Review of the 2018 Lombok Earthquake, Indonesia, and Its Impact from Previous Studies

Achmad Fajar Narotama Sarjan(✉) and Ismail Hoesain Muchtaranda

Department of Civil Engineering, Faculty of Engineering, University of Mataram, Mataram, Indonesia

afana@unram.ac.id

Abstract. A series of strong earthquakes struck Lombok Island on 29 July (M 6.4), 5 August (M 7.0), 9 August (M 5.9), and 19 August (M 6.3 and M. 6.9) 2018 which led to severe damage with more than 500 deaths, 1,833 injured and devastated 186,010 houses (National Disaster Mitigation Agency). Lombok Island is categories as a vulnerable to earthquake zone because located between the Eurasian and Indo-Australian subduction trenches and in the northern part of Lombok lies the Flores back-arc thrust. Lombok Island are also flanked by two strike slip fault system in the west and east side of the Island. Rinjani volcanic complex are also located in the northern side of Lombok. In this manuscript, the 2018 Lombok Earthquake from previous studies were reviewed. The seismic activity and vulnerability from previous study were discussed to make preventive effort and mitigation option in the future.

1 Introduction

Lombok Island has a quite complex geological order characterized by the presence of faults, volcanoes, high and low lands. Due to the existence of those features resulting in the hazard potential in Lombok especially in earthquake. This potential could be caused by Flores back-arc thrust fault which stretches from north Flores to north Bali or from the subduction zone located in the southern of Indonesia. Although many events occurred in the past, the history of seismic events that have occurred is not understood because the amount of data available is limited. The earthquake potential reappears on July 29 to August 19, 2018 (Figure 1) caused more than 500 deaths, 1,833 injured and devastated 186,010 houses according to the data reported by National Disaster Mitigation Agency [1]. Reference [2] reported that there were five massive earthquakes with magnitude greater than 6 struck Lombok during this period with epicenters located on the north of Lombok. These events were followed by aftershock activities extended from northwest

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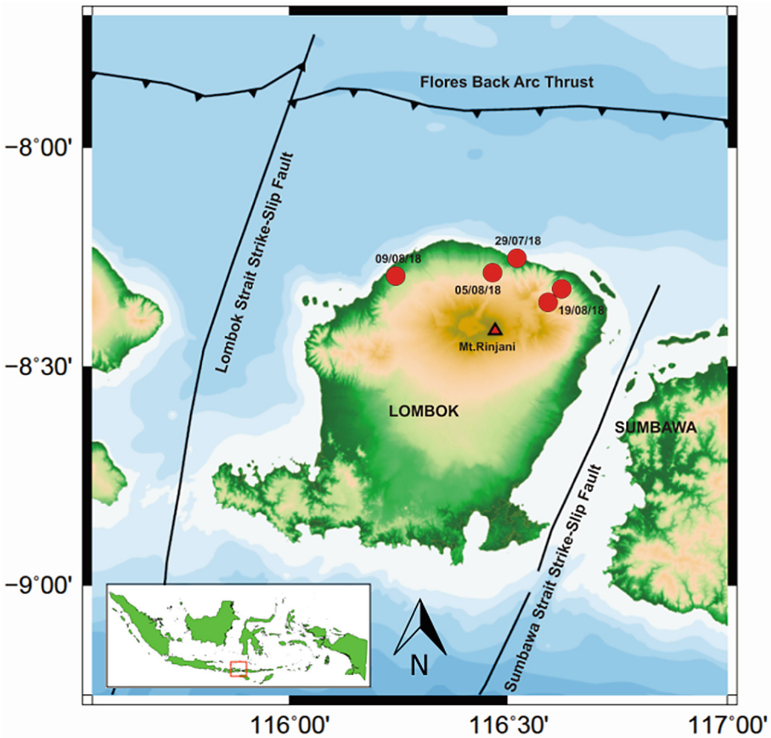

Fig. 1. Map of Lombok Island, Indonesia. Red circle represents 4 significant earthquakes that occurred on 2018 obtained from The Indonesia Meteorological, Climatological, and Geophysical Agency [2]. Red tringle represent volcano; inset map is the Indonesian region.

to northeast. The earthquakes that occurred on this period reach maximum intensity of VIII-IX modified Mercalli intensity (MMI) felt in north, west, and east Lombok [3]. The earthquake series that occurred in 2018 is an interesting topic to be learned as it generated a large number of events in a short time.

