REMOTE SENSING IN THE STUDY OF ACTIVE TECTONICS AND SEISMIC HAZARDS IN SON LA HYDROPOWER DAM

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ABSTRACT

Son la hydropower dam more than 250 m high will be built in an area of complex geological structure. Intensive tectonic activity and strongest earthquakes of Indochinese peninsula locate in this area. Son La hydropower area, north Vietnam is close to the Phong Tho - Nam Pia and Song Da fault. In condition of tropical wet weathering, the existence of tectonic scarp and typical topographical forms such as Triangular facet shows that these faults are operating with high rate. From remote sensing, GIS and field observation, we reveal several active faults in Son La area. Normal fault segments of striking NW-SE, SW dipping is observed clearly from SPOT images. In the field, triangular facets indicate typical dip slip displacement. Basing on different data, vertical slip rate of Phong tho - Nam Pia fault is estimated of 0.2-0.4 mm/y for Pliocene-present, 0.5 - 3 mm/y for Quaternary - present and 0.6 - 1.7 for present time. Basing on fault segments determined from SPOT image and field observation and other data like earthquake depth, state of stress, we estimated Maximum Credible Earthquake for different fault segments by various methods. Due to the lack of specific attenuation law for Vietnam value of the Peak Ground Acceleration, we have to use models 1, 2, 3 of Campbell and formulas of Idriss, Xiang and Gao, Woodward - Clyde, Ambraseys to calculate PGA in our study. We evaluate that Pa Vinh and Ta Bu dam sites to be affected by maximum peak ground acceleration of about 200 cm/s2 provoked by fault segments Muong La 1 and Muong La 2 of the Phong Tho - Nam Pia fault.

1. INTRODUCTION

The process of collision between the India and Asia that took place 50 Ma ago had changed basically the tectonic framework of Asia (Leloup et al. 1995, 2001). Many features of deformation and topographical development of the Northwest region have been clarified thank to analyses of deformation history of the Red River fault zone (Leloup et al. 1995, Phan Trong Trinh, 1995). Son la hydropower, a largest dam in South East Asia with more than 200 m high will be built in an area of complex geological structure. Recently, strong earthquakes of intensity 8 occurred in 1935 and earthquake in Tuan Giao of magnitude 6.7 occurred in 1983. These strong earthquakes appeared in short period less than 50 years yield fast stress accumulation in the region. Son La hydropower area is located near the Phong Tho - Nam Pia and Song Da fault. In condition of tropical weathering, the existence of clear tectonic scarp reveals these faults slip with high rate. For evaluating safety of Son La hydropower dam, measurements in details of remote sensing, geology, geomorphology, tectonophysics and geophysical investigation like seismological cross - section, electricity, mercury gas and nuclear trace carried out in Sonla hydropower zone (Phan Trong Trinh et al. 1999). GIS technique is used to combine various data. In this paper, we demonstrate that remote sensing and GIS is a powerful tool for seismic risk evaluation if we combine them with field observation, geological and geophysical data.

2. ACTIVE TECTONICS

The Northwest region was affected by intensive deformation in tertiary. Overthrusting developed largely in many areas such as Hoabinh arc, Sapa marble and Phong Tho Limestone. Triassic limestones over thrust cretaceous red sediments (Findlay et al., 1997, Lacassin et al., 1998). A series of faults have activated in Pleistocene up to present. The clearest manifestation is the Red River fault, Chay River fault and Dien Bien - Lai Chau fault zones. Within Son La hydropower dam, the Phong Tho - Nam Pia fault is regional boundary between Tule volcanic zone and Da river zone. This fault expresses clearly an active normal fault. Triangular facets are expressed clearly from SPOT image with dipping toward southwest. The height of triangle reaches 300 -500 m. Typical hung valleys prove the fast uplift of NE wing that goes beyond erosion speed of soil and rocks. Phong Tho - Nam Pia fault does not extend continuously but is divided into small segments. The fault changes direction from NW-SE into E-W direction at western side of Tule volcanic zone. In the segment from Muong La to Bac Yen, the fault changes its direction to NW-SE. The fault is divided into 2 discontinuous segments that are called segments by us as segments Muong La 1 and Muong La 2. From Bac Yen to Phu Yen, the fault changes its direction into E-W faults.

