

Concrete properties for long-span post-tensioned slabs

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Abstract. In contrast to foreign practice, in Poland, for many years, there has been a belief that prestressed constructions should use more expensive concretes on basalt aggregates. It is due to low quality of national river and fossil aggregates. They give low concrete strength and modulus of elasticity. In the paper, it has been shown on two examples of post-tensioned slabs that it is possible to use concretes with low value of modulus of elasticity for large-span slabs. This results may be important in popularizing the use of post-tensioned slabs in buildings in poorer countries, making them cheaper in execution.

Introduction

Concretes used for prestressed structures do not differ substantially from those used for reinforced concrete structures. However, there are slightly different requirements for individual concrete properties. In reinforced concrete structures, concrete strength and durability are important parameters. Features such as early strength, modulus of elasticity, shrinkage and creep are secondary. In prestressed structures, early strength, high modulus of elasticity and good rheological characteristics, i.e., low shrinkage and creep will be most desirable.

The rapid development of strength allows early introduction of stress and release of the structure from the supports, which improves the economic attractiveness of the prestressed concrete construction. The high modulus of elasticity reduces immediate losses of prestress force and deflection. Low shrinkage and creep reduce time-dependent losses of prestress force and rheological increases in deflections.

As far as the strength of concrete depends to a greater extent on the characteristics of the cement matrix, the modulus of elasticity, more important for the prestressed structures depends primarily on the quality of the aggregate used. The expected standard values [1] for individual concrete classes have been specified for quartzite aggregates. For limestone aggregates, the given values should be reduced by 10%, while for basalt aggregates they should be increased by 20%.

Therefore, it would be sensible to exclusively use concrete with basalt aggregate for prestressed slabs. However, it should be borne in mind that this very good quality aggregate commonly used in bridge concrete is more difficult to obtain compared to quartzite aggregates and thus, significantly increases the cost of concrete. Thus, author of this work recommends using of high quality concrete with crushed stone aggregates only where it is necessary. This assumption can allow to reduce the cost of execution of post-tensioned concrete structures and their popularization in poorer countries.

Aggregates used for prestressed concretes

From the time of the first Polish construction of prestressed concrete, crushed basalt and granite aggregates began to be used for concrete. Later, due to difficulties in obtaining crushed stone, mixed aggregate, made of basalt or granite and river or fossil aggregate started to be used. In this way, the demand for crushed stone was slightly reduced. Meanwhile other countries, from the very beginning, used the same river and fossil aggregate (quartzite ... etc.) which is used for reinforced concrete structures for prestressed concretes. These aggregates, however, differ from Polish river and fossil aggregates in that they have a rough surface and a rather irregular shape. The shape of these aggregates is stocky, resembling broken aggregate (crushed stone). Lack of dust in the aggregate

composition, rough and generally irregular grain surface in aggregates, create good conditions for the cooperation of the cement paste with aggregate.

Meanwhile, Polish river and fossil aggregates are cobblestone aggregates with smooth or very smooth surfaces. The shape is similar to spheres or more or less flattened ellipsoids. This shape, and above all the smooth surface of the grains, creates unfavorable conditions for the cement paste adhesion. For this reason, the concrete made of this type of aggregate reaches low values of mechanical properties. The author, on the example of two post-tensioned slab with large-span in the buildings, shows that it is possible to construct this type of structures with so poor concrete.

Post-tensioned flat slab in the building of the Laboratory of Energy-efficient Construction in Cracow

The building (Fig. 1a) was erected in year 2013-14. Above the last floor, a post-tensioned flat slab with a span width of 11.3×10.0m and a thickness of 250mm has been designed (Fig. 1b). A system of unbonded tendons (7φ5) is shown in Figure 1c. The ratio of span to depth for the largest span is 40. Therefore, this is a value close to the limit for post-tensioned slabs (see item 4). C30/37

