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Research Paper

Evaluation of the working capacity of components in extradosed bridge by load testing

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A B S T R A C T

Reinforced and prestressed concrete bridges often require structural rehabilitation during their lifespan to address damage and maintain their integrity. Engineers and managers typically rely on completion documents, site investigations, and specialist analysis to evaluate the bearing capacity of extradosed concrete bridges under safe and reliable conditions. However, to see the behaviour of the structure more clearly, a measurement method involves conducting a structural load test, which is usually performed with them. The bridge load testing procedure with static and dynamic measurements is commonly used to evaluate bridge structures. Engineers can gain valuable insights into the bridge's performance under various loading conditions by measuring deformations, deflections, natural frequencies, and other relevant parameters. Additionally, actual reserves in the load-carrying capacity of the new bridge structure can be determined after test evaluation. Thus, this study presented a moving load test method for a rapid bridge capacity evaluation; however, load testing hardly reflects the actual bearing capacity or the remaining life of the bridge. This paper evaluates the reliability of this method in estimating the bearing capacity of an extradosed bridge in Vietnam.

1 Introduction

Like human health inspection, the bridge must be inspected before and during operation through bridge health monitoring. For new bridges in Vietnam with special structures such as extradosed bridges, they are often subjected to load testing before being put into operation. Load tests were carried out before opening bridges to the travelling public to show that the bridge was safe. For existing bridges, common factors contributing to structural deterioration problems include increased traffic loads, poor material quality, poorly designed structures, harsh environmental conditions, and inadequate, irregular maintenance.

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The purpose of loading tests is to determine the bridge's load-bearing capacity and ensure safety for vehicles and people crossing the bridge. Perform load testing to collect results of measuring mechanical effects such as stress, deflection, and displacement of structural components under the effects of static and dynamic loads. After that, the measurement results are compared with the corresponding theoretical calculation results, thereby evaluating the load-bearing capacity of the bridge structure.

In the previous studies, studies related to evaluating the load-carrying capacity of the bridges [1, 2], and recently, structural health monitoring systems have been conducted for special bridges [3-8]. The static and dynamic load tests are widely used to evaluate bridge load-carrying capacity [1, 4-7]. In Vietnam, the common method used for load application is to load trucks of about 25 to 27 tons based on load test calculation results. The load test is sufficient to trigger the needed behaviour of the bridge. Based on the measured results, bridge management agencies can address bridge deterioration by implementing various countermeasures, including repairs, strengthening measures, and traffic regulations. Currently, there is no complete bridge monitoring system in Vietnam. Therefore, the real-time collection of bridge operating status is minimal.

Morever, to the opening of new special bridges with long span such as cable stayed bridge, arch bridge, extradosed bridge and so on, the static and dynamic load tests are often conducted to verify the actual structural behavior compared to theoretical predictions and calibrate calculation models. As part of the bridge's health monitoring program, comprehensive static and dynamic load tests were performed just before its opening. The primary goals of these tests were to better understand the bridge's response to various loading conditions and to establish a baseline database of its undamaged state for future condition assessments. A critical aspect of bridge inspections is determining the bridge's load-carrying capacity. This evaluation can be performed using calculation-based methods, incorporating inspection to create a realistic bridge model [6]. Thus, this study aims to examine the actual condition of the bridge during construction before use. This study evaluates and compares the measured results with the calculated results, thereby better understanding the structural condition and confirming the load-bearing safety of the structure.

2 The purpose for the bridge's load-carrying capacity

In many countries, bridge inspections are conducted regularly, with specific guidelines in place such as the United States every 2 years, China every 3 years, and Japan every 5 years [4]. Some in-depth investigation of the bridge must be carried out in conjunction with computational modelling using a finite element model (FEM). Fig. 1 describes the load test process to determine the bridge's load-carrying capacity.

