A review of the Current Vietnamese Earthquake Design Code

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ABSTRACT: This paper provides a brief overview of the seismic activities in Vietnam. In the past, Vietnam did not have its own earthquake code. A new earthquake code which was based on Eurocode has been issued in 2006. The new earthquake code for Vietnam is reviewed in this paper. Due to the lack of historical records the establishment of the local site factors and design seismic response spectrum for major cities in Vietnam was found problematic. A case study was carried out to determine the full range response spectra for seismic design of building structures in Hanoi, the capital city of Vietnam. The study comprises the following components: (i) development of a seismic activity model for the potential earthquake sources in the region surrounding Hanoi; (ii) the response spectrum modelling for rock sites based on the assumed seismic activity; (iii) soil amplification modelling to represent typical soil conditions in Hanoi. Several representative boreholes have been obtained for soil resonance analyses based on the predicted bedrock motion. This method has been found very useful to produce important seismic parameters for earthquake design.

KEYWORDS: Seismic, ground motion, earthquake code

1 INTRODUCTION

Vietnam is located in the Eurasian Plate close to the Andaman-Sumatra-Myanma plate boundary. A number of faults have been found in Northern Vietnam. The most active fault with maximum shaking intensity of 8-9 (MSK scale) is LaiChau-DienBien-SongMa-SonLa, located in the Northwestern part of Vietnam (Nguyen 1996). In 1983, a number of moderate earthquakes of magnitude 5 to 6.8 struck the Northwestern provinces of Hanoi. These earthquakes caused minor structural damages to some buildings. The people in Hanoi felt the earthquake shaking very strongly. It can be explained that the high intensity was due to the amplification of the earthquake motion through soft clay in Hanoi (up to 50m depth).

In the past, Vietnam did not have its own earthquake code. Earthquake magnitudes were determined according to MSK-64 scale (almost similar to MM scale). Design of structures in seismically active regions were undertaken with instructions from the State Institute of Geology (belonging to the National Centre of Natural Science and Technologies). A number of different earthquake codes were adopted such as: the Russian Earthquake CNIP II 7-1981 or Uniform Building Code UBC.

The application of different codes without taking into account the seismicity of local area resulted in many problems such as inconsistency in determining seismic zoning factors and level of earthquake loading to be used in seismic design. Hence, the Ministry of Construction (MOC) has recently issued the new Vietnamese earthquake loading standard TCXDVN 375:2006. This paper will review seismicity of Vietnam and the new code TCXDVN 375:2006. A case study is carried out to investigate the seismic parameters for earthquake design in Hanoi, Vietnam.

2 SEISMIC ACTIVITIES IN VIETNAM

Results of a research project of the Vietnam Institute of Geophysics (VIG) named “Research and Forecasting Earthquakes and Ground Movements in Vietnam” (VIG 2005a), showed that from 114 AD to 2003 AD Vietnam, either by measurement or by studying the historical archives, recorded 1,645 earthquakes with magnitude (*M*) of 3 or greater than 3 on Richter scale. From 1900 to 2001 strong earthquakes were recorded in the North of Vietnam. These were the Dien Bien Phu earthquake in 1935, the Tuan Giao earthquake in 1983, and Dien Bien Phu earthquake in 2001. All these earthquakes occurred in the Northwest of Vietnam, close to Chinese Yunan province and Laos.

2.1 *Maximum Credible Earthquakes in Vietnam*

Seismic studies by the VIG has established a database for the frequency-magnitude relationship (Fig. 1) and a zoning map for maximum credible earthquakes in Vietnam (Fig. 2).

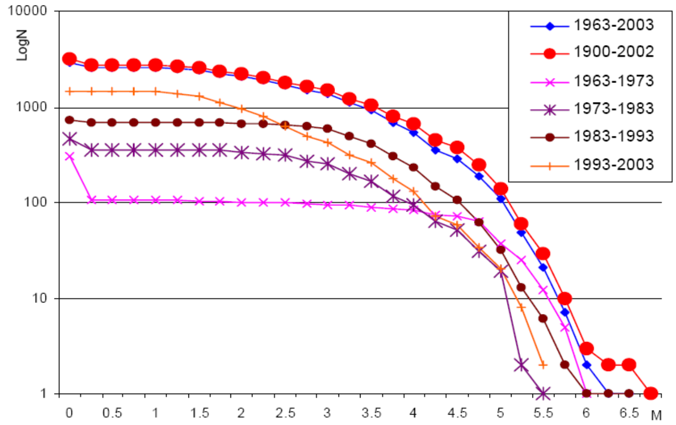

Figure 1. The Gutenberg-Richter frequency-magnitude diagrams for Vietnam (Cao 2006) (accumulated for all events on the whole Vietnam)

