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DYNAMIC ASSESSMENT OF RC BEAMS FLEXURALY STRENGTHENED WITH CFRP STRIPS

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Abstract

In the last few decades externally bonded FRP strips and sheets have been the most commonly used technique for strengthening of RC structures and bridges. The fact that FRP does not corrode and good mechanical performance have made this material very popular to use. Prior to design and application of FRP strengthening, it is of great interest for design engineers to evaluate condition of deteriorated and damaged RC structures. One of the most popular non-destructive techniques to evaluate structural health is modal testing. In this work Experimental Modal Analysis (EMA) is used as a technique to evaluate loss of beam stiffness due to damage and effectiveness of FRP strengthening in terms of stiffness recovery. This experimental technique is based on fact that changes in local stiffness influence on global dynamic parameters (frequencies, mode shapes and modal damping). This paper presents experimental results of experimental modal analysis carried out on damaged concrete beams strengthened with CFRP strips and sheets. Three RC beams with rectangular cross section were tested. Beams were subjected to monotonic loading with increasing load steps with four-point bending setup in order to generate different damage levels in specimens. CFRP strengthening was applied on the specimens after they were damaged by loading to 50% of their flexural capacity. Modal tests were carried out after each loading-unloading cycle. Beams were excited by the impact hammer. Frequency response functions were processed using Dewesoft software to obtain natural frequencies, mode shapes and damping ratios.

Keywords: FRP strengthening, dynamic parameters, experimental modal analysis, concrete beams

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1. Introduction

Durability is the main issue of old concrete bridges. Exposure to aggressive environment and insufficient maintenance leads to deterioration of concrete and reinforcement corrosion, especially in case of bridge decks with poor waterproofing design and thin concrete layer. Durability issues leads to reliability issue especially in case of very old concrete bridges that are not robust and are designed for lighter traffic, wind and seismic loads in comparison to current Eurocode standards. In order to increase reliability, it is necessary to repair and strengthen old deteriorated and damaged bridges. In the last few decades externally bonded FRP strips and sheets have been used to improve load-bearing capacity and serviceability of RC structures and bridges. FRP material does not corrode, it is much lighter in comparison to steel, and it has very high tensile strength.

Prior to design of FRP strengthening, it is of major interest for designers to evaluate the condition of a deteriorated and damaged concrete structure. One of the non-destructive techniques for evaluation of structural health is modal testing. In this research Experimental Modal Analysis (EMA) is used as a technique to evaluate beam stiffness loss due to damage and effectiveness of FRP strengthening in terms of stiffness recovery. This non-destructive technique is based on fact that changes in local stiffness influence on global dynamic parameters which are: eigen frequencies, mode shapes and modal damping. In general, bridge dynamic testing can be performed either to confirm theoretical values of modal parameters for new bridges or to evaluate condition of existing bridges (Vibration Based Structural Health Monitoring). In combination with static load testing (performed with loaded trucks), modal testing on real bridges is expensive. Also, results from modal tests are very susceptible on boundary conditions and temperature. Instead of testing a real bridge superstructure, numerous laboratory tests have been carried out using smaller beam specimens. In the past decade several laboratory tests were carried out with the goal to evaluate effectiveness of FRP flexural strengthening on RC beams by modal testing. In most experiments testing specimens were RC beams, usually with rectangular cross section. Beams were simply supported during three or four-point bending tests and were suspended during modal tests in order to reduce the influence of boundary conditions on modal test results.

2. Experimental research

2.1 Outline of the experiment

Static and dynamic modal tests were carried out on a total of three specimens. One of the specimens was non-strengthened, while the other two were strengthened with CFRP strip or sheet (Table 2). Specimens were built in the concrete factory with concrete class of C40/50. Steel grade of reinforcement bars was B500B (Table 1).

Table 1 – Cross section properties

Beam type	Cross section dimensions [cm]	Tension reinf.	Shear reinf.
RC beam	b/h = 20/30	3ϕ12	ϕ8/15 cm

Beams, with span of 3.0 m, were submitted to monotonic loading with increasing load steps with symmetric four-point bending setup, and with shear span of 1.0 m. CFRP strengthening was applied on the beam specimens after they were damaged by loading to 50 % of their load-bearing capacity (Figure 1). Modal tests were carried out after each loading-unloading cycle. To avoid the influence of rigid support on the modal test results specimens were suspended (Figure 2). An impact excitation was used to induce free vibrations. Dynamic response was registered with one accelerometer located at the midspan (multi input – single output method). Frequency response functions (FRF) were

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processed using Dewesoft software to obtain natural frequencies, and corresponding damping ratios and mode shapes.