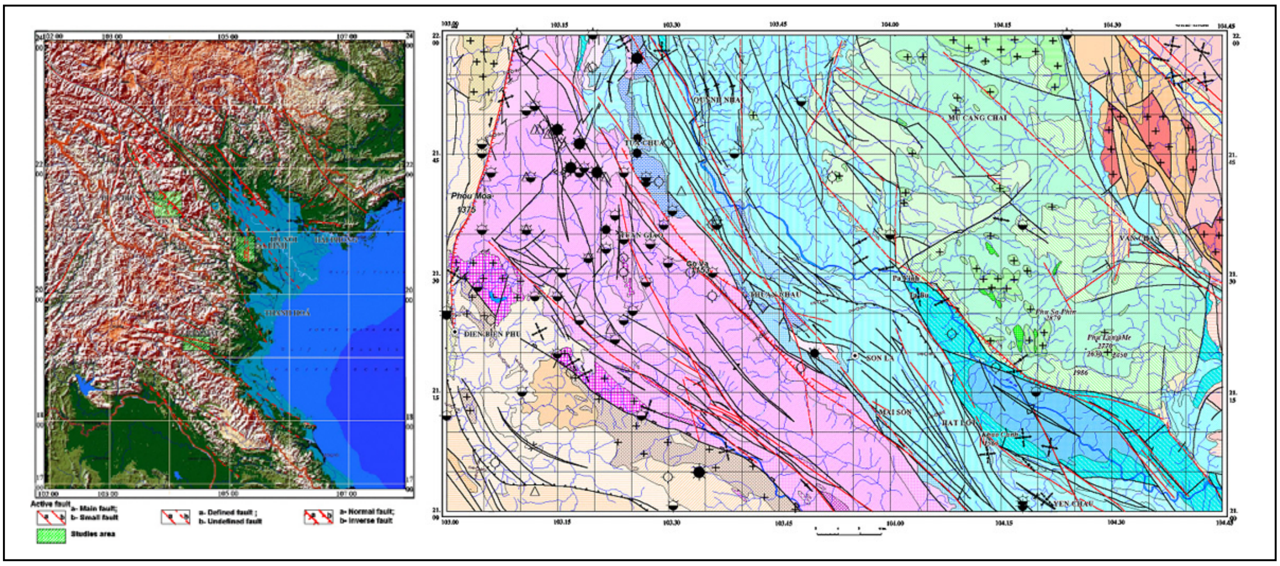

Figure 1. a. Map of active fault in north Vietnam

b. Seismotectonic map of northwest region in North Vietnam

The characteristics of this fault segment changes mainly into right lateral strike-slip. The strongest uplift happened corresponding to the Fanxipan mountain region and with average uplifting rate of about 0.80 - 1.4mm/year from Pliocene up to present. Uplift of 2000 m in Tu Le zone occurred during this time with the rate of 0.6 -0.95 mm / year and the peak with average height of 900 m of the Da River zone had average uplifting rate of 0.3 - 0.45mm/year. The relative displacement rate between the Da river zone and Tule volcanic block is estimated as 0.3-0.5 mm/year (Phan Trong Trinh et al. 1998). Rectifying vaulted displacement and that caused by other small faults in the zone with the size of 1/3 of total displacement amplitude, we estimate the average uplifting rate of the northwest part compared with the southwest wing with the average rate of 0.2 - 0.4 mm / year for Phong tho - Nam Pia fault from Pliocene up to present. For estimating slip rate of Phong Tho - Nam Pia fault in shorter time, we determine vertical slip rate according to geomorphologic materials.

