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EXPERIMENTAL ASSESSMENT OF EXISTING BRIDGE STRUCTURE

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Abstract

Assessing existing bridges is an important task in the sustainable management of infrastructure, particularly for those structures that have been in service for extended periods and lack comprehensive technical documentation. In fact, due to the old age of a large part of the infrastructure assets and the deteriorating conditions affecting the structural elements, their safety with respect to the ultimate limit states may be compromised, making it essential to conduct experimental assessments and additional analyses to accurately determine their current load-bearing capacity and functional viability.

Experimental tests performed on an existing concrete bridge built in the 90s are presented in this paper. The bridge is a single-bay structure with a simply supported beam structural system and a 12.8-meter span. The testing process was divided into two phases. In the first phase, the dynamic characteristics of the bridges were evaluated using the ambient vibration method, while the second phase focused on assessing the bridges' behavior under static and dynamic loads. More in detail, the second phase was carried out through static and dynamic load testing. To measure dynamic characteristics, accelerometers, data acquisition systems, and a PC were employed, whereas strain gauges, accelerometers, and linear potentiometers were used for static and dynamic loading tests.

The results from these experimental tests can be utilized to calibrate and enhance the accuracy of the numerical analyses for the bridge, so more complex analyses and seismic assessment could be performed. Following comprehensive analyses and investigations, conclusions were reached regarding the condition of the bridge structure.

Keywords: bridge, ambient vibration, static and dynamic loading

1. Introduction

The condition and performance of existing bridges built in the past evolve over time. Consequently, obtaining an accurate evaluation of their load-bearing capacity and functionality requires specific experimental testing and additional analyses. This paper discusses the findings from experimental studies conducted on an existing concrete bridge [1] [7] situated in the municipality of Negotino, R. N. Macedonia. The experimental process for this structure involved assessing the dynamic characteristics of the bridge using the ambient vibration method and evaluating its response to static and dynamic loading. Key results from these investigations are presented in this paper.

2. Description of the structure

The bridge is a concrete structure built in the 90s, using construction techniques typical of that time. The bridge is a single-bay structure with a simply supported beam structural system and a 12.8-meter span. The structure consists of eight longitudinal reinforced concrete girders placed side by side, supporting a cast-in-place reinforced concrete slab. The girders have a variable cross-section along their length. At the middle of the span, they have a "T" cross-section with a height of 80 cm, a web width of 20 cm, and a flange thickness of 15 cm. Toward the ends, the cross-section of the girders gradually

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transitions into a rectangular shape with dimensions of 50/80 cm. The reinforced concrete slab consists of the flanges of the girders, which are tightly positioned to each other, and a leveling layer of concrete of 5 cm, over which a layer of asphalt is applied. The primary longitudinal girders are interconnected by transverse girders, positioned at each quarter of the span of the main girders. The main girders are positioned directly on the end columns, which has resulted in localized detachment of surface concrete layers, (Fig. 1).

Figure 1. Location and appearance of the concrete bridge.

3. Methodology of testing

The bridge under investigation is an existing concrete structure for which no construction design documentation is available. Consequently, the design loads, characteristics of the structural elements, type of bearings, and calculated deflections and deformations from the design are unknown. Due to these limitations, the testing procedure could not fully comply with the MKS 1019:2018 standard for bridge testing [2]. Instead, the testing was adapted to the on-site conditions and the resources available [8]. Another major challenge was the absence of detailed information about the bridge's foundation, which condition is crucial to ensuring the structure's overall stability, especially when subjected to future operational loads.

The tests conducted on the bridge were classified as control tests, in accordance with Section 4.1 of MKS 1019:2018 [2], and were carried out during the bridge's operational phase. Due to the lack of documentation, an initial visual inspection was performed. Following this inspection, a testing program was developed, incorporating the tasks outlined in Section 5.2 of MKS 1019:2018:

- Definition of the size and distribution of loads for each phase;
- Identifying measurement points where maximum deflections and deformations are expected;
- Development of an organizational plan for the application of the loads.

Both static and dynamic load tests were performed in accordance with Section 4.3 of MKS 1019:2018.

The static load tests provided the following results (as per Section 5.4 of MKS 1019:2018):

- Measurements of vertical deflections at the midspan of the bridge;
- Occurrence of cracks in the structural elements;
- Measurements of deformations at places of expected extreme effects;
- Measurements of residual deflections and deformations after the removal of the loads.

Unfortunately, due to limited access, it was not possible to measure displacements at the bridge bearings.

The dynamic load tests provided the following results:

- Measurements of vertical deflections at the midspan during the passage of a moving load;
- Measurements of the speed at which the load traveled across the bridge.

