

Unbonded prestressing tendons and their role in the construction of slender elements of buildings

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Abstract. Steel unbonded tendons have been introduced in Europe for construction prestressing many years later than in the USA, Honkong, Singapore or Australia. In Poland, they appeared in the early 1990s. Despite their short application, in the last decade, the Institute of Materials and Building Constructions of the Cracow University of Technology in cooperation with the TCE Structural Design & Consulting company has developed and implemented several interesting and unique designs of building components, using the advantages of this type of prestressing. In the author's work, apart from the short description of these tendons, several selected (own and foreign) projects of unique character have been presented.

1. Introduction

Unbonded steel tendons were developed and introduced to prestressed structures in the 1960s, mainly in the USA. High labor costs and mass production of prestressing tendons by smelters, which are easy and fast the assembly has led to their widespread prevalence. The economic aspects have won with the basic drawback of unbonded tendons - lack of cement injection and therefore risk of losing the tendon if it is cut or if anchorage is damaged. In view of this threat, in Europe, this type of prestressing has encountered great difficulties in adaptation. In European countries, this prestressing found application many years later than in the USA, Asian countries or Australia. The scale of its use was also smaller. In Poland, such tendons were first used to reinforce the structure of a sewage tank in 1991. The first concrete slabs in buildings, prestressed this way, were created at the beginning of the present millennium.

2. Construction and characteristics of unbonded tendons

The unbonded tendon forms a 7 ϕ 5 mm steel strand placed in grease in a hard polyethylene tube (Figure 1). The tendons are delivered to the building site as prefabricated, in spools of a mass of about

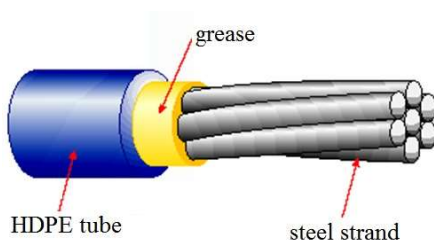


Figure 1. Unbonded tendon construction.



Figure 2. Unbonded tendon in the spool.

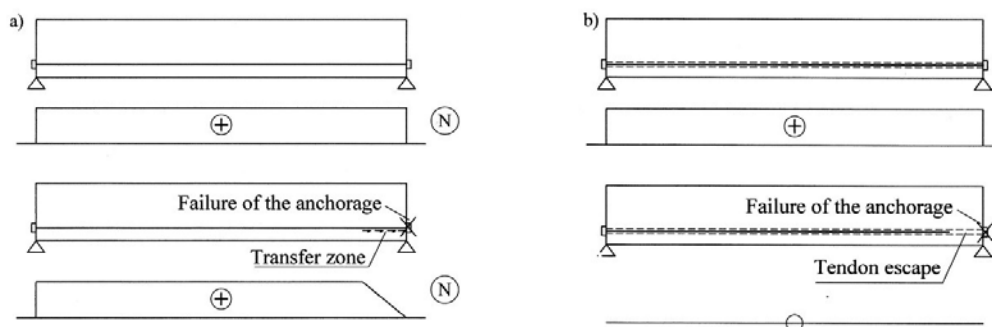


Figure 3. Bonded (a) and unbonded (b) tendon behaviour after anchorage failure.

2 tons (Figure 2). A low friction coefficient (<0.05), small diameter (about 20mm), small curvature radius (500-600mm), lightness and ease of assembly make them superior in particular types of construction, compared to the traditional systems of injected cables. Over the past decade, this new type of prestressing has led to the implementation of several interesting, unprecedented projects in Poland. In addition to several new applications, such as the elimination of thermal cracking in the walls of tanks fixed in the bottom slabs or post-tensioned slabs of vehicle scales, the tendons have been used in extremely thin floor slabs. At this point, it should be stressed that the threat connected with the possibility of damaging such a tendon in the element, e.g., due to its cut, drilling, damage of anchorage, etc. In contrast to a traditional tendon injected with cement paste, lack of bonding causes that the loss of force also includes the whole tendon, and not only the cross-section of the damage and its vicinity (Figures 3 and 4). Since the tendon has the ability to move freely in the tube, it is not possible to transfer force to concrete through adhesion and formation of a transmission zone. The ability to move the strand also causes that local cross-section effort does not induce local increase of stresses and strain in the prestressing steel. These increments cover the entire length of the tendon. Unbonded tendons are thus affected by larger elongations and the structures prestressed with their use are subject to larger deformations.

