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PEDESTRIAN BRIDGE WITH ARCHED CONCRETE SLAB SUPPORTED AND PRESTRESSED BY EXTERNAL CABLES. ANALYSES OF THE STRUCTURAL SYSTEM

Summary. In our research we examine applicability of high-performance concrete for the construction of roofs and pedestrian bridges. New structural system presented in this paper is formed by an arched concrete deck-slab supported and prestressed by external cables placed outside of the perimeter of the cross-section of the deck. Comparison of structure's behaviour for the deck made of high-performance concrete C55/67 and C70/85 is given. Using the higher-strength concrete reduces both the cross-section and necessary amount of prestressing. With regard to structure's slenderness, the comparison is based on the dynamic response analysis of the structure. Further research focuses on the laboratory testing of maximum load-carrying capacity of the bridge on the small-scale model.

MOST DLA PIESZYCH Z BETONOWĄ ŁUKOWĄ PŁYTĄ PODPARTĄ I SPRĘŻONĄ PRZEZ ZEWNĘTRZNE KABLE. ANALIZA SYSTEMU KONSTRUKCYJNEGO

Streszczenie. W naszych badaniach testujemy przydatność wysokowartościowego betonu do konstrukcji dachów i mostów dla pieszych. W referacie przedstawiono nowy, konstrukcyjny system utworzony przez wygiętą, betonową, łukową płytę podpartą i sprężoną przez zewnętrzne kable umieszczone zewnątrz obwodu przekroju poprzecznego płyty. W pracy porównano zachowania konstrukcji dla płyty betonowej wykonanej z betonu wysokowartościowego C55/67 oraz C70/85. Zastosowanie betonu wysokowartościowego zmniejsza zarówno wymiary przekroju poprzecznego, jak i konieczną ilość naprężenia wstępnego. Ze względu na smukłość porównanie oparte jest na dynamicznej odpowiedzi konstrukcji. W dalszej części referatu badanie skupia się na laboratoryjnym przetestowaniu maksymalnej zdolności przeniesienia obciążenia mostu na model w małej skali.

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1. Structural arrangement description

Pedestrian bridge described in this study combines two structural types that have been used independently so far. Stress-ribbon bridges are extremely aesthetic structures joining together slenderness of the deck with its fluent curved shape. Relatively high horizontal force that abutments have to resist is a single disadvantage of this system. Other source of inspiration was today's common use of external tendons forming cables, placed outside the deck, supporting it by means of steel braces. This type of arrangement enables reducing thickness of deck-slab and results in much slender and transparent appearance of the structure.

Joining these two approaches, new structural system presented in this paper is formed by arched concrete deck-slab formed by a prestressed band and supported by cables situated below the deck. Cables are mutually connected by triangular struts – see Fig. 1.

Fig. 1. Structural arrangement of the bridge
Rys. 1. Układ konstrukcyjny mostu

Deck has the shape of second degree parabola with span of 63 m and maximum sag of 0.8 m. It is narrow in the ground plan. The maximum gradient of the deck is p = 5% at the abutments therefore the bridge is fully accessible for disabled people. Lower external cable in form of polygonal line passes over saddles created by a steel tube connected to the joint of struts – see Fig. 2.

Fig. 2. External prestressing cables under the deck
Rys. 2. Zewnętrzne kable sprężające pod płytą

Upper external cables (formed by tendons prestressing the stress ribbon deck) follow the geometry of the deck. Two arrangements of the cross-section of the slab were considered: conventional section with upper cables situated in ducts within the cast in place part of the deck – see Fig. 3a and fined off section with cables situated below the deck (attached to it) – see Fig. 3b. In both cases the deck is assembled of 3 m long precast members. In the former arrangement, cros-section is filled up with upper cast-in- place concrete slab. In the latter, the deck is formed just by the 160 mm thick precast members coated by protective finishing layer.

