Response structure analysis of prestressed box girder concrete bridge due to earthquake loads

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Abstract. The damage of the bridge structure that occurs in Indonesia is almost close to the number of bridge construction. The damage condition is also related to the influence of Indonesia on active tectonics and volcanic pathways which cause damage to the bridge structures. The analysis of the structural response of the prestressed box girder concrete bridge aims to identify the value of the displacement structure on the bridge pier against the earthquake load. Meanwhile, the structure responses numerical analysis of the prestressed box girder concrete bridge using MIDAS CIVIL software. The analysis of structure response prestressed box girder concrete-bridge structure is carried out with three soil conditions, that is hard soil, medium soil, and soft soil. The results of the study, the displacement value on the pier bridge on X direction for hard soil conditions is 1.26 cm, medium soil is 1.53 cm, and soft soil is 2.02 cm. Thus, it can be concluded that the value of the bridge displacement due to the planned earthquake load on hard soil conditions is 21.4% smaller than that in the medium-soil condition and 60.32% smaller than the soft soil.

1. Introduction

According to the Statistics Information Book [1], in 2016, Indonesia recorded has 18,014 bridge units, but around 61.59% of bridges in Indonesia were not in good condition and damaged. Indonesia is one of the most seismically active countries on earth. Indonesia occupies a very active tectonic zone because the three large plates of the world and other small plates meet each other in the territory of Indonesia. The existence of interactions between these plates places the territory of Indonesia as a region that is very prone to earthquakes [2].

The pier system on the bridge can be a single or compound column or can be a full wall. In the SNI 2833-2016 regulation of bridge design against earthquake loads, the difference in pier systems is in the modification factor of the response of earthquake values (R) that can be deployed by each bridge structure system or subsystem [3].

An earthquake is a disaster that can be harmful to the community, such as financial loss and also a risk of death. Pekanbaru is a city located in the middle of Sumatera Island. Even though the city of Pekanbaru is a city that rarely occurs earthquake, but Pekanbaru has ever felt the impact of the big earthquake that occurred in West Sumatera in September 2009 [4].

In the western part of Indonesia, the process of subducting the Indo-Australian Plate into the Eurasian Plate in western Sumatra resulted in the occurrence of earthquakes with magnitudes 8 or 9 that are very vulnerable. For example, in 2004, the earthquake in Banda Aceh City with magnitude 9.2 caused damage to 120 bridges with a category of severe damage [5], [6].

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The purpose of this study was to analyze the earthquake acceleration performance with three soil conditions, namely hard, medium and soft soil on the bridge pier. The choice of analysis on the pier section of the bridge is based on the fact that the failure of the structure on the bridge pier will fail the overall bridge structure. This analysis uses nonlinear static, which is using MIDAS CIVIL software so that the planned bridge has a high earthquake resistance and is more economical.

2. Literature Review

In this analysis, the bridge girder used is a box-type girder type which is designed for prestressed concrete that has a long span, which is 200 meters. According to [7], [8], prestressed concrete is reinforced concrete which has been given low stress to reduce the potential tensile stress in the concrete due to workload. According to [9],[10], loading is the magnitude of the load used in calculating the structure so that it does not experience destruction during the life of the bridge. The loads that must be analyzed in a bridge plan are divided into three groups, namely permanent load, traffic load, and earthquake load.

The permanent load consists of the weight and additional dead load.
1. Self-weight is the weight of materials and the parts of a bridge consisting of structural elements such as girder, floor plate, and diaphragm.
2. An additional dead load is the weight of all materials which give rise to a load on the bridge consisting of non-structural elements. The additional dead loads are asphalt, sidewalks, curbs, and safety fences.

In this study, earthquake analysis was divided into three land categories, namely the categories of hard, medium and soft soil types based on PGA values from the Pekanbaru area around 0.214 g. Based on SNI 2833–2016, the spectrum response is a graph that states the relationship between the period of vibrating structure (T) and the maximum structural response when experiencing existing earthquake vibrations. For practical needs, the spectrum response is simplified in graphical form as can be seen in Figure 1.

![Figure 1. Typical Form of Response to the Earthquake Spectrum](image)

The requirement for the number of variations is regulated in SNI 2833: 2016 where the number of variations must be sufficient to get the participation of combined mass variations of at least 90% of the
actual mass in each orthogonal horizontal direction of the response reviewed by the model. If it is not sufficient, then the amount of variety must be increased to meet the requirements for mass participation.

3. Research Methodology

Bridge structure modeling refers to the case study of the construction of the SEI SIAK II (MYC) prestressed concrete girder bridge on the Pekanbaru-Duri Cross Road located in the Rumbai District area, Pekanbaru City.

