An Effective and Efficient Methodology to Update the Seismic Fragilities of SSCs over Different Seismic Hazard Updates

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An Effective and Efficient Methodology to Update the Seismic Fragilities of SSCs over Different Seismic Hazard Updates - Logistics

- Goal of this presentation is to introduce a framework to minimize the total amount of effort required in acquiring the new fragility data for seismic risk assessment of equipment in a cost effective and efficient manner

An Effective and Efficient Methodology to Update the Seismic Fragilities of SSCs over Different Seismic Hazard Updates - Driver

- U.S utilities are developing seismic PRAs in compliance with the ASME/ANS SPRA Standard for
  - NTTF 2.1 Submittals
  - Risk Informed Applications

- As part of these applications, models have to be maintained and updated on a periodic basis to reflect the current state of knowledge

- Important parameter that could affect the validity of these models over time is the site-specific probabilistic seismic hazard analysis (PSHA)
  - There is an ever evolving understanding of ground motion attenuation

- Updates to the site-specific seismic hazard curves would trigger a change in the seismic response evaluation and in-structure response spectra (ISRS)
  - Seismic fragilities of equipment are based on the input ISRS
  - New fragilities need to be developed in a manner that they are compatible with the updated site-specific seismic hazard curves
  - Updating the seismic fragilities require a significant amount of effort

An Effective and Efficient Methodology to Update the Seismic Fragilities of SSCs over Different Seismic Hazard Updates - Current Guidelines

- To account for higher ground motion levels
  - Scaling of ISRS is considered a technically sound approach
  - Guidance on scaling methods is provided in EPRI documents EPRI NP-6041 and EPRI 103959.

- Scaling of these responses will be based on the similarity between the shapes of the previously and newly generated site-specific seismic hazard curves.

- There is limited guidance on scaling fragilities if the shapes are different.

An Effective and Efficient Methodology to Update the Seismic Fragilities of SSCs over Different Seismic Hazard Updates - Introduction

- Methodology discussed here extends beyond the current guidelines and proposes an approach to scale the seismic fragilities of equipment over different seismic hazard updates

- It is conditional upon the adequacy of the previously and newly generated ISRS
  - Review of the structure models should be performed to ascertain the adequacy of the existing models to predict the response incorporating the updated site-specific rock or soil conditions

- Since the scaling is based on the ISRS, it would be applicable irrespective of the similarity in shapes of the previously and newly generated site-specific seismic hazard curves

An Effective and Efficient Methodology to Update the Seismic Fragilities of SSCs over Different Seismic Hazard Updates - Methodology

- Scaling approach is explained herein with two sets of seismic hazard data and are identified with their corresponding hazard year as follows
  - 2012 Hazard
    - Uses the CEUS 2012 seismic sources and 2004 EPRI ground motion models
  - 2014 Hazard
    - Uses the CEUS 2012 seismic sources and the 2013 EPRI ground motion models

- The following inputs must be completed and verified for adequacy prior to applying the scaling approach
  - Site-specific seismic response evaluation (ISRS) for both sets of hazard data (2012 and 2014 Hazard)
  - Seismic fragilities of equipment based on the seismic response evaluation consistent with the base hazard data (2012 Hazard)

An Effective and Efficient Methodology to Update the Seismic Fragilities of SSCs over Different Seismic Hazard Updates - Methodology

- Seismic fragilities of equipment associated with the new hazard data (2014 Hazard) are obtained by scaling the base fragilities (2012 Hazard)

- Seismic capacities of the equipment are independent of the hazard and only the seismic demand changes over the two sets of hazard data

- Seismic demand parameters associated with the base fragility calculations, for each of the component based on the failure mode, are
  - Frequency range of interest (FROI)
  - Corresponding ISRS node location

An Effective and Efficient Methodology to Update the Seismic Fragilities of SSCs over Different Seismic Hazard Updates - Methodology

- Seismic demand ratio for each of the component is obtained by comparing the 5% damped maximum spectral acceleration within the specified frequency range between 2012 and 2014 Hazard

- Seismic demand comparison is based on the 5% damped unclipped ISRS

$$\text{Seismic Demand Ratio} = \max\left(\frac{\text{PeakX}_{2014}}{\text{PeakX}_{2012}}, \frac{\text{PeakY}_{2014}}{\text{PeakY}_{2012}}, \frac{\text{PeakZ}_{2014}}{\text{PeakZ}_{2012}}\right)$$

- PGA ratio is calculated by comparing the reference level earthquake between the 2012 and 2014 Hazard as follows

$$\text{PGA}_{\text{ratio}} = \frac{\text{PGA}_{2014}}{\text{PGA}_{2012}}$$

An Effective and Efficient Methodology to Update the Seismic Fragilities of SSCs over Different Seismic Hazard Updates - Methodology