The aim of this paper it to review studies that discussed about 2018 Lombok Earthquake and its effects to provide information about how the earthquake caused severe damage around Lombok Island. The potential damage intensity effect causes by this condition and behavior is essential to be investigate by the geophysicist and geotechnical engineering. Figure 2 depict the impact of 2018 Lombok earthquake series occurred near the north coast that caused damages to buildings and roads. As we know that earthquake is the most damaging natural disaster that potentially causes fatal damage on infrastructure in highly populated seismic-prone areas [4]. Based on the explanation it is substantial to assess the seismic hazard on Island of Lombok.

Fig. 2. The impact of Lombok Earthquake on 2018 which damaged most of the resident's houses in North Lombok [15].

2 Geological Setting

Lombok Island is located in the eastern part of Indonesia and is part of the Sunda-Banda arc system [5]. According to [6] in the southern part of Indonesia there is the Indo-Australian Oceanic Plate that subduct beneath the Eurasian Plate with convergence rate approximately 70 mm/year to the north. The.

collision between Indo-Australian and Eurasian plate in the formation of Java-Sunda megathrust structures generated many strong earthquakes in the past where the recent happened in Pangandaran on 2006 [7]. Due to the complex tectonic conditions that exist

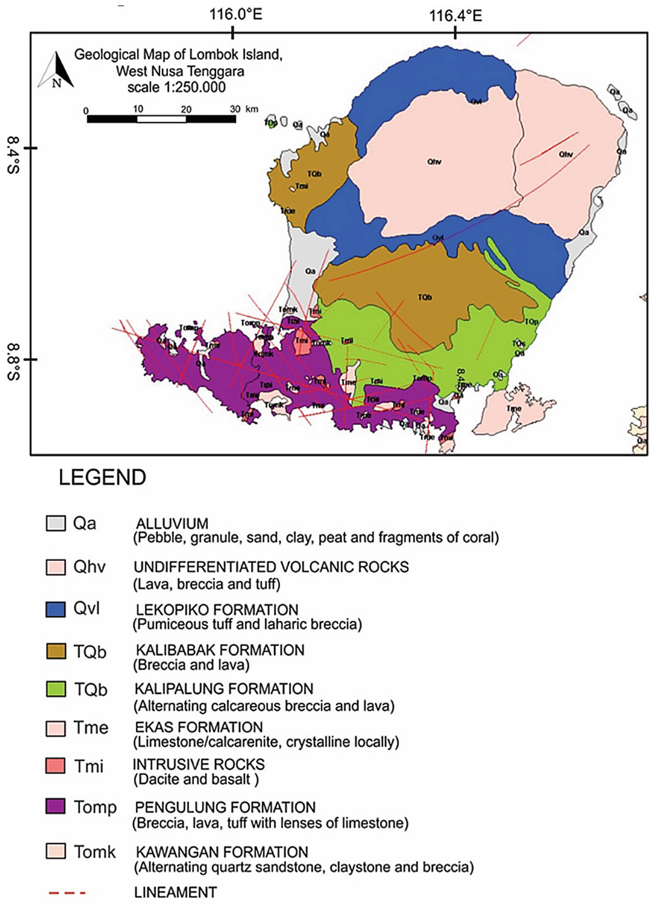

Fig. 3. Geological Map of Lombok Island modified from [12] in [13]

in this region forms the Flores Back-arc Thrust (FBT), which lies in the north of Lombok depict in Fig. 1 [8]. FBT is one of the active faults that first recognized in north Alor according to the 2D seismic reflection profiles [8][9]. The FBT has been known to extend across the Bali Basin due to the convergence with rate approximately 5.6–6 mm/year [9][6]. Over the last century, a number of seismic activities along this region indicates that the FBT system plays an important role in accommodating the stress transfer to the back-arc. Two geological structures (strike-slip fault) are also on the west and east of Lombok Island (Fig. 1) namely the Lombok and Sumbawa Faults, respectively shown in Fig. 1 [10].

Reference [11] stated that Sundaland was largely surrounded by inactive margins with localized strike slip deformation, extension, and subduction from 90 to 45 Ma.

