EXPERIMENTAL RESEARCH OF EARLY-AGE PRESTRESSED CONCRETE FOR ROAD AND AIRPORT PAVEMENTS

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Abstract

In this paper experimental results from research of 3 concrete slabs 1,0 × 3,6 × 0,16 m have been presented. Two of them have been prestressed by unbonded steel tendons 7ϕ5 mm. The value of prestressing force was 50 % of full value after 20 hours from casting, and it was improved to full value after next 20 hours. The concrete strains and the level of prestressing forces have been monitored through 28 days. In the same time set of samples were made and the development of mechanical concrete properties in day-time was indicated. Based on obtained results the conclusion dealing with usability and stability of prestressing in case of very early-age concrete are formulated.

Keywords

Concrete, prestressed concrete, early-age concrete, unbodned tendons, concrete pavement.

1 INTRODUCTION

Expansion joint are the weeknest point of the reinforced concrete pavements, which are made with a lot of few meters long slabs. Many of the problem such as cracking, faulting, pumping, and spalling occur at the joints and adversely affect the riding quality of the pavement. These defects in an important way decrease durability of concrete pavements. It rises the cost of maintenance of this constructions, too. One approach to limiting joint problems is to use pavements without joinsts except at the extreme ends, which is the case in continuously reinforced concrete pavements (CRCP). Another approach is to use transverse joints spaced at greater distances, which is the case in the prestressed concrete pavement. Application of presstressed concrete allows to minimize these disadvantages.

The load-carrying capacity of the concrete pavements can by significantly improved by prestressing. It induces compressive stresses in the concrete pavement slabs, which modify the structural behaviour of this members and in an important way increases their bending and crack resistant. Additional compressive stresses obtained due to prestressing allow to design uncracked high-long continuous slabs with reduction their thickness compared with reinforced concrete ones.

The proper acting of prestressing dependends on two main parameters: concrete age when the prestressing is involved and the level of prestressing stresses in the concrete. The compressive stresses in the concrete should be initialed before the tensile stresses caused by restraint thermal shrinkage exceed the concrete tensile strength which allows to avoid concrete structure the early-age thermal cracking (Fig. 1). On the other hand, it shouldn't be too early because of the viscoelastic behaviour of the early-age concrete. The creep deformation and ralated to it prestressing loses will lead to great reduction of prestressing forces in too early prestressing concrete. In this case, the prestressing will not be able to provide the suffice crack and bending moment resistance under thermal and service loading. Both of these parameters should be the aim of further investigations and must be every considered before the practice application. Therefore, the theoretical analysis with regard the development of mechanical properties concrete and viscoelastic behaviour of the early-age concrete is less reliable. Every realization should by preceded experimental investigation and numerical analysys should be based on experimental results.

A properly designed and constructed prestressed pavement can provide a smooth surface free of cracks and with few transverse joints. In spite of these advanteges, the used of prestressed concrete pavements has not been widespread in the World for the following reasons:

- not many pavements egineers are familiar with the methods of design and construction of prestressed concrete pavements,
- an adequate evaluation of the performance of this type of pavement under various load and environmental conditions is not avalaible,
- the using of relatively high magnitudes of prestressing forces, both in the longitudinal and transverse directions, has been expensive. This has discouraged the widespread use of prestressed concrete pavement. This is in spite of the economic advantages of this type of pavement as a result of its lesser thickness and of its potential for less maintenance as compared to nonprestressed pavements.

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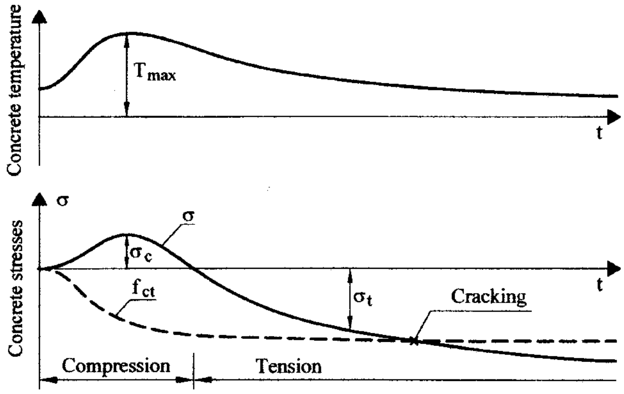


Fig. 1 Development of tensile stresses and concrete strength

The magnitudes of prestressing stresses and the corresponding amounts of prestressing steel can be reduced considerably, as compared to amounts that have been commonly used, if proper attention is paid to the following two important factors:

- The use of low friction media or treatments between the pavement and the supporting media reduces the tensile stresses due to friction that are developed during slab contraction when temperature drop. The reduction of friction allows to reduce the value of the required prestressing forces.
- The consideration of the favourable distribution of shrinkage stresses through the thickness of the slab due to moisture difference between the bottom and top surface (away from the slab edges) reduces the stresses from vehicular loads. These residual stresses, which are compressive at the bottom of the slab: counteract a large part of the tensile stresses, due to vehicular loads and thus reduce the amount of prestressing steel.

