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DEVELOPMENT OF SEISMIC DESIGN REQUIREMENTS FOR BUILDINGS IN BANGKOK AGAINST THE EFFECTS OF DISTANT LARGE EARTHQUAKES

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SUMMARY

Even though Bangkok is located at a remote distance from seismic sources, a recent seismic hazard study shows that Bangkok is still at risk from damaging ground motions induced by distant large earthquakes. The risk is primarily caused by the ability of thick soft surficial deposits in Bangkok to amplify earthquake ground motions about 3 to 4 times. Furthermore, by the near-periodic, long-period, and long-duration nature of the amplified ground motions, tall buildings with fundamental periods near the predominant period of ground motions are likely to be significantly affected due to the resonant amplification of building responses. Three research studies are currently being carried out with an aim to develop appropriate seismic design requirements for buildings in Bangkok against the effects of distant large earthquakes. The first study is a preliminary seismic microzonation of Bangkok and neighboring provinces. Ambient vibrations on the ground surface at more than 150 sites are measured and analyzed by the Nakamura's H/V method. The results show that the predominant period of ground motions varies from notably high values (1.0 s to 1.2 s) at sites near the gulf of Thailand to low values (around 0.4 s) at the boundary of the Bangkok basin. The second study is an ambient vibration survey of nearly 50 buildings with heights varying from 20 m to 210 m in order to identify their dynamic properties. Relationships between building natural periods and building height are obtained. The third study is an evaluation of inherent seismic capacity of several typical non-seismically designed buildings in Bangkok by pushover analysis. Parallel to the analysis work, several quasi-static cyclic loading tests of RC specimens are also conducted to gain more accurate knowledge on seismic performance of typical non-ductile RC columns, beam-column joints, and flat slab-column connections.

INTRODUCTION

Under some special conditions, earthquake disasters can occur at distances from the source (epicentral region) much greater than those usually assumed, say 150 to 200 km at the most. A well-known example is the 1985 Michoacan earthquake, where a large magnitude earthquake ($M_s = 8.1$) on the coastal Mexico caused considerable destruction and loss of life in Mexico City located 350 km from the epicentral location. Much of the destruction was due to significant amplification of earthquake ground motions by

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thick soft soil deposits in the downtown area of Mexico City. Therefore, urban areas located at rather remote distances from earthquake sources may have to be checked for their earthquake disaster potential.

Over the past few decades, rapid urbanization and a massive scale of building construction have taken place in Bangkok (Fig. 1). Since Bangkok has long been viewed as being free from seismic risk, most buildings and structures were designed and constructed without consideration on seismic loading. A recent preliminary paleoseismic investigation, however, indicates that there are several active faults located at about 120 to 300 km from the city (EGAT [1]). Although these active faults exhibit low levels of seismicity, it was estimated from their expected rupture dimensions that a large earthquake of magnitude 7.5 could be generated. Instrumental records of earthquakes in the Thailand-Burma-Indochina region over the past 90 years also show that several active seismic sources, capable of generating large magnitude earthquakes, are located at about 400 km to 1000 km from Bangkok (Fig. 2). Moreover, the surficial geologic setting at Bangkok appears qualitatively similar to the setting of Mexico City, and hence by analogy, Bangkok appears to be susceptible to the same type of soil amplification of ground motions.

Figure 1: Bangkok, the capital city of Thailand

SEISMIC HAZARD ASSESSMENT OF BANGKOK

As a first step toward a more comprehensive investigation on earthquake disaster potential in Bangkok, a probabilistic seismic hazard assessment (PSHA) of Bangkok was carried out by the author and his colleagues at AIT in 1999 (Warnitchai [2]). The scope of work includes the following tasks: (1) formulating models of seismic sources in the Thailand-Burma-Indochina region; (2) identifying attenuation models that can reasonably represent the regional attenuation characteristics of earthquake ground motions; (3) performing probabilistic integration of the individual influences of seismic sources into the probabilistic distribution of peak rock-outcrop acceleration in the Bangkok area by using the Cornell method; and (4) conducting one-dimensional seismic site response analyses for a typical soil profile of Bangkok to quantify the soil amplification of ground motions and to predict the motions at the ground surface in the Bangkok area.