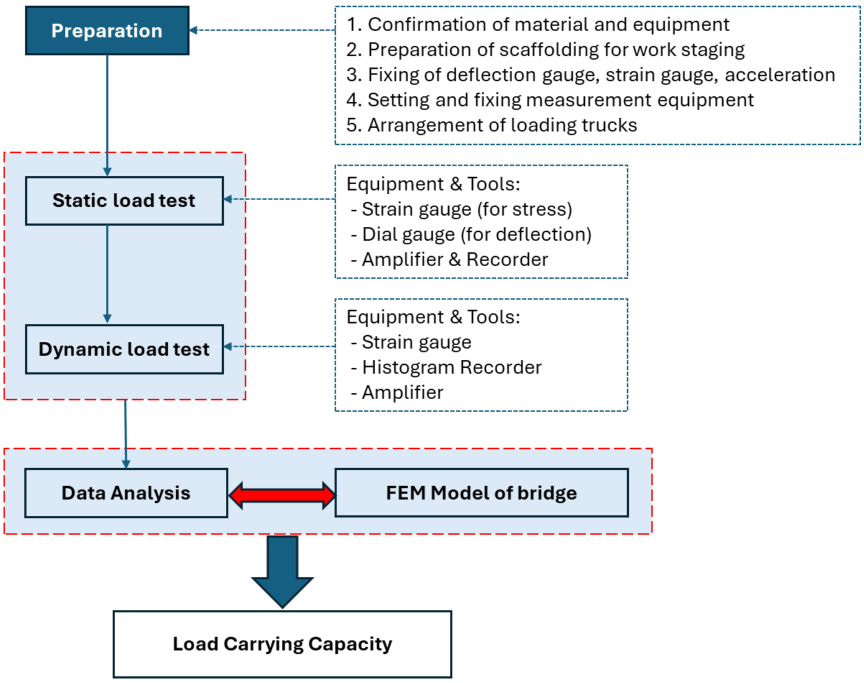

Fig. 1 – Evaluation Sequence for the bridge's load-carrying capacity

The primary goals of load testing a bridge include establishing a baseline database of the undamaged structure to check the bridge's condition for future condition comparisons; validating and calibrating the previously developed finite element model (FEM); verifying the bridge's actual stiffness; understanding the bridge's behaviour and performance under various traffic conditions, including different speeds.

3 Estimation of cable tension force

For the extradosed bridges with additional external cables, thus the measurement is different from that of conventional reinforced concrete bridges. The cables tension is measured indirectly by measuring the cable vibration and then comparing it with the actual tension of the contractor, thereby evaluating the tension force of cables. Any structure or part of a structure will vibrate under one or more dynamic stimuli. When the stimuli are no longer present, the structure will vibrate according to inertia, gradually damping over time. The state of vibration of the structure simultaneously with the stimuli is called the state of forced oscillation. The state of vibration of the structure after the stimuli have been eliminated is called the state of natural vibration. Fig. 2 shows the vibration statement of a simple beam when a vehicle runs on the beam (forced oscillation) and when the vehicle has left the beam (natural vibration).

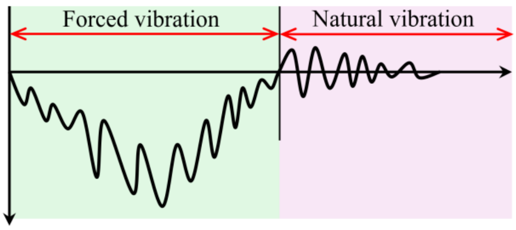

Fig.2 – Structural vibration statement

The basic characteristics of the vibration statement are expressed in its frequency or vibration period. The frequency of natural vibration depends on many factors:

- Structural characteristics of the structure or structural part.
- Stiffness of the structure includes factors of geometric dimensions and elastic modulus of the material.
- Mass of the structure.
- Resistance of the oscillating environment.

The equipment used to measure the natural vibration frequency of the cable consists of an accelerometer and a digital data logger connected to a computer to record the vibration graph of the cables. The frequency is obtained by analyzing the vibration spectrum using the FFT method.

