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Values for peak ground acceleration and peak ground velocity using in seismic hazard assessment for Song Tranh 2 hydropower region

Tran Thi My Thanh*[1], Nguyen Le Minh[1], Vi Van Vung[1], Kojiro Irikura[2]

[1]*Institute of Geophysics, VAST, Hanoi, Vietnam*

[2]*Aichi Institute of Technology, Disaster Prevention Research Center, Japan*

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ABSTRACT

Song Tranh 2 Hydropower Plant was built in 2010 with the seismic design for maximum possible magnitude M= 5.5. On March 2011 the people of Bac Tra My area nearby the Song Tranh 2 dam began to feel slight ground motion accompanying with the sound of explosions. This phenomenon happened with increasing frequency. On November 15, 2012, an earthquake of magnitude M = 4.7 occurred. This earthquake caused some damage to Song Tranh project management office and houses in the Bac Tra My area. An unusual series of frequent earthquakes has alarmed, caused significant worries and stress for both the local people and local authorities. Results of our survey of the area around Song Tranh 2 (December 2012) have shown that recently, the earthquakes occur frequently and caused minor damage on some houses. While the houses had cracks in the walls, but the columns did not experience any damage. The damage is consistent with the shaking of the intensity in the range of VI - VII (MSK scale). However, the maximum value of acceleration (PGA) measured from accelerometer recordings is equivalent to a higher shaking intensity levels of VII - VIII. Value of the maximum velocity (PGV) measured from accelerometer recordings is more in line with the survey results which is equivalent to the shaking intensity levels VI - VII. The reason for this difference is that PGV is less affected by shaking than PGA at high frequencies. The key conclusion from this experience is that we should also consider PGV in earthquake hazard assessment for the design works because so far we have only used the PGA.

Keywords: peak ground acceleration, peak ground velocity.

1. Introduction

Song Tranh 2 hydropower plant has a reservoir capacity of $730\times10^6 m^3$ with a 640m long, 96 m high. For the earthquake design of Song Tranh 2 hydropower dam, the Institute of Geophysics recommended a DBE of $135 cm/s^2$, corresponding to intensity I = VIII, MSK64 scale (According to Vietnam Construction Standard TCXDVN 375: 2006 with equivalent earthquake of magnitude M = 5.5). Song Tranh 2 hydropower plant began filling the reservoir on November 29, 2010. Around March 2011, people living at the Bac Tra My area around the hydropower plant began to feel slight tremors accompanied by explosions. This phenomenon occurred more often and caused alarms to both local citizens and local governments, particularly in the area of Tra My and Hiep Duc districts.

*Corresponding author, Email: tmythanh@igp.vast.vn

The Institute of Geophysics organized a number of delegations to survey the area around Song Tranh 2 after an earthquake greater than magnitude 3 was recorded to assist with the evaluation of the dam safety as well as the safety of buildings and homes of the people in the region. This article presents some results of our study based on the analysis of seismic data after the survey.

2. Seismic activities around Song Tranh 2 hydropower plant area

2.1. Before the reservoir of Song Tranh 2 hydropower plant was filled

Song Tranh 2 hydropower plant is located at about 9 km west of Tra My town on Tranh River. Before going into operation, Song Tranh 2 hydropower is in an area of average seismic activity in Vietnam. A few earthquakes with magnitudes M <5.0 were found in the region of Song Tranh 2 hydroelectricity and nearby (Le Huy Minh et al., 2011) according to the earthquakes recorded in annals and site observations (up to 2003). Earthquake hazard assessment area of Song Tranh 2 by the Institute of Geophysics (Institute of Geophysics, 2003) for areas within the latitude $14^o30'$- $16^o00'$N and longitude $107^o15'$-$109^o00'$ E from 1715 to 2003 have shown 8 major earthquakes. A significant earthquake occurred in 1715 with Ms = 4.7 and an intensity of I = V at the epicenter. According to observations by instrument, an earthquake with Ms = 4.8 occurred in 1957 at about 100 km southeast of the hydropower plant. It was the second largest earthquake in the area of Song Tranh 2 hydropower and neighboring stages before the reservoir was filled.

