
Long-Period Ground Motions and Tall Building Response in Bangkok during the 28 March 2025 Earthquake

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ABSTRACT

The Mw 7.7 earthquake of 28 March 2025 generated pronounced long-period ground motions in the Bangkok Basin, causing widespread perceptible shaking and notable responses in tall buildings located more than 1,000 km from the epicentre. Recorded motions show strong basin-induced amplification, with particularly high spectral accelerations in the 2–6 s period range that coincides with the fundamental periods of many high-rise reinforced concrete buildings in Bangkok. The observed motions resulted in amplitude-dependent period elongation in instrumented buildings, with partial recovery after the event. This paper presents site characteristics of the Bangkok Basin derived from extensive microtremor observations, analyses of basin-scale amplification using records from basin-centre and stiff-soil sites, and observed tall building response during the 2025 earthquake. Comparisons between recorded motions and conventional one-dimensional equivalent-linear site response analyses highlight their limitations in reproducing strong long-period amplification. The findings emphasise the importance of basin effects and the role of structural health monitoring in improving seismic assessment and post-earthquake decision-making in deep-basin cities.

1 INTRODUCTION

Bangkok is situated in a deep alluvial basin formed by thick sequences of soft clay and sand deposits overlying deep sedimentary layers and bedrock. Although the city is located far from major active faults, it has repeatedly experienced noticeable shaking from distant large earthquakes originating in regional seismic sources such as the Sagaing Fault system in Myanmar and the Sunda subduction zone. These events have highlighted the

vulnerability of basin cities to long-period ground motions, which can be strongly amplified and prolonged by deep soft soil deposits.

The Mw 7.7 earthquake of 28 March 2025, with an epicentre in central Myanmar, produced unprecedented long-duration shaking in Bangkok. Despite the large source-to-site distance, the event caused widespread public concern, temporary evacuation of high-rise buildings, disruption to critical facilities, and the collapse of a 33-storey building under construction. The observed response of tall buildings was particularly significant, as the dominant periods of the incoming ground motions coincided with the natural periods of many high-rise structures in the city.

Conventional one-dimensional site response analyses are widely used in practice, but their applicability to strong long-period ground motions in deep sedimentary basins remains uncertain and requires validation against observed records. Furthermore, limited strong-motion records in Thailand have historically constrained the validation of analytical models and the assessment of structural response under realistic seismic demand. The 28 March 2025 earthquake therefore provides a rare and valuable dataset to investigate basin amplification and tall building response under strong long-period excitation.

This paper presents the site characteristics of the Bangkok Basin derived from extensive microtremor surveys, examines the amplification of long-period ground motions from distant earthquakes with emphasis on the 28 March 2025 event, and discusses the observed response of tall buildings, including period elongation identified from structural health monitoring and ambient vibration measurements. The results provide important insights for seismic hazard assessment, structural design, and earthquake preparedness in Bangkok and other deep-basin cities.

2 SITE CHARACTERISTICS OF THE 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 and evenly distributed to provide representative coverage of the entire basin area (Poovarodom and Warnitchai, 2016, Jirasakjamroonsri 2017). The survey and analysis methods included the Horizontal-to-Vertical Spectral Ratio (H/V, Nakamura 1989) technique to estimate site predominant periods, and the Spatial Autocorrelation (SPAC, Aki 1957) and Centerless Circular Array (CCA, Cho et al. 2006) methods to evaluate surface-wave phase velocities. The derived phase velocity dispersion curves were inverted to obtain shear wave velocity profiles with depth. The inversions were constrained by a priori information from existing borehole data in the region to define the initial parameter ranges, including P-wave and S-wave velocities, layer thicknesses, Poisson's ratio, and densities, with the maximum depth of the model limited to 1,000 m.

The results indicate that areas near the Gulf of Thailand and the south-eastern part of the basin are characterised by extremely soft near-surface soils, with average shear wave velocity in the upper 30 m (V_{s30}) of approximately 100 m/s and predominant periods of around 1.2 s. In contrast, locations near the basin margins exhibit much stiffer ground conditions, with V_{s30} values exceeding 900 m/s and predominant periods shorter than 0.2 s. In general, shear wave velocities within the upper 100 m are lower than 500 m/s and increase gradually with depth. Stiffer soil layers reach velocities of approximately 1,000 m/s, while the bedrock is characterised by shear wave velocities of about 2,000 m/s or higher.

