LONG-PERIOD GROUND MOTION AMPLIFICATION AND DYNAMIC RESPONSE OF TALL BUILDINGS FROM THE 28 MARCH 2025 EARTHQUAKE

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1. INTRODUCTION

Bangkok and the surrounding metropolitan area are situated on thick layers of soft soil, estimated to extend several hundred meters in depth. This geological condition results from the location within the lower floodplain of the Chao Phraya River delta, which has formed over thousands of years through the continuous deposition of clay, silt, and sand transported by river flows and marine incursions. These soil characteristics make the area highly susceptible to the amplification of long-period seismic waves from distant earthquakes, resulting in prolonged shaking with predominant periods of several seconds.

Significant historical events include the 5 May 2014 earthquake in Mae Lao District, Chiang Rai Province (Mw 6.3), located approximately 670 km north of Bangkok, which caused noticeable shaking in many high-rise buildings throughout the city. More recently, the 28 March 2025 earthquake (Mw 7.7), with an epicentral distance of about 1,000 km, caused the collapse of a high-rise building under construction and produced strong shaking in many others. The event resulted in major structural damage in some buildings, rendering them uninhabitable, and moderate damage in others.

This paper presents a preliminary investigation of the seismic waves generated by the 28 March 2025 event. Shear-wave velocity models derived from array microtremor measurements were employed to evaluate site amplification characteristics at the ground surface, and the results were compared with recorded ground motion data. The seismic response of high-rise buildings was also assessed using data from structural instrumentation that captured building motion during the earthquake, in conjunction with dynamic properties determined through ambient vibration testing.

2. SITE CHARACTERISTICS OF BANGKOK BASIN

The influence of local soil conditions on earthquake ground motion in the Bangkok Basin was investigated through a detailed study of the deep subsurface structure. The subsurface characteristics were examined using microtremor observations to determine the predominant period and the shear wave velocity profile from the ground surface to the underlying bedrock. A total of 170 survey sites were selected, evenly distributed to cover the entire basin area.

The survey and analysis methods included the Horizontal-to-Vertical Spectral Ratio (H/V) technique for estimating the predominant period, and the Spatial Autocorrelation (SPAC) and Centerless Circular Array (CCA) methods for evaluating phase velocity. The phase velocity data were then inverted to derive the shear wave velocity profile with depth.

The results show that areas near the Gulf of Thailand and in the southeastern part of the basin have very low average shear wave velocity in the upper 30 meters (Vs_{30}), approximately 97 m/s, with a predominant period of about 1.2 seconds. In contrast, locations near the basin margins exhibit Vs_{30} values exceeding 900 m/s and a predominant period shorter than 0.2 seconds. In general, shear wave velocities within the upper 100 meters are below 500 m/s, increasing with depth. Stiffer soil layers reach velocities of approximately 1,000 m/s, while the bedrock is characterized by velocities of about 2,000 m/s or higher.

The depth to bedrock varies across the basin, from less than 70 meters near the margins to as much as 900 meters in the central area. Figure 1 shows the distribution of Vs_{30} across the basin. Figure 2 presents the estimated depth to the rock-like layer, and Figure 3 is the predominant period map obtained from the study [1].

