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Structure Performance on the Long Span Bridge in Riau Province (Case on Siak I Bridge)

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Abstract – Siak I Bridge is located in Pekanbaru City and was constructed in 1975 and used in April 1977. The bridge has undergone a functional change; initially, Siak I Bridge served as a Class IIA collector road but was later reclassified as a Class I arterial road. This change resulted in performance degradation due to cracking in the piers/columns, which has been repaired using grouting methods and reinforced with steel jackets. Cracks were also observed on the deck slab, and grouting has been applied to these cracks as well. Therefore, an evaluation of the bridge's serviceability and a structural strengthening study are necessary. The methods used in structural assessment/research include Ultrasonic Pulse Velocity (UPV) testing, thickness test, rebar scanning, dynamic loading test and frequency testing. These tests aim to verify the bridge's serviceability capacity. Based on the vibration frequency tests conducted on the bridge, there are three points where the actual vibration frequencies are lower than the theoretical natural frequencies. Meanwhile, thirteen other points show actual frequencies exceeding the natural frequencies. Hence, the structural health condition of Siak I Bridge comprises both healthy and unhealthy sections. Strengthening or repair was suggested on the unhealthy parts.

Keywords: long span, frequency test, UPV test, thickness test, rebar scanner test, dynamic loading Test

1. Introduction

A bridge is a critical component of transportation infrastructure that plays a vital role in facilitating smooth traffic flow and enhancing connectivity between regions. In the context of road network planning and construction, a bridge functions to overcome geographical obstacles such as rivers, valleys, railway lines, and other highways. This enables more efficient human mobility and goods distribution.

In general, a bridge is an engineered structure designed to effectively transfer both live loads and dead loads from the roadway surface to the ground through an integrated system consisting of the superstructure and substructure. The superstructure typically comprises main girders, the deck slab, and lateral or transverse bracing elements, which function to distribute and stabilize loads. Meanwhile, the substructure includes piers, abutments, and foundations, which serve to support and transmit the loads safely to the underlying soil or rock strata.

Bridge planning requires comprehensive considerations of design load capacities, long term material durability, geotechnical profiles, and anticipated dynamic effects from vehicular movement. As service life progresses and traffic intensifies, structural deterioration may occur, manifested through cracking, differential settlement, or geometric deformation. Periodic structural evaluations are critical to ensure continued safety and functionality. These evaluations involve visual inspections, non-destructive material testing, and dynamic response analysis, including vibration monitoring. The findings serve as technical references for determining appropriate maintenance strategies, structural strengthening, or full rehabilitation measures.


Figure 1. Siak I Bridge

Siak I Bridge, is a long span bridge located in Pekanbaru City, Riau Province. The bridge was constructed in 1975, and officially inaugurated in April 1977.

It features a simple composite steel girder superstructure with a "Gerber"-type configuration at the center span. The substructure consists of column-shaped piers supported by steel pile foundations. The bridge comprises 13 spans with a total length of 350 meters (125 m – 150 m – 75 m). The bridge deck has a width of 7.32 meters and a thickness ranging from 18 cm to 20 cm. the piers consist of four circular columns, each with a diameter of 95 cm, and are supported by steel pile foundations with a diameter of 40 cm

Initially, this bridge served as a Class IIa collector road but was later reclassified as a Class I arterial road due to changed function, which resulted in a decline in the bridge's performance. This degradation was caused by cracking in the piers/columns; however, repairs have been carried out using grouting methods and the application of steel jacketing. Cracks were also observed on the deck slab and have been treated with grouting. Nevertheless, an evaluation of the bridge's serviceability and further structural strengthening research for Siak I Bridge remain necessary.

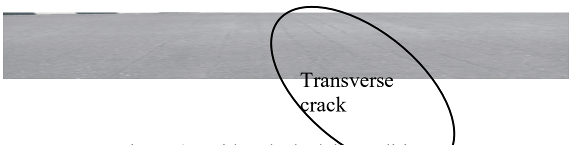

Figure 2. Bridge deck slab condition

The purpose of conducting the structural evaluation of Siak I Bridge is to ensure its serviceability for continued use. Additionally, it aims to determine the load-carrying capacity of the bridge structure, which can provide guidance for repair measures to improve or maintain its durability.