- Scale factor for each of the equipment is obtained as follows

$$\text{ScaleFactor} = \frac{\text{PGA}_{\text{ratio}}}{\text{Seismic Demand Ratio}}$$

- Scaled seismic fragility for each of the equipment is calculated using the following approach
  - If the scale factor is less than unity, then the scaled seismic fragility is reduced to reflect the effect of the 2014 Hazard.
  - If the scale factor is greater than unity, the scaled seismic fragility would be limited to the base fragility value

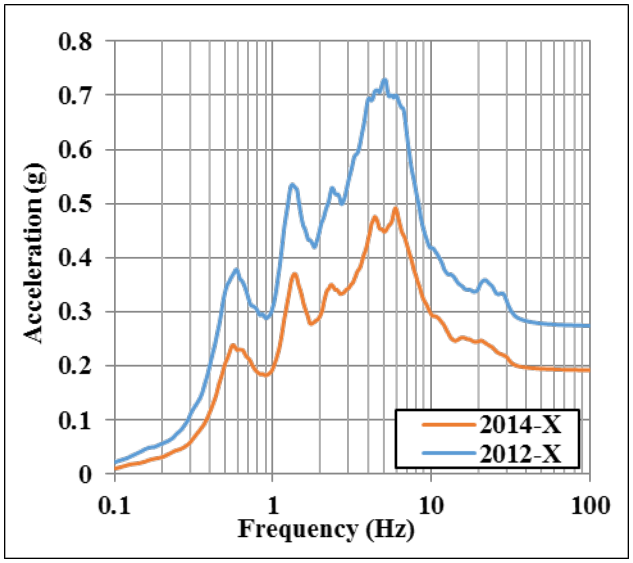
$$\text{Fragility}_{2014} = \text{If}(\text{ScaleFactor} > 1, 1, \text{ScaleFactor}) * \text{Fragility}_{2012}$$

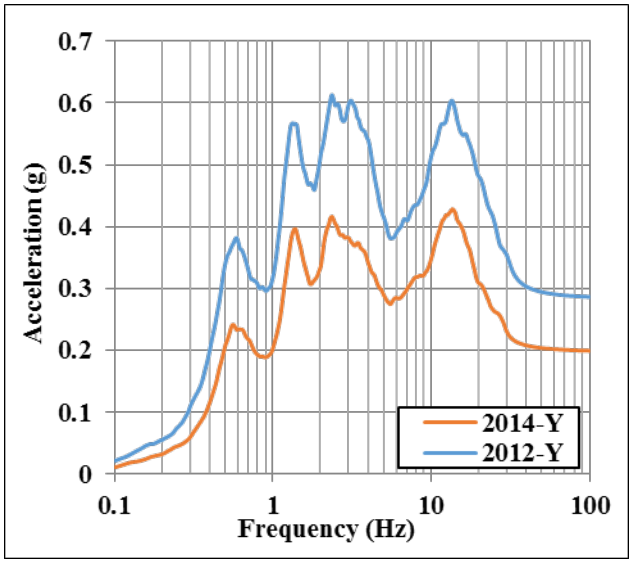
- Thus, the approach does not increase the base fragility value without performing a detailed fragility evaluation

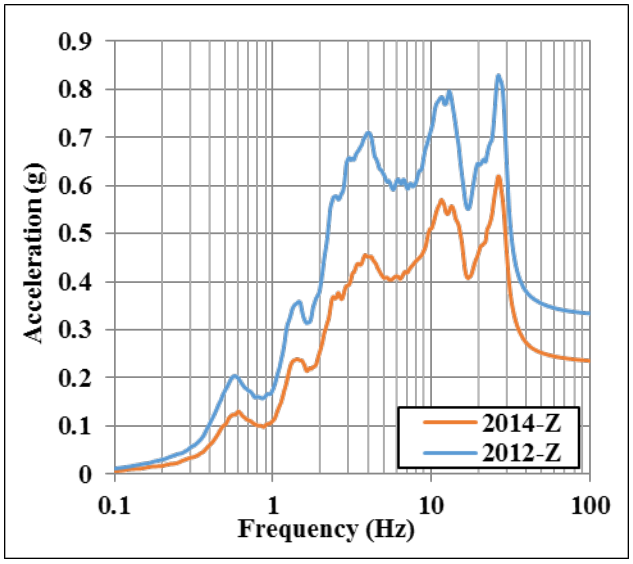
An Effective and Efficient Methodology to Update the Seismic Fragilities of SSCs over Different Seismic Hazard Updates - Example

