SEISMIC HAZARD ASSESSMENT FOR THE
PAKLAY HYDROPOWER DAM AT THE MEKONG RIVER
(Lite version)

Contents

1 SCOPE OF THE STUDY

1.1 Context

PowerChina ZhongNan requested GEOTER SAS, an operating company of the FUGRO Group, to conduct a seismic hazard assessment for the Paklay Hydropower dam project in Laos (Figure 1).

The Paklay hydropower dam project is located in northwest Laos, south East Asia, on the Mekong River. The Paklay HPP dam will be made of concrete with a maximum height of 51.2 m for a storage capacity of 890 million m3. This size of dam corresponds to a large dam according to the ICOL guideline (2010) definition.

The Seismic Hazard Analysis (SHA) is conducted in compliance with the current international standards and local practice. The approach used follows the requirements and methodology of the ICOLD guideline (2010) which is the main current standard for large dams.

1.2 OBJECTIVES OF THE STUDY

The aim of the study is to perform a seismic hazard assessment at the dam site (Figure 1) in order to define the seismic parameters that should be considered for the design. The seismic ground motions are defined by response spectra and associated time histories, for specific seismic levels (return periods) defined for the project.

The ICOLD guideline describes three different seismic levels: Maximum Credible Earthquake - MCE, Safety Evaluation Earthquake - SEE and Operating Basis Earthquake - OBE. The terminology used in ICOLD Bulletin 148 (2010), to define the different seismic levels is the following:

- **Maximum Credible Earthquake (MCE)**: is the largest reasonably conceivable earthquake magnitude that is considered possible along a recognized fault or within a geographically defined tectonic province, under the presently known or presumed tectonic framework. The most severe ground motion affecting a dam site due to an MCE scenario is referred to as the MCE ground motion. Evaluation of the MCE ground motion is generally performed using a deterministic approach;
- **Safety Evaluation Earthquake (SEE)**: The SEE is the maximum level of ground motion for which the dam should be designed or analyzed. For dams whose failure would present a great social hazard the SEE is normally

characterized by a level of motion equal to that expected at the dam site from the occurrence of a deterministically-evaluated maximum credible earthquake or of the probabilistically-evaluated earthquake ground motion with a very long return period, for example 10,000 years. Where there is not a great risk to human life the SEE may be chosen to have a lower return period depending on the consequences of dam failure. In agreement with the client, the return period considered for the SEE is 5,000 years for the Paklay HPP project. However, a return period of 2,475 years is also added at the request of PowerChina;

- **Operating Basis Earthquake (OBE)**: It represents the level of ground motion at the dam site for which only minor damage is acceptable. In theory the OBE can be determined from an economic risk analysis but this is not always practical or feasible. In many cases, it is appropriate to choose a minimum return period of 145 years *(i.e.* a 50 % probability of not being exceeded in 100 years). Since the consequences of exceeding the OBE are normally economic, it may be justified to use a more severe or less severe event for the OBE (*i.e.* longer or shorter recurrence period). In agreement with the client, a return period of 475 years (10% probability of exceedance in 50 years) for the OBE seismic level is adopted for this study, in addition to the return period of 145 years. Furthermore, the return period of 475 years is a general reference return period for PSHA and design purposes for normal buildings (*i.e.* Eurocode 8).

Figure 1: Location of the Paklay HPP dam project

In summary, the return periods considered for the Paklay HPP project are: T1=145, T2=475, T3=2,475 and T4=5,000 years.

2 SYNTHESIS OF THE REGIONAL GEODYNAMIC SETTING

2.1 GEODYNAMIC AND SEISMOTECTONIC SETTING

At the scale of tectonic plates (Figure 2), the Paklay HPP dam site is located in northwest Laos, South East Asia (SEA), on the boundary of the Indo-Australian and Eurasian plates, in the Sunda plate. A convergence rate of 65–70 mm/year as a result of Australia moving toward SEA is reported by McCaffrey (1996). This boundary zone comprises the convergent margins, including the Burma oblique subduction zone (Arakan trench), Andaman subduction and Sunda arc, to the northwest, west and south, respectively.

Although the Paklay HPP site is far away from the subduction zones (>800 km), we note that the observed seismicity and seismotectonic settings of these plate boundaries clearly indicate the capability of producing large events such as the 26 December 2004 mega-thrust earthquake (Mw=9.1-9.3) that occurred along the Sumatra trench, with a megathrust rupture that has propagated northward along the Andaman subduction.

Closer to the Paklay dam site, seismicity is localized in active faults regions inside Indochina continental terranes (Figure 3) for which most of geological patterns are linked to a complex history (Figure 4), combining marine sedimentation, oceanic suture closures and post-orogeny fault reactivations. Indeed, two main tectonic phases have affected the region: the Indosinian tectonics and the Cenozoic tectonics.

Indonesian orogeny

Several important suture zones of the paleo-Tethys ocean have been recognized in southern east of Asia including the Song Ma suture zone in northern Vietnam, the Nan suture zones and the Loei tectonic zone in northern Thailand and the Luang Prabang tectonic zone in northwestern (NW) Laos (*Figure 5*). The Luang Prabang tectonic zone is located between the Sukhothai Terrane and the Indochina Block and roughly parallels the Dien Bien Phu Fault (DBPF) to the north and the Nan suture to the south. This zone lies in the area that aligns with the Nan suture zone to the southwest.

From a chronological point of view, the Indochina Terrane is suggested to have originated from the India–Australian margin of northwestern Gondwana in the Early Paleozoic and separated and drifted from Gondwana in the Early Devonian (Metcalfe, 2011, 2013).

Following the Indochina Terrane, the Shan-Thai Terrane (Figure 4) rifted from Gondwana in the Early Permian. After drifting northwards, these two tectonic terranes may have collided and amalgamated in the southern Eurasia Margin during the Triassic, causing the closure of the Paleo-Tethys Ocean in the current Loei Fold Belt region (Kamvong *et al.,* 2014).

In addition to Late Permian to Early Mesozoic subduction, the Song Ma ocean plate, a branch of Paleo-Tethys, was subducted under the Eastern Indochina Terrane during Late Carboniferous to Late Permian. The collision between the Indochina and South China terranes occurred at about 270–260 Ma in Central Vietnam along the Song Ma suture and the current Truong Son Fold Belt (*Figure 5*) (Lai *et al.*, 2012, Kamvong *et al.,* 2014).

