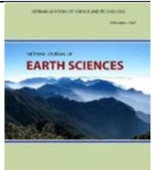
Vietnam Journal of Earth Sciences, 38(2), 188-201, DOI: 10.15625/0866-7187/38/2/8601

(VAST)
Vietnam Academy of Science and Technology
Vietnam Journal of Earth Sciences
http://www.vjs.ac.vn/index.php/jse



Probabilistic seismic hazard assessment for the Tranh River hydropower plant N^{o}2 site, Quang Nam province

Nguyen Hong Phuong*, Pham The Truyen, Nguyen Ta Nam

Institute of Geophysics, Vietnam Academy of Science and Technology

Received 16 February 2016. Accepted 5 June 2016

ABSTRACT

In this paper, the results of probabilistic seismic hazard assessment (PSHA) for the Tranh river hydropower plant N^{o}2 site, Quang Nam province, are presented. A regional earthquake catalog updated until 2014 and most recent data on active faulting in the area with a radial extent of 100 km from the HPP site were used. Applied modern techniques in the PSHA methodology including logic tree and hazard disaggregation allow to adopt different models of seismicity, seismic sources and ground motions for the study area. A set of the probabilistic seismic hazard maps showing distribution of the median peak ground acceleration (PGA) and intensity I (according to the MSK-64 scale) predicted for the periods of approximately 200, 500, 1000 and 10,000 years, respectively was compiled for the region. For the HPP site, the calculated hazard is presented in terms of the hazard curves and the seismic hazard disaggregation graphics at the site. For the 500 year period, maximum shaking in the area with a radial extent of 100 km from the HPP site reaches the level VIII-IX of the MSK-64 scale (in the Tam Ky-Phuoc Son fault zone). At the HPP site, the maximum PGA value ranges between 0.1g and 0.13 g (VII-VIII levels in the MSK-64 scale). The PGA maps present both short - term and long - term forecasts of seismic hazard in Quang Nam province. Calculated shakings at the HPP's site can be used for seismic safety evaluation and antiseismic design for the HPP's facilities during its operational time.

Keywords: Tranh River hydropower plant N^{o}2; probabilistic seismic hazard assessment; seismic sources; logic tree; seismic hazard curve; seismic hazard disaggregation.

1. Introduction

The Tranh River hydropower plant N^{o}2 is located in the Northern Tra My and Southern Tra My Districts, Quang Nam province and started its operation since 2010. A few months after impounding of the hydropower plant reservoir, reports of earth tremors in the hydropower plant vicinity became to be prevalent. During the period from 2011 to 2015, within a radius of nearly 100 km around the dam site, about 1200 tremors with the moment magnitudes exceeding 1.0 have been recorded, among which there were 6 events with magnitudes from 4.0 to 4.7. As all of the recorded events were located at the shallow depth from 5 to 7 km and majority of them were accompanied with the blast sounds in the epicentral zones, the seismic activity within the area has been disturbed the local commu-

---

[*] Corresponding author, Email: phuong.dongdat@gmail.com

nity life, attracted the attention of the public media and makes the "Tranh river HPP" issue one of the breaking hot events around the country. The occurrence of earthquakes swarms in the Tranh river hydropower plant N^{o}2 (here and after referred as HPP) area since 2011 also attracts the attention of the scientific community and preliminarily was suggested to have an induced seismicity origin. Coupling with the investigation of the seismic characteristic in the vicinity of the HPP, the seismic hazard assessment for the HPP site region has been required by the local authority as an urgent task. On the one hand, results of the assessment of maximum shakings at the HPP site for a long-term period will provide the important information for the periodical seismic safety evaluation for the HPP. On the other hand, the seismic hazard maps compiled for the HPP site region can be used by local authorities in development of emergency response planning and strategy against earthquakes in the future in order to secure the local community around the HPP site during the HPP's operation. This paper presents the results of probabilistic seismic hazard assessment (PSHA) for the Tranh river HPP N^{o}2 site, using the most update data set of earthquakes and active faults in the territory and the continental shelf of Vietnam up to now. The following terminologies are used on the paper for specifying different study areas:

"Site" is the area covering the entire dam of the Tranh river HPP N^{o}2.

"Site vicinity" is the area with 100 km in radius counting from the dam of the Tranh river HPP N^{o}2.

"Study region" is the area with 500 km in radius counting from the dam of the Tranh river HPP N^{o}2.

2. Theoretical background

In this paper, the classical PSHA methodology first proposed by Cornell and Esteva in 1968 is used (Cornell, 1968, Esteva, 1968). In the original Cornell-Esteva approach, if the study area can be divided into seismic sources according to geotectonic considerations, it can be assumed that, within a seismic source, an independent earthquake-occurrence process is taking place. Earthquake recurrence relationships, also known as the Gutenberg-Richter, express the annual frequency (which is usually assumed to be constant in time) of earthquakes having various magnitudes up to the maximum magnitude and can be written as:

$$Log_{10}N(M) = a - bM \quad (1)$$

where N(M) is the number of earthquakes with magnitudes exceeding M, a and b are regionally dependent constants.

Thus, for each seismic source, magnitude exceedance rates, λ(M) can be estimated by means of statistical analysis of earthquake catalogs. These rates are the number of earthquakes, per unit time, in which magnitude M is exceeded, and they characterize the seismicity of the source.

The PSHA methodology also assumes that, within a seismic source, all points are equally likely to be an earthquake hypocenter. In this case, acceleration exceedance rates due to a single source, say, the i-th source, are computed using the following expression:

$$\nu_i(a)=\sum_j w_{ij} \int_{M_0}^{M_u} \left(-\frac{d\lambda_i(M)}{dM}\right) \Pr\left(A > a \,|M, R_{ij}\right) dM \quad (2)$$

where M_0 and M_u are the smallest and largest magnitudes considered in the analysis respectively, Pr(A>a|M,R_{ij})) is the probability that acceleration exceeds the value a at the site, given that at distance R_{ij} an earthquake of magnitude M originates. R_{ij} are the distances between the site and the sub elements into which the source has been divided. A weight w_{ij} has been assigned to each sub-element, and the expression above assumes that $\Sigma w_{ij}=1$. Finally, the contributions of all N sources to earthquake hazard at the site are added:

$$\nu(a) = \sum_{i=1}^{N} \nu_i\,(a) \quad (3)$$

The seismicity model used in this paper is called the modified Gutenberg-Richter model, for which the earthquake magnitude exceedance rate is given by:

$$\lambda(M) = \lambda_0 \frac{e^{-\beta M} - e^{-\beta M_0}}{e^{-\beta M_0} - e^{-\beta M_u}}, \quad M_0 \leq M \leq M_u \quad (4)$$

where λ_0 is the exceedance rate of magnitude M_0, β is a parameter equivalent to the "b-value" for the source (except that it is given in terms of the natural logarithm) and M_u is the maximum magnitude for the source.

