Basin structure from a dense nodal seismic array in Yangon, Myanmar: Contributions to seismic hazard estimates

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Summary

Myanmar is surrounded by complex seismotectonic elements and threatened by a high seismic risk. The Central Myanmar Basin (CMB) hosts the largest and fastest growing cities of Myanmar. The CMB is bounded by the Indo-Myanmar subduction zone to the west and the Sagaing fault to the east and is a seismically active tectonic block that has experienced large earthquakes (up to magnitude 8.0). A large earthquake in this region would affect Yangon and its surrounding population of around 8 million. Sedimentary basins have a significant contribution to seismic wave propagation, amplification and duration of ground shaking. Thus, to more accurately estimate the seismic hazard, a clear understanding of the detailed basin structures is required. The goal of our study is to map crustal structures, i.e. crustal thickness, crustal blocks, basin shape, size and depth, fault geometry, dipping layers and intra-crustal layers beneath the Yangon region. We will present receiver functions from a dense array of 168 nodal seismometers with the goal of revealing high-resolution seismic images of the basin. Our dense array will improve basin imaging by reducing uncertainties in receiver function interpretations. Developing a better understanding of basin structures will help our understanding of seismic amplification in the basin and thus will help to more accurately estimate the seismic hazard of this region.

Introduction

Myanmar lies in the Alpine-Himalayan seismic belt that extends from Java-Sumatra through the Himalayas, to the northern Mediterranean in the west (K. Zaw et al., 2017). The subduction zone (with a collision in the north) between the Indian and Eurasian plates, the northward movement of the Burma plate from a spreading center near the Andaman sea, and numerous active faults namely Sagaing Fault, Kyaukkyan Fault, Kabaw Fault and some unnamed major thrust faults are the major potential seismic sources in this region (Thein and Swe, 2006; Thant, 2014). Knowledge of the detailed basin and crustal structure in this region will be very beneficial for earthquake hazard estimation, ground motion simulation of a large earthquake and overall in mitigating seismic hazard.

Myanmar has several active tectonic blocks (Fig. 1). In the west, the Indo-Myanmar range (IMR) is a wide forearc and accretionary wedge formed by the oblique subduction of the India plate beneath the Burma plate (Steckler et al., 2016; Maurin and Rangin, 2009; Than et al., 2017; Khin et al.,

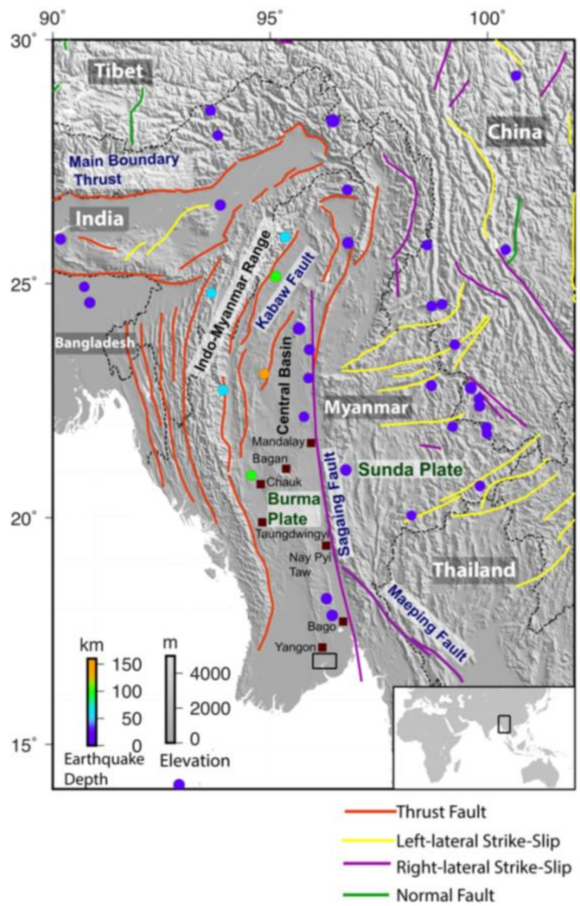

Figure 1: Tectonic map of Myanmar and the surrounding region. Earthquakes from 1900 to present of magnitude >6.5 are represented by dots color-coded by focal depth (ANSS earthquake catalogue USGS). The black rectangle in the southern part of the map represents our study area in Yangon which is shown in Figure 2.