2.2. After the reservoir Song Tranh 2 hydropower plant was filled

In late 2010, Song Tranh 2 hydropower was put in operation. From the beginning of 2011, the seismic station at Hue, located at about 120 km north of Song Tranh 2, started to record many small earthquakes occurring around Song Tranh 2. The government and people of this region, at first, thought the ground shaking was due to rock blasting. Only until June 11, 2011 after records showing two M = 3.4 earthquake on the Richter scale had occurred and that the ground shaking in the area continued, it was then recognized that the shakings were due to earthquakes (Le Huy Minh et al., 2012). According to the earthquakes survey of Song Tranh 2 (Le Huy Minh et al., 2011, 2012), earthquakes with magnitude 3.0 occurred approximately from occurring late 2011. During November 2011 there were 2 earthquakes of magnitude M = 3.4 on 17th and 27th. From December 24, 2011 to April 15, 2012, 37 earthquakes were recorded in near the dam site. Three of those, on January 30, March 02 and April 15, 2012, with a maximum acceleration recorded at the dam, corresponding to the intensity I = VII (MSK-64 scale). These 3 earthquakes were recorded at the station in the network of the Institute of Geophysics with magnitude M <3.2.

According to the Department of Seismological Survey, Institute of Geophysics, from November 03, 2011 to March 2014, there were over 468 earthquakes with magnitude M ≥ 1 occurred near the Song Tranh 2 and adjacent area. So in just over 2 years of hydropower operations , there were five earthquakes with magnitude greater than 4.0, and in which there was on with M = 4.6 and one with M = 4.7; 19 earthquakes greater or equal to M=3; 36 earthquakes with magnitude greater or equal to M=2.5 (Department of Seismological Survey, 2014) (Figure 1). These data have shown clearly that after the reservoir was filled, the earthquake activity at and around Song Tranh 2 had increased markedly.

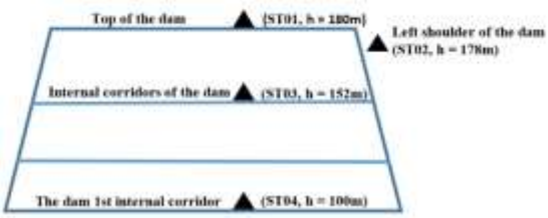

Figure 1. The seismic stations of the Project Management Board

3. Strong motion data

The seismic data for Song Tranh 2 hydropower plant was recorded by seismic stations network of the Institute of Geophysics and the seismic stations installed by the Project Management Board (PMU). Besides recording seismic data such as location, time, magnitude, depth of earthquakes we also use the acceleration and velocity data of the earthquakes recorded.

3.1. Regional seismic network station at Song Tranh 2

Before the earthquakes struck the area, there was no seismic stations at Song Tranh 2. Data from the earthquakes as before the hydroelectric reservoir was filled, was based on records from the seismic station of the Institute of Geophysics installed at Hue. From December 2011, when more earthquakes occur, the Project Management Board (PMU) of Song Tranh 2 hydropower plant installed two acceleration stations on the dam. During April 2012, the PMU installed two more acceleration stations. Their locations are as follows: the top of the dam (180m high), 3 internal corridors of the dam (158m elevation) and the dam 1st internal corridor (100 m elevation) and the external face of the dam, the left shoulder of the dam (178m elevation) (Figure 2). This is the network stations which recorded many earthquakes occurred in the region from January 11, 2011 to October 2012. The records showed two earthquake events in November 2011 of M = 3.4, March 2012 of M = 3.1 in. In September 2012, there were 3 events of M = 4.0, 4.1, and 4.2, one event with M = 3.8 on October 21, 2012 and one event of M = 4.6, on November 15, 2012.

At the end of 2012, the Institute of Geophysics installed one acceleration station at bedrock outside the dam. By now, the Institute of Geophysics has a network stations in the Song Tranh 2 area including those velocity station (Figure 2).