With the Poissonian assumption of earthquake occurrence within each seismic source, the probability density of the earthquake magnitude is given by:

$$p(M) = -\frac{d\lambda(M)}{dM} = \lambda_0 \beta \frac{e^{-\beta M}}{e^{-\beta M_0} - e^{-\beta M_u}}, \quad M_0 \leq M \leq M_u \quad (5)$$

3. Seismicity models

3.1. Determination of study region

The Tranh River HPP N^o2 is located in Quang Nam province, Central Vietnam. Being far from giant tectonic margins, not experienced strong tectonic changes since 15 million years, Central Vietnam is considered to be a passive marginal zone, belonging to a stable part of continental crust. From a tectonic standpoint, this region is located in a stable tectonic plate named Sunda, which is characterized by low level of seismicity and deformation. Up to now, earthquakes recorded in the HPP site vicinity are small to medium events, with low occurrence frequency and sparse distribution. The incompleteness of the seismic dataset requires considering a suitable seismicity model to be used for hazard calculation.

The first criterion for selecting seismicity model is the tectonic activity of the region. As pointed out by scientists, Vietnam in general, as well as Central Vietnam are located within the stable Sunda tectonic plate and is characterized by low seismicity and strain rates (Petersen et al., 2004). Thus, it can be assumed that the stable seismicity model should be more appropriate for the study region. However, when a PSHA methodology is used, both assumptions of stable and active tectonic regimes have to be considered for the study region. This can be done by using the logic tree technique, when both options of applying the stable and active seismicity models are considered with different weights.

The criterion on tectonic activity leads to the criterion on shaking attenuation from source to site. In practice, there are distances beyond which detailed source characterization is not necessary. It has been empirically proved that shaking attenuation in the region with stable tectonic regime is more gradual comparing with the attenuation in the region with active tectonic regime (e.g. Budnitz et al., 1997). For that reason, it is assumed that for application of PSHA to a certain region, a radius of 300 km from the site is appropriate for the study region in the active case, while a radius of 500 km is more appropriate in the stable case of tectonic activity.

Based on all above-described arguments, the study region is defined as the area with radius of 500 km from the Tranh River HPP N^o2 site.

3.2. Earthquake catalog

An earthquake catalog of the study region was established based on the earthquake database of the Institute of Geophysics, Vietnam Academia of Science and Technology. The catalog includes all historical events (collected from 1311 to 1903) and instrumental events (recorded from 1903 to 2014) within the region with radius of 500 km from the dam site of the Tranh River HPP N^o2. All events of magnitude lower 4.0 then were removed from the catalog. The final catalog of the study region consists of 58 earthquakes was used for the hazard calculation. The epicenter map of the study region is shown in Figure 1.

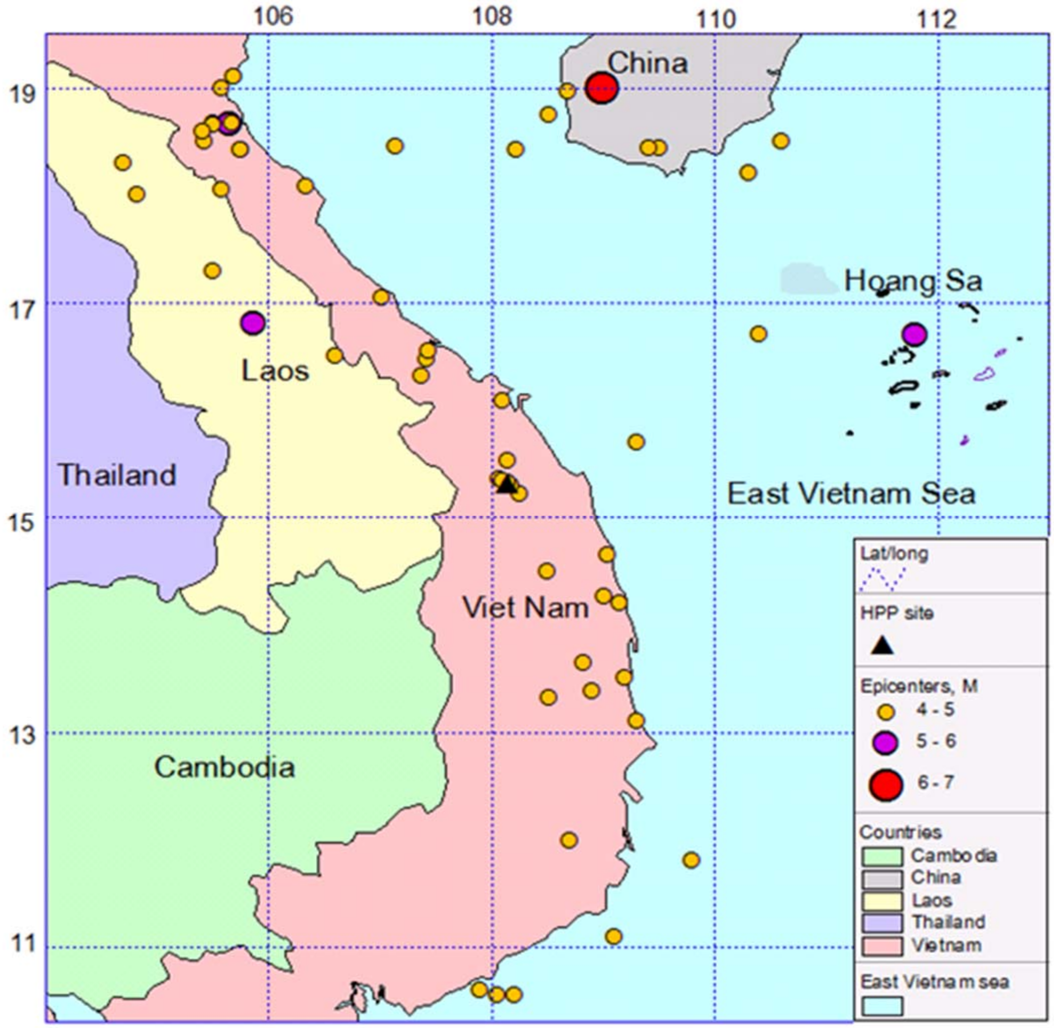


Figure 1. Epicenter map of the study region

4. Seismic source models

4.1. Model construction

In this paper, three following seismic source models were independently built and used as input for seismic hazard calculations:

The fault source model (line sources), developed using a GIS database of active faults of Vietnam and adjacent sea area. For construction of this model, all seismically active faults of I and II ranks that traced within the site vicinity area were chosen. The active faults of I and II rank are the ones, which capable of originating earthquakes (Nguyen H.P. et al., 2013; Vu V.C. et al., 2015).

The source zone model (areal sources), developed using the update seismotectonic model of Vietnam and adjacent sea area (Nguyen H.P. et al., 2013). For construction of this model, all seismic source zones delineated within the site vicinity area were chosen.

The hybrid model, which is a combination of the two above models.

The three models were put in the logic tree scheme to investigate the uncertainty of the calculated hazard results, which affected by the error in determination of the seismic sources. In all of these cases, a logic tree procedure is an effective way to sequence the models and parameters leading to the recurrence estimates and to propagate the uncertainties into the recurrence distributions. For fault and even areal sources, the observed seismicity is usually too sparse to provide a strong constraint on the recurrence rate, but, for more active faults, could control the recurrence rates in the lower magnitude part of the distribution.

4.2. Determination of the faults sources

The most update data on the active faults obtained from recent scientific research projects was used for constructing the line source model (Nguyen H.P. et al., 2013, Vu V.C. et al., 2015). The constructed line source model consists of 7 faults sources determined within the site vicinity area, including:

The I rank Truong Son fault
The I rank Tam Ky - Phuoc Son fault
The I rank Po Ko river fault
The I rank 109^o Meridian fault
The II rank Nam O - Nam Dong fault
The II rank Hung Nhuong - Ta Vi fault
The II rank Tra Bong river fault

In the list above, the Tra Bong river, although was ranked III by the geologists (Vu V. C. et al., 2015), has been upgraded in the II rank according to the seismic data observed in the site vicinity area.

4.3. Determination of the source zones

The seismic source zones are defined on the basis of the well-known features of earthquake manifestation and their relationship with the geologic structure and the tectonic movement evidence in the study area. For this study, a seismic source zone is defined along seismically active faults by summing all the possible rupture zones caused by maximum earthquakes, which might occur within the given zone. In another word, this is the projection of tectonic fault plans counting from the lowest active layer to the Earth's surface. However, while delineating a seismic source zone boundary, this principle is rather flexible and sometimes extended, depending on certain observed earthquake epicenter distribution, a set of faults or related volcanic arcs, particularly in cases of scattered earthquake data. The acceptable boundary for a seismic source zone has to maintain all seismotectonic characteristics of the zone as a whole, namely the azimuthal location, direction of main geologic structures and cluster of earthquake epicenters. Following above-described rule, 6 seismic source zones were delineated in the site vicinity area. These seismic source zones are (Figure 2):

The Truong Son source zone;
The Tam Ky - Phuoc Son source zone;
The 109^o Meridian source zone;
The Da Nang - Nam Dong source zone;
The Hung Nhuong - Ta Vi source zone;
The Po Ko River source zone.

4.4. Estimation of seismicity parameters for the seismic source zones

Earthquake recurrence for individual seismic sources is defined by the seismicity parameters, which are a-value (also called the activity rate), b-value (slope of the recurrence curve expressing a relative number of exponentially distributed small and large-magnitude earthquakes), and M_{max}. Due to the scattered seismic data, the a- and b- values were estimated for the entire site vicinity area using the Gumbel's I type asymptotic extreme value distribution. Regarding M_{max}, this parameter was estimated for each seismic source zone using the Maximum likelihood method. Detail description of the M_{max} estimation procedure can be found in Nguyen H.P. (1991), Nguyen H.P. et al., (2012). As the area source model was constructed based on the fault source model, the M_{max} value estimated for each source zone then was assigned accordingly to the corresponding fault source.

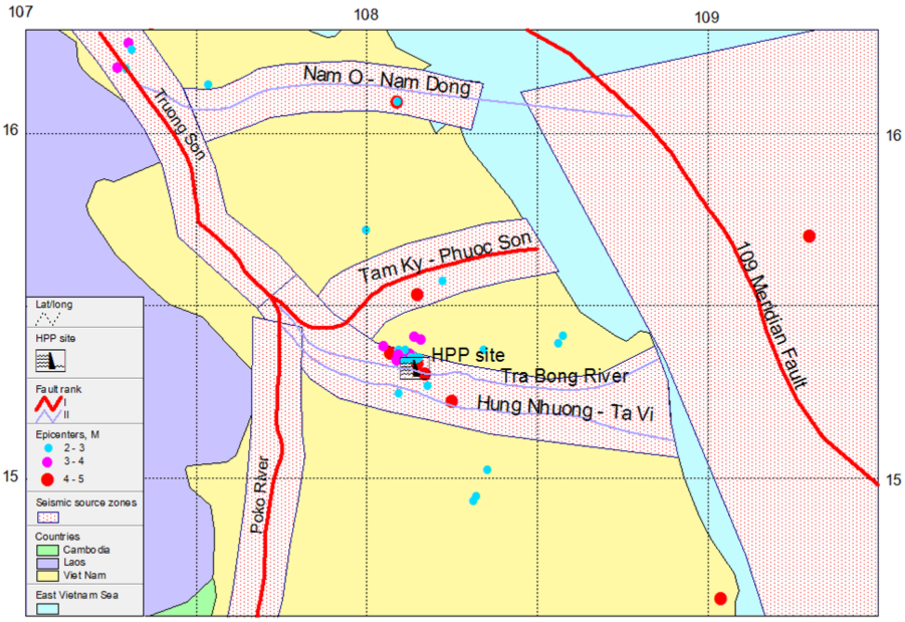


Figure 2. Map of the seismic sources in the Tranh River hydropower plant N^{o}2 site vicinity, including the line sources (faults) and area sources (source zones)

5. Ground motion prediction models

The establishment of an attenuation equation to be applied to a study region is important and usually considered as a separate stage in PSHA procedure. In Vietnam, due to the lack of strong ground motion data, for a long time no local attenuation equations have been developed. Although since 2011, two attenuation equations have been published by Vietnamese scientists, none of them are used, until now, as the reliability of these equations has been in the process of verification (Nguyen, L. M. et al., 2012, T. V. Hung and Kiyomiya, 2012).

