Reliability Assessment of Cable Element in Jembatan Merah Putih Cable-Stayed Bridge Using Weigh-In-Motion Vehicle Data

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ABSTRACT

Jembatan Merah Putih is a cable-stayed bridge spanning across Teluk Dalam Pulau Ambon in Ambon City, Maluku Province, Indonesia. The bridge connects Desa Rumah Tiga in Sirimau District on the north side with Desa Hative Kecil/Galala in Teluk Ambon District on the south side, and has a length of 1,140 meters, making it one of the longest bridges in Eastern Indonesia. Reliability assessment of the cable element of the bridge was conducted using one-year Weigh-In-Motion (WIM) measurement vehicle data from the Central Java National Road Bridge-WIM (B-WIM) system, which has high traffic density and traffic load. A model of the bridge was created using Finite Element Method (FEM), and vehicle loading was simulated on the model to determine the load effect on the cable element. The load effect was found to follow a lognormal distribution, and the obtained value was projected using Extreme value theory to the 75-year return period, which is the bridge's design lifetime. To assess the reliability, First-Order Reliability Method (FORM) and Rosenblatt transformation were used, resulting in a reliability index of 3.85, which is higher than the reliability target set for important bridges in Indonesia (3.72). The findings suggest that the cable element of the Jembatan Merah Putih cable-stayed bridge is reliable and safe for use. The study provides valuable insights into the reliability assessment of cable-stayed bridges and highlights the importance of such assessments for ensuring the safety of bridges in Indonesia.

Keywords: Jembatan Merah Putih, cable-stayed bridge, reliability assessment, Weigh-In-Motion, Finite Element Method

1. INTRODUCTION

Jembatan Merah Putih, a stunning cable-stayed bridge, stands tall in the heart of Ambon City, Maluku Province, Indonesia. The bridge spans across Teluk Dalam Pulau

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assessments and use vehicle load data from Weigh-In-Motion (WIM) measurement and wind loading measurement to calculate the cable reliability index. Previous research by Ohorella and Harsoyo in 2017 has shown that the bridge has good stability against aerodynamic effects caused by wind. However, with the increasing traffic potential on the bridge, it is essential to evaluate the bridge's behavior under the vehicle load to ensure its safety and structural reliability. To assess Jembatan Merah Putih cable-stayed bridge reliability, a study was conducted using the one-year WIM measurement vehicle data collected from the Bridge WIM (B-WIM) system installed at the North Coast National Road of Central Java. This B-WIM system has higher traffic density and load compared to other B-WIM sites in Indonesia, making it a suitable source of data for reliability assessment (Nugraha et al. 2022).

WIM technology has become a widely used method for collecting traffic data on highways and bridges. It provides a non-intrusive way of measuring the weight and speed of vehicles as they pass over a sensor (Haugen et al. 2016). B-WIM is a type of WIM that uses sensors installed on a bridge to measure the weight and speed of vehicles passing over it (Nugraha and Sukmara 2018). The collected data can include vehicle type, speed, gross vehicle weight, axle configuration, and each respective axle load (Hang, Xie, and He 2013). This information can be used for various purposes, such as monitoring bridge health, assessing the impact of heavy vehicles on the bridge, and determining the tolls for vehicles passing over the bridge (Kalin, Znidarič, and Kreslin 2015). In this study, the B-WIM measurement data is used to assess the reliability of cable elements on a cable-stayed bridge by simulating vehicle loading and calculating the cable forces induced by the load.

To determine the load effect on the cable element of the Jembatan Merah Putih, a model of the bridge was created using the Finite Element Method (FEM). The vehicle loading from B-WIM measurements was simulated on the model to investigate the load effect on the cable element. Previous studies have shown that the load effect on bridge elements is a random variable with a unique distribution that can differ from the vehicle load distribution due to factors such as axle distance, axle load, and bridge length, which affects the number of vehicles that can fit on the bridge deck at full length simultaneously (Hou, Sun, and Chen 2021). This research will study the daily maximum load effect distribution on the cable element and project it to a 75-year return period, which will be calculated using Extreme Value Theory (Anitori, Casas, and Ghosn 2017).

