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GEOTECHNICAL HAZARDS IN BANGKOK - PRESENT AND FUTURE

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ABSTRACT: Geotechnical hazards in Bangkok, the capital of Thailand, are cited with reference to floods, land subsidence and earthquakes, bearing the characteristic subsoil conditions in mind. First, geotechnical engineering works concerning the implementation of flood protection schemes are briefly outlined. Second, the cause of land subsidence, i.e., the drawdown of pore pressures in clay layer induced by water pumping in the aquifer, together with the current situations are described by showing the results of geotechnical site investigation performed recently. Finally, a risk of seismic hazard in Bangkok is roused by referring to a statement that “the surficial geologic setting at Bangkok is similar to the setting of Mexico City, and hence Bangkok, by analogy, appears to be susceptible to the same type of soil amplification of ground motions (Warnitchai et al. 2000)”.

Key words: Bangkok, hazard, soft soil

GEOLOGY AND GROUND CONDITIONS IN BANGKOK

Geology

Subsoil in the Bangkok (BKK) area consists of Quaternary deposits, which originated from the sedimentation at the delta of the ancient river in the Chao Phraya. The other soil deposits are marine deposits, which are the result of changes in sea levels during the Quaternary period. Bangkok is situated on the central part of the Chao Phraya plain, which is about 20 km north of the Gulf of Thailand (Fig. 1). It is bordered on the west by the Tanowsri Mountain range and on the East by the Horat Plateau. The major drainage system of the plain is the Chao Phraya River and its tributaries from the surrounding highlands. The terrestrial elevation is about 0 to 5 m above the mean sea level. The Chao Phraya basin filled with sedimentary soil deposits, which form alternative layers of sand, gravel and clay. The marine clay is the uppermost clay layer, and it is generally found in the lower deltaic area of Bangkok plain, which extends from 200 to 250 km in the East-West direction and 250 to 300 km in the North-South direction. Formation of the uppermost layer, known as Bangkok clay, is believed to be approximately 4000 years ago.

As shown in Fig. 2, this plain consists of a deep geological basin, which is mainly filled with alluvial, deltaic and shallow marine sediments. Such deposits, which are confined within the radius of 60 to 80 km from BKK, had taken place during the Pleistocene and Holocene period. The exact profile of the bedrock is still unknown but it’s

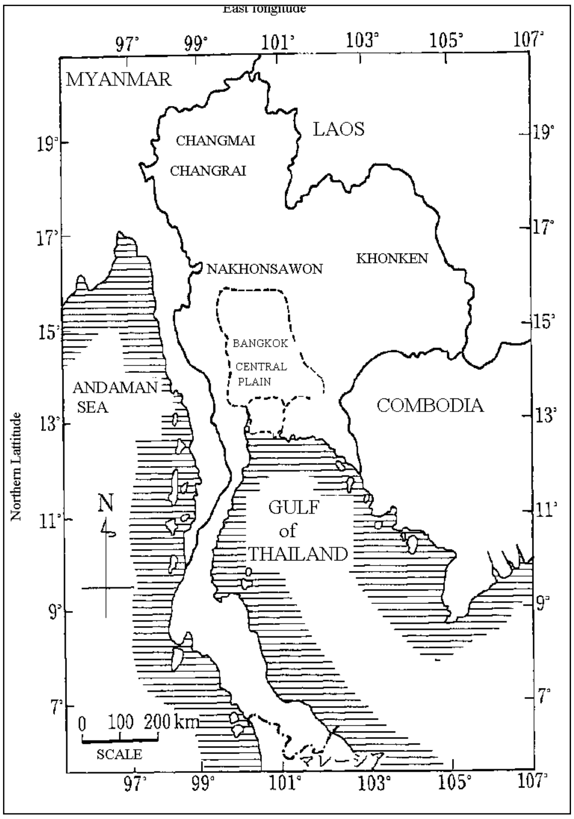

Fig. 1 Lower central plain in Bangkok

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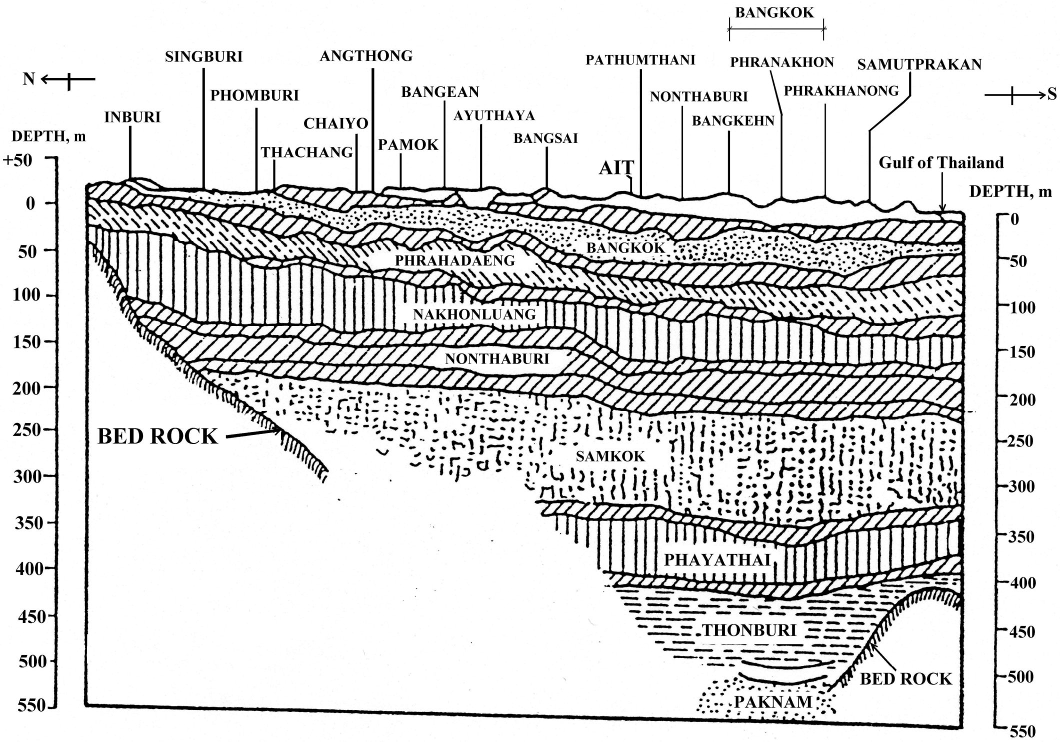

Fig. 2 Geological map of Bangkok area

level in the BKK area is known to vary over the range of 550 to 2000 m. A Bedrock profile was generated by fault block tectonics during the Tertiary period. As described in detail later on, a fault zone is known to trend North-South following the line of the Chao Phraya River with its upthrow on the east (BKK) side forming the Bang Poo Horst and Saladaeng Graben on the west (Rau and Nutalaya 1981).