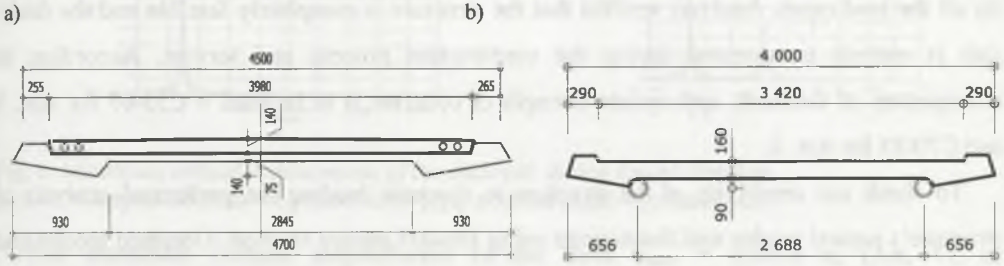

Fig. 3. a) Arrangement 1, b) arrangement 2
Rys. 3. a) Układ 1, b) układ 2

For presented structure a special construction technique was developed. Bridge can be easily erected without any falsework or barks. After construction of foundations and abutments, all the precast members of the deck are launched on provisional cables. Then the steel struts are attached to the deck members and external cable is laced through the tubes forming saddles. The deck is lifted up to its final position by prestressing the external cable. Finally the cabels prestressing the deck-slab are activated. Once the bridge is assembled, the horizontal forces in the abutments are balanced with regard to the dead load of the bridge and therefore the foundations carry just vertical forces. Fig. 4 pictures aluminium mock-up created to demonstrate the lifting procedure of the bridge.

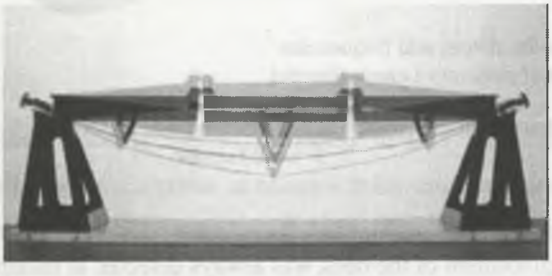

Fig. 4. Lifting of the deck to its final position by prestressing the external cable
Rys. 4. Podnoszenie płyty do jej położenia końcowego przez sprężanie zewnętrznego kabla

2. Methodological and conceptual approach

Structure was analysed as 2D geometrically nonlinear structure using ANSYS 10.0 structural analysis software. Model of the bridge was analysed in all major stages of the construction process. In static analysis, dead loads and live loads (crowd load 4 kN/m^2, temperature load ±20°C) according to the Czech standard CSN 73 6203 were considered. We obtained presteressing forces necessary to bring the structure into geometry appropriate to each stage of construction process, state of stress and displacements of all structural members for all the load cases. Analysis verified that the structure is completely feasible and the deck-slab is entirely compressed during the construction process and service. According to arrangement of the deck, appropriate strength of concrete is to be used – C55/67 for Arr. 1 and C70/85 for Arr. 2.

To check out sensitivity of the structure to dynamic loading we performed analysis of structure's natural modes and frequencies using Block-Lanczos method. Obtained modes and frequencies – see Fig. 5 – were used as input data for the subsequent harmonic response analysis. Performing harmonic response analysis is necessary to compute speed of motion and acceleration of the bridge's deck caused by forced vibrations, which represent the effects of moving people.

a) First vertical bending mode
Arr. 1: $f_1 = 0.838$ Hz, Arr.2: $f_1 = 0.8660$Hz

b) First torsional mode
Arr. 1: $f_2 = 1.674$ Hz, Arr.2: $f_2 = 1.167$ Hz

c) Second vertical bending mode
Arr. 1: $f_3 = 1.774$ Hz, Arr.2: $f_3 = 1.551$ Hz

d) Second torsional mode
Arr.1: $f_4 = 4.350$ Hz, Arr.2: $f_4 = 2.829$ Hz

Fig. 5. Structure´s modal shapes and frequencies
Rys. 5. Modalny kształt struktury i częstotliwości

Dynamic load by a pedestrian can be represented by a pulsating load F as follows:

$$F = 180 \sin \varpi t \tag{1}$$

where:

$\varpi = 2\pi f_0$, with f_0 being fundamental frequency

The biggest displacement of the deck was always detected at midspan. Absolute maximum displacement is achieved at midspan while the frequency of the pulsating load is equal to the fundamental frequency of the bridge. These relations can be demonstrated on following graphs: relation between the vertical displacement of the deck at midspan (uy_STRED), in the quarter point of the span (uy_CTVRT) and in a control point in the stationing 41 m (uy_KONTROLA) and the frequency of the pulsating load (FREQ) whose point of application is at midspan – see Graph 1 – or in the quarter point of the span – see Graph 2. Values given in graphs apply to Arr. 2 of the cross-section of the deck slab.

