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CONDITION ASSESSMENT AND STRENGTHENING OF A CONCRETE BRIDGE FOR TRAM PASSAGE

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ABSTRACT: Heavy traffic road bridges in Greece are mostly designed to the 60/30 class loading – DIN1072 with two three-axle trucks weighing 60t and 30t and 6.0m in length each. The objective of this research is to assess the adequacy of an existing multi-spam concrete bridge for tram passage where the axle loads are quite high locally. Numerical analysis is conducted for three representative single spans. Results are tabulated by comparing the maximum effects due to the tram loading with those of 60/30 class loading. The results raised a concern as they revealed some inadequacies of the load model 1 of Eurocode 1 part 2 and the tram in comparison with 60/30 class loading. Extensive field measurements and laboratory testing, as well as analytical work is performed to assess the condition of the superstructure and propose a strengthening scheme.

KEYWORDS: Concrete; bridge; axle loads; tram loads; strengthening; experimental fields; testing.

1 INTRODUCTION

Road bridges are a substantial part of infrastructure of a modern country like Greece. They provide the vital links for communication and transportation within a city, and it is essential that these links remain functional throughout the design life of the structure. Even a minor disruption of a heavy traffic bridge in a city can be consequential.

The present work concerns the condition assessment and strengthening study of an existing concrete road bridge located in the city of Piraeus (Lambraki Avenue) that was build in the late 60's and will accommodate tram passage. The main part of the study focuses on the structural performance of the bridge under the loads as defined by the old regulations (i.e., traffic loads according to DIN 1072), followed by a study on it's performance to the loads due to the tram and load model 1 of EC1-Part 2. The study provides also the necessary technical details for the required stiffening and improvement measures for the bridge.

The bridge structure is constituted by nine simply supported parts (decks) with width 17.35m resting on concrete wall-pylons with variable height. The 1st, 8th and 9th parts of the bridge are skew solid plates with length 14.75m and height 0.80m. The 2nd part consists of a skew deck plate with thickness 0.30m lying on a grid of longitudinal and transverse beams with a total height of 1.60m. The length of this part is 31.55m, while the longitudinal beams are made of prestressed concrete. The rest 3rd to 7th parts are 18.0m long and each part consists of an orthogonal deck plate with thickness 0.30m lying on a grid of longitudinal and transverse beams with a total height of 1.60m. The reinforced concrete material properties are assumed to correspond to qualities B25/BSt400 (DIN 1045). A plan view of the bridge arrangement is shown in Fig. 1 and perspective views of parts 1 and 2 are shown in Fig. 2.

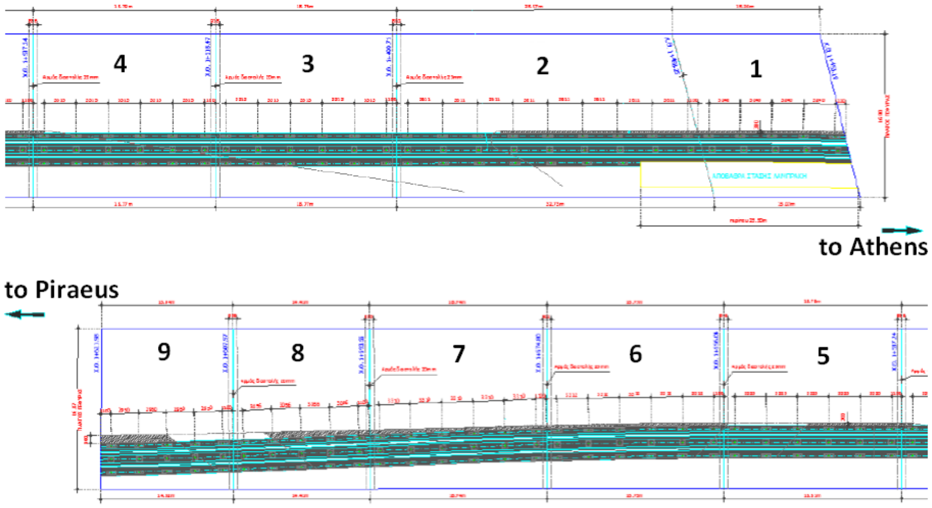


Figure 1. Plan view of the bridge

Figure 2. Perspective views of the 1st and 2nd parts

The grid arrangement of the 3rd part is similar to the one of the 2nd part with one additional transverse beam, while both parts have six longitudinal main beams. All subsequent parts are simply supported on concrete wall pylons as shown in

Fig. 2. Each pylon has a rectangular cross-section (concrete wall) and accommodates 12 elastomeric bearings for the 6 main beams for each left and right subsequent part.

