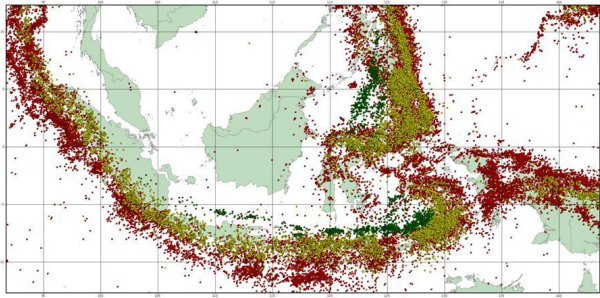


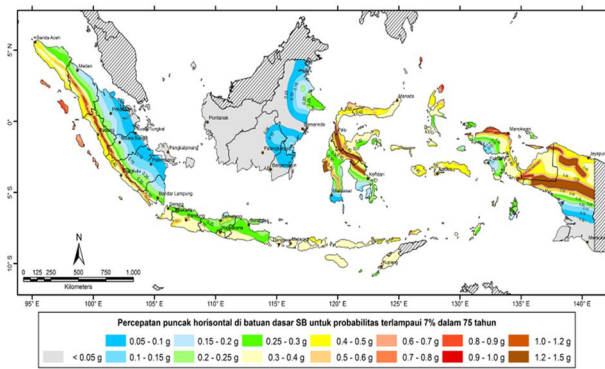


Island. Indonesia Earthquake happening is shown in the following figure.

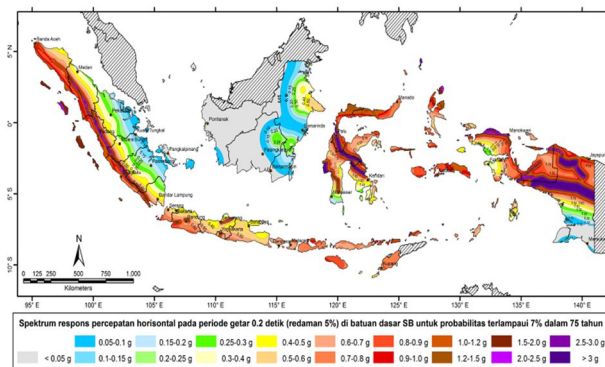


**Fig. 3.** Records of Earthquake in Indonesia

The red dot color is shallow earthquake (<70 km), yellow dot color is intermediate earthquake (70-300 km), green dot color is deep earthquake (>300 km), Iswandi Imran, E.K. Kertapati, 2018 [4]. The earthquake in Indonesia has been regulated in SNI 2833:2016 with a map in the year 2017.



**Fig. 4.** Bed Rock Tremor Acceleration with probability exceeding 7% within 75 years

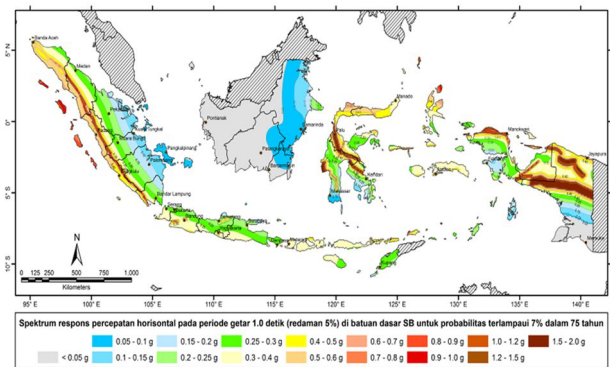


**Fig. 5.** Bed Rock Tremor Acceleration with probability exceeding 7% within 75 years on the 0,2 second period of vibration (damping 5%)

In Indonesia, the bridge is divided into [2]:

1. Critical Bridge
2. Essential Bridge
3. Other Bridge

The foundation of the bridge must be stronger than the pier, so the magnitude was divided into the earthquake with 1,5 typically. For the detail analysis reader can refer to push over design.



