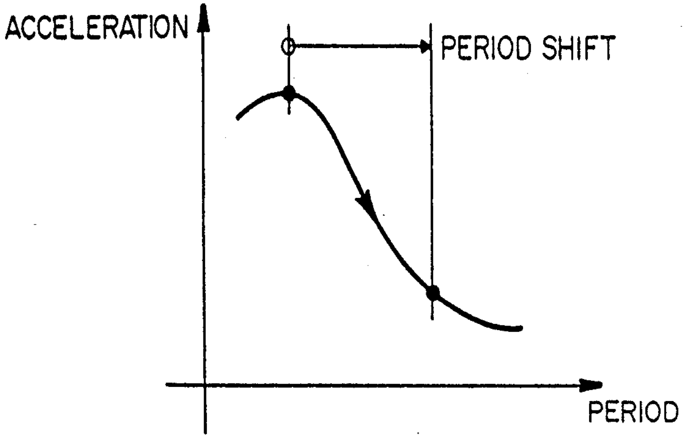
SC SOLUTIONS
Value Through Innovation.

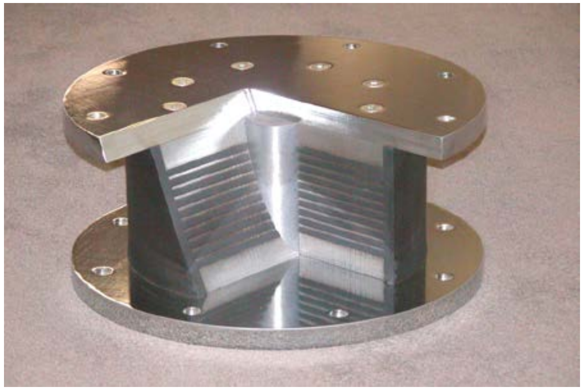
MCEER
EARTHQUAKE ENGINEERING TO EXTREME EVENTS

SC SOLUTIONS
Value Through Innovation.

Outline

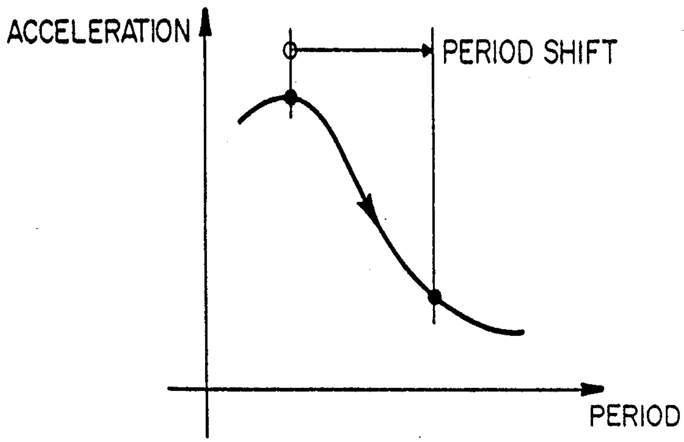
- Introduction
- Seismic isolation
- New build NPPs
  - Cost
  - Seismic penalty
- Benefits of isolation
  - 5+ fold reductions in seismic loading
  - Standardize plants, SSCs
  - Reduced risk
  - Proven technology
  - Proven US supply chains
  - Regulatory guidance available
- Conclusions
- Acknowledgments

