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

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ABSTRACT

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 40 buildings with heights varying from 20 m to 150 m in order to identify their dynamic properties. A Bangkok-specific empirical formula for estimating building period is proposed. The third study is an evaluation of inherent seismic capacity of several typical non-seismically designed buildings in Bangkok by pushover analysis. A special care is given to the modeling of non-ductile RC columns, beam-column joints, flat slab-column connections, and pile foundations. The results from all these three studies will be critical ingredients for the development of Bangkok-specific seismic design criteria in the near future.

1. INTRODUCTION

Under some special conditions, earthquake disasters can occur at distances from the source (epicentral region) much greater than those usually assumed, which are about 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, which is located at 350 km from the epicentral location. Much of the destruction was due to significant amplification of earthquake ground motions by 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. Bangkok, a mega city with an estimated population of nearly 10 million people, is a good case in this regard.

Over the past few decades, a rapid urbanization and a massive scale of building construction have taken place in Bangkok. Since Bangkok has long been considered by most people as being free from seismic risk, most buildings and structures were designed and constructed without any 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 Bangkok. 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. 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.

2. SEISMIC HAZARD ASSESSMENT OF BANGKOK

As a first step toward a more comprehensive investigation on the 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, 2000). 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.

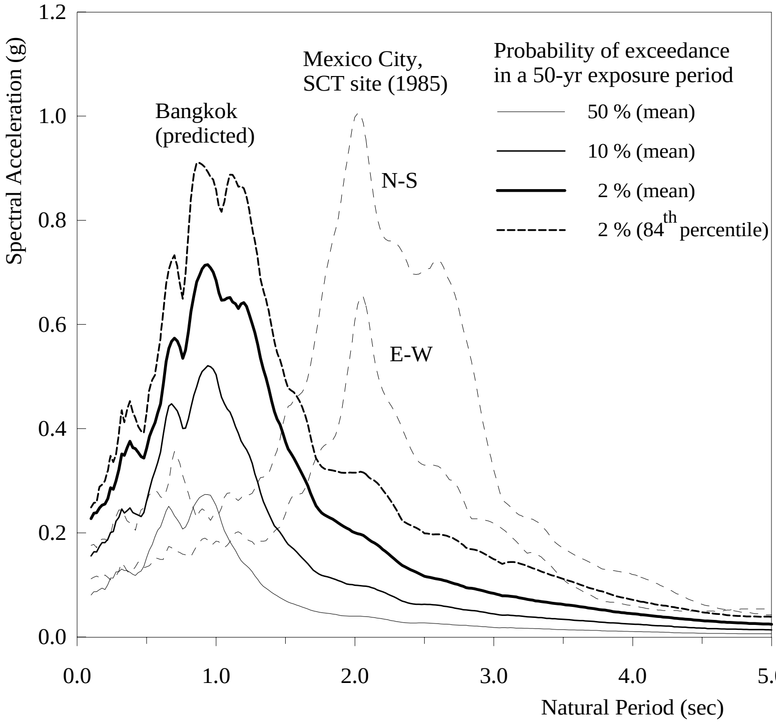

Figure 1: A comparison between the elastic response spectra of predicted earthquake ground motions in Bangkok and those of damaging ground motions in Mexico City during the 1985 event.

The site response analyses show that the surficial deposits in Bangkok have the ability to amplify earthquake ground motions about 3 to 4 times, and 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. 1. 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 some cases in such rare events.

3. MITIGATION OF SEISMIC RISK

It is generally understood that to mitigate seismic risk in any urban area, the most effective measures are: (1) to introduce statutory seismic design requirements for new constructions, and (2) to retrofit some important existing structures that are vulnerable to the expected earthquake ground motions in that area. In the case of 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. By this reason, most people are not willing to pay extra costs for seismic resistant design and construction of their buildings. Seismic design is also not included in standard civil engineering curriculum in Thai universities, and hence most design engineers are not familiar with concepts and design procedures in seismic design.

The second reason is that the characteristics of earthquake ground motions in Bangkok are rather unique. Compared to other damaging earthquake ground motions elsewhere, the 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 the 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 specific conditions in Bangkok. The development will definitely require more accurate knowledge about the seismic risk as described in the following sections.

4. 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 may 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 the 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, 1989), and it was found to be reasonably accurate and practical in identifying the site natural period. 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 in the year 2002 (Tuladhar, 2003). 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 very 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 was then developed based on the results of microtremor analysis (Fig. 2). An extension of this work to identify the variation of site amplification factor will be made in the future.

