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The 2019 M 3.4 Yangon Earthquake in Ayeyarwady Delta Basin

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Abstract

An earthquake of M 3.4 occurred in Yangon with epicenter at Dalah, 6 km SSE of Yangon at 15:24:18 pm (UTC) on 12th November, 2019. Its epicenter was situated at 16.751°N, 96.18°E and at depth 10 km (6.2 miles) (USGS, NEIC). It was a slight earthquake and vibration was severe and people felt strong shaking in almost every townships of the Yangon Region but no severe damages. The event was preceded by a loud sound and heavy shaking last 8 seconds. Ground deformation by this event is slanting of the high-rise buildings in some townships, liquefaction features like water seepage from underground to the surface and slight cracks on the wall of the buildings. The causative fault for the earthquake is believed to be a reverse fault with strike-slip component of the NNW-SSE trending Yangon fault. This is due to basin inversion in Ayeyawady Delta Basin. On 13th January 2013 an earthquake with the same magnitude occurred at 10 km depth. It was a slight earthquake and vibration was felt in several townships of Yangon. In 17 December, 1927, an earthquake with magnitude 7.0 hit Yangon and caused certain amount of damages. It was felt15,000 sq.km from Kyangin to Dedaye along the western slope of Bago Yoma. In Yangon, the shock was much severer causing widespread alarm and damage to concrete buildings. Focal mechanism solution of the 1927 event was a strike-slip faulting (USGS). In July, 1930 Bago earthquake with M=7.3 effected Yangon, vibration spread caused damage to the buildings and 500 persons in Bago and 50 persons were killed in Yangon respectively. The last record of significant earthquakes that struck Yangon is on 30th September,1978 with M 5.7 at 10 km depth.

Keywords: vibration; reverse fault; strike-slip fault; liquefaction; deformation; basin inversion.

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1. Introduction

Yangon is located between latitudes 16° 45’ N-17° 4’N and longitudes 96°1’E-96° 20’E, on the southeastern corner of the Ayeyarwady Delta basin, at the mouth of three rivers: Yangon, Ngamoyeik and Bago rivers and 34km from the sea in the coastal area. It has a tropical Monsoon climate with annual precipitation of 2366 mm. It has population of about more than 6 million. Due to the annual increase of population, the size of the city has expanded several times than its prewar size. When population increases, urban development expends. Yangon’s pride: the Shwedagon Pagoda was built on the top of Singuttara Hill , on the southern spur of Bago Yoma.

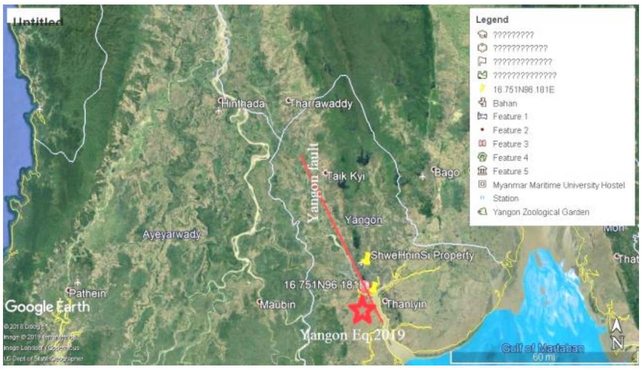
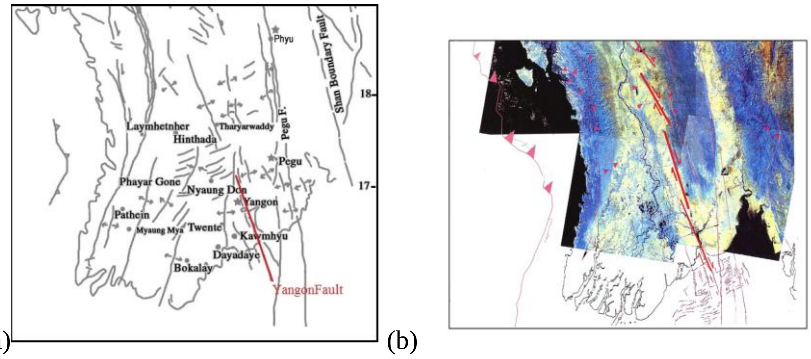


Figure 1: Google Earth image of Yangon area, epicenter was situated south-south-east of Yangon at 16.751°N, 96.18°E and at depth 10 km (6.2 miles) (USGS, NEIC).