The BKK subsoil is relatively uniform throughout the entire metropolitan. It consists of marine and terrestrial deposits. Terrestrial deposits start from the elevation of zero meter to about 4 to 5 m above the mean sea level while the other soil layers are marine deposits induced as the result of changes in sea levels during the Quaternary period. In the upper 550 m deposits, there are eight principal aquifers which consist of sand and gravel with clay inclusions separated by relatively impermeable clay layers laid down during the Pleistocene period (AIT 1981; Rau and Nutalaya 1981). These clay layers may be discontinuous and it is found that these aquifers are interconnected. The soft clay layer, which covers the aquifers, was deposited during the Holocene period. The top two aquifers of 550 m thick sediments are known as Bangkok soft clay (0 to 15 m) and Bangkok aquifer (15 to 70 m). A typical soil profile of the top 70 m sediment is presented in Table 1 (after Sambhandharakasa and Pitupakonr 1985).

Ground Conditions

The top 70 m thick soil layer (see Fig. 2) is of major concern for geotechnical engineers working in Bangkok. It can be broadly divided into four layers:

a) Crust: The crust is hard and dark gray in color. The weathered crust showing the shear strength of about 40 kPa

Table 1 A typical soil profile in the Bangkok area (after Sambhandharakasa and Ptupakonr 1985)

Depth (m)	Strata
0 to 14	Bangkok Soft Clay-dark grey highly compressible soft clay with 2m weathered zone forming a hard crust
14 to 25	First Stiff Clay-light grey and brown fissured stiff clay
25 to 40	First Sand layer-dense alluvial non-uniform sand, occasionally interbedded with stiff clay. Classified in parts as clayey sand
40 to 44	Second Stiff Clay-light grey and brown, stiff often fissured silty clay
44 to >70	Second Sand layer-clean light grey silty sand

Table 2 Natural disasters affecting Thailand (after Vasanasomwithi 2002)

Type of disaster	Frequency of occurrence	Rate of risk	Risk area
Floods	high	high	entire country especially the northern, central and southern region
Typhoon and storm surges	low	moderate	southern region
Strong wind	high	low	entire country
Droughts	high	moderate	entire country especially the north-eastern and northern region
Earthquakes	low	moderate	northern region
Landslides	low	moderate	southern region
Forest fire	low	moderate	northern region

on average varies considerably from 1 to 3 m in thickness. It is resulted due to weathering and desiccation processes. The weathering process includes such features as fluctuation of ground water level, leaching, ion exchange and precipitation of cementious materials due to drying and wetting during dry and wet seasons.

b) Soft clay: The results of the geotechnical site investigation performed in conjunction of the project for the construction of Outer Bangkok Ring Road (OBRR) (refer to Fig. 3) are shown in Figs. 4 and 5. The thickness of soft clay layer varies from 12 to 17 m, from the north to the south, by showing the value of about 14 m in central Bangkok. This layer covers an area of about 14,000 km^2, implying that the entire metropolitan is underlained by this soft clay. This layer is highly compressible with the over-consolidation ratio *OCR* of 1.0 to 1.5. The *OCR* value in excess of unity is simply due to aging, since this layer has never been subjected to greater effective overburden pressures than the pressures at present. Its general properties are; natural water content, w_n=60 to 100%, liquid limit, w_L=50 to 100%; plasticity index, I_P=30 to 80 and the undrained shear strength, s_u=10 to 25 kPa.

c) Stiff clay: A distinct unconformity exists between the base of the soft clay and the underlying first stiff clay layer. It is also hard in nature and the stiffness of this layer is seemingly due to desiccation and to some extent due to erosion (AIT 1981). In many places, it is mottled, fissured, with red and yellow colors indicating that it was exposed to

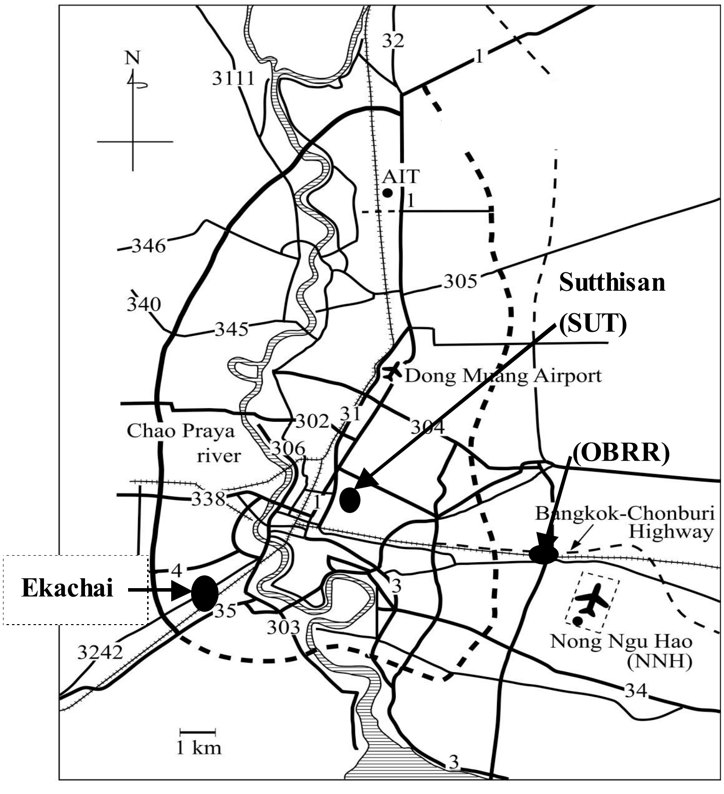

Fig. 3 A map of Bangkok metropolitan

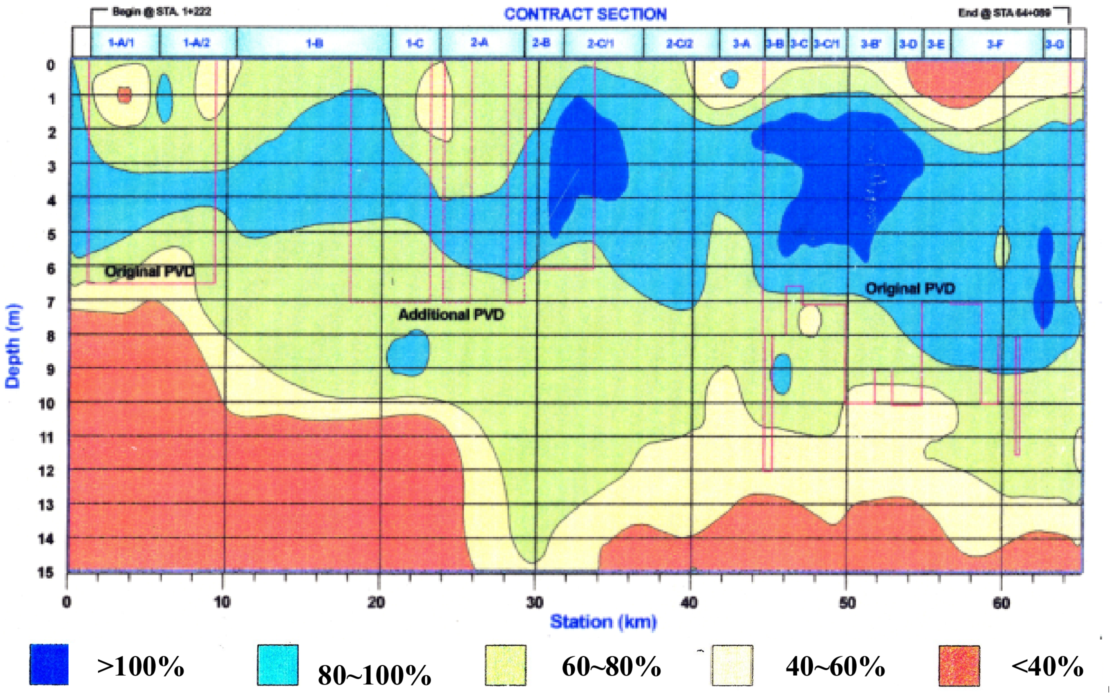

Fig. 4 Natural water content in soft clay along outer Bangkok ring road (OBRR)