2 CODES OF PRACTICE

In Greece, the early bridge design guidelines were based on the allowable stress design approach with loading models according to DIN 1072. After 1990, the DIN Fachberichten along with directive E39/99 have been adopted based on the ultimate stress design approach. The last decade, design according to Eurocodes has fully prevailed in the field of bridge engineering. The three loading models employed in this study are summarized as follows:

(i) DIN 1072

The loading model for class 60/30 of DIN 1072 consists of two subsequent trucks weighing 60t and 30t, respectively. Both have 3 axles that are 1.50m apart to each other as shown in Fig. 3. The main lane has width 3.0m and is loaded with 500kg/m^2 uniform load in front and the back of the two trucks, while the rest of the deck is loaded with 300kg/m^2.

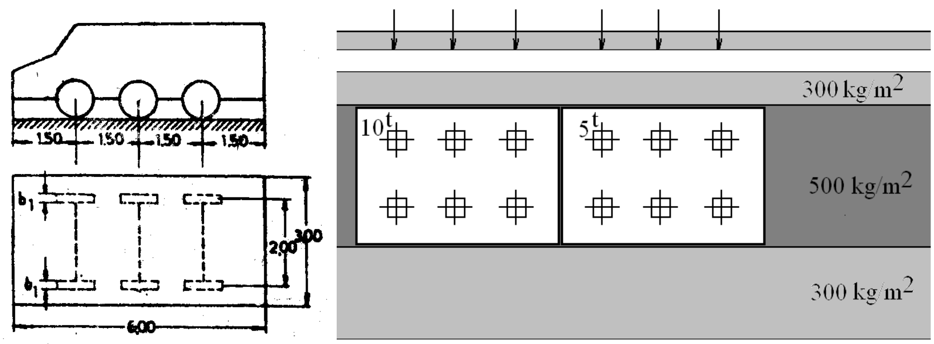


Figure 3. Load model for class 60/30 of DIN 1072

(ii) Eurocode 1 – Part 2

The loading model 1 for of EC1 consists of three lanes that have width 3.0m with a two-axle truck model each, weighing 600kN, 300kN and 200kN, respectively. The main lane is loaded with 9.0kN/m^2 uniform load, while the secondary lanes and the rest of the deck are loaded with 2.5kN/m^2.

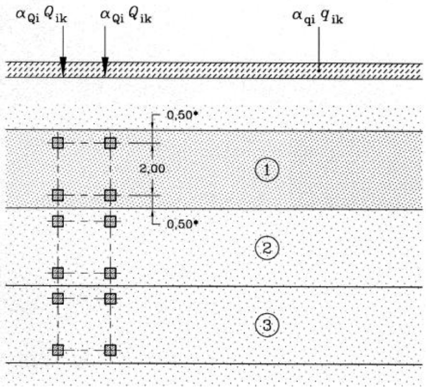


Figure 4. Load model 1 of EC1 - Part 2

(iii) Tram Loading

The tram loading is provided by the Athens Tram Authority and consists of three wagons with 3 pairs of axes weighing 120kN each as shown in Fig. 5.

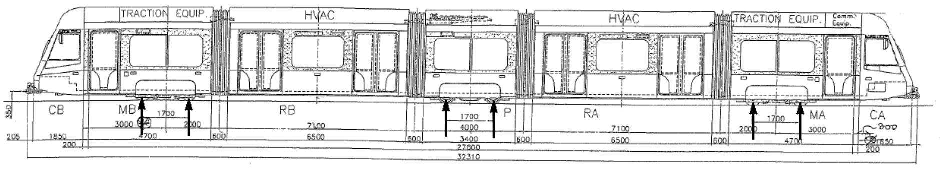


Figure 5. Load model for tram

3 DEVELOPMENT OF FE ANALYTICAL MODELS

A separate analysis using finite element models is performed for each of the three different parts by considering the simply supported span based on elastomeric bearings with lengths 14.75m, 31.55m, and 18.00m, respectively. Based on these analyses, the stresses and deformations (because of bending) under the operation loads according to DIN 1072 were determined.

