ROCZNIKI INŻYNIERII BUDOWLANEJ – ZESZYT 10/2010
Komisja Inżynierii Budowlanej Oddział Polskiej Akademii Nauk w Katowicach

ANALYSIS OF POST-TENSIONED CONCRETE ROAD BRIDGE GIRDERS STRENGTHENED BY CFRP STRIPS USING FEM UNDER STATIC LOAD

Arkadiusz Grzegorz MORDAK
Opole University of Technology, Opole
Zbigniew MAŃKO
Wroclaw University of Environmental and Life Sciences, Wroclaw

1. Introduction

The subject of this study is the road bridge made of concrete spans with post-tensioned main girders over the Nysa Klodzka River situated in Klodzko. This paper shows the range and the way of the conducted research and some of the results, given in the form of figures, acquired from the measurements and FEM calculations of different quantities, e.g. displacements and strains as well as views showing the structure before and after strengthen by CFRP strips. It presents also an analysis of obtained results and main conclusions concerning testing conducted on this stage are presented. The research was conducted at two different stages of repair, that is, before performing the main research on static field load tests [1], which was aimed to determine the efficiency of the applied repairing methods. The bridge load capacity before its repair, determined in expertise, was classified as class E, that is 150 kN in accordance with the Polish Loads Standard (PN-85/S-10030), mainly due to a very poor technical condition of the load-carrying structure of bridge span, resulting mostly from transverse cracks in the main girders. The main aim of the repair was to increase the object load capacity to class C (300 kN).

The aim of the conducted research was to determine the behavior of span structure subject to considerable static loads for various load schemes [2]. The research allowed to find out on which elements of the span load-carrying structure the biggest forces were exerted during the progress of repair works of the bridge. The inspection of spans and analysis of the obtained results performed each time after the accomplishment of repairs allow determining the influence of the same load on the quality and durability of this object in the process of strengthening as well as the efficiency and purposefulness of this process.

2. Brief bridge description and range of conducted research

The tests were carried out on the one-span road bridge (Figure 1). The examined span consists of four main girders integrated with the new reinforced concrete deck slab of B50

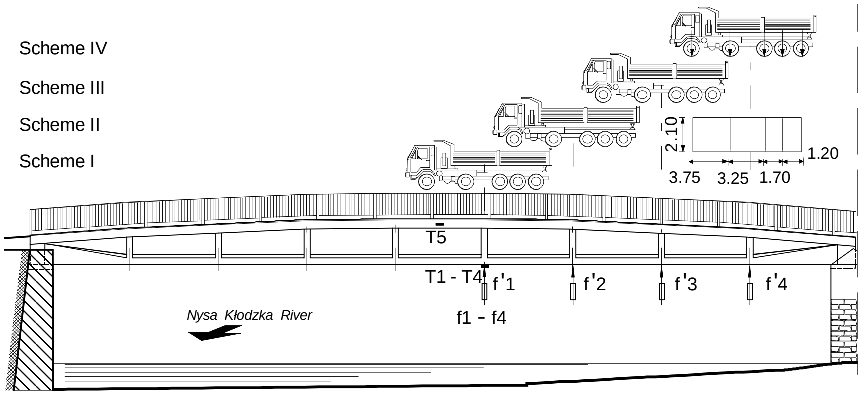

Fig. 1. Side view and longitudinal section of road bridge
Rys. 1. Widok z boku i przekrój podłużny mostu

concrete class (50 MPa compressive strength). The total width of the individual spans is constant along the bridge length and it is 6.50 m (Fig. 2). The effective length of the span is 30.60 m. The span is simple-supported and made from post-tensioned concrete girders of length, *L*, of 31.60 m and are integrated with the RC deck slab over interior supports. The bridge was designed to serve under the II class load (150 kN) in accordance with the PN-66/B- 02015 (or D from the actual Standard PN-85/S-10030). There are eight span crossbeams, all made as concrete. The bridge supports are in the form of massive concrete pier and abutments on spread foundation, fixed in a reinforced concrete footing. The foundation rests directly on the virgin soil. The main girders rest on single-roller and fixed steel bearings (Fig.1). The roadway was covered with bituminous pavement, 0.05 m thick, with incorporated insulation of an average thickness 0.01 m and 0.02 m thick protective concrete layer. The usable width of the bridge amounts to 6.10 m which includes the 3.50 m