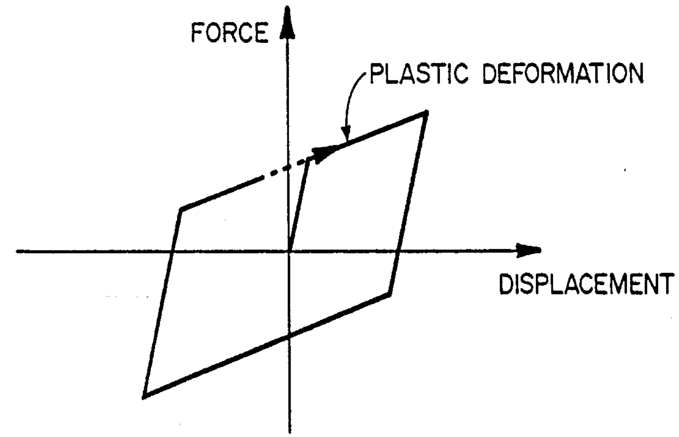


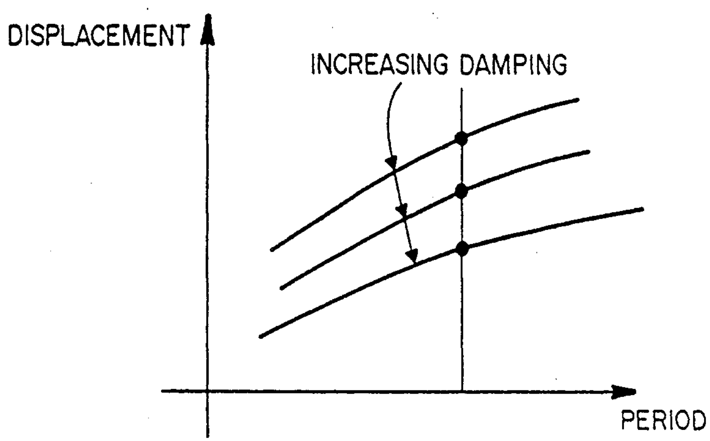


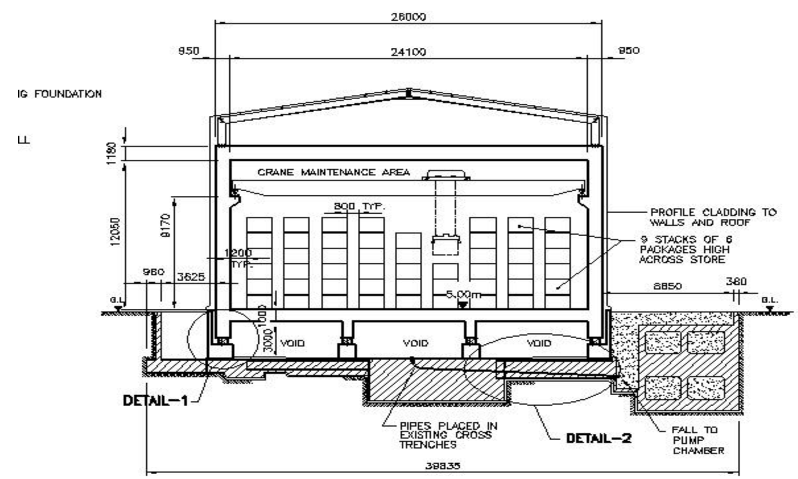
MCEER
EARTHQUAKE ENGINEERING TO EXTREME EVENTS

Seismic isolation

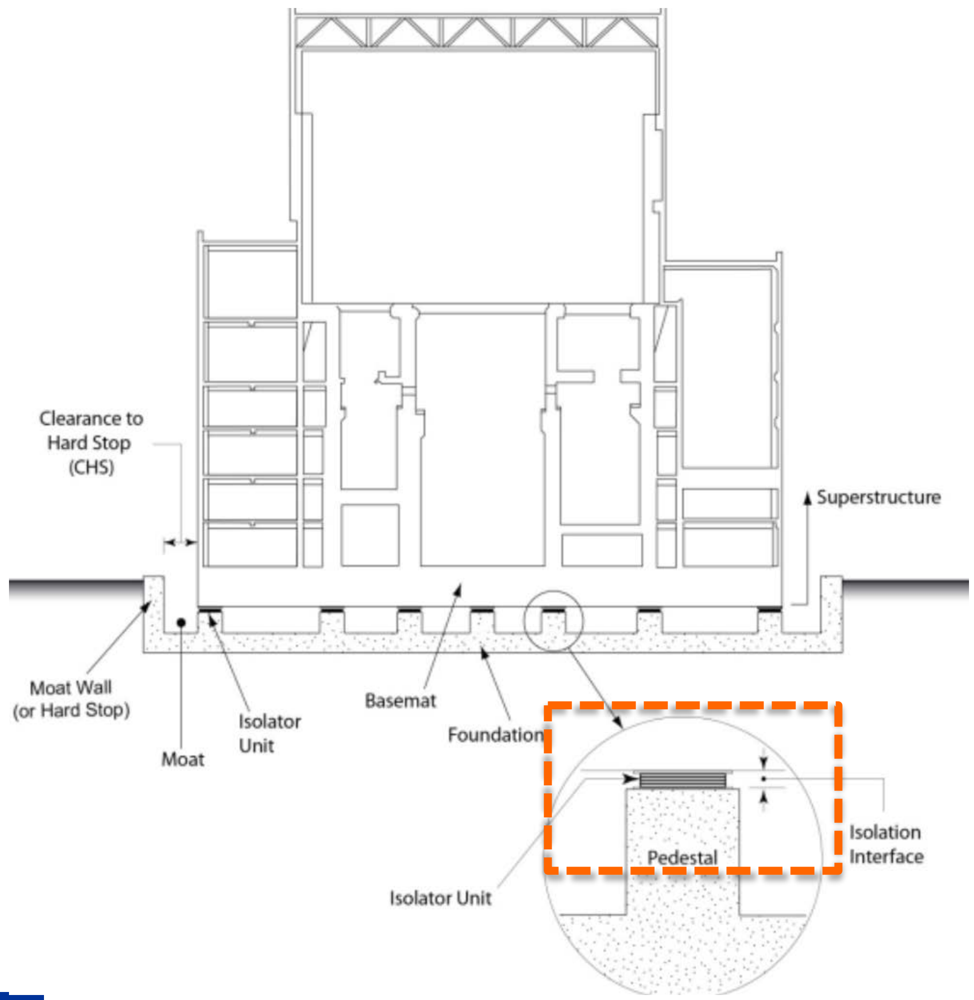


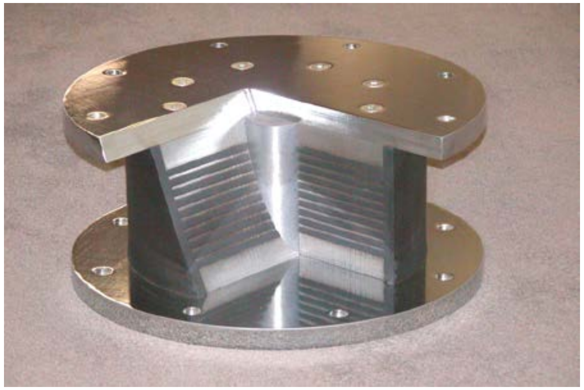




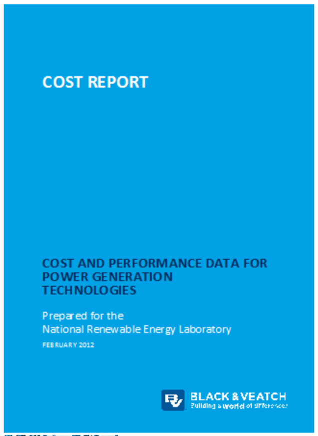


Seismic isolation





New build NPPs


COST REPORT

COST AND PERFORMANCE DATA FOR POWER GENERATION TECHNOLOGIES