For PSHA of the Tranh River HPP N^{o}2 site region, the following ground motion prediction equations (GMPE) were chosen:

The Toro, Abrahamson and Schneider (2002) model;

The Campbell and Bozorgnia (2008) model (CB08) ;

The Boore & Atkinson (2008) model (BA08);

The Chiou & Young (2008) model (CY08).

The attenuation equation developed by Toro, Abrahamson and Schneider (1997) was developed for the Central and Eastern North America, which is known as a seismically stable region. As the seismicity condition of the Eastern US and the Central Vietnam is comparable, it is preferable to use the Toro, Abrahamson and Schneider (1997) as one of the options in the PSHA for the study region.

The three other GMPEs were developed recently within the Next Generation Attenuation of Ground Motion (NGA08) project lead by the Pacific Earthquake Engineering Research Center (PEER, 2008). Although these models were developed for an active seismic region, they can be used for shallow crust earthquakes. The main advantage of these models is that they have been developed using the most complete up to now the database of strong-motion records of all over the world.

The consideration of applying GMPEs developed for both stable and active seismic regions in hazard calculations follows the important principle of PSHA methodology, where different input options can be weighted by means of the logic tree technique.

6. The logic tree

Logic trees are widely used in probabilistic seismic hazard analysis as a tool to capture the epistemic uncertainty associated with the seismogenic sources and the ground-motion prediction models used in estimating the hazard. In this paper, a logic tree was constructed for the study region based on the previously described seismic source model and ground motion prediction model.

6.1. Logic tree for the fault sources

For the line source model (fault sources), reliability ofdetermination of all fault sources within the site vicinity area has been evaluated and assigned corresponding epistemic weights. The evaluation criteria for a fault source includes segmentation, dip angle, and capable maximum earthquake magnitude. For the GMPE models, the weights were assigned for four selected attenuation equations. Table 1 lists the characteristics of the line source model (fault sources) and the GMPE model used for construction of the logic tree for the study region.

Table 1. Characteristics of the line source model (fault sources) and the GMPEs used for construction of the logic tree for the site vicinity area

N^{o}	Fault name	Rank	Segmentation (activity level)	Dip angle (degree)	a value	b value	M$_{max}$	GMPE (weight)		Note/Reference
								active	stable	
1	Truong Son	I (II)	TS-1 TS-2	75 82	1.72	0.73	5.0	AB08 (0.33) CB08 (0.34) CY08 (0.33)	Toro et al., 2003 (1.0)	The segment closest to the site has medium activity (Vu V. C. et al., 2015)
2	Tam Ky - Phuoc Son	I	TK-PS1 (Medium) TK-PS2 (Medium) TK-PS3 (Active) TK-PS4 (Medium)	70-75 70-80 80-85 65-85			5.2	AB08 (0.33) CB08 (0.34) CY08 (0.33)	Toro et al., 2003 (1.0)	Nguyen H. P. and Pham T. T., 2015
3	Po Ko River	II	SPC	65			5.0	AB08 (0.33) CB08 (0.34) CY08 (0.33)	Toro et al., 2003 (1.0)	The segment closest to the site has medium activity (Vu V. C. et al., 2015)
4	Nam O - Nam Dong	II	NONĐ	90			5.0	AB08 (0.33) CB08 (0.34) CY08 (0.33)	Toro et al., 2003 (1.0)	Far from the site
5	Hung Nhuong - Ta Vi	II	HNTV	82			5.0	AB08 (0.33) CB08 (0.34) CY08 (0.33)	Toro et al., (2003) 1.0	
6	109^{o} meridian	I	KT109a	90			6.1	AB08 (0.33)	Toro et al., (2003) 1.0	
7	Tra Bong River	II	HNTV-1 HNTV-2	80 90			5.0	AB08 (0.33) CB08 (0.34) CY08 (0.33)	Toro et al., (2003) 1.0	The fault rank is upgraded according to the earthquake data (a M4.7 event near the fault.

6.2. Logic tree for the source zones

For the areal source model (source zones), reliability of determination of all fault sources within the site vicinity area has been evaluated and assigned corresponding epistemic weights. The evaluation criteria for a source zone includes a- and b- and M_{max} values. The epistemic weights for GMPE models were chosen similar with those in the case of fault sources. Table 2 lists the characteristics of the areal seismic source model (source zones) and the GMPE model used for construction of the logic tree for the study region. Figure 3 illustrates structure of the logic tree established for the fault source and areal source models.

Table 2. Characteristics of the area source model (source zones) and the GMPEs used for construction of the logic tree for the site vicinity area

N^o	Source zone name	a value	b value	M_{max}	GMPE		Note/Reference
					Active	Stable	
1	Truong Son	1.72	0.73	5.0	AB08 (0.333) CB08 (0.333) CY08 (0.333)	Toro et al, 2003 (1.0)	Nguyen H. P. and Pham T. T., 2015
2	Tam Ky - Phuoc Son			5.2	AB08 (0.333) CB08 (0.333) CY08 (0.333)	Toro et al, 2003 (1.0)	
3	Po Ko River			5.0	AB08 (0.333) CB08 (0.333) CY08 (0.333)	Toro et al, 2003 (1.0)	
4	Da Nang			5.0	AB08 (0.333) CB08 (0.333) CY08 (0.333)	Toro et al, 2003 (1.0)	
5	Hung Nhuong - Ta Vi			5.0	AB08 (0.333) CB08 (0.333) CY08 (0.333)	Toro et al, 2003 (1.0)	
6	109^o meridian			6.1	AB08 (0.333) CB08 (0.333) CY08 (0.333)	Toro et al, 2003 (1.0)	