- The proposed methodology is identical for all the classes of equipment and relays
- Equipment considered in this example is a horizontal pump
- Only the anchorage failure mode is evaluated
- Other failure modes of this pump would be evaluated similar to the following procedure
- Inputs
  - PGA for the 2012 Hazard (0.567g) and the PGA for the 2014 Hazard (0.436g)
  - Base seismic fragility (2012 Hazard) of this horizontal pump was calculated using separation of variables (SOV) approach
    - Median capacity was estimated to be 2.33g
  - Frequency range of interest for this horizontal pump was greater than 33 Hz
  - 2012 and 2014 Hazard ISRS (5% damped) of the corresponding node for this horizontal pump

An Effective and Efficient Methodology to Update the Seismic Fragilities of SSCs over Different Seismic Hazard Updates - Example







ISRS (5% damped) comparison between 2012 and 2014 Hazard in all the three orthogonal directions of the corresponding input node for this horizontal pump

An Effective and Efficient Methodology to Update the Seismic Fragilities of SSCs over Different Seismic Hazard Updates - Example

- Scaled fragility for this horizontal pump is limited to the base fragility value of 2.33g, since the scale factor computed was greater than unity

Scaling Approach:

$$\frac{\text{PeakX}_{2014}}{\text{PeakX}_{2012}} = \frac{0.2028g}{0.2935g} = 0.69$$

$$\frac{\text{PeakY}_{2014}}{\text{PeakY}_{2012}} = \frac{0.2161g}{0.3235g} = 0.67$$

$$\frac{\text{PeakZ}_{2014}}{\text{PeakZ}_{2012}} = \frac{0.3310g}{0.4518g} = 0.73$$

$$\text{Seismic Demand Ratio} = \max(0.69, 0.67, 0.73) = 0.73$$

$$\text{PGA}_{\text{ratio}} = \frac{\text{PGA}_{2014}}{\text{PGA}_{2012}} = \frac{0.436g}{0.567g} = 0.77$$

$$\text{ScaleFactor} = \frac{0.77}{0.73} = 1.05$$

$$\text{Fragility}_{2012} = 2.33g$$

$$\text{Fragility}_{2014} = 1 * \text{Fragility}_{2012} = 1 * 2.33g = 2.33g$$

An Effective and Efficient Methodology to Update the Seismic Fragilities of SSCs over Different Seismic Hazard Updates - Implementation

- Systematic nature of this scaling process between hazard years allowed for it to be automated

- Automation required storing three sets of information
  - Hazard year spectral accelerations
  - Calculation details
  - PGA values for each hazard year

- Unclipped spectral accelerations for each hazard year

NodeName	Damping	Frequency	Average X	Average Y	Average Z
AFWPH-728	5	0.1	0.01124	0.01124	0.00587
AFWPH-728	5	0.10233	0.01191	0.01191	0.00617
AFWPH-728	5	0.10471	0.0126	0.0126	0.00649
AFWPH-728	5	0.10715	0.01339	0.01339	0.0068
AFWPH-728	5	0.10965	0.01426	0.01426	0.00713

An Effective and Efficient Methodology to Update the Seismic Fragilities of SSCs over Different Seismic Hazard Updates - Implementation

- Detailed fragility evaluation performed for the base hazard year is stored in a database using the following data
  - ISRS node
  - Frequency range of interest (FROI)
  - Am, Br, and Bu

ID	Equipment Type	Fragility Type	Fragility Method	Node	FROI XLB	FROI XUB	FROI YLB	FROI YUB	FROI ZLB	FROI ZUB	Am	Bu	Br	Hazard Year
1	Horizontal Pump	Anchorage	SOV	AB-68714	32.26	100	32.26	100	32.26	100	2.33	0.24	0.24	2012
2	Control Panel	Anchorage	SOV	AFWPH-728	0.1	100	0.1	100	0.1	100	2.97	0.13	0.25	2012
3	Control Panel	Functional (After)	TRS	AFWPH-728	14.79	100	14.79	100	14.13	100	2.03	0.33	0.25	2012
4	Control Panel	Functional (During)	TRS	AFWPH-728	14.79	100	14.79	100	14.13	100	1.46	0.28	0.25	2012
5	Air Silencer	Anchorage	SOV	CB-53338	0.1	100	0.1	100	0.1	100	4.31	0.31	0.26	2012

- Based on these information, then an automated program calculates the scaled seismic fragility for each of the component following the methodology outlined in the example

An Effective and Efficient Methodology to Update the Seismic Fragilities of SSCs over Different Seismic Hazard Updates – Non Seismic Demands

- Certain equipment class like heat exchangers where the non-seismic loads are significant to the overall demand, the base fragility evaluation should be reviewed to understand on how the non-seismic demands are implemented into the calculation

- General median capacity equation would be as follows

$$\text{Median Capacity (Base)} = \text{Safety Factor} * \text{PGAref}$$

$$\text{Safety Factor} = \frac{\text{Strength} - \text{NonSeismic Demand}}{\text{Seismic Demand}}$$

