The ground deformation of the Luk Barat Bridge after Lombok earthquakes 2018

D S Agustawijaya\textsuperscript{1}, T Sulistyowati\textsuperscript{1}, B A Layli\textsuperscript{1}, A R Agustawijaya\textsuperscript{2}

\textsuperscript{1}Department of Civil Engineering, University of Mataram, Mataram, Indonesia
\textsuperscript{2}Department of Geomatics Engineering, ITS, Surabaya, Indonesia

Abstract. The Luk Barat Bridge has an important role in transportation infrastructures in the North Lombok District, connecting cities in Lombok Island. Unfortunately, the bridge is located where the most vulnerable area in Lombok Island, as earthquakes occurred in 2018 have ruined almost one third of the island and destroyed thousands of buildings. The bridge has been deformed after the earthquakes. Geodetic measurement showed that the bridge has displaced in total of 0.36 m measured from the datum point of BM2 near located closed to the bridge area. Numerical modeling also indicated a similar value of displacements.

1. Introduction
The Luk Barat Bridge is located in the North Lombok District of the West Nusa Tenggara Province in Indonesia. The bridge is one of many important transportation infrastructures, connecting cities in Lombok Island (Figure 1). Unfortunately, the location is the most vulnerable site within the island, since multiple earthquakes continuously occurred during 29\textsuperscript{th} July – 30\textsuperscript{th} September 2018 (Figure 2), have ruined one third of the island [1].

\textbf{Figure 1.} The Luk Barat Bridge in Kayangan of North Lombok District
In general, earthquakes around the island are generated by two sources: southern subduction mega-thrust and northern back-arc thrust. These two sources create different types of seismic events. The subduction tends to generate deep events; conversely the back-arc thrust tends to generate shallow seismic events [3]. During 29th July – 30th September 2018, earthquake events mostly located in the north part of Lombok Island, where were positioned in the back arc basin called the Bali basin [4]. Unfortunately, the events might re-activate the Flores reverse fault located along the back arc of Lombok and Flores Islands [5].

The Luk Barat Bridge is just located within the epicenter zone of the earthquake occurred on the 5th August 2018, it certainly should be influenced by the earthquake causing the displacement of the bridge. Thus, this paper focuses on measuring the deformation induced by earthquake forces on the Luk Barat Bridge.

2. Method

Earthquake catalogue from the United State geological Survey [6] was used to calculate peak ground acceleration. The Boore-Atkinson empirical equation might be suitable to the tectonic conditions of Lombok Island; so, it was then applied for the calculation of the peak ground motion (PGA) of the shallow back-arc reverse fault sources [7] [8] [9]. The calculation of the bridge weights followed the Indonesian Standards for bridge [10]; while, the SNI 2833:2016 procedures [11] were followed for earthquake force calculations, involving short spectrum acceleration (S_s) at 0.2 second, and long spectrum acceleration (S_l) at 1 second parameters. The earthquake forces (V) were consequently calculated as follows:

\[ V = C_s W \]

Where,

\[ C_s = \frac{S_{DS}}{R} \]

\[ S_{DS} = \frac{2}{3} S_M \]

\[ S_M = S_S F_A \]

\[ S_S = \text{short spectrum acceleration at 0.2 second} \]

\[ F_A = \text{coefficient of acceleration} \]

\[ R = \text{reduction factor} \]
Geodetic surveys were conducted to the bridge to measure displacement in vertical and horizontal directions. Then, numerical modeling was conducted to evaluate the deformation of the bridge. To support ground data, Dutch cone penetrometer tests were also conducted to gain the information of soil layers [12].

