RECOMMENDATION ON PROJECT-SPECIFIC SEISMIC HAZARD ASSESSMENT FOR INTERNATIONAL ENERGY PROJECTS

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Abstract

This paper recommends a use of project-specific seismic hazard assessment (SHA) for international energy projects.

A seismic hazard is recognized as one of the most important concerns for investors as the world has experienced many catastrophic earthquake events in the past. Therefore, the seismic hazard should be quantitatively assessed, and the earthquake risk should be considered into the asset value.

SHA is a powerful tool for the facility owners as well as facility designers since it provides accountabilities about the seismic hazards and countermeasures. On internationally financed projects in emerging countries, the design requirements are likely complicated as it has to cover both local country's design codes and internationally recognized design codes. In addition, SHA enables to assess the seismic risk costs quantitatively by defining the operating level earthquake (OLE) and evaluating the cost associated with the production interruption and repair for recovery.

The SHA procedure is getting standardized and the open source software is available. It is proposed that the seismic hazard must be considered as "design parameters to be assessed", although it has been recognized as "given conditions".

Keywords: Seismic Hazard Assessment; Seismic Design Codes; Continuous Functionality; Energy Projects

1. Introduction

1.1 General

Because of worldwide trend of electricity liberalization and a shift from fossil fuel to clean energy, investment opportunities at energy sector are significantly increasing and diversified with new developers and investors from multiple countries. A large-scale energy project is commonly backed-up by a series of studies which aim to maximize the investment efficiency based on a scale of economy. Under this circumstance, a design accountability becomes more and more important to overcome a process of technical due diligence for internationally financed projects. Particularly, a seismic hazard is recognized as one of the most important concerns for investors as the world has experienced many catastrophic earthquake events in the past. Therefore, the seismic hazard should be quantitatively assessed, and the earthquake risk should be considered into the asset value. A proper SHA and risk assessment should allow investors to take final investment decisions and/or optimize the geohazard insurance cost.

1.2 Seismic Design Requirements

For internationally financed projects in emerging countries, it is common to apply the internationally recognized design codes (hereafter "international design codes") such as ASCE 7 [1] and EN 1998 [2], and accordingly the seismic hazard complying with the international design codes as well as the local country's design codes must be considered in the design. For a Liquefied Natural Gas (LNG) project, NFPA 59A [3] or EN 14620 [4] are applied as primary design codes and it requires a consideration of Safe Shutdown Earthquake (SSE) and Operational Base Earthquake (OBE), which represents a more stringent requirement than those of ASCE 7 and EN 1998.

Although the local country's design code specifies the seismic hazard to be considered in design, when a compliance to the international design codes is required, it is recommended to perform a SHA to evaluate the project-specific seismic hazard. Particularly for an LNG project where more stringent seismic design is required, it now becomes a common practice to conduct the project-specific SHA.

1.3 Safety V.S. Continuous Functionality

The seismic design requirements in the design codes are primarily purposed to preserve the human life, public health and welfare and may not be intended to keep the continuous functionality of facility, which is important for facility owners. The seismic design requirements for continuous functionality should vary depending on a project demand, e.g.: One facility can be designed without any significant damage, i.e., typically meant for structural plastic deformation, against a seismic hazard of 10% probability of exceedance in 50 years; Or another facility to be designed without any significant damage against a seismic hazard of 20% PoE in 50 years. It is possible to comply to such demands through the SHA that can output the seismic hazard for the required hazard level.

1.4 Seismic Hazard Assessment

Due to the above reasons, the need for SHA is increasing in order to comply with the various seismic design requirements and meet stakeholder's expectations.
SHA procedure is getting standardized because of the development of open source software such as OpenQuake Engine [5]. Accordingly, the SHA now becomes a task that a design engineer can perform. A schematic design flow of SHA and hazard disaggregation is shown in Figure-1.

The seismic design conditions specified based on the seismic hazard has been recognized as "given conditions" in the past, but nowadays value engineering practices tend to consider it as "design parameters to be assessed".