2. Research Method

The methodology employed in this research comprises direct field surveys coupled with in-situ inspections and measurements. Furthermore, vibration testing was conducted utilizing an accelerometer. The objective of the vibration testing is to assess the dynamic response of the bridge structure to operational dynamic loads, specifically those induced by vehicular traffic. This approach aims to extract vibration parameters including natural frequencies, damping ratios, and mode shapes, which are critical for structural condition assessment as well as for evaluating the potential risks of resonance and vibration amplification

The preliminary preparation for performing vibration testing entails identifying the measurement locations on the bridge structure. Thereafter, accelerometer sensors ae installed at these designated points with the appropriate axis alignment (vertical, transverse, or longitudinal). in accordance with the analysis objectives. Subsequently, the sensors are connected to the data acquisition system, and the operational status of the supporting software is verified to ensure proper functionality.

The dynamic loading applied in this study involves vehicles of specified weight and axle configuration functioning as moving loads. The testing was carried out under various vehicle speed scenarios (e.g., 20 km/h, 30 km/h, 40 km/h), in addition to Jumping Load tests conducted at the ¼, ½, and ¾ span positions, each performed in three repetitions. These dynamic load tests are designed to simulate the range of dynamic effects typically encountered under real-world service conditions. Each test scenario was executed in both forward and reverse directions to verify the consistency and repeatability of the structural response

Vibration data acquired from the accelerometers are continuously recorded throughout the vehicles passage over the bridge. Upon completion of the testing, the data are extracted and processed using the Fast Fourier Transform (FFT) or alternative modal identification methods to determine the bridge's dynamic parameters. The resulting analysis is then compared against references or historical datasets, if available, to evaluate any changes in dynamic characteristics indicative of potential structural damage or degradation in stiffness.

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3. Results and Discussion

This study explains the structural quality and verifies the serviceability of the bridge to ensure its continued use. This naturally requires several relevant tests within the scope of this research, including frequency testing, UPV (Ultrasonic Pulse Velocity) testing, thickness test, rebar scanner inspection, hardness test, and dynamic loading test.

3.1. Bridge Frequency Test

Bridge frequency testing is a component of the dynamic structural assessment carried out to evaluate the bridges response to dynamic loads, particularly in long-span bridges that are more vurnerable to vibrations.

The frequency tesing on the Siak I Bridge is highly beneficial for assessing the bridges serviceability, particularly given the presence of several crack locations on the structure.

3.2. UPV (Ultrasonic Pulse Velocity) Test

This testing method is conducted using the UPV (Ultrasonic Pulse Velocity) device. UPV Testing is a non-destructive testing method used to evaluate the condition of concrete or other construction materials by

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measuring the velocity of ultrasonic waves propagating through the material. This method is based on the principle that the wave propagation speed through a solid medium depends on the elastic properties of that medium. When properly applied, this device can provide information regarding the compressive strength of concrete, provided that the relationship between the elastic properties of the solid material and its compressive strength is known. The Ultrasonic Pulse Velocity Test was carried out in accordance with (BS 1881 Part 203; ASTM C597-16). The following are the resultes of the UPV test conducted on the Siak I Bridge