However, because of the particularly high traffic loads of the examined bridge, but also its significant importance for the transportation network of Piraeus City, the loading model 1 of EC1 is also included. Thus, the load model 1 of EC1 and the tram load were applied, the stresses and deformations of the three models were recalculated and the requirements of strengthening measures were accessed. Figures 6, 7 and 8 present the perspectives of the 1st, 2nd and 3rd parts, respectively.

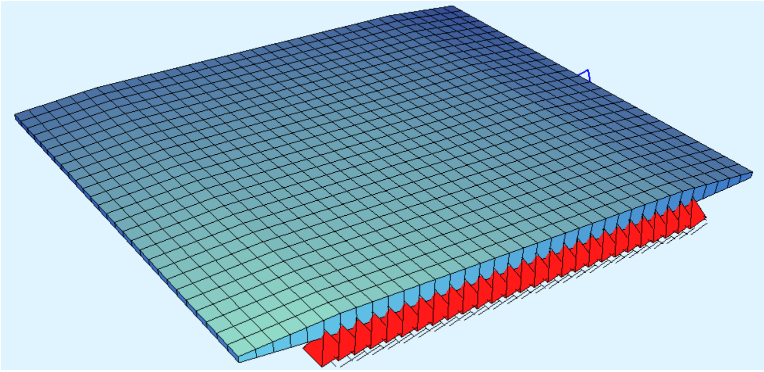


Figure 6. FE model for the 1st part (solid plate deck, *l*=17.45m)

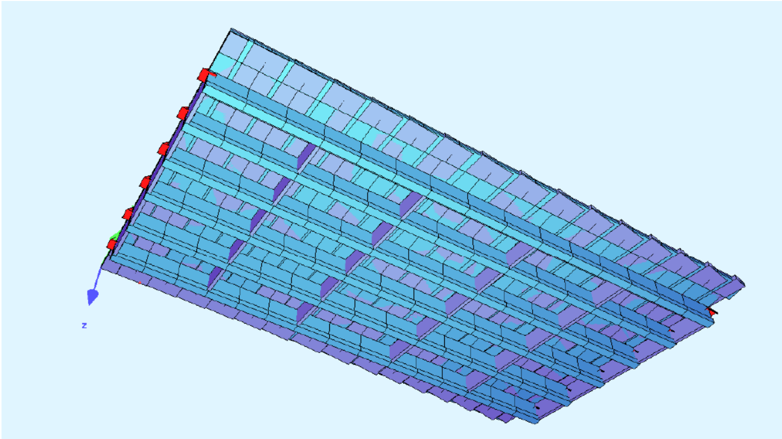


Figure 7. FE model for the 2nd part (deck on grid, *l*=31.55m)

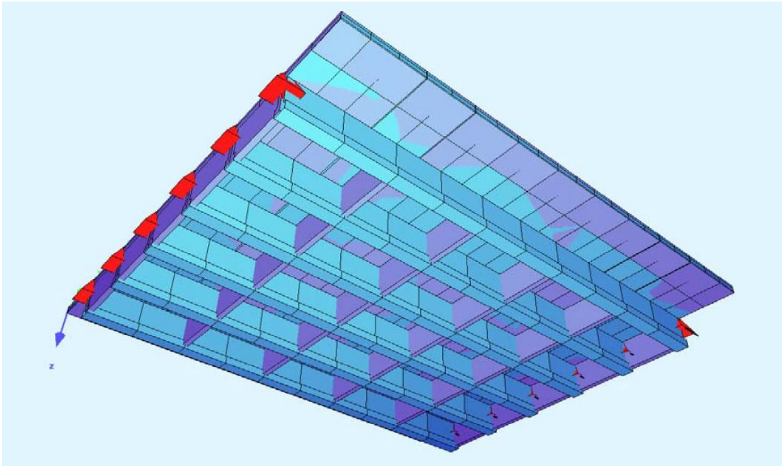


Figure 8. FE model for the 3rd part (deck on grid, *l*=18.00m)

Note that the above bridge is overloaded with traffic loads classified into the category of heavy traffic (according to the Technical Notes of the Ministry of Public Works for bridges with traffic over 8,000 passages of vehicles per day) and, moreover, due to the fact the actual number of passages exceeds the above limit.