**Fig. 6.** Bed Rock Tremor Acceleration with probability exceeding 7% within 75 years on the 1 second period of vibration (damping 5%)

### Upper Structure Earthquake Force Design

$$= \frac{\text{Earthquake Force Design}}{1,5} \quad (1)$$

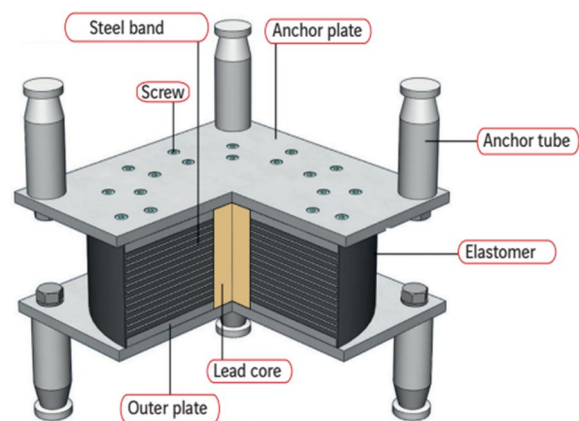
### Foundation Structure Earthquake Force Design

$$= 1x \text{ Earthquake Force Design} \quad (2)$$

Foundation Earthquake design takes into account all the earthquake magnitude without reduction to avoid plastic hinge formed in a pile.

## 2 Method

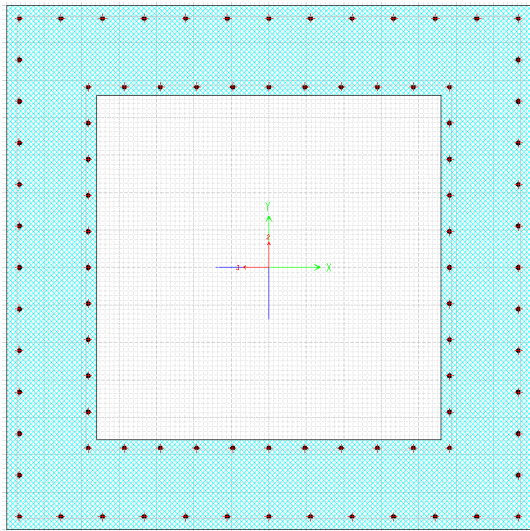
To mitigate the earthquake that we discussed here, we use LRB (Lead Rubber Bearing), with the properties of the material as follows.



**Fig. 7.** Lead Rubber Bearing Section View

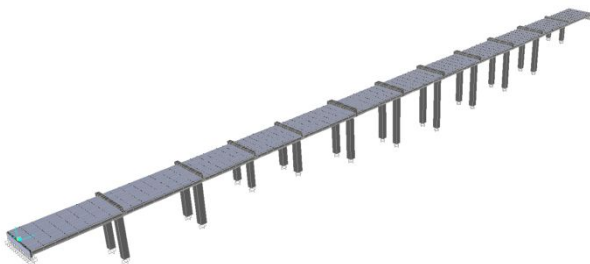
The lead core is a smart material that can return to its original form once it is deformed (by the earthquake).

First, the structural model was created. The column is modeled as follows:



**Fig. 8.** The Cross-Section of the Pier (The Biggest Pier)

The inner part is an Opening. And we define the structure as follows, extruded view.

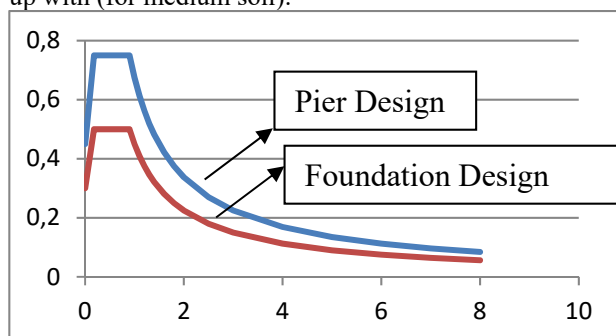


**Fig. 9.** The Structural Modelling of The Bridge (Kenteng Bridge)

The span between each pier is 30 meter-40 meters. The dimension of the column is 3000x3000 (with 400 mm thickness), 3500x3500 (with 500 mm thickness), and 3500x3500 (with 600 mm thickness). The slab thickness is 220 mm. The design use PCI girder (I girder).