Table 1.
Results of UPV Test

Struct Ure	Number	Element of Structure	P-Wave	Average Velocity (m/s)	Standard Deviation	Description	Classification Of The Quality Of Concrete On The Basis Of Pulse Velocity	Dynamic Poisson Ratio	Density (Kg/m3)	Ec(Mpa)	Fc'Mpa
Pillar of Siak Bridge 1	1	PL 5 A	4,004	4038	152	Good to Very Good	Good to Very Good	0.2	2,400	2,8742.50	3
	2	PL 3 D	4,008				Good to Very Good	0.2	2,400	2,9950.81	4
	3	PL 4 B	3,747				Good to Very Good	0.2	2,400	2,5170.93	2
	4	PL 5 D	4,166				Good to Very Good	0.2	2,400	3,1115.04	4
	5	PL 5 C	4,169				Good to Very Good	0.2	2,400	3,1159.87	4
	6	PL 4 B	3,962				Good to Very Good	0.2	2,400	2,8142.38	3
	7	PL 4 A	3,893				Good to Very Good	0.2	2,400	2,7170.69	3
	8	PL 4 C	4,281				Good to Very Good	0.2	2,400	3,2856.58	4
	9	PL 4 D	4,036				Good to Very Good	0.2	2,400	2,9203.45	3
Pillar of Siak Bridge 1	10	PLT 3	4,205	4200	140	Good to Very Good	Good to Very Good	0.2	2,400	3,1715.41	4
	110	PLT 5	4,256				Good to Very Good	0.2	2,400	3,2473.95	4
	12	PLT 7	4,357				Good to Very Good	0.2	2,400	3,4033.53	5
	13	PLT 6	4,178				Good to Very Good	0.2	2,400	3,1294.55	4
	14	PLT 4	4,318				Good to Very Good	0.2	2,400	3,3426.98	5
	15	PLT 2	3,991				Good to Very Good	0.2	2,400	2,8555.86	3
	16	PLT 1 C	4,102				Good to Very Good	0.2	2,400	3,0166.38	4
	17	PLT 1 B	4,398				Good to Very Good	0.2	2,400	3,4677.06	5
	18	PLT 1 A	3,995				Good to Very Good	0.2	2,400	2,8627.46	3

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Note

Project	Number	Type Of Structure	Average Direct Velocity (m/s) (P-Wave)	Ed (Mpa)	Ec (Mpa)	Average Estimation Of Fc' (Mpa)	Classification Of The Quality Of Concrete On The Basis Of Pulse Velocity
Pillar of Siak Bridge 1	1	Pillar	4,032	35,228	29,239	38.70	Good to Vey Good
Pillar of Siak Bridge 1	2	Plate	4,200	38,106	31,628	45.29	Good to Vey Good

Note

Pulse Velocity (m/s)	Concrete Quality
>4500	Very Good to Exelient
3500-4500	Good to Very good, Slight porosity may exist
3000-3500	Satisfactory but loss of integrity is suspected
<3000	Poor an dloss of integrity exist

Thickness Test

Steel thickness measurement on the bridges constitutes a critical aspect of structural inspection and maintenance. The objective is to assess the actual condition of the steel elements, particularly to detect any corrosion or material loss due to loading, weather exposure, or other environmental influences

At the Siak I Bridge, it was observed that the steel thickness values varied across different test locations. Presented below are the results of the steel thickness measurements conducted in the inspected areas.

Table 2.
Thickness Test inspection results

				Profil Dimension			Thicknes Measurement		
No.	Sample Code	Type of Structure	Profile Type	Width (mm)	Length (mm)	Dia meter	Flange Thickness (mm)	Web	Thick (mm)
1	T1	Girder	IWF	650	900		32	21.82	
2	T2	Girder	IWF	650	900		35.13	22.15	
3	T3	Stiffener							31.35
4	T4	Girder	IWF	650	900		32.65	21.82	
5	T5	Girder	IWF	650	900		34.88	21.7	
6	T6	Stiffener							31.57
7	T7	Bracing	Equal Angle	200	200		25.1	25.06	
8	T8	Bracing	Equal Angle	200	200		25.38	25.11	

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ults were then averaged per structural element to determine the thickness value of each structural component.

Table 3.
Conclusion of the Thickness Test results

No.	Location	Type of Structure	Profile Type	Width (mm)	Length (mm)	Dia meter	Flange Bottom (mm)	Web (mm)	Thick (mm)
1	Siak 1 Bridge	GIRDER	IWF	650	900		33.67	2.87	
2	Siak 1 Bridge	STIFFENER							31.46
3	Siak 1 Bridge	BRACING	EQUAL ANGLE	200	200		25.24	25.24	

Rebar Scanner Test

Rebar scanner testing on bridges is a non-destructive test (NDT). Technique employed to accurately locate, quantify, and determine the depth and diameter of reinforcing steel bars (rebar) embedded in the concrete.