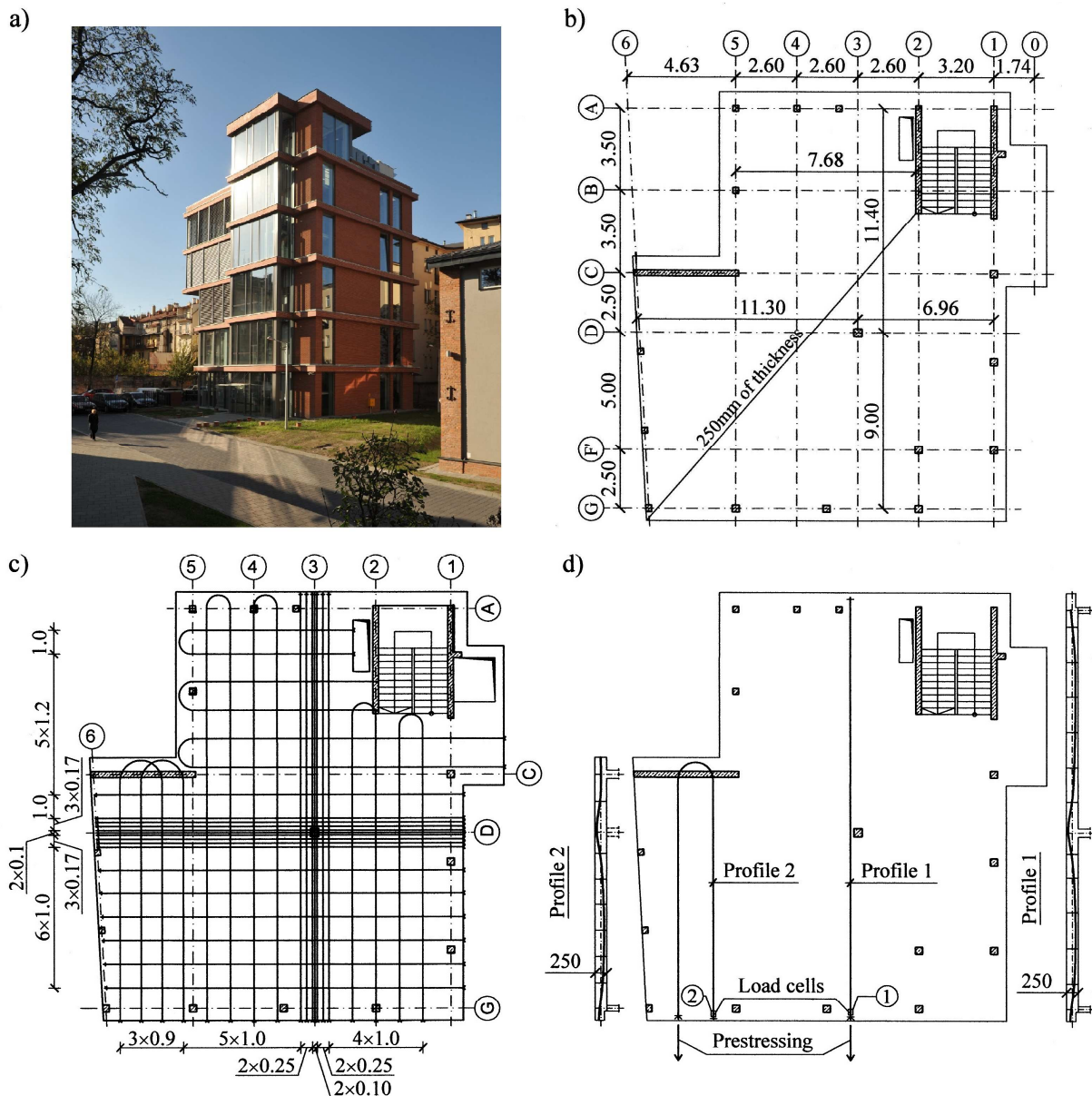


Fig. 1 Autors' slab in the building of Laboratory of Energy-efficient Construction in Cracow: building view (a), slab layout (b), tendon arrangement (c), tendon profile and force transducers location (d).

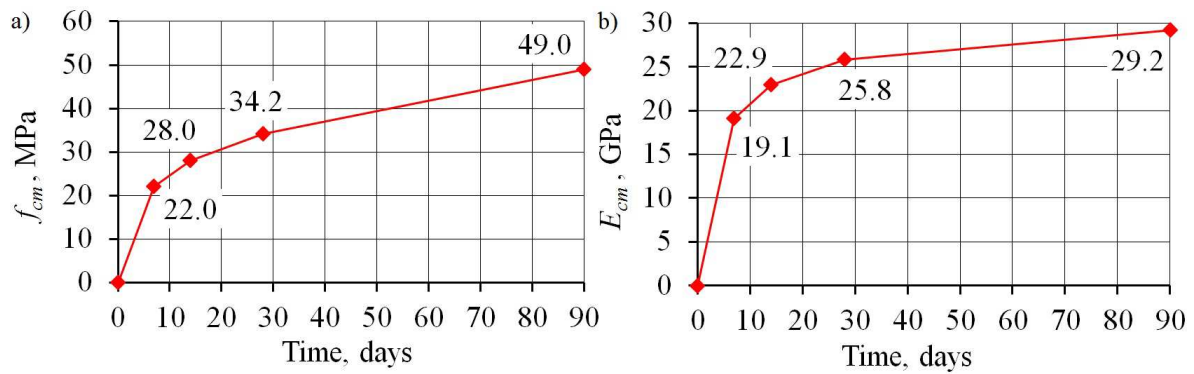


Fig. 2 Mean compressive strength (a) and Young's modulus (b) development in day-time.