2017). The adjacent N-S trending tectonic block is the CMB bounded by the Sagaing fault to the east. The Sagaing Fault is the most prominent and active fault in Myanmar (Wang et al., 2014; Gardiner et al., 2018; Sloan et al., 2017). It is an ~1500 km long right-lateral strike-slip transform plate boundary between the Sunda and Burma plates (Tun et al., 2017). Yangon, the largest city of Myanmar and former capital is located ~35 km west of the Sagaing Fault (Fig. 1). Other fastest growing and populous cities of Myanmar namely Mandalay, Bago, and the capital, Nay Pyi Taw are also located in the vicinity of the Sagaing Fault. Most of the earthquakes in the Yangon region are related to the Sagaing Fault (Thant 2014; Thiam et al., 2017; Aung, 2015). However, some earthquakes in the region are associated with underlying blind faults and some corresponds to other faults that are not very well-known (Thant, 2014; Aung, 2015). Our study aims at mapping basin-scale subsurface structures that includes determining fault geometry and connectivity beneath this region.

Being in the close proximity to several seismo-tectonic elements, a high rate of seismicity is expected in Yangon and its surrounding region. Besides the Indo-Myanmar subduction zone and Sagaing fault, Yangon is also surrounded by the Kyaykkyan fault in the north-east, West Bago Yoma fault in the north and the Andaman spreading zone in the south. Yangon is located in the southern part of CMB that has several forearc and back arc basins (K. Zaw et al., 2017; Pivnik et al., 1998). The CMB has a sedimentary thickness of up to ~15 km (Wang et al., 2018). Sedimentary basins have a significant impact on ground motion and shaking from an earthquake. Soft rocks in the basin and the basin's shape and depth are responsible for focusing and trapping seismic energy and amplify seismic waves which can enhance the ground shaking hazard (e.g., Day et al., 2012). For an accurate earthquake hazard estimation, it is crucial to understand basin amplification, and a detailed basin structure is required for that. The goal of our study is to map the crustal structures underlying the Yangon region. Precise information on basin size, shape and depth, underlying fault geometry and crustal thickness will help our understanding of basin amplification in the region for any future earthquake.

Our study focuses on the city of Yangon, where crustal-scale and basin-scale structures will be identified using receiver functions computed from nodal seismic data.

Impacts of Large Historical Earthquakes in Myanmar

Myanmar has experienced a number of destructive earthquakes in the past as well as in recent times (Fig. 1; Aung, 2015). The largest historical earthquake occurred on May 23, 1912 with an estimated magnitude of 8.0 associated with the Kyaukkyan Fault (Crosetto et al., 2019).

Summarizing from Aung (2015), a series of earthquakes took place from 1929-1932 that was predated in Yangon by a 1927 M 7.0 earthquake. The first event in the 1929-1932 sequence was the 1929 M 7.0 Swa earthquake along the Sagaing fault and the largest was the M 7.3 Pegu or Bago earthquake on May 5, 1930. This is the largest earthquake in the southern part of the Sagaing fault. It was the most destructive earthquake causing the deaths of 550 people. In the same year, another big M 7.5 earthquake hit central Myanmar along the southern segment of the Sagaing Fault causing major damage to railways and buildings and 30 casualties. The 1956 M 7.0 Sagaing earthquake killed 40-50 people. The 1975 M 6.9 Bagan earthquake ruined the whole city including damage of ancient religious monuments and Pagodas and at least one death and one injury.

In 2003, a M 6.6 earthquake destroyed the Taungdwingyi town with at least 7 casualties. Significant earthquakes in the past decade include the 2011 M 6.8 earthquake that killed ~74 people, destroyed ~300 houses and left ~124 injured. Another event was the 2016 M 6.8 Chauk earthquake which caused extensive damage to historical monuments (S. H. Zaw et al., 2017; Aung et al., 2019). Most of these earthquakes in the central basin are shallow focus as shown in Fig. 1, few intermediate focus earthquakes have occurred along the western fold-belt with a maximum depth of ~160 km (Stroke et al., 2008). These earthquakes clearly represent active seismicity in Myanmar and a potential for future earthquakes. A seismic gap of ~260 km has been identified along the Sagaing fault near Nay Pyi Taw and the fault is expected to have accumulated elastic strain and to be capable of an ~7.9 magnitude earthquake in the near future (Hurukawa and Maung, 2011).