From Physiographic aspect, Lombok Island is included in the Nusa Tenggara Volcanic arc which is part of the eastern Sunda arc and the western Banda Volcano arc [12]. From the geological map of [12] there were eight rock groups on the Island of Lombok

(Fig. 3): igneous intrusive and sedimentary rock groups as the oldest lithological unit located in the southern part of Lombok. Tertiary and Quaternary lavas rock groups as the younger units spread on the northern part of Lombok. Alluvium deposits (pebble, granule, sand, clay, peat and also fragments of coral) as the youngest unit accumulated along lowland zone in the eastern and western coasts including Mataram City as the provincial capital. Overall, the lithology on Lombok is mostly controlled by the activity of Rinjani volcano located in the north-east of Lombok. The most recent eruption of this volcano occurred in September 2016 [14].

The lack of data and observation in the back-arc resulting in the unclear mechanism of thrusting system. Therefore, an evaluation of seismic study of Lombok is essential to be intensified for understanding more about the earthquakes mechanism in this system for assessing the associated seismic hazards.

3 Previous Geological and Geophysical Studies

The data that discussed in this study are from the previous research that conducted by [10, 13, 16], and [17]. The seismic data interval of the deployment was one month from 3 August to 9 September 2018 by 20 seismographs from Bandung Institute of Technology, the Earth Observatory of Singapore/Nanyang Technological University, and the Center of Volcanology and Hazard Mitigation.

The deployment duration of seismograph around Lombok Island was for approximately 34 days and captured several big earthquake events, such as the 5 August (M 7.0), 9 August (M 5.9), and 19 August (M 6.3 and M 6.9). From previous study of [10] was first identified a total of 3,259 aftershock events ranging from M 1.7 to M 6.7. The results proved that the earthquake events distributed in the northern part of Lombok Island and have a reverse fault mechanism with an east-west orientation strike parallel to the FBT. By using the hypocenter distribution and the focal mechanism of the events, [10] stated that the earthquake series triggered by the subducting Flores crust in which this crust is segmented, and the failure of each successive segment leads the failure of the next segment to create a large earthquake shortly afterward [17]. Reference [10] concluded the hypocenters of the earthquake series that occurred was at a depth less than 35 km triggered by the movement of Flores Oceanic Crust to the south. The shallow rupture can explain the ground damage that happened in Lombok Island. Figure 4 depict the damage that occurred during the earthquake series, which the red, yellow and green zones indicate the severe, moderate and light damage zones, respectively [1].

For the seismic vulnerability index, the previous study from [16] calculated the value after the predominant frequency and amplification factors were obtained according to the equation that proposed by [18].

The result obtained from [16] study shows high values in the western region of Lombok that can be interpreted as the alluvium deposits (Fig. 5). This is in accordance with the geological map provide by [12]. The discrepancies between the damage map from National Disaster Mitigation Agency and the seismic vulnerability map shows that there are other factors that affect the damage such as building construction and material used. Reference [19] stated buildings that have the same frequency with the soil characteristics below will lead to resonance and have a greater chance of being severely damaged.