The self-weight of the concrete structure (load case LC-1) is considered as γ_b=25.0 kN/m^3. For the pavements a plate thickness t=20 cm is considered with γ_b=25.0 kN/m^3, while for the asphalt layer a thickness t=8 cm is considered with γ_a=22.5 kN/m^3.

According to DIN 1072, for the main traffic lane a load 5.0 kN/m^2 is considered over the whole length of the bridge, while for the rest area of the deck the load is taken as 2.0 kN/m^2. A live load of 2.5 kN/m^2 is also considered for the pavements. These uniform loads constitute the load case LC-2a.

The concentrated loads of vehicles are applied according to DIN 1072, as follows: the vehicles in the main lane have 6 wheels with total loads 200 kN per axis and 100 kN per axis, respectively. The vehicles are placed at 4 different positions (load cases LC-3a to LC-6a), which are expected to give the most unfavorable results for the various elements of the bridge.

According to EC-1 for the main traffic lane, a load 9.0 kN/m^2 is considered over the whole length of the bridge, while for the secondary lane the load is 2.5 kN/m^2. A live load of 2.5 kN/m^2 is also considered for the pavements. These uniform loads constitute the load case LC-2b.

The concentrated loads of vehicles are applied according to EC-1 as follows: the vehicle in the main lane has 4 wheels with total load 300 kN per axis while the vehicle in the secondary lane has also 4 wheels with total load 200 kN per axis. The vehicle loads together with the tram loads are placed at 4 different positions (load cases LC-3b to LC-6b). The most unfavorable combination of loads produces the stress envelope that is used to evaluate the various structural elements of the bridge.

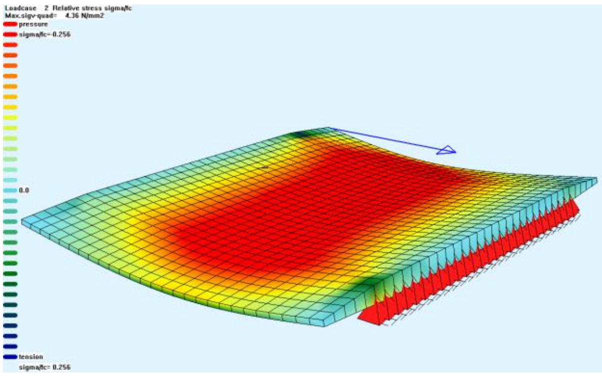


Figure 9. Stress distribution and deflections of the 1st part

The Figures 9, 10 and 11 show the stress distribution and deflections because of dead and live loads according to EC-1 and tram of the 1^{st}, the 2^{nd} and the 3^{rd} parts, respectively.