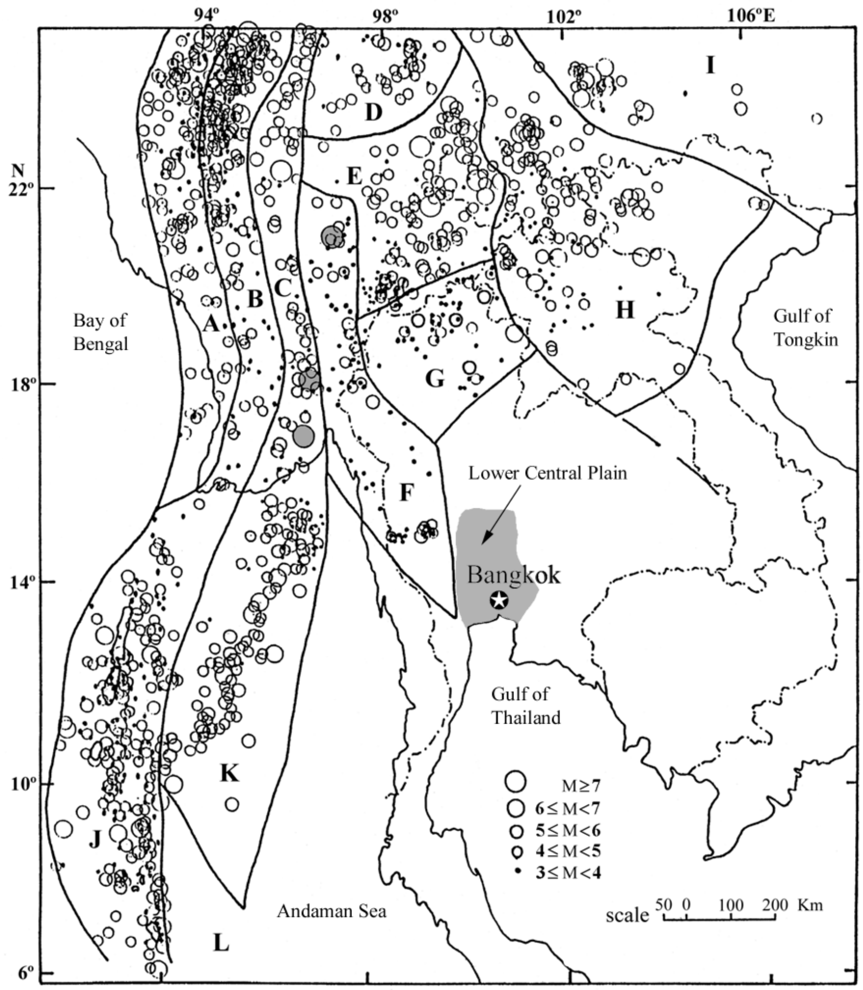

Figure 2: Regional seismic source zones (A-K) of the Thailand-Burma-Indochina region and recorded earthquakes during 1910 – 2000.

The site response analyses show that the surficial deposits in Bangkok have the ability to amplify earthquake ground motions about 3 to 4 times. The amplified ground motions can be described as narrowband random motions with a long predominant period of about 1 second. Owing to a further resonant amplification, buildings and structures with natural periods near 1 second are likely to be much more affected by this type of ground motions.

From the PHSA, the best-estimate elastic response spectra of ground motions for various levels of probability of exceedance (P_e) in a 50-yr exposure period are obtained and presented in Fig. 3. Every spectrum shows a relatively high spectral acceleration in a narrow range of periods centered at about 1 second. Since the predicted peak spectral accelerations in Bangkok for rare events (2% P_e) are comparable to those of the damaging ground motions in Mexico City during the 1985 event, the results then indicate the possibility of an earthquake disaster in Bangkok similar to that in Mexico City. A large number of buildings and structures, particularly those having fundamental periods close to 1 second, would be severely damaged or even collapsed in such rare events.