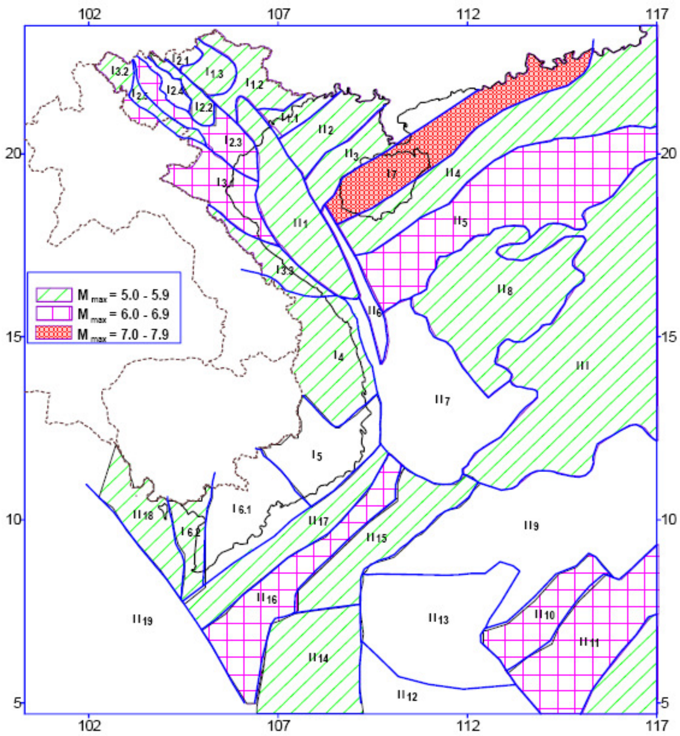

Figure 2. Maximum credible earthquakes in Vietnam (Cao 2006)

- The maximum earthquake observed in the Dong Back region (index I.1) is: Co To zone (M_s=5.0-5.9), An Chau – Song Hiem (M_s=5.0-5.9), and Phu Ngu (M_s=5.0-5.9).
- The maximum earthquake observed in the Tay Bac region (index I.2) is: Hoang Lien Son (M_s=5.0-5.9), Song Da - Son La (M_s=6.0-6.9), and Song Ma (M_s=5.0-5.9).
- The maximum earthquake observed in the Truong Son region (index I.3) is: Thanh Nghe Tinh zone (M_s=6.0-6.9), Muong Te (M_s=5.0-5.9), and Binh Tri Thien (M_s=6.0-6.9). The maximum earthquake observed in the Kon Tum (I.4) Ms=6.0, Ha Tien (I.7) Ms=5.0-5.9, Song Hong basin (II.1) Ms=5.0-5.9, Bach Long Vi (II.2) Ms=5.0-5.9, Loi Chau (II.3) Ms=5.0-5.9, Chau Giang (II.4) Ms=5.0-5.9, Bac Hoang Sa (II.5) Ms=6.0-6.9, Hoang Sa (II.8) Ms=5.0-5.9, Suoi Nga-Trang Khuyet (II.10) Ms=6.0-6.9, Sabah (II.11) Ms=6.0-6.9, Natuna (II.14) Ms=5.0=5.9, Nam Con Son (II.15) Ms=5.0-5.9, Con Son (II.16) Ms=6.0-6.9, Cuu Long (II.17) Ms=7.0, Phu Quoc (II.18) Ms=5.0-5.9, and Trung Tam Bien Dong (III) Ms=5.0-5.9.

The earthquake that occurred in the Southwest of Dien Bien Phu city on 1 Nov. 1935, was estimated at M = 6.8 (Richter scale) and considered as the strongest earthquake occurring in the past 100 years in Vietnam. The seismic intensity (I) (that is a measure of the effects of the earthquake on the buildings and structures) was between VIII and IX degree based on the MSK-64 scale. The Tuan Giao earthquake of 24 June 1983 at Lai Chau province had magnitude of 6.7 and I = VIII. Many houses suffered damage and collapse during the earthquake.

The 2001 Dien Bien Phu earthquake which occurred on 19 Feb 2001, had the epicenter in Nam Oun (Laos), about 15 km from Dien Bien Phu city. The recorded magnitude was 5.3 on the Richter scale and the intensity was between VII and VIII. There were hundreds of aftershocks of which the strongest had magnitude up to 4.9. The quake damaged almost all masonry structures in the region and injured 4 people but no one was killed. The effects on constructions were quite severe: 130 houses were damaged and had to be reconstructed, 1044 houses needed to be strengthened or retrofitted and 2044 houses were slightly damaged. The quake had very severe social and economic impact on the people and the local government in the region.

In 2005, there were many earthquakes recorded not only in the North but also in the South of Vietnam (where the seismic activity is considered very low, and the effects of earthquakes on the houses and other structures constructed in the South of Vietnam were never considered). These are the Nghe An earthquake, the Thanh Hoa earthquake, the Ha Giang earthquake, the Ninh Binh earthquake and the Lao Cai earthquake in the North of Vietnam; the Vung Tau earthquakes in the South of Vietnam.

The Nghe An earthquake occurred on 9:25:23 pm, 7 Jan. 2005 (local time), location: 19.020°N and 105.300°E, at Tan Ky mountainous area, about 120 km from Vinh city, Nghe An province (Middle part of Vietnam). According to data from VIG, the earthquake had M = 4.7, and intensity I varying between VI and VII. The quake's focus was at a depth of 13 km. Site investigation indicated 5 houses suffering light damage with small cracks developed on the masonry walls. The investigation also showed that the Nghe An earthquake did not cause any significant damages to buildings and structures in the region.

The Thanh Hoa earthquake occurred at 2:38:35.5 AM, 8 Jan. 2005, with M=4, at Cam Thuy commune, Thanh Hoa province. Its location is 20.360°N and 105.37°E. Duration of the earthquake was 260 sec. The effect of the earthquake was not significant.

In July and August 2005, earthquakes were recorded in Ha Giang province (M = 4.7, I = VI), in Ninh Binh province (on 3 August, M = 3.1, I = VI), and in Lao Cai province (epicenter about 60 km North-West from Lao Cai city, the depth is 10.8 km, I = VI (MSK-64) for Lao Cai city and I = VII for the epicenter zone). Generally, these earthquakes did not cause any problems to houses, buildings and other structures in these regions.