The depth to bedrock varies significantly across the basin, ranging from less than 70 m near the basin margins to as much as 900 m in the central basin area. These spatial variations strongly control the amplification and resonance characteristics of ground motions in Bangkok. Figure 1(a) shows the distribution of V_{s30} across the Bangkok Basin, which was spatially interpolated from the shear wave velocity profiles of 170 microtremor

survey sites, while Figure 1(b) presents the estimated depth to the rock-like layer based on microtremor array inversions.

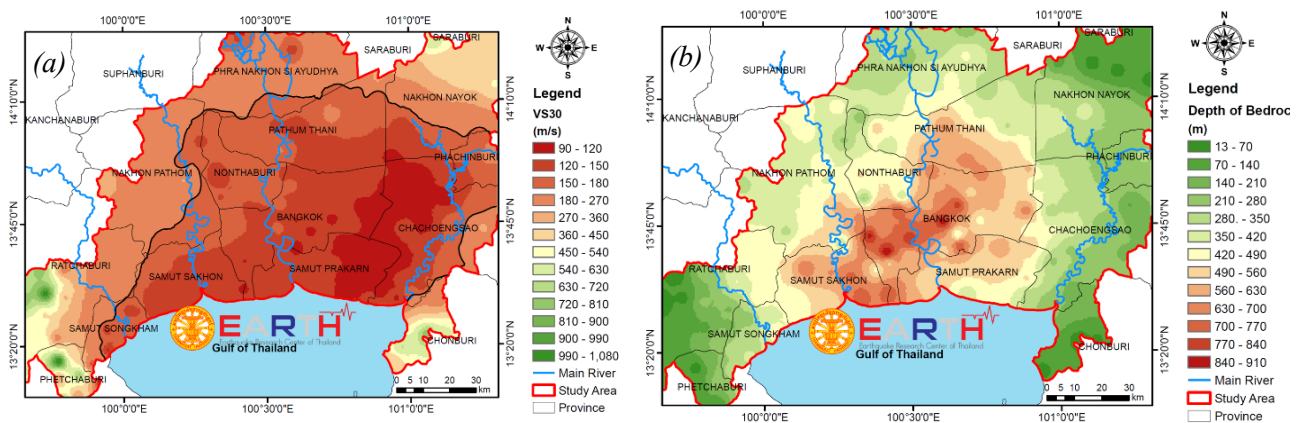


Figure 1: (a) Distribution of V_{s30} across the Bangkok Basin and (b) estimated depth to the rock-like layer.

3 AMPLIFICATION OF THE BANGKOK BASIN FROM DISTANT EARTHQUAKES

Bangkok has long been recognised as being susceptible to soil amplification effects from distant earthquakes due to its deep soft soil deposits. Noticeable tremors have been repeatedly observed in the city, particularly affecting long-period structures, even when earthquake epicentres are located several hundred kilometres away. Two representative examples of basin amplification were recorded during distant earthquakes in (a) 2011, with a magnitude of 6.9 and an epicentral distance of approximately 780 km, and (b) 2014, with a magnitude of 6.3 and an epicentral distance of about 720 km. For both events, ground motions were recorded by the Thai Meteorological Department at stations in Bangkok, located on soft soil, and in Surin, located at rock site. To provide context for the observed amplification patterns, the Bangkok station is characterized by a V_{s30} of 112 m/s, a predominant period of 0.89 seconds (derived from the horizontal-to-vertical spectral ratio), and an estimated bedrock depth of 531 m. While specific site investigation data are not available for the Surin station, it is located well outside the deep basin and is broadly classified as a stiff ground site. The epicentral distances to both stations were comparable for each event.

Figure 2 presents the 5%-damped spectral acceleration (S_a) of the recorded motions, where the solid blue line represents the Bangkok station and the dashed line represents the Surin station. The results show that ground motions in Bangkok were amplified by several times compared to those at the rock site. Spectral accelerations in Bangkok reached levels perceptible to occupants and triggered widespread evacuation of buildings during both events. Even conservative estimates of approximately 3 gal at 5% damping are sufficient to cause noticeable motion in tall buildings.