In this study, the reliability of the cable element of the cable-stayed bridge will be assessed using the First-Order Reliability Method (FORM) and Rosenblatt transformation (Rosenblatt 1952). The resulting reliability index will be evaluated and compared with the target reliability of 3.72 set for Jembatan Merah Putih cable-stayed bridge, as it is classified as an important bridge in Indonesia. The cable reliability findings of Jembatan Merah Putih cable-stayed bridge will be discussed and summarized.

2. MERAH PUTIH BRIDGE FEM MODEL

The Jembatan Merah Putih cable stayed bridge's main span comprises of two pylons and their respective cable stayed system with a length of 300 meters. The pylon height is 89.50 meters from the pile cap, while the pile cap height is 6 meters. The deck has a width of 21.50 meters, consisting of a two-way road with two lanes for each way, where one lane width is 3600 millimeters, 500 millimeters median, and 1500 millimeters sideline. The height of the deck system, which consists of composite steel girder with concrete slab, is 2.55 meters. The materials used for the slab and pylon are compressive strength f_c' of 40 MPa concrete, while the pile cap uses compressive strength f_c' of 30 MPa concrete. The material used on the steel girder is ASTM A709M grade 345 with a yield strength f_y of 345 MPa and an ultimate strength fu of 450 MPa. The material used for the prestress tendon is ASTM A416 grade 270 low relaxation-strand with a yield strength f_{py} of 1670 MPa. The material used for the cable is steel strand with a breaking load f_{pu} of 1770 MPa and an allowable stress of 0.45 f_{pu}, which is 796 MPa.

The FEM model was created using Midas Civil software based on the detailed information of the bridge. The FEM model was created specifically to calculate the cable forces caused by the vehicle load, which was based on B-WIM measurement. To create the model, beam elements were used to model the bridge girders and the pylon, while tension-only elements were used to model the cables. The bearing restraints between the girders and pylons were modeled according to specifications. The bearing was simulated as a spring with three directions, and the spring stiffness of the constrained direction was set at 1×10^8 kN/m while the spring stiffness of the unconstrained direction was set to zero. The steel composite girders with reinforced concrete slabs as the deck system, and the pylons were modeled in detail. The FEM model created, which is depicted in Fig. 2, provides a comprehensive representation of the bridge and its components, allowing for accurate analysis of the cable forces induced by the vehicle load.