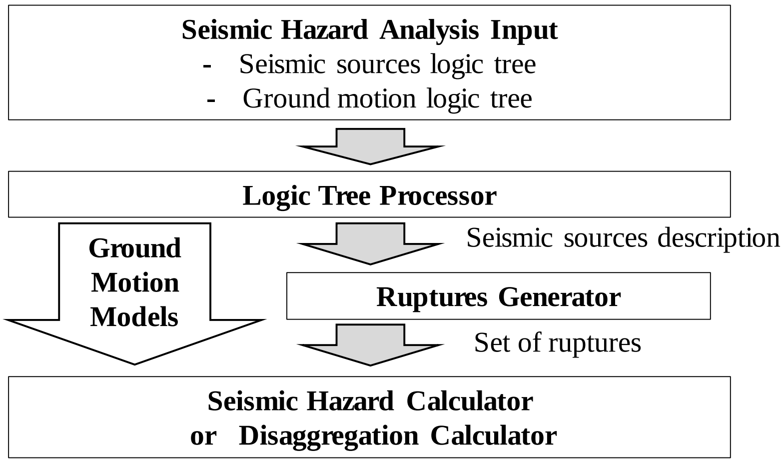


Fig. 1 – Schematic Design Flow of SHA and Hazard Disaggregation

2. Seismic Design Requirements in Various Design Codes

The seismic hazard to be considered is defined in the design codes as the uniform hazard spectrum (UHS) with a certain probability of exceedance (PoE) in 50 years or the risk-targeted spectrum (RTS) with a certain probability of collapse (PoC) in 50 years.

The compliance with the international design codes as well as the local country's design codes is required for internationally financed projects in emerging countries. In almost of these cases, the seismic hazard at the project site in accordance with the international design codes is not available, since the seismic hazard is pre-defined for their own countries according to local seismic codes which often do not comply with international design codes.

In general, the seismic requirements in the local country's design codes have been established learning from those of UBC [6], ASCE 7 or EN 1998. However, because both local and international design codes are developed individually, differences may appear among them. In addition, a mixed use of design codes may be requested depending on the stakeholders or a type of facility and this causes requirement disagreements and conflicts.

Here, the seismic design requirements in various design codes are discussed and summarized in Table-1.

- In American codes, UBC was widely used in the past, which specified the seismic hazard as UHS with 10% PoE in 50 years. Then, ASCE 7 superseded UBC and updated the seismic hazard as the maximum considered earthquake (MCE) which is defined as UHS of 2% PoE in 50 years. Since 2011 update, ASCE 7 has introduced the concept of the risk-targeted maximum considered earthquake (MCE_R) as 1% PoC in 50 years.
- In European codes, due to lower seismic activity in the region, the earthquake load was not included in the scope of design codes but referenced to other codes such as UBC if necessary. Then, EN 1998 has introduced two seismic hazard levels, UHS of 10% PoE of 50 years for no-collapse requirement and UHS of 10% PoE in 10 years for damage limitation requirement.
- For LNG facilities, NFPA 59A applies and specifies SSE and OBE for LNG tank systems, i.e., including those required to isolate the LNG tank systems and the fire protection systems. SSE is defined equivalently to MCE and MCE_R, following ASCE 7 update and OBE is defined as UHS of 10% PoE in 50 years. EN 14620 also specifies the SSE and OBE but the definition of SSE is different from NFPA 59A (UHS of 1% PoE in 50 years).
- JSCE provides an example of seismic hazards in accordance with the descriptions of Level 1 and Level 2 earthquakes, yet the seismic hazard is not clearly defined probabilistically.
- ASCE 7 is stipulated to preserve the human life, public health and welfare. OBE requirement of NFPA 59A is applied only for LNG tank system for safety reasons and not intended to keep the continuous functionality of overall facilities. On the other hand, EN 1998, EN 14620, ASCE 61 [7] and JSCE [8] specify the frequent occurrence seismic hazard to ensure the continuous functionality.

To integrate the various seismic design requirements among the applied design codes, the project-specific SHA should be effectively utilized. The next section introduces a SHA and its sample application.