Southern Vietnam was always considered as a region with low seismicity, compared to the North. However, the earthquakes that occurred in this region in August and November 2005 surprised many scientists because the South of Vietnam was not expected to have major tectonic activities. On 5 August 2005, an earthquake occurred offshore of Vung Tau city with M = 4.6 and I =V. On 8 November, an earthquake rocked Ho Chi Minh City and claimed the life of a 48-year-old man. The quake warned the authorities, designers and contractors to consider the effects of earthquakes on buildings and structures. Magnitude of the earthquake was 5.5 and is thought to be an aftershock of an earlier tremor (in the morning of 8 Nov 2006), centered some 100 km off the coast of Vung Tau city, which shook the southern provinces of Vietnam. This earthquake could possibly be the strongest earthquake in the South of Vietnam (VIG 2005b).

Vietnam has in the past been considered a safe country in terms of earthquake hazards. However, the recent earthquakes in the North and the South of Vietnam urged the government and society to pay more attention to earthquake engineering. If large earthquakes occur in densely populated areas such as Hanoi and Ho Chi Minh city, the damages and losses may possibly be much more than those caused by typhoons or floods.

3 CURRENT SEISMIC DESIGN PRACTICE IN VIETNAM

During 1975-1985, Ministry of Construction (MoC) of Vietnam sent groups of engineers and architects to the former Soviet Union and Bulgaria for technical tours to study and discuss with experts and engineers from these countries on the field of earthquake engineering and structural design. The Russian seismic code SNiP II-7-81 was hence adopted in the design practice in Vietnam where buildings were required to be designed for earthquake actions. From 1980 to 1990, in Hanoi, very few multi-story buildings and important structures were actually designed and constructed with considerations of the earthquake effects.

The Russian code SNiP II-7-81 (or the 81*-updated version) is frequently used by engineers and architects (even until now) due to its consistency with the present Vietnamese design standards which were also based on the Russian codes.

Since 1995, as many high-rise buildings were built in Hanoi and Ho Chi Minh City, issues related to earthquake resistance were intensively raised due to safety requirements of these projects. Vietnamese Building Code (VBC: 1997), published in 1997, requires the buildings and structures, depending on their grade of importance and seismic intensity at the site, to consider the effect of earthquakes. The code of practice TCXD 198:1997 *Design of multi-story monolithic reinforced concrete buildings* (issued by MoC), provides guidelines for design of tall concrete buildings against earthquakes. Seismic analysis under TCXD 198:1997 is based on SNiP II-7-81*. The design earthquake intensity I is taken by the MSK-64 scale, the formulation to determine the seismic loads is the same as that from SNiP II-7-81*. It should be noted that before 1997, there was no approved national seismic zoning map, and the design earthquake intensity was usually determined for each project on a case-by-case basis.

As Vietnam economy opened up to the world, there was a real need to adopt international standards for the design of buildings and structures, especially for international projects or foreign investment projects. The owners would have to propose a specific code that they intend to use to the MoC of Vietnam for approval beforehand. With earthquake resistance design of structures, engineers and architects (especially young engineers and foreign consultants) usually prefer using the American Uniform Building Code (UBC: 1997) in practice. Due to the fact that a proper Vietnamese seismic design standard was not available until 2006, the Russian SNiP II-7-81* and the American UBC:1997 in combination with other Vietnamese design standards have been adopted for the design of structures built in the earthquake affected regions. The question of the design earthquake intensity for each project at a specific location and its transformation to UBC:1997 zoning has always been an issue although the seismic intensity can be obtained from maps of UBC:1997 (for return period of 500 years). For example, in Hanoi, it is generally considered as equivalent to 2B zone (UBC) or a region with seismic intensity of between 7 and 8 (MSK-64 scale).

Following the 2001 Dien Bien Phu earthquake, engineers and experts in the fields of earthquake engineering and construction had agreed that a Vietnamese seismic design standard needs to be prepared and published. In 2002, the 1st version of the Vietnamese seismic design standard was drafted but based on the Chinese earthquake code GBJ-1989. However, there were many problems related to inconsistencies with the present Vietnamese design standards. This version was therefore not accepted. Then, the 2nd version of the seismic design standard was prepared based on UBC:1997. Again, this version could not be approved due to the fact that UBC:1997 was not widely used in the US because the IBC 2003 was published with the purposes to replace UBC:1997. In harmony with the world and the regions, the Vietnamese design codes are required to be changed. The Vietnamese structural design codes will be prepared based on the Eurocodes (Nguyen et al. 2003). Therefore, since 2004 the seismic design code was asked to be prepared based on Eurocode 8: *Design of structures for earthquake resistance* (EN 1998-1:2004). The design code was completed and issued by MoC in 2006 with the code-number TCXDVN 375:2006. This code has come to effect in November 2006.

4 THE VIETNAMESE EARTHQUAKE CODE TCXDVN 375:2006

4.1 *Background and key information*

The new Vietnamese seismic design code was prepared based on Eurocode 8. However, compared to the Eurocode 8, TCXDVN 375:2006 has several minor changes such as the values of the importance factor lightly different from those of Eurocode 8. The seismic map adopted in the standard is established for Vietnam based on the studies of the VIG.