This inspection is essential for the comprehensive assessment of reinforced concrete structural integrity without destructive.

The following are the results of the Rebar Scanner inspection conducted on the Siak I Bridge.

Table 4.
Rebar Scanner inspection results

Structur ID	Structure Name	Orientation	No. of Bars	Concrete Cover			Bar Spacing		
				max	min	avg	max	min	avg
PL.5 D	Pillar	Horizontal	3	53	50	51.7	60.5	52.3	56.4
		Vertical	5	63	48	56.4	34.2	20.9	24.9
36	Pillar	Horizontal	6	61	56	58.3	11.1	6.8	8.6
		Vertical	6	63	46	55.8	21.6	11.3	1.7
PLT.1	Pillar	Horizontal	4	46	34	39.5	33.7	9.4	9.1
		Vertical	4	61	45	56.3	22.4	20.4	21.6

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Hardness Test

Hardness testing is a mechanical evaluation method employed to assess the resistance of steel materials to permanent deformation. This property is directly related to the steels ability to withstand wear, scratching, or deformation under applied loads or stresses.

The hardness test performed on the steel in the bridge aims to evaluate the material quality. Steel used in bridge construction must comply with specific hardness standards to effectively resists loads and stresses during its service life. Ensuring proper hardness is critical for structural durability, as it indicates the steels capacity to withstand wear and damage, thus maintaining the bridges safety.

Additionally, this test serves to detect any material degradation or defects by revealing changes in properties caused by corrosion, fatigue, or prior repairs.

The results of the steel hardness test on the Siak I Bridge constitute the data used to estimate the steels quality by correlating the hardness values obtained. These hardness value were then interpreted according to the ASTM E 140-97 TENSILE STRENGTH TO HARDNESS CONVERSION CHART, which serves as the standard reference for hardness conversion of metals (based on ASTM E10-08/Brinell test: Standard Hardness Conversion Tables for Metals). The relevant tables and graph are presented below.

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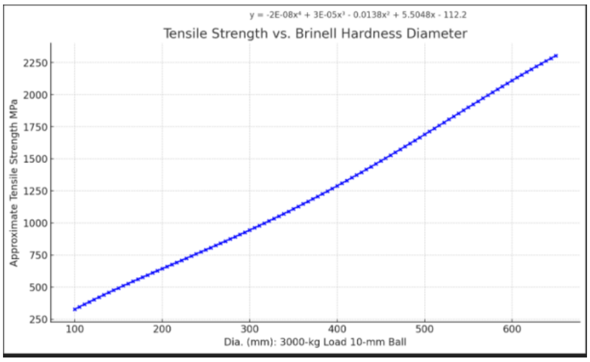

Figure 3. Conversion of HB values to MPA (UTS)

The hardness values obtained from field data were then compiled and summarized as shown in the table below

Table 5.
Recapitulation of Hardness test values

`No.	Area Location	Structure Code	Type of Structure	Profile Type	Number Of Hardness Brinell (HB)			AVERAGE (HB)	Dir.	UTS (Fu) Mpa	Yield Strength (Fy) Mpa
					1x HB	2x HB	3x HB				
1	Siak 1 Bridge	T1	GIRDER	IWF	216	210	218	215	→	687,86	440,94
2	Siak 1 Bridge	T2	GIRDER	IWF	242	242	243	242	→	769,35	493,17
3	Siak 1 Bridge	T3	STIFFENER	IWF	244	245	245	245	→	776,27	497,61
4	Siak 1 Bridge	T4	GIRDER	IWF	226	230	228	228	→	727,04	466,05
5	Siak 1 Bridge	T5	GIRDER	IWF	222	219	224	222	→	700,47	447,79
6	Siak 1 Bridge	T6	STIFFENER	IWF	244	242	245	244	→	772,25	495,12
7	Siak 1 Bridge	T7	BRACING	EQUAL ANGLE	234	235	232	234	→	743,73	476,75
8	Siak 1 Bridge	T8	BRACING	EQUAL ANGLE	241	240	237	239	→	760,46	486,3

The above results were then averaged for each structural element to determine the hardness value of each structural component.

