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THE POTENTIAL OF PRESTRESSED CONCRETE

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Unusual architectural forms force constructors to seek innovative and at the same time more daring solutions. An example of using such solutions is the project of a Music Pavilion in Muszyna.

Post-tensioned concrete in building construction in Poland is a relatively young solution. The first post-tensioned concrete slabs were implemented only in the present century, and the breakthrough year is indicated to be 2002, when the first post-tensioned slabs with flat cables were made [1]. Since then, newer and more sophisticated forms of prestressed slabs in buildings have been constantly sought for, in a post-tensioned [2.3], but also prefabricated variant [4]. It is worth mentioning that research was also undertaken to apply lightweight aggregate concrete to post-tensioned slabs [5].

Construction of the Music Pavilion in Muszyna

One of the examples of solutions for post--tensioned slabs recently developed is the construction of the Music Pavilion implemented as part of the development project "Nad Popradem" in Muszyna. The developed construction solutions, in particular designed prestressed elements of the beam and slab allowed to implement the adopted architectural concept, emphasising the preservation of the unity of the structure with the existing surroundings.

The single-storey Music Pavilion is designed on a circular plan with a diameter of 19.40 m and a total height of 4.40 m. The building is mounted on a foundation reinforced concrete slab with the bearing structure made up by external and internal walls of reinforced concrete on which a flat roof that covers the object is supported. The vision and expectations regarding the final project are shown in the visualisation in Figure 1. The main goal and assumption adopted at the design stage are to reflect the unity of the structure with the surroundings. This effect was obtained by partially covering the building with soil and partially leaving the glazed structure, thus limiting the possibility of using supports in the glazed segment. Glazing designed on almost 1/3 of the circumference forced construction of a perimeter beam with an angle of 140 degrees and a span of 16.1 m. The floor plan and cross-section of the object together with the description of the main structural elements are shown in Figure 2.

COMMENTARY

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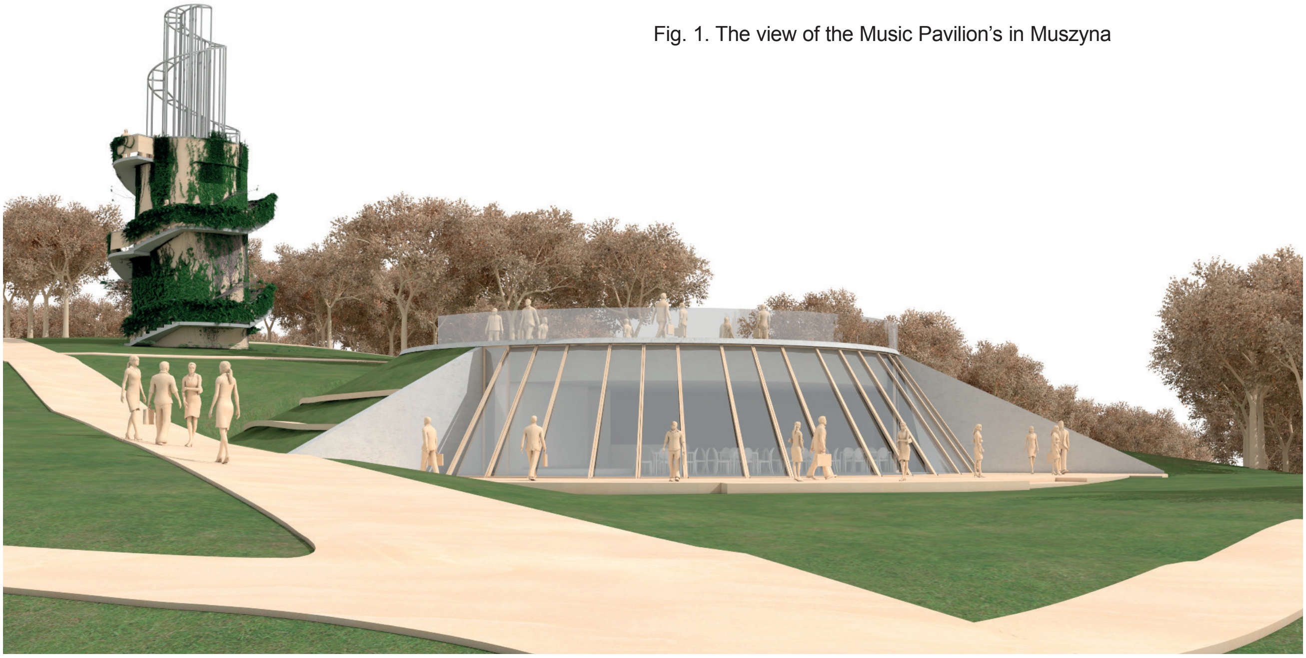
This article is about a very interesting application unbonded steel tendons in the design and implementation of the Pavilion Muzyczny in Muszyna on the Poprad in Poland. In addition, the author supported the solution by conducted detailed FEM calculations, with giving elastic deflections of the post-tensioned beam and slab from the characteristic and prestressing loads.