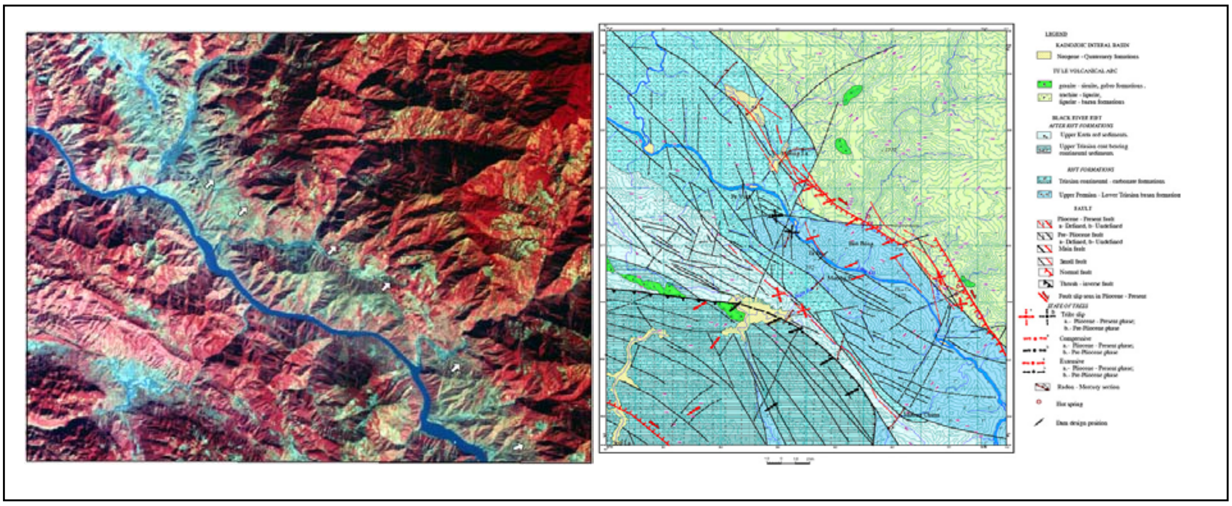

Figure 2. a. Normal active fault, dipping to SE observed from SPOT image

b. Seismotectonic map in Son la hydropower area

The average displacement rate of Phong Tho - Nam Pia fault estimated by geomorphologic method will be about 0.5 -3mm/year. From geodetic measurement data, we have two approaching ways. The first is from the map interpolating present movement rate established by Tran Dinh To and Nguyen Trong Yem. The height difference of interpolated contour in two sides of the fault wing is of 1mm / year. The different rates of the Da River centre and Tu Le centre is of 2.5 mm/year. If less 1/3 due to vaulted displacement or movement occurring along smaller zones of the block, the displacement rate between the two sings is estimated of 1.0 -1.7mm/year. The second approaching way is based directly on the analysis of repeated geodetic measurement during 20 years. Present displacement rate of Phong Tho - Nam Pia fault zone can be estimated of about 0.62 - 1.7mm/year. The displacement rate of Phong Tho - Nam Pia fault can be also estimated through analysis of seismotectonics. Slip rate of the fault segment Muong La 1 is estimated of 0.14 and the rate of the segment Muong La 2 is of 0.44.