Table 1 – Various Design Code Requirements

Design Code	Scope	Seismic Hazard	Design Criteria
ASCE 7-2005	Buildings, other structures, etc.	Design Earthquake (DE): 2/3 of MCE MCE: 2% PoE in 50 years (RP 2475 years)	Safety (No collapse)
ASCE 7-2016	Buildings, other structures, etc.	Design Earthquake (DE): 2/3 of MCE$_R$ MCE$_R$: 1% PoC in 50 years	Safety (No collapse)
UBC	Building, other structures, etc.	Design Earthquake (DE): 10% PoE in 50 years (RP 475 years)	Safety (No collapse)
EN 1998	Building and civil works	No-collapse requirement: 10% PoE in 50 years (RP 475 years)	Safety (No collapse)
		Damage limitation requirement: 10% PoE in 10 years (RP: 95 years)	Continuous Functionality
NFPA 59A	LNG Tank System	Safe Shutdown Earthquake (SSE): 1% PoC in 50 years	Safety (No collapse, No leakage)
		Operating basis earthquake (OBE): 10% PoE in 50 years (RP 475 years)	Continuous Functionality
EN 14620	LNG Tank System	Safe Shutdown Earthquake (SSE): 1% PoE in 50 years (RP 4975 years)	Safety (No collapse, No leakage)
		Operating basis earthquake (OBE): 10% PoE in 50 years (RP 475 years)	Continuous Functionality
ASCE 61	Ports and Harbors	Design earthquake (DE): Same as ASCE 7-2005	Safety (No collapse)
		Contingency level earthquake (CLE): 10% or 20% PoE in 50 years for design classification High or Moderate, respectively (RP 475 or 224 years)	Continuous Functionality
		Operating level earthquake (OLE): 50% PoE in 50 years for design classification High (RP 72 years)	Continuous Functionality
JSCE	Building, Infrastructure	Level 2 earthquake (inland and ocean trench types)	Safety (No collapse)
		Level 1 earthquake	Continuous Functionality

3. Use of SHA

3.1 Example SHA Condition

A selected example is based on a site in Pakistan. The local country's design code [9] is the UBC-based one and the project site is located in zone 2A, i.e., PGA 0.15g as shown in Figure 2 according to Pakistan design code [9]. The seismic hazards of SSE, OBE and design earthquake (DE), i.e., 2/3 of MCE$_R$, were evaluated for safety design criteria, and the operating level earthquakes (OLE) were also assessed to be used for continuous functionality design criteria as 10% and 20% PoE in 50 years.

The seismic hazards and their applications are summarized in Table 2. There are three categories of facility - LNG tank systems, onshore and offshore facilities, which must be designed for the different seismic hazards.

Table 2 – Example Project: Lists of Seismic Hazard

No	Seismic Hazard		Application
1	SSE (MCE_R)	1% PoC in 50 years	LNG Tank Systems
2	OBE	10% PoE in 50 years (RP 475 years)	LNG Tank Systems
3	DE (ASCE 7-2016)	2/3 of SSE (MCE_R)	Onshore Facilities Offshore Facilities
4	DE (UBC)	10% PoE in 50 years (RP 475 years)	Onshore Facilities Offshore Facilities
5	OLE (Project specific)	50% PoE in 50 years (RP 72 years)	Onshore Facilities
6	OLE (Project specific)	20% PoE in 50 years (RP 224 years)	Offshore Facilities

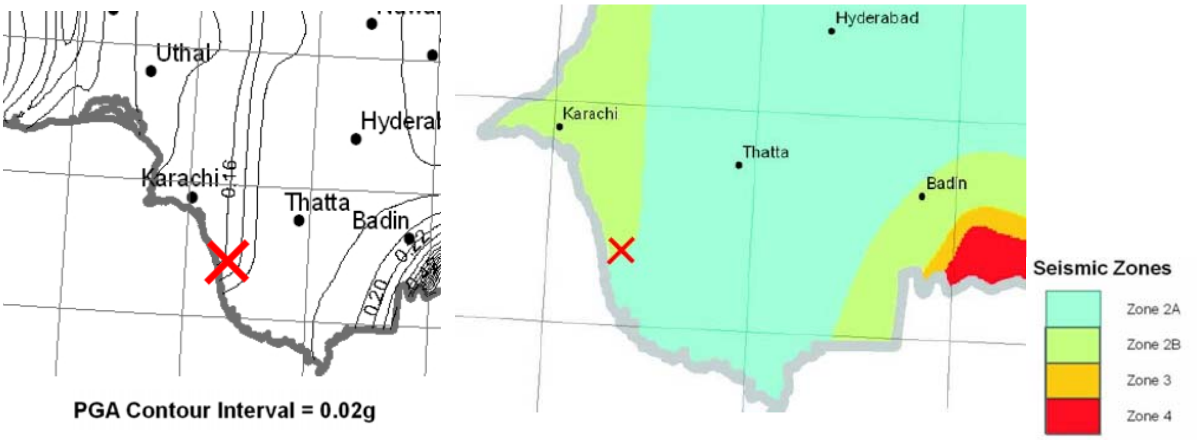


Fig. 2 –PGA Contour and Seismic Zoning Map in Pakistan [9]