Table 6.
Summary of Hardness Test values with UTS

No.	Area Location	Structure Code	Type of Structure	Profile Type	UTS (fu) MPa	Yield Strength (Fy) MPa
1		G	GIRDER	IWF	731,26	468,76
2	Sink Bridge 1	S	STIFFENER	-	776,76	497,92
3		Br	BRACING	EQUAL ANGLE	752,1	482,11

Dynamic Loading Test

Dynamic loading tests on the bridge are essential to determine its natural vibration frequencies, vibration behavior, and deformation characteristics. The assessment includes vibration frequency obtained through two methods at each stage: The Jumping Load method, which identifies the actual frequency values, and the Moving Load method, conducted three times at speeds of 20 km/h,

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30 km/h, and 40 km/h. The moving load involves a single truck operating at its maximum load capacity. Furthermore, dynamic load testing may also be carried out using actual traffic loads on the bridge (ambient loading conditions).

Dynamic load testing is performed to evaluate the stiffness on the bridge structure under dynamic loading conditions by utilizing the daily traffic loads in the bridge. The assessment if the bridge superstructure condition is based on criteria derived from previous research, as presented in the table below. Additionally, visual inspection findings should be incorporated into the evaluation of the superstructure condition.

Table 7.
Assessment of the Bridge Superstructure Condition

Condition Rating	Type of Damage	Relative Damage Level (D_Relatif)	Capacity Reduction (D_Kapasitas)
Good	Intact	0% – 5%	0% – 10%
Fair	Minor damage (non-structural)	6% – 10%	11% – 20%
Moderate	Minor damage (structural)	11% – 17%	21% – 34%
Bad	Severe damage (structural)	18% – 20%	35% – 40%

Installation of Sensors

Figure 3 illustrates the sensor installation layout in the field, consisting of a total of 10 points, with a requirement of 16 accelerometer sensors.

