PRELIMINARY EVALUATION OF THE SEISMIC RESPONSE OF TALL BUILDINGS DURING THE 28 MARCH 2025 M_w 7.8 MYANMAR EARTHQUAKE

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1. INTRODUCTION

On March 28, 2025, a M_w 7.8 earthquake occurred on the Sagaing fault, which is a shallow crustal right-lateral strike-slip fault with an approximate north–south strike in central Myanmar. The earthquake ruptured approximately 480 km of this fault at a super shear velocity of 5–6 km/s southward (Ye et al., 2025).

The earthquake, which occurred at 12:50 PM local time in Myanmar (06:20 UTC, 1:20 pm Thailand time), caused extensive damage, resulting in over 3500 fatalities and more than 11,400 injuries in Myanmar. It has been estimated that more than 48,000 residences collapsed and more than 120,000 were damaged in the country. A very large number of important facilities were also damaged, including 640 hospitals and clinics, over 2,600 schools, and many fire stations (AP 2025).

The earthquake also caused widespread damage in Thailand. In the Bangkok metropolitan area, nearly 103 fatalities were reported, despite being almost 1,000 km away from the epicenter. Most of these fatalities (96 deaths) occurred as a result of the collapse of a 33-story office building that was under construction in the Chatuchak district. However, damage was also observed in many other tall buildings, some of which experienced lateral displacements of more than 1 m relative to the ground.

The objective of this study is to provide a preliminary analysis of the apparently unusual large response and damage of tall buildings in Bangkok caused by this large-magnitude, very-distant earthquake. Several factors are identified that help explain the observed behavior. Further investigations are being conducted by the authors in collaboration with professors in Bangkok.

2. CONTRIBUTING FACTORS

Unexpected seismic performance or failure of engineered structures is rarely the result of a single factor. A far more common situation is that it results from multiple factors that combine and compound. Often, careful identification and consideration of these factors prior to the event could have perhaps, at least partially, predicted some of the aspects of the observed performance. A brief summary of these factors is presented in the following paragraphs.

A) *Large magnitude of the event*. It is well known that the earthquake magnitude is not a linear function of the size or energy released during a seismic event. For example, one of the first and best-known magnitude scales is the Richter magnitude, developed by Professor Charles Richter in 1935 at the California Institute of Technology (also known as Caltech) as a measure of the size of moderate earthquake events. Richter adopted both the term magnitude and its logarithmic scale from the magnitude scale used by astronomers for quantifying and describing the light intensity of stars. In particular, his magnitude was determined from the logarithm of the amplitude of waves recorded by a particular type of seismograph that is no longer in use today. Furthermore, many years later, it was found that his magnitude scale tended to saturate for large magnitude events, and that is why, although the term Richter magnitude is still commonly used in the media and among non-technical audiences, a better scale known as moment magnitude, M_w, is used today. The moment magnitude is based on physical properties of the earthquake as it is computed from an analysis of many waveforms recorded during an earthquake. To determine its amplitude, the seismic moment of the seismic event is computed, and then it is converted to a magnitude scale designed to be roughly equal to the Richter Scale in the magnitude range where they overlap. Similar to the Richter magnitude, each whole number increase in moment magnitude represents a tenfold increase in the measured amplitude, but it also corresponds to a much greater release of energy (32 times more). So, this means that this Myanmar earthquake with a M_w of 7.8 not only produced an amplitude on a seismograph that is approximately 10 times larger and released approximately 32 times more energy than a M_w 6.8 event, but it also produced ground motions with significantly different frequency content than what would have occurred in smaller magnitude events. On one hand, the amplitudes of high-frequency (short-period) waves tend to saturate more in large magnitude events, but on the other hand, and more importantly for tall buildings, large magnitude events contain far more energy in the low-frequency (long-period) spectral region. This means that the increase in spectral ordinates with increasing magnitude, which engineering seismologists often refer to as the "magnitude scaling", is very different and more dangerous for long periods than for short periods, making large magnitude events more dangerous for tall buildings.

B) *Long distance to the source*. In general, the longer the distance to the source, the smaller the expected ground motion intensity. Most media outlets described the effects in Bangkok as being produced by an earthquake approximately 1,000 km away. However, that is the approximate distance to the epicenter, which is the surface projection of the hypocenter (the point where the rupture was initiated). For this earthquake, the epicenter was located near the city of Mandalay. The epicentral distance was used in early ground motion models (formerly known as attenuation relationships) to estimate ground motion intensities (e.g., peak ground accelerations as a function of magnitude and distance). However, recent ground motion models obtain much better estimates of ground motion intensity by using distances to the rupture or to the surface projection of the rupture. This is particularly important in the case of large magnitude events such as the 28 March 2025, M_w 7.8 earthquake, because their ruptures tend to be very long and they release energy from many different points along the rupture. In this earthquake, the epicenter was located close to the uppermost point of the rupture and therefore very far from Bangkok. However, the southernmost point of the rupture was much closer, at about 600 km from Bangkok. This is very important because the largest component of the attenuation of seismic waves is the geometric attenuation. For these crustal events occurring very far away, geometric attenuation is approximately inversely proportional to the square of the distance to the source. Therefore, the same earthquake with a distance to the rupture of 650 km generates waves with amplitudes about 2.4 times larger than those produced by an earthquake of the same magnitude but with a distance to the rupture of 1000 km. So, it is important to describe this event as an event that occurred approximately 600 km. This is why several researchers in Bangkok have warned several times about the danger posed by distant large magnitude events such as this one (e.g. Warnitchai et al., 2000, 2018).