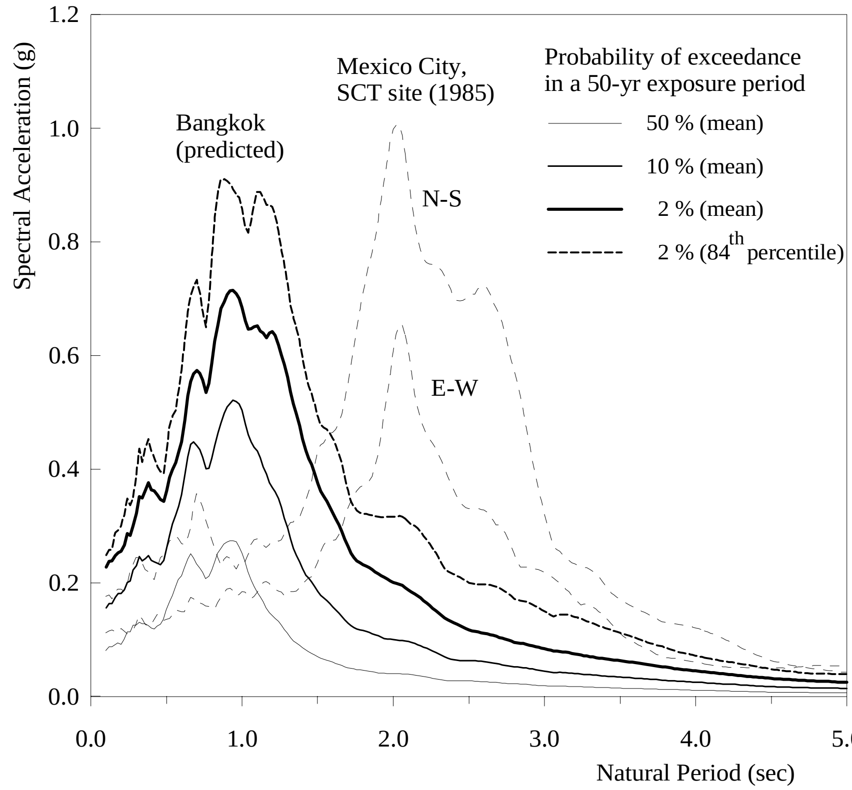

Figure 3: A comparison between the elastic response spectra of predicted earthquake ground motions in Bangkok and those of damaging ground motions in Mexico City during the 1985 event.

MITIGATION OF SEISMIC RISK

The most effective measures to mitigate seismic risk in any urban area are to introduce statutory seismic design requirements for new constructions and to retrofit existing structures that are vulnerable to expected earthquake ground motions. In Bangkok, the actual implementation of such measures appears to be rather difficult due to several reasons.

The first (and probably the most important) reason is that the general public, as well as engineers, are not aware of the potential earthquake disaster. This is quite understandable because throughout the two-century history of Bangkok a destructive earthquake has never happened so far. Thus, many are not willing to pay extra costs for seismic resistant design and construction of their buildings. Furthermore, seismic design is not included in standard civil engineering curriculum of Thai universities, and hence most design engineers are not familiar with seismic design concepts and design procedures.

The second reason is that the characteristics of earthquake ground motions in Bangkok are rather unique. Compared with damaging earthquake ground motions in other places, ground motions in Bangkok may be described as near periodic motions with relatively long period, long duration, large displacement, and low acceleration. The effects of such motions on buildings and structures are significantly different from those of other typical earthquake ground motions. Hence, it may not be justified to simply adopt seismic design requirements stipulated in codes and standards of other countries for the case of Bangkok. Instead, it is more rational to develop seismic design requirements that are fit to the specific conditions of Bangkok. The development will definitely require more accurate knowledge on seismic risk as described in the following sections.

MICROZONATION OF THE GREATER BANGKOK AREA

Bangkok is situated on a large basin filled with soil deposits. The average lengths from north to south and east to west of this basin are longer than 100 km. Within this large basin, the dynamic properties of soil deposits vary from place to place, and so do the soil amplification characteristics. It is therefore necessary to subdivide the basin area into zones with respect to geological characteristics of the sites, so that seismic hazards at different locations within this large basin can correctly be identified. This process is called "seismic microzonation".

The conventional means for determining the dynamic properties of soil deposits is the borehole method, which is costly, time consuming and generally not suitable for microzonation of a large area. The microtremor method, on the other hand, is much more attractive for this purpose. In this method, ambient vibrations in the order of microns present on the ground surface are first measured and recorded. The main sources of these microtremors are traffic and industrial activities. The predominant period of ground motions at the site is then determined from the ratio of horizontal to vertical Fourier spectra of the recorded microtremors. This spectral ratio technique was proposed by Dr. Yutaka Nakamura in 1989 (Nakamura [3]), and was recently confirmed to be reasonably accurate in identifying the site natural period (Rodriguez [4]). However, the site response spectral amplification ratio cannot be reliably determined by this technique.