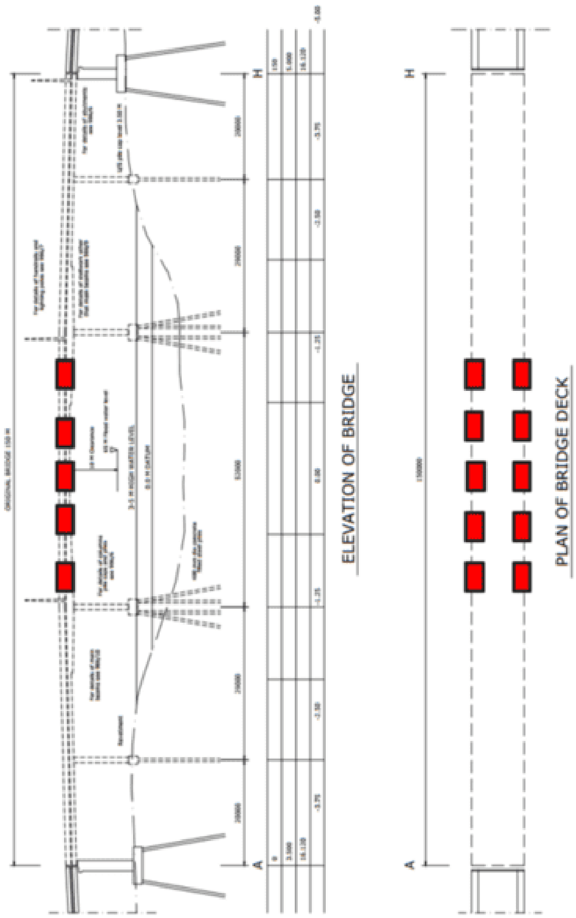

Figure 4. Accelerometer Tests Positions

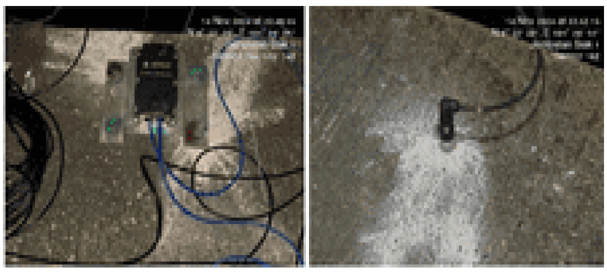

Figure 5. Installation of Sensors

A. Dynamic Loading Test using the Moving Load Method

The method involves inducing vibrations in the bridge using a single truck travelling at planned speed of 20 km/h, 30 km/h, and 40 km/h across the full span of the bridge. The following outlines the stages of the dynamic loading test using a planned loaded truck passage.

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Table 8.
Stages of the Dynamic Loading Test using the Moving Load Method

No.	Phase	Number of Trucks	Speed
1	Initial Data	0	No Load
2	Phase 1	1	20 km/h
3	Phase 2	1	30 km/h
4	Phase 3	1	40 km/h

In the Moving Load testing method, a fully loaded truck is driven across the entire bridge span at designated speeds of 20, 30, 40 km/h to evaluate the dynamic response of the structure

Figure 6. Implementation of the Moving Load Test

B. Dynamic Loading test using the Jumping Load Method

This method involves exciting the bridge by positioning a single truck at ¼, ½, ¾ long span, with one of its axles placed on a speed trap approximately 20 cm in height. The axle is then released in a controlled manner, allowing it ti drop and impart a dynamic impulse to the bridge structure.

Table 9.
Stages of the Dynamic Loading Test using Truck Impact Load Method

No.	Phase	Number of Trucks
1	Initial Data	0
2	Phase 1	1
3	Phase 2	1
4	Phase 3	1

The Jumping Load testing method was conducted at the ¼, ½, ¾ spans of the bridge by driving truck/vehicle over a speed trap.

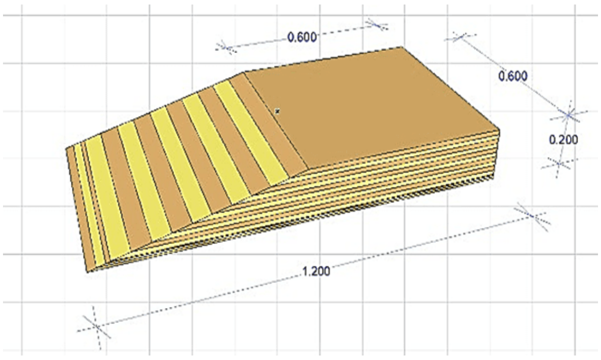

Figure 7. Design of Speed Trap

Figure 8. Implementation of Jumping Load

The recorded data from the dynamic loading tests were processed using the Fourier Transform method to determine the structural frequency values immediately after the truck traversed the bridge, use dewetron software. Peak vibration readings were extracted based on the recorded time stamps shortly after the application of impact loads and moving loads on the bridge. The vibration tests were conducted three times, applying impact loads via a speed trap and moving loads at speeds of 20 km/h, 30 km/h, 40 km/h. multiple test iterations were necessary to obtain consistent vibration peaks in accordance with engineering standards. The following summarizes the conclusions drawn from the actual vibration testing on the Siak I Bridge