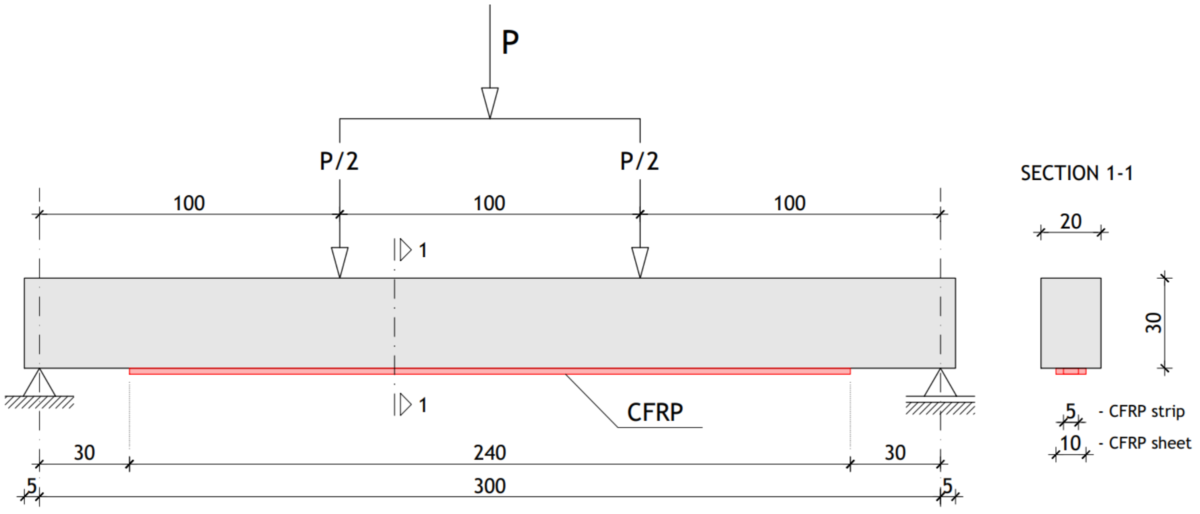

Figure 1. Four point bending test scheme

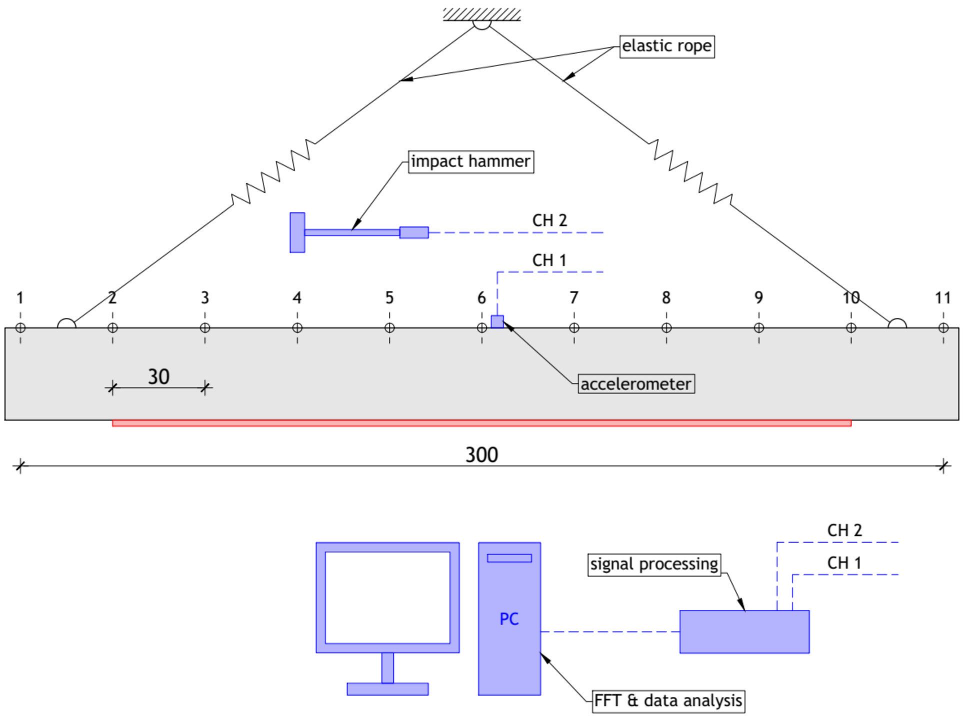

Figure 2. Modal test scheme

2.2 Results and discussion

Results from static and dynamic modal tests are presented on Figure 3 in forms of P-δ diagrams and related P-f diagrams. After strengthening, and after the applied load in phase 3, the first eigen frequency of strengthened specimens 2/3 and 3/3 