### 3 Analysis

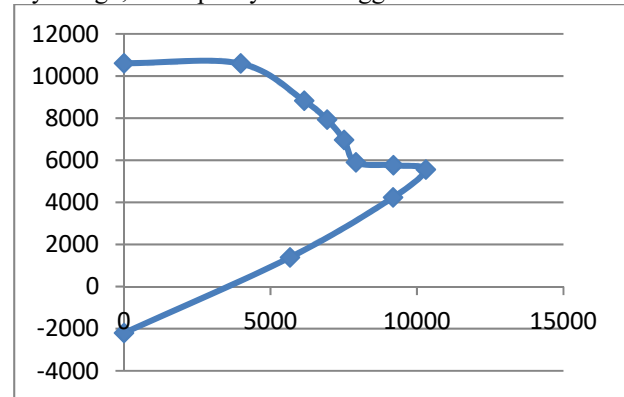
After the calculation of the response spectrum, we come up with (for medium soil):



**Fig. 10.** Response Spectrum Chart Period (second) x Axis vs Tremor Acceleration (g) y Axis

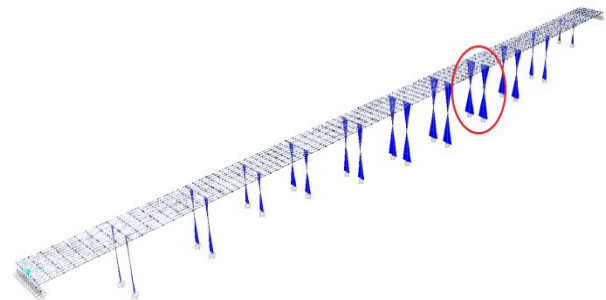
For the live load, we simplify only take into account the 9 kPa (0,9 ton/m<sup>2</sup>) [1] multiply by the earthquake live load reduction factor 0,3 for essential bridge. For simplicity, we only take into account the lateral earthquake force (1 direction).

By design, the capacity of the biggest columns is:



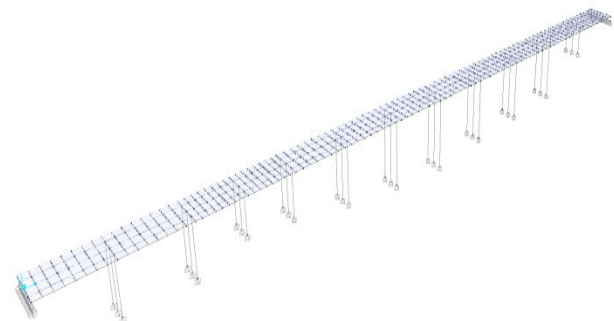
**Fig. 11.** Column Interaction Diagram of Axial Force (y-axis: ton) vs. Moment (x-axis: ton-m)

The biggest moment that can be resisted by the column is 10.000 ton-m. However, the actual happen column moment that due to the earthquake is 15.000 ton-m as follows.



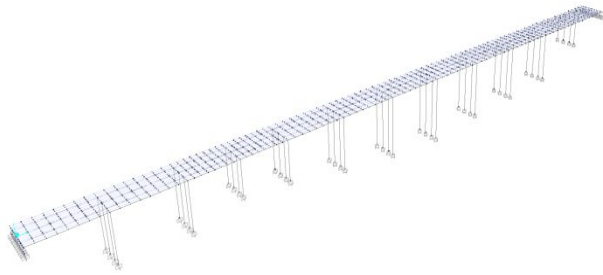
**Fig. 12.** Response Spectrum Moment that is used for the design criteria for non-LRB structure analysis.

First, we add the column in the middle of the pier head as follows.