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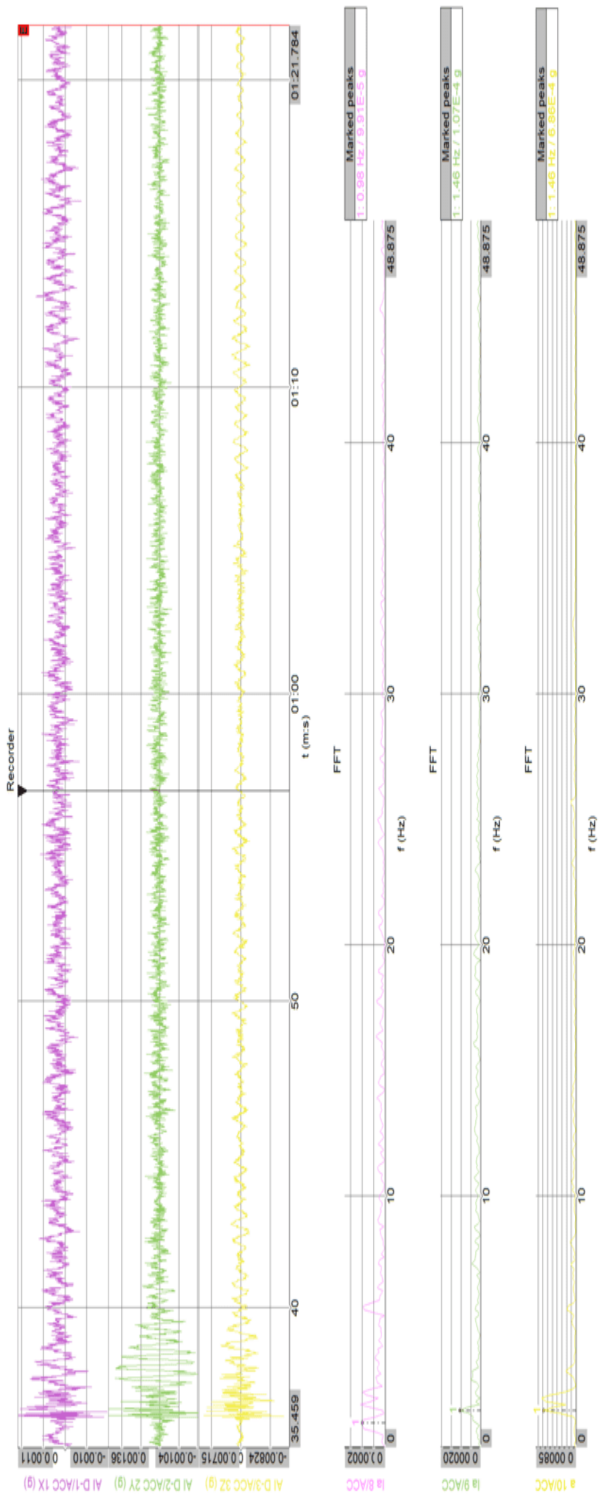