increased by 6.5 % and 9.2 % respectively. The first eigen frequency of the non-strengthened specimen (1/3), after the load phase 3, remained the same. Higher value of the first eigen frequency indicates that CFRP strengthening increased the flexural stiffness of concrete beams by crack bridging and reducing the crack propagation.

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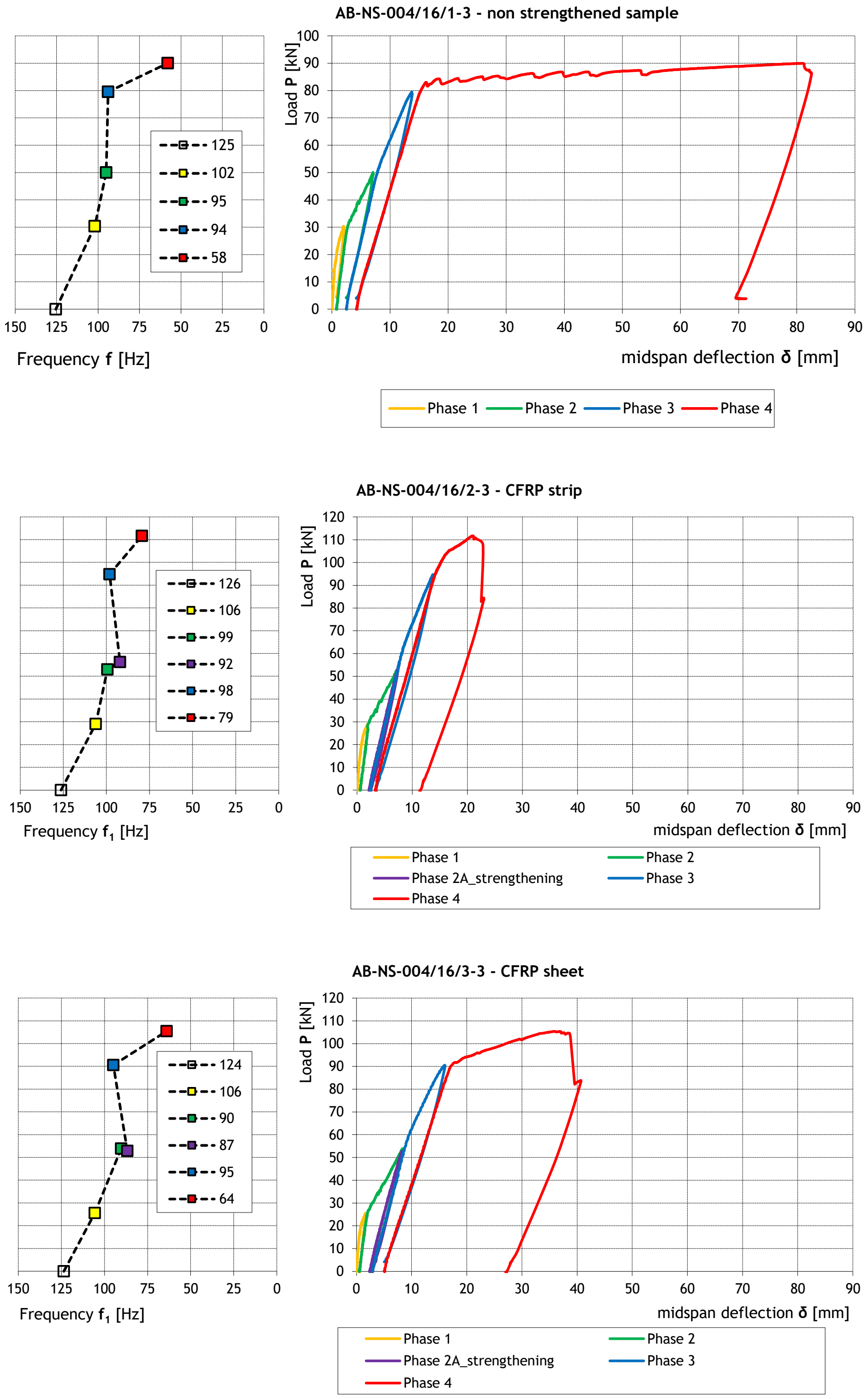