Prepared for the
National Renewable Energy Laboratory
FEBRUARY 2012

BLACK & VEATCH

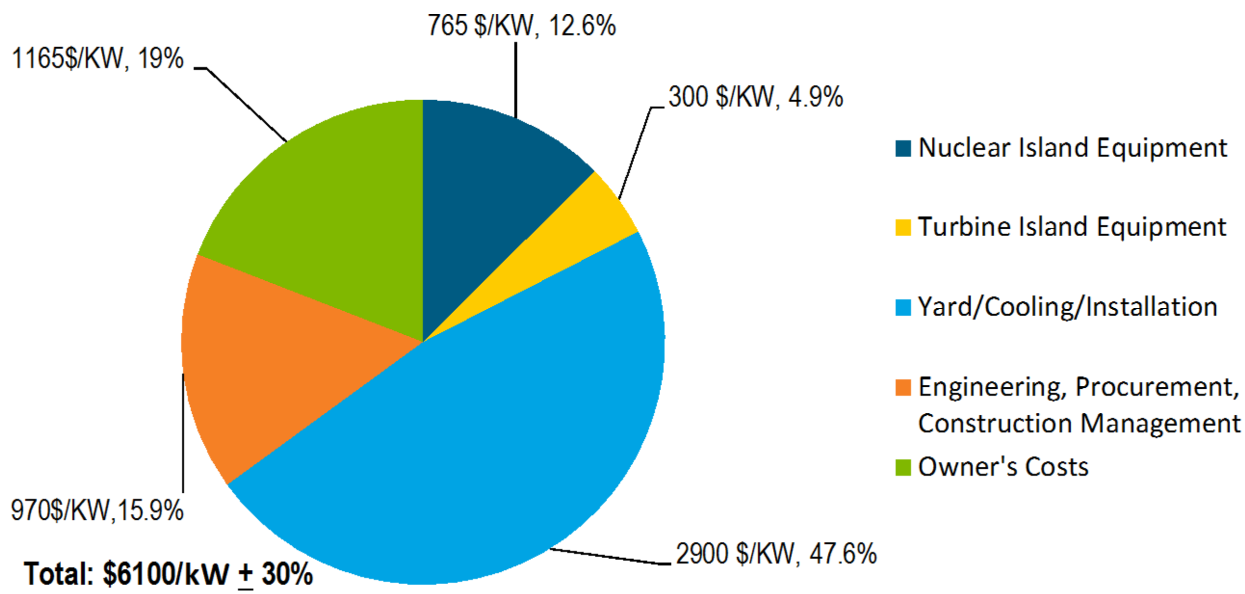
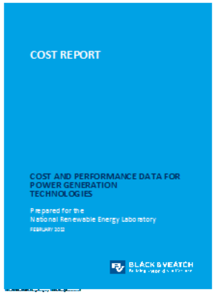


Figure 1. Capital cost breakdown for a nuclear power plant

SC SOLUTIONS
Value Through Innovation.

New build NPPs

- Cost drivers for new build NPPs
  - Site-specific analysis, design and construction