The fundamental requirements of TCXDVN 375:2006 are the no-collapse and damage limitation requirements. For the no-collapse requirement, the structure shall be designed to withstand the *design seismic action* without local or global collapse, retaining its structural integrity and a residual load bearing capacity after the seismic events. The *design seismic action* is expressed in terms of: a) the reference seismic action associated with a probability of exceedance of 10% in 50 years or a return period of 475 years, b) the importance factor γ_I to take into account reliability differentiation.

For the damage limitation requirement, the structure shall be designed to withstand seismic action having a larger probability of occurrence than the *design seismic action*, without damages or the limitations of the use of the structure. The seismic action to be taken into account for the damage limitation requirement has a probability of exceedance of 10% in 10 years or a return period of 95 years.

In order to satisfy the fundamental requirements of TCXDVN 375:2006, the ultimate limit states and the damage limit states shall be checked in the structural analysis against earthquake loading.

For buildings with height less than 40 m, the seismic base shear force F_b for each horizontal direction of the building shall be determined by the following equation:

$$F_b = S_d(T_1)\ .\ m\ .\ \lambda \qquad (1)$$

where:

$S_d(T_1)$ is the ordinate of the design spectrum (see formulae (2) to (5)) at the period T_1;

T_1 is the fundamental period of natural vibration of the building for lateral motion in the direction considered;

m is the total mass of the building above the foundation or above the top of a rigid basement;

$\lambda = 0.85$ (if $T_1 \leq 2\ T_C$ for building with more than two storeys) or $\lambda = 1.0$ (for other cases), value of T_C can be found in Table 1 depending on the ground type.

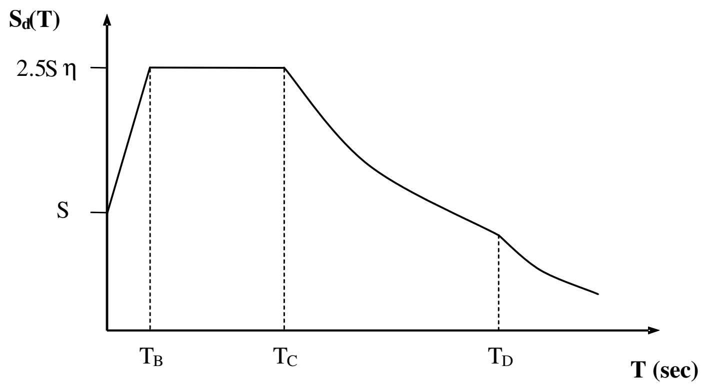

Figure 3. Design response spectrum (TCXDVN 375:2006)

The design spectrum $S_d(T)$ for the natural period T of the buildings (Fig. 3) can be determined by the following formula:

$$0 \le T \le T_B : S_d(T) = a_g.S.\left[\frac{2}{3} + \frac{T}{T_B}\left(\frac{2,5}{q} - \frac{2}{3}\right)\right] \quad (2)$$

$$T_B \le T \le T_C : S_d(T) = a_g.S.\frac{2,5}{q} \quad (3)$$

$$T_C \le T \le T_D : S_d(T) \begin{cases} = a_g.S \cdot \dfrac{2,5}{q} \cdot \dfrac{T_C}{T} \\ \ge \beta.a_g \end{cases} \quad (4)$$

$$T_D \le T : S_d(T) \begin{cases} = a_g.S \cdot \dfrac{2,5}{q} \cdot \dfrac{T_C.T_D}{T^2} \\ \ge \beta.a_g \end{cases} \quad (5)$$

in which:

$\beta = 0.2$ (is the lower bound factor for the horizontal design spectrum);

q - the behaviour factor taking into account for the non-linear response of the structure, associated with the material, the structural system and the design procedures;

a_g – the design peak ground acceleration (PGA),

- for the ultimate limit states, PGA is calculated by

$$a_g = a_{gR}\ \gamma_I \quad (6)$$

where:

a_{gR} is determined from Vietnam Seismic map attached to the code (see Fig. 4),

γ_I – the importance factor equal to 1.25, 1.0, 0.75 and 0.0 for building of class I, II, III and IV according to TCXDVN 375:2006. For very important structures that are not allowed to have damages during an earthquake, maximum ground acceleration possibly occurred at the site shall be taken for value of a_g.

- for the damage limitation states, value of PGA is taken by $0.585a_{gR}$.

S, T_B, T_C and T_D - determined from Table 1 below:

Table 1. Values of S, TB, TC and TD

Ground types	S	T_B (s)	T_C (s)	T_D (s)
A	1.00	0.15	0.4	2.0
B	1.20	0.15	0.5	2.0
C	1.15	0.20	0.6	2.0
D	1.35	0.20	0.8	2.0
E	1.40	0.15	0.5	2.0

Note: Ground types A, B, C, D & E, refer to Eurocode 8 or TCXDVN 375:2006.

Because of the lack of data to establish the spectral curves and formulation to determine the design spectrum $S_d(T)$, TCXDVN 375:2006 has adopted the elastic spectral curve type 1 in Eurocode 8 (Fig. 3) as most earthquake regions in Vietnam have a magnitude greater than 5.5 (Richter scale). The selection of the spectral curve type 1 is still in debate among researchers and engineers involved in seismic analysis and design.

4.2 *Vietnamese seismic map*

In TCXDVN 375:2006, seismic hazards are assessed based on the referenced peak ground acceleration a_{gR} on ground type A which could be determined from the seismic zone map attached to the code (Fig. 4) or provided by authorised government bodies. The seismic zone map in TCXDVN 375:2006 was the result of the long-term research project conducted by VIG. This map has been approved by the government authority at ministerial level. Ground type A (according to Eurocode 8 ground classification) is rock or other rock-like geological formation, including at most 5 m of weaker material at the surface, with the average shear wave velocity $v_{s,30}$ exceeding 800 (m/s).