concrete, made of gravel aggregate with a grain size of up to 16mm. In addition, the supplier made concrete on CEM II/B-V 32.5 R cement and water-cement ratio of 0.47. The low quality aggregate caused a low value of the final modulus of elasticity, and the cement with an extended hydration rate caused slow growth of the mechanical properties. Development of medium compressive strength and modulus of elasticity in the first 90 days, indicated on $\phi 150 \times 300$ mm samples is presented in Figure 2. At the moment of introducing the prestressing (14 days after concreting), the compressive strength was 28.0MPa, and the modulus of elasticity was 22.9GPa. Meanwhile, the 28-day values were 34.2MPa and 25.8GPa, respectively. It is clearly visible that concrete after 28 days did not reach the value expected by the standard. Actual values were 90% and 81% of norm values, respectively. Such a low modulus of elasticity is justified by the use of gravel aggregate. However, this is a very low value for prestressed structures. It might seem that the low values of strength and modulus are reflected in the decrease in forces in the tendons and deflections of the slab.

Figure 3 shows the change in force value in two tendons located in Figure 1d. Each tendon was tensioned with a force of 200kN. The lower value after the anchorage in cable 2 is due to the fact that it was measured under dead anchorage of the looped cable. Its lower value is caused by the friction of the strand by the sheath. Rheological force drops amount to 8.2% in cable 1 and 7.8% in cable 2.

Despite the use of weak concrete, both immediate decreases in forces during prestressing and rheological losses are at a low and satisfactory level.

Figure 4 shows the results of measurements of roof deflections after prestressing (4a) and after 4 years (4b). The value of deflection of the largest span after 4 years is 6.5mm, which, with a span of 10.0m, constitutes 1/1538 of the span. So, it is a negligible value.

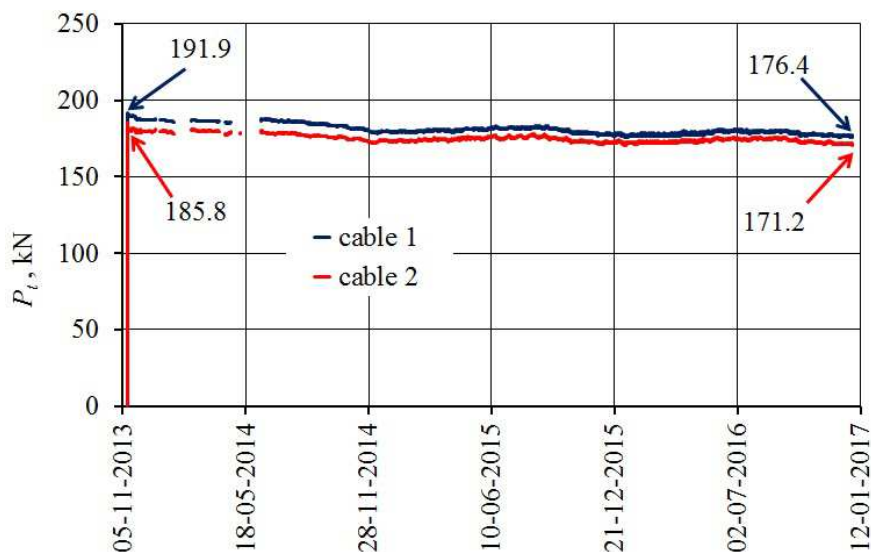


Fig. 3 Prestress force value in two monitored tendons during first 3 years from tensioning.