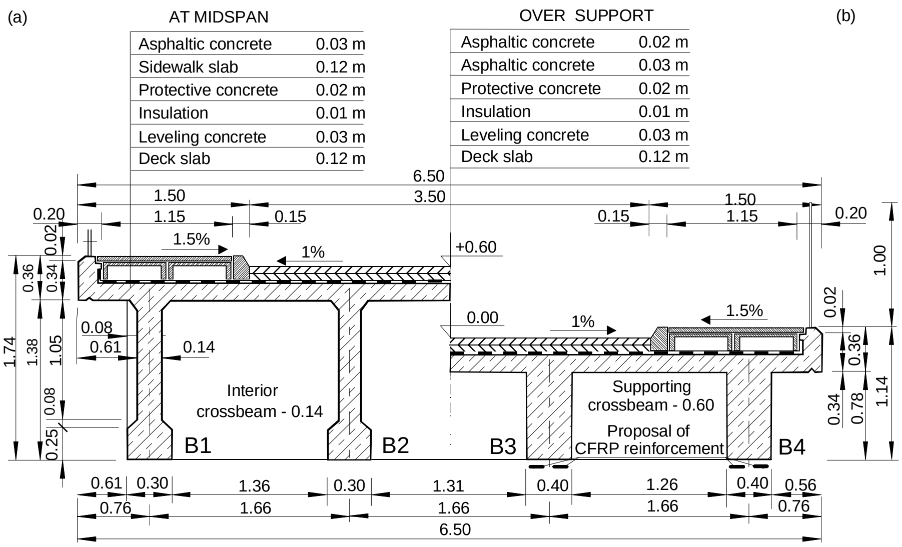

Fig. 2. Cross-sections of post-tensioned concrete span at: (a) midspan (before repair), (b) support (after its renovation)
Rys. 2. Przekroje sprężonych belek mostowych: a) w środku przęsła (przed naprawą), b) przy podporze (po remoncie)

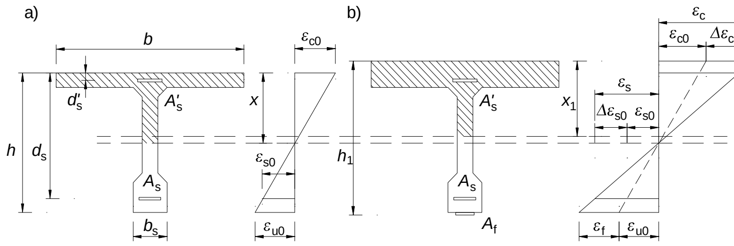

Fig. 3. The graphs of main girder strains: a) before and b) after repair
Rys. 3. Wykresy głównych odkształceń dźwigarów: a) przed i b) po naprawie

wide roadway and a 1.30 m sidewalk on each side (Figure 2). The considering strengthening coneption of the bridge span was accomplished by gluing the CFRP strips SikaDur M1214 type (two for girder) to the bottom flanges of the main girders [3].

The final results of the bridge acceptance inspection, conducted after the complete repair under the trial static and dynamic load [2], allowed for a comprehensive evaluation of the efficiency of the main girders strengthening by applying CFRP strips. Moreover, it enabled a comprehensive evaluation of the change of the spans structures behavior under the same load during the different stages of repair works.

During the bridge repairs, the research was conducted at two different stages (phases). Fig. 1 shows the load schemes on the tested span with the measurement points localization. The following quantities were made:

– four main girders deflections made by dial indicators with 1×10^{-5} m accuracy,

– vertical and horizontal displacements of the expansion and fixed bearings,

– strains (indirectly – normal stresses) in the main girder and in the CFRP, which were performed by strain gages (extensometers) and mechanical indicators.

3. FEM analysis results

The program COSMOS/M was used for computation. Finite element analysis was used to model the behavior numerically to as to provide a valuable supplement to the field investigations, particularly in parametric studies. The state of strains in main girders cross-section respectively before and after repair (ε_{c0}, $\Delta\varepsilon_c$ – concrete, ε_{s0}, $\Delta\varepsilon_s$ – steel reinforcement, ε_{f0} – CFRP strips) are shown in Fig. 3. Modeling the complex behavior of reinforced concrete, which is both nonhomogeneous and anisotropic, is a difficult challenge in the finite element analysis of bridge engineering structures. A majority of the early finite element models of reinforced concrete included the effects of cracking based on a pre-defined crack pattern. With this approach, changes in the topology of the models were required as the load increased; therefore, the ease and speed of the analysis were limited.