Under the leadership of Prof. Fumio Yamazaki, microtremor measurements were carried out at more than 150 sites in the greater Bangkok area in the year 2002 (Tuladhar [5]). The results show that the predominant period varies from notably high values (around 1.0 s to 1.2 s) at sites near the gulf of Thailand to low values (around 0.4 s) at the boundary of the basin. The Bangkok metropolitan area has considerably long predominant period of around 0.8 s to 1.0 s. A microzonation map for the greater Bangkok area was then developed based on the results of microtremor analysis (Fig. 4).

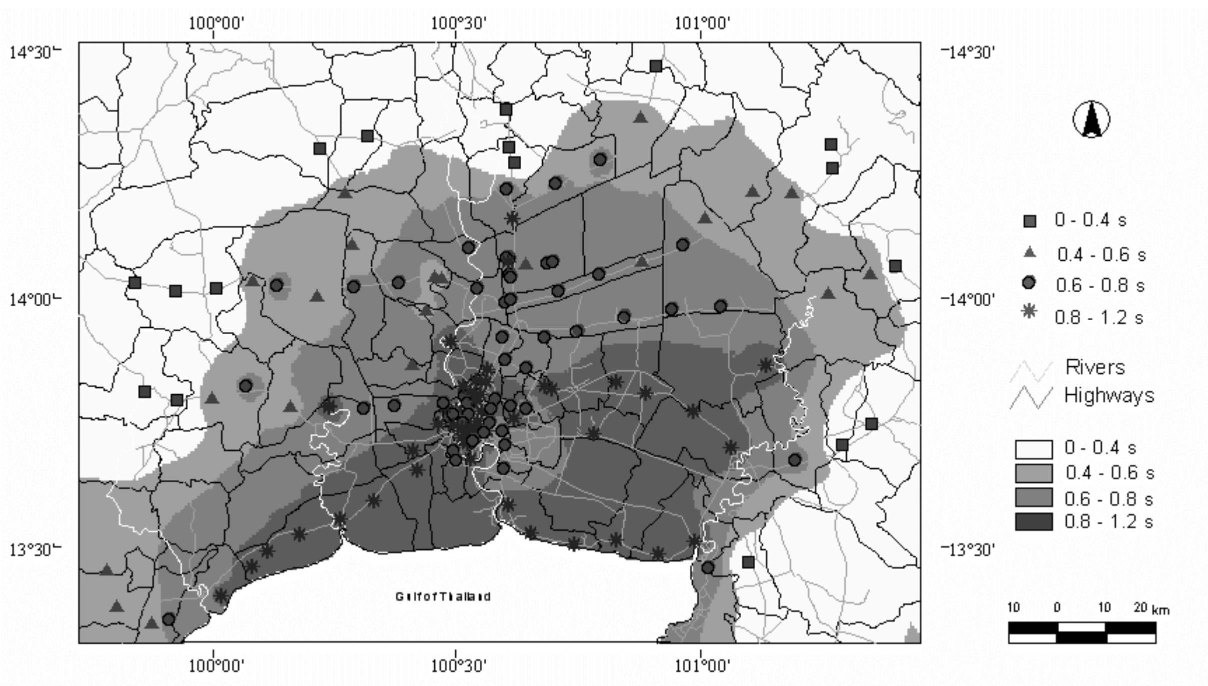

Figure 4: Microzonation of the greater Bangkok area on the basis of the variation of the predominant period of ground motions

An extension of the seismic microzonation work is presently conducted to identify the variation of site amplification factor and other important parameters for the seismic design of buildings and structures within the Bangkok basin. The work utilizes not only the microtremor analysis results but also an extensive database of basic soil properties and soil profiles in the area. Ten representative soil profiles have already been identified (Fig. 5). In the near future, one-dimensional seismic site response analyses will be carried out using these soil profiles.