  - Site-specific equipment designs and qualification
  - Regulatory review
  - Legacy methods for design and construction
  - Supply chains
  - Seismic load effects, vary by site
    - 30+% of overnight capital cost
    - 10+% to time to construct


COST REPORT

COST AND PERFORMANCE DATA FOR POWER GENERATION TECHNOLOGIES

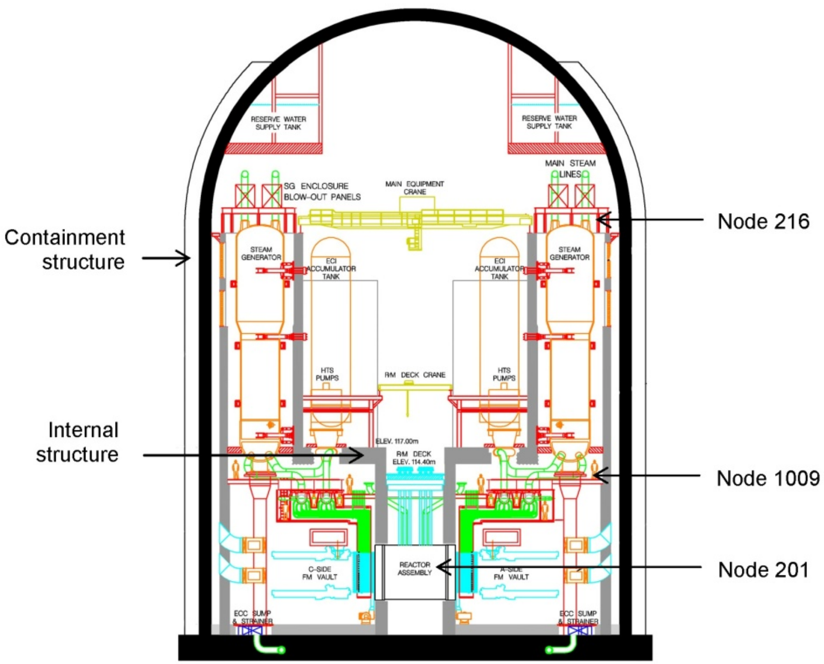
Prepared for the
National Renewable Energy Laboratory
FEBRUARY 2012