3.2 Seismic Hazard Assessment

To evaluate the seismic hazard to be considered in design, SHA was performed with OpenQuake Engine following the SHA procedure. The SHA inputs were prepared based on the available earthquake catalogs on USGS website (https://earthquake.usgs.gov/) and local sources. The earthquake sources considered in the SHA are shown in Figure 3. UHS were calculated for the corresponding PoE, and the RTS was developed for SSE (MCE_R) by applying the fragility curve. The obtained design response spectra are presented in Figure 4.

First, the SHA result of OBE (No.2 of Table 2) is compared with the UBC-based spectra (zone 2A) in Figure 4 (a) to verify the SHA calculations as the PoE of both spectra were kept constant. The shapes of two spectra are considered equivalent with having the similar peak accelerations of 0.375g, however, the acceleration of OBE at T=1.0sec. is smaller than those of UBC-based spectrum by about 50%. The standardized UBC-based spectra may include a margin while the OBE is more refined as it is evaluated at the project-specific location and using the latest earthquake catalogues. In this sense, the SHA may enable design optimizations and can be considered as a good example of value engineering.

The benefit of SHA is that any response spectra can be produced at the required hazard level in accordance with safety or operational functionality requirements. Figure 4 (b) to (d) show the resulting response spectra for the design of LNG tank system, onshore facilities and offshore facilities.

Furthermore, the OLE evaluated by SHA and the damage prevention design against it can be utilized to estimate the earthquake risk cost. The next section discusses further benefits of project-specific SHA.