sub-aerial processes of desiccation and chemical weathering before burial by the soft clay (Moh et al. 1969). Sub-aerial processes take place in the zone below ground level and above the groundwater table. There is also evidence that the first stiff clay has been eroded in places prior to deposition of soft clay. Thickness of the first stiff clay varies between 7 to 14 m in central Bangkok. Low compressibility, high *OCR* and low w_n as compared to soft clay are some of its properties. This layer is light gray and yellow-brown in color. The shear strength tends to increase with depth, having the strength of about 100 kPa on average.

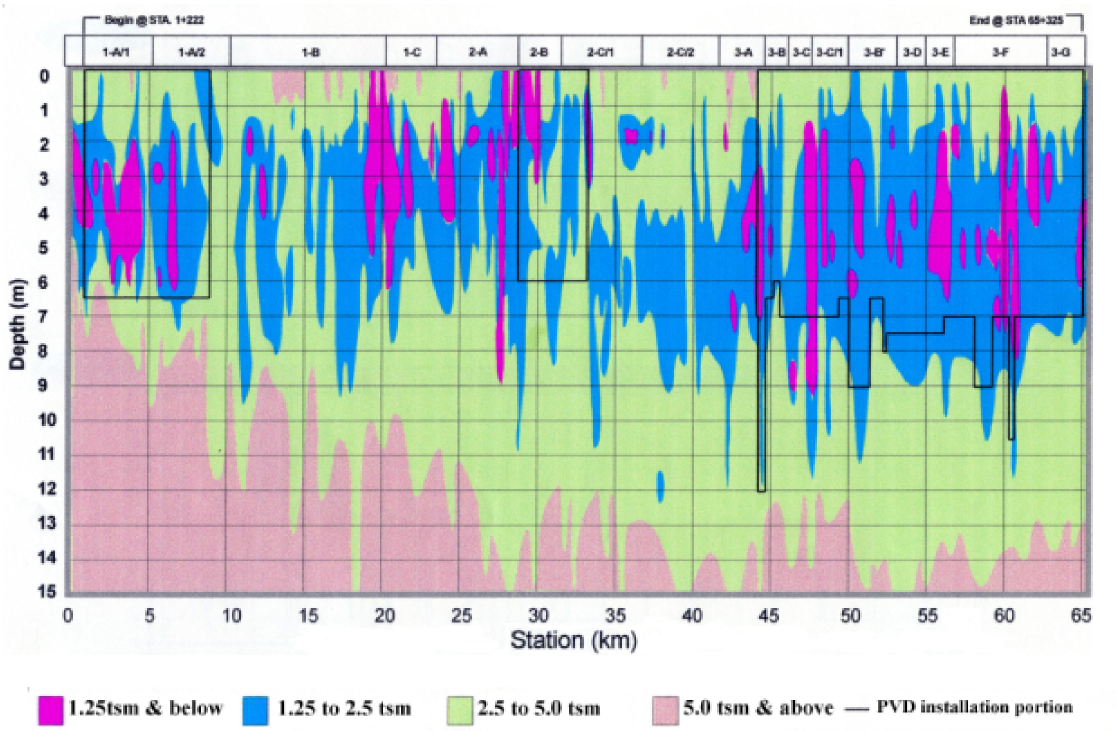

Fig. 5 Field vane shear strength in soft clay along the Outer Bangkok Ring Road (OBRR)

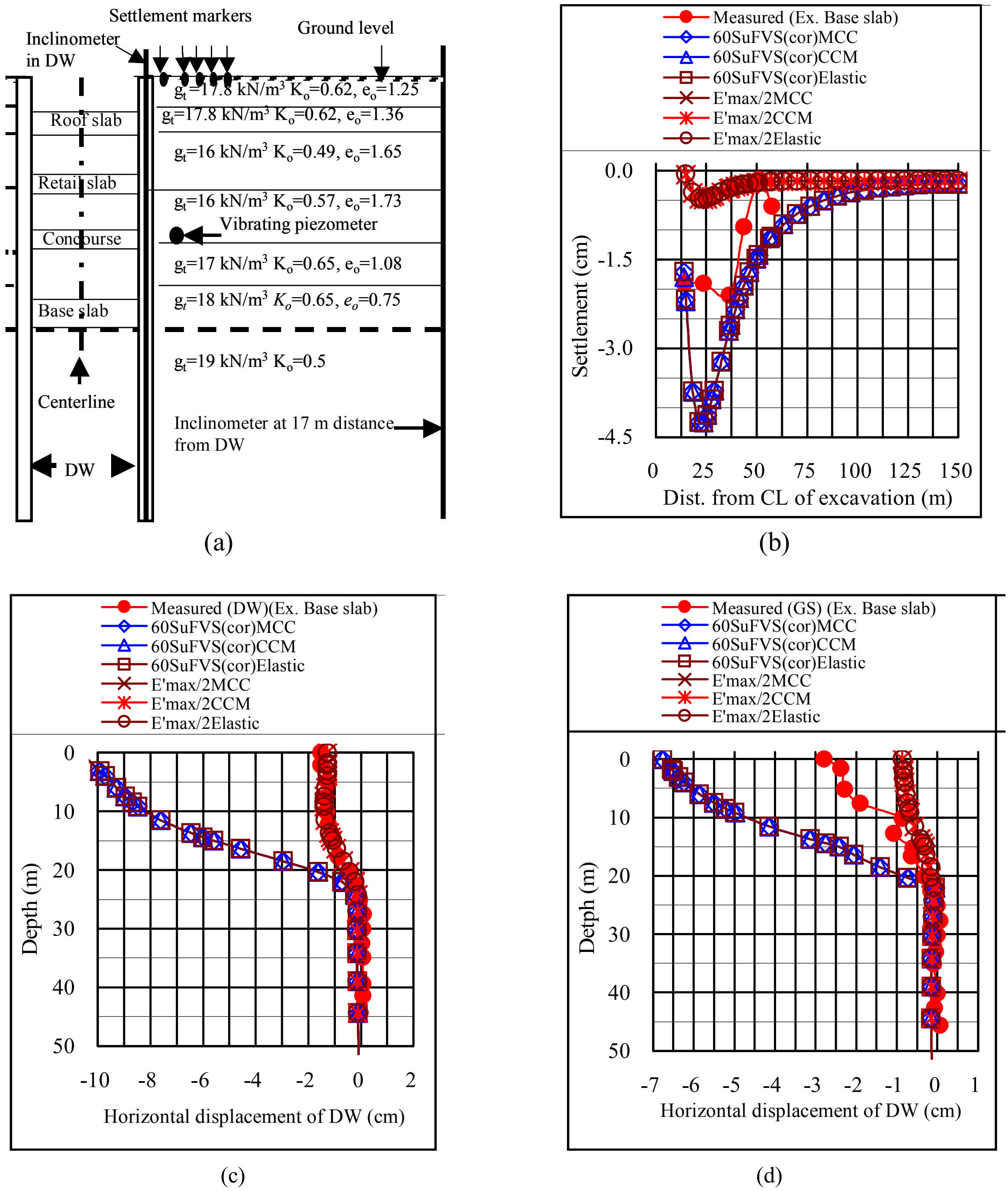

Fig. 6 Prediction of ground movement in deep excavation using diaphragm walls (Tamrakar et al. 2001)