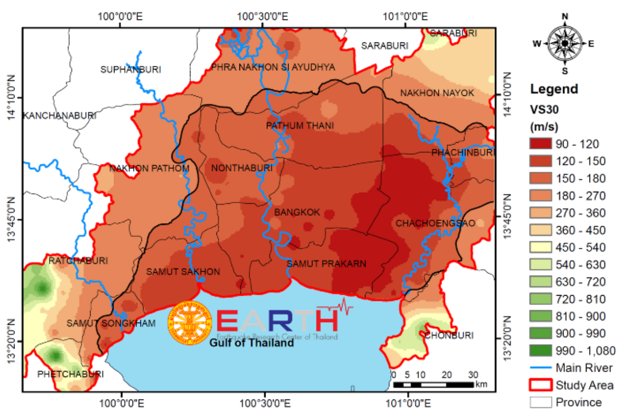

Figure 1. Distribution of Vs_{30} in Bangkok basin

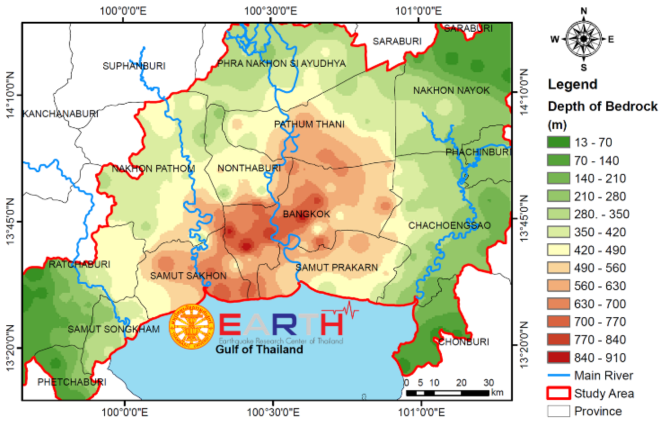

Figure 2. Distribution of basement depth in Bangkok basin

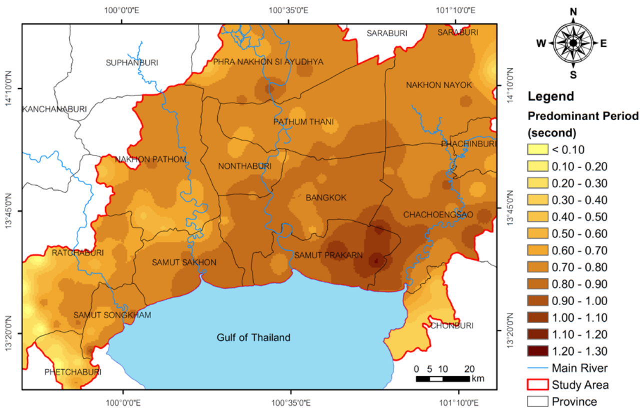

Figure 3. Distribution of predominant period in Bangkok basin

3. DYNAMIC CHARACTERISTICS OF BUILDINGS IN THAILAND

Most buildings in Thailand are reinforced concrete moment resisting frame (RC-MRF) structures, especially medium- to high-rise buildings constructed after the first seismic building design code in 1997. These buildings were primarily designed to resist wind loads, with limited consideration for seismic forces. For newer high-rise buildings, particularly those built after the 2007 code revision, a combination of moment resisting frames and shear walls is often used to enhance lateral stiffness.

Research on the dynamic characteristics of buildings, which affect their seismic response, has been carried out through ambient vibration measurements. A total of 121 buildings in Bangkok and Chiang Mai were measured. The data was analyzed and used in a regression analysis to determine the relationship between the fundamental period and the physical characteristics of the buildings. The results showed that the fundamental period (T in seconds) has a linear relationship with the building height (H in meters). By applying the lower-bound equation and considering period elongation due to seismic response, a suitable formula for estimating the fundamental period for seismic design in Thailand was proposed as $T = 0.02H$ [2]. This formula has been adopted in the seismic design standard and remains in use today [3]. More recent research [4] expanded the database by including 112 additional buildings and applied more advanced analysis methods to improve the results.

4. LESSONS LEARNED FROM THE 28 MARCH 2025 EARTHQUAKE

4.1 Ground Motion Amplification in Bangkok Basin

Ground motions recorded by four stations of the Thai Meteorological Department located within the soft soil basin of Bangkok during the 28 March 2025 earthquake showed maximum acceleration values of approximately 20 gal. Additionally, data from the Surin station, located outside the soft soil basin to the east and at a similar epicentral distance, were used to examine the seismic wave amplification behavior within the Bangkok basin.

This study developed soil profile models at the recording stations based on shear wave velocity data obtained from microtremor surveys. Using seismic waves recorded at the Surin station as input motion beneath these soil profiles, a one-dimensional (1D) ground response analysis was performed. The spectral acceleration (Sa) results from the 1D analysis were then compared with the actual recorded data at the stations. Figures 4 (a) to (d) show the Sa for 5% damping for stations located approximately 0.2 to 5 km from the microtremor survey sites.

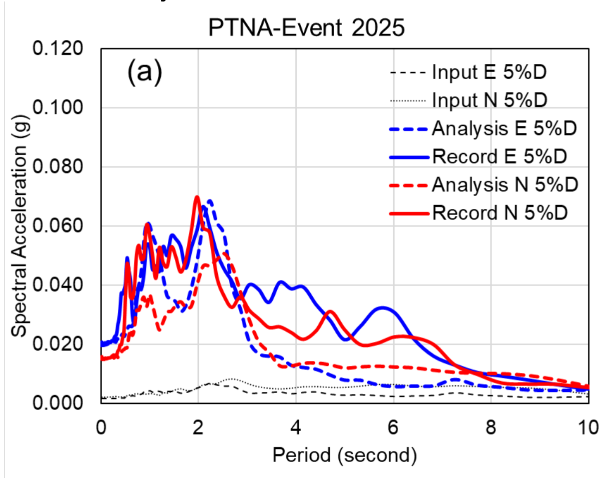

Figure 4. Spectral acceleration (5% damping) from recordings and 1D analysis at stations near microtremor sites.

