

Displacement Evaluation on Suspension Bridge with Vertical Hanger Configuration

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The configuration of the hanger is one of the important parameters that affect the performance of the suspension bridge structure. Vertical hanger configurations are the most common configuration used in suspension bridge design. Displacement is one of the structural performance parameters that determines whether a structural system can be said to be safe or not. The bridge structure system is allowed to have a large deflection (vertical displacement). This study aims to evaluate the displacement of the suspension bridge structure with a vertical hanger configuration. The evaluation of the displacement hanger can be based on the principle of performance-based design, where the performance value is measured based on the displacement and stress acting on the bridge. This evaluation was carried out on the simulation of traffic load based on SNI 1725:2016 and SNI 2833:2016. The vehicle configuration, as well as the values of axle load and distance between, according to the standard, are used as loading inputs in the structural analysis using MIDAS CIVIL. The results of the analysis showed that the displacement in the static nonlinear analysis was greater than the spectrum response analysis. The maximum vertical deflection value is 278,385 mm in the Kuat 1 combination. The maximum deflection results meet the requirements of the Minister of PUPR Decree No. 10 2010 ($278,385 < 400$ mm). On the other hand, the maximum transverse direction lateral displacement value is 18,185 mm, and the longitudinal direction is 1,298 mm. In the lateral direction, the biggest factor that increases the displacement value is a combination factor due to wind load. In wind loads, the load acts transversely but also result displacement in the longitudinal direction. The results of this study, compared to previous studies, found that the comparative value of lateral deflection and span length was smaller than in several previous studies.

Keywords: Cable Bridge; Vertical hanger configuration; Performance Suspension Bridge; Displacement; Deflection Ratio; Span.

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Introduction

Bridges are complementary buildings that function to connect trajectories that are cut off due to obstacles such as rivers, valleys, or other infrastructure (Saputra et al., 2021). Suspension bridges have the potential to reach long spans (Sun et al., 2017), but the long span has several influences, such as traffic, wind, and seismicity (Miyata et al., 2017; Qi et al., 2017; Sun & Zhang, 2014). one of the problems that cannot be taken into account in planning are the magnitude of environmental conditions that exceed regulations (Xu et al., 2023) and the increase in span length in direct proportion to the increase in inner force on the pull rod of the suspension bridge (Zhang et al., 2024).

Suspension bridges are flexible structures; Compared with other types of bridges, the deformation of the structure under the live load is relatively large, which affects the comfort of passengers or pedestrians and even controls the design of the structure (Chai et al., 2023). Gravitational stiffness can be used to measure the resistance of a suspension bridge to live loads: large stiffness to additional live loads, and deformation of small cables subjected to live loads can be attributed to large cable gravitational stiffness (Buonopane & Billington, 1993; Jennings, 1983; Park et al., 2018; Pugsley, 1952). In reality, the elastic rigidity of suspension bridges is relatively small due to the inertia value of the girder, which tends to be small, so that a significant increase in load and stiffness problems can

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be a performance problem in the structural system Suspension Bridge (Fei et al., 2021).

A configuration pendant is considered to provide positive performance for the stability of the suspension bridge. (Gimsing & Georgakis, 2012). One of the most commonly used configurations is the vertical hanger configuration (Harazaki et al., 2000). In the simplification of the case Suspension Bridge, the configuration used in the preliminary design is based on the force decomposition on the vertical hanger configuration (Gimsing & Georgakis, 2012) (Figure 1).

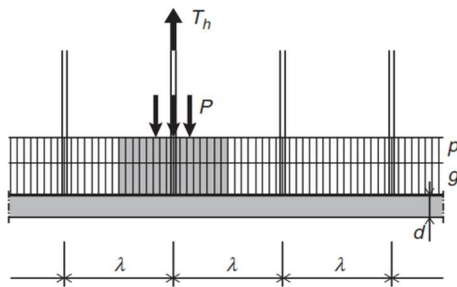


Figure 1 Preliminary Design Hanger Size (Gimsing & Georgakis, 2012)

Based on the most common suspension bridge model used in design. There has never been a thorough evaluation related to the displacement of the vertical hanger configuration to assess one of the performance points of the suspension bridge structure system.