d) Sand (aquifer): The sand layers of the Bangkok Aquifer System start below the first stiff clay layer and extend up to 70 m below the ground level (Rau and Nutalaya, 1981). This part of the formation is broadly divided into three parts namely; i) upper sand, ii) stiff clay and iii) lower sand. The upper sand layer has a medium to high density with 10 to 15 m thick. It is classified as silty sand (SM). The SPT blow count in the upper sand layer is about 30 blows/ft whereas the SPT value in the lower sand layer is more than 50 blows/ft.

FLOODS

Thailand is relatively less prone to natural disasters as compared to the situations of several other countries in the region of South East Asia. Table 2 shows natural disasters affecting Thailand (Vasanasomwithi 2002). As mentioned in the previous section, the geological conditions surrounding BKK; i.e., a low land plain covered by a wide spread soft clay having a low permeability, inevitably brings about a high frequency of occurrence of floods every

Table 3 Flood situation in Thailand during 1996-2000 (after Vasanasomwithi, 2002)

Year	No. of affected provinces	No. of deaths	No. of injuries	Loss (million baht)
1996	74	158	21	7160.68
1997	64	98	427	3842.22
1998	65	8	3	1706.03
1999	69	53	—	1381.64
2000	NA	120	—	1032.93

year. Table 3 summarizes the flood situation in all of Thailand during the period between 1996 and 2000. While the number of casualties due to flash floods in the provinces exceeded 100 in 1996 and was close to 100 in the following year. Bangkok suffered no casualties but severe economic loss caused by inundation.

Bangkok Metropolitan Administration (BMA) has positively implemented many flood protection schemes as part of the natural disaster prevention plan. Bangkok Metropolitan Flood Control Center, for example, runs remote stations by which real-time data such as water level in the canal, water level in the Chao Phraya River, rainfall, pump status and water quality, and quantity for flood protection are collected automatically for instantaneous decision making.

Since BKK is a flat and lowland area, the Polder System is used as flood protection. To supplement the Polder system, some areas are allocated for use as retention basins. These retention basins called "Monkey Cheeks" detain water from flooding the lowland areas, roads and streets and release it when the water level has returned to normal. Several Monkey Cheeks have been constructed to detain a large amount of water from the canals. At present the quantity of water these Monkey Cheeks can retain amounts to seven million cubic meters. The BMA has a plan to accelerate the allocation of retention basins to sufficiently detain floodwaters.

Construction of the retention basins often involves excavation work made by using concrete diaphragm walls pre-installed through the soft clay. In predicting the deformation behaviour of the surrounding soft clay ground prior to the construction work, the use of a reduced value of elastic stiffness from in-situ seismic survey has been recommended in performing the elastic FE analysis (Tamrakar et al. 2001). An example for the construction of Bangkok Metro is shown in Fig. 6.

LAND SUBSIDENCE

Ground Water Conditions

The piezometer profile identified for Bangkok is hydrostatic from 1~2 m below the ground surface to a depth of about 7~10 m. But, beyond this depth, owing to water pumping from the aquifer underneath the clay, non-hydrostatic distribution can be seen, which in turn exhibits underdrainage effectively within the stiff clays and the sand. It should be mentioned that the water pressure was virtually zero at the bottom of the stiff clay layer. Figure 7 shows the profile of pore water pressures in central BKK area (Shibuya et al., 1998 and 2001, Itou et al., 2002).

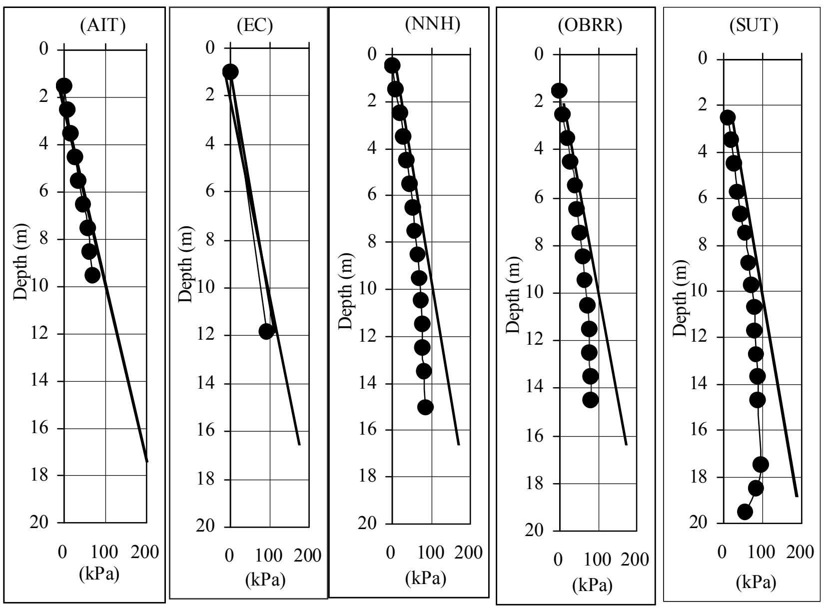

Fig. 7 Profiles of pore pressures in soft clay (Shibuya et al. 1998 and 2001, Itoh et al. 2002)