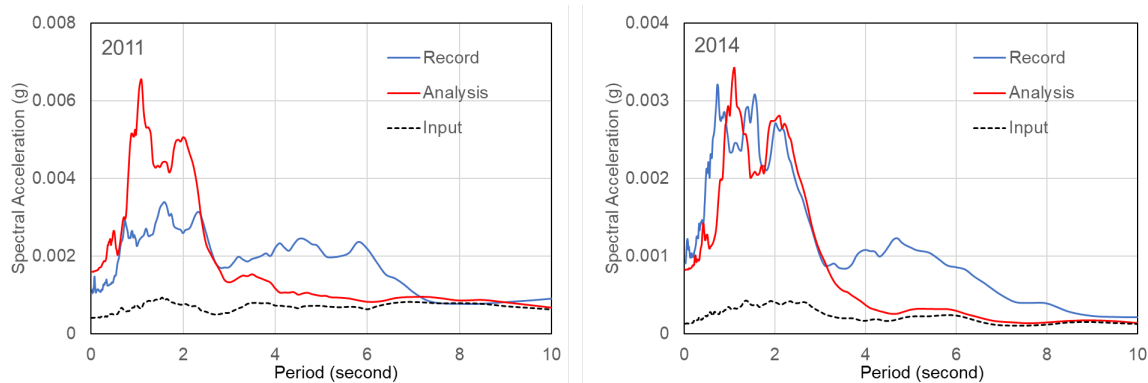


Figure 2: Comparison of 5%-damped spectral acceleration recorded at Bangkok (soft soil) and Surin (rock site) during distant earthquakes, together with results from one-dimensional site response analysis.

The amplification is particularly pronounced in the period range of 0.6–2.5 s, with a secondary amplification peak observed in the longer period range of approximately 4–6 s. Also shown in Figure 2 are the results of one-dimensional equivalent-linear site response analyses using a shear wave velocity profile obtained near the Bangkok station. To account for the non-linear behaviour of the geomaterials, the analyses utilized the modulus reduction and damping curves proposed by Vucetic and Dobry (1991) for clay layers with Plasticity Index (PI) values of 15, 30, and 50; Seed and Idriss (1970) for sand layers; and Schnabel (1973) for the underlying rock layer. In these analyses, the input motion at the base of the soft soil layer was assumed to be similar to the motion recorded at the Surin station. The results indicate that the simple one-dimensional model can reasonably reproduce amplification behavior for periods shorter than about 3 s. This is theoretically expected, as the geological conditions at the basin centre are broadly 1D, characterized by relatively flat and horizontally stratified soil deposits over a large area, where the response is primarily governed by the vertical propagation of shear waves. However, the model significantly underestimates the observed amplification at longer periods

For the 28 March 2025 earthquake, multiple strong-motion stations were available both at the basin centre (KMUA) and around the basin edges (NGPA, RATC, NAYO and CHAC), where ground conditions are relatively stiff, as shown in Figure 3. To establish a reference input motion at the basin centre for analytical and comparative purposes, the response spectra from the surrounding stations were first considered as representative bedrock motions given their locations on firm outcrops with minimal site effects. These spectral values were then spatially interpolated strictly based on distance using an inverse-distance weighting (IDW) method. To address the non-uniqueness of converting this interpolated spectrum into a time-history, spectral matching was performed in the time domain. Specifically, a seed time-history recorded at one of the margin stations was modified to match the distance-interpolated target spectrum. This matched time-history was subsequently used as the input motion for the site response analyses at KMUA.

Figure 4 compares the observed and analysed ground motions at KMUA for (a) the 28 March 2025 main shock and (b) the 29 March 2025 aftershock. The results for the main shock demonstrate extremely strong amplification at the basin centre, exceeding the surrounding rock sites by more than an order of magnitude over a wide period range. The conventional one-dimensional equivalent-linear model fails to reproduce both the amplitude and the long-period range of amplification observed during the main shock.