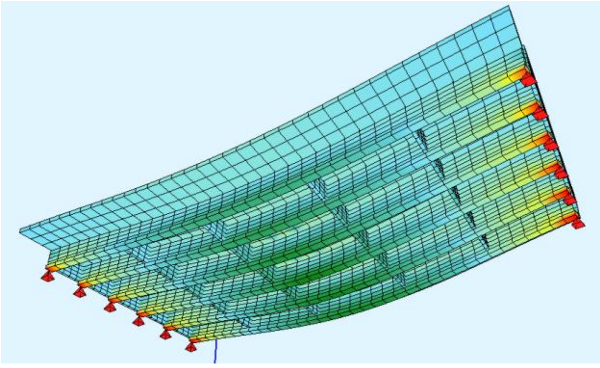


Figure 10. Stress distribution and deflections of the 2^{nd} part

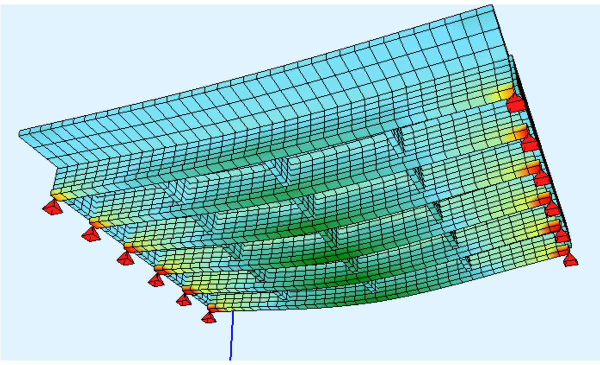


Figure 11. Stress distribution and deflections of the 3^{rd} part

From the analyses of the three representative models of the bridge with the DIN 1072 loading in comparison with the EC1-Part 2 and the tram loading, it results that the 1^{st} and the 5^{th} parts have adequate carrying capacity. In contrast, the 2^{nd} part requires additional reinforcement in order to undertake the bending moment. This finding was considered to be very important and further investigation based on field measurements and tests have been performed, as presented in the next sessions.

4 FIELD MEASUREMENTS AND TESTS

The measurements were also used to assess the finite element models for the three representative spans of the bridge that correspond to the parts 1, 2 and 5 shown in Fig. 1.

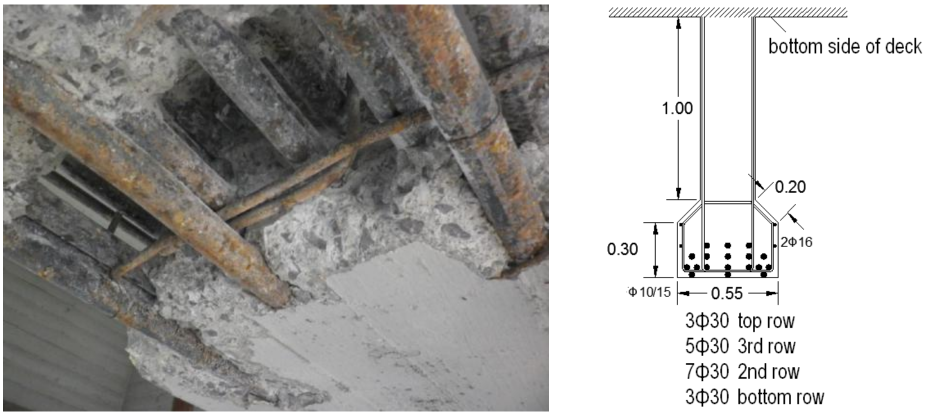
4.1 Steel reinforcement and concrete

A number of cylindrical specimens were obtained from representative spans according to the testing standards (Fig. 12). From these measurements, it was concluded that the concrete corresponds the mean value of B25 quality with compressive strength 25MPa.

Figure 12. Cylindrical concrete specimens for evaluation of the material qualities

Moreover, additional test employing impact and ultrasonic devices have verified these results. Regarding the reinforcement, the corresponding quality is classified to S220 with yield strength 220 MPa.

The reinforcements of the main girders were revealed at selected positions. In Fig. 13a one can see the main girder reinforcement at the bottom, which is also schematically drawn in Fig. 13b.



(a) (b)

Figure 13. Reinforcement of a representative main girder: (a) section after removal of concrete cover; (b) girder reinforcement.

4.2 Test loads

The bridge is also subjected to a static test loading in order to validate the vertical deformations. The test load model consists of two identical trucks with 4 axles each with between distances 1.70m, 2.48m and 1.33m, while the left row is 2.32m apart from the right raw. The first truck (Truck #1) is partially loaded (medium) while the second one is fully loaded (heavy). The medium weight truck has 11333kg per axis in the 4 rear wheels (i.e. 2833.25kg per wheel) and 9477kg in the 4 front wheels (i.e. 2369.25kg per wheel). The heavy truck (Truck #2) has 22178kg per axis in the 4 rear wheels (i.e. 5544.50kg per wheel) and 11662kg in the 4 front wheels (i.e. 2915.5kg per wheel).