(a) (b)

Figure 2: a. Generalized map of Ayeyawady Delta Basin showing structural features and existence of Yangon fault which triggered Yangon earthquake on 12th November,2019 .(b). Map showing segmented, right-stepping faults in NNW-SSE direction and they are basin bounding faults of the rift basins.

1.1Tectonic setting

Yangon region is tectonically located on the southern spur of the NNW-SSE trending Bago anticlinal ridge which lies immediately on the western site of Sagaing Fault. Eastern folds approach Bago whereas the western fold extends further south to the central part of Yangon as a ridge. Alluvial deposits are found in the surrounding areas of the ridge while lateritic soils can be found along the ridge. NNW-SSE trending folds and

NNE-SSW striking transverse faults occur in Yangon area. The Ayeyawady Delta basin is one of the rift basins in N-S trending elongated Central Myanmar Basin. It is bounded with NNW-SSE trending fault to the east and a fault that separates the basin from Rakhine Yoma in the west. The general trend of the rift basins in the Central Myanmar (Burma) Basin are N-S, NNE-SSW, NNW-SSE. And NE-SW, divided by E-W,ENE-WSW,ESE-WNW trending uplifted area between them In all these basins, the southward transport of sediments predominated [6]. All the basins are more or less rhomb-shaped and oblique to the Sagaing fault. Sagaing fault is dextral strike-slip fault with displacement of 10-25mm/yr [11] and it extends into the Gulf of Mottama with horse-tail strutures and then connect to the Central Andaman spreading centre with a series of transform faults and spreading centres. Ayeyarwady Delta Basin is tectonically more related to the Mottama basin [8, 259-271]. These basins, developed during the Miocene are controlled by simple shear scheme and can be found for 2000 km length from south to north from the Central Andaman Basin in Andaman sea to Hukawng basin in northernmost part of Myanmar. These basin bounding faults are capable of triggering earthquakes in area. Historical and recent earthquakes have shaken the Yangon including the M7.0 1927 earthquake and the M5.7 1978 earthquake [5]. These earthquakes reflect the existence of a blind fault underneath the soft sediments of Yangon region. The Yangon earthquake ruptured this fault and this fault has no name, so that the author attempts to give a name to this fault as Yangon fault.