Figure 9. Fast Fourier Transform (FFT) Graph

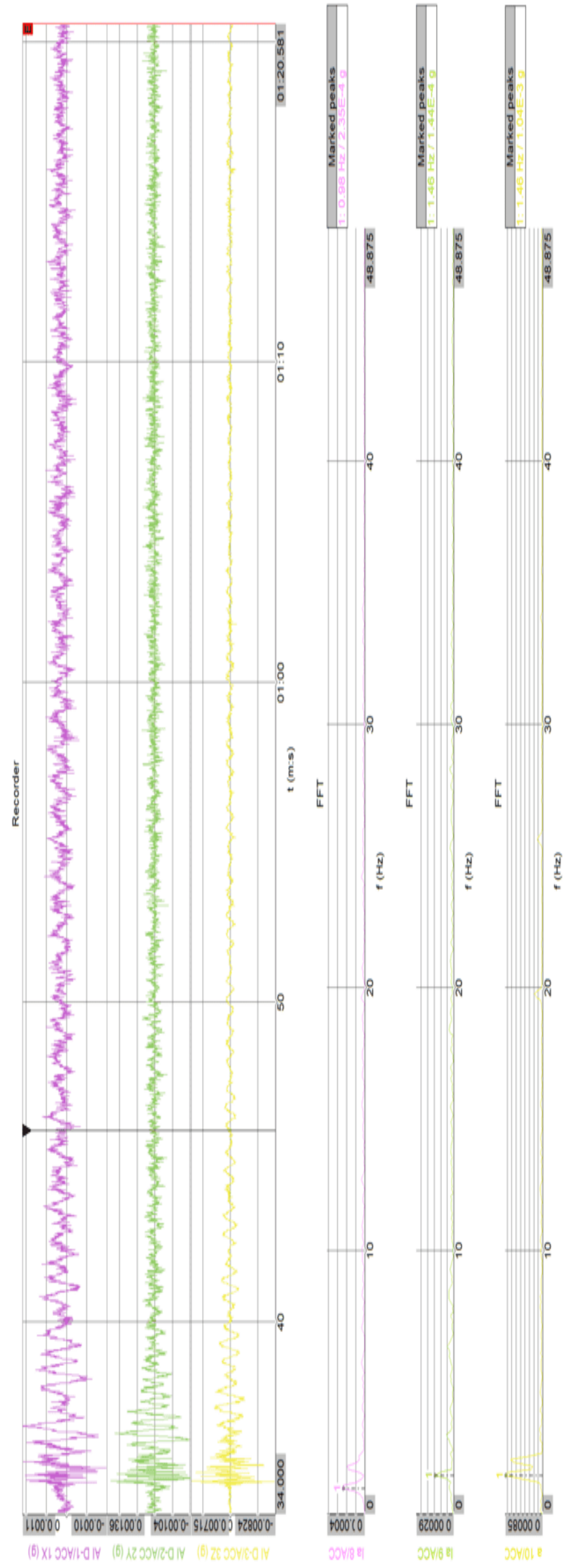

Figure 10. Fast Fourier Transform (FFT) Graph

Figure 9 and Figure 10 provide the Fast Fourier Transform (FFT) result of the Dynamic Loading Test.

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The result of actual frequency that compares with theoretical frequency as follow in Table 10.

Table 10.
Comparison of Actual and Theoretical Bridge

	Frequency (Hz)		
Sensor - Direction	Actual	Theoretical 125/L	Information
ACC-1 (X)	1.04	1.3	Actual < Theoretical
ACC-2 (Y)	1.46	1.3	Actual > Theoretical
ACC-3 (Z)	1.47	1.3	Actual > Theoretical
ACC-4 (Z)	1.48	1.3	Actual > Theoretical
ACC-5 (X)	1.06	1.3	Actual < Theoretical
ACC-6 (Y)	1.46	1.3	Actual > Theoretical
ACC-7 (Z)	1.46	1.3	Actual > Theoretical
ACC-8 (Z)	1.46	1.3	Actual > Theoretical
ACC-9 (Z)	1.46	1.3	Actual > Theoretical
ACC-10 (Z)	1.46	1,3	Actual > Theoretical
ACC-11 (Z)	1.46	1.3	Actual > Theoretical
ACC-12 (X)	1,06	1,3	Actual < Theoretical
ACC-13 (Y)	1.46	1.3	Actual > Theoretical
ACC-14 (Z)	1.46	1.3	Actual > Theoretical
ACC-15 (Z)	1.46	1.3	Actual > Theoretical
ACC-16 (Z)	1.46	1.3	Actual > Theoretical

Category of good condition if actual frequency greater than theoretical frequency, and the opposite category of bad condition if actual frequency less than theoretical frequency.

4. Conclusion

Based on the results of the construction material quality tests and the frequency tests conducted on the Siak I Bridge, the following conclusions can be drawn:

a. The results of the vibration frequency test indicate the presence of actual vibration freuencies. 3 measurement points exhibited actual vibration frequencies lower than the theoretical natural frequencies , while the remaining 13 points showed actual frequencies exceeding the natural frequencies.
b. Therefore, the “structural health condition” of the Siak I Bridge indicates that some components are in good condition, while others show signs of deterioration

5. Recommendations

Based on the inspection results of the Siak I Bridge, the following recommendations are provided:

a. It is recommended that repair or replacement be carried out on the concrete deck sections that do not meet the minimum required concrete strength (min fc’: 17 MPa).
b. The installation of Telkom cables and other utilities on the sidewalk of the Siak I Bridge should be avoided.
c. Based on the results of the bridge frequency test and observed structural damage, it is recommended to repair portions of the bridge deck slab, particularly in areas where the measured frequency is below the natural frequency. The relevant position is outlined as follows:
d. It is recommended to maintain the existing portal structure.
e. It is recommended to implement a Structural Health Monitoring System (SHMS).

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