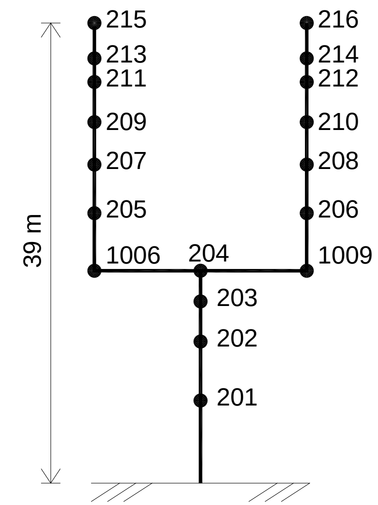
BLACK & VEATCH

MCEER
EARTHQUAKE ENGINEERING TO EXTREME EVENTS

Benefits of isolation

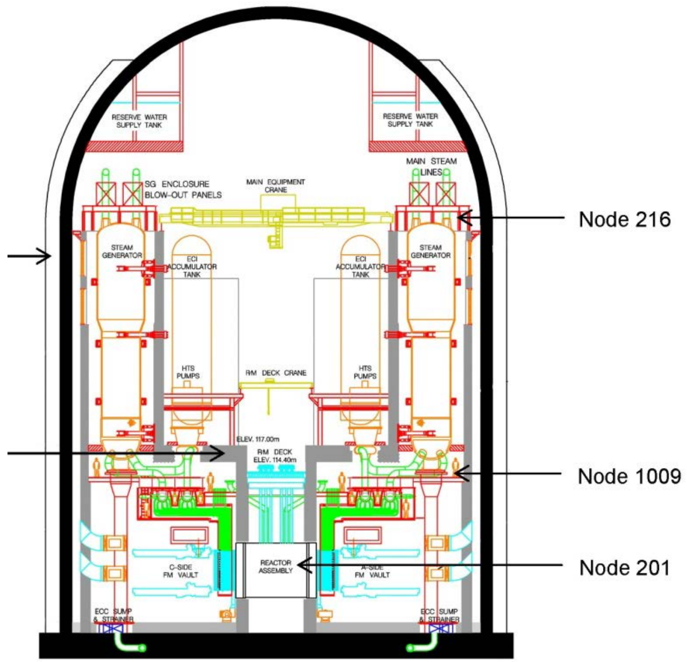
- 5+ fold reductions in horizontal shaking
  - SSCs more robust for vertical shaking