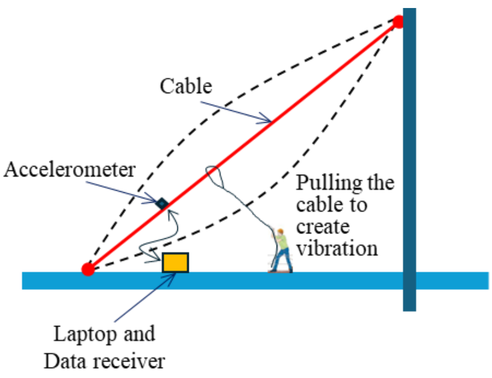

Fig. 3 – Layout diagram of cable vibration frequency measuring device

The sequence of determining internal force (tension or stress) in the cable stay by the method of creating oscillating pulses applied to measuring the tension in the cable is as follows:

Step 1: Attach the cable vibration measuring device.

Step 2: Create a pulse to cause the cable to vibrate to test the device.

Step 3: Create a pulse to cause the cable to vibrate, measure and determine the natural vibration frequency of the cable (f0).

Step 4: Determine internal force (tension or stress) in the cable by the FEM model from the vibration frequency (enter the tension forces running out of frequency, the tension force with the same frequency as the measured tension force is the tension force in the cable to be found) (shown in Fig. 4).