3. Post-tensioned slabs of large span

In recent years, several large-span slender post-tensioned slabs with the use of prestressing without bonding have been designed and erected in Poland. In the building of the Cultural and Artistic Center in Kozienice which was put into operation in 2015; due to the limited height of the building and the need to obtain as much space as possible, an opportunity of creating the thinnest construction panels possible was sought. Three post-tensioned floor slabs with the largest span and unprecedented slenderness have been designed (Figure 4 to 6). All three slabs were designed in post-tensioning technology, prestressed with unbonded tendons:

- slab SI-1 +9.68m horizontally, with a span of 11.15m and thickness of 200mm located above the theater room. The ratio of span to depth is 55.8;
- slab SI-2 +14.08m horizontally, with a span of 12.65m and thickness of 250mm, as flat roof over the theater room. The ratio of span to depth is 51.4;
- slab SI-3 with projection dimensions of 17.65×19.6m and thickness of 350mm designed above a cinema hall. The ratio of span to depth is 50.4.

The largest slab SI-3 over the cinema was the subject of computational analyses presented in the paper [1]. The constructional details of all three slabs, together with the results of measurements during the implementation, are given in the paper [2].

Here, reference should be made guidelines in literature regarding the maximum span and slenderness of such slabs. According to [3], the maximum span of one-way slabs, with a thickness of 250mm and a load over dead weight of 1.75 kN/m^2 (corresponding to flat roof SI-2) should not exceed 9.4m for the simply supported slab and 10.8m for the inner span of the continuous slab (compare with the span of slab SI-2). Meanwhile, for a thickness of 200mm and a load of over dead weight of 4.0 kN/m^2

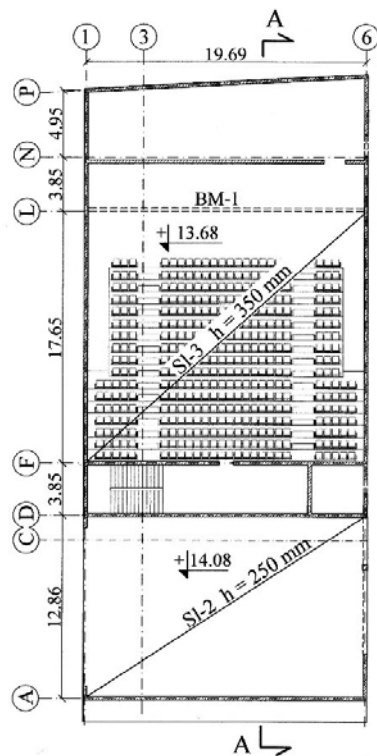


Figure 4. Plan of the building segment with post-tensioned slabs.



Figure 5. View of CKA in Kozenice..

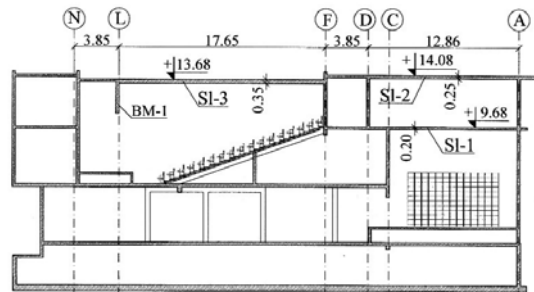


Figure 6. A-A cross section.

(corresponding to floor slab SI-1), the recommended spans are 7.2m for the simply supported span and 8.0m for the inner span of the continuous slab (compare with span of slab SI-1). In the case of two-way slab, with a load exceeding the dead weight of 1.75kN/m^2 and a thickness of 300mm, the largest suggested span for the simply supported slab is 13.2m. Meanwhile, slab SI-3 over the cinema was 350mm thick but as large as 17.65m. The recommended maximum ratio of span to depth, with a minimum of two spans in each direction, is 42 for ceilings and 48 for flat roofs.

In their work [4], Khan and William have a different approach towards the maximum ratio of span to depth, depending on the construction of the ceiling and loads exceeding dead weight. For one-way solid slabs, the full ratio is 30÷45, ribbed slabs - 25÷35, flat solid slabs - 35÷45, waffle slabs - 20÷30. The upper value corresponds to a load exceeding dead weight - 2.5kN/m², and the lower value corresponds to a load of 15kN/m².