C) *Directivity effects*. The energy released by an earthquake is not distributed equally in all directions (for example, in a circular pattern in the case of a point source). This is what is referred to as directivity effects, in which for the same distance to the source, the ground motion intensity can be much larger in some azimuths than in others. Although directivity effects are often described in the near-field region, that is at distances comparable to the rupture length, earthquake directivity effects can be observed at considerably larger distances from the fault rupture, though the strength of the effect diminishes with distance. This directivity typically produces larger intensities in the direction of rupture propagation and weaker shaking in the opposite direction. While the most pronounced directivity effects are typically observed near the fault, they can still influence ground motion at greater distances, especially for larger earthquakes and at longer periods. Since this was a large magnitude event with a rupture length of almost 500 km, it is very likely that ground motion intensities recorded in Bangkok were at least partially influenced by directivity effects, particularly at long periods. Unfortunately, the number of seismic recording stations in Thailand, and particularly in Myanmar, is relatively small, so a detailed evaluation of directivity effects is not possible.

D) *Ground motion directionality*. In addition to directivity, which is the change in ground motion intensity from one station to another located at the same distance but at a different azimuth, ground motion intensities also have what is referred to as ground motion directionality. Directionality is the change in intensity at a given point (e.g., at a single recording station) with changes in azimuth. Although a few recent ground motion models now incorporate directivity effects, they typically neglect directionality as most of them only provide an estimate of a (scalar) measure of central tendency of the intensity at the recording station. Early models used the geometric means of the two recorded intensities (e.g., in the NS and EW directions for free field stations), while recent models use RotD50 intensities, which are the median intensities of those in all horizontal orientations. However, in certain orientations, the ground motion intensity can be much larger than the RotD50 intensity (up to 41% larger), while in others it can be much smaller (e.g., half or even less). Similarly, recent studies have shown that the ground motion intensity in the direction of strongest intensity can be 3 to 5 times larger than that in the orientation of the weakest intensity (Poulos and Miranda, 2022a). This is particularly true in the long-period range, which makes consideration of directionality particularly significant to tall buildings. Yet, ground motion models today neglect ground motion directionality. Another recent study found that the probability of exceeding the RotD50 ground motion intensity in one of the two principal axes of a structure, that is, in either the longitudinal or transverse direction of a building, is as high as 92% for short-period structures and becomes even greater, reaching 98% for long-period structures such as tall buildings (Poulos and Miranda, 2022b). A recent study has shown that for strike-slip earthquakes, such as the 2025 M_w 7.8 Myanmar earthquake, it is possible to estimate the approximate orientation at which maximum ground motion intensity will occur. In particular, the maximum intensity often occurs near the earthquake transverse orientation, that is, an orientation perpendicular to a straight line connecting the point of interest to the epicenter (Poulos and Miranda, 2023a). These findings from previous strike-slip earthquakes contained in the NGA2-west database have now been confirmed for several large, more recent, seismic events (Poulos and Miranda, 2024; Girmay et al., 2024a, 2024b). A model is now available to explicitly incorporate these effects in ground motion models (Poulos and Miranda, 2023b). The approach consists of computing modification factors, that are a function of the angular distance between the orientation of interest (e.g. the principal axes of a particular structure being designed or evaluated) relative to the transverse orientation, and applying them to response spectral ordinates estimated with existing ground motion models.

E) *Soft soils*. It is well known that most of the Bangkok metropolitan region is built on soft soil deposits. These deposits can lead to what is known as "local resonances", in which response spectral ordinates are greatly amplified at certain, very specific, periods corresponding to the modal periods of vibration of the soil deposits (e.g. Warnitchai et al., 2000, 2018). These studies lead to important increments of design spectral ordinates at periods corresponding to the shallow (12 to 18 m) deposits of the Bangkok basin having Bangkok clay, which have very low shear velocities between 60 to 100 m/s (comparable to those of the soft soil clays in Mexico City). These shallow soft layers produce very large amplifications of spectral ordinates for periods between 0.8 and 1.4 s. For example, Tasi et al. (2017) documented very strong amplification in the soft soil deposits of Osaka in the 2011 Tohoku earthquake despite being 770 km south of the epicenter. Deposits in Bangkok at deeper depths are characterized by alternate layers of sand and stiff clay. The bedrock is located at the deeper depths that vary between 500 and 2000 m, but the structure and details of the deep unconsolidated deposits are not well understood at the present time. Recent studies have shown that large magnitude events, which have significantly more energy in long periods than that produced by small or moderate magnitude earthquakes, can excite the fundamental and second mode of vibration that are primarily produced by these deep soil deposits, giving rise to large amplifications at much longer periods between 4 and 7 s (Subedi et al. 2021). For example, Ornthammarath et al. (2023) documented large amplifications at very long periods by using horizontal to vertical spectral ratios (HVSR) computed from ground motions recorded during several large magnitude distant events. There is no doubt that the amplifications caused by these deep deposits played a major role in the large seismic demands observed in tall buildings in Bangkok during this earthquake.