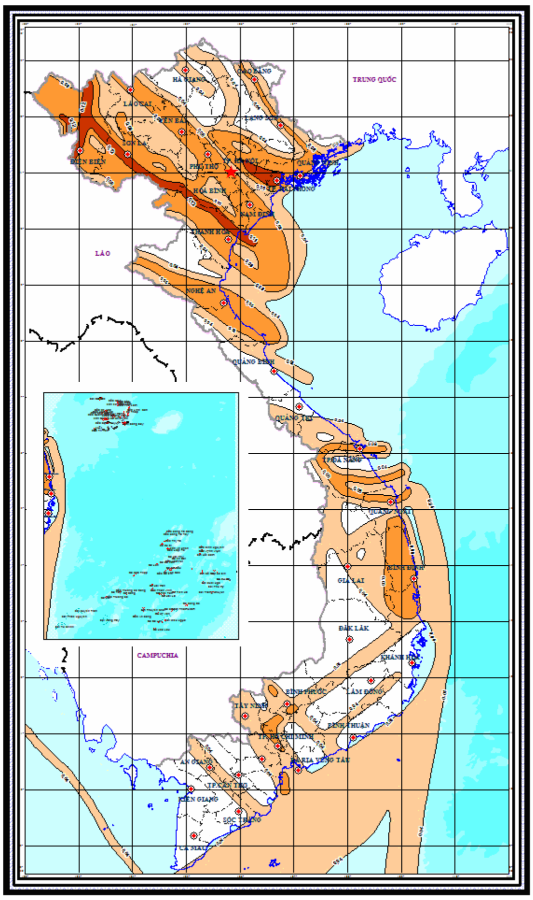

Figure 4. Ground acceleration zone map of Vietnam

4.3 *Comments*

Although TCXDVN 375:2006 is based on the advanced design principles of earthquake resistant construction, there are difficulties in the practical applications of this standard such as the selection of the behaviour factor *q* (because the values given in the code are only the upper values of *q*), the detailing must meet the ductility requirements related to the selected values of *q*, etc. Furthermore, the importance factors given in TCXDVN 375:2006 may possibly be more conservative considering living standards, technical and economical bases of Vietnam compared to those of the European Union. The construction cost may considerably be increased despite the fact that Vietnam is a country with low to medium seismicity. The challenge is also in the training of engineers and students in the use of TCXDVN 375:2006 . The concrete and steel design codes need also be updated following the Eurocodes 2 and 3 for consistency with TCXDVN 375:2006.

5 CASE STUDY - HANOI

As mentioned earlier, one of the main issues in the current code is the establishment of the local site factors and the seismic map for major cities in Vietnam due to the lack of historical records. In this research, a case study was carried out to determine the full range response spectra for seismic design of building structures in Hanoi.

Several major potential seismic sources capable of generating large magnitude earthquakes (magnitude 8) have been identified in the region surrounding Hanoi, within a radius of about 250km (Fig. 5). The response spectrum for rock sites in Hanoi was then modelled using the Component Attenuation Model (CAM) (Lam et al. 2000a, 2000b). The input for this model includes local seismological and geological information related to seismic activity levels and ground motion attenuation behaviour in the region surrounding Hanoi. Such information has been utilized within the framework of CAM to determine the response spectral attenuation functions.

Several representative boreholes in Hanoi have been obtained for soil resonance analyses based on the predicted bedrock motion from CAM. The well-known computer program SHAKE was used for the soil response analysis. Alternatively, a simplified soil amplification modelling, known as the Frame Analogy Soil Amplification (FASA) model (developed at the University of Melbourne,) was also applied. In this model, the response spectrum of the broad band bedrock excitation from CAM was scaled to obtain the response spectrum for the periodic ground motions transmitted to the soil surface.

5.1 *Seismic Source Modelling for Hanoi*

In this research, a seismic activity model for the potential earthquake sources in the region surrounding Hanoi was developed. In low to moderate seismic regions like Hanoi, which are generally free of distinct major active faults, source zones are often arbitrarily defined from broad geographical or seismological considerations, and are sometimes known as seismotectonic provinces within which earthquakes are assumed to occur at random (Reiter 1990, Yeats et al. 1997). A given site is usually located within one such large areal source zone, in which the level of uniform seismicity may be defined by the Gutenberg-Richter magnitude recurrence relationship as follows:

$$log_{10}N(M) = a_5 - b(M-5) \quad (7)$$

where a_5 is the logarithm to base 10 of the total number of earthquakes per 100 years (with $M_w = 5.0$) over an area of 100,000km^2, and the *b* value is proportion between large and small earthquakes.