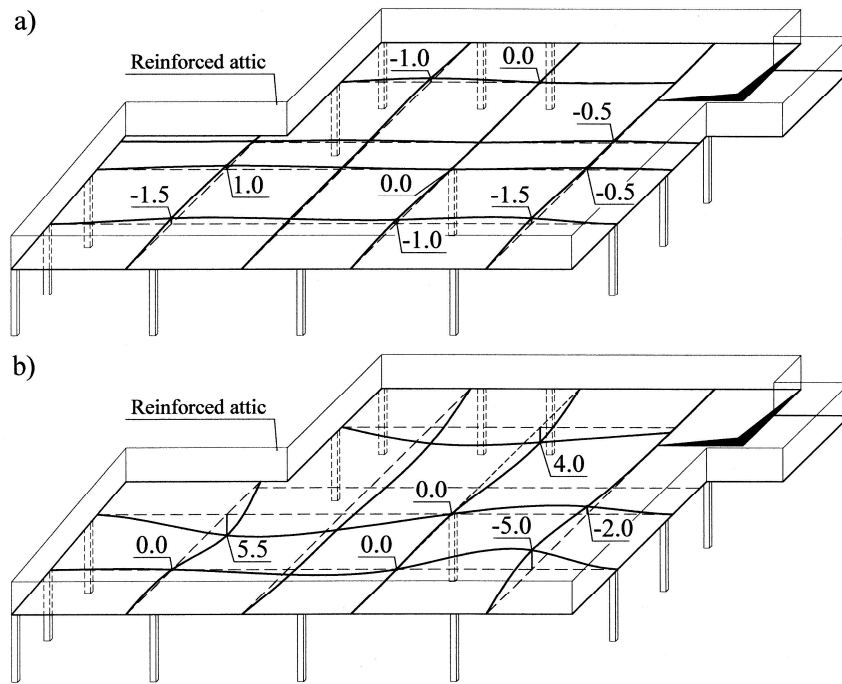


Fig. 4 Slab deformation in millimeters: after tensioning (a), 4 years from construction (b).

Post-tensioned slabs in the building of the Cultural and Artistic Center in Kozenice

In the building that was put into use in 2015, the possibilities of constructing thin slabs of large spans were sought after [3]. This was dictated by the limited construction height of the building. The building has been designed with 3 post-tensioned slabs (Figure 5). SI-1 one-way floor slab with a span