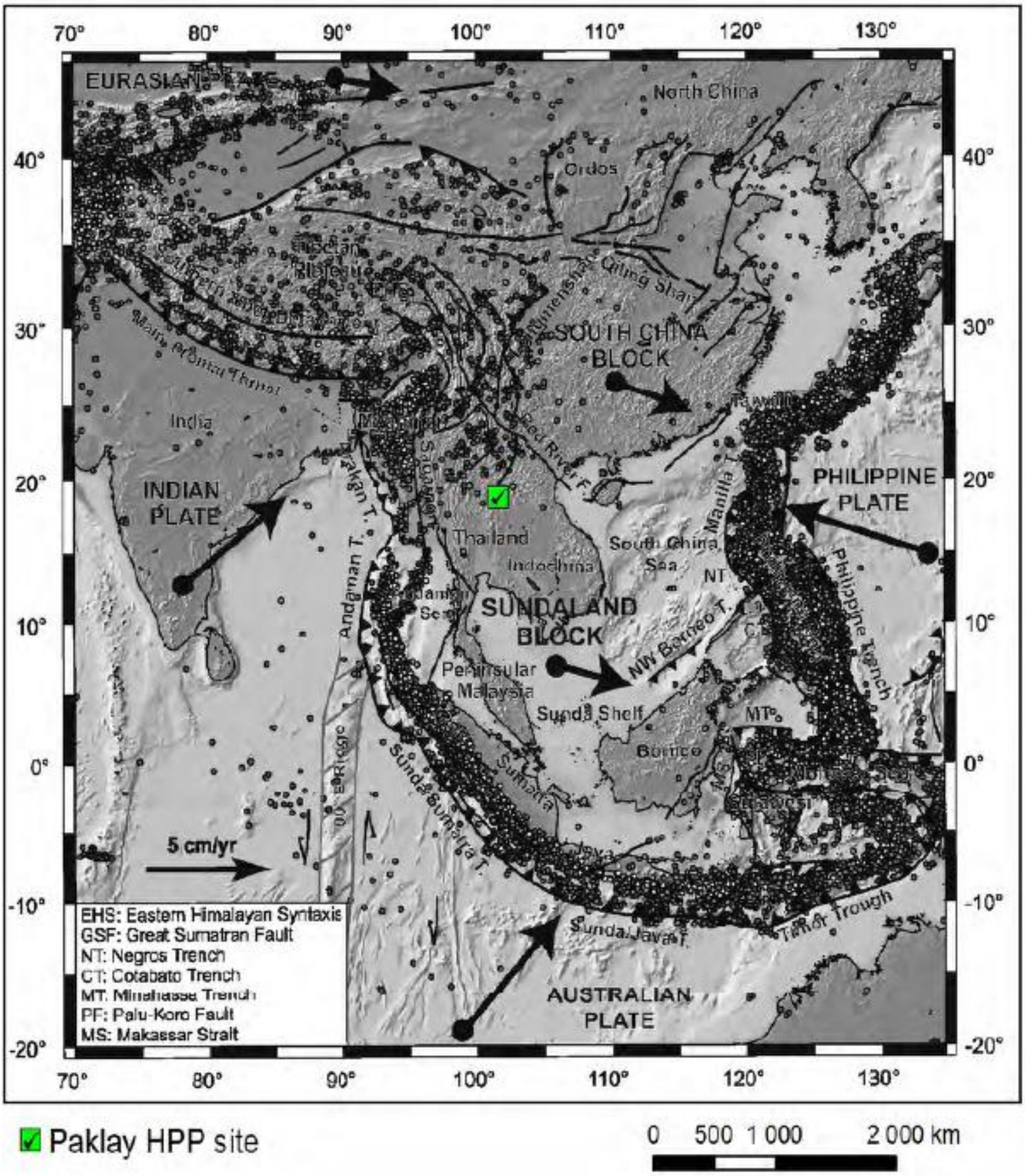

Figure 2 : Seismicity, main active faults and absolute motion (ITRF2000) of the plates around the Paklay dam site(after Simons et al., 2007)