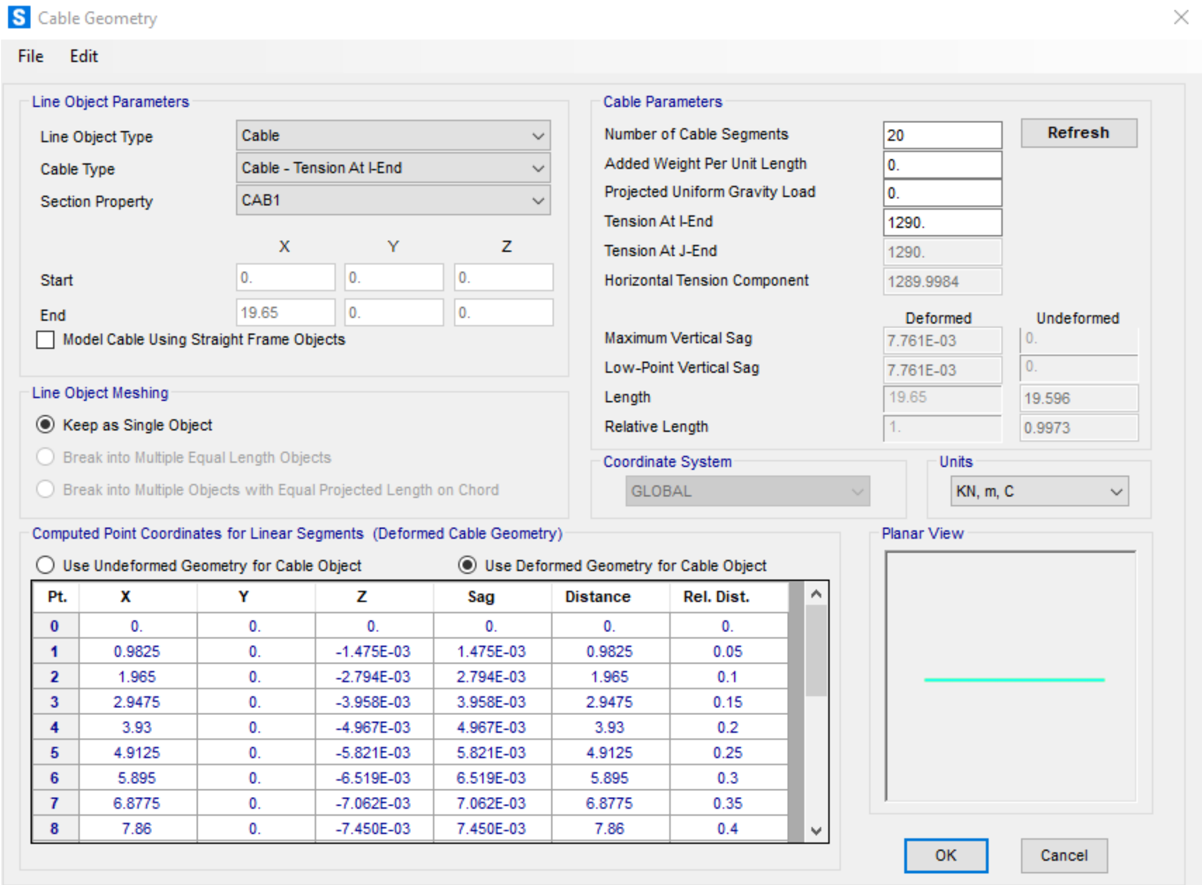

Fig. 4 – Illustration of model cable parameters in SAP2000

4 Case study description

4.1 General features of the extradosed bridge

Fig. 5 shown the extradosed concrete bridge with a bascule section in the middle, located in Hai Phong city in Vietnam. The main span bridge is a 2-span extradosed cable girder bridge with span length of 60m+60m, the cross-section of main span is a box girder structure with girder height varying from 2.1m~3.2m corresponding form middle span to top of tower. The height of the box girder at the tower H=3.2m; at the end of the edge span H=2.1m. The concrete of the box girder is f'c=45 Mpa. The approach span is 2 continuous prestressed reinforced concrete box girder spans 39.1m+40m, girder height 2.1m. The concrete of the girder is f'c=45 Mpa.

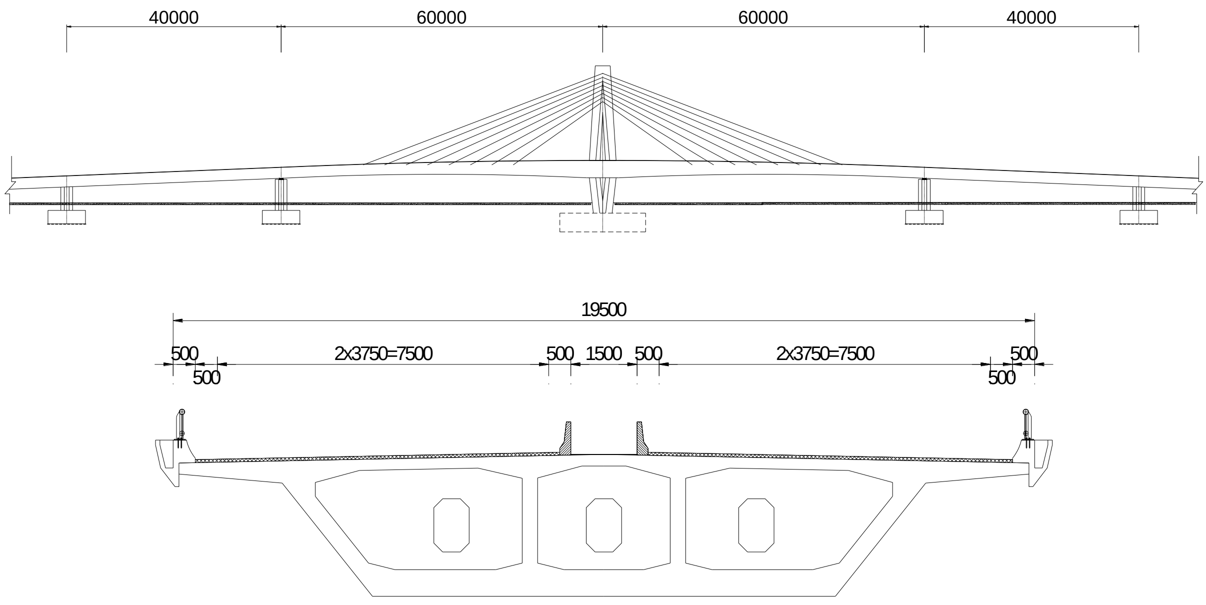

Fig. 5 – A profile and cross-section of the bridge (Note: Unit is mm)

4.2 Instrumentation and loading plan

Load testing equipment, including strain gauges, deflection gauges, and acceleration gauges, was installed at designated locations on the bridge to conduct the testing. The sensor device is arranged to measure the strain as shown in Fig. 6to 9. Fig. 6a and6b show the static load arrangement diagrams of the central loads and the measurement point locations on the bridge cross-section, respectively.