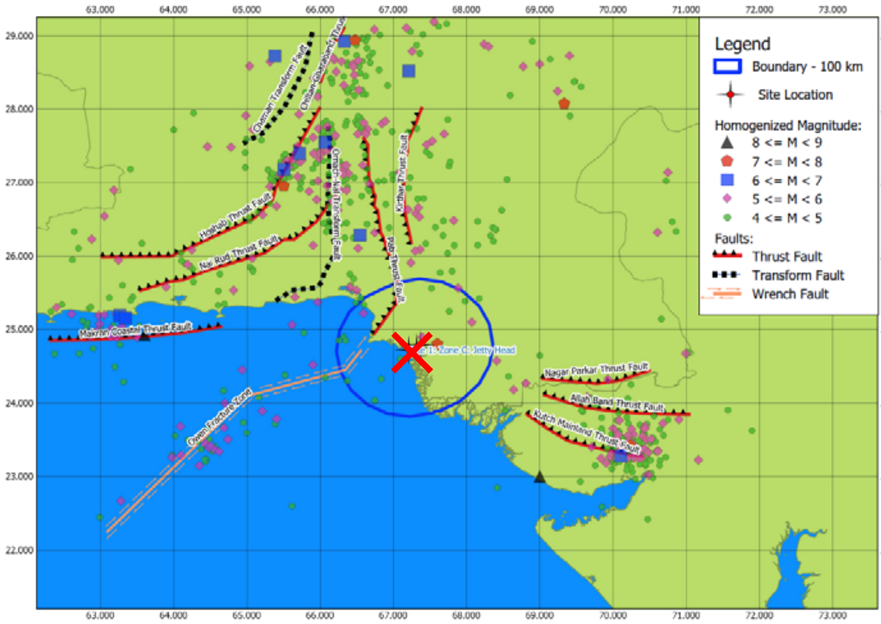
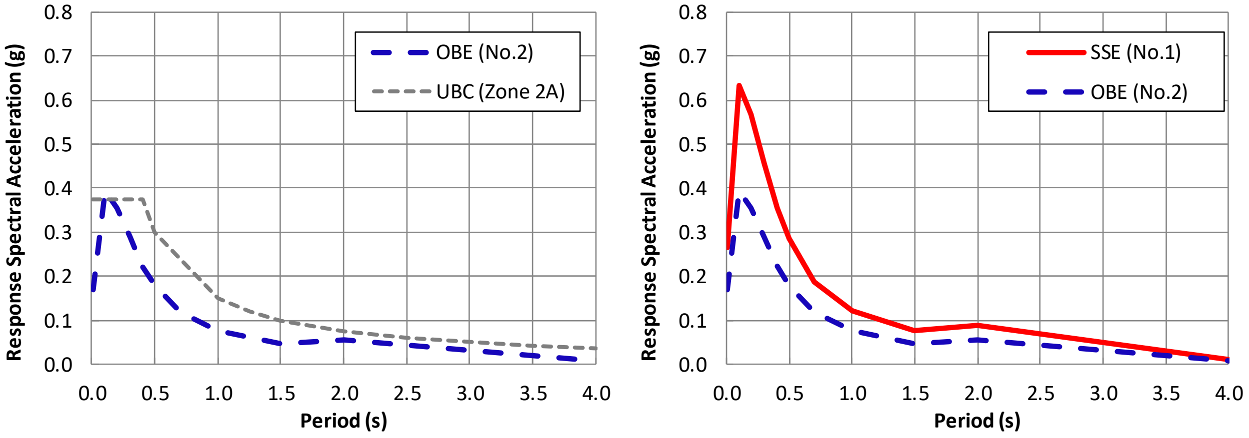
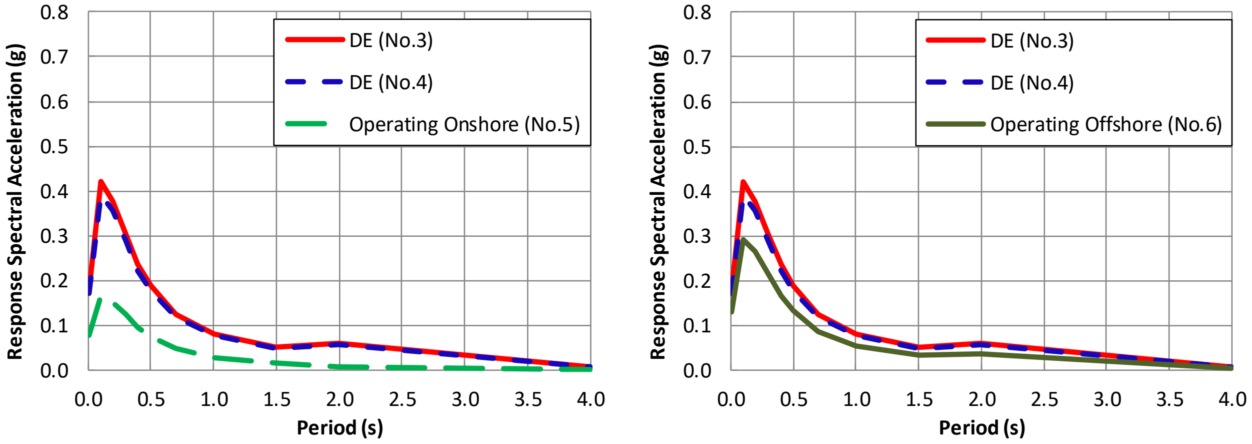


Fig. 3 –Earthquake Sources around the Project Site



(a) Verification of SHA results

(b) Design Spectra for LNG Tank System



(c) Design Spectra for Onshore Facilities

(d) Design Spectra for Offshore Facilities

Fig. 4 –Design Response Spectra

4. Earthquake Risk Cost

For energy projects, it is common to assess a process operation risk by means of reliability, availability and maintainability (RAM) studies and quantitative risk assessment (QRA) and consider it into the asset value. However, an earthquake risk may not be duly evaluated. The first earthquake risk is about the safety that threatens the human life, public health and welfare. This risk has already been compensated by the seismic design against DE with the purpose of collapse prevention. The second earthquake risk is about the business continuity such as the production interruption, opportunity loss and local economic damage.