3. Results and Discussion

3.1. Peak Ground Acceleration and Earthquake Forces

A single event of the magnitude of 6.9 of the 5th August from the USGS catalogue [6] was used for the Luk Barat Bridge, which resulted in the PGA of 0.6. This PGA might be is higher than that the SNI value of 0.4 g [9]; but, it should be relevant to calculate the current earthquake forces. All parameters are calculated using (1), as follows (Table 1):

Table 1. Parameters for earthquake forces

| Parameter  | Value       |
|------------|-------------|
| PGA (g)    | 0.45        |
| S₅ (g)     | 1.025       |
| S₁ (g)     | 0.418       |
| Fₘ         | 0.9         |
| Fᵥ         | 2.4         |
| Sₘ (g)     | 0.923       |
| Sₘ₁ (g)    | 1.003       |
| S₃ (g)     | 0.615       |
| S₃₁ (g)    | 0.669       |
| T₀         | 0.218       |
| Tₛ         | 1.089       |
| W (kg/m²)  | 253726.03   |
| Iₑ         | 1.0         |
| R          | 1.5         |

Using data on Table 1, the calculation of earthquake forces resulted in a value of shear forces (V) of 10.4 kg/cm². This value might be sufficient to displace the bridge, as measured using a geodetic method.

3.2. Geodetic Measurement

Geodetic measurements were conducted on the surface of the Luk Barat Bridge along and cross the bridge. The distance was 42 m measured in every 1 m distance, while the datum point was a 10 m distance from the bridge. Three lines along the bridge were measured: left (Ki), middle (T) and right (Ka). Results of measurements can be seen in Figure 3.
Figure 3. Long section geodetic measurements on: A) the left side (Ki); B) middle; C) right side of the Luk Barat Bridge in Kayangan of the North Lombok District.

In Figure 3, the whole left side of the bridge has displaced with a maximum vertical displacement of 0.298 m on the point 6; while, the bridge had a maximum displacement of 0.388 m on the middle part of the point 5. The right side of the bridge had higher displacements compared to left and middle parts of the bridge. The maximum displacement on the right side was on the point number 10 which was 0.406 m. Thus, the vertical displacement of the bridge was 0.364 from all measurements.

For horizontal displacements, measurements were focused on the point number 10, which resulted in a horizontal displacement of 0.043 m from the centre point of the bridge away towards the direction of Mataram City (West direction).

Figure 4. Cross section geodetic measurements on the point number 10 of the Luk Barat Bridge in Kayangan of the North Lombok District.
3.3. Dutch cone penetrometer test (DCPT)

Four locations were tested with DCP on both sides of the bridge: west and east sides. Results of the test had four different depths, but for displacement analysis only two locations on SO-1 and SO-2 with depths of 2.4 and 10.8 m. respectively, were applied. Then, both DCPT data were put on each side of the bridge: west and east, as can be seen in Figure 5.

Soils under the bridge could be divided into four types based on the values of penetration cone resistances: silty sand at depths of 0 – 2.2 m; sand at depths of 2.2 – 6.0 m; silty sand at depths of 6.0 – 9.5 m; sand at depths of 9.5 – 10.8 m.

3.4. Deformation modelling

Deformation modeling has been conducted to evaluate numerical ground displacements. The model used plain-stain conditions with linear-elastic Mohr-Coulomb failure mechanisms [13] [14]. Data of soils obtained from laboratory can be seen in Table 2.

| Parameter                             | Sand      | Silty sand |
|---------------------------------------|-----------|------------|
| Saturation                            | Drained   | Drained    |
| Saturated unit weight (γ_sat) (kN/m³) | 13.96     | 13.85      |
| Unsaturated unit weight (γ_unsat) (kN/m³) | 11.14     | 10.09      |
| Plasticity index                      | Non plastic | Non plastic |
| Horizontal Permeability koef (kx) (m/s) | 1 x 10⁻⁵  | 5 x 10⁻⁵   |
| Vertical permeability koef (ky) (m/s)  | 1 x 10⁻⁵  | 5 x 10⁻⁵   |
| Young’s modulus (E) (kN/m²)            | 10000     | 12000      |
| Poisson ratio (υ)                     | 0.3       | 0.3        |
| Cohesion (C) (kN/m²)                  | 0.216     | 0.063      |
| Friction (ψ₀)                         | 35        | 33         |
| Dilatancy (ψ₀)                        | 0         | 0          |