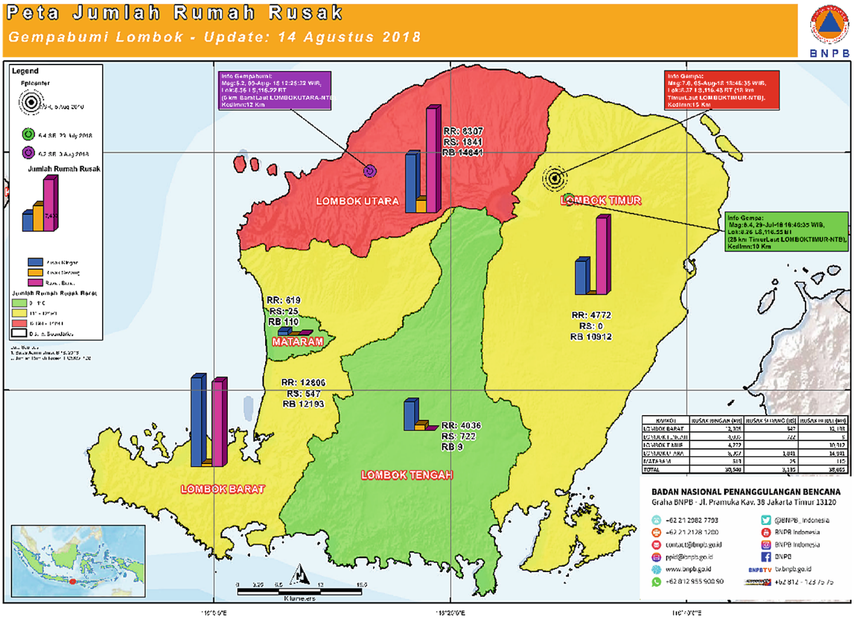

Fig. 4. Map of damage caused by the Lombok Earthquake series on 2018 [1].

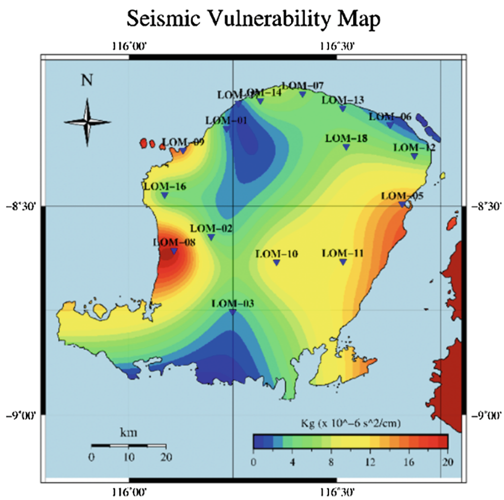

Fig. 5. Seismic Vulnerability Map [16]

4 Earthquake Effect on Civil Engineering Structures

Earthquakes are natural phenomena that yet cannot be predicted but the resulting impact can be minimized. A significant earthquake event that occurs in densely populated area such as urban area, will causes many forms of damage in facilities and buildings [20].

The destruction caused by an earthquake not only rely on the magnitude and intensity of the event, but also the building techniques and the local geological condition [21]. Furthermore, buildings will be more vulnerable to earthquake when using poor construction method. Buildings that effectively apply appropriate construction codes tend to be more resistant to damage [22]. In earthquake-prone areas such as Island of Lombok, it is necessary for the buildings to be designed to resist most earthquakes. To improve the quality of earthquake-resistant buildings, it is required for civil engineer to collaborate with geologist, seismologist, and urban engineer to provide decent construction codes.

Reference [23] was the first develop the construction code as follows: 1) Design of the buildings and the floor plan should be nearly symmetrical on two orthogonal axes with reference to walls, weight, and all other structural elements; 2) the length of the structure should be $\leq$2.5 times its width as well as the height to the base; 3) the required floor system are rigid and resistant for each level of the structure; 4) The columns must be bounded in two orthogonal directions; 5) the structural floor plan irregularity threshold of the total length is less than 20% and calculated parallel to the direction of deviation; 6) the roof openings dimension is less than 20% of the plan dimension; 7)There is no floor of a structure may have an area larger than the floor below or less than 70% of that level, except the last floor; and 8) each floor of the structure should not weigh less than 75% of the floor below or more than the weight of the floor below.

5 Conclusions

There are several studies that examine about 2018 Lombok Earthquake series such as [7, 10, 13, 16], and [17]. Reference [7] from InSAR measurements revealed that earthquake sequences occurred in Lombok on 2018 was triggered from three segments in the north side of Lombok. Due the ruptured of the three segments, it resulted in more than 3000 earthquakes which were successfully measured and relocated by [10] using 28,728 P- and 20,713 S-wave arrival times. The majority of the earthquake events were at a depth of 5 and 25 km.

The vulnerability map produced by [16] indicates there is a zone with a high potential for earthquake damage located on the west of Lombok associated with a large thickness of alluvium unit. However, there are discrepancies between the earthquake damage map provided by National Disaster Mitigation Agency and vulnerability map. This indicates that there are other factors that affect the damage index such as building construction and max ground acceleration.

From several studies that have been carried out related to the Lombok earthquake series, there is still a lot of room that needs to be investigated further regarding the earthquakes potential in Lombok and to be considered in building construction on future civil engineering design. It is essential for introducing the safe structure design with the seismic construction code in seismic-prone areas such as in Lombok to prevent from the severe devastation of the structure.

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