The bridge structure data analyzed are as follows:

1. Type of girder = box girder
2. The quality of concrete girder = fc'45
3. Total length = 200 meters
4. Total width = 10.6 meters
5. Number of spans = 1 span
6. Total lane = 2 lanes
7. Width of lane = 5 meters
8. Number of girder = 51 pieces
9. Girder dimensions = varies
10. Floor plate thickness = 0.25 meters
11. Pier depth = 5 meters

Mechanical Properties of Structural Materials

Structural Concrete with characteristics:
1. Concrete compressive strength, fc' = 45 Mpa
2. Modulus of Elasticity, Ec = 4700√(fc') = 4700 √45 = 31528,55848 Mpa

Tendon with characteristics:
1. Steel Structure, BJ 37
2. Melting Point 240 Mpa
3. Modulus of Elasticity, E = 200000 Mpa
4. Types of strands: uncoated 7 wire super strands ASTM A-416 grade 270
5. Diameter strands = 0, 01270 m

The number of strands is used as follows:
1. ns1 = 11 tendons, 19 strands / tendons = 209 strands with tendon sheaths = 85 mm
2. ns2 = 11 tendons, 19 strands / tendon = 209 strands with tendon sheath = 85 mm

Loading Bridge Structure

Permanent Load

1. Weight of box girder (QMS)
   a. Box girder weight per m (QMS)
      = Average × γ
      = 9.224 × 25.5
      = 235,212 kN / m
   b. Maximum shear force (VMS)
      = 10/8 × QMS × L
      = 10/8 × 235,212 × 200
      = 14974.84 KN

2. Additional dead load (MA)
   a. Weight (bitumen + rainwater) = 13,384 kN / m

3. Traffic Load
   Line load on the girder:
   QTD = q × S × YTD
   = 9.0 × 4.8 × 1.8
   = 48.6 kN / m
   PTD = (1 + DLA) × p × S × DTD
   = (1 + 0.3) × 49.0 × 4.8 × 1.8
MTD = \left( \frac{1}{8} \times QTD \times L^2 \right) + \left( \frac{1}{4} \times PTD \times L \right) = 260199 \text{kNm}

Maximum shear force:
\text{VTD} = \left( \frac{1}{2} \times QTD \times L \right) + PTD = 5203.98 \text{kN}

Earthquake Load

For Hard Soil
\text{AS} = FPGA \times PGA = 1.187 \times 0.213 = 0.253 \text{g}
\text{SM1} = Fv \times S1 = 1.526 \times 0.274 = 0.418 \text{g}
\text{SD1} = 2/3 \times \text{SMS} = 2/3 \times 0.520 = 0.346 \text{g}

Calculates the parameters T0 and Ts
\text{T0} = 0.2 \times \text{SD1}/\text{SDS} = 0.2 \times 0.279/0.346 = 0.161 \text{s}
\text{Ts} = \text{SD1}/\text{SDS} = 0.279/0.346 = 0.805 \text{s}

For Medium Soil
\text{AS} = FPGA \times PGA = 1.374 \times 0.213 = 0.293 \text{g}
\text{SM1} = Fv \times S1 = 1.851 \times 0.507 = 0.507 \text{g}
\text{SD1} = 2/3 \times \text{SMS} = 2/3 \times 0.629 = 0.419 \text{g}

\text{T0} = 0.2 \times \text{SD1}/\text{SDS} = 0.2 \times 0.338/0.419 = 0.161 \text{s}
\text{Ts} = \text{SD1}/\text{SDS} = 0.338/0.419 = 0.806 \text{s}

For Soft Soil
\text{AS} = FPGA \times PGA = 1.636 \times 0.213 = 0.348 \text{g}
\text{SM1} = Fv \times S1 = 2.903 \times 0.274 = 0.795 \text{g}
\text{SD1} = 2/3 \times \text{SMS} = 2/3 \times 0.828 = 0.552 \text{g}

\text{T0} = 0.2 \times \text{SD1}/\text{SDS} = 0.2 \times 0.530/0.552 = 0.192 \text{s}
\text{Ts} = \text{SD1}/\text{SDS} = 0.530/0.552 = 0.960 \text{s}

4. Results and Discussion
4.1 Analysis of Spectrum Response Variety of Bridges (Capital Analysis)
The natural period and natural frequency of the bridge model must consider the percentage of the mass participation factor (capital mass participation factor). Based on SNI 2833: 2016, the amount of diversity must be taken in such a way as to produce cumulative mass participation of more than 90%. Analysis of variance was carried out up to 88th variance with cumulative mass participation reaching 100% and 100%, for X and Y directions. Because cumulative mass participation had exceeded 90%, the SNI 2833: 2016 requirement to continue the earthquake spectrum response analysis had fulfilled. The cumulative mass participation of the bridge model in this study can be seen in Figure 2.
The free vibration period of structure \((T)\) is a product of structural mass and structural rigidity. The first three forms of vibrating structures are shown in Figure 3. The period in the first range of 0.38374 seconds is called the fundamental period of vibration because it has the highest period value.