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Additional measurements during the dynamic tests included:

- Deformations at critical locations under extreme effects;
- Transverse and longitudinal displacements at the midspan of selected spans;
- Remaining dynamic characteristics of the bridge structure.

Some of the results are presented in this paper.

4. Determination of the bridge's dynamic characteristics using the ambient vibration method

4.1. Testing procedure and Instrument layout

The ambient vibration method was used for determination of the current dynamic characteristics of the bridge. The testing procedure involved capturing real-time accelerations and analyzing the data in both the time and frequency domains. Accelerometers were strategically placed at predefined locations on the bridge structure. The placement of these measurement points was carefully planned to ensure the collection of sufficient data for accurately determining the required dynamic characteristics [3][4][5].

Ten measurement points were defined for the bridge. At each point, three accelerometers were installed to measure accelerations in the transverse, longitudinal, and vertical directions, total 30 accelerometers. One point (Point 2, Fig. 2) was selected as a reference point, where the accelerometers remained in a fixed position throughout all measurements. The other 27 accelerometers were moved across the remaining predefined points. Fig. 2 illustrates the placement of the accelerometers at these measurement points. To record the acceleration time histories at all predefined points, 3 measurements were conducted. Each dataset consisted of acceleration time histories with a duration of 300 seconds and a sampling frequency of 2048 Hz (2048 samples per second). During the field measurements, the bridge and surrounding structures were in a state of rest.

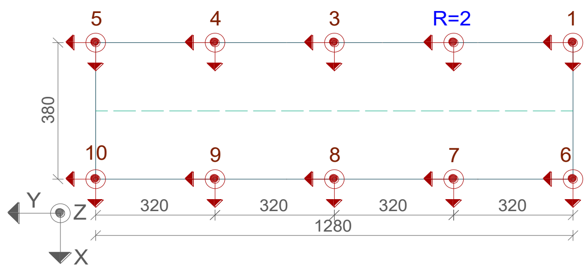

Figure 2. Position of accelerometers at measuring points

4.2. Results and Discussion

The recorded ambient vibration data were analyzed and processed using the ARTeMIS Modal software (version 7.1), developed by Structural Vibration Solutions A/S [6]. The dynamic characteristics of the bridge—natural frequencies, mode shapes in different directions, and damping coefficients—were determined using the Peak Picking (PP) technique, an identification method applied in the frequency domain to the recorded data. Table 1 presents the identified dominant frequencies of the bridge and their corresponding mode shapes.

Table 1. Dominant frequencies of the structure – model of the integral bridge

Frequency [Hz]	Mode
11.0	First mode – vertical direction
14.0	First mode - torsion
17.8	Second mode – vertical direction

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By analyzing the determined dynamic characteristics of the bridge, it can be concluded that the fundamental natural frequencies are in general clearly defined, and the mode shapes exhibit a continuous deformation pattern. This suggests a uniform distribution of stiffness across the structure. The modes of vibrations are given in Fig. 3, Fig. 4, and Fig. 5.

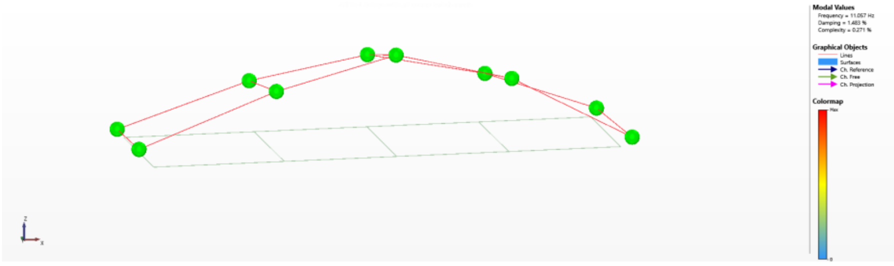

Figure 3. First mode – vertical direction [11.0 Hz]

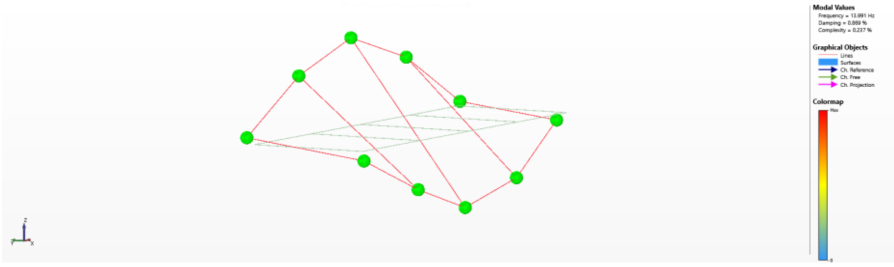

Figure 4. First mode – torsion [14.0 Hz]