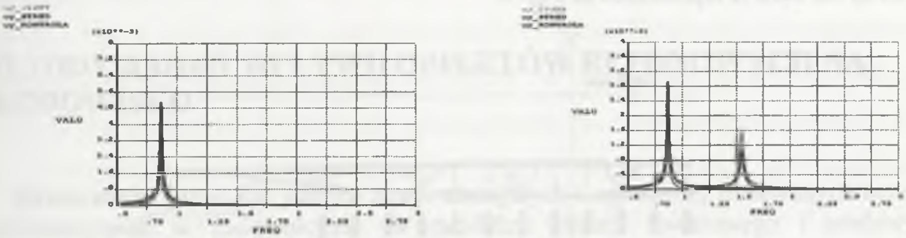
a) Graph1
b) Graph 2

Fig. 6. Maximum vertical displacement of the deck slab during forced vibration
Rys. 6. Maksymalne pionowe przesuwanie płyty podczas drgań wymuszonych

For maximum vertical displacement of the deck u_{max} = 0,0035 m (Arr. 1), or u_{max} = 0,0045 m (Arr. 2), the relevant maximum vertical acceleration was calculated and compared to critical values presented in [1].

a_{max}= 0,098 m/s^2 $\leq$0,5.$(f_0)^{0,5}$ = 0,458 m/s^2 (Arr. 1); a_{max}= 0,151 m/s^2 $\leq$0,5.$(f_0)^{0,5}$ = 0,466 m/s^2 (Arr. 2)

3. Results

Modal analysis proved low natural frequencies of the structure. However commonly required value of fundamental frequency (e.g. $f_0 \geq 3.0$ Hz) cannot be reached within this type of structure, it is necessary to avoid resonance of the deck. Calculations of maximum vertical acceleration verified that the bridge exhibits acceptable performance from the point of view of the physiological effect of vibrations. The Arr. 2 of the slab cross-section using higher-strength concrete seems to be highly favourable solution.

4. Further research

Further studies of the structural system presented in this paper are focused on its maximum load-carrying capacity. To prove structure´s behaviour and mode of collapse, we are building a small-scale model to be tested until destruction in laboratory conditions. The experiment is designed with respect to the rules of the model similarity. The model of the structure will be built in a scale of 1/8 using the same materials and construction techniques as the real structure. Weight ballast needed to raise the equal stresses in comparison to the real structure was calculated and will be applied during the erection process. Arrangement of the small-scale model ready for loading as well as simplified cross-section of the precast members of the deck is represented in Fig. 7.

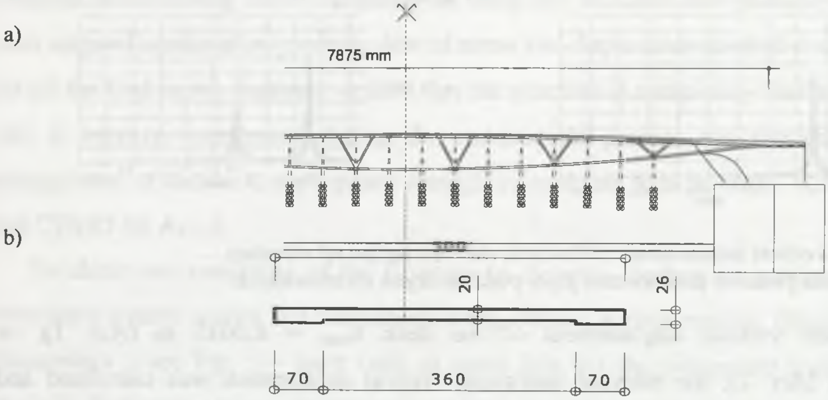

Fig. 7. a) Arrangement of the model for testing of maximum load carrying capacity, b) simplified cross-section of the concrete deck members
Rys. 7. a) Układ modelu dla przetestowywania maksymalnej nośności, b) uproszczony przekrój poprzeczny betonowych elementów płyty

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