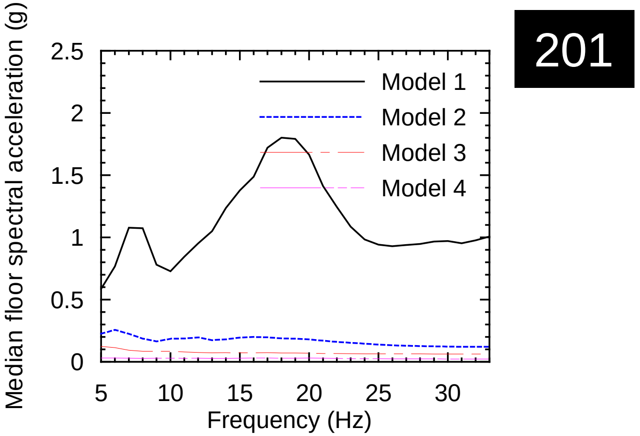


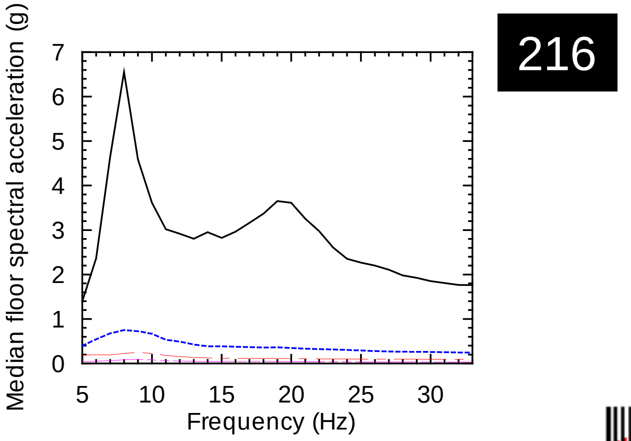


Benefits of isolation

- 5+ fold reductions in horizontal shaking







SC SOLUTIONS
Value Through Innovation.

Benefits of isolation

- Standardize buildings and internal SSCs
  - For CIS, horizontal spectral demand approximately constant with height
    - Increases substantially for conventional NPPs
  - Site-specific designs to address ONLY the isolation system
    - Internal equipment optimized for operation
      - No seismic penalty; one time qualification, if needed at all
      - Site independent; dramatic cost savings across *N* plants
    - Greatly simplified building design and seismic PRA
    - Reduced construction time, regulatory review
  - *Insurance* against increasing hazard at site
  - Enables construction of NPPs anywhere in the US

MCEER
EARTHQUAKE ENGINEERING TO EXTREME EVENTS

SC SOLUTIONS
Value Through Innovation.

Benefits of isolation

- Reduce seismic risk
  - Isolation of a conventional NPP will reduce seismic risk by a factor of between 1000 and 1,000,000
    - Studies by Huang et al. in the late 2000s, Kumar et al. in 2016; Yu et al. in 2016
    - Explicit consideration of accident sequences triggered by failure of the isolation system
    - Can trade risk with overnight capital cost
  - Enables a more balanced risk portfolio across external hazards

MCEER
EARTHQUAKE ENGINEERING TO EXTREME EVENTS

Benefits of isolation

- Proven technology and supply chain
  - US utilized technology
    - LR bearings (Dynamic Isolation Systems)
    - FP bearings (Earthquake Protection Systems)
    - ISO QA procedures used to date
    - Commercial grade dedication or NQA-1
  - Very high confidence in isolator behavior
    - Dynamic testing of prototype testing
    - Testing of ALL production bearings for design-basis demands
  - Deployed in mission-critical buildings in CA
    - Very high seismic hazard
    - 30+ year history of applications from both vendors
    - Design and testing all peer reviewed

Benefits of isolation

- Regulatory guidance available
  - ASCE
    - Chapter 12 of ASCE 4-16
      - Analysis of isolated NPPs
    - Chapter 9 of ASCE 43-18
      - Design/testing of isolated NPPs
  - Seismic isolation NUREG
    - Technical considerations
    - Expected in Q2 of 2018
  - NUREG/CRs
    - Isolation of NPPs with elastomeric bearings
    - Isolation of NPPs with sliding bearings
    - Expected in Q3 of 2018

SC SOLUTIONS
Value Through Innovation.

Conclusions

- Isolation of NPPs
  - Suitable for large light water reactors and advanced reactors
  - Reduces overnight capital cost
  - Reduces seismic risk
  - Enables standardization of designs
    - Dramatic reductions in forces on buildings and SSCs
    - Equipment designs not compromised by seismic loadings
    - Standardized equipment across *N* plants
    - Modify ONLY the isolation system for different sites
  - Proven technology and supply chains
  - *Insurance* against increasing seismic hazard
  - Regulatory guidance already in place

MCEER
EARTHQUAKE ENGINEERING TO EXTREME EVENTS

Acknowledgments

- MCEER/University at Buffalo
  - Michael Constantinou
  - Manish Kumar, IITB
  - Manish Kumar, IITGN
  - Yin-Nan Huang, NTU
- INL
  - Justin Coleman
  - Chandrakanth Bolisetti
- LBNL
  - Dr. Robert Budnitz
- US NRC
  - Dr. Jose Pires