This study aims to evaluate the displacement of maximum suspension bridges with vertical hanger configurations in longitudinal, transverse, and vertical directions, and compare them with the boundaries allowable displacement based on the Decree of the Minister of PUPR No. 10 of 2010. Evaluation Displacement on Suspension bridge with configuration pendant vertically performed to assess the effectiveness of the structure. Value Displacement maximum then compared to the allowable displacement in accordance with the SE of the Minister of PUPR Number 10, 2010 (Kementerian Pekerjaan Umum, 2010).

Method

This study takes a case study on the Cemara Ujung – Andai River Suspension Bridge, Banjarmasin City. The data in the case study uses secondary data from the case study planning data (property hanger rope can be

seen in Table 1. This study uses the finite element, which is accommodated by the MIDAS CIVIL 2022 software. The bridge Case Study can be seen in Figure 2.

Table 1. Properties of Cable Hanger

Property	Value
Diameter (mm)	12.7
Density (kN/m ³)	78
Young Modulus (MPa)	200
Yield Strength (MPa)	1600
Fish Ratio	0.3

The static load on the model is calculated based on SNI 1725:2016. Static loading only inputs major loads such as self-weight (MS), Utility Load (MA), Lane Load (TD), Brake Load (TB), Structural Wind Load (EWS), Vehicle Wind Load (EWL), and Seismic Load (EQ). The combination of static loads can be seen as follows:

Kuat 1 : MS + MA + 1.8TD + 1.8TB

Kuat 2 : MS + MA + 1.4TD + 1.4TB

Kuat 3 : MS+MA +1.4EWS

Kuat 4 : MS+MA

Kuat 5 : MS+MA +0.4EWS+EWL

Layan 1 : MS + MA + TD+ TB+ 0.3EWS+ EWL

Layan 2 : MS + MA + 1.3TD + 1.3TB

Layan 3 : MS + MA + 0.8 TD+ 0.8TB

Layan 4 : MS+MA+0.7 EWS

Kuat refers to Ultimate Limit State, ULS and Layan refers to Serviceability Limit State (SLS).

Static analysis is carried out by a nonlinear static analysis with the Newton-Raphson scheme. This is based on the behavior of Newton-Raphson analysis, which can cause the structure to deform (large deformation). Structural systems Suspension Bridge is categorized as a structural system with geometric nonlinearity, so that the deformation that occurs is quite large, and the rigidity of the structure changes along with the change in the position of the structural elements (Bathe, 1996; Crisfield, 1991).

Furthermore, to analyze the response of the structure under the earthquake load, the earthquake load was used in accordance with the earthquake map and the combination according to SNI 2833:2016. The combination of dynamic loading is as follows:

Dynamic X : MS + MA + TD + TB ± EQX ± 0.3EQY

Dynamic Y : MS + MA + TD + TB ± EQY ± 0.3EQX

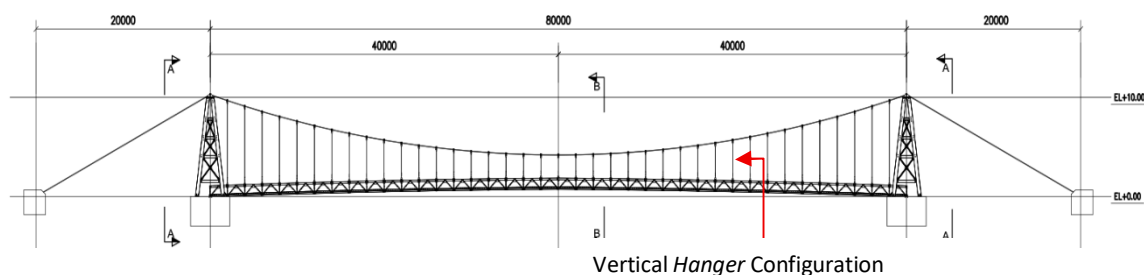


Figure 2 Plan View of the Cemara Ujung – Sungai Andai Bridge

A dynamic analysis is carried out with a schematic Response Spectrum Analysis with calculations according to SNI 2833:2016. “Ekstrem” combination in SNI 1725:2016 was not included in the analysis because the Ekstrem combination only considered static earthquakes. Meanwhile, the analysis of the combination of Dynamic X and Y according to SNI 2833:2016 is a combination of dynamic earthquakes. In addition, the combination of Extreme in SNI 1725:2016 does not specifically consider the direction of the coming of earthquake forces, while in SNI 2833:2016, it considers the direction of the coming of earthquake forces more specifically.

The calculation of the seismic load takes the coordinates of the bridge location (Figure 4) at latitude and longitude coordinates (-3.289452; 114.6667).

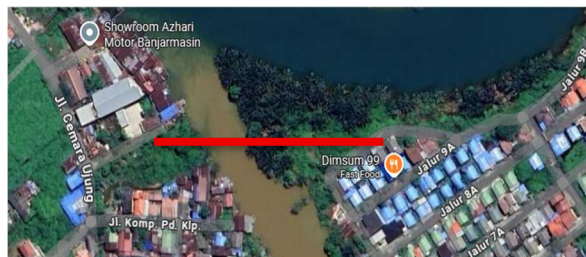


Figure 3 Bridge Location (-3.289452; 114.6667)

Results

Load Analysis

The load calculation is carried out in accordance with SNI 1725: 2016 for static loads and SNI 2866: 2016 for seismic loads. The recapitulation of the value of the static load can be seen in Table 2 As for the spectral response graph, the design results can be seen in Figure 4.

Table 2. Static Load Recapitulation

Load Type	Quantity	Units
MS	Automatic	kN /m3
AND	0,5	kN /m3
TD (BTR)	6,19	kN /m2
TD (BGT)	68,60	kN /m
ID	202,5	kN
TB	56,25	kN
EW _s	4,29	kN/Joint
EW _L	1,50	kN/m

Numerical Modeling

Bridge modeling using MIDAS CIVIL 2022 software. The modeling only models the main structures that are actively working to withstand the load, some secondary structures are assigned as dead load (MS) on MIDAS CIVIL 2022. The results of Numerical modeling can be seen in Figure 5.

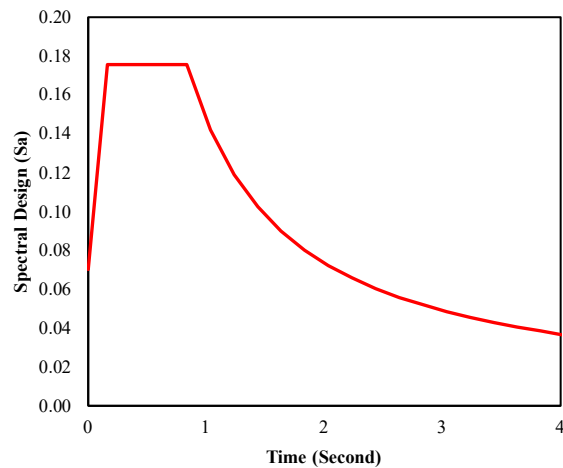


Figure 4 Design Spectral

Vertical Displacement

From Figure 6 it is known that the value of Displacement vertical experiences a maximum in the combination of Kuat 1 in the middle of the bridge spa (Figure 5 and Figure 6). Value the maximum displacement at vertical is set on 02/SE/M/2010 allowed at L/200. As for the calculation allowable displacement are as follows:

$$\begin{aligned}
 D_{\max} &= 278.385 \text{ mm (Figure 5)} \\
 D_{\text{allowable}} &= L/200 \\
 &= 80000/200 \text{ mm} \\
 &= 400 \text{ mm}
 \end{aligned}$$

$$D_{\max} < D_{\text{all}}$$

So that the value of 278,385 mm < 400 mm meets the requirements for allowable deflection.