Prestressed flat roof

The predicted loads in the form of a green roof with access for users, the proposed support system and the resulting significant spans of up to 9.40 m caused that the most structurally justified and at the same time economical solution was to design a prestressed flat roof. Four bundles of unbonded tendons were laid out in 250-mm thick slabs, in which the tendons were spaced at 200 and 300 mm. In total, 44 unbonded tendons with a maximum overhang of 125 mm, made of Y1860 steel were assumed. The layout of tendons is shown in Figure 2a. The geometry of the slab and the support system as key factors influenced the distribution of the strands in the plan. Figure 2a shows that one of the four bundles, with a 200-mm spacing of strands, follows the string of the structure and is anchored in the edge beam and in the outer wall. Figure 2b shows that two consecutive bundles with a spacing of strands at a level of 200 and 300 mm are similarly straight tendons in the plan, however, due to the adverse effect of such a large number of strands in the area separated by internal walls, they have not been dragged to the outer walls. Hence, they are unilaterally anchored in the beam and the external wall, while the other end of the tie beams is anchored behind the reinforced con-

Fig. 1. The view of the Music Pavilion's in Muszyna



crete inner walls at distances of 1.0 and 1.5 m. The high density of the strands around the intersection of axes A and B determined the use of parts of the tendons curved in the plan. As shown in the project of the Małopolska Laboratory of Energy-Efficient Construction in Cracow [3] developed and implemented in the years 2012-2013, the use of curved unbonded tendons does not cause excessive drops in the prestressing force, which allows a successful application of the adopted solution.

Prestressed beam

An edge beam with a span of 19.09 m (Fig. 2 and 3) was designed with a cross-section of 0.30 x 1.40 m. However, due to the solution of the anchorage zone accepted by the contractor, it was necessary to widen its ends. Finally, the cross-section in the anchorage zones was increased by 100 mm, creating a transition zone of 1.0-m length. Based on computational analysis, 15 unbonded tendons 7 5 mm of Y1860 steel and an assumed maximum overhang of 730 mm were used to prestress the beam. In addition, a minimum normal reinforcement was applied to the bottom and top in the form of 4 bars of 16 mm. Due to the twisting of the beam caused by a one-sided slab load and prestressing, longitudinal reinforcement was assumed at the side surfaces of the beam in the form of 16 mm bars every 180 mm and stirrups from a 10 mm rod in a spacing of 150 mm. The extended anchorage zone and tendons layout are shown in Figure 3.

Computational analysis

The physical model of the structure was built using rod and shell elements, with geometrical and material parameters consistent with those adopted in the project. The model assumes an additional dead load with layers of green roof with a value of 2.60 kN/m2, service load 2.00 kN/m2, snow load 1.70 kN/m^2 and equivalent loads caused by prestressing applied to the beam (vertical and horizontal radial loads) and slabs (vertical, horizontal and edge loads), taking into account temporary losses of 6% for the beam and 10% for the slab and delayed at 10%.