The current population of Myanmar is 54.4 million (Department of Population, Myanmar) which is a 270% increase above the 1931 census (Maung, 1986). A large earthquake like the Bago earthquake could potentially cause a lot more damage and loss of life than in the past.

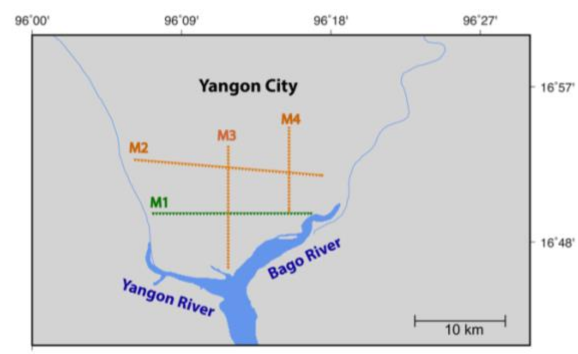

Figure 2: Map showing the MUSE seismic deployment profiles in Yangon. Orange profiles were deployed in March 2020; the green profile is yet to be deployed. The small triangles in each line represent nodal station locations.

Dense nodal seismic array in Yangon, Myanmar

Deployment of Nodal Seismometers in Yangon

As part of the Myanmar Universities Seismic Experiment (MUSE), we are deploying three-component nodal seismometers or nodes in Yangon city (Fig. 2). A dense array of 168 nodal stations is being deployed along four seismic profiles, M1, M2, M3 and M4 having 48, 57, 37, 26 nodes respectively with an inline-spacing of approximately 250-350 m. Nodes are short-period, battery operated seismometers that can record continuously for up to ~35 days. Nodes are ~six inches tall and five inches in diameter with spikes in the bottom. They are perfect seismic instruments for an urban setting because of their size and ease of installation. Moreover, the low cost allowed us to have a dense seismic array for higher resolution imaging. 112 nodes were deployed in March 2020 along the M2, M3 and M4 lines. Those nodes will be picked up at the end of April 2020 and would have recorded local, regional and teleseismic earthquakes, as well as ambient noise for 30 days at 4 ms sampling interval.

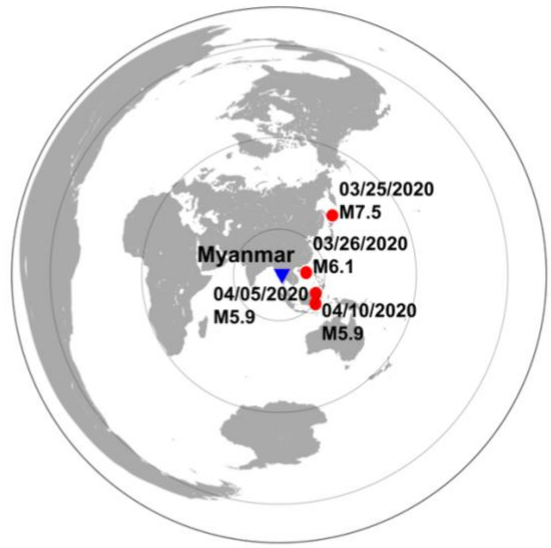

Figure 3: Teleseismic earthquakes with magnitudes ≥5.9 recorded by the MUSE array in Yangon from 03/20/2020 to 04/10/2020. These events will be used in our receiver function computation.

Method

We will be using receiver functions computed from the nodal dataset to map basin structure and other subsurface interfaces. Receiver function is a well-established seismological technique for extracting information on earth's internal structures. The process involves deconvolving the vertical seismogram from the horizontal seismograms to get rid of source and path contributions (Oldenburg, 1981). Receiver functions will be computed using teleseismic earthquakes with magnitudes >5.5 and epicentral distances between 30º and 90º. Horizontal seismograms will be rotated into radial and tangential seismograms and the power spectral density (PSD) of noise will be determined from the pre-signal noise following the method of Di Bona (1998). A frequency domain deconvolution will be performed where the noise PSD will be used as a preliminary estimate of the noise in receiver functions. After that, the receiver functions will be filtered with a Gaussian filter to control the high-frequency noise content.