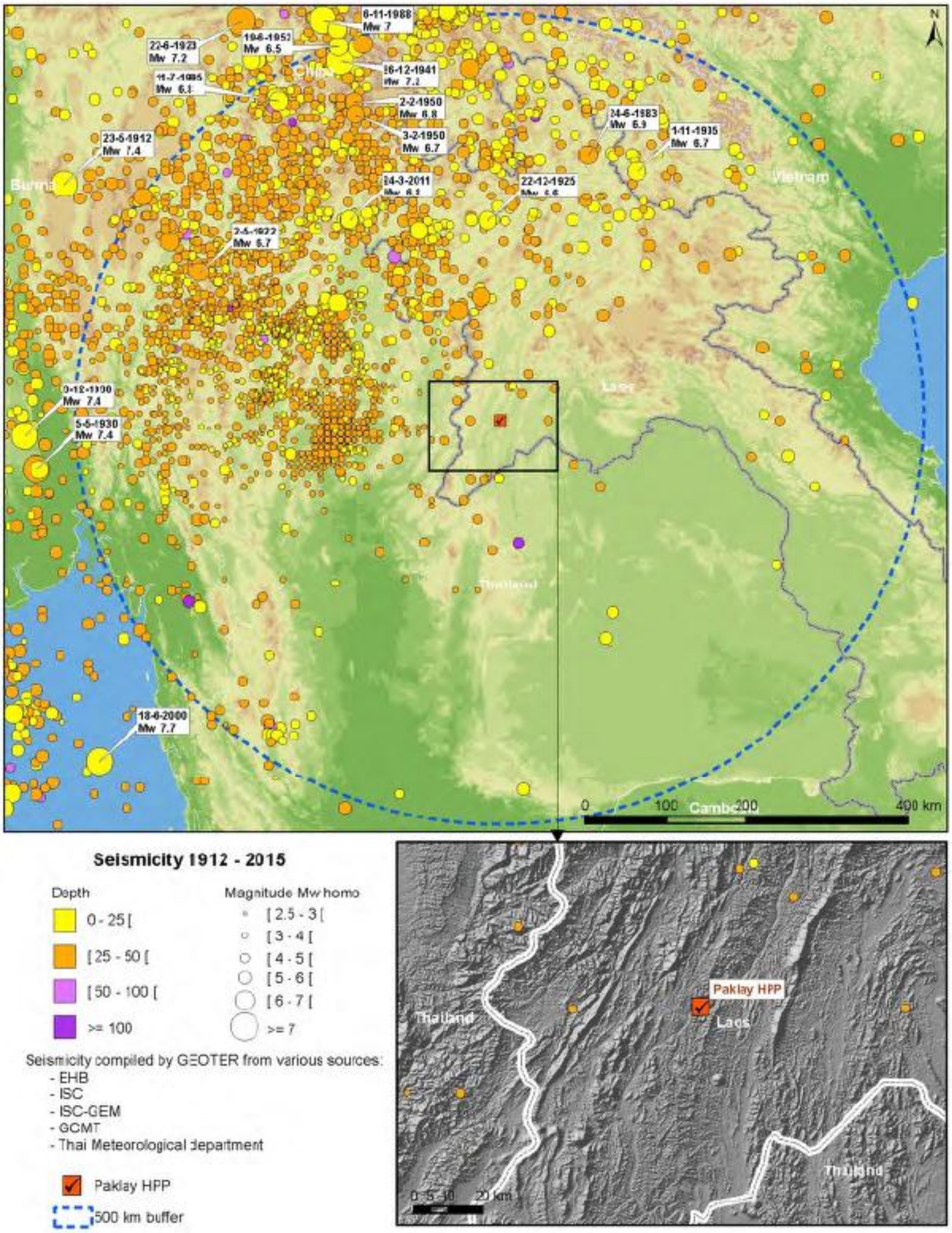

Figure 3 : Regional seismicity around the Paklay HPP dam site

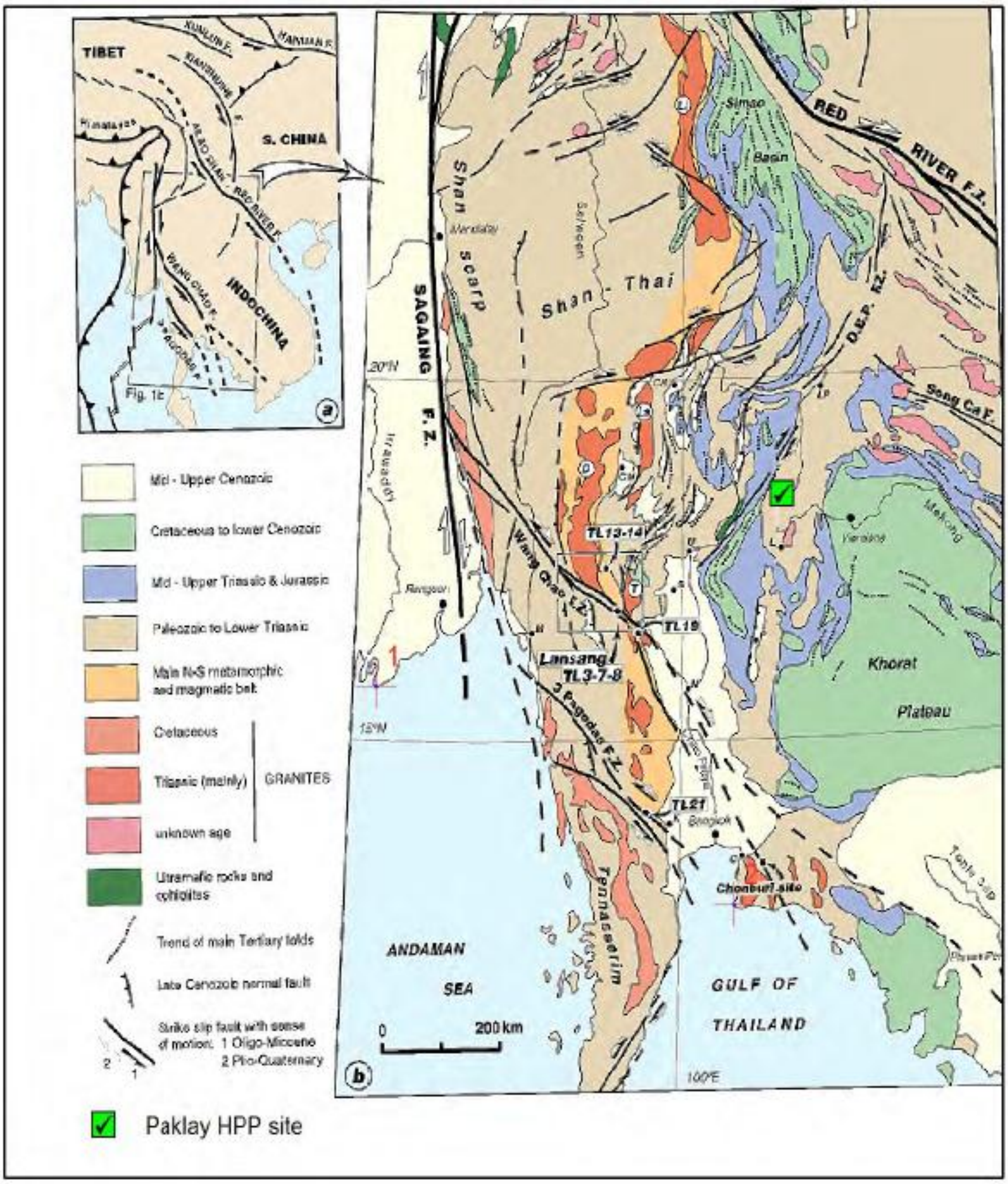

Figure 4 : Simplified geological map of the study region by Lacassin et al., (1997)