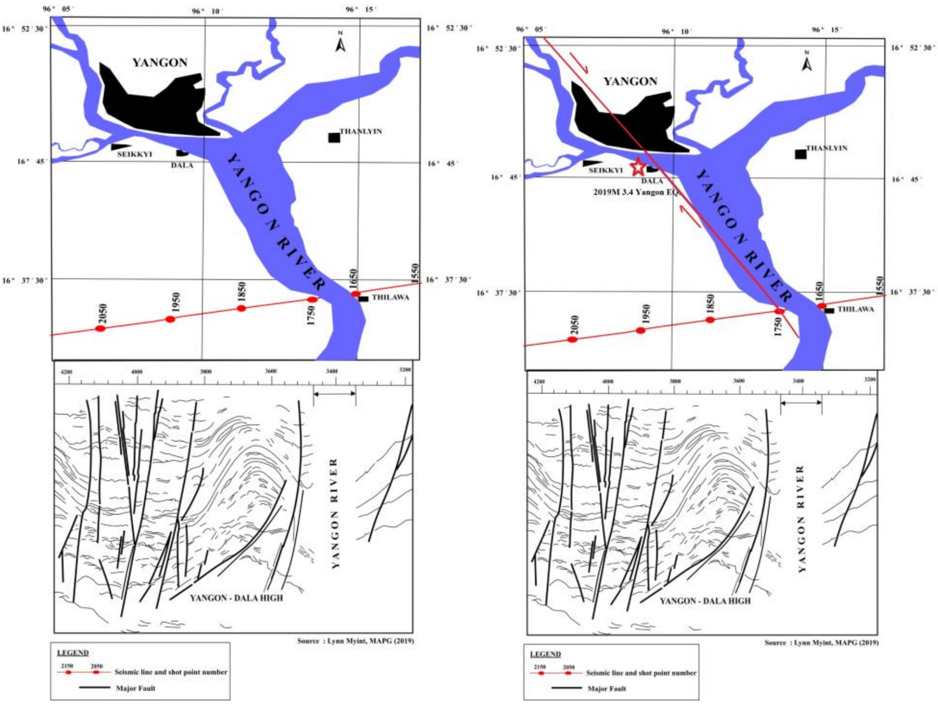


Figure 3: Simplified cross-section of the Yangon river fault zone in E-W direction showing several active faults

A series of basin for 1100 km from south to north in Myanmar were first described by Bender (1983) [3] and in which Tertiary continental deposits prograded southward over marine sedimentary environment and continental sedimentation took place since late Miocene in the all these basins. This is interpreted as a result of tectonic inversion and uplift of the basin [10, 1837-1878]. Integrated interpretation of geophysical methods, drilling data and well logs reveal listric growth faults associated with roll-over anticline structures in lower and middle

Miocene sediments of Pyawbwe and Kyaukkok formations in the Ayeyawady basin, at deeper levels of more than 10,000 feet, as a result of rifting in entire basin due to the extentional deformation. Listric growth faults are the primary deformational structures during sedimentation, formed in unconsolidated, freshly filled sediments in the basin which are actively growing in depth and breadth. They are characteristics of intensive petroleum exploration. In the seismic section (Fig. 3), listric growth fault system can easily be identified.

Figure 4: Google Earth map showing the location of epicenter of Yangon Earthquake at Dalah on the bank of three rivers: Rangon River, Ngemoyeik and Bago river. Dalah is located on alluvial fan and plain.

2. The 2019 Yangon Earthquake and seismic deformation

At 9:55:31, on 12th November 2019, an earthquake with magnitude 3.4 occurred in Yangon and epicenter is at 16.751°N, 96.18°E in the place of Dalah area, at the depth of 10km (Fig.4). The earthquake spread to a wide area including 34 townships and surrounding Yangon of Thone gwa, Thanlyin, Dala. The felt area of earthquake was 91 square kilometer, concentrated and distributed in a band with 13 km long and 7 km wide along the strike of the Yangon fault. Yangon is located between latitudes 16° 45' N-17° 4'N and longitudes 96°1'E-96° 20'E, on the southeastern corner of the Ayeyarwady Delta basin, at the mouth of three rivers: Yangon, Ngamoyeik and Bago rivers and, 34km from the sea in the coastal area. Yangon city is situated on the coast of the Andaman Sea, formed alluvium fans and plains. Two terraces are found near Yangon with 10m thick of alluvial clays. They are situated 70 km north from Yangon and raised 20m above the sea level due to the uplifting connected to the development of Bago anticline. These terraces are controlled by Neo-tectonic movement in the region [6]. The cause of earthquake damage is due to the geological condition of the crust and the foundation of building itself. One is controlled by the shallow conditions of engineering geology and the other by geological structures and stress fields. The main factors in earthquake damage are the occurrence of river-deposited soil and mud marine beds. On the inside of the old river channel near Dalah, recently deposited soil is developed and mud marine beds are wide spread along the coastal area. With strong shaking, the loose materials are in the state of liquefaction which generates a channel in loose deposits and can cause an earthquake disaster. The characteristic of the earthquake damage reflect the earthquake hazard level.