As seen in Figure 6, in combination with the influence of large winds (Kuat 3, Kuat 4, Kuat 5, and Layan 4), has a value displacement tends to be smaller than a combination without the influence of wind.

Figure 7 shows that under the influence of seismic conditions, vertical displacements exhibit the same behavior across combinations. This is due to the very small effect of the earthquake's base force (EQX and EQY) on the vertical displacements (See Figure 8) so that the value of vertical displacement is dominated by gravitational loads acting on seismic combinations.

Longitudinal Directional Lateral Displacement (X-Direction)

Displacement longitudinal (X-direction) refers to Figure 9. It has 2 groups of behaviors, namely positive in the 0 – 40 span (marked by a continuous line) and negative behavior in the 0– 40 m span (marked by a dashed line).

The first group of behaviors (continuous line) is filled by a combination of Kuat 3, Kuat 4, Kuat 5, Layan 1, and Layan 4, where this combination is a combination that has a wind influence factor, so that the displacement value tends to be larger.

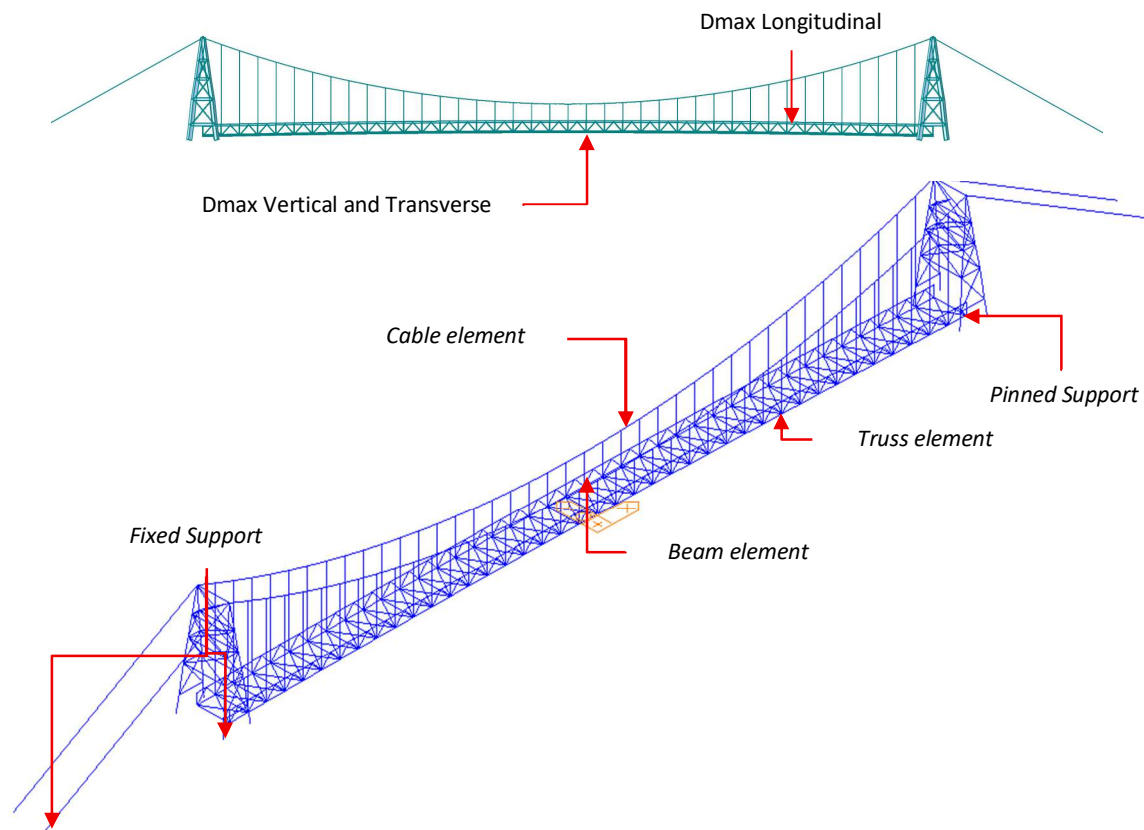


Figure 5 Finite Element Model

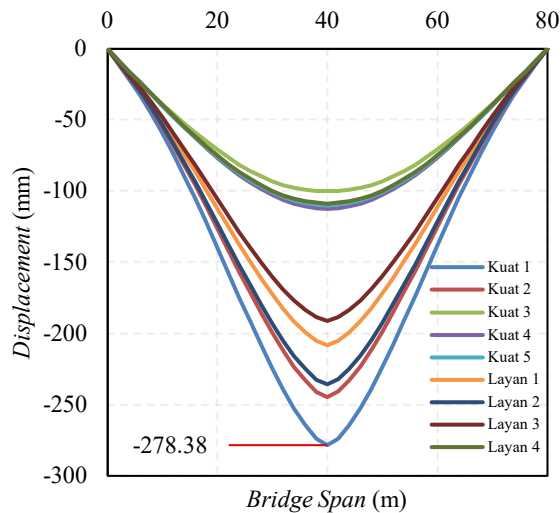


Figure 6 Vertical Displacement Curve (Z Direction)