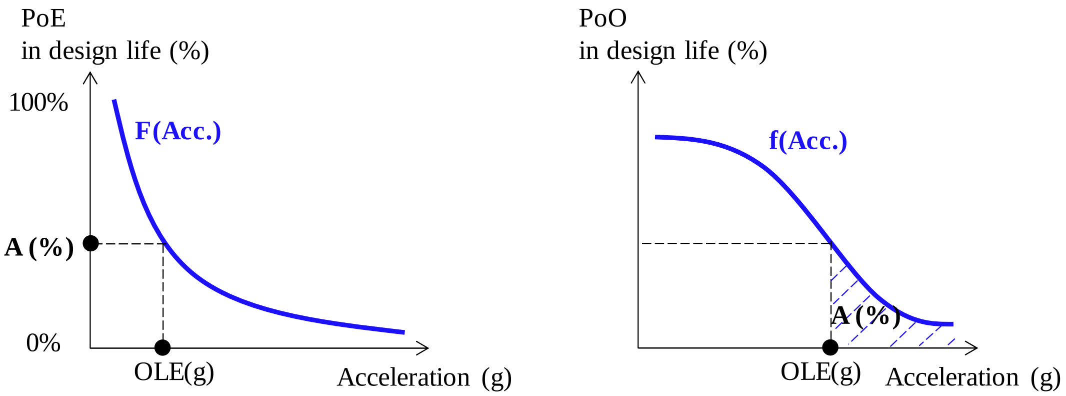
The facility damages after an earthquake shall vary depending on what was done in the seismic design. When the facility is designed against only DE, the available information is only that the facility will not be collapsed when the maximum considered earthquake was occurred. Then, if the facility is designed against OLE with the purpose of continuous functionality, more information is available to assist in making investment decisions regarding business continuity after the earthquake.

The earthquake risk can be quantitatively assessed with OLE. Figures 5(a) and (b) show the hazard curves of PoE and Probability of Occurrence (PoO), respectively, which are generated as a result of SHA. Figure 5(c) shows the conceptual probabilistic fragility curves. The expected values of seismic risk costs can be calculated by integrating the hazard curve of PoO, the fragility curve and the cost for production interruption and repair [10]. If the fragility curve is simply provided as the deterministic form as of Figure 5(d), the expression of the earthquake risk cost is reduced to the following equation.

$$\textit{(Risk cost)} = \textit{A\% (PoE in design life)} \times \textit{(Cost for production interruption and repair)} \qquad (1)$$

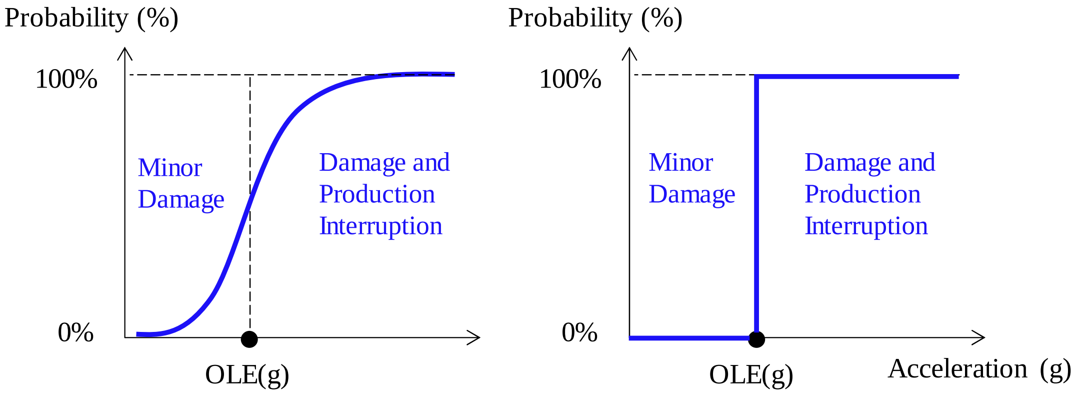
For example, if the facility is designed against the OLE with 20% PoE in 50 years of design life and the cost for production interruption and repair is estimated to be 10% of facility EPC cost, the seismic risk cost can be evaluated as 2% of facility EPC cost.

The facility owners and investors can now consider the earthquake risk about the business continuity into the asset value. It is also possible to optimize the balance of the investment and the risk cost by adopting the appropriate OLE.



(a) Hazard Curve

(b) Hazard Curve (Differential of (a))



(c) Fragility Curve (Probabilistic)

(d) Fragility Curve (Deterministic)

Fig. 5 Earthquake Damage of Facilities and PoE in design Life

5. Conclusions

The project-specific SHA is a powerful tool for the facility owners as well as the facility designers. This paper presented the various aspects regarding the project-specific SHA.

The project-specific SHA provides;

1. Accountabilities about the seismic hazards and countermeasures on an internationally financed project in emerging countries covering the complex design requirements,
2. Quantitative seismic hazards for the required hazard levels,
3. Quantitative seismic risks and associated costs for assisting in making investment decisions regarding business continuity after the earthquake

The SHA procedure is getting standardized and the open source software is available. It is proposed that the seismic hazard must be considered as “design parameters to be assessed”, although it has been recognized as “given conditions”.

6. References

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