By comparing the geometrical parameters of the constructed slabs and the corresponding values recommended as the maximum, it is easy to see that the slabs are well above the recommended values. Despite this, they have shown surprisingly small deflections. For example, ceiling slab SI-1 which, half a year after its execution, after all the components of the equipment on the ceiling, with fixed loads exceeding the dead weight of 3.9 kN/m^2 , was deflected by 11mm, i.e. 1/1014 of the span. Slab SI-2, after 3 years of execution, is deflected by 24mm, i.e., 1/538 of the span, and the increase in deflection in time has significantly reduced.

Another post-tensioned slab with a large span constructed with the use of unbounded tendons is presented in [5]. A one-way simply supported slab over a concert hall, with a span of 21.3m and a thickness of 550mm, was designed. In order to reduce dead weight, lightweight internal relief inserts were used in the form of balls with a diameter of 315mm. This reduced the weight of the slab by 20%, reducing flexural stiffness by 10%, which resulted in a significant reduction in the expected

deflections. Although the ratio of span to depth (38.7) is not impressive, the span for such a slab is a record value.

4. Church buildings

For the first time in Poland, prestressing with unbounded tendons has been used in two church projects. In the church of St. Peter and Paul in Bodzanow (near Wieliczka), a prestressed post-tensioned peripheral tie beam was used. The structure of the roof is built on a circular plan (Figure 7a) with a diameter of 25.5m. The wall-bearing construction is constituted by 12 columns evenly spaced on the circumference with a cross-section of 0.4×0.6 m. The roof structure is constituted by 12 girders from glued timber with a cross-section of 300×700 mm, pivotally attached at the peak and supported on reinforced concrete columns (Figure 7b). In order to avoid the use of additional steel ties running through the chords, or the construction of a massive reinforced concrete ring beam capable of

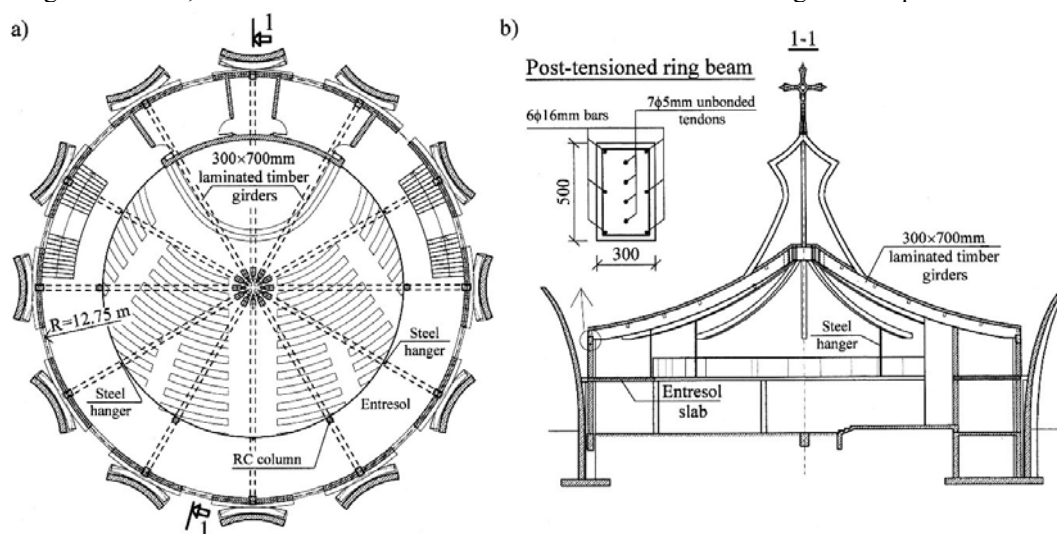


Figure 7. The church plan (a), vertical cross-section and post-tensioned ring beam (b).

transferring tensile forces from the roof with additional bending moments, a slender post-tensioned ring beam was constructed, with a cross-section of 300×500 mm, hidden in the thickness of the wall. For the prestressing of the ring beam, 4 unbonded tendons were used, wrapping the entire circumference and anchored alternately on both sides of the circumference. The construction and technological details of the project are presented in the paper [6].

Another example of the use of unbonded tendons in churches is the church of St. Jack in Cracow, where, in the interior, a very thin, concrete structure of a mezzanine for the choir was used. A 3.0m wide and 250mm thick slab with a central span of 10.0m was prestressed along the ring with 10 unbonded tendons. This project is expected to be implemented and will be the subject of future publications.