The load is measured before static loading on the bridge according to the calculated loading diagram. Determining the number of vehicles, vehicle distance, and vehicle weight is calculated in detail through a calculation model, based on determining the load effect on the cross-sections to be measured.

Static load measurements focused on girder stress, girder deflection, tower foot stress, tower top displacement, and cable tension. Trucks were positioned at critical load points on the bridge, and strain and deflection were recorded.

Additionally, to measure bridge vibrations, a truck was driven at approximately 30-40 km/h, and vibrations were recorded using an accelerometer.

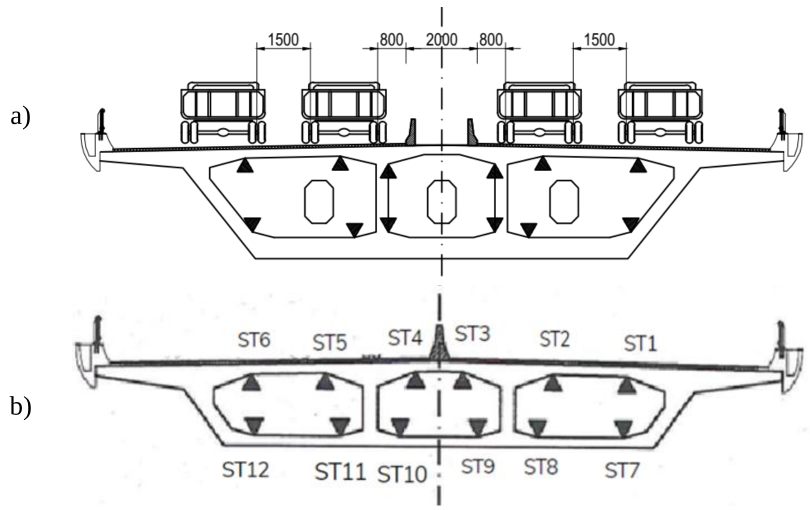

Fig. 6 – Illustration of measuring and loading points on the bridge

Fig. 7 – Strain Gauge Sensor

Fig. 8 – Layout diagram of trucks (symmetrical about the bridge's center)

Fig. 9 – Layout diagram of trucks (load on one side of the bridge)

4.3 FE Model of the bridge

The computational model of the bridge was completed with the use of program MIDAS Civil (MIDAS Engineering Software). Model of the bridge include 74 beam elements; 16 truss elements; 75 nodes. Table 1 describes the material characteristics used in the analysis model. Table 2 describes the characteristics of the changing sections, for beams it is the assignment of elements from beam 1 to beam 2 and for towers it is the assignment of elements from tower 1 to tower 4.

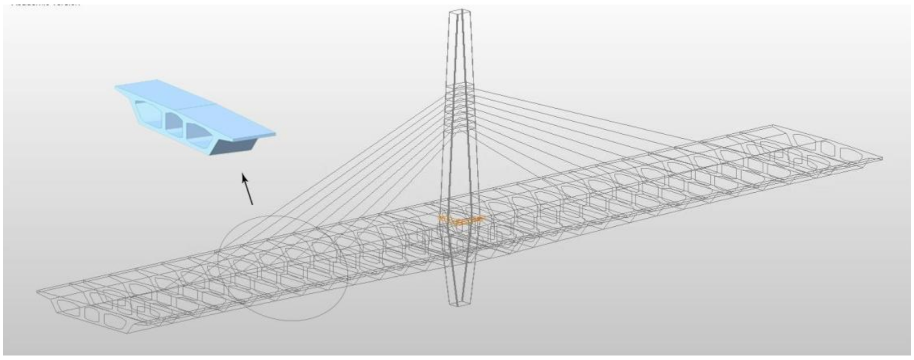

Fig. 10 – FE Model of the bridge

Table 1 – Material properties

Type	Name	Elasticity (kN/m²)	Poission	Density (kN/m³)
Steel	A416-270(Normal)	196500000	0.3	77.09
Concrete of beam	Grade C7000	33238000	0.2	23.56
Concrete of tower	Grade C6000	30772000	0.2	23.56