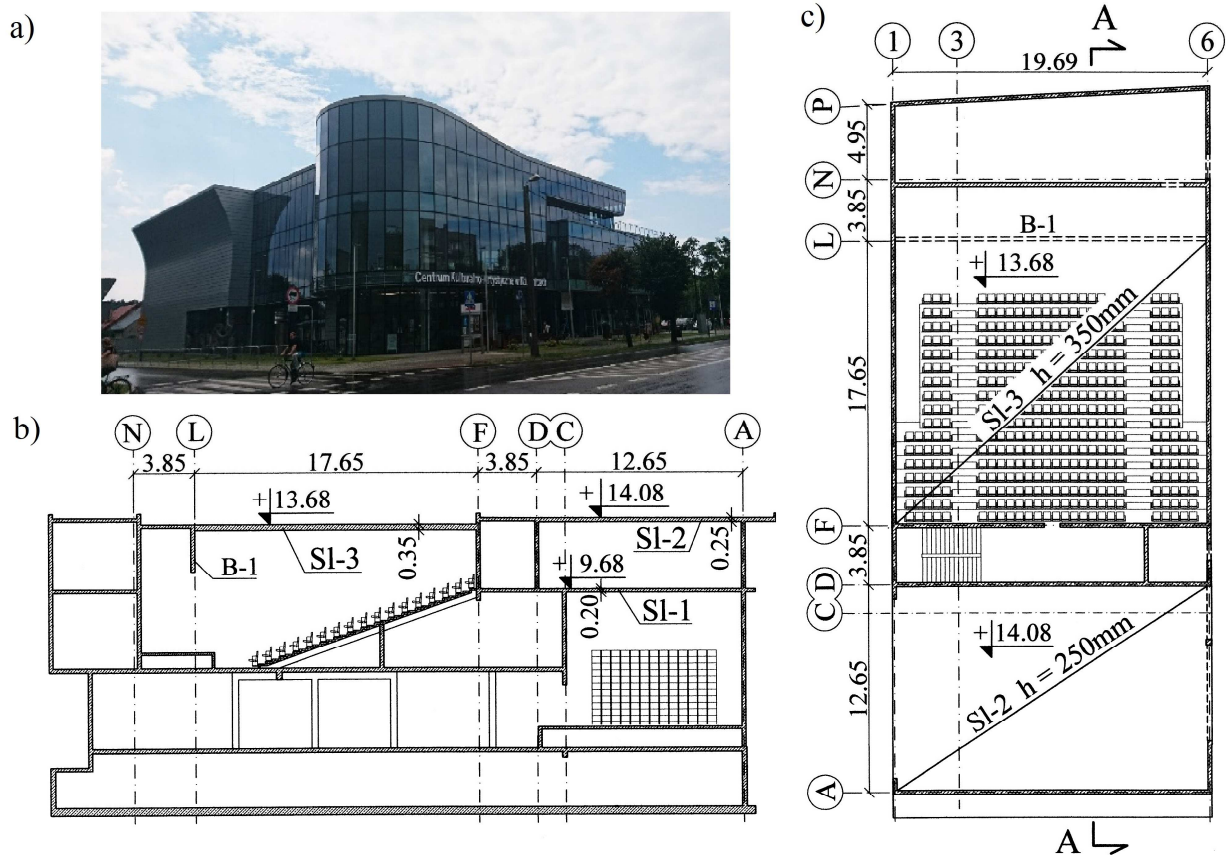


Fig. 5 The building of Artistic and Cultural Center in Kozenice according to the authors' project: general view (a), vertical section (b), plan of a building segment with large-span slabs (c).

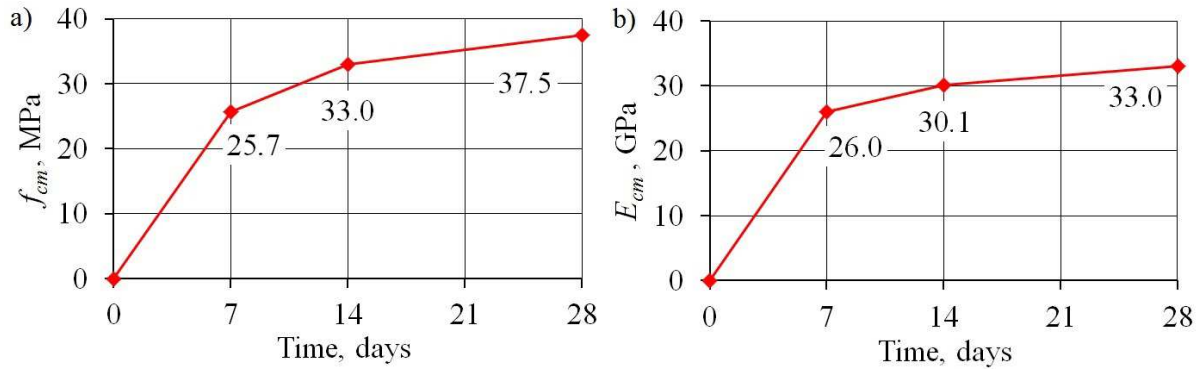


Fig. 6 Mean compressive strength (a) and Young's modulus (b) development in day-time.

of 11.15m and thickness 200mm ($L/h = 55.8$), one-way flat roof slab SI-2 with a span of 12.65m and a thickness of 250mm ($L/h = 50.6$) and two-way flat roof slab SI-3 with a span of 17.65×19.69 m and a thickness of 350mm ($L/h = 50.4$). C35/45 class concrete with Portland cement CEM I 52.5 was used. Dolomite grit with a grain size of $2 \div 16$ mm was used as fine aggregate. Prestressing of all slabs was carried out after 14 ± 2 days from concreting. The development of compressive strength and modulus of elasticity for samples taken during concreting of the SI-2 slab is shown in Figure 6. During prestressing, the values were respectively 33.0MPa and 30.1GPa. After 28 days, values of 37.5MPa and 33.0GPa were obtained. As in the previous case, after 28 days, no average compressive strength (43MPa) was obtained. The modulus of elasticity was almost reached (34GPa).

Table 1 Recommended span-depth ratios for slabs according to Khan and Williams [5]

Slab type	Span to depth ratio
One-way solid slab	$30 \div 45$
Ribbed slab	$25 \div 35$
Solid flat slab	$35 \div 45$
Waffle slab	$20 \div 30$