Figure 3. P-δ and P-f relation for RC beams

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Table 2 Results from the static four point bending test

Specimen	**Type of strengthening**	**Failure mode**	**P_u [kN]**	**P_u/P_{ref}**	**δ_u [mm]**	**δ_u/δ_{ref}**
AB-NS-004/16/1-3	-	SY/CC	90.0	-	80.8	-
AB-NS-004/16/2-3	CFRP strip	BL	111.7	1.24	20.9	0.26
AB-NS-004/16/3-3	CFRP sheet	BL	105.4	1.17	36.8	0.46

SY/CC – Steel yielding followed by concrete crushing; BL – bond loss

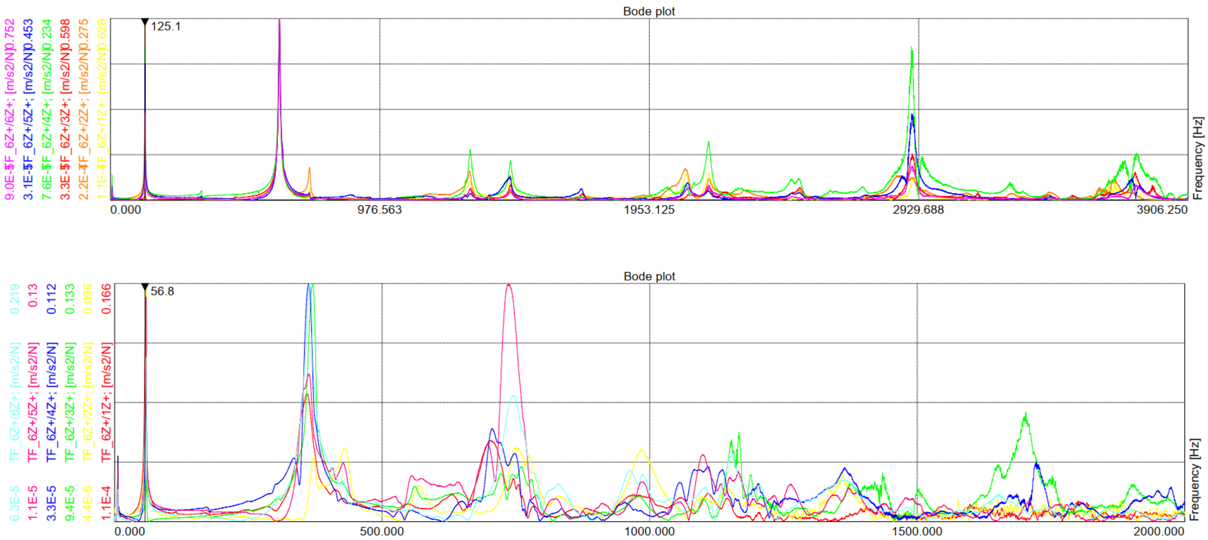

Figure 4. Comparison of the magnitude spectra of the FRF functions n virgin and failure step mode for the non-strengthened specimen

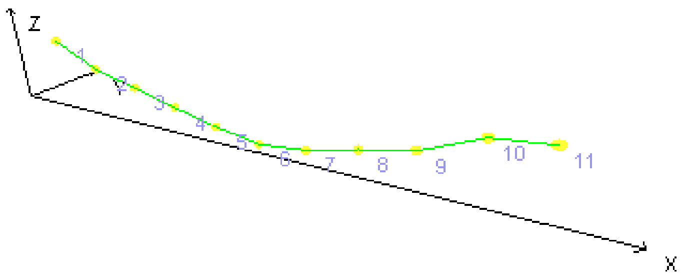

Figure 5. First bending mode shape

From the P-δ diagram of the specimen that was strengthened with CFRP strip (PB-NS-004/16/2-3), deficiency of ductility can be noticed. Bond failure mode in terms of peeling-off in an anchorage zone occurs on both strengthened specimens (Fig 6). Specimen that was strengthened with CFRP sheet had a bigger value of ductility coefficient than the one strengthened with CFRP strip.