Table 2 – Section properties

Section	Area (m²)	Ixx (m⁴)	Iyy(m⁴)	Izz(m⁴)
Beam 1	12.6303	21.0195	6.6752	295.692
Beam 2	12.6719	22.2144	7.002	326.246
Tower 1	17.0553	60.6971	24.368	370.473
Tower 2	5.4	2.0367	0.8303	13.734
Tower 3	6.117	3.9917	1.2851	7.2709
Tower 4	5.2979	3.602	1.2857	4.063
Cable	0.0048	0	0	0

4.4 The result of load test

4.4.1 Static load test

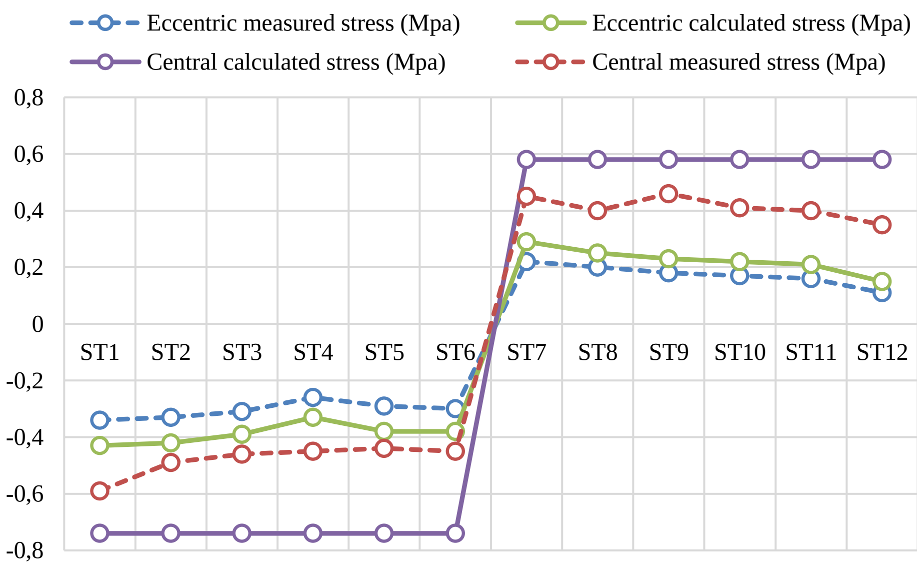

Fig. 11 – Stress results at the mid-span of main span (N3)

A proof test's basic description is to determine a safe load limit experimentally. Conduct measurements at the cross-section at the mid-span of main-span (N3) and at tower (T3) (primary beam stress measurement). After measuring in the field, process the measurement results combined with the theoretical calculation results with the actual load to obtain the results as shown in Fig. 11 and 12. The results show that the measured stress is about 60% to 80% smaller than the calculated stress with the static load test, respectively. The above results show that the cross-section ensures the strength for the static load test.