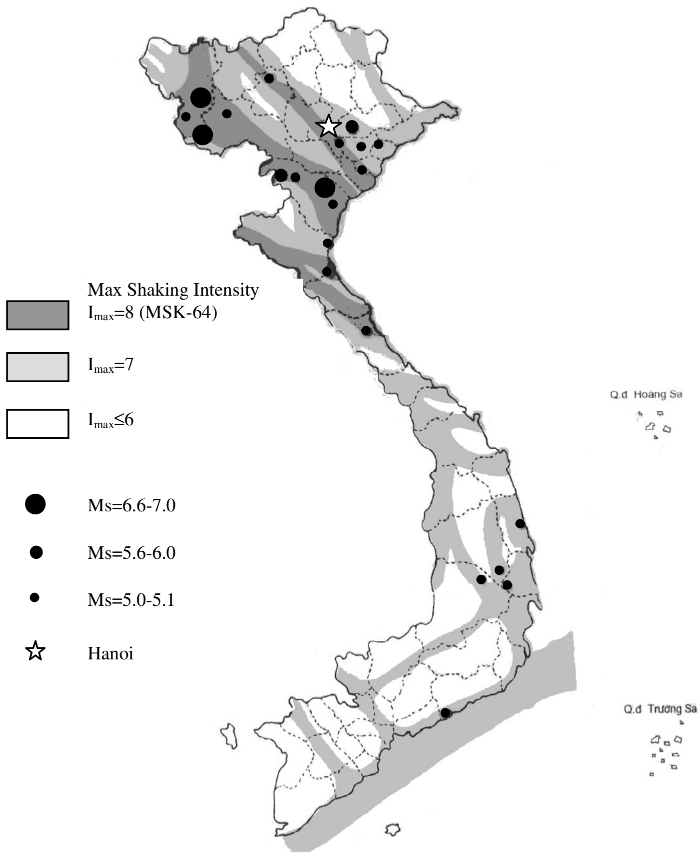

Figure 5. Ground acceleration zone map of Vietnam

Based on data collected from the VIG, two different seismic source zones have been modelled: 1) whole of Northern Vietnam (representing near field earthquakes); and 2) Northwestern part of Vietnam (Laichau-Dienbien fault, represents far field earthquakes). The seismic activity for these two zones are a_5 = 1.30 and 1.67, b = 0.836 and 0.814, respectively (Nguyen et al. 1996). Several Magnitude-Distance (M-R) combinations corresponding to the estimated seismic activity level and Return Periods have been identified for these two seismic source zones.

5.2 *Attenuation Relationship of Ground Motions in Hanoi*

The Component Attenuation Model (CAM) used in the seismic hazard analysis was developed by Lam *et al* (2000a,b) based on the stochastic simulations of the seismological model of Atkinson & Boore (1998). The seismological model was originally developed in the United States to define the average frequency contents of earthquake ground motion in both the Generic Hard Rock and the Generic Rock regions of Eastern North America (ENA) and Western North America (WNA), respectively. CAM effectively utilizes the seismological model to construct response spectra for direct engineering applications in different crustal conditions, and has made a useful contribution to seismic hazard studies in various regions outside North America, particularly in areas lacking local indigenous strong motion data. In this study, CAM has been applied to Hanoi where the crustal condition is, with respect to attenuation, similar to the generic hard rock condition of ENA.

CAM provides estimates for the maximum response spectral velocity Sv_{max} (highest point in the average velocity response spectrum) for a given earthquake magnitude (*M*) and site-source distance (*R*) in a generic rock crust as shown by Eq.8.

$$Sv_{max}\,(mm/sec) = 0.78(93.5)(0.35+0.65*(M-5)^{1.8})*G(R,D)*(30/R)^{0.005}*(1) \quad (8)$$

The first three terms represent the source effects whilst the fourth term, *G(R,D)*, is the geometrical attenuation factor which takes into account the effects of the crustal thickness (Atkinson & Boore 1998, Somerville 1999) where *R* is the source-site distance and *D* is the crustal thickness. For this study the crustal thickness has been assumed to be 30 km, as the maximum depth of Northern Vietnam earthquakes is about 20-30 km, and there is a higher velocity lower crust to a depth of about 35km. *G(R,D)* is defined by Eqn.9a – 9c.

$$G(R,D)= 30/R \quad for\ R<45km \quad (9a)$$
$$G(R,D)= 30/45 \quad for\ 75km<R<45km \quad (9b)$$
$$G(R,D)=(30/45)\sqrt{(75/R)} \quad for\ R>75km \quad (9c)$$

The fifth term, $(30/R)^{0.005}$, accounts for anelastic whole path attenuation (energy dissipation along the wave travel path). The last term represents mid-crust amplification and accounts for the wave modification effects of the upper crust and can be taken as 1 because of the generic hard rock condition (Atkinson & Silva 1997, Boore & Joyner 1997). It has been recommended that the peak ground velocity is of the order of half of the predicted $Sv_{max.}$ (Lam et al. 2000a, 2000b). Similar expressions for the prediction of the acceleration and displacement parameters have also been developed so that response spectra can be constructed over the entire period range of interest (Further details can be found in Lam *et al.* 2000a, 2000b).

Figs 7 - 9 show the results of the velocity response spectra for 200, 500, and 1000 year return periods predicted by the CAM model for Hanoi rock sites. It was shown that, for the 200 year return period, the far field earthquakes govern the design. In contrast, for earthquakes of 500 and 1000 year return period, near field earthquakes are more critical given that the maximum considered earthquake (MCE) is of M8.

5.3 *Soil Amplification*

Soil conditions in Hanoi consists of a broad deep basin filled with alluvial and deltaic sediments with occasional shallow sea sedimentation, forming alternate layers of sand, gravel and clay. The uppermost soil layer is a soft silty clay. The clay is about 10 to 20 m thick in the Hanoi metropolitan area. The clay is highly compressible and its shear strength is very low. The soft clay is underlain by a layer of stiff silty clay. The shear strength of the stiff clay is much greater than that of the soft clay, and the compressibility is much less. The deeper strata consist of alternate layers of sand deposits and sandy clay with high strength and low compressibility.