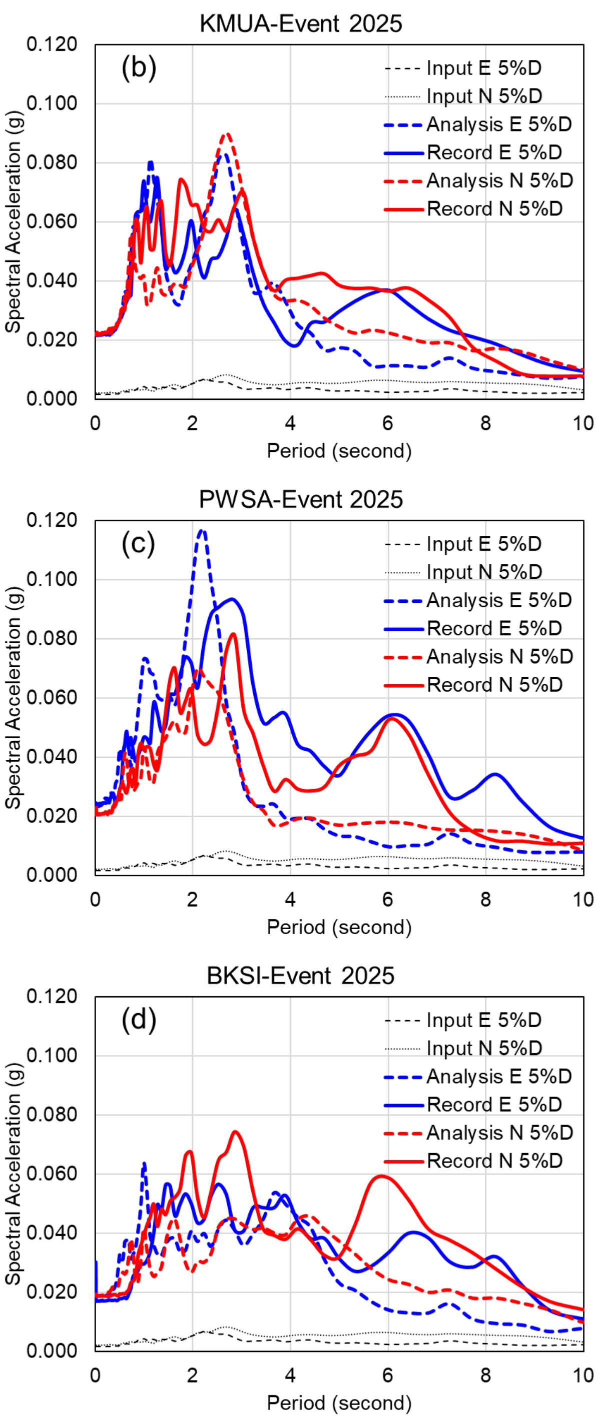

Figure 4 (cont.). Spectral acceleration (5% damping) from recordings and 1D analysis at stations near microtremor sites.

The findings indicate that the 1D ground response model produces Sa values comparable to recorded data for predominant periods up to 3.5 to 4 seconds. For periods longer than 4 seconds, the observed Sa values from recordings are significantly higher, reflecting the presence of strong long-period ground motion with significant shaking up to periods of 6 seconds. The inability of the model to accurately predict long-period amplification highlights the need for further detailed studies of the soil properties within the Bangkok basin. Such investigations are essential to improve the accuracy of seismic hazard assessments from distant earthquakes.

4.2 Dynamic Responses of Tall Buildings

The dynamic response of a 155-meter tall building (37 stories) during the earthquake was thoroughly recorded using MEMS accelerometers installed near the building rooftop. Figure 5 shows the acceleration time histories in each direction from two sensors. The peak acceleration reached 124 gal, with shaking above 2 gal lasting approximately 10 minutes.

Continuous monitoring of the building's dynamic properties revealed an increase in the vibration periods during the earthquake, indicating a loss of stiffness. Structural inspection found no damage to the structural elements, but observed damage to the masonry walls. This suggests that the stiffness reduction was likely due to cracking or detachment of the non-structural walls from the main structural system. Post-earthquake measurements showed a reduction in the period compared to during the earthquake, but it remained longer than the pre-earthquake period, indicating permanent damage, as shown in Figure 6. For this building, the permanent period elongation reached as high as 20%.