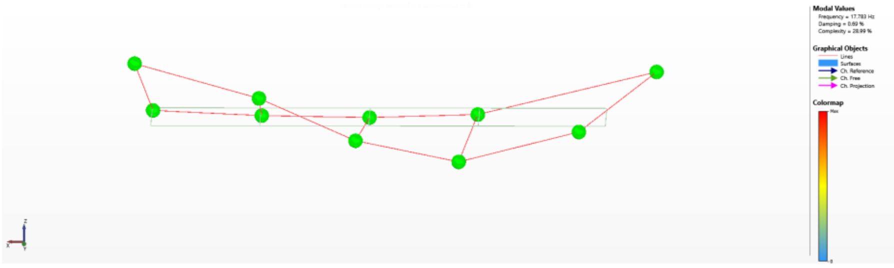

Figure 5. Second mode – vertical direction [17.8 Hz]

5. Static and Dynamic loading

To determine the control parameters during serviceability of the bridge, appropriate instrumentation was installed, as shown in Fig. 6. A total of 21 instruments were placed, including 4 strain gauges (SG) positioned at key locations to measure strains, 15 accelerometers (ACC) placed at five points to measure acceleration in the three directions (x, y, and z), and 2 linear potentiometers (LP) for measuring deflections (vertical deformations).

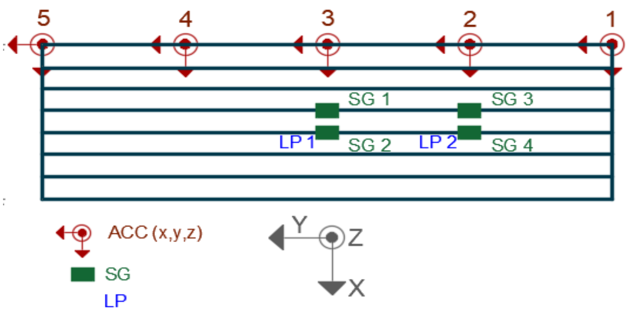

Figure 6. Scheme of instruments on the bridge

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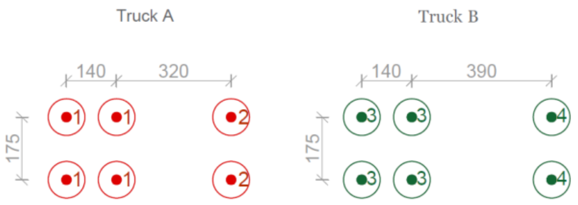
For the static and dynamic loading tests, two types of trucks were used, with a total of four trucks. The characteristics of the trucks used, Truck A and B, along with a the distribution of forces on the wheels during the static loading test are provided in Fig. 7.



Truck A ≈ 24.8t	
Point	Force [kN]
1	46.5
2	31.5
Truck B ≈ 24.5t	
Point	Force [kN]
3	46
4	31.9

Figure 7. Axial distance of wheels of trucks A and B

According to the size of the bridge and the trucks, the test loading was conducted using a maximum of two trucks. Initially, the bridge was loaded with a single truck, weighing approximately 24.8 tons, of which around 18.6 tons were on the rear wheels. Subsequently, the load was increased by adding another truck of the same type, resulting in an additional load of 24.8 tons. Between the static load tests, unloading (empty measurements without load) were performed. All tests lasted three minutes, Table 2.

Table 2. List of static loadings

No of loading	Duration	Mass [t]
1	3 min	0
2	3 min	24
3	3 min	0
4	3 min	48
5	3 min	0

It is important to note that due to insufficient space to position both trucks as a concentrated load in the middle of the span, they were aligned lengthwise along the entire span. Consequently, the maximum concentrated load at the center of the span was approximately 37 tons, while the maximum applied mass of nearly 49 tons acted as a uniformly distributed load across the entire span. The technical positioning of the trucks, for static loading, is illustrated in Fig. 8, whereas Fig. 9 presents photograph of the static loading number 4.