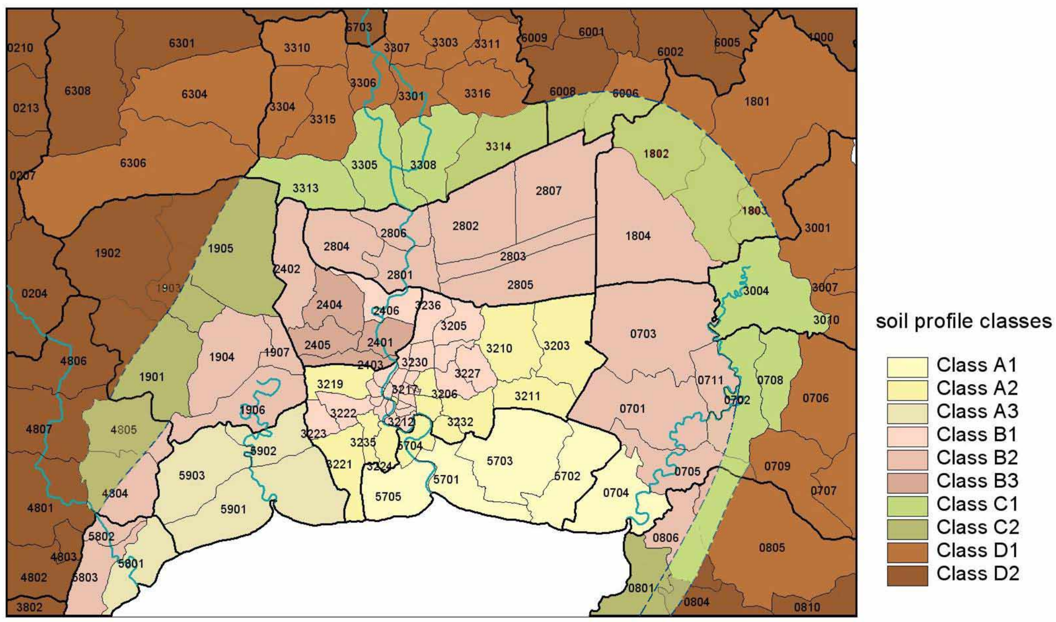

Figure 5: Classification of soil profiles for Seismic Microzonation

DYNAMIC PROPERTIES OF TALL BUILDINGS

As mentioned earlier, tall buildings with natural vibration periods near the predominant period of ground motions are likely to be significantly affected by ground motions due to the resonant amplification of building responses. In normal practice, the natural period of a building can be approximately estimated using simple empirical formulas recommended in building design codes. However, the code formulas in one country may be different from those of other countries due to the differences in the required level of design forces and the characteristics of building construction. So far, no reliable empirical formula is available for Bangkok. It is thus critical to acquire more accurate data on building natural periods in Bangkok and use them to develop reliable formulas for the case of Bangkok.

The author and his colleagues [6, 7] have, in the past three years, identified the dynamic properties of nearly 50 buildings in Bangkok with heights varying from 20 to 210 meters from their ambient vibrations. A frequency-domain identification method proposed by Dr. Trifunac in 1970 (Trifunac [8]) is adopted. A few modifications are made to this method in order to extract more detailed information on 3-D vibration mode shapes and to improve the accuracy of estimated damping values.

Figures 6 and 7 give some ideas about what can be derived from the obtained measurement results. Figure 6 shows relationships between the first and second mode periods (T_1, T_2) and building height (H). These relationships can be used in the development of Bangkok-specific empirical formulas for