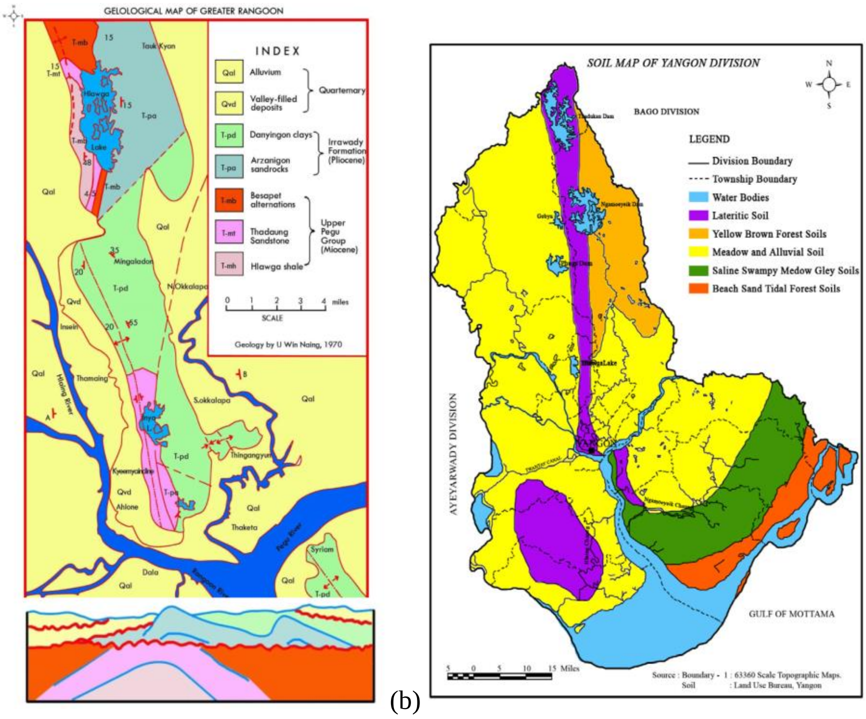
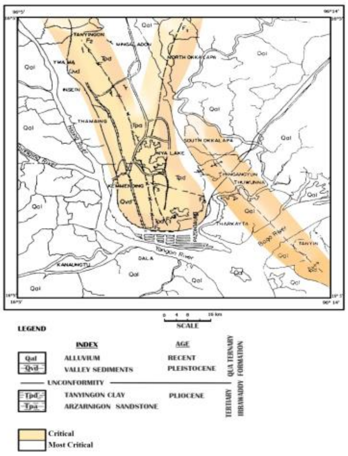
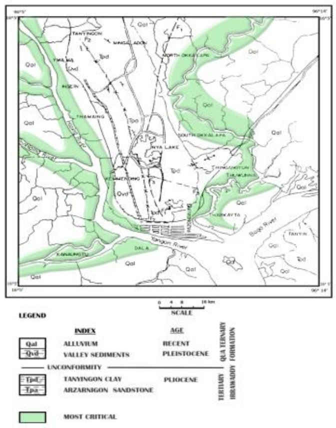


Figure 5: (a) Generalized geological map and its cross-section showing structures and Lithology of Yangon. (b) Soil map showing the distribution of soft soil and Alluvium in most part of Yangon.

The extent of destruction of buildings in general was controlled by three factors as follow: magnitude of earthquake; earthquake resistance design of the buildings, site characteristics and foundations. The general situation of buildings in Yangon is that the shallower the bed-rock buried depth, the lighter the destruction and the deeper the bed-rock depth the heavier the destruction. Seismic waves travel faster through hard rocks than through softer rocks and sediments. As the waves pass from deeper, harder to shallow, softer rocks they slow down and get bigger in amplitude as the energy pile up. The softer the rocks or soil, the larger the waves is. Softer soil amplifies ground motion. Such situation has been happening in Yangon. BecauseYangon area is underlain by alluvial deposits (Pleistocene to Recent), the non-marine fluvialtile sediments of Irrawady formation (Pliocene), and hard, massive sandstone of Pegu series (early–late Miocene). Alluvial deposits are composed of gravel, clay, silts, sands and laterite, which lies upon the eroded surface of Irrawaddy formation at 3–4.6m above sea level. The central part of Yangon area is occupied by the anticlinal ridge as a backbone, 30m above mean sea level and covered with sands, sand rock, soft sandstones, shale,clays, and laterite of Irrawaddy formation. The hard compact sandstone and shale of Pegu series can be found at the northwest corner of Hlawg lake with NNW–SSE strike dipping to the east. Alluvial deposits are found in the surrounding areas of the ridge (Fig.5,a), whereas lateritic soils can be found along the ridge (Fig.5,b). The top soil layer is clayey soil layers with a thickness of 4.0m to 8.0m with fine to medium-grained sand, silty sand and clayey sand. Based on the lithology and the structure of the area, two areas are divided in the micro-zonation map (Fig.6.a). The area along fault and fold covered with sand rock is a critical area and the area covered with loose sand and alluvial deposits are the most critical area because such alluvial soil are the most vulnerable area for earthquake hazard.