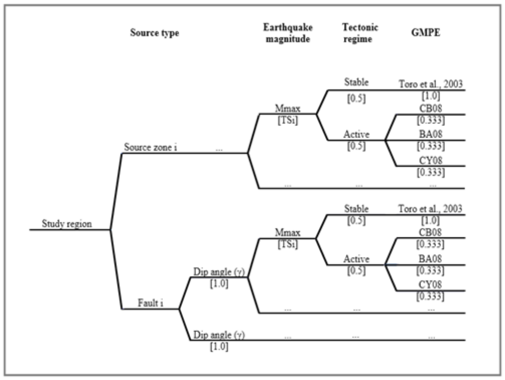


Figure 3. A logic tree model for the line- and area-seismic source models. TS_i is the weight that specific to the i-th seismic source

7. Probabilistic seismic hazard assessment for the Tranh River HPP N^o2 site area

7.1. Probabilistic seismic hazard maps

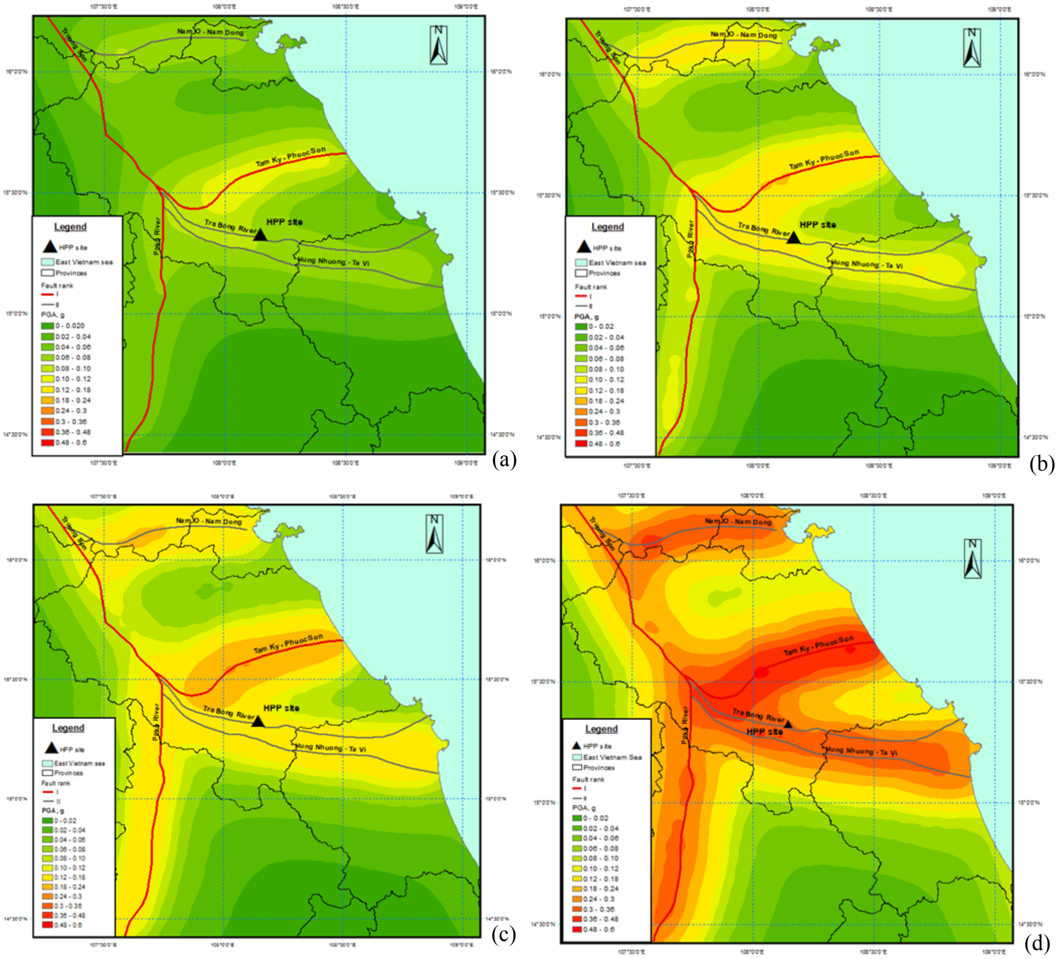
In this paper, the OpenQuake tool was used for computing seismic hazard of the study region. OpenQuake is an open-source software developed by GEM (Crowley et al., 2011). The OpenQuake computes options following all branches of the logic tree and therefore allows obtaining a huge amount of results. In this paper, only median values of PGA are used for illustrations.

Results obtained from three seismic source models, namely the fault-, the areal and the hybrid ones, were used for compiling seismic hazard maps for the study region. The probabilistic seismic hazard maps show distribution of the median peak ground acceleration (PGA) in unit of % g and intensity I (according to the MSK-64 scale) predicted for the periods of approximately 200, 500, 1000 and 10,000 years, respectively. Figure 4 illustrates the PGA maps obtained from the hybrid model. From the seismic hazard maps compiled for the study region, some preliminary conclusion can be made as follows:

The spatial distribution of the ground motion values clearly reflects seismic sources in the study region.

The line sources, contributing highest shaking effect to the HPP's dam site are the II rank Hung Nhuong - Ta Vi, Tra Bong River faults and the I rank Tam Ky - Phuoc Son fault. The areal sources, contributing highest shaking effect to the HPP's dam site are the Hung Nhuong - Ta Vi and Tam Ky - Phuoc Son source zones.

Comparison of the results obtained from three seismic source model shows that the line source model gave the highest hazard values, while the lowest hazard values earned from the hybrid model. Geometrically, the shape of zones with highest shaking calculated from the hybrid model somewhat harmonizes the shape of the corresponding zones calculated from the line source and area source models.



(a) (b) (c) (d)

Figure 4. PGA maps of the Tranh River hydropower plant N^{o}2 site region predicted for the periods of 200, 500, 1000 and 10,000 years, respectively (in order from top left to lower right)

7.2. Results of site analysis

The results of shaking at the Tranh River HPP N^{o}2's dam site calculated from three seismic source models are compared in Table 3. The maximum ground shaking values for the time periods of 200 and 10,000 years can be used as a reference for construction of the Operating Basis Earthquakes (OBE) and the Safety Evaluation Earthquake (SEE) in antiseismic design for the HPP's dam (Wieland, 2010).