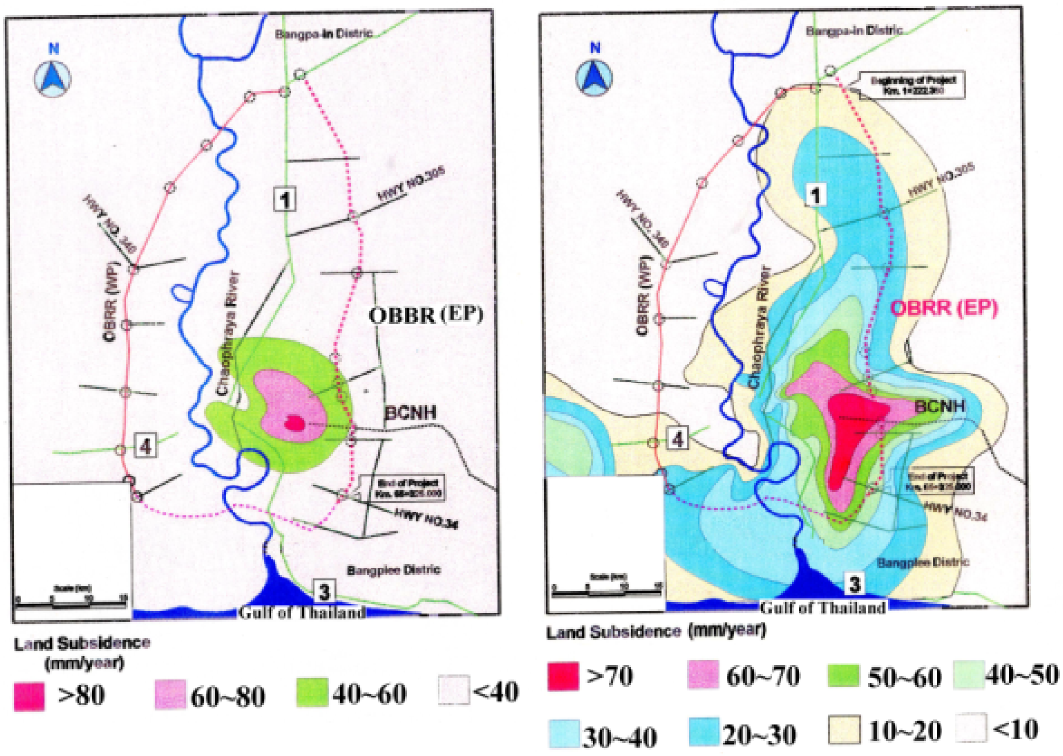

Fig. 8 Observed land subsidence in Bangkok

History of Land Subsidence in Central Bangkok

The groundwater abstraction has been continuously causing severe land subsidence over the past 30 to 40 years. Land subsidence due to groundwater pumping in the Bangkok area was first noted by Cox (1968). Nevertheless, until 1978, a coordinated and thorough investigation was not conducted to see the effect of pumping (AIT, 1981). At present, the majority of the water extraction is taking place from the aquifer systems in the top 200 m of deposits. Only minor pumping is taking place below this level. Initially, wells exploited the Bangkok Aquifer System down to 70 m but this soon became contaminated with salt water. From 1960's onwards the wells were progressively sunk deeper into the Phra Pradaeng Aquifer (70 to 120 m), the Nakhon Luang Aquifer (121 to 164 m) and the Nonthaburi Aquifer (165 to 185 m) (Rau and Nutalaya 1981) (see Fig. 2). The resulting decline in pore water pressure in the aquifers has been great with a decrease of 20-m head of water at 50-m depth and 43 m at a depth of 200 m noted in 1980.

In the period from 1978 to 1981, settlements in the order of 5 cm/year were observed for central Bangkok. A higher rate of 10 cm/year was noted for an area passing around the edge of the city from Huamak to Bangkhen. Since 1978, some improvements have been made to the water supply for the city and well pumping has been reduced. By 1985, the rates had fallen to 3 cm/year for central Bangkok but still 10 cm/year for the other nearby area such as Huamak (JICA 1986). Ground subsidence rate observed at Lad Kraband, near Nong Ngu Hao (NNH) site was reported to be about 4 cm/year, whereas the rate of 2.84 cm/year was observed at NNH area (Nutalaya and Rau 1990). As seen in Fig. 8, the average settlement over the past 10 years lies between 1.3 to 2.4 cm/year. Note that the places where the rates of ground subsidence are higher exhibit significant drawdown of water pressures in the clay layer (refer to Fig. 7).

Pore Pressure Drawdown Affecting Ground Improvement Scheme

In the construction of embankments on the soft clay ground, the installment of pre-fabricated vertical drain (PVD) combined with pre-loading has rapidly arrested interest of geotechnical engineers working in BKK as an efficient way to gain the prescribed strength and compressibility of soft clay over a short period of time. The vacuum preloading method (Kjellman 1952) has also been widely used for land reclamation and soil improvement work in the Bangkok area where sandy soils are scarce (Balasubramaniam et al. 1996, Bergado et al. 1996).

In principle, the installment of PVDs deep into the domain currently showing the drawdown of pore pressures brings about excessive land subsidence involved with a further drawdown of pore pressures over the whole domain covered by PVDs (Moh et al. 1969). The vacuum pre-

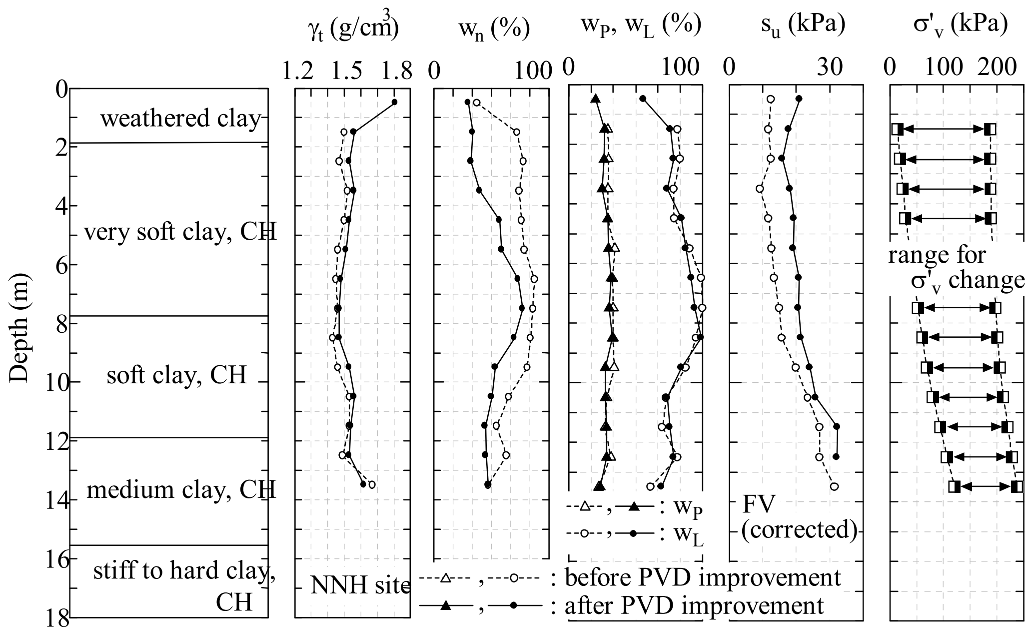

Fig. 9 Soil profile at Nong Ngu Hao (NNH) (Shibuya and Hanh 2001)

loading coupled with PVDs seems to enable us to overcome this problem. A case study as such performed at the Nong Ngu Hao (NNH) site has been described by Shibuya and Hanh (2001). The subsoil profile at NNH site is shown in Fig. 9. Note that the piezometric pressure profile of the original subsoil was lower than the hydrostatic pressure below 6 m. The profile of test embankment, together with the pattern of PVD installment is shown in Fig. 10. The horizontal drainage using a geotextile combined with perforated pipe was placed on top of the PVDs. The embankment was afterwards constructed in stages in order to provide the surcharge. The full-scale test embankment at the NNH site had the dimension of 40 m x 40 m at the base with a height of 2.5 m, which comprised a sand mat of 0.8 m in thickness at the base. The pre-loading was provided not only by embankment but also by applying a partial vacuum pressure (Bergado et al. 1998). Figure 11 shows the time-history of the pre-loading, together with the settlement-time curves at different depths in the subsoil right below the center of the test fill. It should be mentioned