5. Other, new use of unbonded tendons in a building

An interesting use of this type of prestressing in the construction of prefabricated Slimfloor slabs was proposed in [7]. Such ceilings are constructed of pre-tensioned prestressed concrete slabs supported on steel delta-shaped beams. The slabs are based on the bottom shelf of the beam, which is hidden in the ceiling. It is obvious that the spacing of the columns and the space between them are conditioned by the span of the heavily loaded and low beam. In the analyzed case [7], slabs with a span of 10.2m and a thickness of 320mm and an additional 60mm thickness of concrete overlay were used. Strength conditions, with the standard version of commonly used beams, allowed the use of a beam with a span of 7.2m. In the original version of the project, 2 unbonded tendons (Figure 8) with a parabolic route

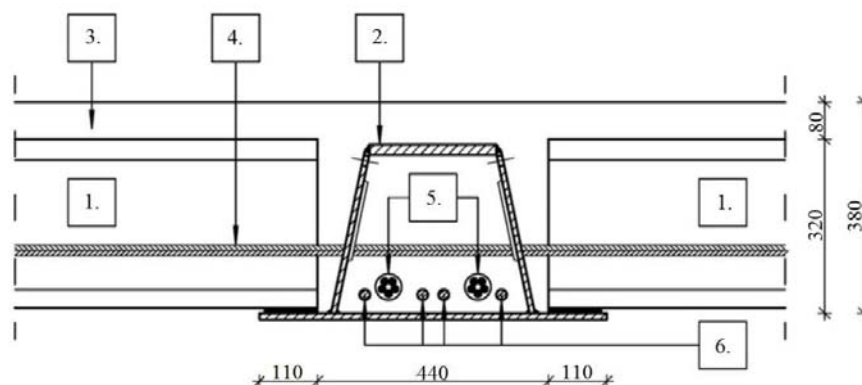


Figure 8. The church plan (a), vertical cross-section and post-tensioned ring beam (b) [7].

1. Hollow core slab, 2. Delta-shaped steel profile, 3. Concrete slab with mesh reinforcement, 4. Transverse reinforcement, 5. Prestressing cables, 6. Fibre rebars.

were used inside the beam. This solution allowed to increase the span of the beam, and thus the span of the ceiling in the direction of the beam, from 7.2 to 9.0m.

6. Conclusions

The work presents some interesting examples of the use of unbonded tendons in post-tensioned elements in buildings in Poland. It should be emphasized that despite their relatively recent appearance in our country, they are currently used on a mass scale in the construction of buildings. The presented projects, however, are of innovative nature; they are a result of a scientific research and were created as an effect of the cooperation of an academic institution with a design company, under strict scientific supervision. Positive results obtained from the implementation are the basis for calibrating the long-standing calculation methods and contributing to the development of bold new projects.

7. References

- [1] Mieszczak M 2013 Płaskie stropy sprężone cięgnami bez przyczepności (Flat concrete floors post-tensioned with 5 nbonded tendons) *3rd National Student Building Conference "Euroinżynier" Cracow*
- [2] Szydłowski R, Mieszczak M 2015 Gdzie jest granica smukłości sprężonych płyt stropowych? O projekcie i badaniach stropów sprężonych w budynku Centrum Kulturalno-Artystycznego w Kozienicach (Where is the limit to span-depth ratio for prestressed slabs? About the design and research on prestresse slab in Art Gallery in Kozienice) in *Aktualne kierunki rozwoju teorii i praktyki konstrukcji sprężonych w Polsce (Current trends in the development of the theory and practice of prestressed structures in Poland)* Cracow University of Technology pp 67–78
- [3] Fib-Bulletin No. 31 2005 *Post-tensioning in building* Lausanne p 109
- [4] Khan S, Williams M 1994 *Post-tensioned Concrete Floors* Butterworth-Heinemann Bodmin-UK p 312
- [5] Szydłowski R, Labuzek B 2017 Post-Tensioned Concrete Long-Span Slabs in Projects of Modern Building Construction *IOP Conf. Series: Materials Science and Engineering* 245 (2017) 022065
- [6] Szydłowski R, Labuzek B, Turcz M 2017 Prestressed Ring Beam in the Church of St. Peter's and Paul's in Bodzanow, Design and Realization *IOP Conf. Series: Materials Science and Engineering* 245 (2017) 022066
- [7] Derkowski W, Skalski P 2017 New Concept of Slimfloor with Prestressed Composite Beams *Procedia Engineering* 193 pp 176-183