In Figure 14a the test loading trucks are shown. In order to measure the vertical deflections of the 3 representative spans due to bending, high accuracy instruments have been mounted at the bottom of the bridge (see Fig. 14b) connected to the floor below the bridge (see Figs 14c, d).

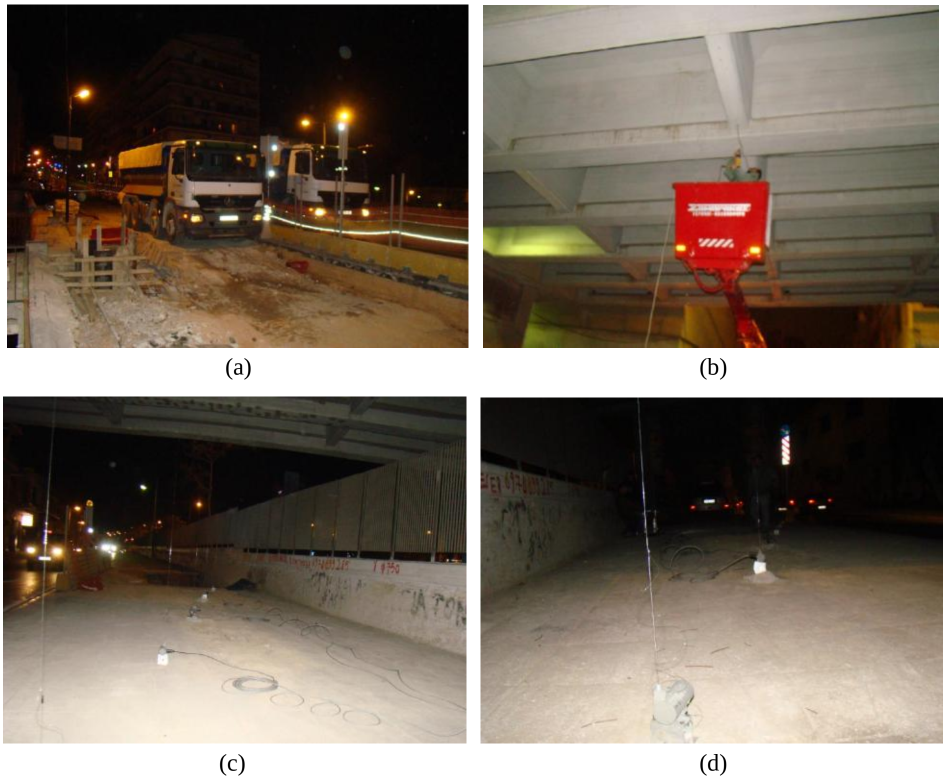


Figure 14. Test loading trucks and vertical deflection measurement devices

In Figure 15, one can see the positions of the test loading trucks and the measurement instruments. Six measurements were taken in the 5th and 2nd spans while 4 measurements were taken in the 1st span (see Fig. 15). The results from the test loading were compared to the corresponding numerical results obtained from the finite element models developed with shell and beam elements. The vertical deflections are tabulated in Table 1.