Figure 5 shows the hazard curves developed for the Tranh River HPP N^{o}2's dam site from the three source models. Each hazard curve is a plot of the annual frequency of exceedance versus peak ground acceleration at the site. As can be seen from Figure 5, the negligible difference in shape between the three curves shows that the variation of the calculated hazard from the three source models is inconsiderable as well.

Table 3. Comparison of ground motion values calculated at the Tranh River HPP N^{o}2's dam site from three seismic source models

N^{0}	T=200 years		T = 500 years		T = 1000 years		T = 4750 years		T = 10000 years		Source model
	PGA (g)	I (MSK64)	PGA (g)	I (MSK64)	PGA (g)	I (MSK64)	PGA (g)	I (MSK64)	PGA (g)	I (MSK64)	
1	0.092	VII	0.142	VIII	0.189	VIII	0.307	IX	0.359	IX	Faults
2	0.0679	VII	0.108	VII	0.150	VIII	0.278	IX	0.341	IX	Source zones
3	0.0737	VII	0.128	VIII	0.173	VIII	0.296	IX	0.350	IX	Hybrid

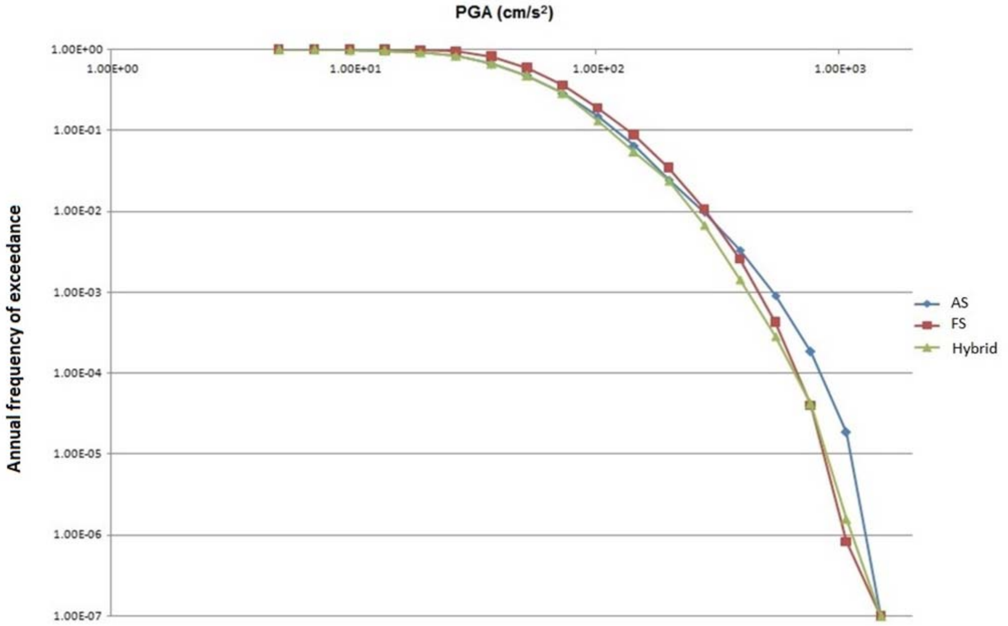
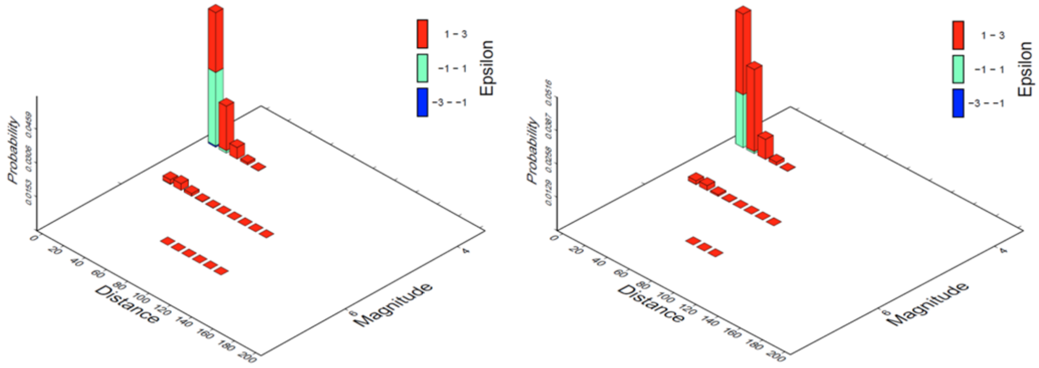


Figure 5. The hazard curves for the HPP's site obtained from the three seismic source models: AS-area source; FS- fault source and the Hybrid model

Figure 6 compares the results of seismic hazard disaggregation at the Tranh River HPP N^{o}2 dam site through the functional relationship between the ground motion versus earthquake maximum magnitude, applying for active and stable seismicity models. The hazard disaggregation results show that the highest impact to the dam site might be caused by any earthquake with a magnitude ranged from 4.0 to 5.0 at a distance of 20 km from the site.



(a)

(b)

Figure 6. Results of seismic hazard disaggregation for the active seismicity models (a) and the stable seismicity model (b): impact of the magnitude M and distance R to the dam site

8. Discussion

In 2003, during the siting process, Nguyen N. T. et al. (2003) carried out a PSHA for the Tranh River HPP N^o2 site area. Abrupt changes in seismicity of the area after operation of the HPP, particularly since 2010 require the re-evaluation of the seismic hazard for the site.

Results of re-evaluation of the seismic hazard for the HPP site are presented in this paper. Some innovation has been incorporated into the implementation of this work. For seismic hazard calculation, not only the earthquake data has been updated until 2014, but a lot of new geological data have been supplemented to make the regional seismotectonic model more accurate and detailed. Besides, it is worth emphasizing the use of such advanced tool and techniques, first applied to the PSHA in Vietnam like the logic tree approach and disaggregation method.