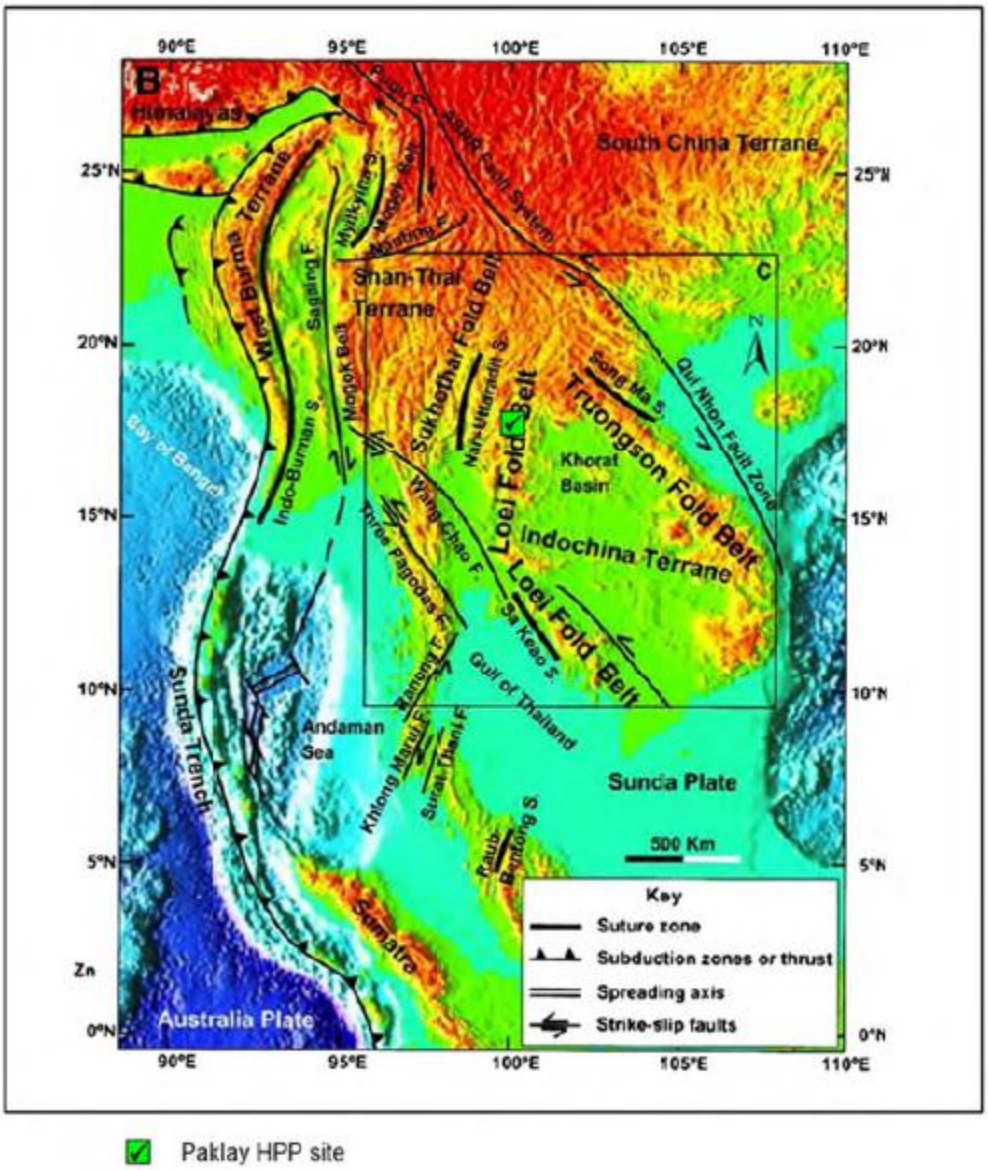

Figure 5 : Map of mainland Southeast Asia with major terranes, suture zones and faults (after Kamvong et al., 2014).

In the middle Triassic, the right-lateral strike-slip motion along the DBPF accommodated the SW–NE shortening on the various thrust faults forming the Song Ma suture zone (Roger et al., 2014). In late Triassic, a rapid cooling/exhumation of granites up to the surface induces the development of the Upper Triassic unconformity on the exposed granites. Then, the Ladinian–Carnian sedimentation over the whole area marks the end of the Indosinian tectonic phase.

Until the Early Cretaceous, a generalized thick (several kilometers) sedimentation burying the previous granites, before a reactivation of the DBPF and the Song Ma Suture in a similar way as during the Triassic, leading to erosion of the Jurassic to Lower Cretaceous sediments which have been then transported towards the Khorat basin (Figure 4) to the south (Carter *et al.,* 2003).

Cenozoic tectonics

Afterwards, the Cenozoic tectonics that occurred in the region is a consequence of collision of India with Eurasia in the Middle Eocene. Most of the current tectonics framework results from this phase.

As India drove into the southern margin of Eurasia since about 50 Ma, numerous north- to northeast-striking faults developed in northern Indochina as a result of roughly east–west trending compression. Furthermore, Indochina has rotated clockwise about 25° and extruded to the southeast by approximately 800 km along the Red River (RRF) and Three Pagoda (TPFZ in the *Figure 6*) strike-slip fault zones during the first 20–30 million years of the collision (Fenton *et al.,* 2003). Because of this block's rotation, the motion sense of the RRF and TPF was progressively reversed from left-lateral to right-lateral. To the west of the Indochina block, the TPF system is connected to the Sagaing Fault (SF), a major N-S right-lateral continental transform fault. The SF motion results from the strain partitioning linked to the India northward intrusion and absorbs about 18 mm/yr of the resulting 35 mm/yr India/Sundaland strike-slip motion (Socquet *et al.,* 2006; Simons *et al.,* 2007).

To accommodate the motion of these major right-lateral strike-slip faults, one common pattern of active faults in Indochina region is left-lateral NE-SW to ENE-SWS striking faults. As the block’s rotation evolves around the eastern Himalayan syntaxis, the velocities increase southwards Indochina (*Figure 7*) and induce a transtensional regime. This feature results in the opening of tertiary basins, bounded by north to northwest-striking normal faults.

The major tectonics elements that may impact the site seismic hazard are described in the following section.