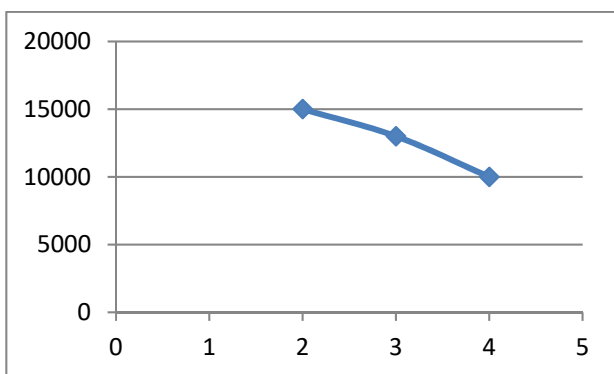
**Fig. 13.** Trial by Adding 1 Column in the Middle

The three-column configuration result in 13.000 ton-m moment due to earthquake shock. Since 13.000 ton-m is still higher than 10.000 ton-m, the column capacity, we add more one column in the trial as follows.



**Fig. 14.** Trial by Adding 2 Column in (1 in the middle, one on the side)

After we add one more column, the moment happens in the analysis due to the earthquake reduced to 10.000 ton-m, which is equal to the column capacity. By combining two piers, the moment that happens is only somehow 10.000 ton-m. So it is clear that without LRB, the volume of concrete to create pier will be multiplied by two times. From this moment, we can also conclude that the volume of footing/pile cap will be multiplied by two times, and so does the pile. This conclusion leads to the use of LRB is the right decision. The trial chart is as follows.



**Fig. 15.** The trial chart to get 10.000 ton-m moment (X-Axis: The Number of Column/Pier; Y-Axis: The Moment Due to Earthquake ton-m)

To compare whether using LRB [3] will be more economical, we use the price data of LRB. LRB price (including installation and procurement): 94 million rupiah. There are 360 LRB installed on-site, in Kendeng Bridge. So the cost of the LRB will be 33,840 million rupiah (360 \* 94 million rupiah). The contract price is 424,000 million rupiah. So. The deducted price without LRB will be 390,160 million rupiahs. This number (390,160 million rupiah) is the price without the earthquake-resistant system. By multiplying the number of the pier, footing, and foundation with 2 resulted in the additional number of price 111,081 million rupiah, it was 19 percent more than 424,000 million rupiah [5]. The more detailed calculation of the additional amount is as follows.

1. Pier = 2563 m<sup>3</sup> \* 1,986,000 rupiah = 5,090,118,000 rupiah

2. Footing = 20,394 m<sup>3</sup> \* 1,896,000 rupiah = 38,667,024,000 rupiah
  3. Soil Bored Pile Diameter 1,5 meter = 3,370 m<sup>1</sup> \* 7,500,000 rupiah = 25,275,000,000 rupiah
  4. Stone Bored Pile Diameter 1,5 meter = 2,564 m<sup>1</sup> \* 16,400,000 rupiah = 42,049,600,000 rupiah
  5. Elastomeric Bearing Pad = 360 each \* 4,000,000 rupiah = 1,440,000,000 rupiah
- Total Additional Cost = 5,090,118,000 + 38,667,024,000 + 25,275,000,000 + 42,049,600,000 + 1,440,000,000 = 112,521,742,000 rupiah
- The total cost of the construction without LRB will be: 112,521,742,000 + 424,000,000,000 = 502,681,742,000 rupiah

$$Saving = \frac{Price\ without\ LRB - Price\ with\ LRB}{Price\ without\ LRB} * 100\% \quad (3)$$

$$Saving = \frac{502,681,742,000 - 424,000,000,000}{502,681,742,000} * 100\% \quad (4)$$

$$Saving = 16\% \quad (5)$$

## 4 Conclusion

The price increase without using LRB will be 16% of the budget. It can be concluded that by using LRB the saving of the budget for this type of bridge is 16%. It is important to use LRB in nowadays bridge as it will reduce the earthquake force a lot. This study is only limited to the simple span structure and continuous beams, further study need to be developed into more detail study of the behaviour of the LRB during and after the earthquake for more sophisticated bridge such as cable stayed or balance cantilever bridge.

## 5 Reference

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