In Table 4, the ground motions at the HPP's site calculated by this study (hereafter referred as the new results) and those results obtained by Nguyen N. T. et al., 2003 (hereafter referred as the old results) are compared. Analyzing the results shown in Table 4 allows making the following remarks:

Table 4. Comparison of ground motion values at the Tranh River HPP N^o2's dam site calculated in this study and those of Nguyen N.T. et al., 2003

Authors	T=200 years		T = 500 years		T = 1000 years		T = 4750 years	
	PGA (g)	I -MSK64	PGA (g)	I -MSK64	PGA (g)	PGA (g)	I -MSK64	PGA (g)
Nguyen N.T. et al., 2003	0.069	VII	0.089	VII	0.103	VII	0.135	VIII
This study	0.076	VII	0.109	VII	0.147	VIII	0.303	IX

In general, the new results show higher values of ground motions at the site, comparing to the old ones. However, the difference in shaking intensity I (according to the MSK-64 scale) only becomes noticeable from the time period exceeding 1000 years. For the periods of 200 and 500 years, both new and old results reach the Intensity VII at the same time. For the 1000 year period, the new Intensity value at the site increases up one unit (I=VIII) comparing to the old value (I=VII). Similarly, for the 4750 year period, the new Intensity value at the site also increases up one unit (I=IX) comparing to the old value (I= VIII).

The increase of ground motion at the site in the new research compared with those results by Nguyen N. T. et al., (2003) can be explained as a result of the application of new attenuation equations in hazard calculation. In Nguyen N. T. et al., (2003), the calculation of ground motions at the site was based on old attenuation equations (developed during 1973 and 1997). In this paper, the new attenuation equations developed from 2002 to 2008 were used. It should be noted that the NGA08 attenuation equations used in this paper were developed by the same authors of the old attenuation equations by using most complete and update ground motions data of the World.

9. Conclusions

In this paper, the results of probabilistic seismic hazard assessment (PSHA) for the Tranh river hydropower plant N^{o}2 site, Quang Nam province, are presented. A regional earthquake catalog updated until 2014 and most-recent data on active faulting in the area with a radial extent of 100 km from the HPP site were used. Advanced techniques in the PSHA methodology including logic tree and hazard disaggregation allow to adopt different models of seismicity, seismic sources and ground motions for the study area.

A set of the probabilistic seismic hazard maps showing distribution of the median peak ground acceleration (PGA) and intensity I (according to the MSK-64 scale) predicted for the periods of approximately 200, 500, 1000 and 10,000 years, respectively was compiled for the study region. For the HPP site, the calculated hazard is presented in terms of the hazard curves and the seismic hazard disaggregation graphics. For the 500 year period, maximum shaking in the area with a radial extent of 100 km from the HPP site reaches the level VIII-IX of the MSK-64 scale (in the Tam Ky-Phuoc Son fault zone). At the HPP site, the maximum PGA value ranges between 0.108 g and 0.142 g (VII-VIII levels of the MSK-64 scale).

The new results show the higher PGA values compared to those calculated by Nguyen N. T. et al., (2003). However, the increase of PGA values of the new results only starts at the period of 1000 years and longer, with deviation of one unit of the Intensity MSK-64 scale.

The PGA maps present both short - term and long - term forecasts of seismic hazard in Quang Nam province. Calculated shakings at the HPP's site can be used for seismic safety evaluation and antiseismic design for the HPP's facilities during its operational time.

Acknowledgements

This research is supported by the project "Study of seismotectonic effect on the stability of Tranh River N^{o}2 Hydropower plant, Bac Tra My district, Quang Nam province" under grant number: ĐTĐL.2013-G.

References

Budnitz, R.J., Apostolakis G., Boore D. M., Cluff L. S., Coppersmith K. J., Cornell C. A., Morris P. A., 1997. Recommendation for Probabilistic Seismic Hazard Analysis: Guidance on Uncertainty and Use of Experts. NUREG/CR-6732, Vol.1, pp 54.

Cornell, C.A., 1968. Engineering Seismic Risk Analysis, Bull. Seim. Soc. Am., 58, 1583-1606.

Crowley, H., D. Monelli, M. Pagani, V. Silva, G. Weatherill, 2011. OpenQuake Book. The GEM Foundation, Pavia, Italy.

Esteva, L., 1968. Bases para la formulacion de decisiones de diseno sismico. PhD thesis, Universidad Autonoma Nacional de Mexico.

Gumbel, E. J., 1958. Statistics of Extremes, Columbia University Press.

Nguyen Hong Phuong (Editor), 2013. Assessment of earthquake and tsunami hazards in the Ninh Thuan province for site approval of the NPPs". Final report of the 2013 National Scentific Research Project, Institute of Geophysics, Hanoi (in Vietnamese).

Nguyen Hong Phuong , Que Cong Bui, Xuyen Dinh Nguyen. Investigation of tsunami sources, capable of affecting the Vietnamese coast. Natural Hazards, 64(1) pp 311-327. DOI: 10.1007/s11069-012-0240-3, October 2012.

Nguyen Hong Phuong, 2004. Seismic Hazard Maps of Vietnam and the East Vietnam Sea. Journal of Earth's Sciences, 26(2), 97-111 (in Vietnamese).

Nguyen Hong Phuong, Bui Cong Que, Vu Ha Phuong and Pham The Truyen, 2014. Scenario-based Tsunami Hazard Assessment for the coast of Vietnam from the Manila Trench source. Physics of the Earth and Planetary Interiors. DOI: 10.1016/j.pepi.2014.07.003.

Nguyen Hong Phuong, Pham The Truyen, 2015. Probabilistic Seismic Hazard Maps of Vietnam and the East Vietnam Sea. Journal of Marine Science and Technology, Vol. 15, $N^0$1; : 77-90. DOI: 10.15625/1859-3097/15/1/6083 (inVietnamese).

Nguyen Ngoc Thuy et al., 2003. Assessment of seismic hazard for the Tranh River hydropower plant N^o2. A pre-feasebility report, Institute of Geophysics, Hanoi, October, 75p (in Vietnamese).

Nguyen, L. M., et al, 2012. The first peak ground motion attenuation relationships for North of Vietnam, Journal of Asian Earth Sciences, doi: 10.1016/j.jseaes.2011.09.012.