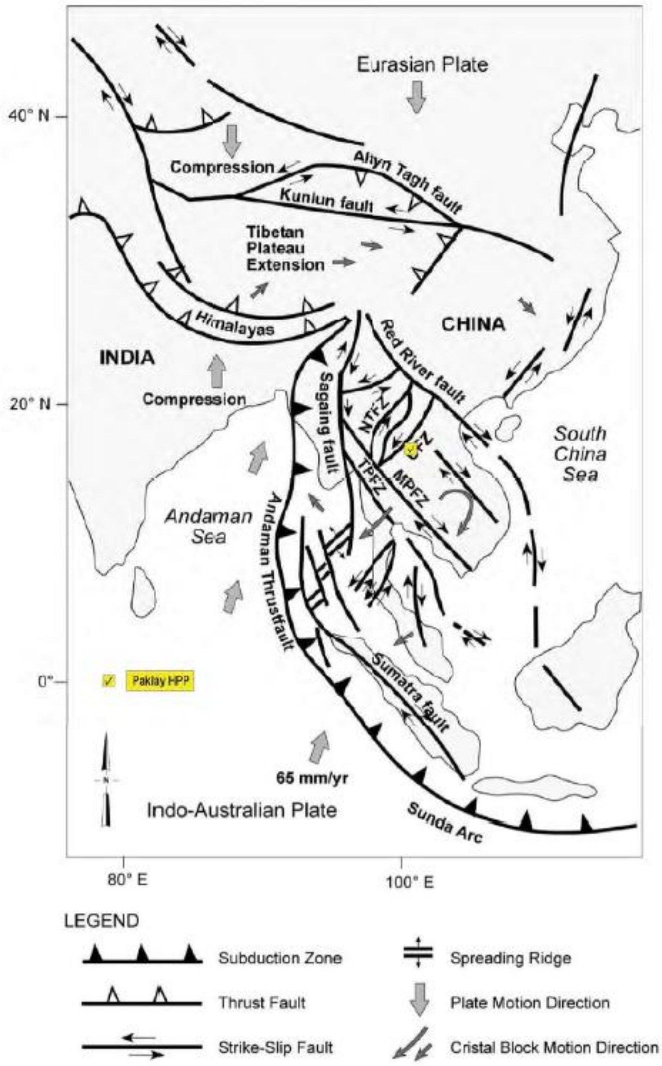

Figure 6 : Major tectonic structures in Southeast Asia and Southern China after Fenton et al., (2003).

2.2 MAIN REGIONAL FAULTS SYSTEM

2.2.1 The Sagaing Fault

The Sagaing fault (Figure 13) is a continental transform fault ~1200 km long that accommodates right-lateral motion between the India and Sunda plates. It connects spreading centers in the Andaman Sea and a continental convergence zone along the Himalayan front (Figure 6). Portions of the Sagaing Fault ruptured during large historical earthquakes in the past two centuries (Tsutsumi and Sato, 2009). This major continental fault is considered to be one of the most active in the world with a geodesic derived slip rate of 18 mm/yr (Socquet et al., 2006). This is about half of the rate of motion between the India and Sunda plates, which includes displacements at the Arakan Trench and Arakan Yoma range in addition to the Sagaing Fault.

The Sagaing Fault has been seismically active in the past 200 years with several destructive earthquakes along the fault, such as the 1839 Ava (Innwa), May 1930 Pegu (Bago), December 1930 Pyu, and 1956 Sagaing earthquakes.

Geologic field investigations was conducted by Tsutsumi and Sato (2009) along the southernmost 120 km long stretch of the fault zone that ruptured during the Mw=7.4 May 05, 1930 Pegu (Bago) earthquake. The sense of displacement is predominantly right-lateral strike-slip. Tsutsumi and Sato (2009) estimated at least 3.0 m coseismic right-lateral displacement. Taking into account the 18 mm/yr of slip-rate, the recurrence interval of surface-rupturing earthquakes on the Sagaing Fault is evaluated as about 160 yr or longer. Although this fault is a major active structure, the distance from the dam site (>500 km) is high enough to consider its effect as negligible, relative to the seismic sources closer to the dam site.

2.2.2 Three Pagoda and Mae Ping strike-slip fault zones

These northwest to southeast orientated fault zones are delineated along the border between eastern Myanmar and western Thailand (Figure 13), such as the Three Pagoda (TPFZ in Figure 6) and Wang Chao fault zones (along MPFZ in Figure 6) (Pailoplee et al., 2009).

As the Sagaing fault, these faults are dextral. They extend for about 450 km and probably continue toward the Gulf of Thailand (Lacassin *et al.,* 1997). Based on morphological analyses and paleoseismological investigations, the rate of fault slip of these fault zones has been estimated at around 0.73–2.00 mm/y (Fenton *et al.,* 2003; Charusiri *et al.,* 2004). No large events have been historically reported.

2.2.3 The Red River Fault

The Red River Fault Zone (RRFZ) is a major tectonic feature separating South China from Indochina (Figure 13). This zone, extending more than 900 km between eastern Tibet and the South China Sea, is the most conspicuous geologic and geomorphic discontinuity in Southeast Asia (Zuchiewicz et Cuong, 2009; Zuchiewicz *et al.,* 2011).

RRFZ was formed during Oligocene as a sinistral shear zone which was later transformed into a dextral one (Tapponier *et al*., 1986). The pre-Late Miocene sinistral shift along the RRFZ was largely confirmed by the results of subsequent studies (*e.g.* Leloup *et al.,* 1995, 2001, and references therein). According to these results, the RRFZ was a sinistral lithospheric discontinuity since at least 34 until 17 Ma.

The RRFZ is rooted in an horizontal shear zone at the brittle/ductile transition separating the upper and middle crust from the lower crust, and the sinistral strike-slip motion was first transpressional (40-25 Ma), and then transtensional, leading to fast exhumation from 24 to 17 Ma (Jolivet *et al.,* 2001).

From morphotectonics studies, rates of Quaternary dextral slip range between 1 and 9 mm/yr (Allen *et al.,* 1984; Weldon *et al.,* 1994), whereas geodetically measured rates of recent motions do not exceed 4 mm/yr (Cong and Feigl 1999) or 2 mm/yr (To *et al.,* 2001). Recently, Schoenbohm *et al.* (2005, 2006) have concluded about continuous dextral, 5 mm/yr, long-term slip rate. Considering the post-Miocene fault behaviour and the lack of strong seismicity in historical times led Zuchiewicz and Cuong (2009) to conclude that the axis of maximum horizontal compression associated with dextral slip of the RRFZ was aligned NNW-SSE to N-S, and the fault motion resulted mainly from aseismic creep. As for the Sagaing fault, this structure is not considered in the analysis of this present study, considering its distance to the dam site (~500km).

2.2.4 The Dien Bien Phu Fault

The Dien Bien Phu fault zone (DBPF) appears to the south of the Red River fault zone (*Figure 13* and *Figure 7*), sharing the spatial alignment of the Xiaojiang fault and extending over a distance of 150 km from Yunnan, China, through northwest Vietnam and Laos. It separates the Indochina block from the Shan Plateau.

The DBPF is very likely to be a boundary accommodating the deformation of crustal rotation due to its critical location (Simons *et al.,* 2007), despite its relatively small size compared to other major faults. For the purpose of understanding the active tectonics and the seismic hazard mitigation for the dam site, the DBPF is an important target in this region.