Example of Potential Results

A recent comparison of nodal and broadband data in the greater Los Angeles area showed that nodal teleseismic waveforms have sufficient bandwidth for receiver functions (Liu et al., 2018). Moreover, the densely spaced nodal data provide receiver functions with high lateral resolution that reveal more continuous crustal structures. The four teleseismic earthquakes shown in Fig. 3 are suitable for receiver function computation from the data recorded by our nodal stations deployed in March-April 2020.

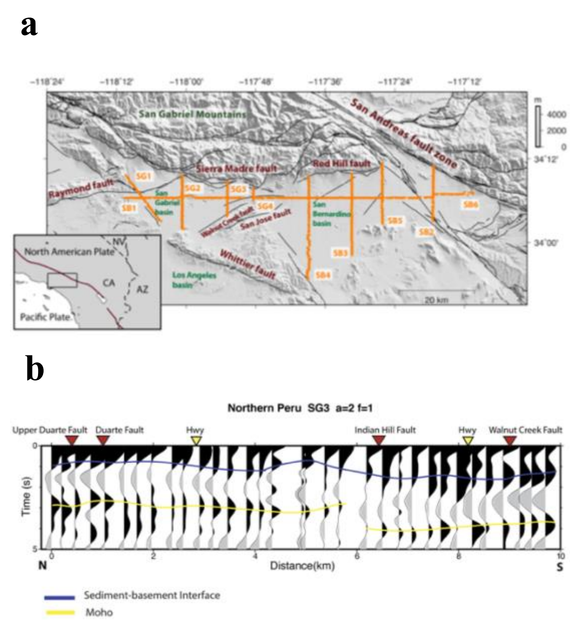

Figure 4: a) Nodal seismic profiles in the greater Los Angeles, California area. b) Receiver functions from the SG3 profile were calculated from a teleseismic earthquake in Northern Peru using a Gaussian parameter of 2 (1 Hz). The profile location is shown in a).

An example nodal receiver function profile from Southern California is presented in (Fig. 4). Receiver functions in Fig 4b have been computed using a teleseismic earthquake of magnitude 8.0 and an epicentral distance of 57º along the SG3 line in the northern Los Angeles area. 1 Hz receiver functions revealed the Moho at 3 s in the northern and central parts of the profile and at 4 s in the south. A possible Moho offset can be interpreted from preliminary results close to the Indian Hill Fault. The sedimentary basin deepens from north to south. This is a great example that shows how multiple stations along the profile reduce uncertainties in receiver function interpretations and allow us to determine the detail basin-scale structures.

Discussion and Significance of the Study

A high seismic potential as well as the anticipated amplification in basins enhances the vulnerability to seismic hazards in Myanmar. Because the Yangon region is covered by alluvial deposits, the surface geology is not very well exposed (Aung, 2015). Moreover, the presence of blind and unknown faults is another obstacle in understanding the future seismic hazard in this region. Our passive seismic survey with 168 nodal seismometers is being conducted to map the subsurface basin structures in detail. Our array of nodal geophones will provide a dense sampling of the seismic wavefield to reveal crustal-scale lateral heterogeneities.

Some approaches have been taken to determine basin structures in Myanmar. For example, Pivnik et al. (1998) used seismic reflection surveys to determine basin thickness. Combining seismic reflection results with other geologic and stratigraphic data, they came up with a depth of 18 km for the central basins. The study had the limitation of a small number of instruments and shallow depth of penetration. A recent study has been conducted by Wang et al. (2018) using 56 broadband seismic stations in Myanmar and Bangladesh. A basin depth of 15 km was interpreted with a Moho depth of 30 km beneath the central basins. They came up with the first 3D velocity model for this region. However, the sparse distribution of seismic stations does not provide precise information on subsurface structures. Our study aims at identifying the detailed basin structure beneath the stations from receiver functions. This approach will help reduce uncertainty and represent basin structure variability more precisely in earth models for this region. This will in turn provide more accurate estimates of basin amplification effects, potential seismic sources and overall seismic hazard estimation.

Acknowledgements

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