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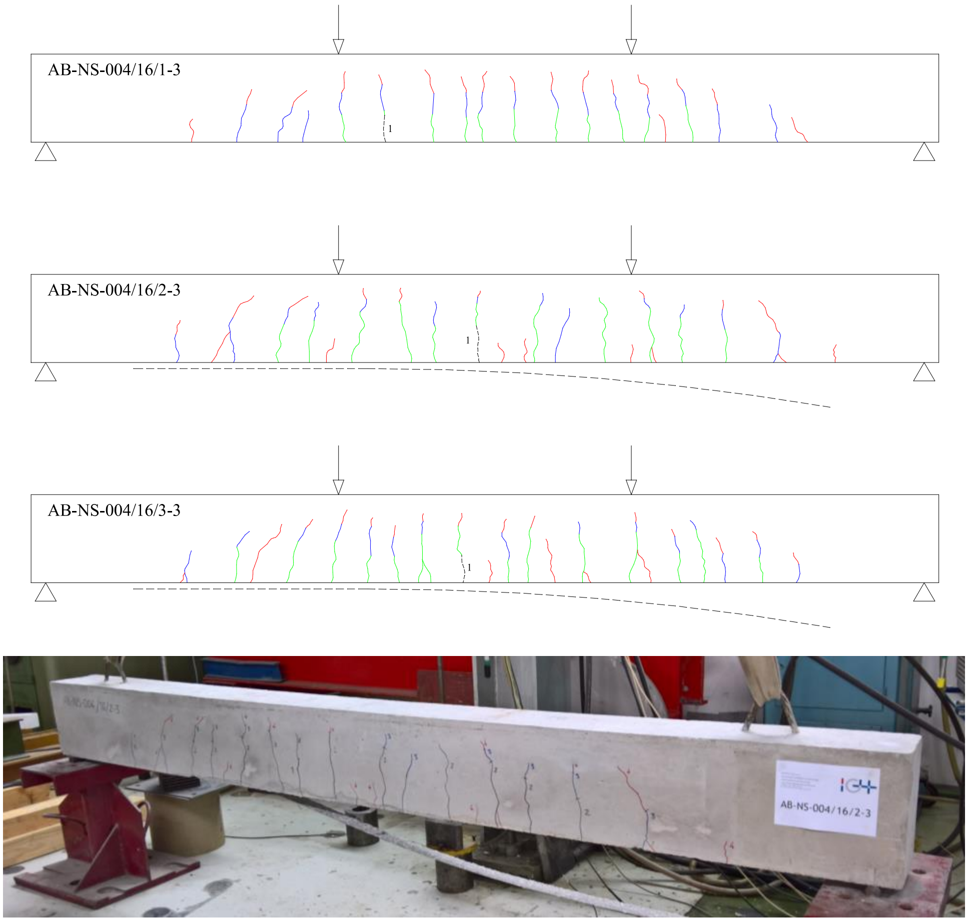

Figure 6. Cracking pattern and failure mode caused by loss of composite action

3. Conclusion

In this paper experimental results of the static and dynamic tests carried out on damaged RC beams flexural strengthened with CFRP are presented.

Static load tests confirmed that flexural strengthening increase load bearing capacity and flexural stiffness; and decreases the ductility of RC beams. Numerous tests have shown that bond failure modes are dominant, and it is very hard to reach full tension strength of the FRP and ULS with full composite action. Therefore, the bond failure modes are well investigated and propositions for anchor length design and other calculations were proposed in a standards and technical reports issued by the fib, ACI and other national committees. Nevertheless, it is obvious that in force transfer between composite and concrete in most of the cases bond failure occur due to shear concrete failure and de-bonding in concrete near the surface. So extra effort must be made to increase the capability of the bond shear force transfer, either with shear connectors or concrete surface preparation before applying FRP strengthening system. These issues will be investigated further.

Dynamic modal test presented in this paper, confirmed previous investigations that with precise measurements it is possible to determine and evaluate decrease of stiffness due to damage caused by static loading and evaluate effectiveness of the FRP flexural strengthening on the stiffness recovery. Modal analysis is a popular and useful non-destructive method for damage detection and structural health monitoring of the bridges and other structures. In the future research activities this method should be proved also on a real case study to evaluate the effectiveness of FRP flexural strengthening on a real bridge superstructure.

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