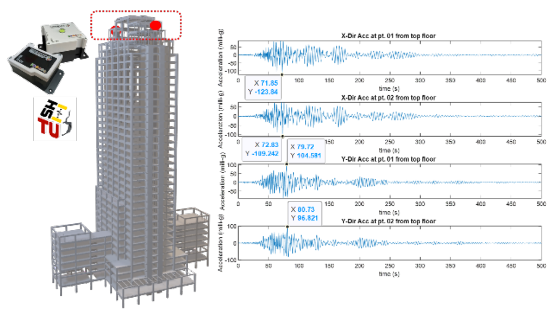

Figure 5 Acceleration time histories at the top of a 155-m tall building.

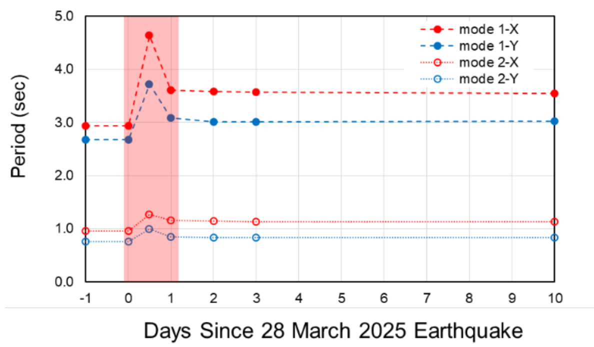

Figure 6 Variation of vibration periods before, during, and after the earthquake for the 155-m tall building.

Additionally, dynamic property measurements were conducted on a group of buildings previously studied before the earthquake. The comparison of natural periods before and after the earthquake, shown in Figure 7, indicates that period elongation generally increases with building height, with some buildings exhibiting elongations up to 30%.

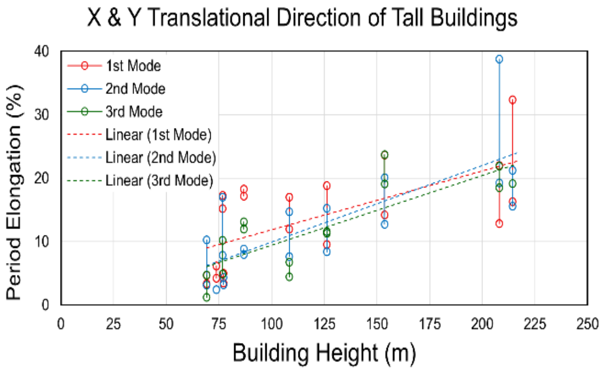

Figure 7 Period elongation versus height for a group of tall buildings.

These findings highlight the critical need to study the dynamic behavior of tall buildings in Thailand, especially under strong shaking conditions. Implementing structural health monitoring systems will provide more comprehensive data on building responses and damage progression, supporting improved seismic resilience in the future.

5. REMARKS

The 28 March 2025 earthquake revealed significant long-period ground motion amplification in the Bangkok basin, intensifying shaking in tall buildings. Monitoring showed stiffness loss and permanent period elongation, with non-structural damage despite minimal structural damage. These findings highlight the need for ongoing study and monitoring of tall buildings on deep soft soils.

To improve earthquake resilience in Bangkok and similar regions, it is recommended to:

1) Conduct further detailed investigations of deep soil characteristics in the basin, with emphasis on understanding and modeling long-period ground motion amplification.
2) Expand structural health monitoring systems in tall buildings to provide comprehensive data for damage detection and assessment.
3) Incorporate observed ground motion amplification effects and building dynamic characteristics into seismic design codes and risk mitigation strategies.

These measures will support more accurate seismic hazard evaluations, improved building performance, and better preparedness for future earthquakes in Thailand.

6. REFERENCE

[1] A. Jirasakjamroonsri, Assessment of seismic site effects and development of design response spectrum in Bangkok Basin, Ph.D. dissertation, Faculty of Engineering, Thammasat University, 2017

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[3] Department of Public Works and Town & Country Planning, Standard for Seismic Resistant Design of Buildings (DPT 1301/1302-61), Bangkok, 2018.

[4] N. Poovarodom et al., “Development of database of dynamic properties of buildings and long-term structural health monitoring system,” Research Report, the National Research Council of Thailand, 2024.