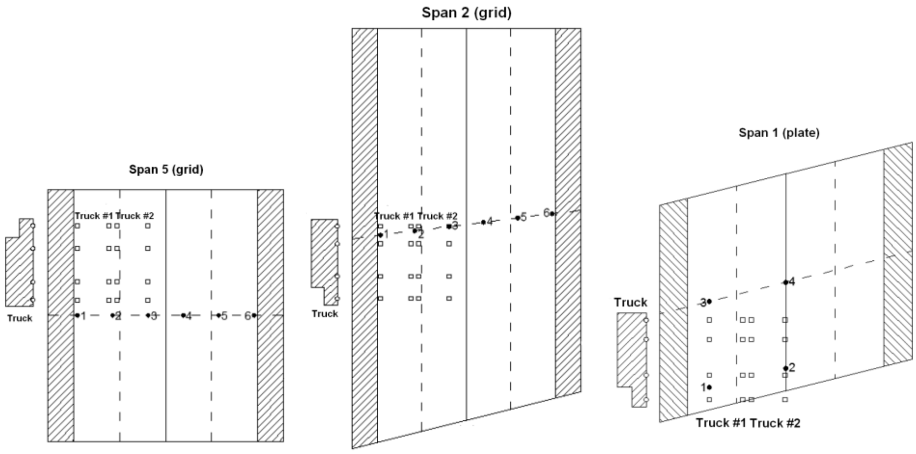


Figure 15. Positions of the test loading trucks and measurement instruments

Table 1. Measured Deflections (mm) for test truck loading

		Ch1	Ch2	Ch3	Ch4	Ch5	Ch6
Span 5	Measured	1.61	1.23	1.08	0.28	0.25	0.21
Span 2	Measured	2.19	2.27	3.33	2.46	1.93	2.03
Span 1	Measured	0.76	0.79	1.18	1.21	-	-

Comparison between the measured and the numerically evaluated deflections demonstrated differences not exceeding 15%.

4.3 Free vibration characteristics

Besides the static analysis for validation of the FE models, the dynamical characteristics of the 3 representative spans have been also investigated. More specifically, a special vibration survey system VSS with 3 channels and electromagnetic receivers SS-1 (ranger seismometer) with signal conditioner SC-1 has been employed to measure the eigenfrequencies of each span (see Fig. 16). This dynamical frequency check has been performed since it is known that damages can alter the dynamical characteristics of the originally intact structure. The results are tabulated in Table 2. Notice that several eigenfrequencies were measured for each one of the three spans along the two horizontal x and y axes as well as along the vertical z axis.

Comparison between the measured with the analytical calculations indicated that for the spans 2 and 5 there was a difference of above 12%.

Table 2. Dynamical characteristics of the 3 representative spans

Span	Measurement #	Direction	Eigenfrequency (Hz)
5	1	X	1.80, 4.69, 5.46
	2	Y	1.84, 3.82, 5.27
	3	Z	8.42, 8.79, 9.74
2	4	X	4.43, 4.79
	5	Y	4.73, 5.80, 7.27
	6	Z	1.85, 4.49
1	7	X	1.14, 1.69, 5.64
	8	Y	5.40, 10.62
	9	Z	9.16

5 STRENGTHENING MEASURES

The results obtained from the analytical model for both the static measurements and the eigenfrequencies were used to calibrate the finite element model. Consequently, an analysis of the span was performed for the design loads. Based on the results the following strengthening measures were recommended.

(i) The 1st and the 5th parts of bridge were adequate and no strengthening was required.

(ii) The pylons of bridge were considered adequate and no further investigation was proposed.

(iii) The 2nd span of 31.55 was found not adequate and strengthening measures have been taken. A reinforcement of 2 FRP lamina 10 cm width and 4 mm depth with E=170 GPa and f_j=2200 MPa was recommended.

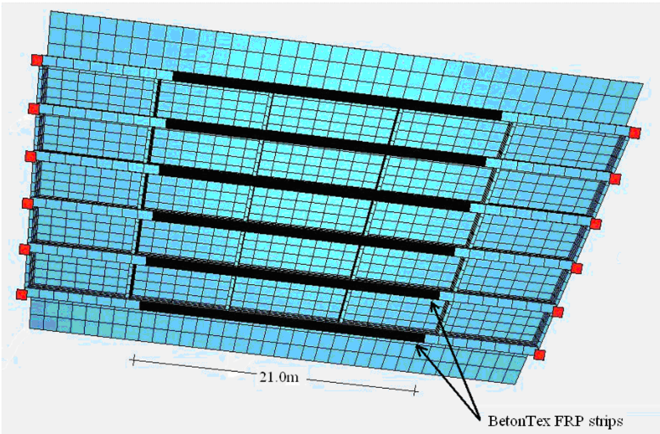


Figure 16. Application of FRP strips for strengthening of the Part 2

6 CONCLUSIONS

Modification of the current use of existing bridges requires in-situ extensive testing in order to reproduce the unavailable "as built" plans of the structure.

Consequently, calibrated FEA models can be developed to assess the current condition of the bridge as well as the necessary interventions to fulfill the new requirements of the structure. This work presents the sequential procedure that lead to the selection of the strengthening measures to be taken on a multi-span bridge for vehicle and tram loads.

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