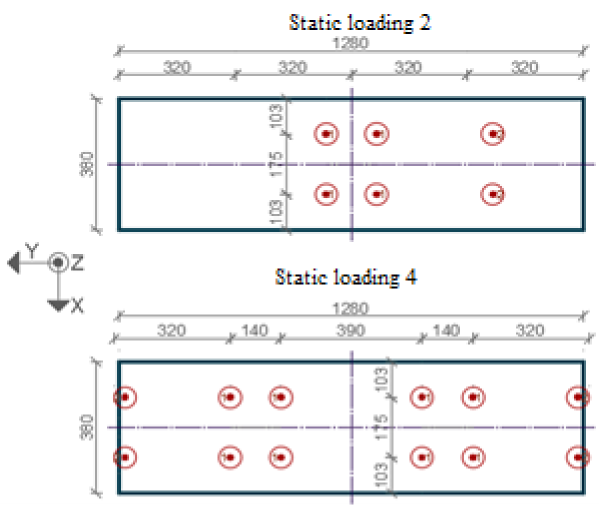


Figure 8. Position of trucks during static loading 2 and 4, respectively

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Figure 9. Photo of static loading 4

Table 3 presents the maximum values of strains and deflections under characteristic static loadings. From the results of the vertical displacements, it can be concluded that the measured vertical deformations are smaller than the allowable limit of L/750. Furthermore, Fig. 10 shows the strains measured by the strain gauges during static loadings.

Table 3. Maximum values from instruments under static trial loadings

	SG1 [mstr]	SG2 [mstr]	SG3 [mstr]	SG4 [mstr]	LP1 [mm]	LP2 [mm]
Static loading 2	77.28	86.84	34.32	33.24	1.62	1.35
Static loading 4	167.94	161.02	171.76	142.18	1.84	1.26

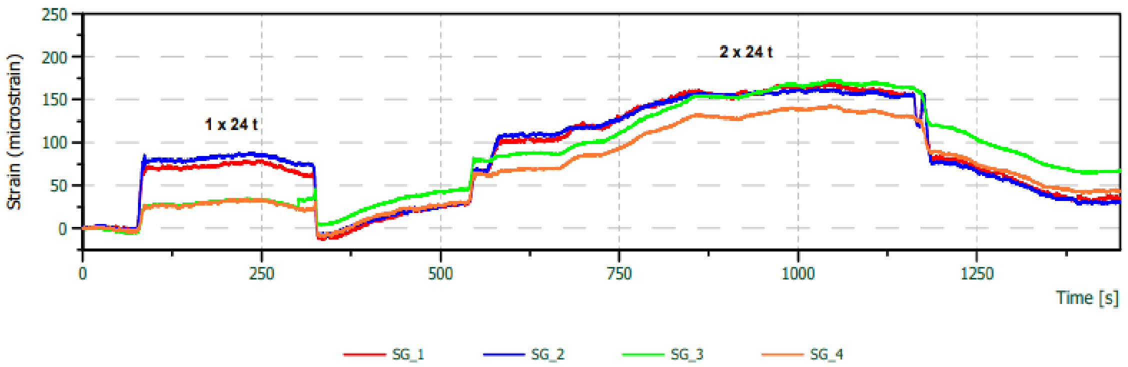

Figure 10. Time histories from strains measured by strain gauges during static loading

The dynamic loading was conducted through two different tests. Specifically, the trucks crossed the bridge at various characteristic speeds (5 km/h – 10 km/h). A metal plate obstacle was placed at the first third point of the bridge, to simulate an impulsive dynamic excitation. Table 4 presents the maximum deflections (vertical deformations) during the dynamic tests.

Table 4. Tabular presentation of deflections during the dynamic tests

Instrument	Vertical deformation due to static load [mm]	Vertical deformation due to dynamic load – 5km/h [mm]	Vertical deformation due to dynamic load – 10km/h [mm]
LP1	2.64	2.04	2.25
LP2	2.05	1.41	1.56

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6. Conclusion

Based on the experimental investigations conducted, the following conclusions can be drawn:

- Dynamic characteristics: The dynamic properties of the bridge, such as natural frequencies and mode shapes, were clearly defined. The bridge shows a consistent deformation pattern, indicating a uniform distribution of stiffness across its structure.
- Deflections and deformations: Both static and dynamic deflections and deformations were within acceptable limits set by the standards. The vertical deflections after unloading were below the allowed limits for reinforced concrete bridges.
- Impact on functionality: The deflections and vibrations do not affect the bridge's use, safety, or appearance. Vibrations did not cause discomfort for users, showing that the bridge works well under the applied loads.
- Conformance to standards: Although the tests could not fully follow the MKS 1019:2018 standard due to missing design data, the methods were adjusted to fit the available conditions on-site, ensuring reliable results.
- Further investigations: More studies are needed to check the condition of the foundation, as the lack of detailed information about it could affect the bridge's overall stability and long-term performance.

Based on all the results obtained, it was determined that the bridge is in good condition and performs well under the loads applied during the tests. Furthermore, the findings from these experimental tests can be used to calibrate and improve the numerical model for the bridge, enabling more advanced evaluations and a more precise seismic assessment according to the current codes.

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