The second combination group (dashed line) showed a smaller displacement value. This is due to the fact that the load combination factor in this combination is only dominated by loads with the direction of gravity, so the maximum displacement value of the longitudinal direction tends to be very small (< 1 mm).

In contrast to static loads, under the influence of seismic loads, the same behavior is exhibited across all seismic combinations. This can be seen in Figure 10.

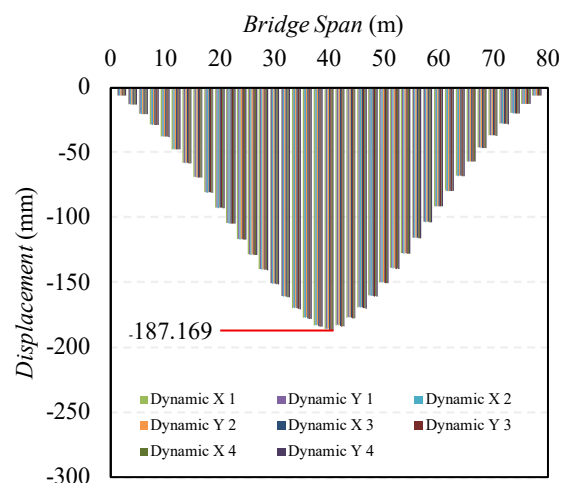


Figure 7 Vertical Displacement Curve (Z-Direction) in Seismic Combinations

The displacement direction X, as shown in Figure 10, generally have the same distribution behavior on all dynamic load combinations. But in terms of the amount of value, the value displacement in the positive X direction tends to be greater than in the negative X direction. This is due to the seismic base force leading in the positive direction seen on the blue and orange curves. Value Displacement, the largest in the seismic combination, is shown in the combination Dynamic Y 2.

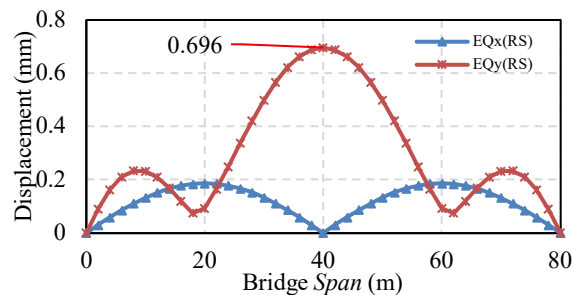


Figure 8 Curve of the Influence of Seismic Base Force on Vertical Displacement

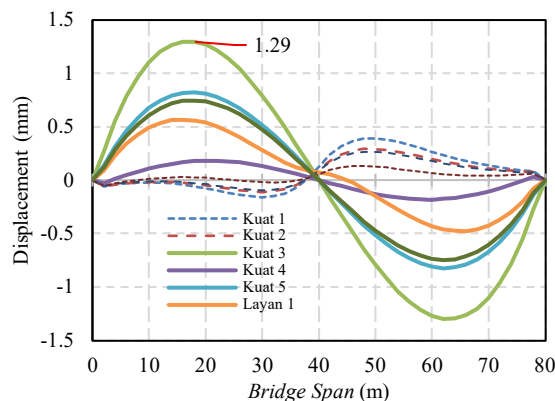


Figure 9 Longitudinal Directional Displacement Curve (X)