As a result of the application of permanent loads, we obtained an elastic deflection of the beam equal to 52.2 mm, and camber from prestressing (taking into account all prestressing losses) +63.5 mm. Finally, after taking into account all the loads, including 50% of variable loads (snow load and service load), elastic camber of the beam was obtained equal to +0.7 mm, while the deflection of the slab was equal to -6.4 mm.

Figure 4 presents graphs of selected values of internal forces in the beam. Figure 4a shows a graph of bending moments from dead loads. It can be easily noticed that the obtained bending moment value equal to 1,118.3 kNm is dominant and accounts for almost 3 times the bending moment of the service load and snow load (375.7 kNm, Fig. 4b), and thus largely determines the final deflections, hence the idea of using light aggregate concrete in post-tensioned concrete structures [8]. Figures 4c and 4d show the values of bending moments (Fig. 4c) and longitudinal compression forces (Fig. 4d) caused by prestressing applied to the beam (963.0 kNm) and longitudinal compression forces from all strands applied to the beam and slab. The values are respectively 963.0 kNm and 832.2 kN. An interesting conclusion from figure 4d is that most of the prestressing force has been taken over by the slab, and not the beam. This is

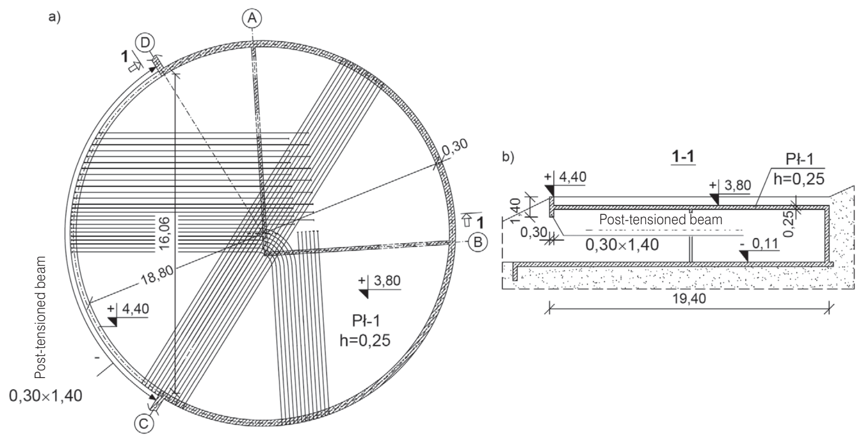


Fig. 2. Music Pavilion's plan (a), vertical cross-section (b)

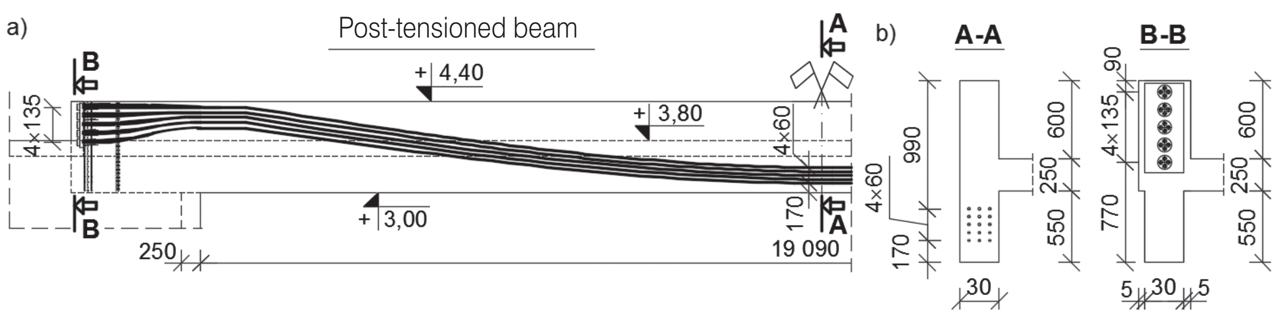


Fig. 3. Longitudinal (a) and tranverse (b) cross-sections of post-tensioned circumference beam.