The proper determination final concrete strains and stresses in the corss-section considering the act of prestresing, moisture distribution, enviromental conditions and the time-dependence is very difficult. The modulus of elasticity depends on the lot of parameters e.g. moisture contens, time under loading. Therefore, in analyse of the prestressed concrete pavements the sustained modulus of elsticity E_s should been taken. This value includes the effect of both the immediate elastic deformations and the deformations due to creep. The sustain modulus has the same units as the elastic modulus, although its value is smaller and decreases with the time under stresses. ACI Commitee 209, in its interpretations of creep and shrinkage behaviour of concrete, has attempted to further simplify these behaviours by considering concept of age – adjusted effective modulus. Its value depends on the secant modulus of elsticity E_c, the creep coefficient ϕ, and an aging coefficient χ which ranges between 0,6 and 0,9.

$$\overline{E}_c = \frac{E_c}{1+\chi\cdot\phi} \tag{1}$$

Concrete creep depends on moisture. The moisture content is higher in the bottom parts of the slab then the upper ones because of the difficulty in evaporation of water from the bottom of the slab. Accordingly, different values of the creep coeficient should by used in calculation the sustained modulus of elasticity top (E_{ST}) and bottom (E_{SB}) surfaces of the slab when the stress distribution on sections that are fully retrained are estimated. These sections are away from the ends and must have the same deformations at top and bottom to remain flat without deflections.

2 PROGRAM OF INVESTIGATION

Preliminary investigations preceding realization of continuous post-tensioned concrete pavement, have been done in Laboratory of Institute of Building Materials and Structures of Cracow University of Technology. The aim of investigation was to evaluate the strains and stresses states in the concrete slabs and the changes in time in the prestressing forces in the tendons. Three 1,0 × 3,6 × 0,16 m conrete slabs have been casted without the reinforcing steel. To minimize the friction forces two layers of polyethylene between slab and subbase have been used. Two of three slabs have been prestressed by unbonded steel tendons 7ϕ5 mm in the longitudinal direction to different concrete stresses. Slab 1 was prestressed by two tendons applied at the ends of slab in the distance 0,50 m. In case of slab 2 four post tensioning tendons were applied in the distance 0,25 m. Slab 3 was nonprestressed, for monitoring shrinkage, thermal strains and friction resistance what has allowed to separate the creep strains from the results obtained from slab 1 and 2. General view of the slabs is shown on Fig. 2.