A generalized soil profile for Hanoi metropolitan area is selected for soil amplification analysis (Fig. 6). The method of one-dimensional site response analysis using the computer program SHAKE (Idriss & Sun, 1992) is adopted in this study. The method assumes that the main responses in a soil deposit are caused by the upward propagation of shear waves from the underlying rock formation. The method has been shown to give results in good agreement with field observations in many cases.

Results from SHAKE (Fig. 10, 11) clearly indicate that the soil profile underlying Hanoi has the ability to amplify earthquake ground motions about 4 to 7 times depending on the rock type (representing by the shear wave velocity) and the accelerogram of the bedrock motion. For a return period of 200-years, far field earthquakes tend to produce higher soil resonance effects compared to near field earthquakes. In contrast, for 500 and 1000-year return period, soil amplifications induced by the near field earthquakes are more critical for short period structures. It is noted that soil resonance effects on hard bedrock condition is much higher than on soft rock.

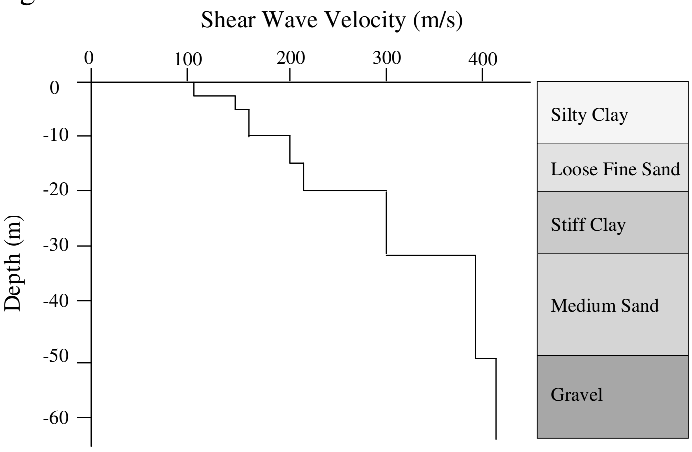

Figure 6. Generalized soil and shear wave velocity profiles in Hanoi Metropolitan Area

The peak ground acceleration (PGA) for 200 year return period is about 0.27g (Fig. 10). Based on these results, it is reasonable to predict that the maximum credible ground motion, if it occurred, would most likely cause severe damage or even complete collapse to structures with fundamental periods ranging from about 0.5 sec to 1 sec as well as to short-period structures that do not have sufficient lateral strength.

It should be noted that, input for SHAKE requires comprehensive information on dynamic soil properties like shear wave velocity, mass density, and relationships for variation of dynamic shear modulus and damping ratio as a function of strain. Thus, a simple, easy-to-use procedure is highly demanded, especially in Vietnam where practicing engineers are not familiar with concepts of seismic hazard assessment. A more direct procedure is presented in this study as an alternative approach for soil response analysis. The alternative approach, known as the Frame Analogy Soil Amplification (FASA) model is a scaling procedure which addresses soil resonance, particularly for the assessment of displacement demand since the soil surface displacement is highly dependent on the site natural period (T_g) (Lam et al. 2000). The FASA model has been developed to address these issues by scaling the response spectrum of the bedrock excitation to obtain the soil response spectrum based on a pre-determined site period. The theoretical basis of the procedure facilitates its application in low and moderate seismicity regions where only limited field data is available for verification and calibration. Early development of FASA was based on modelling accelerations. In contrast, this paper describes a revised, and a more effective, approach in which velocity and displacement (as opposed to acceleration) have been used as the basis for modelling.

FASA consists of three steps. Firstly, the peak ground velocity (PGV) and peak ground displacement (PGD) at the soil surface is predicted in accordance with the response spectral velocity of the bedrock motion. Secondly, soil damping and the associated damping factors are predicted in accordance with the soil deformation which is in turn related to the PGD. Finally, the response spectral velocity and displacement for structures founded on soil is determined in accordance with bedrock motions predicted for the Hanoi Metropolitan Area (see Fig. 8). The displacements predicted by FASA for structures with periods from 0.5 to 1 sec are ranging from 40mm to 70mm for 500 year return period.

6 CONCLUDING REMARKS

The new Vietnamese earthquake code is reviewed in this paper. It has been found that the lack of historical data and lack of information on the local site soil conditions has created difficulties in using the code for design or assessment of structures in Vietnam, especially major cities such as Hanoi. The seismic hazard assessment presented in this paper indicates that Hanoi is at risk of strong earthquake ground motions. The risk is essentially caused by the ability of regional seismic sources to generate large earthquakes, and the ability of thick unconsolidated surficial deposits in Hanoi to considerably amplify earthquake ground motions. The response spectra (soil/rock) obtained from CAM and FASA show that, for structures with periods greater than 0.5 sec, the far field earthquakes will govern the design. For shorter structural periods (<0.5 sec), the near field earthquakes must also be considered in seismic design.