- Following the proposed scaling methodology the new median capacity would be estimated using the below equation

$$\text{Median Capacity (New)} = \text{Median Capacity (Base)} * \text{ScaleFactor}$$

An Effective and Efficient Methodology to Update the Seismic Fragilities of SSCs over Different Seismic Hazard Updates - Non Seismic Demands

- If the following equation is used for calculating the safety factor while estimating the base median capacity
  - Proposed scaling approach would multiply both the seismic demand and the non-seismic demand present in the denominator of this safety factor equation
  - This would lead to an unconservative value if the seismic demand ratio is less than unity which in turn would reduce both the seismic and non-seismic demand

$$\text{Safety Factor} = \frac{\text{Strength}}{\text{Seismic Demand} + \text{NonSeismic Demand}}$$

An Effective and Efficient Methodology to Update the Seismic Fragilities of SSCs over Different Seismic Hazard Updates – Uncertainty Parameters

- To estimate the uncertainty parameters associated with the new median capacity calculated using the scaling approach
  - Site-specific sensitivity studies should be performed to justify using the same uncertainty parameters associated with the base median capacity
  - Compute additional uncertainty associated with the seismic demand

- Sensitivity study adopted for the horizontal pump example
  - Seismic response evaluation for this fragility is based on the soil-structure interaction (SSI) analysis
  - SSI analysis are performed for both the 2012 and 2014 Hazard data
    - Since the ISRS shapes are similar
    - Effects of the revised soil properties on the resulting ISRS are small
  - Uncertainties and randomness associated with the scaled seismic fragility of this component are judged to be the same as of the base seismic fragility

- If the sensitivity study shows different ISRS shapes and significant changes in the transfer functions due to the revised soil properties, then additional uncertainty would need to be accounted for the seismic demand

An Effective and Efficient Methodology to Update the Seismic Fragilities of SSCs over Different Seismic Hazard Updates - Conditional upon Adequate ISRS

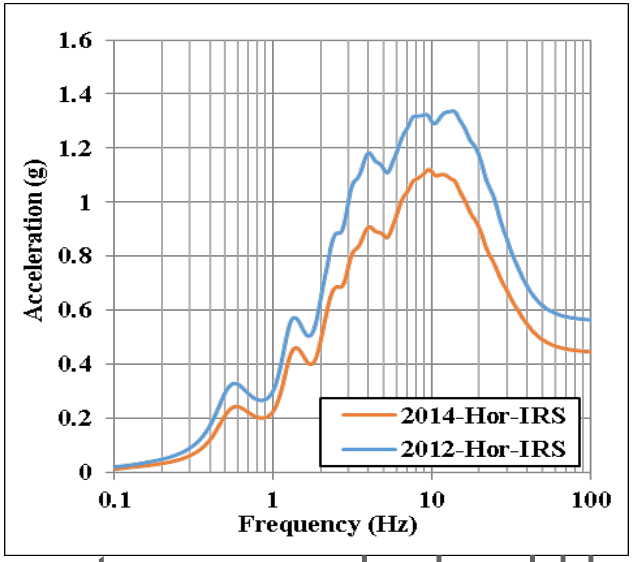
- Scaling approach proposed is conditional upon the generated ISRS being adequate for both the base fragility and the new scaled fragility evaluation

- Scaling approach of the seismic fragilities can be extended further by combining the current guidelines on scaling ISRS which are provided in EPRI documents

- Performing a detailed SSI analysis over different hazard updates is both time consuming and resource intensive
  - An alternative approach for future is to minimize the effort involved in performing a detailed SSI analysis
  - Seismic demand ratio illustrated in the examples could be modified to use the input response spectra (IRS) at the corresponding foundation elevation of the building for both the 2012 and 2014 Hazard data instead of the ISRS

An Effective and Efficient Methodology to Update the Seismic Fragilities of SSCs over Different Seismic Hazard Updates - Conditional upon Adequate ISRS

- It can be observed that the results are closer if IRS method is used
  - Since similar input response spectra shapes as shown in the figure below and the effects of the revised soil properties being small



Input response spectra (IRS) at the foundation elevation of the building where the component is mounted on. This building is a surface founded structure

- This alternate approach should be validated for the site

- Site-specific sensitivity analysis should be performed to estimate the uncertainty parameters.

An Effective and Efficient Methodology to Update the Seismic Fragilities of SSCs over Different Seismic Hazard Updates - Summary

- A systematic approach to scale seismic fragilities over different PSHA studies for the same site
- Approach allows updates to the seismic PRA model to be more streamlined and less cumbersome
  - scaling fragilities to be compatible with the updated hazard rather than the tedious and costly approach of manually updating the fragility evaluations
- Database framework is proposed to automate the scaling process
- Alternative approach for future study that could minimize the effort involved in performing a detailed SSI analysis is proposed