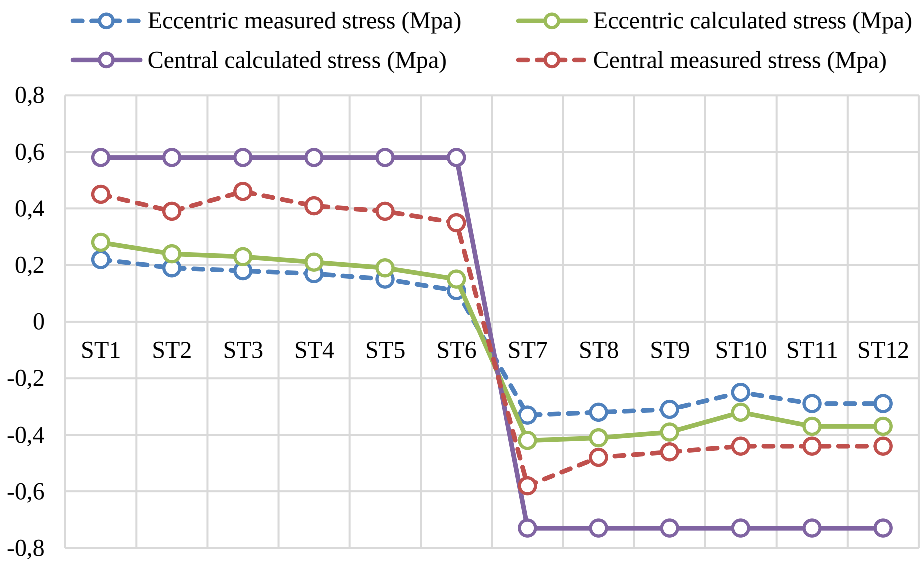

Fig. 12 – Stress results at tower (T3)

Fig. 13 – Arrangement of cable vibration measuring equipment

The cable tension force is measured by the vibration method. After agitation, the cable vibration acceleration results are obtained. FFT analysis is conducted to get the vibration frequency results. From the vibration frequency results, the cable tension forcesare calculated. The bridge uses a 16-strand cable bundle with individual strands of 15.7mm diameter and 149.09mm² cross-sectional area. Fig. 13 shows the cable vibration measurement setup as described in the vibration measurement method section presented in section 2. Fig. 14 shows the example of FFT analysis for the vibration measurement results of cable. Tables 3 and 4 show the analysis results of the cable tension force measured by the vibration method, which has a negligible error compared to the cable tension measured by lift off (error about ±6%). This proves that the vibration measurement method has high accuracy and can be used to evaluate and calculate the cable tension indirectly through cable vibration measurement.