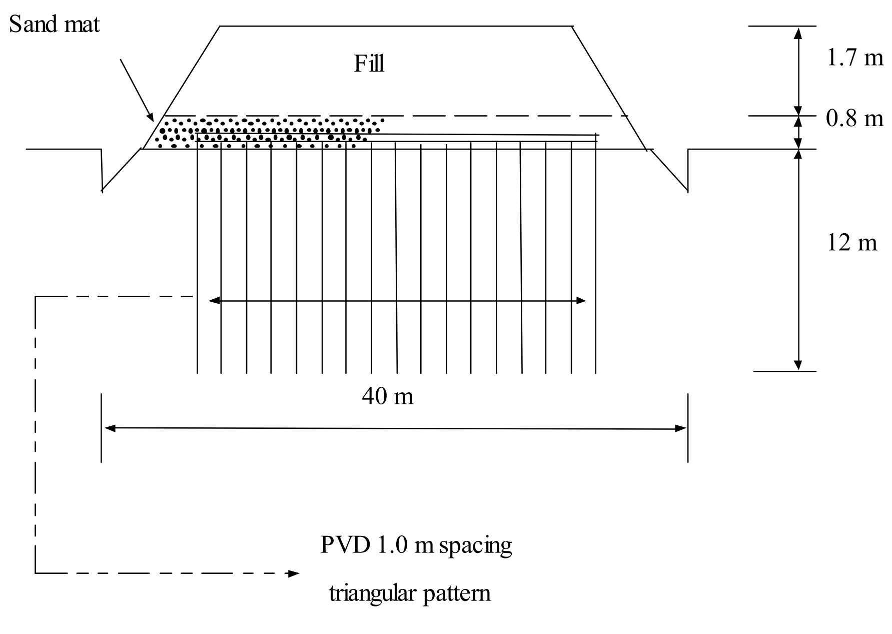

Fig. 10 Test embankment at NNH site (Bergado et al. 1998)

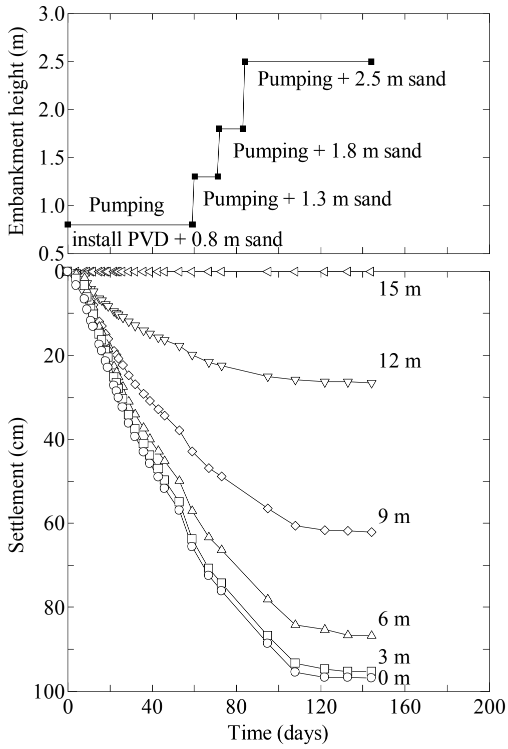

Fig. 11 Settlement of soft Bangkok clay due to pre-loading (Bergado et al. 1998)

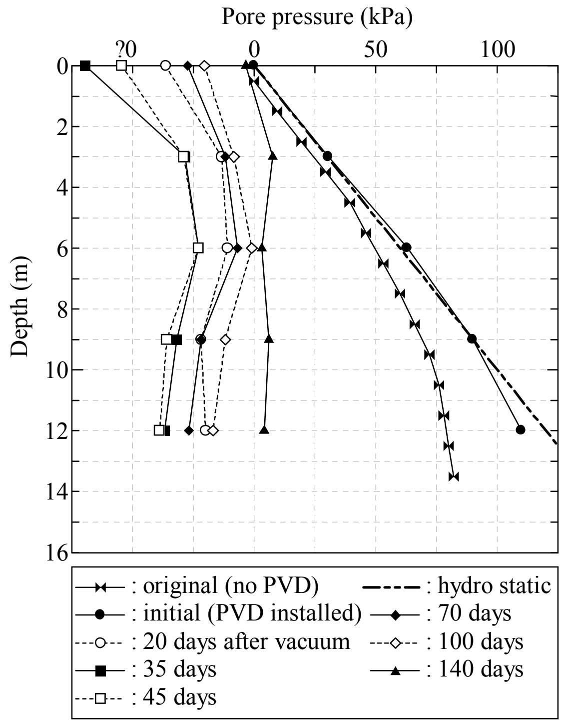

Fig. 12 Pore pressure change with time during vacuum pre-loading at NNH site (Shibuya and Hanh 2001, data from Bergado et al. 1998)

that a partial vacuum of not less than 70 kPa at the source was applied over the sand mat. Note that the settlements showed a common tendency to stabilize with time after about five months.

The variation of pore pressures with varying depth at different stages of construction is shown in Fig. 12. The measurements were made based on the readings of five piezometers installed vertically in-between the PVDs (Bergado et al. 1998). As stated earlier, the piezometric pressure was lower than the hydrostatic pressure below a 6 m depth due to the excessive pumping in the lower sand layer. When the PVDs were installed, the piezometric pore pressure shifted close to the hydrostatic line because of water recharge along the drains. On the application of a partial vacuum, the pore pressure decreased dramatically throughout the entire depths examined. The upper bound of σ'_v shown in Fig. 2 refers to the maximum effective overburden pressure experienced during the vacuum preloading. As can be seen in Fig. 12, the maximum value of σ'_v was reached at around 45 days after the vacuum application, and the pore pressures increased gradually back to the atmospheric pressure over the entire PVD-treated zone. Note also that after the improvement, the total unit weight increased, involving some decrease of natural water content over the full depth (see Fig. 9). Figure 13 shows the s_u profile with depth before and after the ground improvement. The results of the direct s_u measurements show considerable increases throughout the depths examined.

In summary, the vacuum preloading with PVD in soft clay ground was found effective in that the pore water pressures in soft clay decreased soon after the application of a partial vacuum over the full depth down to the tip of the PVDs. Accordingly, the excessive subsidence when the PVDs are installed deep into the domain currently showing the drawdown of pore pressures can theoretically be avoided since the domain improved by PVDs reaches to the state of over consolidation. By applying this technique, the construction period of embankment may be reduced considerably by approximately half.