The Dien Bien Phu fault zone is one of the most seismically active zones in Indochina. Minimum slip rates of leftlateral strike-slip ranging from 0.6 to 2 mm/year in Holocene and 0.5–3.8 mm/year in Pleistocene times are reported for the the Dien Bien Phu fault. Rates of Quaternary strike-slip are comparable with those of the Red River fault. According to Zuchiewicz *et al.* (2004), the Red River and Dien Bien Phu faults are conjugate faults capable of generating relatively strong earthquakes in the future. Some historical earthquakes may have been caused by the Dien Bien Phu fault.

The main known earthquakes that occurred on this fault are:

- the Mw 6.8 earthquake of November 1935 which occurred near the southern end of the Vietnam segment.
- the Mw 6.2 earthquake of 24 June 1983 which has a focal mechanism consistent with the strike of the fault.

According to the feasibility study provided by PowerChina ZhongNan, the Dien Bien

Phu fault zone is located at about 120 km from the Paklay Dam site. However, this fault system is strongly supposed to be connected to the Nan (Nan-Uttaradit) suture (*Figure 5*) in Thailand (Lepvrier *et al.*, 2004). Indeed, along its southern reaches, the Dien Bien Phu fault exists within the Triassic Nan Suture zone, and multiple linear valleys imply that it fans into multiple left-lateral faults within a wide deformation belt (Wang *et al.,* 2014).

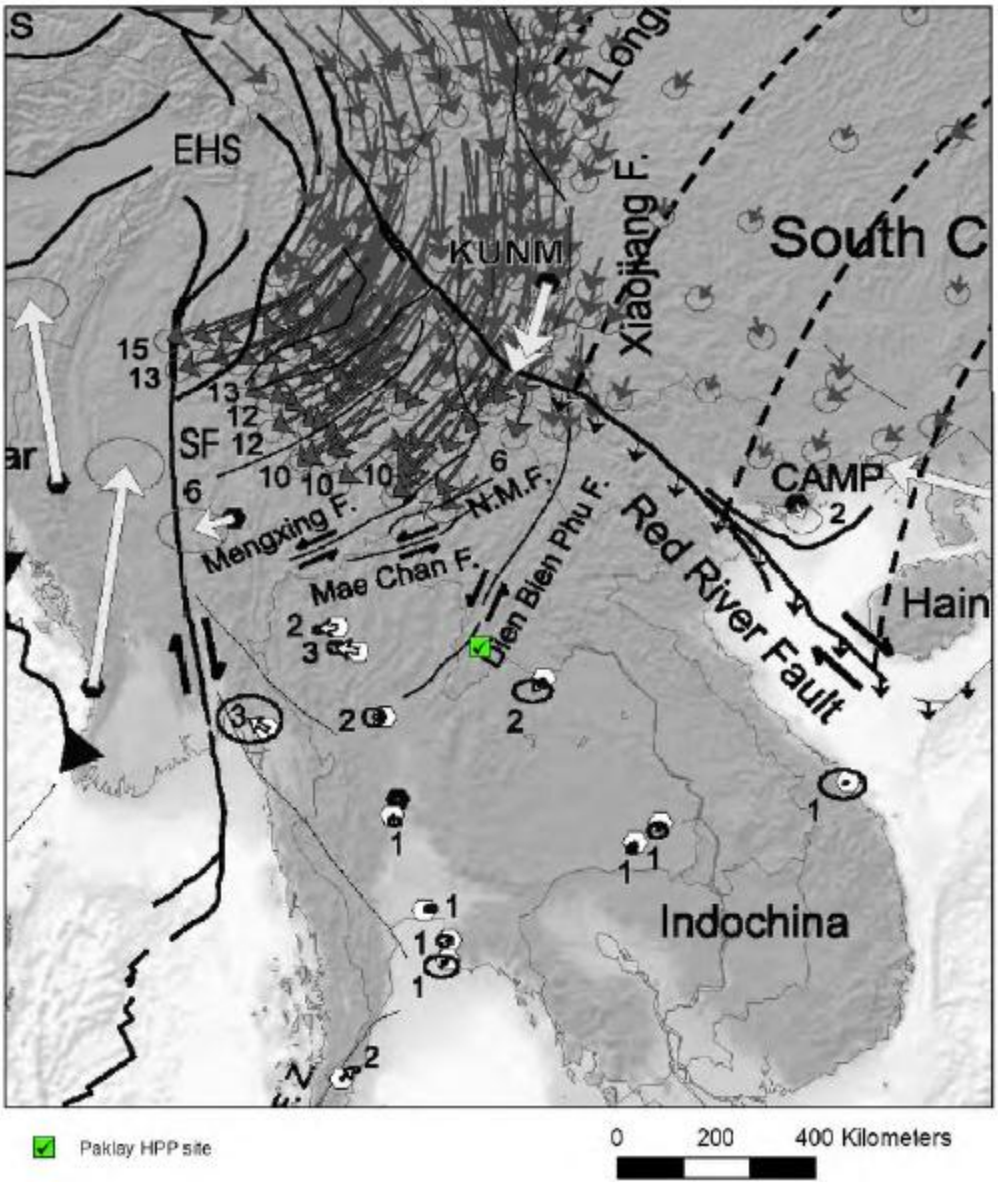

Figure 7 : Velocities in Southeast Asia with respect to Sundaland (after Simons et al., 2007). The accommodatingleft-lateral strike-slip faults, naming convention and traces are based on Lacassin et al.

2.2.5 The Mengxing and Mae Chan strike-slip fault zones

A group of northeast-southwest left-lateral active faults occupies the central part of the Shan domain (*Figure 13* and *Figure 7*). The most prominent of these are the Menglian, Jinghong, Mengxing, Nam Ma, and Mae Chan faults. All of these faults are more limited in their eastern and western extent that the large fault systems just discussed. Three features in common are that they strike NE-SW, their lengths range from roughly 100 to about 200 km (Wang *et al.,*2014). The rate of fault slip of these fault zones are in the range of 0.5–5 mm/yr (Fenton *et al.,* 2003; Pailoplee *et al.,* 2009,).

The main historical and instrumental earthquakes that occurred on this fault zone are:

- the Mw 5.9 foreshock and Mw 6.8 earthquakes that are attributed to the Menglian fault in the China-Myanmar border region in July 1995. Focal mechanisms are consistent with a left-lateral slip.
- the Mw 7.1 earthquake on 2 February 1950 which was caused by rupture of the Jinghong fault. The epicenter of mainshock is very close the central part of the fault, and several Chinese cities north of theJinghong fault were damaged (Xie and Tsai, 1983).
- Two more recent and more moderate earthquakes (Mw 5.6 and Mw 5.4) on 23 June 2007 are potentially linked to the failure of parts of the Jinghong fault. Their GCMT focal mechanisms are consistent with the fault's strike.