OYO corporation, 2013. Research, Detailed Review of Geological Condition, Geodynamics and Geological Activities in Song Tranh 2 Hydropower Area (Bac Tra My District, Quang Nam Province). Draft Final Report No.: 01/2013/SACQI-OYO, 19 September 2013, 101.

Pacific Earthquake Engineering Research Center, 2008. NGA model for average horizontal component of peak ground motion and response spectra. Earthquake Spectra, Vol.24, No.1, 1-341.

Petersen Mark D., James Dewey, Stephan Hartzell, Charles Mueller, Stephan Harmsen, Arthur D. Frankel, Ken Rukstales, 2004. Probabilistic seismic hazard analysis for Sumatra, Indonesia and across the Southern Malaysian Peninsula. Tectonophysics, 390, 141-158.

Toro, G. R., 2002. Modification of the Toro et al. (1997) attenuation equations for large magnitudes and short distances. Risk Engineering Incl., June, 2012.

Toro, G. R., Abrahamson, N. A., and Schneider, J. F., 1997. Engineering model of strong ground motions from earthquakes in the central and eastern United States. Seismological Research Letters, 68(1), 41-57.

Tran Viet Hung and Kiyomiya, O., 2012. Ground motion attenuation relationship for shallow strike-slip earthquakes in northern Vietnam based on strong motion records from Japan, Vietnam and adjacent regions, Structural Eng./Earthquake Eng., JSCE, 29, 23-39.

Vu Van Chinh (Editor), 2015. Study and detailed evaluation of the regional seismotectonic characteristics and their impact to the stability of the Tranh River hydropower plant N^o2 and Northern Tra My area, Quang Nam province. A Thematic report of the 2013 National Scentific Research Project " Study of the seismotectonic impact to the stability of the Tranh River hydropower plant N^o2 in Northern Tra My area, Quang Nam province", Institute of Geophysics, Hanoi (in Vietnamese).

Wieland M., 2010. Selecting seismic parameters for large dames - Guidelines. ICOLD Bulletin 72, 2010 Revision.

APPENDIX

Earthquake catalog of the study region (within a radius R=500 km from the Tranh River HPP N^o2 dam site)

N^0	Year	Month	Day	Hour	Min	Sec	Lat	Long	Depth (km)	Magnitude (M)
1	1131	2	1	1	1	0	18.67	105.66	10	5.1
2	1666	3	1	5	1	0	17.05	107.01	12	4.1
3	1685	5	1	1	1	0	16.5	106.59	12	4.1
4	1715	3	1	1	1	0	15.52	108.15	12	4.7
5	1715	3	1	1	1	0	13.5	109.2	12	4.1
6	1715	3	1	1	0	0	19.11	105.69	10	4.1
7	1767	1	1	1	0	0	19.11	105.69	10	5.1
8	1821	7	1	1	0	0	18.67	105.66	17	6
9	1829	11	1	1	0	0	16.48	107.41	12	4.8
10	1877	1	1	1	0	0	10.56	108.05	12	5.1
11	1882	1	1	1	0	0	10.56	108.2	12	5.1
12	1903	7	1	1	1	0	18.67	105.67	10	5.2
13	1913	3	1	1	1	0	18.42	105.75	11	4.5
14	1920	5	27	12	49	0	19	109	12	6.5
15	1920	8	1	11	1	0	18.67	105.5	12	4.6
16	1923	8	1	5	1	0	18.66	105.5	12	4.8
17	1928	6	1	1	1	0	13.32	108.52	12	5
18	1928	8	1	22	0	0	18.42	105.75	15	4.2
19	1928	8	1	5	0	0	18.5	105.42	7	4.2
20	1932	6	22	5	59	0	16.69	111.8	10	5.6
21	1933	4	1	1	0	0	19	105.56	12	4.3

22	1936	8	20	1	0	0	14.21	109.14	12	5.1
23	1936	8	24	22	3	0	14.26	109.01	14	4
24	1938	1	1	1	1	0	14.65	109.04	12	4.1
25	1942	1	1	1	15	0	18.05	105.58	8	4.3
26	1943	7	1	14	1	0	18.07	106.33	14	4.7
27	1947	1	1	1	1	0	16.55	107.43	0	4.4
28	1947	1	1	1	1	0	16.09	108.09	12	4.8
29	1950	1	1	1	1	0	13.1	109.3	12	4.8
30	1957	12	25	21	1	0	14.5	108.5	12	4.8
31	1960	2	29	3	13	0	11.1	109.09	12	4.1
32	1965	1	17	1	41	0	11.8	109.8	12	4.8
33	1965	7	3	4	48	0	18.6	105.4	12	4.1
34	1967	1	1	1	1	0	18.43	105.75	19	4.3
35	1967	3	13	6	16	0	12	108.7	12	4
36	1968	5	16	22	9	0	17.3	105.5	12	5
37	1968	6	18	9	52	0	15.69	109.3	12	4.8
38	1969	9	2	11	14	0	16.69	110.4	12	5.3
39	1969	12	17	15	0	0	18.5	110.59	10	5.1
40	1969	12	20	9	9	0	18.19	110.3	24	5.2
41	1970	1	23	12	53	0	18.44	109.5	10	5.3
42	1970	4	12	12	37	0	13.39	108.9	13	5.3
43	1972	5	24	20	18	0	13.64	108.81	13	5.3
44	1982	1	25	14	50	0	18.44	109.41	33	4.5
45	1982	2	18	22	56	0	18.3	104.7	33	4.5
46	1985	10	18	15	37	0	18.01	104.81	21	4.6
47	1991	6	1	1	1	0	10.6	107.9	5	4
48	1992	1	4	22	1	0	18.44	107.13	19	4
49	1992	5	26	17	43	0	18.73	108.52	7	4
50	1995	6	5	7	17	0	18.96	108.69	25	4.4
51	1995	6	5	7	16	0	18.43	108.22	10	4.1
52	1997	3	12	2	25	0	16.82	105.87	24	5.7
53	2012	9	3	20	46	0	15.22	108.25	7	4.2
54	2012	9	7	9	26	0	15.3	108.17	10	4.2
55	2012	9	23	10	57	0	15.35	108.06	6	4.1
56	2012	10	22	20	41	0	15.33	108.15	7	4.6
57	2012	11	15	14	24	0	15.35	108.09	10	4.7
58	2014	5	15	19	34	0	16.32	107.37	10	4.7