EARTHQUAKES

History of Seismic Hazards in BKK

As indicated in Table 2, the risk of seismic hazard is considered very low in BKK. According to Nutalaya et al. (1990), more than 20 earthquake ground shaking events have been felt and recorded in BKK over the last two centuries. Although some were strong enough to cause general panic among the people, there has never been a destructive earthquake so far. As a result, most buildings

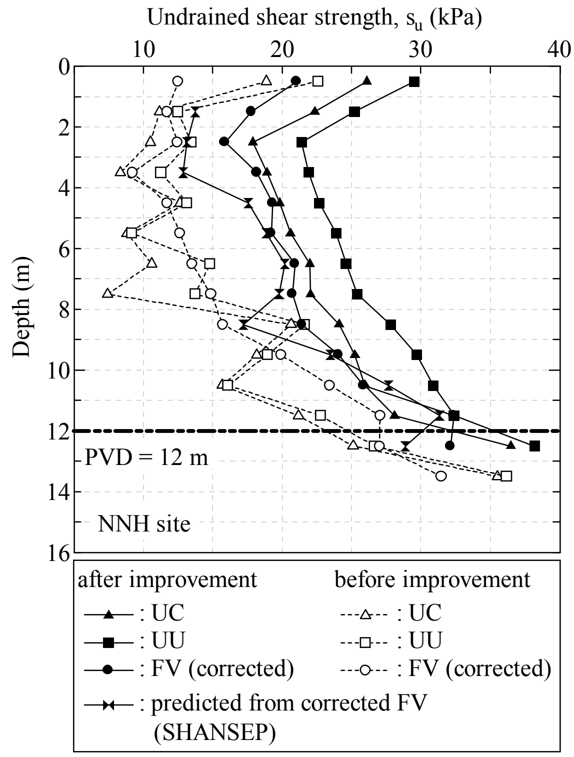

Fig. 13 Undrained strength profile at NNH site (Shibuya and Hanh 2001)

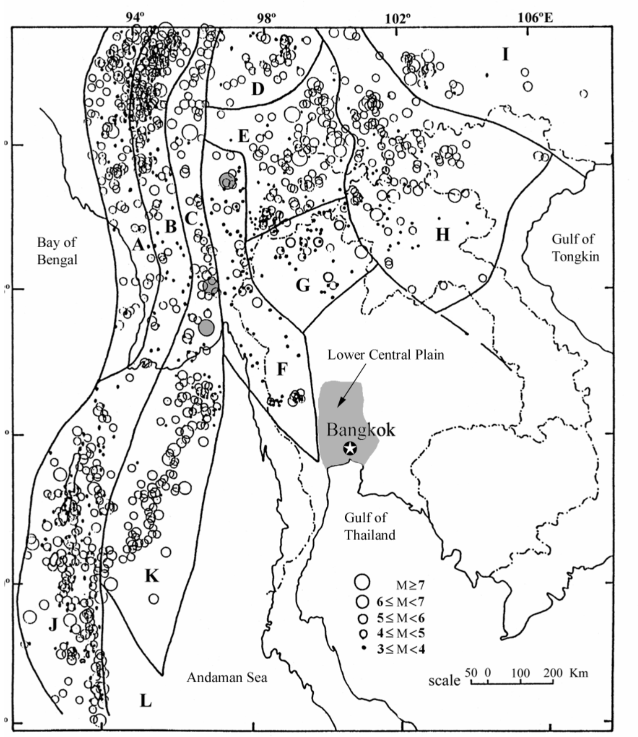

Fig. 14 Regional seismic sources zones and epicenters of earthquakes during 1910-present

and structures in Bangkok have been designed and constructed without any consideration on seismic loading.

Conversely, it is well recognized that urban areas located at rather remote distances from earthquake sources may, under some special conditions, possess a danger of earthquake disaster. A well-known example is the 1985 Mexican earthquake, in which a large earthquake (Ms = 8.1) on coastal Mexico caused considerable destruction and loss of life in Mexico City, 350 km from the epicentral location. Much of the destruction was due to significant amplification of earthquake ground motions by thick surfacial deposits in the downtown area of Mexico City (for example, see Seed et al. 1987).

Based on the seismotectonic features of the Burma-Thailand-Indochina region and the spatial distribution of earthquake epicenters, twelve seismic source zones in this region were identified by Nutalaya et al. (1985). They are named zones A to L as shown in Fig. 14. An earthquake catalogue containing instrumental data of earthquakes occurring in this region from 1910 to 1983 was also compiled by Nutalaya et al. (1985) using data collected from USGS, ISC (U.K.), the Thai Meteorological Department (TMD), and several other agencies. Note that the nearest zone of active faults is located only about 120 to 300 km from the city (c.f., in zone K), but their rate of seismic activity is rather low. More active seismic sources are between 400 km and 1000 km from Bangkok (i.e., in zones A and B). The surficial geologic setting at Bangkok also appears qualitatively similar to the setting of Mexico City, and hence Bangkok, by analogy, appears to be susceptible to the same type of soil amplification of ground motions.

Probabilistic Seismic Hazard Analysis Performed by Warnitchai et al. (2000)

Since the soil deposits underlying all of Bangkok and its surrounding areas consist of nearly uniform and horizontal layers of clay and sand, the response of these deposits to bedrock motions can be reasonably evaluated by a one-dimensional wave propagation analysis. Thus, the method of one-dimensional site response analysis using the computer program SHAKE91 (Idriss and Sun 1992) was adopted in the seismic response analysis performed by Warnitchai et al. (2000).

The generalized V_s profile obtained by Ashford et al. (1996) and, also Shibuya and Tamrakar (1999) shows an extremely low V_s in soft Bangkok clay (about 60 to 100 m/s). This is comparable to Mexico City clay. The velocity increases sharply and considerably to about 200 to 250 m/s in the first stiff clay, and it continues to increase at a slower rate in the deeper strata. The high contrast in V_s between the uppermost soft clay layer and the underlying layer in the Bangkok area is similar to that in Mexico City as shown in Fig. 15. In Mexico City, the V_s discontinuity interface allows the upward propagating shear waves to easily

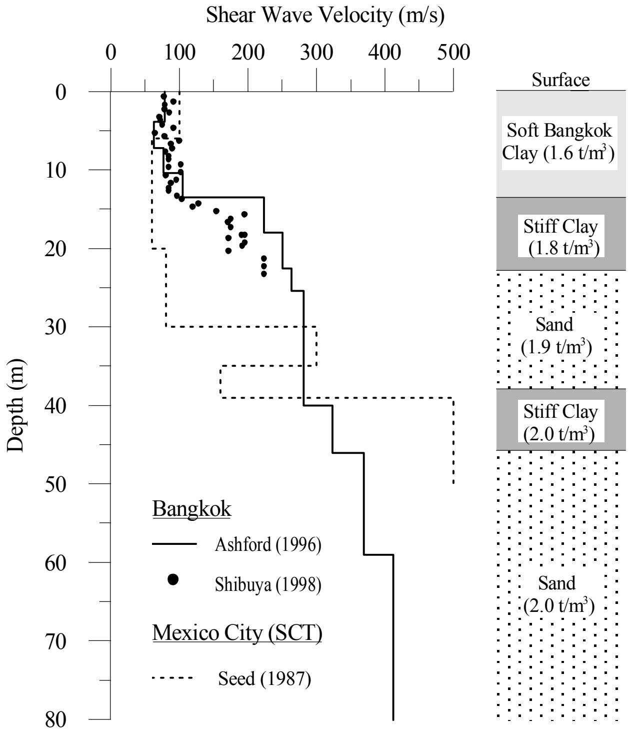

Fig. 15 Generalized Bangkok soil and shear wave velocity profiles (Warnitchai et al. 2000)

propagate through, but it acts more like a reflector to the downward propagating shear waves coming from the reflection at the ground surface. Hence, a major portion of the shear waves is trapped within the soft clay layer. During the 1985 earthquake, this created a wave resonance when the trapped waves interacted constructively with the continual upward propagating waves from the bedrock, and resulted in a significant amplification of motions in the soft clay layer. Therefore, the discontinuity of the V_s profile in Bangkok, though not as sharp as in Mexico City, suggests that a similar amplification mechanism may occur in this area.