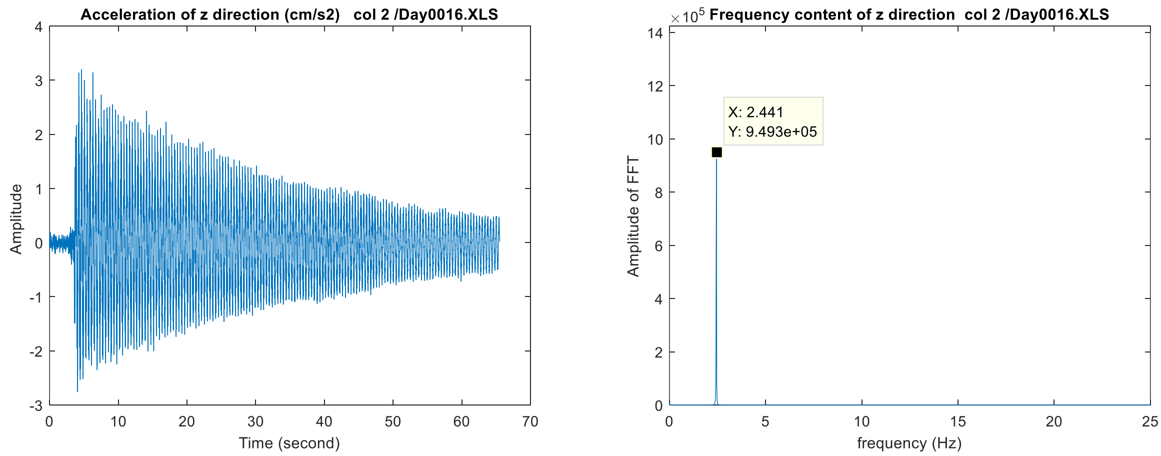

Fig. 14 – Example of FFT analysis for the vibration measurement results of cable

Table 3 – Results of calculating cable tension on the left side of the tower

Cable	Frequencies(Hz)	Actual measured tension(kN)	Lift-off measured tension(kN)	Error
No. 1	6.226	1290	1334.02	-3%
No. 2	5.249	1320	1325.48	0%
No. 3	4.578	1360	1284.17	6%
No. 4	3.906	1300	1326.76	-2%
No. 5	3.326	1200	1254.28	-4%
No. 6	2.960	1200	1213.26	-3%
No. 7	2.686	1190	1209.68	-2%
No. 8	2.457	1190	1212.92	-2%

Table 4 – Results of calculating cable tension on the right side of the tower

Cable	Frequencies (Hz)	Actual measured tension (kN)	Lift-off measured tension (kN)	Error
No. 1	6.195	1284	1334.02	-4%
No. 2	5.081	1278	1325.48	-4%
No. 3	4.637	1372	1284.17	7%
No. 4	3.860	1285	1326.76	-3%
No. 5	3.281	1184	1254.28	-6%
No. 6	2.945	1174	1213.26	-3%
No. 7	2.670	1183	1209.68	-2%
No. 8	2.441	1182	1212.92	-3%

4.4.2 Dynamic load test

The dynamic load test uses a moving load at various speeds to assess the bridge's response to dynamic effects. This complements static load tests. The dynamic load test of the bridge was conducted with the 3-axle vehicles driven in the centre of the road at a constant speed. Testing started at approximately 30 km/h and increased to 40 km/h.

Table 5 shows the measurement results of the bridge's main span, a truck running at 30km/h. The vertical natural vibration period of the span structure is outside the forbidden zone of 0.45s-0.6s; the horizontal natural vibration period is not a multiple of the vertical natural vibration period. Therefore, the span structure ensures stable working ability in terms of dynamics.

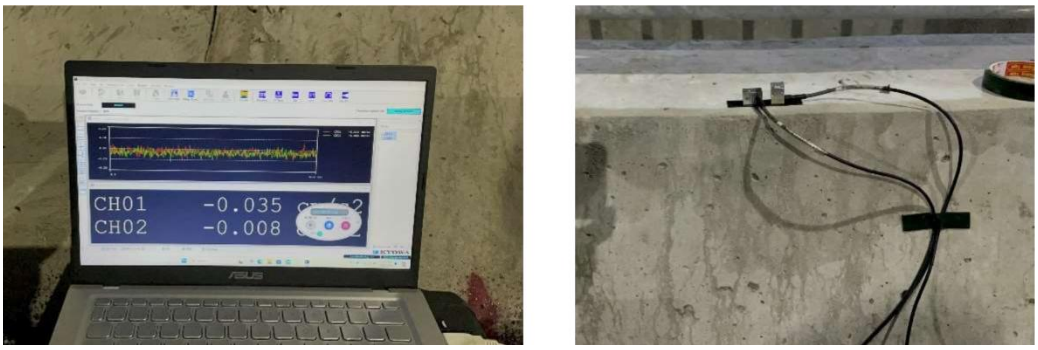

Fig. 15 – Dynamic measuring device

Table 5 – Dynamic measurement results of span bridge

Location	**Velocity**	**Calculated vibration period T(s)**		**Measured vibration period T(s)**	
		Vertical direction	**Horizontal direction**	**Vertical direction**	**Horizontal direction**
N3 span	30km/h	0,41	0,17	0,38	0,15

5 Conclusion

The paper presented a bridge load testing procedure with static and dynamic measurements. Based on the field test data and theoretical calculations for the bridge's structural components show the span structure is designed to support the specified load safely, the response of the span structure and cable tension is within the allowable limits, the stress and deformation state of the span structure is in the elastic phase, the cable tension force measured by the vibration method has a negligible error compared to that measured by lift-off.

Bridge load testing is crucial for assessing load-bearing capacity and informing maintenance and repair decisions. This helps bridge management agencies accurately evaluate the bridge's health.

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