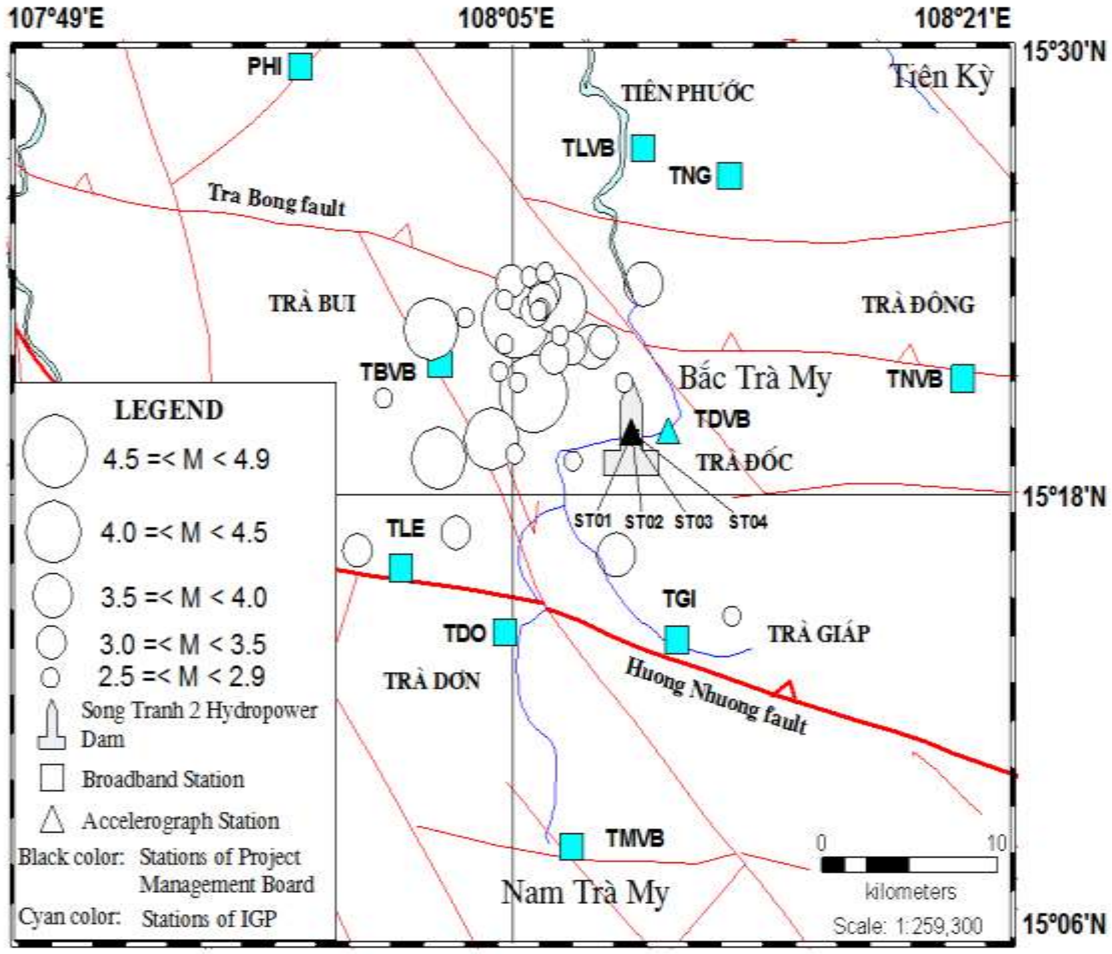

Figure 2. Distribution of earthquakes around Song Tranh 2 dam area

3.2. Strong motion data

The seismic data from Department of Seismological Survey, Institute of Geophysics from late 2011 to early March 2014 showed 36 earthquakes with magnitude M ≥ 2.5 and many smaller earthquakes occurred in the study area (Department of Seismological Survey, 2014). The data we chose to study are those earthquakes with M ≥ 3.0. Furthermore, we also selected earthquakes recorded at least two seismic stations for comparison. This is because when an earthquake occurs, not all the stations recorded reliably data due to by many factors such as power outages, the recorders malfunctioned etc., at the moment the earthquake struck. That also happened to the seismic network installed by the PMU. The data we used for the study are presented in Table 1.

Table 1. The list of earthquakes use in this study

No	Time (GMT)						Epicentral		H	M	Station
	Year	Month	Day	H	min	Sec	Latitude	Longitude			
1	2012	9	23	3	57	31.7	15.379	108.046	5.7	4	ST04, ST03, ST02, ST01
2	2012	9	27	6	34	12.9	15.39	108.114	6	4.1	ST04, ST03, ST02, ST01
3	2012	10	16	02	29	40	15.399	108.158	8	3.5	ST03, ST02, ST01
4	2012	10	22	13	41	39.5	15.383	108.091	6.8	4.6	ST02, ST01
5	2012	11	15	7	24	8.6	15.35	108.1	5.5	4.7	ST04, ST02

The data we used to assess the effects on the buildings due to seismic ground motion is based on the acceleration data. The stations installed by Song Tranh 2 PMU have 3 dimensions: North - South and East - West, and Up - Down so for every earthquake, at each station we have 3 different acceleration recordings with 3 components. So there are 6 earthquake recordsfor acceleration analysis (2 stations).

4. The impact of earthquakes on the construction sites of Song Tranh 2 and adjacent area

To evaluate the effect of earthquakes on buildings at data (value of maximum acceleration, maximum velocity measured from the seismic records).