3. SEISMIC EVALUATION

First In areas with high density of seismicity, seismic hazard is normally assessed by the probabilistic model (Nguyen Hong Phuong, 1991). This methodology is less efficiency when recording time is too short in areas with long return period of earthquake. It is necessary to assess seismic hazard by seismotectonic method combining with probabilistic analysis in forecasting seismic hazard for each position. For the evaluation of seismic hazard in Son La hydropower dam area, we focus on the faults with significant size and near the dam. Phong Tho-Nam Pia stretches from Phong Tho to Phu Yen. This fault zone is divided into many fault segments with different activity levels. From SPOT image, we reveal fault segment length, direction of fault dipping and fault characteristics (normal fault related to extensive stress regime). These parameters are most important for the assessment of seismic hazard. In Son La hydropower dam area, 2 fault segments Muong La 1 stretching 10 - 12 km and fault segment Muong La 2 stretching 30 km. The shortest distance from section Muong La 1 to Pa Vinh dam is of 4,4 km and to of Ta Bu dam - 4,2 km. The fault dip is determined of 75^0 thanks to observation of surfaces joining the fault. fault depth can not be determined directly. However, in order to calculate maximum credible earthquake, the fault depth can be estimated by 2 ways. The first way is based on seismic characteristics of the area and along the fault zone. Normally, the depth of hypocenter in the area is of 10 to 20 km. The second way is based on the change of mechanical characteristics of the earth crust with the depth. Depending on the state of tectonic stress, the hardness will change, for state of extension stress, the hardness will reach maximum at shallower position, from 10 to 15 km. Generally, earthquake depth depends on destructive length on the surface. It does not exceed 2/3 of size on the surface. Therefore, it is assumed that the maximum depth arising earthquake for segment Muong La 1 is of 10 km. The segment Muong La 2 belonging to Phong Tho-Nam Pia fault has the length of 30 km, the depth is estimated of 15 km, its dip of 75 of southwest direction. From Spot image, one can observe triangular facet demonstrating Phong Tho-Nam Pia fault is a normal fault related to extensive tress regime. The shortest distance from this fault segment to Pa Vinh is of 17 km, and to Ta Bu is of 10 km. The fault segment Muong La 1 is very near to Pa Vinh and Ta Bu dams. Therefore, determination of its size has a very important significance in forecasting maximum earthquake. That's why, a series of special measurements of seismic cross-section, electrical cross section, nuclear trace detector have been carried out near the end of fault segment to determine the termination of fault segment Muong La 1. The International committee for great dams recommended that 3 magnitudes of earthquake used for dam design are Maximum Credible Earthquake, (MCE), Maximum Design Earthquake (MDE) and Operation Basis Earthquake (OBE). Coefficient b taken from Nguyen Dinh Xuyen for the entire northwest region is 0.814. MCE is the special value of an earthquake source, which means the ability of appearing the strongest earthquake along fault segment. In our study, we used methods of calculating maximum magnitude from the fault surface area of Well-Coppersmith, Wyss, woodward - Clyde and especially using the formula of calculating MCE from earthquake moment. For combining various methods, we take average value by weight number, of which the method of calculating by earthquake moment takes coefficient 3, method based on fault surface area take coefficient 2, and methods based on destroyed fault length take coefficient 1 distance from earthquake source to the dam. Calculating results obtained by using various methods that are stated in details below. In order to get average value, the method based on earthquake moment is used with coefficient 3 due to its highest confidence, methods based on fault surface use coefficient 2, and methods based on fault length has coefficient 1. It should be noted that in our work, fault slip rate cannot be used for calculating MCE, but in contrast, MCE can be used for estimation of fault displacement rate. For example, displacement rate of the fault segment Muong La 2 in Phong Tho-Nam Pia fault zone is estimated of 0,44 mm/year (method of Woodwar - clyde). For calculation seismic moment, we have to know displacement value along fault segment. However, this is an unknown parameter in our case. That why, we have to use the iteration technique. At first step of calculation, from fault surface, we calculate magnitude by method of Well-Coppersmith. At second step, we use average displacement deduced from method of Well-Coppersmith to calculate seismic moment and first average MCE. At third step, we calculate seismic moment from first average MCE and second average MCE. The process continues until the difference between MCE of two successive steps is acceptable. Due to the lack of specific attenuation law for Vietnam value of the Peak Ground Acceleration, we have to use models 1, 2, 3 of Campbell and formulas of Idriss, Xiang and Gao, Woodward - Clyde, Ambraseys to calculate PGA in our study. Formula of Cornell, Mc Guire, Estena & Rosenblueth has value for reference only. Therefore, when taking weight average to summarize the peak ground acceleration by different methods, 3 methods above cannot be used. Models 1, 2, 3 of Campbell based on global data of vibration near the source, so it has high reliability in case of assessing earthquakes with in 50 km or less.