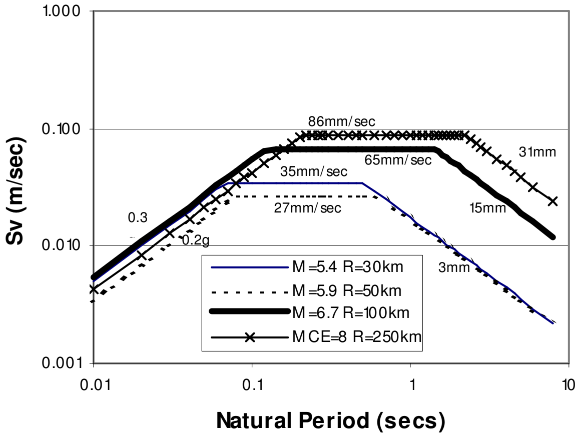

Figure 7. Velocity Response Spectrum (predicted by CAM) (200 year return period)

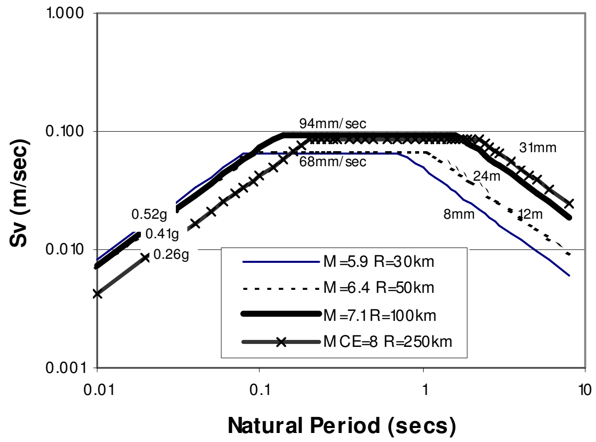

Figure 8. Velocity Response Spectrum (predicted by CAM) (500 year return period)

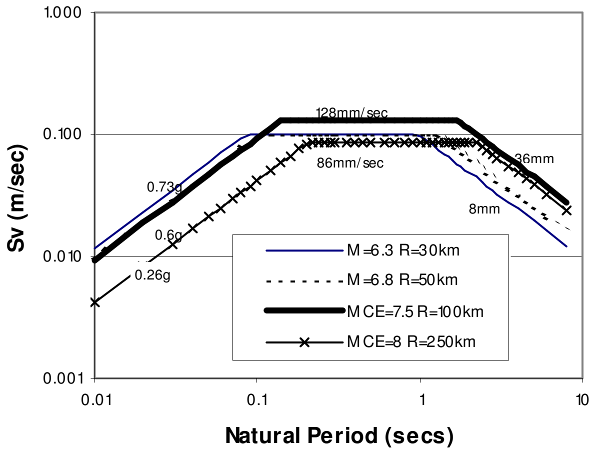

Figure 9. Velocity Response Spectrum (predicted by CAM) (1000 year return period)

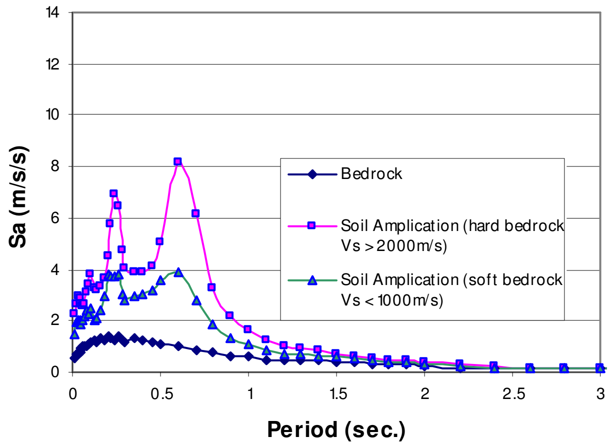

Fig. 10 - Acceleration Response Spectrum (200 year return period)

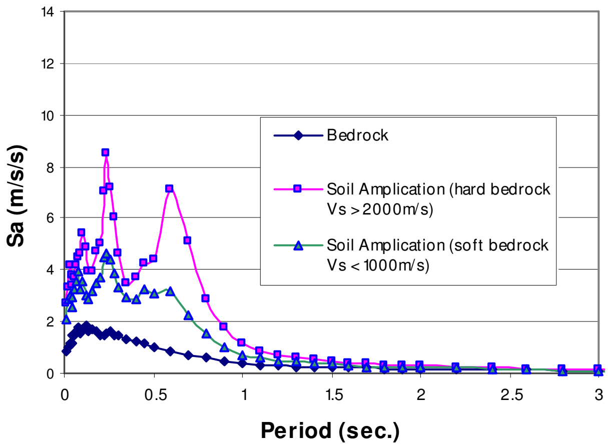

Figure 11. Acceleration Response Spectrum (500 year return period)

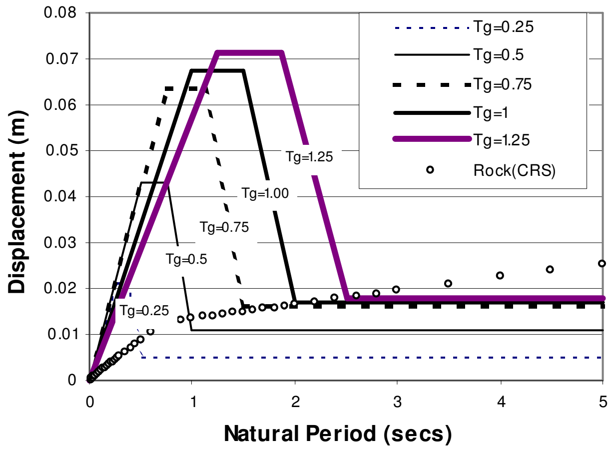

Figure 12. Soil Response Spectrum Model of FASA (a_5=1.3, b=0.836, 500 year return period)

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