Using data from Table 1 for soils, load calculations Table 1 for bridge weights and earthquake forces, the total displacement model of the Luk Barat Bridge can be seen in Figure 6.
Deformation numerical model showed that displacements mostly occurred within sandy soils (layer 2) that had a thickness of 3.8 m. The total displacements, resultant of horizontal and vertical displacements, under the foundations of the bridge were from the E to the point I within the layer 2, which were from 0.3 m to 0.7 m. The average total displacement would be 0.5 m under the bridge.

4. Conclusions
A series of Lombok earthquakes in 2018 has deformed the Luk Barat Bridge in Kayangan of the North Lombok District. Geodetic measurements resulted in vertical and horizontal displacements of 0.364 and 0.043 m, respectively. Numerical modeling supported the geodetic measurement with an average total displacement of 0.5 m occurred mostly within sandy soils at depths of 2.2 – 6.0 m.

References
[1] Indonesian Agency for Meteorology, Climate and Geophysics (BMKG) 2018 Press Release No: UM.505/3/D3/VIII/2018 (Jakarta: BMKG)
[2] Indonesian Agency for Meteorology, Climate and Geophysics (BMKG) 2018 Katalog Gempabumi Signifikan dan Merusak 1821-2018 (Jakarta: BMKG) https://cdn.bmkg.go.id/Web/Katalog-Gempabumi-Signifikan-dan-Merusak-1821-2018.pdf
[3] Agustawijaya D S, Sulistiyono H, Elhuda I 2018 Determination of the seismicity and peak ground acceleration for Lombok island: an evaluation on tectonic setting, MATEC Web of Conferences, 195 03018. https://doi.org/10.1051/matecconf/201819503018
[4] Hamilton W 1974 Earthquake Map of Indonesian Region, USGS, Miscellaneous Investigation Serial Map 1-875-C, scale 1:5.000.000.
[5] Hamilton W 1979 Tectonics of the Indonesian Region. USGS Professional Paper 1078.
[6] United State Geological Survey (USGS) 2018 Search Earthquake Catalogue. https://earthquake.usgs.gov/earthquakes/search/ (accessed on 30th September 2018)
[7] Boore D M, Atkinson G M 2008 Ground-motion prediction equations for the average horizontal component of PGA, PGV, and 5%-damped PSA at spectral periods between 0.01 s and 10.0s Earth. Spec. 24 1 pp 99–138
[8] Douglas J 2017 Ground Motion Prediction Equations 1964-2017 Report (c (Glasgow, UK: Dept. Civil Env. Eng., Uni. Strathclyd)
[9] Pusat Gempa Nasional (PUSGEN) 2017 Peta Sumber dan Bahaya Gempa Indonesia Tahun 2017 Irsyam M, et al. (Editors) (Jakarta: Kementerian Pekerjaan Umum dan Perumahan Rakyat) (in Indonesian)
[10] Standar Nasional Indonesia 2016 Pembebanan untuk Jembatan SNI 1725:2016 (Jakarta: Badan Standardisasi Nasional) (in Indonesian)
[11] Standar Nasional Indonesia 2016 Pembebanan Jembatan Terhadap Beban Gempa SNI
2833:2016 (Jakarta: Badan Standardisasi Nasional) (in Indonesian)

[12] Standard Test Method for Mechanical Cone Penetration Testing of Soils ASTM D3441 – 16
https://www.astm.org/Standards/D3441.htm

[13] Agustawijaya D S 2018 Influence of rock properties in estimating rock Strength for shallow underground structures in weak rocks Ind. J. Geosci. 5 2 pp 93-205 DOI: 10.17014/ijog.5.2.93-105

[14] Agustawijaya D S 2019 Practical applications of strength criteria in civil engineering designs for shallow tunnels in weak rock Int. J. Tech. 10 1 pp 16-26