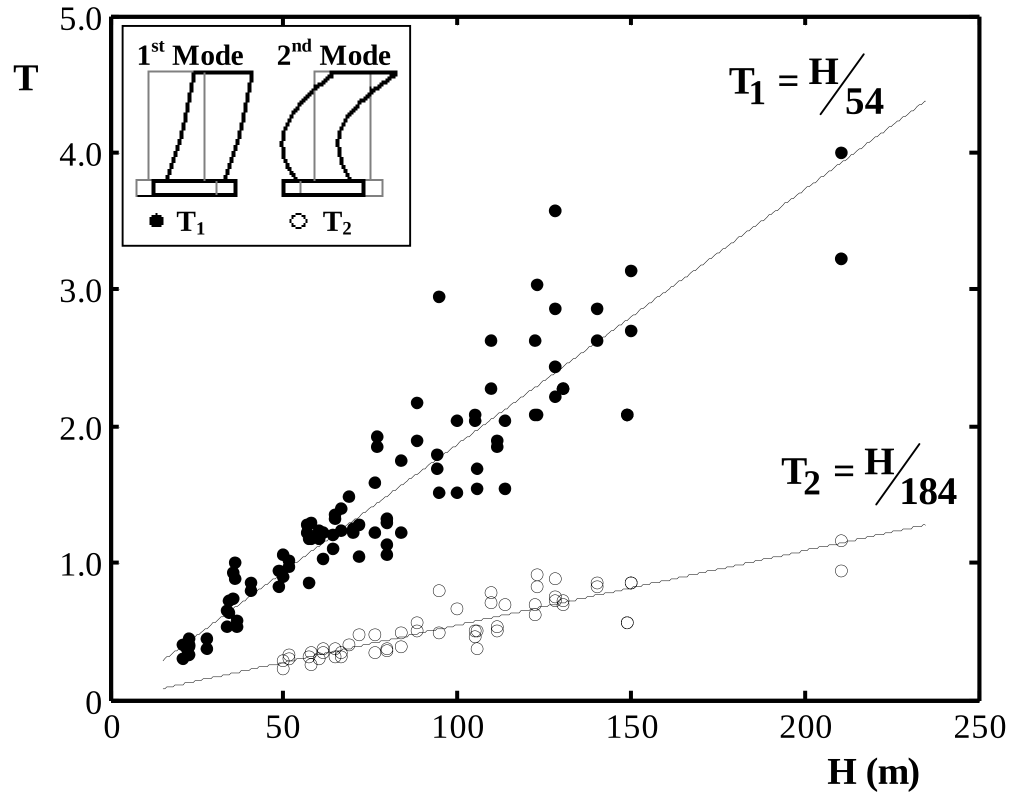

Figure 6: Relationships between the first and second mode periods and building height

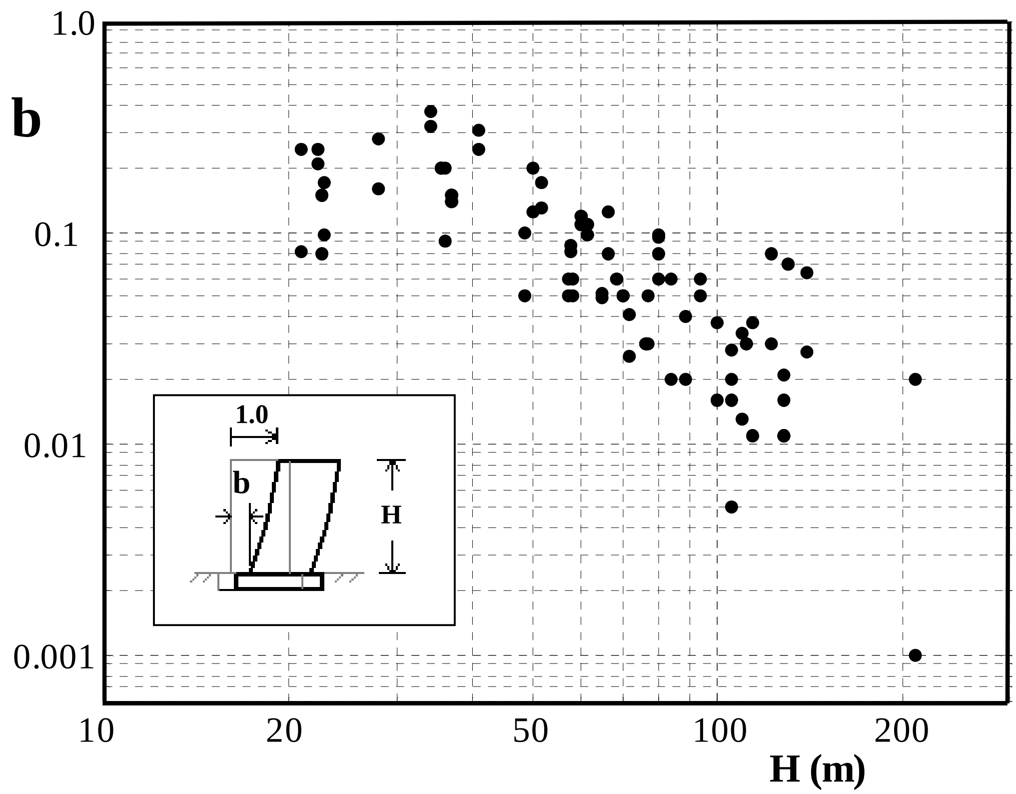

Figure 7: Normalized base movement of the first vibration mode

estimating building natural periods. These relationships also indicate that the resonant amplification of building responses is likely to occur in buildings with heights about 40 to 60 m (the first-mode resonance) and about 150 to 230 m (the second-mode resonance). Furthermore, as shown by Figure 7, the lower the building height, the higher normalized movement at the building base in the first mode. These results signify that soil-structure interaction is more pronounced in smaller buildings, and the interaction should be taken into account in the development of seismic design criteria for Bangkok.