F) *Directionality in soft soils.* A recent study by Dávalos et al. (2024), published just a few months before the 2025 Myanmar earthquake, documented that in very soft soil sites like those in Mexico City, there is directionality that occurs at or near the fundamental period of vibration of the soil deposit. This soft-soil directionality is in addition to the increase in polarization and directionality with increasing period observed in rock and firm soil sites. Current studies by the authors are examining this effect by using ground motions recorded in Bangkok during the M_w 7.8 earthquake. If this additional directionality is confirmed, it would have created even greater intensities at long periods in certain orientations as a result of the increase in polarization near 6 s.

G) *Low damping in tall buildings.* For many years, it was believed that buildings have damping ratios of 5%. This was determined back in the 50s and 60s based on a few measurements of low- or medium-height buildings. However, for many years now, we have known that the level of damping in buildings decreases with increasing building height. The most comprehensive study on this was recently published by Cruz and Miranda (2021), in which they conducted a statistical study of more than 1,000 high-quality (i.e., reliable) damping ratios inferred from measured seismic responses in 154 instrumented buildings in California during various earthquakes. They showed that for buildings taller than 100 m, the damping ratios are typically lower than 2.5%, and for those taller than 200 m, the first mode damping ratios are around 1% (or even lower). Another recent investigation by the same authors showed that these low damping ratios are the result of soil structure interaction, in which the damping ratio decreases as the shear wave velocity of the soil deposits decreases and as the building slenderness increases (Cruz and Miranda 2021b). They also showed that there is a strong correlation between building height and slenderness ratio, meaning that taller buildings are usually more slender since typical lots are small relative to the height of taller buildings, leading to very low damping ratios. These levels of damping are much lower than those currently used in seismic design provisions, and therefore, seismic demands in tall buildings could be much larger than those currently in use.

H) *Effect of damping for structures built on soft soils.* The seismic response of structures is very sensitive to changes in the level of damping. The smaller the damping in the structure, the greater the peak seismic response. The seismic hazard intensity is usually only estimated for 5%-damped oscillators (single-degree-of-freedom systems). In order to account for structures having damping ratios higher or lower than 5%, seismic provisions make use of simplified damping modification factors (DMFs). In most cases, these modification factors are oversimplified and, for example, do not take into account the effects of changes in the period of vibration or of the shear wave velocity in the upper 30m of the soil deposits where the motions were recorded. Recent studies (e.g., Dávalos et al., 2022; Bantis and Miranda, 2025) show that DMFs obtained from ground motions recorded in very soft soil sites, such as those in Mexico City or the bay mud deposits of the San Francisco Bay Area, are significantly different from those obtained from motions recorded on rock or firm soil (e.g., Rezaeian et al. 2014). In particular, for structures with damping ratios lower than 5% (such as tall buildings), if their periods are close to one of the soil deposit's modal periods of vibration, they could experience lateral displacement demands that are much larger than those calculated using DMF developed from seismic motions recorded on rock or firm soil. It is very likely that this also played a major role in the large lateral displacement demands experienced by tall buildings in Bangkok during the 2025 Myanmar earthquake.

3. CONCLUSIONS

Tall buildings in Bangkok were subjected to unusually large lateral displacement demands, especially considering that the metropolitan area is located very far from both the epicenter and rupture of the 2025 Myanmar earthquake. It is very likely that these very large lateral displacement demands were created by a combination of factors. This preliminary analysis has made use of very recent research, most of which was published in the last three years, to identify possible factors that resulted in these large lateral displacement demands. Some of these factors would have been difficult to predict using the state of knowledge just five years ago, suggesting significant progress is being made to understand factors that influence building response in soft soil deposits. The authors are currently collaborating with professors Warnitchai, Ornthammarath, Poovarodom, and their students and colleagues on some of the aspects discussed in this preliminary study. It is hoped that this collaboration will produce results that help reduce the seismic risk of structures in Bangkok.

4. ACKNOWLEDGEMENTS

The first author would like to thank the organizing committee of the Thailand Symposium on Earthquake Research (TSER) for their kind invitation to participate as a keynote lecturer in this event. The author also thanks Profs. Warnitchai, Ornthammarath, and Poovarodom for their invitation to collaborate on topics of mutual interest related to this recent earthquake. Partial funding of the directionality research mentioned in this manuscript was provided by the California Strong Motion Instrumentation Program of the California Geological Survey through agreement number 1023-003. The second author has received partial funding from the Shah Fellowship on Catastrophic Risk from Stanford University. This funding is greatly appreciated.

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