This faults zone is one of the more important seismic active sources for the Paklay dam site.

2.2.6 The Basin and Range normal faults

This region is characterized by an extended crust, with basin and range topography linked to the rifting in the early Tertiary. Normal faults are clearly visible on DEM (SRTM 90m) and triangular faceted spurs are often observed (Fenton *et al.,* 2003) such as along the Phrae fault, the Mae Tha fault, the Nam Pat fault and the Thoen fault (*Figure 13* and *Figure 15*). Slip rates are in the range of 0.1-0.6 mm/yr. The longest fault is the Thoen fault with about 120 km and a slip rate of 0.6 mm/yr.

The Thoen fault is regarded as an active fault (Fenton *et al.*, 2003; Wiwegwin *et al.,* 2011). It is an extensional structure (Fenton *et al.,* 2003, Danphaiboonphon, 2005), and the displacements are mainly normal dip-slip and subordinate left-lateral slip.

No large events have been recorded and seismicity appears as diffuse in the region (*Figure 3*). However, these faults are located within 300 km of the dam site and have to be taken in account in our analyses.

2.2.7 The Nan-Uttaradit strike-slip fault zone

The previous described basin and range region is bounded to the southeast by a strike-slip fault system which lies along the Uttaradit-Nan suture zone probably connected to the south extremity of the Dien Bien Phu fault system (*Figure 13*). The average slip rate is about 0.1 mm/yr along the Uttaradit fault zone (Pailoplee *et al.,* 2009). To the east, other strike-slip faults parallel to the Nan-suture lie along the Loei-Petchabun suture (*Figure 13*). Slip rates of these faults are not known and seismic activity is very low (Figure 3).

2.2.8 The Song Ca strike-slip fault zone

Extending to the eastern part of Southeast Asia (northern Vietnam), some strike-slip fault zones have been identified in this region, such as the Song Ca, Song Da, and Song Ma fault zones (Pailoplee and Choowong, 2013) (*Figure 13*). These fault zones have a NW–SE orientation limited locally in the northern part of Vietnam. They are parallel to the Song Ma suture (*Figure 5* and *Figure 13*). Although most of fault slip rates are not known in this region, the instrumental records show that earthquakes are commonly associated with these fault zones (Figure 3).

2.3 NEAR REGIONAL FAULTS

The near regional faults concern the faults lying in the vicinity area (radius of 50 km) of the HPP Paklay dam site (*Figure 8*).

The faults retained in the seismotectonic model developed for the Paklay dam project are:

- F1: fault segment selected using digital elevation model (DEM) SRTM (90 m resolution) and according to Pailoplee *et al.,* (2009).
- F2: oblique fault segment selected using digital elevation model (DEM) SRTM (90 m resolution) and according to Pailoplee *et al.,* (2009).
- F3: fault segment selected using digital elevation model (DEM) SRTM (90 m resolution) and according to the feasibility report where it is also referred as “F3”.
- F4: fault segment selected using digital elevation model (DEM) SRTM (90 m resolution) and probably according to the feasibility report where it is referred as “F2”. We suppose that the spatial resolution of the satellite images used in the feasibility report was not high enough to identify the closest segment that we mapped using DEM. Moreover, we suggest that the “F2”

segment corresponds to a crest rather than to a true fault scarp.

We note that the feasibility study report also indicates the existence of a major fault referred as “F1” within the near region of the dam site. However, this segment is never described in maps and in the bibliography that we found. Although we agree that the morphology indicates some short lineaments in this area, we don’t dispose of precise enough data to select this fault as a major structure which could maximize the calculated seismic motion on the site. As evoked in the proposal, field investigations in the site region would be more appropriate to clearly characterize the geometry and activity this structure.

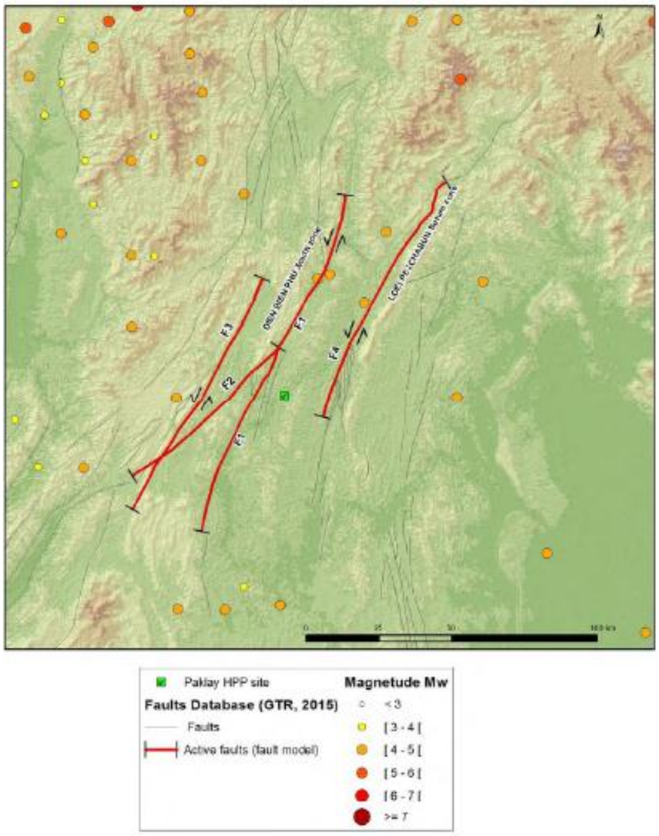

Figure 8 : Near regional faults considered for seismic hazard calculations

3 EVALUATION OF GROUND MOTION HAZARD

3.1 LEVELS OF GROUND MOTION HAZARD

The study aims to define appropriate earthquake loading conditions in terms of response spectral acceleration and associated time-histories for design purposes at the site location. The seismic behavior of the Paklay dam site is checked for two earthquake levels: OBE (Operating Basis Earthquake) and SSE (Safety Evaluation

Earthquake). The return periods considered for design purposes are the following:

- **T1 (Operating Basis Earthquake, OBE): 145 years**. According to the guideline ICOLD 2010, it corresponds to OBE earthquake level (50% exceedance probability in 100 years);
- **T2: 475 years** of return period (10% probability of exceedance in 50 years) is also considered since it is a general reference return period for PSHA.
- **T3 (Safety Evaluation Earthquake, SEE): 2,475 years**. It is associated with SEE earthquake level following the requirements of Powerchina (2% exceedance probability in 50 years).
- **T4 (Safety Evaluation Earthquake, SEE): 5,000 years**. It is associated with SEE earthquake level according to ICOLD (2010) (2% exceedance probability in 100 years).