SEISMIC PERFORMANCE OF NON-SEISMICALLY DESIGNED BUILDINGS

It is widely recognized that buildings and structures designed only for gravity loads and wind load (as in the case of Bangkok) may have nevertheless some inherent capacity to resist earthquake actions of some intensity. Therefore, in order to develop 'economic' seismic design requirements, the inherent seismic capacity of non-seismically designed buildings must be taken into account.

Our research strategy is to employ a comprehensive pushover analysis procedure to evaluate the seismic performance of several 'typical' buildings in Bangkok. By this way, we will be able to (1) investigate the inherent seismic capacity of buildings in various typical forms that are designed according to the local engineering practice; (2) identify typical weak spots, detailing deficiencies, and poorly performed structural configurations; and (3) find out economic and effective ways to improve the building design or to retrofit existing buildings. An example of pushover analysis results is shown in Fig. 8. Practical guidelines for seismic design of new buildings and for seismic retrofit of existing buildings in Bangkok will be developed in the future by combining the results from the seismic performance study with those from microzonation and building dynamic properties identification.

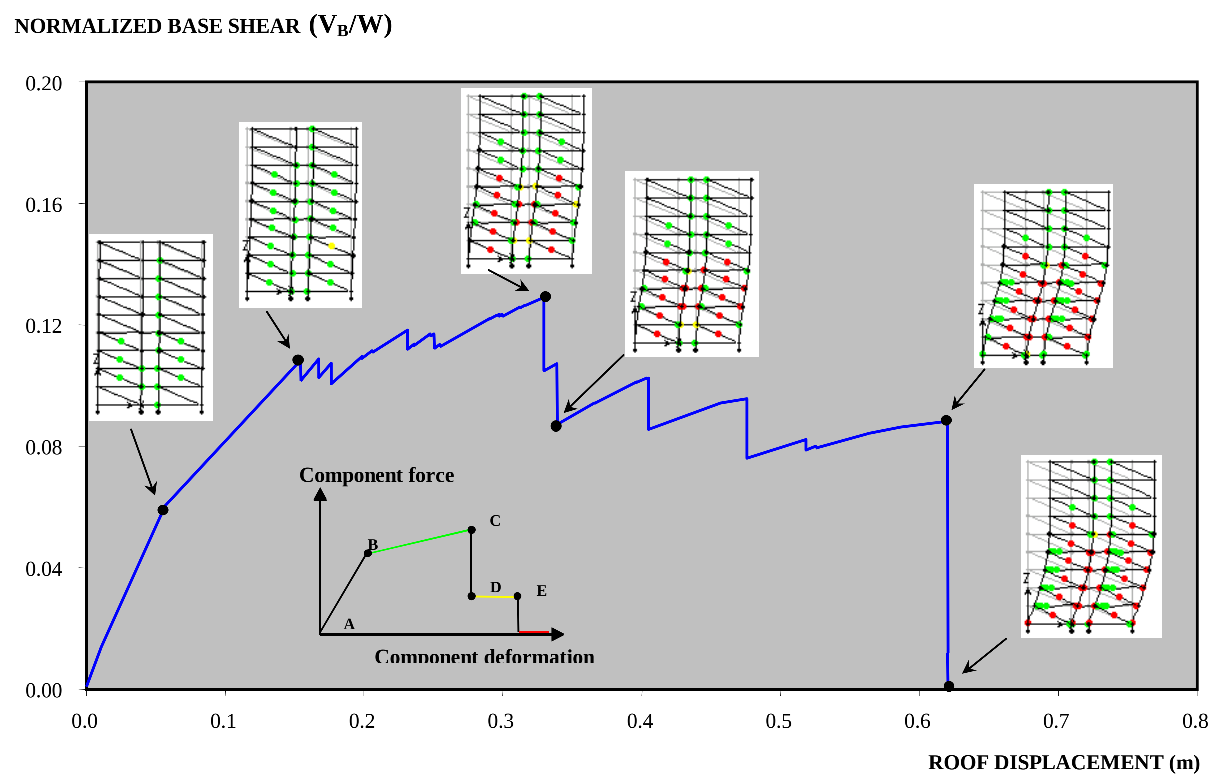

Figure 8: Capacity curve of a mid-rise RC frame building with infill walls and damage distribution patterns at various loading stages obtained from pushover analysis