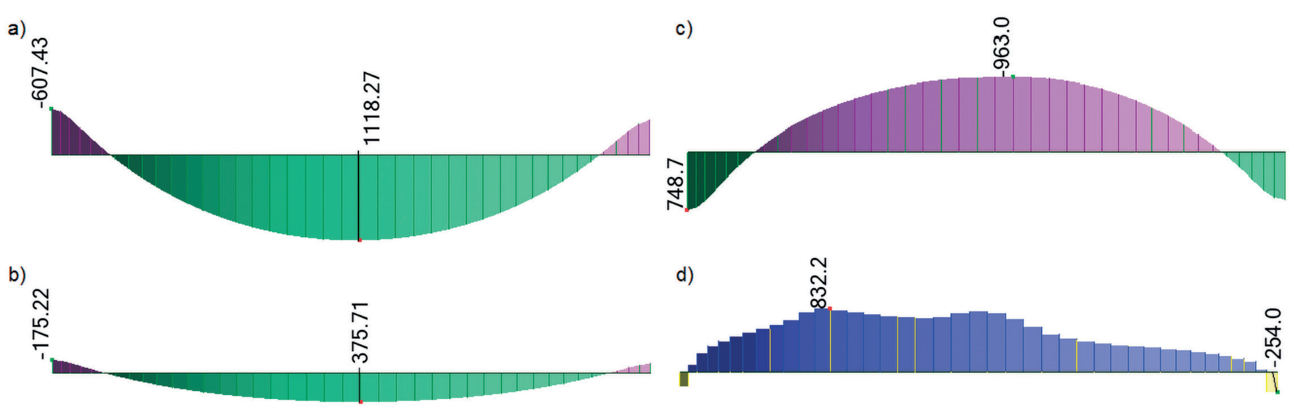


Fig. 4. Diagrams of bending moment in kNm due to dead load (a), live and snow load (b), prestressing (c) and longitudinal force in kN due to prestressing (d)

evidenced by the fact that by introducing a force of 2772 kN into the beam (15 tendons, force 220 kN each, total losses 16%), a longitudinal force of only 832.2 kN was obtained in the beam in response.

Conclusion

The paper presents a case of interesting use of post-tensioned concrete with unbonded tendons in the structure of a building on a circle plan. The irregular layout of the slab resulting from the circular shape of the building and the layout of internal supports has forced the design of a complicated prestressing system with non-standard layout of tendons. This allowed for the use of unbonded tendons with a small curvature radius and small diameters, which can be successfully used for tendons with a curved route in the layout, as shown by experience from previous implementations. A detailed approach to the issue at the design stage has allowed to avoid a collision of tendons, but it should be kept in mind that not all problems can always be solved at the design stage, which can be seen on the example of the solution of the anchorage zone in the prestressed beam, hence the doubts which arose were solved during the preparation for construction.. ■

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Streszczenie: W artykule przedstawiono przypadek ciekawego wykorzystania kablobetonu z cięgnami bez przyczepności w konstrukcji Pawilonu Muzycznego w Muszynie. Opracowane rozwiązania konstrukcyjne, a w szczególności zaprojektowane elementy sprężone – belka i strop – pozwoliły na zrealizowanie przyjętej koncepcji architektonicznej kładącej nacisk na zachowanie jedności konstrukcji z istniejącym otoczeniem.

Słowa kluczowe: cięgna bez przyczepności, belka sprężona, płyta sprężona

Abstract: THE USAGE OF PRESTRESSED CONCRETE IN THE PROJECT OF THE MUSIC PAVILION IN MUSZYNA
The work presents a description of the proposed solutions, assumptions along with the reults of static and strength analysis and relevant applications. The design of The Music Pavilion in Muszyna is an example of the innovative application of construction elements made in the cable-concrete technology.

Key words: post-tensioned beam, post-tensioned slab, unbonded tendon