In contrast, the comparison for the 29 March aftershock, which had much smaller amplitudes and a higher proportion of short-period energy, shows better agreement between observed and analysed results. This contrast highlights that the observed discrepancy during the main shock is a combined consequence of two main factors. First, the equivalent-linear approximation tends to over-damp responses and poorly captures true non-linear soil behaviour at the larger shear strains induced by the main shock. Second, the fundamental 1D assumption cannot account for the generation and propagation of basin-induced surface waves, which are

primarily responsible for the significant amplification in the long-period range (4–6 s). These findings emphasise the need for more advanced modelling approaches capable of capturing both complex non-linear soil dynamics and 2D/3D basin-scale effects in Bangkok.

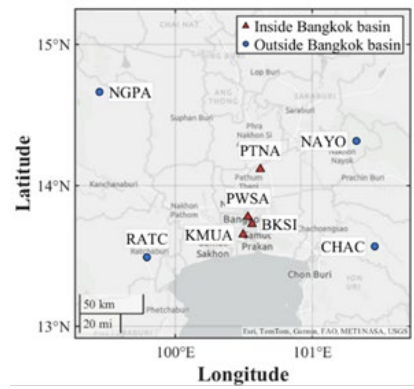


Figure 3: Locations of strong-motion stations at the basin centre and around the Bangkok Basin.

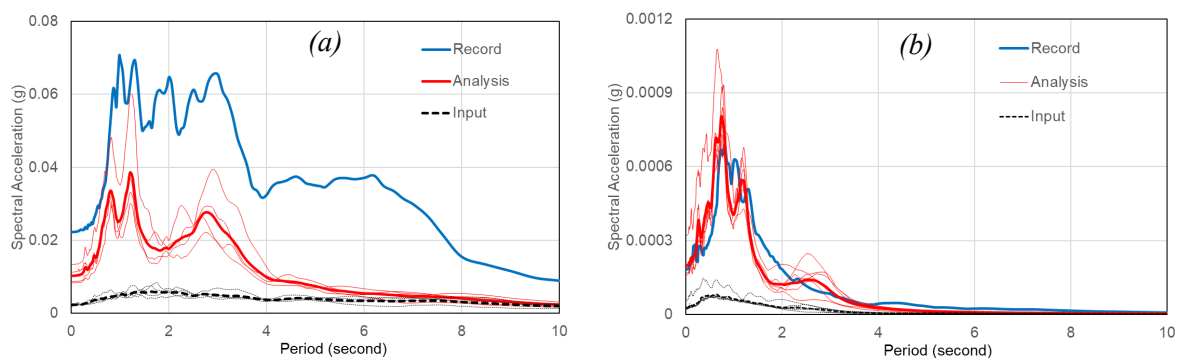


Figure 4: Observed and analysed ground motions at KMUA for (a) the main shock on 28 March 2025 and (b) the aftershock on 29 March 2025.

4 TALL BUILDING RESPONSE AND STRUCTURAL HEALTH MONITORING

The amplified long-period ground motions generated in the Bangkok Basin during the 28 March 2025 earthquake had a pronounced effect on tall buildings throughout the city. Many high-rise reinforced concrete buildings in Bangkok have fundamental periods within the range of 2–6 s, coinciding with the dominant periods of the amplified basin motions.

One tall building in Bangkok was instrumented with a permanent structural health monitoring (SHM) system at the time of the earthquake. The recorded response provides a rare opportunity to examine changes in dynamic properties before, during and after strong long-period shaking. Figure 5 shows the identified fundamental period of the building, clearly demonstrating amplitude-dependent period elongation during the main shock. After the shaking subsided, the period partially recovered but did not return fully to its pre-earthquake value. This behaviour is consistent with temporary opening and closing of cracks in reinforced concrete elements, together with residual stiffness degradation.

In addition to the instrumented building, ambient vibration measurements were conducted on several tall buildings before and after the earthquake. These measurements reveal systematic increases in fundamental periods after the event, as illustrated in Figure 6. The results indicate that even in buildings without permanent instrumentation, changes in dynamic properties can be detected using low-amplitude ambient vibration testing.