The results of the amplification factor, i.e. the ratio of PGA (peak ground acceleration) to input PRA (peak rock outcrop acceleration) are shown in Fig. 16. In the seismic response analysis performed by Warnitchai et al. (2000), seven different accelerograms were employed to represent rock outcrop motions in the Bangkok area. These accelerograms were selected from actual acceleration records at rock sites generated by magnitude 7 to 8 earthquakes at source-to-site distances from 80 to 350 km. The peak acceleration values of these selected records vary from 0.005 g to 0.09 g (g: ground acceleration) and the predominant periods from 0.5 sec to 2 sec. The relationship between the amplification factor and PRA, shown in Fig. 16, clearly indicates that the soil profile underlying Bangkok has the ability to amplify earthquake ground motions about 3 to 6 times for extremely low intensity input motions and about 3 to 4 times for relatively stronger input motions. This range of amplification factors is comparable to those found in Mexico City.

The amplified ground motions can be described as

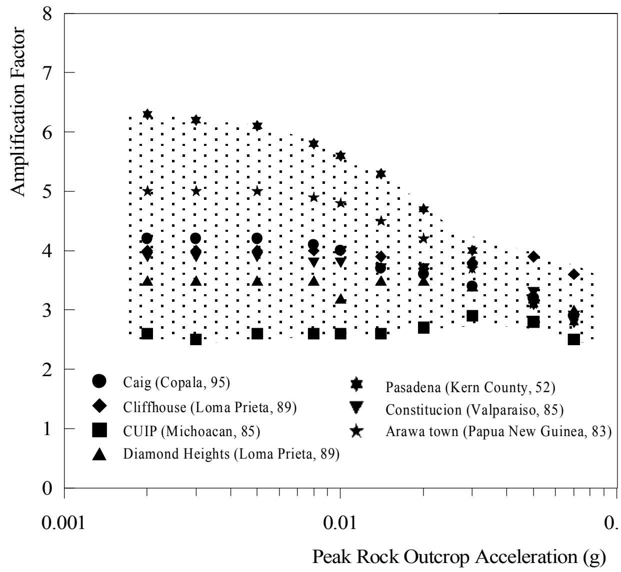

Fig. 16 Relationship between computed amplification factor and peak rock outcrop acceleration (Warnitchai et al. 2000)

narrowband random motions with a relatively long predominant period of about 1 second. This is clearly illustrated by the mean elastic response spectra (5% damping) for computed ground motions of 50%, 10%, and 2% Pe as shown in Fig. 17. Each spectrum shows a high spectral amplification in a narrow range of periods centered at about 1 second. The mean and 84th percentile spectra for the ground motions of 2% Pe, which characterize the maximum capable earthquake ground motion in the Bangkok area, are comparable in peak spectral acceleration to those of the damaging ground motions in Mexico City during the 1985 earthquake event. Based on these results, Warnitchai et al. (2000) gives us a serious warning that the maximum capable 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 to 1.5 seconds as well as to short-period structures that do not have sufficient lateral strength.

CONCLUSIONS

The city of Bangkok is located on a low land plain. The near-surface soil conditions can be featured with the top soft clay having low permeability, which in turn brings about a high frequency of occurrence of floods every year. In the public flood protection scheme, retention basins for detaining water to prevent flooding in lowland areas, called

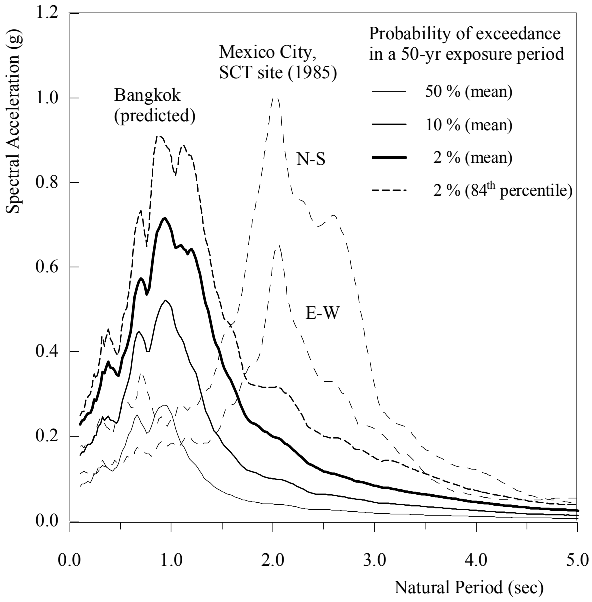

Fig. 17 Elastic response spectra of predicted ground motions (Warnitchai et al. 2000)

"Monkey Cheeks", have been and will be constructed in near future to detain large amount of water from the canals. The construction of large-scale retention basins involves excavation work with concrete diaphragm walls pre-installed into the soft clay. In predicting the deformation behavior of the soft clay ground prior to such excavations, the profile of elastic stiffness should be manifested by performing in-situ seismic survey, and the result may be properly plugged into the elastic FE analysis as demonstrated by Tamrakar et al. (2001).

The groundwater abstraction has been continuously causing severe land subsidence over the past 30 to 40 years. Ground subsidence rate observed recently in central Bangkok was reported to be about 4 cm/year. Recent site investigations into pore pressures in the clay layer indicate that the places where the rate of ground subsidence is higher are showing a significant drawdown of water pressures in the clay layer. Therefore, the need to reduce the amount of water abstraction from the aquifer is strongly encouraged. As to the improvement scheme of soft clay ground, the installment of PVDs deep into the domain currently showing the drawdown of pore pressures brings about excessive land subsidence involved with a further drawdown of pore pressures over the whole domain covered by PVDs. The vacuum preloading with PVDs in soft clay ground seems effective to overcome this problem.

The seismic hazard assessment performed recently by Warnitchai et al. (2000) indicates that Bangkok, though located at a remote distance from seismic sources, is still at risk of strong earthquake ground motions. The risk is essentially caused by three major factors; the ability of regional seismic sources to generate large earthquakes, the low attenuation rate of ground motions in this region, and the ability of thick soft clay deposits to considerably amplify earthquake ground motions. The predicted strong earthquake ground motions could cause extensive building destruction and considerable loss of life in Bangkok. To avoid such unacceptable economic and social consequences, the existing building design code must be improved by incorporating the necessary seismic design requirements, and the safety of existing important buildings and hazardous facilities must be critically reviewed.

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