4.1. Evaluate the effect of earthquakes on construction sites based on field surveys the state of the civil and construction sites

After 3 earthquakes with magnitude greater than 3.0 occurred in North Tra My area in 2011, and a number of earthquakes larger than magnitude 4.0 occurred in 2012, the Institute of Geophysics Group organized a number of field surveys. There were 3 surveys undertaken by members of the Vietnam Academy of Science and Technology, and organized by the Institute of Geophysics in November 2011, April 2012 and September 2012 (Le Huy Minh et al., 2011, 2012). At the end of November and beginning of December 12, 2011, the survey team investigated the ground shaking caused by two M = 3.4 earthquakes occurred at the beginning of November 2011 and constructed a isoseismic map I = IV on the MSK-64 scale of earthquakes.

Regional with intensity VI contour is a small area between North Tra My and South Tra My with an elliptical shape elongated along the northwest-southeast with the semi-axis lengths of about 5-10km (Le Huy Minh et al., 2012). From December 24, 2011 to April 15, 2012, Song Tranh 2 hydropower dam recorded 37 earthquakes near the dam area in which 3 occurred on January 30, March 2 and April 15, 2012. The maximum acceleration recorded at the dam is equivalent to the earthquake vibration I = VII according to the MSK64 scale (Le Huy Minh et al., 2012). Investigation of the intensity of shaking caused by the earthquake M = 4.2 on September 03, 2012 (Le Huy Minh et al., 2012) has found that the maximum shaking in the epicenter area is I = VI on the MSK-64 scale, the seismic zone-level class IV, V and VI. In the intensity VI areas (Tra Doc, Tra Giac, Tra Bui,...), dozens of homes in North Tra My area were found to have many cracks causing major worries and feeling of uncertainties for both citizens and local governments, particularly in the area of Tra My district and Hiep Duc district (district downstream of Song Tranh 2). On November 15, 2012, an earthquake of

M = 4.7 occurred causing tremors to a maximum intensity VII in the dam area. Our seismic survey took place in early December 2012, after the M = 4.7 earthquake occurred. We focused on the office of Song Tranh 2 Project Management Board on top of the dam. The local staff, who were seated in this room when the quake struck, said that at the time the ground shaking caused the building to shake. Tables, chairs, filing cabinet were overturned and small light weight items the table fell to the ground. Figures 3 shows the clear effect of the ground shaking caused by earthquakes. The walls have many cracks. However, upon a closer inspection we noticed that cracks only appeared on the plaster wall. The load-bearing parts and the main structure were not affected. The office on top of the dam showed cracks on inside walls but no cracks on the outside (Figure 3) Thus the initial conclusion is that the earthquake had an effect but caused no destruction of this building. It can be concluded that the maximum Intensity was about VI - VII on the MSK scale.

Figures 3. The effect of the ground motion caused by earthquakes

4.2. Evaluate the effect of the earthquakes on construction works using maximum ground acceleration and velocity

Network of seismic stations installed by the project management unit recorded ground acceleration for a number of earthquakes as a basis for comparing the value of maximum ground acceleration of the earthquakes (PGA), in addition we have also determine the value of the maximum ground velocity (PGV) and the maximum ground displacement (PGD). According to table 2, earthquake magnitude M = 4.7 on November 15, 2012 caused maximum value of acceleration relatively high, recorded at stations located between the dam is 364 cm/s^2 (NS component), 268 cm/s^2 (EW component) recorded at the station and at abutments is 271 cm/s^2 (EW component). The maximum value of acceleration due to earthquake M = 4.6 dated October 22, 2012 is 307 cm/s^2 (EW), recorded at the station on the dam. So the maximum acceleration recorded at the stations of the earthquake M = 4.7 earthquake dated November 15, 2012 and dated October 22, 2012 M = 4.6 corresponds to the vibration level VII - VIII under the MM scale (table 2). These results are inconsistent with the findings of earthquakes we have presented in section 3b, as well as the report of the Institute of Geophysics (Le Huy Minh et al., 2011, 2012). This can be attributed to the fact that shaking is affected by soil conditions. Figure 1 shows the earthquake M = 4.7 and 4.6 occurred very close to the dam, close to the base station recording and ground acceleration was greatly affected at high frequencies (Cosenza and Manfredi, 2000) and was amplified.

Nicos Makris and Cameron J. Black (Makris and Black, 2004) have shown that maximum ground shaking velocity is a better parameter to use than maximum ground to assess the seismic effect on residential buildings. Maximum velocity is also less affected in the high frequency domain. From these recordings we have the maximum acceleration and calculate the value of the PGV. These values are presented in Table 2. In Table 2, the maximum ground velocity by earthquakes of magnitude M = 4.7 dated November 15, 2012 recorded at the station at the dam body is between 7.5 cm/s (NS component), 6.0 cm/s (EW) and recorded at the abutments of 3.8 cm/s (EW); value of the maximum velocity due to the earthquake M = 4.6 days October 22, 2012 is 0.0063 cm/s (EW) recorded at stations on the top of the dam.