Together, the SHM data and ambient vibration measurements demonstrate that long-period basin motions can induce nonlinear response in tall buildings in Bangkok, even for distant earthquakes. The observed period elongation has important implications for seismic performance assessment, as elastic models based on pre-earthquake properties may underestimate deformation demands. The results also highlight the value of combining permanent SHM systems with targeted post-earthquake field measurements to support rapid and reliable assessment of tall buildings in deep-basin cities.

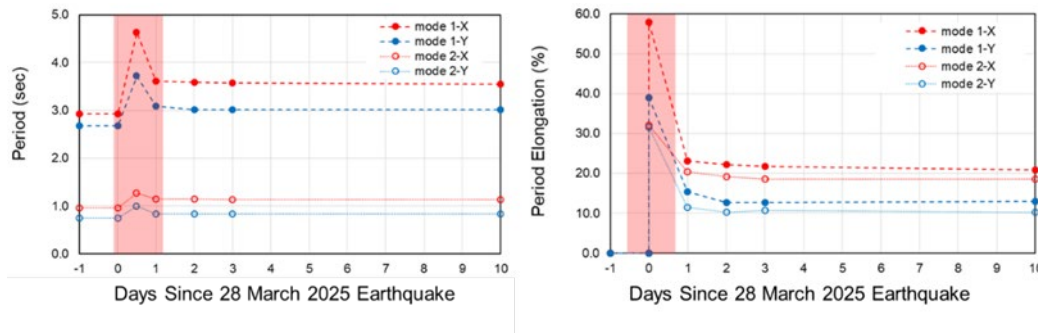


Figure 5: Fundamental period of an instrumented tall building before, during and after the 28 March 2025 earthquake, illustrating amplitude-dependent period elongation and partial recovery.

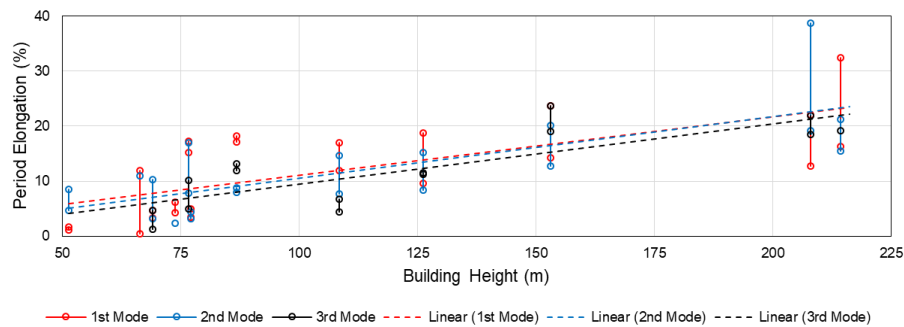


Figure 6: Changes in natural periods of tall buildings identified from ambient vibration measurements before and after the 28 March 2025 earthquake.

5 CONCLUDING REMARKS

The Mw 7.7 earthquake of 28 March 2025 provided a unique opportunity to investigate long-period ground motion amplification and tall building response in the Bangkok Basin. Extensive microtremor observations confirm that Bangkok is underlain by extremely soft and deep soil deposits, which strongly amplify long-period ground motions from distant large earthquakes.

Ground motion records demonstrate that amplification at the basin centre can exceed that at surrounding rock sites by more than an order of magnitude over a wide period range. Conventional one-dimensional equivalent-linear site response analyses are unable to capture the extreme amplification observed during strong long-period shaking, highlighting the need for improved modelling approaches that account for basin geometry and nonlinear effects.

The response of tall buildings during the earthquake was characterised by significant amplitude-dependent period elongation, with partial but incomplete recovery after the event. These observations emphasise the importance of considering nonlinear structural behaviour and post-earthquake condition assessment in seismic evaluation of high-rise buildings.

Finally, the successful application of cost-effective structural health monitoring systems during the 28 March 2025 earthquake demonstrates their value for real-time response assessment and public communication. Expanding such monitoring networks, together with improved basin-scale ground motion modelling, will significantly enhance seismic preparedness and resilience in Bangkok and other deep-basin cities.

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