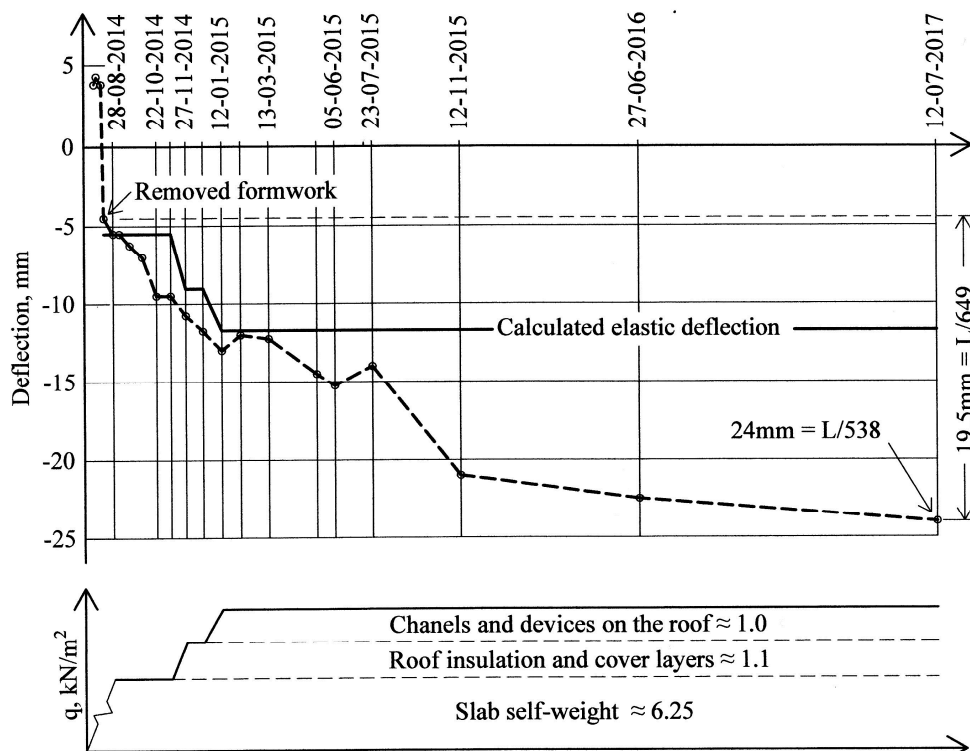


Fig. 7 Development of slab SI-2 deflection during 3 years from construction.

At this point, it is worth quoting foreign guidelines for the construction of post-tensioned slabs. According to [4], the ratio of span to depth, with a minimum of two spans in each direction, should not exceed 42 for floors and 48 for flat roofs. In [5], Khan and Williams give values listed in Table 1 as maximum. The lower values refer to the imposed load of 15 kN/m^2 , whereas the higher ones – 2.5 kN/m^2 . It is easy to observe that all three designed slabs exceed the sought-after values of slenderness.

Figure 8 shows the development of deflection for the SI-2 slab during the first 3 years after concreting. The final value of the deflection, relative to the position after concreting, is 24mm. It constitutes 1/538 of the span. The value of the deflection calculated from the moment of removing supports, much more important for the finishing elements lying below and above the slab, is 19.5mm. This constitutes 1/649 of the span. Despite the fact that the recommended slenderness of slabs is significantly exceeded, the deflections are safe and well below the limit values of the standard [1] ($L/250$ and $L/500$ for increment of deflections from the moment of removing supports). It should be kept in mind that these are not final values yet. Assuming, however, that after about 3 years, about 80% of creep already takes place, it can be concluded that these deflections are approaching the final values. This was confirmed by a decrease in the rate of growth in the last year (Fig. 8). The deflections of the other two slabs are also well below the permissible values.

Conclusions

The paper presents two examples of the use of ordinary commercial concretes with low quality for post-tensioned prestressed slabs. In the first case, as a result of using gravel aggregate and improper selection of cement for environmental conditions, concrete with very low modulus of elasticity and slow growth rate of mechanical properties was obtained. In spite of this, a large-span post-tensioned slab was made. The low quality of the concrete did not cause significant decreases in the force in the tendons, and the deflection of the slab after 4 years is extremely small. In the second case, most likely as a result of technological errors, low concrete strength was obtained. In spite of large-span slabs with slenderness significantly exceeding the recommended values, after three years from the execution of slabs, satisfactory values of deflections were obtained even if dolomite aggregate was used, although it would be much better in this case to use basalt aggregate (increase in the elasticity modulus by 20%). The examples presented show that in the case of post-tensioned slabs, good results can be obtained without the use of expensive high modulus of elasticity concrete, even with the use of gravel aggregate. Such an assumption may be important in popularizing the use of post-tensioned slabs in buildings, making them cheaper in execution. It can be noted, the investigation on application of lightweight aggregate concrete for construction of long-span post tensioned slabs should be started in Poland [6]. Reduction of the slab weight can allow them to achieve greater span and slenderness.

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