284

Contents lists available at ScienceDirect

Nuclear Engineering and Design

journal homepage: www.elsevier.com/locate/nucengdes

Using seismic isolation to reduce risk and capital cost of safety-related nuclear structures

Ching-Ching Yu[a,*], Chandrakanth Bolisetti[b], Justin L. Coleman[b], Ben Kosbab[c], Andrew S. Whittaker[a]

[a] University at Buffalo, The State University of New York, 212 Ketter Hall, Amherst, NY 14260, USA
[b] Idaho National Laboratory, 2525 Fremont Avenue, Idaho Falls, ID 83402, USA
[c] SC Solutions, 188 Anderson St SE, Suite 250, Marietta, GA 30060, USA

ARTICLE INFO

Keywords:
Nuclear facilities
Seismic isolation
Seismic probabilistic risk assessment
Capital cost

ABSTRACT

The implementation of seismic base isolation can substantially reduce horizontal seismic demands on structures, systems, and components (SSCs) in a nuclear facility, potentially providing significant benefits in terms of increased safety (smaller seismic risk) and reduced capital construction cost. Although increased safety of SSCs has been demonstrated previously, the possible reduction in their capital cost has not been explored. To quantify the reduction in risk enabled by isolation, nonlinear response-history analysis of a conventionally founded and a base-isolated model of a generic nuclear facility (GNF) is performed at the sites of the Idaho National Laboratory and the Los Alamos National Laboratory: sites of moderate and high seismic hazard, respectively. Seismic probabilistic risk assessment is performed to compute the mean annual frequency of unacceptable performance. The seismic risk is reduced by 7 to 8 orders of magnitude by the implementation of isolation. The costs of addressing seismic loadings are estimated for the GNF in both the conventionally founded and base-isolated GNF. The possible reductions in the required seismic ruggedness and in the cost of SSCs in the isolated GNF are quantified at both sites. A reduction in cost enabled by isolation is possible at nearly all sites of nuclear facilities in the United States, with the greatest benefit at sites of high seismic hazard, such as LANL. Two risk-calculation procedures are used in the assessment: a simplified method based on Boolean mathematics and a rigorous method based on Monte Carlo analysis. The simplified procedure, which is suitable for implementation with preliminary design calculations, produces accurate estimates of risk unless the mean annual frequencies of unacceptable performance are very small, measured here as smaller than 10^{-10}. The sensitivity of the calculated risk in the conventionally founded GNF, to the choice of anchor period for the seismic hazard curve, is investigated and found to be insignificant over the range considered: 0 to 0.10 s.

1. Introduction

The reduction in horizontal seismic demands enabled by the use of seismic isolation yields four possible benefits for nuclear facilities: 1) *economic*: reduction in capital cost, 2) *increased safety*: reduction in the mean annual frequency of unacceptable performance, 3) *insurance*: protection against increases in the known seismic hazard during and after construction by minimizing or eliminating the effort to re-qualify and re-certify, or back-fit structures, systems and components, and 4) *recertification*: the opportunity to certify an existing NPP design for a region of higher seismic hazard. To date, only the second benefit has been explored (e.g., Huang et al., 2008a, 2011a, 2011b). In this paper, the potential benefits of *reduced capital cost* and *increased safety* are investigated for an archetype building, described herein as a generic nuclear facility (GNF).

To enable some generalization of the outcomes, two sites are considered for a conventionally founded and a base-isolated GNF: 1) the Idaho National Laboratory (INL) in Idaho Falls, ID and 2) the Los Alamos National Laboratory (LANL) in Los Alamos, NM. Seismic hazard calculations are performed and suites of ground motion time series are generated for each site. The GNF is assumed to handle materials at risk (MAR) and so structures, systems and components (SSCs) that are common to safety-related nuclear structures are used to populate the facility for risk calculations. The finite element code LS-DYNA (LSTC, 2013) is used to perform nonlinear response-history analysis of the conventionally founded (non-isolated) and base-isolated building; the

* Corresponding author.

https://doi.org/10.1016/j.nucengdes.2017.11.016
Received 15 March 2017; Received in revised form 27 October 2017; Accepted 4 November 2017
Available online 20 November 2017