(a)



(b)

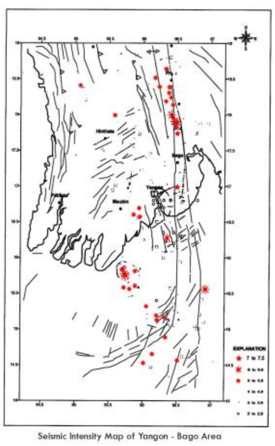
Figure 6: (a) Seismic hazard map of Yangon area.(b) Landslide hazard map of Yangon area

Since earthquake can trigger landslides, slope stability studies are very important for future urban development. In Yangon area, most of the areas are flat-lying lowland in the deltaic region where slope gradient is gentle so that landslide can only be taken account along the river bank (Fig.6.b). To define which area in Yangon has the highest risk is super-imposing the seismic hazard micro-zone map on the slope stability map. For Yangon area, the most suitable area for further urban development sits outside the most vulnerable seismic zone and landslide-prone area.

3. Stress field

Earthquake disasters are related to the seismic stress field and geological structures. In this tectonically active continental rift setting, the majority of strains is accommodated along border faults of the basins. Slip on these faults lead to uplift, where they interact with other bounding faults of adjacent basins. Within these transfer zones, fault may accommodate differential horizontal or vertical displacement between adjacent basins [1, 153-164].

(a)



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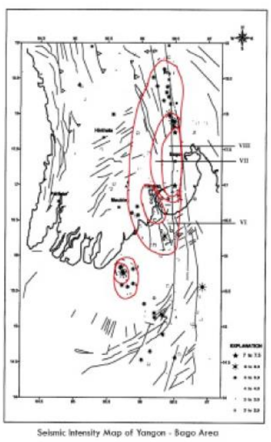

Figure 7: (a). Seismic intensity map of Bago-Yangon region(Source: USGS earthquake catalog). (b).Seismic zonation map of Bago-Yangon region (base on seismic intensity map)

Deformation in the basin uplift region involves a combination of normal and strike-slip displacement. The present-day deformation field of the Basin-Uplift province is revealed by the patterns of seismicity of horizontal velocity estimates data derived from GPS, which show 8mm/yr between basin and uplift [1, 153-164]. Focal mechanism solution of earthquakes gives strong extension axis in an NNW–SSE direction and maximum compression axis direction in an E–W or ENE–WSW). Depth distribution of earthquakes shows that the majority of earthquakes occur at depth from 0 to 40 km (CMT from Harvard and epicenters from ENGDHAL) (Fig. 7). Seismicity in Central Myanmar Basin occurs as a result of the stresses and strain set-up within the plate, on the pre-existing normal and strike-slip faults that have an appropriate orientation with respect to the present-day stress field.

4. Concluding Remark

The cause of earthquake damage is due to both the geological condition of an area and the foundation of the building itself. Ground shaking and movement along the faults are hazards for an area. The shaking can break power lines, pipelines, buildings, roads , bridges and other structures that are very close to the fault. So the simplest strategy would be not to build near the fault zones. However, many ancient cities of Myanmar such as Tagaung, Ava (Inwa), Sagaing, Taungoo, Bago and Bagan have already developed near major faults and they have been destroyed by earthquakes repeatedly through history. Designing earthquake- resistance buildings or building codes is a great challenge for the buildings to withstand strong earthquakes. A further complication is that the same building codes cannot be applied everywhere. Neither all earthquakes produce the same pattern of ground motion nor all geological structure be the same in a country. It is also important to consider type of soil on which the structures are built. Buildings built on the bed rocks seem to suffer far less damage than those built on deep soil. Ground shaking is amplified by seismic waves within the sedimentary basin. The liquefaction is a major cause of damage to the building where the ground is covered with alluvial soil and in filled land near the coast.

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