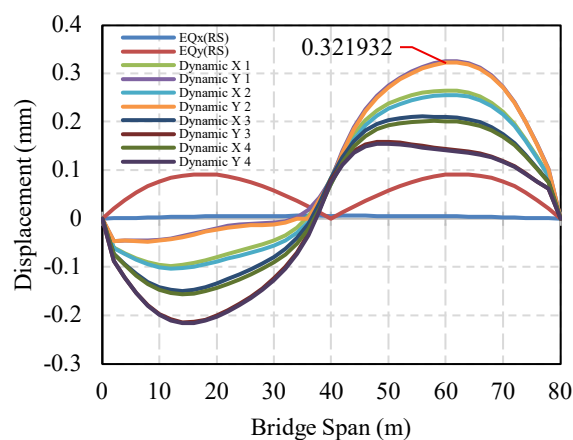


Figure 10 Longitudinal Directional Displacement Curve (X) in Seismic Combinations

Lateral Displacement of Transverse Direction (Y Direction)

Displacement The Y direction is dominated by the combination of Kuat 3, Kuat 5, Layan 1, and Layan 4 (Figure 11). These four combinations, according to SNI 1725:2016, are combinations that have wind load factors, both wind in the structure (EW_s) and wind in vehicles (EW_L).

In seismic combination, the displacement the Y direction is dominated by the Y direction seismic load (Y1, Y2, Y3, and Y4). In general, displacement the dominant Y direction is caused by the inertia girder in Y direction lower than X direction, so that the

displacement of Y direction in seismic basic force tend to be larger than X direction. This can be seen from the basic seismic force of the Y direction which causes displacement by 1.39 of 1.41 mm displacement total (99%). Curve Displacement the Y direction is seen on Figure 12 and Figure 13.

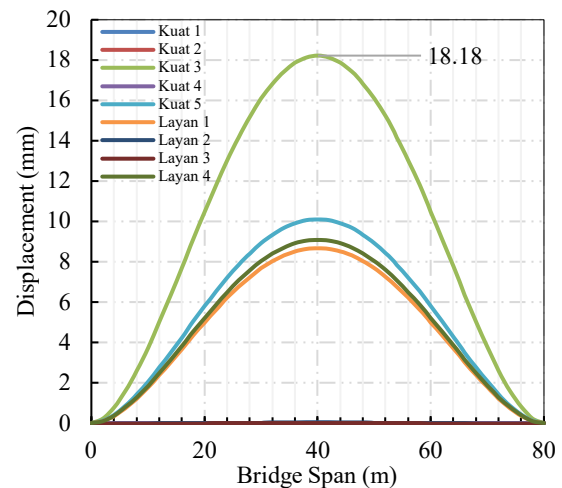


Figure 11 Transverse Directional Displacement Curve (Y)