Table 1: Maximum Credible Earthquake MCE of Phong Tho - Nam Pia fault, segment Muong La 1 calculated by various methods

Fault length(km)	depth(km)	dip	displacement(m)	state of stress	
12.000	10.000	75.000	.200	EXTENSIVE	
Method of Slemmons,1982 for fault length					6.279
Method of Well-coppersmith, 1994 for fault length					6.285
Method of Well-coppersmith, 1994 for fault area					6.066
Method of Wyss, 1979 for fault area					6.244
Method of Woodward-clyde,1983 for fault area					6.154
Method of seismic moment, Hanks- Kanamori					5.882
Slip rate (mm) of fault segment, Woodward-clyde, 1983					0.142
Maximum displacement (m) , Well-Coppersmith, 1994					0.315

Table 2: Peak Ground Acceleration at Pa Vinh provoked by MCE of Phong Tho - Nam Pia fault, Muong La 1 segment.

Magnitude	Distance to source	fault depth	fault dip depth		weight
6.100	4.400	10.000	75.000		
PGA calculated from model 1 of Campell				0.1720	2
PGA calculated from model 2 of Campell				0.1618	2
PGA calculated from model 2 of Campell (with M>6)				0.1895	2
PGA calculated from model of Boore-1982				0.2146	1
PGA calculated from model of Boor, 1982:				0.2715	1
PGA from model of Xiang J.-Gao Dong, 1989:				0 .1848	2
PGA calculated from model of Woodward - clyde, 1983:				0.2064	1
PGA calculated from model of Cornell, 1979:				0.2702	1

The above formulas can use coefficient 2 for calculating weight average. The formula of Xiang and Gao can also use coefficient 2, because it is set up from data of earthquake in Yunnan close to geological condition and structure of Vietnam. Formulas of Woodward & Rosenblueth, Idriss and Ambraseys can be used with coefficient 1, because it is set up by data from different sources with distance form 0 to more than 400 km. Peak Ground acceleration unit calculated as g with 1g ~ 980 cm/s^2. We present as example the result of estimation of MCE of Muong la 1 segment by different methods in table 1. We note that 3 decimal numbers in the estimation have only signification of calculation of average MCE. Table 2 is the result of estimation PGA produced by MCE of Muong la 1 segment at Pa Vinh site. Although, practical signification is only 2 decimal numbers presented in table 4, but we take 4 decimal numbers in the calculation of PGA average and its RMS. Although Son La fault is a great fault in the area that is able to generate strong earthquake (Magnitude = 6,9), however its influence on position of hydropower dams (Pa Vinh and Ra Bu) is not so strong as the influence of 2 fault segments Muong La 1 and Muong La 2. Peak Ground Acceleration (PGA) caused by 2 fault segments Muong La 1 and Muong La 2 is the highest, PGA correspondent to maximum credible earthquake at Pa Vinh and Tabu is of 200 ± 30 cm.s^{-2}. Although jointly subjected to PGA of 200 ± 30 cm.s^{-2} but Ta Bu dam position will be subjected to probability of appearing maximum credible earthquake higher than Pa Vinh position.

4. CONCLUSION

From remote sensing, geological and geophysical observation, we can mapping in detail active fault in Son La hydropower dam. Remote sensing helps us not only locate fault segment but also determine active fault length, dipping direction and related stress regime. These most important parameters are combined with other values determined from geological and geophysical data to calculate maximum credible earthquake and peak ground acceleration. The latest value is used for optimal dam design.

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