Table 1: Results of the deflections at midspan of four girders B1–B4 obtained from the research and calculation (10^{-3}m) before and after reinforcement

Test stage	Result nature	B1	B2	B3	B4
Before repair	measured	5.82	6.37	6.86	7.39
	calculated	8.86	8.86	8.86	8.86
With CFRP	calculated	8.69	8.69	8.69	8.69
After repair	measured	5.16	5.19	5.48	5.55
	calculated	6.83	6.85	6.85	6.83

Only recently we have attempted to simulate the behavior of reinforced concrete strengthened with FRP composites using the finite element method on the basis of past experiences. A number of reinforced concrete girders strengthened with FRP strips were tested in the laboratory. Therefore, it was decided to conduct own calculations on real assumptions with 3*D* SOLID elements, from the nonlinear contact elements of interface type. The FRP strips were modeled with 2*D* plate elements in that study, however, and crack patterns of those girders were not predicted by the finite element analysis. The two-dimensional plate elements are surface-like elements, which have no actual thickness. Therefore, stress and strain results at the actual surfaces of the CFRP strips were estimated by theoretical calculations. Some examples of FEM results are presented in Figure 4.

The practical experience in the light of the conducted FEM calculations and research of the bridge span under the static load during the road bridge construction (I stage of tests),

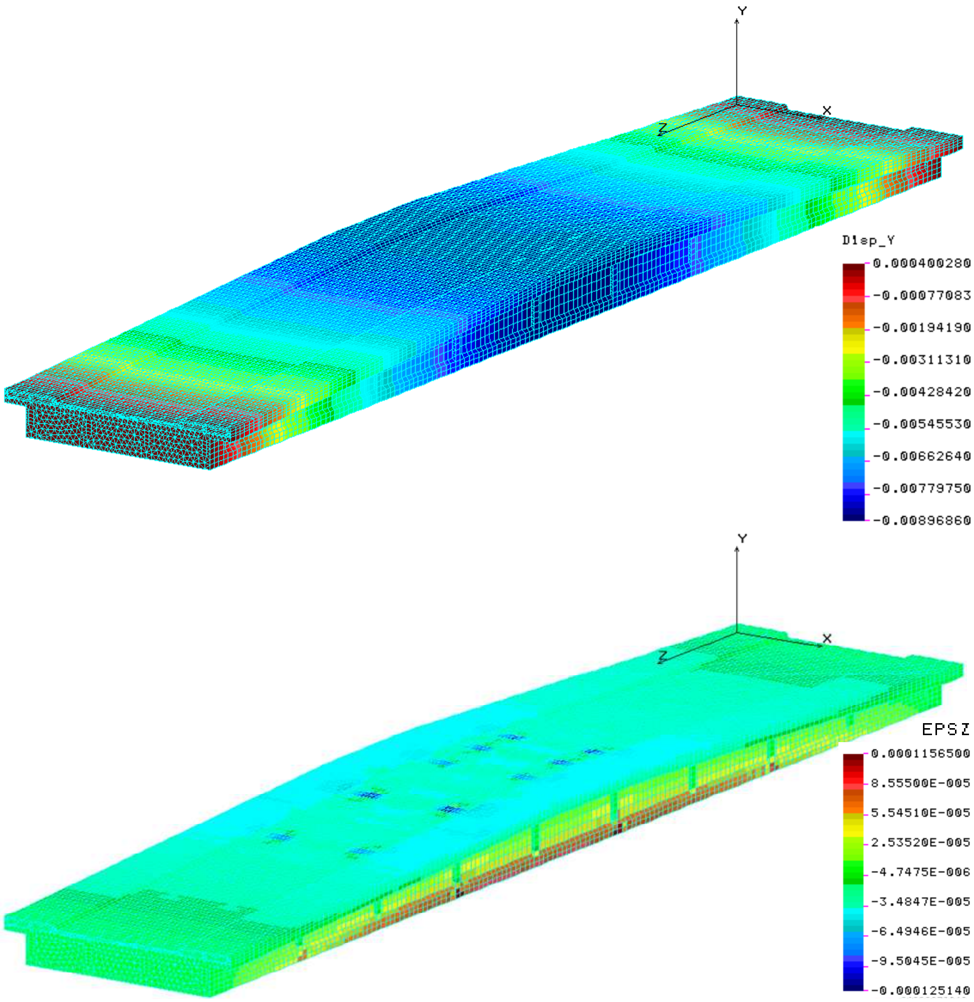

Fig. 4. Some results of the bridge span calculation: (a) vertical displacements, (b) strains

Rys. 4. Wybrane rezultaty obliczeń przęsła mostowego: a) przemieszczenie pionowe, b) odkształcenie comprehensive analysis of displacement and strain (indirectly normal stress) load bearing structure results obtained from the formulating between them and calculated values (Fig. 4) allowed for the following conclusions:

1. The span structure made of post-tensioned concrete girders did not raise reservations as far as average sizes of section forces, displacement and strain values obtained from research and were lower than calculated ones. causes of small differences between the results obtained both from calculations and measurements stay mainly from the calculations with assumed estimated value of the span cross-section stiffness and cautious good estimation of interaction of the girders with the plate deck and pavement layers of the roadway at particular repair stages. They amount in range for deflections 18.74–34.32% (Table 1) and strains 7.24–20.27%, it proves that the section has higher span cross-section stiffness. The good interaction (interface type elements using) between the girders and the CFRP strips can be caused such small differences. However, the applied of CFRP strips did not bring about the significant changes in deflections and strains values of main girders.

2. The strains and displacements of the prestressed concrete girders during the bridge construction demonstrated basically elastic character. They were also lower than the expected values calculated theoretically and also the limit values were not exceeded. It means that construction work was conducted on a high level of technical quality and under constant control. As it was found during the research the minor displacements and permanent strains of the span were partially the girders permanent displacements and most frequently originated partially from the supports settlement and readings errors as well as measuring equipment errors (the change of air temperature and humidity during the time of measurements). Only to a small rate, they were caused by the permanent strains of the load bearing structure (less then 2% of total displacements). This shows a correctness of assumptions taken for calculation and static-strength analysis of this span or also the correctness of assumed analytical structure model with their real behavior in particular repairs phases.

3. The grid model of variable load-capacity structure that was assumed at the first step of calculation in different repair phases in dependence of layers and strengthening strips seems to be sufficient tool to determine the deflections and strains in tested structures on the engineering level. For the detailed analysis of interaction between particular pavement layers and structure components and the assumed strengthening manner is necessary to use more complex model which should be better reflecting a real interaction in a such type of span structures in the considered repair stages of bridge, especially on the contact section of concrete and CFRP strips.

4. As the effect of executed calculations by the FEM and experimental tests on the real object was affirmed, that for the engineering aims the bridge structures analysis it is possible to carry out in the plane state of strains (the two-dimensional 2*D* analysis) with the contact elements of the *interface* type between girders and strips. In the some special cases, the calculations were possible also to execute in the 3*D* space in aim of more detailed analysis. The modeling of bituminous parameters as elastic-plastic is recommended or as elastic-plastic material with reinforcement. Whereas the span as the bilinear elastic material is possible to analyzing. The contact layers of *interface* type with non-linear proprieties should be considering between CFRP strip and concrete girder.

The conclusions concerning the behavior of such structures can be of great practical significance. As the most loaded span structure elements, which need a detailed study and analysis, one should concern the elements of the bridge deck plate where stresses caused by their direct load with stresses due to their interaction with main girders and crossbeams sum up. In the fact, above summary and main conclusions refer to structures of the tested span elements of preset geometric characteristics, particular element stiffness, and determined effective spans. However, it may be stated that spans strengthening constructed by lamels is not the best solution as far as this type of structures is concerned, mostly from the economical point of view. In order to use an expensive CFRP strips to a higher extent, one should install on the girders already known prestressing devices for the CFRP strips.

References

[1] Manko, Z.: "Investigation of Prestressed Road Bridge Span over the Nysa Klodzka River in Klodzko before its Modernization", Proceedings of I Symposium on Bridge Diagnostics and Testing, April 4–6, 2001, Opole, Poland, pp. 399-417.

[2] Manko, Z., and Mordak, A.: "Research of Road Bridge over Nysa Klodzka River along Matejko Street in Klodzko after Repair." Scientific-Research Center for the Development of Bridge Industry MOSTAR, Wrocław 1999.

[3] Meier, U., and Deuring, M.: The Application of Fiber Composites in Bridge Repair. Strasse und Verkehr, Vol. 9, 1991, pp. 7-11.

ANALIZA MES BELEK MOSTU SPRĘŻONEGO WZMOCNIONYCH TAŚMAMI CFRP POD OBCIĄŻENIEM STATYCZNYM

Summary

W artykule opisano badania mostu drogowego o konstrukcji sprężonej. Przedstawiono zakres i sposób przeprowadzenia badań doświadczalnych oraz wyniki badań w formie graficznej i tabelarycznej. Przedstawiono również wykonaną analizę konstrukcji z wykorzystaniem MES i wyniki obliczeń numerycznych. Badania prowadzono w dwóch różnych etapach remontu mostu, tj. przed jego wyremontowaniem oraz po zakończeniu prac naprawczych i zastosowaniu wzmocnienia w postaci Taśm CFRP i nadbetonu.