This seismic performance study is still in the initial phase. Only a few buildings have been evaluated so far. Nevertheless, the initial results indicate the need to have a more accurate knowledge on the seismic performance of non-ductile RC columns, beam-column joints, and flat slab-column connections. Therefore, several quasi-static cyclic loading tests of RC components have been carried out since 2002. These components include seven column specimens with short lap splice of reinforcement bars at the column base (Worakanchana [9]), four beam-column subassemblages (Warnitchai [10]), and one interior post-tensioned flat slab-column connection (Fig. 9, and Pimanmas [11]). All these specimens were made following the engineering practice in Thailand. Many forms of brittle failure have been identified (Fig. 10, for example). In the near future, it is expected that first-hand information on critical components in typical RC buildings in Bangkok will be made available.

Figure 9: A cyclic loading test of a 3/5 scaled interior post-tensioned flat slab-column connection

CONCLUDING REMARKS

Several research studies are currently ongoing to acquire more accurate knowledge on the seismic risk of Bangkok. The results from these studies are critical ingredients for the development of Bangkok-specific seismic design criteria. The end in mind is essentially to promote the mitigation of seismic risk by reducing the vulnerability of buildings and structures to the effects of distant large earthquakes.

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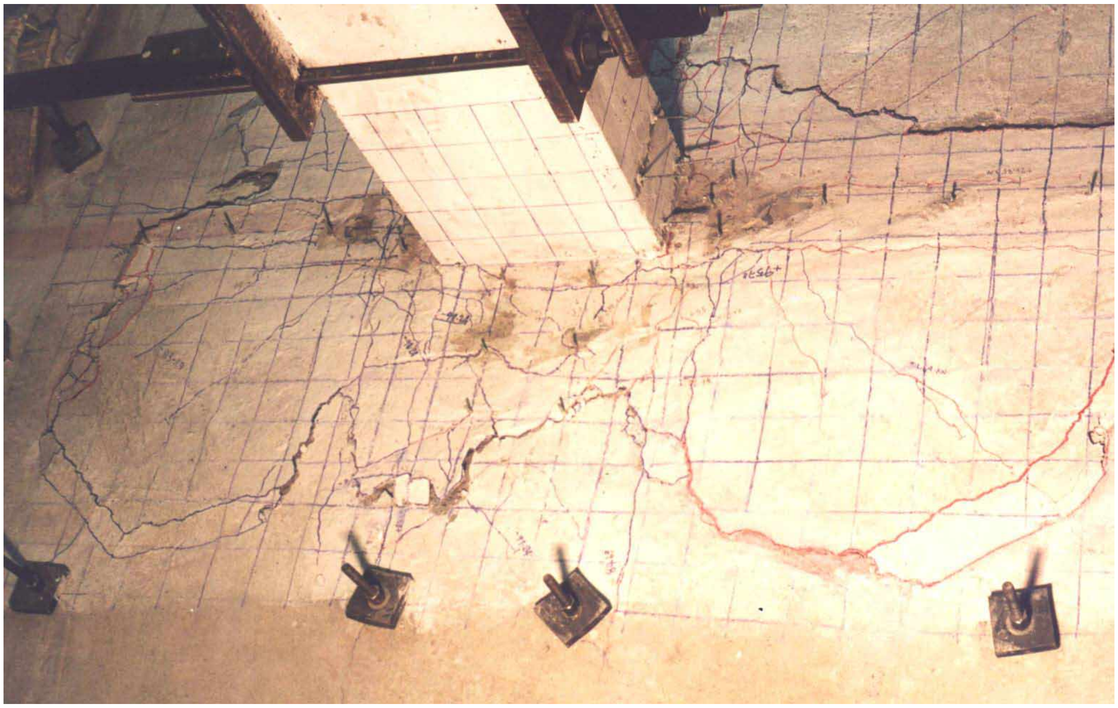

Figure 10: Punching shear failure at the slab-column connection

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