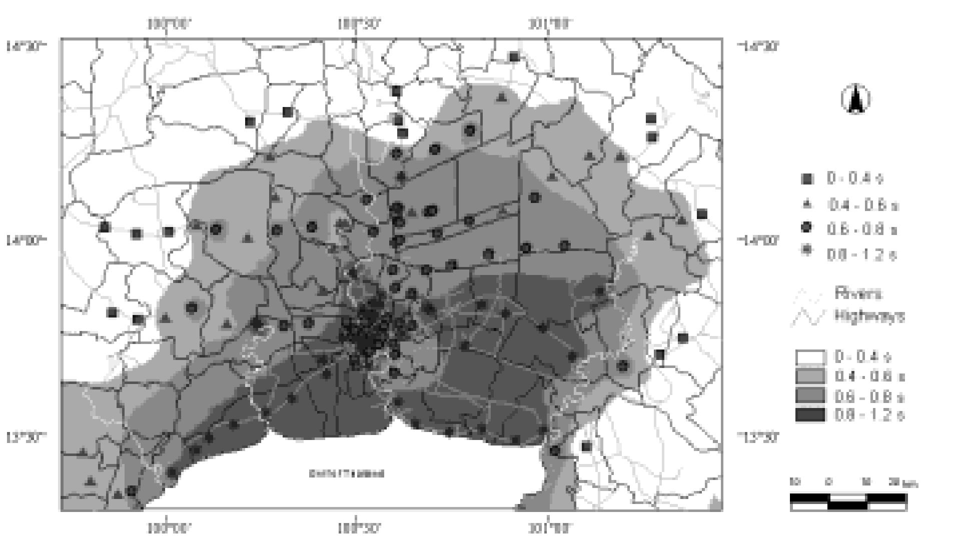

Figure 2: Microzonation of the greater Bangkok area on the basis of the variation of the predominant period of ground motions

5. IDENTIFICATION OF DYNAMIC PROPERTIES OF TALL BUILDINGS

As mentioned earlier, tall buildings with fundamental vibration periods near the predominant period of ground motions are likely to be much more affected by the ground motions due to the resonant amplification of building responses. In normal practice, the fundamental period of a building can be approximately estimated by 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 their differences in the required level of design forces and the characteristics of building construction. Moreover, no reliable empirical formula is available so far for the case of Bangkok. It is therefore necessary to acquire more accurate data on building fundamental periods in Bangkok and use them to develop reliable formulas for this case.

During the past three years, the dynamic properties of nearly 40 buildings in Bangkok with heights varying from 20 m to 150 m have been identified from their ambient vibrations by the author and his students. A frequency-domain identification method proposed by Dr. Trifunac in 1970 (Trifunac, 1970) is adopted. A few modifications are also 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. The results are presented in Fig. 3. They will be used in the development of Bangkok-specific empirical formulas for estimating building fundamental period in the near future.

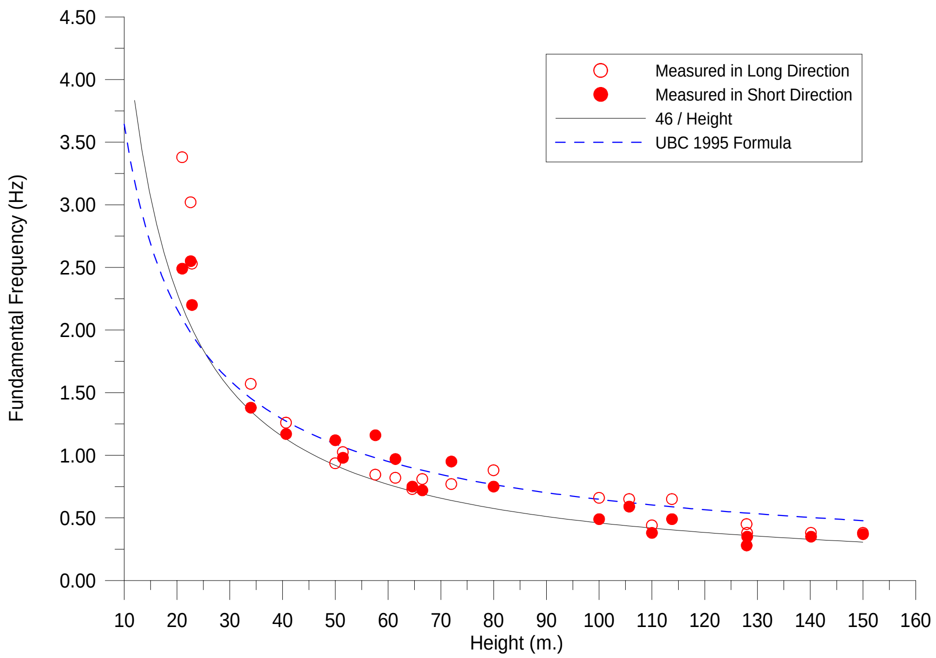

Figure 3: A comparison of building fundamental frequencies from measurement and empirical formulas

6. EVALUATION OF SEISMIC PERFORMANCE OF NON-SEISMICALLY DESIGNED BUILDINGS

It has been 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 for buildings in Bangkok, the inherent seismic capacity of non-seismically designed buildings must be taken into account.

Our research strategy is to first develop an analysis procedure that can provide realistic and accurate estimate of seismic performance of non-seismically designed buildings. We will then apply this 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. Combining the results from seismic performance study with those from microzonation and building dynamic properties identification works, we will be able to develop practical guidelines for seismic design of new buildings and for seismic retrofit of existing buildings in Bangkok in the future.

This seismic performance study is still in the beginning phase. Only a few buildings have been evaluated so far. Nevertheless, the initial results indicate the need to have 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 column specimens with short lap splice of reinforcement bars at the column base have been carried out since last year (Worakanchana, 2002). These specimens were made according to the engineering practice in Thailand. Many forms of brittle failure modes have been identified. At the moment, we are conducting cyclic loading tests on interior post-tensioned flat slab-column connections (Fig. 4) and interior beam-column connections. In the near future, we will have more first-hand information about these critical components in typical RC buildings in Bangkok.

Figure 4: A cyclic loading test of an interior post-tensioned flat slab-column connection

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