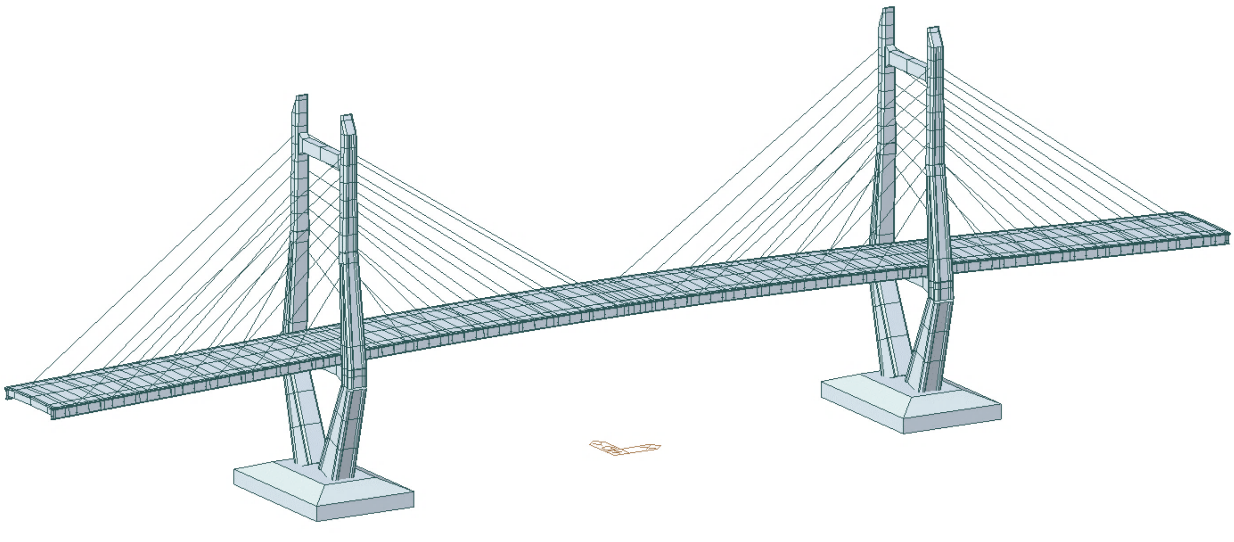

Fig. 2 FEM model for Merah Putih Cable-stayed bridge

In order to assess the stability of Jembatan Merah Putih, a moving load analysis was conducted using a simulation of a 300-meter-long queue of vehicles, equivalent to the length of the bridge. This was based on B-WIM daily measurement data, and the headway between vehicles was modeled based on the timestamp of the measurement. The number of load cases per day varied depending on the number of vehicles measured by the B-WIM. One of the heaviest load cases was taken from December 2nd, 2018, consisting of 32 vehicles with a total length of 298.2 meters. The vehicles in this load case were listed in Table 1, with the heaviest vehicle being vehicle no. 11, which was a 6-axle vehicle with a 95.2 ton GVW. There were four vehicles with a GVW greater than 50 tons in the list, which would significantly impact the cable force of the Jembatan Merah Putih stay cable.

Table 1 One of the heaviest load cases from December 2nd, 2018

No	Vehicle Subclass	Axle Load (ton)						Gross Vehicle Weight (ton)	Axle Distance (m)					Total Length (m)
		W1	W2	W3	W4	W5	W6		A1	A2	A3	A4	A5	
1	111	6.92	6.56	6.56	9.53			29.56	3.32	1.44	10.39			15.16
2	30	3.38	10.12					13.49	3.27					3.27
3	101	3.74	4.57	2.98	2.98			14.27	3.16	9.49	1.51			14.16
4	51	5.61	14.06	14.06				33.74	5.60	1.46				7.06
5	102	5.21	25.21	16.05	16.05	16.05		78.58	3.30	6.41	1.39	1.39		12.49
6	51	9.13	15.75	15.75				40.63	5.66	1.46				7.13
7	41	6.08	11.57					17.65	5.76					5.76
8	41	8.59	20.46					29.05	5.77					5.77
9	30	2.83	8.01					10.84	3.30					3.30
10	41	6.86	10.50					17.36	5.96					5.96
11	120	6.40	17.69	17.69	17.81	17.81	17.81	95.22	3.25	1.34	6.28	1.37	1.34	13.56
12	120	5.25	12.18	12.18	11.73	11.73	11.73	64.80	2.72	1.36	4.06	1.33	1.36	10.83
13	30	3.02	7.47					10.49	3.13					3.13
14	41	6.30	11.54					17.85	5.83					5.83
15	41	6.12	10.52					16.64	5.79					5.79
16	30	2.78	4.00					6.78	3.36					3.36
17	41	3.61	7.50					11.11	5.28					5.28
18	30	2.54	7.31					9.86	3.37					3.37
19	20	0.89	1.03					1.92	2.53					2.53
20	51	5.66	9.31	9.31				24.29	5.02	1.48				6.50
21	41	5.76	9.48					15.24	5.88					5.88
22	102	8.45	20.94	16.61	16.61	16.61		79.23	3.46	6.10	1.33	1.33		12.22
23	40	2.46	12.69					15.15	3.98					3.98
24	51	7.81	13.12	13.12				34.05	5.75	1.53				7.27
25	41	6.21	9.41					15.62	5.85					5.85
26	51	7.82	12.76	12.76				33.33	5.65	1.47				7.12
27	51	6.38	9.56	9.56				25.50	4.94	1.47				6.41
28	30	2.82	9.19					12.01	3.06					3.06
29	51	4.34	2.72	2.72				9.77	5.78	1.42				7.19
30	30	3.81	10.38					14.19	3.33					3.33
31	51	5.16	4.08	4.08				13.33	5.69	1.37				7.05
32	30	3.05	9.99					13.04	3.31					3.31

To accurately evaluate the impact of vehicle loading on the Jembatan Merah Putih, a moving load analysis was conducted using a realistic scenario. This involved inputting the axle load and distance of all 32 vehicles from one of the heaviest load cases on Table 1 above into Midas Civil as a single train moving load. By using a B-WIM measurement data, a more accurate simulation of the actual load effect on the bridge was achieved. This simulation was repeated for another load case and then for each day in a year's worth of data. The daily maximum cable force due to the moving load vehicle analysis result was then projected to the 75-year return period of maximum cable force for the next step of analysis. By conducting this analysis, a more realistic picture of the impact of vehicle loading on the Jembatan Merah Putih could be obtained, allowing for better assessment of its reliability.