These return periods were validated by PowerChina before to start the final probabilistic seismic hazard calculations.

3.2 PROBABILISTIC SEISMIC HAZARD RESULTS

3.2.1 Seismic hazard curves

The results of a probabilistic seismic hazard analysis consist of seismic hazard curves calculated for each spectral period. The statistical analysis of the hazard curves from all the logic tree branches leads to the definition of the mean and 50^{th}, 16^{th} and 84^{th} centile values of the hazard curves.

The hazard curves are processed to define the mean Uniform Hazard Response Spectra (UHRS) for the horizontal component at different return periods, as well as the UHRS corresponding to the 16%, 50% and 84% centiles that represent the hazard uncertainties at the site.

Figure 9, Figure 10, Figure 11 and Figure 12 show the 16th, 50th, 84th, and the mean centiles seismic hazard curves, respectively.

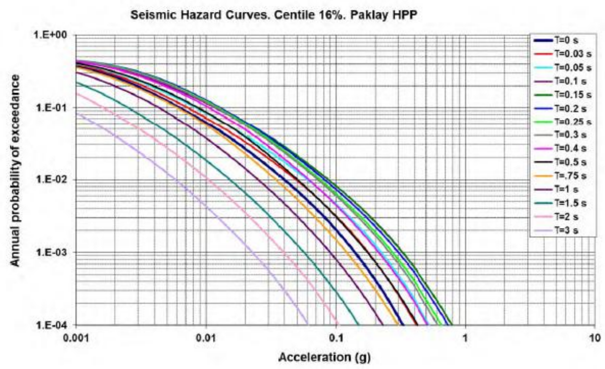

Figure 9: Centile 16% seismic hazard curves for Paklay HPP site

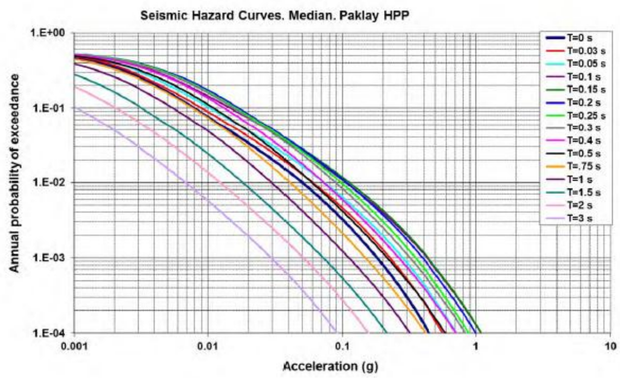

Figure 10: Median seismic hazard curves for Paklay HPP site.

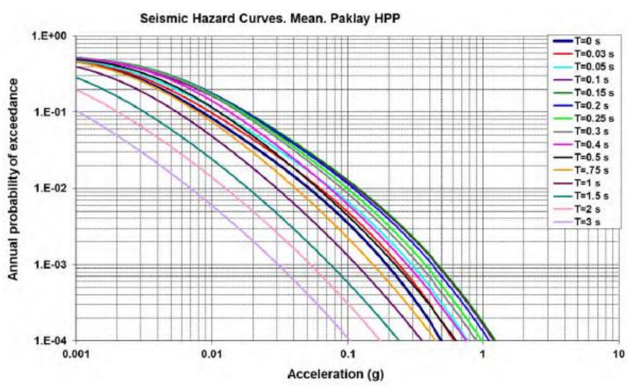

Figure 11: Mean seismic hazard curves for Paklay HPP site.

Figure 12: Centile 84% seismic hazard curves for Paklay HPP site.`

3.2.2 UHRS

The hazard curves are processed to define the mean horizontal uniform hazard response spectra (UHRS) at return periods of 145, 475, 2,475 and 5,000 years, as well as the UHRS corresponding to the 16^{th}, 50^{th} and 84^{th} centiles, which characterize the uncertainties at the site.

Results of the probabilistic seismic hazard assessment are presented in the form of PGA values and UHRS. A uniform hazard spectrum means that all spectral accelerations have the same probability of exceedance, and consequently the same return period.

The mean PGA values are respectively:

- 0.066 g for a return period of 145 years;
- 0.133 g for a return period of 475 years.
- 0.290 g for a return period of 2,475 years;
- 0.384 g for a return period of 5,000 years;

3.2.3 Design response spectra

The client required to know the needed parameters of the standard design spectra to be used for the project. According with the information provided by Powerchina, for this project, the engineering site design seismic response spectrum should be defined using the following formulae:

$$S_a(T) = A_{max}\beta(T)$$

Where:

- A_{max}: it is the "*design seismic peak ground acceleration"* (it means, the PGA, in cm/s^2)

- □β(T): this parameter is "*the amplification factor response spectrum for Design seismic peak ground acceleration*" :

$$\beta(T)=\begin{cases}1+(\beta_{max}-1)T/T_1 & 0.04\le T<T_1(s)\\ \beta_{max} & T_1\le T\le T_g(s)\\ \beta_{max}(T_g/T)^{\gamma} & T_g<T\le 5T_g(s)\\ 0.2\beta_{max} & 5T_g\le T\le 6.0(s)\end{cases}$$

- T_1 : it is fixed to 0.1s
- □γ : it is supposed to be equal to 1.0.
- T_g : it is the "*eigenperiod*", also the characteristic period of the acceleration response spectrum

The standard design spectra for the 4 return periods considered can be drawn using the parameters of the Table 1:

Designed seismic dynamic parameter	50-year exceeding probability	100-year exceeding probability		
	10%	50%	4%	2%
Return years	475	145	2475	5000
A_{max}(gal)	64.9	130.0	284.3	376.8
β max	2.32	2.38	2.44	2.49
T_g(sec)	0.26	0.25	0.27	0.28
a_h(g)(= A_{max}/980)	0.066	0.133	0.290	0.384
γ	1	1	1	1

Table 1. Seismic parameters used to define the seismic design spectra at 145, 475, 2475 and 5000 years return period.