Table 2. PGA, PGV and PGD of the earthquakes use in this study

No	Time(GMT)		M	PGA (cm/s^2)		PGV (cm/s)		PGD (cm)		PGV/PGA		Station
	Date	Hour		NS	EW	NS	EW	NS	EW	NS	EW	
1	September 23, 2012	3:57:32	4.1	39.2	40.18	0.5292	0.4704	0.0165	0.0096	0.014	0.012	ST04
				56.84	54.88	0.686	0.9604	0.0238	0.0211	0.012	0.018	ST03
				72.52	90.16	0.7938	0.735	0.0215	0.0165	0.011	0.008	ST02
				83.3	276.36	1.1858	3.8612	0.0191	0.0753	0.014	0.014	ST01
2	September 27, 2012	6:34:13	4.1	15.68	28.42	0.343	0.4508	0.0109	0.0117	0.022	0.016	ST04
				29.4	42.14	0.5978	0.8428	0.0158	0.0263	0.02	0.02	ST03
				29.4	38.22	0.5194	0.392	0.0126	0.0161	0.018	0.01	ST02
				57.82	161.7	0.9016	3.6946	0.0203	0.0784	0.016	0.023	ST01
3	October 16, 2012	2:29:40	3.5	31.36	30.38	0.4018	0.3332	0.0961	0.0062	0.013	0.011	ST03
				36.26	24.5	0.3626	0.147	0.0056	0.0045	0.01	0.006	ST02
				45.08	141.12	0.5194	2.1854	0.0067	0.0234	0.012	0.015	ST01
4	October 22, 2012	13:41:40	4.6	79.38	107.8	1.4994	0.98	0.0474	0.0489	0.019	0.009	ST02
				101.92	307.72	1.4112	6.1838	0.0485	0.1521	0.014	0.02	ST01
5	November 15, 2012	7:24:09	4.7	364.56	268.52	7.595	5.9682	0.2382	0.1541	0.021	0.022	ST04
				112.7	271.46	1.9306	3.8514	0.0939	0.0707	0.017	0.014	ST02

According to table 3, the correlation between the level of the earthquake (MM) and maximum velocity shows that the maximum velocity recorded at stations between the dam and abutments corresponding vibration V - VI (MM scale). Table 4 of the relationship between MM and MSK scale shows from level I to level VI two scale earthquake MM and MSK are similar to each other. That means if PGV values based on the earthquake shock not exceeding level VI. This result is consistent with the results of field surveys. This result is consistent with reports assess the seismic hazard of the Institute of Geophysics serve the design. Thus it can be concluded for the earthquake occurred near the station using the value of vibration velocity maxima background to evaluate the effects of earthquakes on civil works better fit using the maximum acceleration values.

Table 3. Correlation between the intensity I (MM scale) and maximum acceleration, maximum velocity (David J. Wald, et al., 1999)

Intensity I(MM scale)	PGA (cm/s^2)	PGV(cm/s)
I	< 1.7	< 0.1
II III	1.7 - 14	0. 1 – 1.1
IV	14 - 39	1.10 - 03.4
V	39 - 92	3.4 – 8.1
VI	92 - 180	8.1 - 16
VII	180 - 340	15 - 31
VIII	340 - 650	31 - 60
IX	650 - 1240	60 - 116
X	> 1240	> 116

Table 4. Comparison of seismic intensity scales (Reiter, 1999; Murphy and O’Brien, 1977; Richter, 1958); MM -Modified Mercalli; RF - Rossi-Forel; JMA - Japanese Meteorological Agency; MCS - Mercalli-Cancani-Sieberg; MSK - Medvedev-Sponheuer-Karnik

MM	RF	JMA	MCS	MSK
I	I		II	I
II	II	I	III	II
III	III		IV	III
IV	IV, V	II	V	IV
V	VI	III	VI	V
VI	VII	IV	VII	VI
VII	VIII	V	VIII, IX	VII
VIII				VIII
IX	IX	VI	X, XI	IX
X	X		XII	X
XI		VII		XI
XII				XII

5. Conclusion

- Based on the results of this study we recommend that for the seismic hazard assessment for Vietnam we should calculate the maps of PGA and PGV together.

- A solution to improve the quality of seismic hazard assessment is the simulation of earthquake scenarios. Song Tranh 2 Hydropower plant is designed with a magnitude 5.5. We can estimate ground motions at the sites from M 5.5 using the Empirical Green's function method. The strong motion data record of earthquakes from 4.6 can be used as the Empirical Green’s function.

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