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PRE-DESIGN OF A MODULAR FOOTBRIDGE SYSTEM WITH PRE-TENSIONED CFRP REINFORCEMENT

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Summary

A common problem of concrete bridges are corrosion damages of the steel reinforcement. The related loss of capacity as well as visual effects often require expensive and elaborate refurbishment or even reconstruction. To overcome these drawbacks, a modular footbridge system without steel reinforcement is developed. The application of non-corrosive carbon fiber reinforced polymer (CFRP) reinforcement is suitable for building slender constructions, which are durable and longlasting. For the elements of the modular bridge system CFRP reinforcement is applied as mesh fabrics and pre-tensioned rebars. In this paper, the dimensioning and pre-design of the modular footbridge system are presented. In a first step, the requirements regarding cross-sections, spans and level of prestressing are defined based on natural conditions and applied loads. In a second step, the flexural pre-design of the pre-tensioned footbridge is explained exemplarily. In a final step, the dynamic behavior of the designed concepts is analyzed.

Keywords: CFRP; new materials; pre-tensioning; durability; sustainability; dynamics

1. Introduction

A pilot project was started in 2010 in Albstadt, Germany to build a footbridge with a superstructure made of precast textile-reinforced concrete (TRC) elements [1]. The bridge consists of six precast bridge elements with a length of 17.2 m and spans of 15 m. The cross-section of the superstructure is a T-beam with seven webs with a width of 120 mm each. The footbridge is reinforced with textile reinforcement (AR-glass) and prestressed with steel strands (unbonded post-tensioning). Based on the design of the footbridge in Albstadt, the new modular footbridge system with pre-tensioned CFRP reinforcement is developed.

2. Pre-design

In a first step, the requirements regarding cross-sections, spans and level of prestressing were defined based on loading and natural conditions. As a result, two concepts with short (C1) and long (C2) spans were selected to explain the pre-design exemplarily. The dimensions of the cross-sections were determined considering the recommendations of current guidelines and limitations due to fabrication and transport. The spans of the presented concepts were chosen as 12.0 m and 25.0 m to cover a wide range of possible spans. A width of 3.00 m was defined uniformly for both concepts. Following the footbridge in Albstadt [1], a T-beam cross-section with a reduced number of four webs was chosen for both concepts. Later on, the web widths need to be adjusted with respect to the number of required CFRP tendons. The total height of the superstructure was set to 430 mm and 900 mm, respectively, resulting in a slenderness of H/L = 1/28 for both constructions.

In Germany, current guidelines do not yet provide standards for the design of concrete structures prestressed with FRP tendons. Thus, the presented pre-design is based on own considerations in compliance with EC 2 and assumed material characteristics based on EC 2 [3]. For pre-designing, the following loads were considered in compliance with Eurocode 1 [2]: dead loads, live loads due to pedestrians and wind, a service vehicle (5.0 ton) and an unplanned presence of vehicle for accidental situation (12.0 ton). According to Eurocode 2, the level of prestressing for footbridges with steel tendons is determined by verification of decompression for the frequent load combination [3]. Using non-corrosive CFRP tendons, there are no specifications because the crack formation does not have to be limited due to durability reasons. Thus, the level was defined by verification of decompression for the quasi-permanent combination. Assuming a permissible tendon stress σ_{pm0} immediately after tensioning of 1500 MPa and prestressing losses of α_{csr} = 25 %, five tendons (A = 51 mm^2) for C1 and eleven tendons for C2 are needed.

Because of the brittle material behaviour of the CFRP reinforcement, the flexural capacity of a cross-section for the ultimate limit state (ULS) has to be determined iteratively. In a first step, the strain distribution of the cross-section is assumed. Regarding the concepts presented in this paper, the strain distribution for the ULS is given by the maximum potential strain increase $\Delta\varepsilon_{p,max}$ of the bottommost CFRP layer. This is specified by the difference of design fracture strain ε_{pud} of the tendons and the strain due to pre-tensioning ε_{pmt}. Subsequently, the respective stresses of the CFRP reinforcement and the concrete can be calculated. In a second step, the horizontal equilibrium of the resulting forces is checked. The strain distribution has to be adjusted iteratively until equilibrium is achieved. With the final strain distribution, the flexural load capacity of the cross-section can be calculated. If the resulting bending capacity is higher than the bending action due to applied loads, the pre-design of the footbridge is complete in terms of bending. For concepts C1 and C2, the flexural capacity had to be increased by providing more tendons. Fig. 1 shows exemplarily the resulting cross-sections for C1.

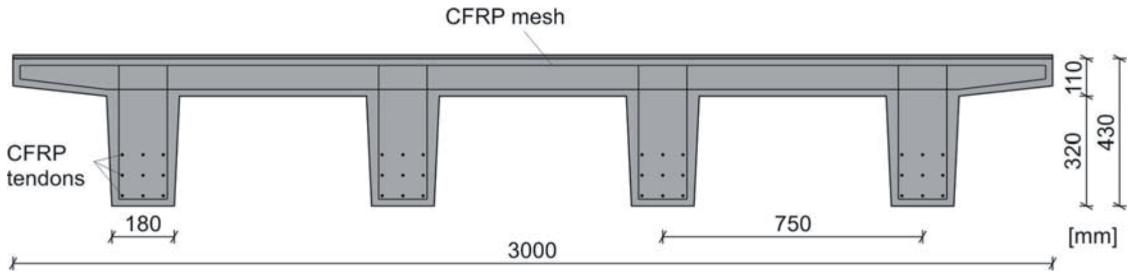

Fig. 1. Final cross-section of C1

To complete the flexural pre-design, the dynamic behavior of the final design concepts was investigated. Using a simplified approach, the first eigenfrequency was determined for both concepts and for C2 an additionally required verification of the comfort criterion for pedestrians was checked. The limit values regarding eigenfrequency ($\geq$ 3.0 Hz) and vertical acceleration ($\leq$ 0.7 m/s^2) are fulfilled for all relevant scenarios.

3. Conclusions

The development of a modular footbridge system without steel reinforcement enables the construction of durable and economical footbridges that provide high load capacity. Based on requirements by loading and natural conditions, initial drafts of two concepts were determined in a first step. In a second step, the the pre-design of the two concepts was explained exemplarily in compliance with EC 2 [3]. Because of the brittle behavior of the CFRP reinforcement, the flexural capacities for the ultimate limit state (ULS) were determined in an iterative process. Next, the level of pre-tensioning and the cross-sections were adjusted regarding the required load capacities. In a last step, the dynamic sensitivity of the final designs was checked. For both concepts no critical dynamic behavior is expected based on the pre-design.

4. References

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