**Figure 2. Cumulative Variety Mass Participation**

MODE I

Period = 0.383734 seconds  
Frequency = 2.605972 Hz

**Figure 3. The fundamental period of Structural Vibration**

4.2 Response Analysis of Earthquake Structures of Bridge Structures

This section contains an explanation of the results of the spectrum response analysis. The observation point on the bridge reviewed is located on the bridge pier which can be seen in Figure 4. The spectrum response analysis in this study was conducted to obtain the structural response results on the box girder prestressed concrete bridges in the form of displacements.
The response structure reviewed is located on the bridge pier. The result of the structural response from the MIDAS CIVIL software for hard soil, as shown in Table 1 and Figure 5.

**Table 1** Displacement Value of the Right Pier and Left Pier with Hard Soil Conditions.

| Pier Height (m) | Displacement Value (m) |
|-----------------|------------------------|
| 5.0             | 0.877832               |
| 4.4             | 0.658374               |
| 3.8             | 0.658374               |
| 3.1             | 0.438916               |
| 2.5             | 0.438916               |
| 1.9             | 0.438916               |
| 1.3             | 0.219458               |
| 0.6             | 0.219458               |
| 0.0             | 0.000000               |

**Figure 4** Observation Point

The response structure reviewed is located on the bridge pier. The result of the structural response from the MIDAS CIVIL software for hard soil, as shown in Table 1 and Figure 5.

**Figure 5** The Value of Displacement Graph and Contour for Hard Soil Conditions
From the graph, it can be seen that the displacement of the bridge pier structure with hard soil conditions increases at the top of the structure, whereas displacement value for Medium soil and soft soil can be shown in Table 2 and Table 3. The description of the displacement pattern for each type of soil in a sequence is shown in the Figure 7.

**Table 2** Displacement Value of X Direction in the Right Pillar and Left Pillar with Medium Soil Conditions On the Pillar of the Bridge

| Pier Height (m) | Displacement Value (m) |
|----------------|------------------------|
| 5.0            | 1.06330                |
| 4.4            | 0.79748                |
| 3.8            | 0.79748                |
| 3.1            | 0.53165                |
| 2.5            | 0.53165                |
| 1.9            | 0.53165                |
| 1.3            | 0.26583                |
| 0.6            | 0.26583                |
| 0.0            | 0.00000                |

**Figure 6** The Value of Displacement Graph and Contour for Medium Soil Conditions in X Direction

**Table 3** Displacement Value of the Right Pillar and Left Pillar with Soft Soil Conditions

| Pier Height (m) | Displacement Value (m) |
|----------------|------------------------|
| 5.0            | 1.39570                |
| 4.4            | 1.04678                |
| 3.8            | 1.04678                |
| 3.1            | 0.69875                |
| 2.5            | 0.69875                |
| 1.9            | 0.69875                |
| 1.3            | 0.34893                |
| 0.6            | 0.34893                |
| 0.0            | 0.00000                |
Figure 7. The Value of Displacement Graph and Contour for Soft Soil Conditions

Table 4. Maximum Displacement Summary Value for Multiple Soil Types

| No. | Location | Type of soil | Max Displacement (mm) |
|-----|----------|--------------|-----------------------|
| 1.  | Pekanbaru| Hard         | 0.8778                |
| 2.  | Medium   | 1.0633       |
| 3.  | Soft     | 1.3957       |

The maximum of displacement for three types of soil can be shown in Figure 8.

Figure 8. Maximum Displacement Value Graph on The Bridge Pier

5. Conclusions

Based on the results of the study can conclude several things as follows:

1. The pattern of maximum displacement value follows the pattern of peak surface soil spectrum (SDS); the higher the SDS for a type of soil, causes the value of displacement will also be higher. The bridge structure model has a relatively low vibration period (<0.3837 seconds). Meanwhile, the bridge structure is quite rigid in resisting dynamic loads from the earthquake load of the city of Pekanbaru.

2. The results of the structural girder prestressed concrete bridge structural response responses based on the Indonesian Earthquake Spectrum Response to SNI 2833: 2016, show that the structural response in the city of Pekanbaru in the longitudinal direction on the pillar section of the largest box girder prestressed concrete bridge occurs in the condition of soft soil with a displacement value of 1.40 mm. Meanwhile, the structural response in the city of Pekanbaru the smallest longitudinal direction occurred in hard soil conditions with a displacement value of 0.88 mm, while for medium conditions the displacement value of 1.06 mm was obtained. Thus, it can be concluded that the value of the bridge displacement due to earthquake load planned for the transverse direction in hard
soil conditions is 16.98% smaller than in medium soil conditions and 59.10% smaller than in soft soils.

6. References

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