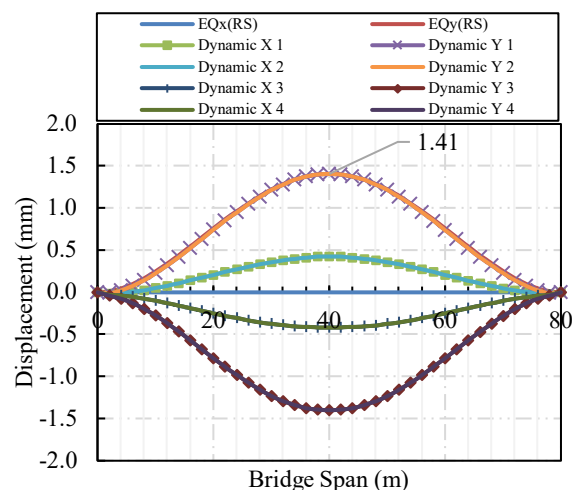


Figure 12 Transverse Directional Displacement Curve (X) in Seismic Combinations

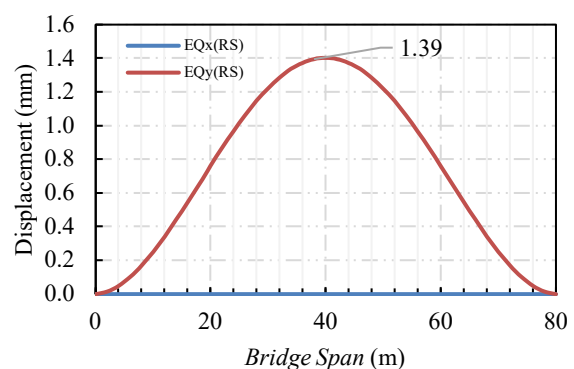


Figure 13 Curve of the Influence of Seismic Basic Force on Y-Direction Displacement

From all the analysis results, it is known that in suspension bridge analysis, static nonlinear analysis is more predominantly shown by the size of displacement than seismic analysis. This is in accordance with the principle of seismic load, where the seismic load works based on the base reaction and the weight of the structure in general. In the case of suspension bridges, the level value of the structure is classified as a light structure so that seismic influence factors can be minimized (Chen & Duan L, 2014). This then causes the dominance of lateral directional displacement due to the combination factor of the wind (Figure 11 and Figure 12) (Gimsing & Georgakis, 2012).

From the three directions of displacement, it can be seen that the combination of Kuat shows a greater displacement value than the Layan condition. This is in accordance with SNI 1725: 2016, which states that the Kuat condition refers to the Ultimate Limit State (ULS), which is used to check the ultimate limit of the structural system. in contrast, the Layan condition refers to the Serviceability Limit State (SLS) which is used to check the comfort of use during the service life of the bridge. In addition, from the results of non-linear static and dynamic analysis, data was obtained that for bridges located in the city of Banjarmasin, the displacement value resulting from the overall combination of earthquakes was smaller than the combination of static loads.

Previous research such as that conducted by Widyaningsih (2020), indicate that with a span length of 127. 34 m obtained Displacement maximum vertical of 433. 63 mm. This shows the difference between Displacement $L/200$ (635 mm) clearance with a Displacement maximum of 31.7%. Other research conducted by Herdiansah & Nurhuda (2025) shows the difference in Displacement maximum and allowable displacements of 28.1%. In another case carried out by Masagala (2023), a displacement of 720 mm with a clearance of 270 mm. In this case, Displacement does not meet the requirements of a allowable displacement because, in this study, the bridge analyzed is an existing bridge that has undergone repeated loading cycles. So that in the analysis, a reduction was made to the strength of structural elements. The results of this study show the difference between permit placement and displacement, with a maximum of 121.62 mm or 30.4%. This has similarities with research conducted by Widyaningsih, (2020) and Herdiansah & Nurhuda (2025).

In the transversal direction of research Herdiansah & Nurhuda (2025), indicate the value Displacement transverse by 427 mm. When compared to the length of the span, it has a ratio of 1:0.0017. In this study, the comparative value between the maximum transverse with a bridge length of 1:0.00025. This significant difference is due to the object of research conducted by Herdiansah & Nurhuda (2025) which is a bridge with

multiple spans, so it has a different behavior from the object of this research.

In the longitudinal direction, this study has exactly the same pattern as the results of the research conducted by Jing (2024). Patterns as in Figure 9 especially in the pattern with a dotted line, which is exactly the same curve pattern as the results of analytical and numerical analysis carried out under dead load and live load.

Conclusion

From the results of the calculation with the finite element, the vertical configuration shows a fairly stable behavior in bearing loads. This is shown by the displacement values in the direction of X, Y, and Z meeting the prerequisites of SNI 1725:2016. In addition, in resisting earthquake forces, the vertical configuration of the hanger shows better resistance, as seen from the displacement in all directions under a seismic load that is smaller than the displacement of static nonlinear analysis results.

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