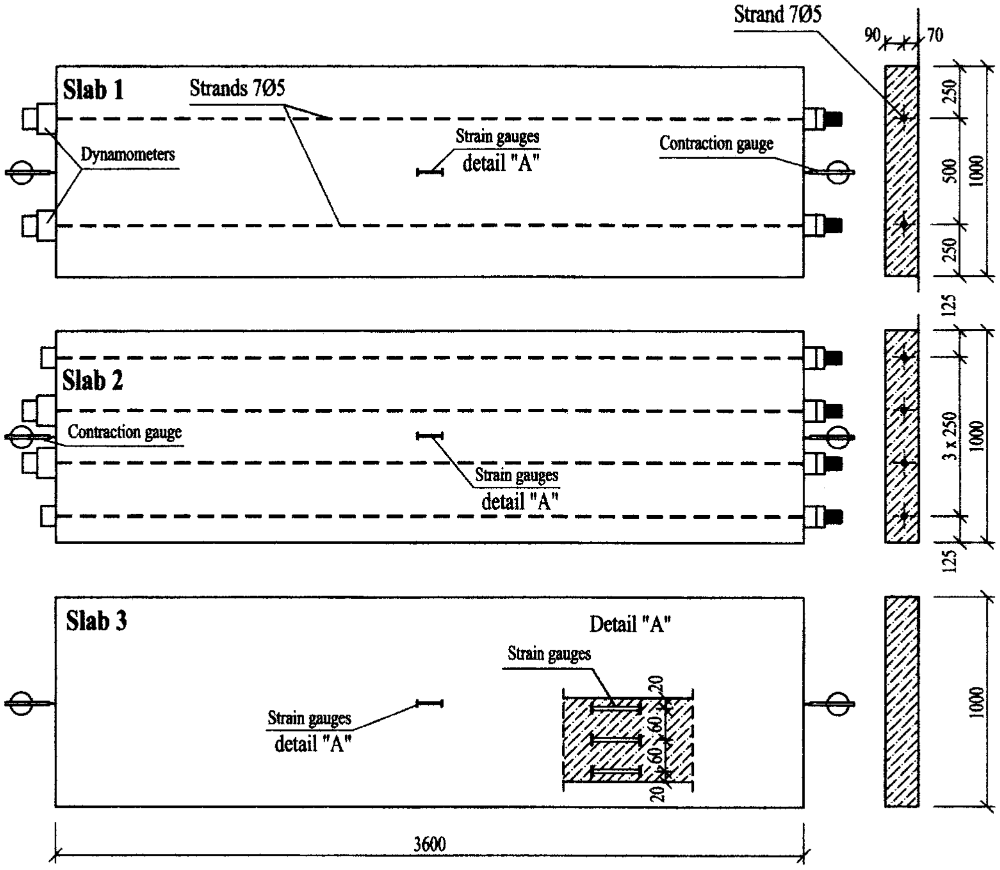


Fig. 2 General view of slab samples

The prestressing was realized in two stages. I stage – about 50 % of final prestressing force was applied at 20 hours after casting, II stage – the prestressing force was improved to final value at 40 hours after casting. The average values of prestressing force and corresponding values of concrete stresses are set in Table 1.

Tab. 1 *Avarage prestressing forces and corresponding concrete stresses values ($\sigma_{c,b}$ – on the bottom surface, $\sigma_{c,t}$ – on the top surface)*

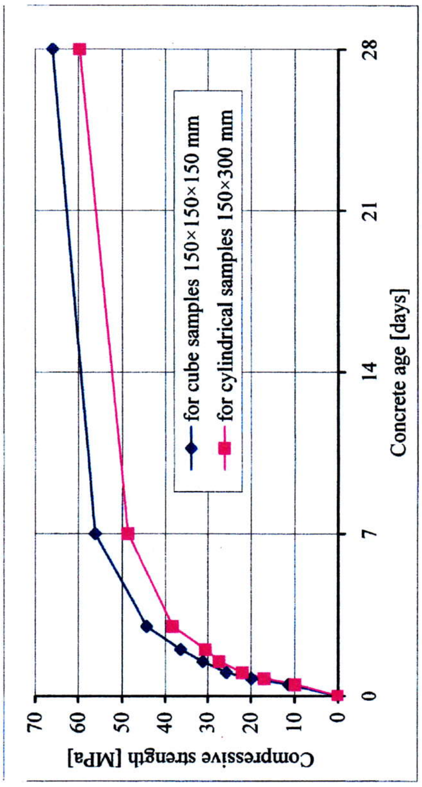
Number of slab	I stage of loading			II stage of loading		
	P_{01} [kN]	$\sigma_{c,b}$ [MPa]	$\sigma_{c,t}$ [MPa]	P_{02} [kN]	$\sigma_{c,b}$ [MPa]	$\sigma_{c,t}$ [MPa]
Slab 1	100,1	1,72	0,78	189,9	3,26	1,48
Slab 2	99,0	3,40	1,55	189,4	6,61	2,96

The special air-entrained concrete mixture designed for prestressed concrete structures has been used. Portland cement CEM I MSR NA 42,5 have been used in quantity 440 kg/m^3, w/c = 0,37. Because of the necessity of improving the concrete modulus of elasticity, basalt aggregate has been used. The concrete has been tested before and during the investigations. Following mechanical properties of concrete have been determined at 12, 18, 24, 36, 48 hours and 3, 7, 28 days before investigations:

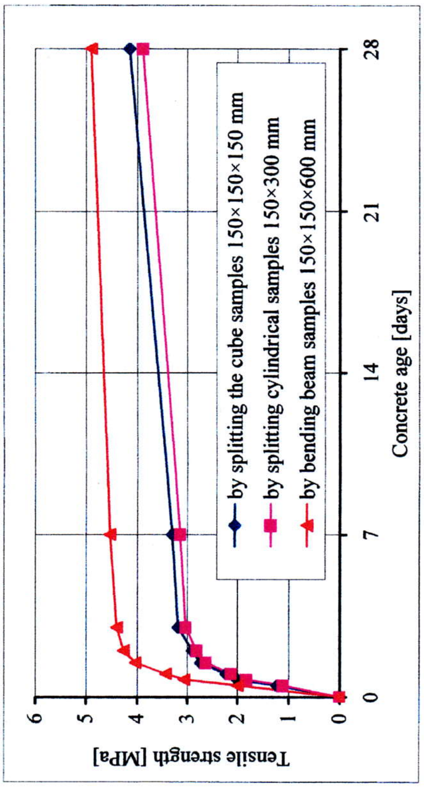
- compressive strength (cube samples 150 mm × 150 mm ×150 mm),
- compressive strength (cylindrical samples ϕ150 mm × 300 mm),
- axial tensile strength (cylindrical samples ϕ150 mm × 300 mm),
- splitting tensile strength (cube samples 150 mm × 150 mm ×150 mm),
- modulus of ruptures (beam samples 150 mm × 150 mm × 600 mm), two points bending,
- modulus of elasticity of concrete (cylindrical samples ϕ150 mm × 300 mm),
- concrete shrinkage (beam samples 100 mm × 100 mm × 500 mm).

The results of these tests are shown in Graph 1 ÷ 4.

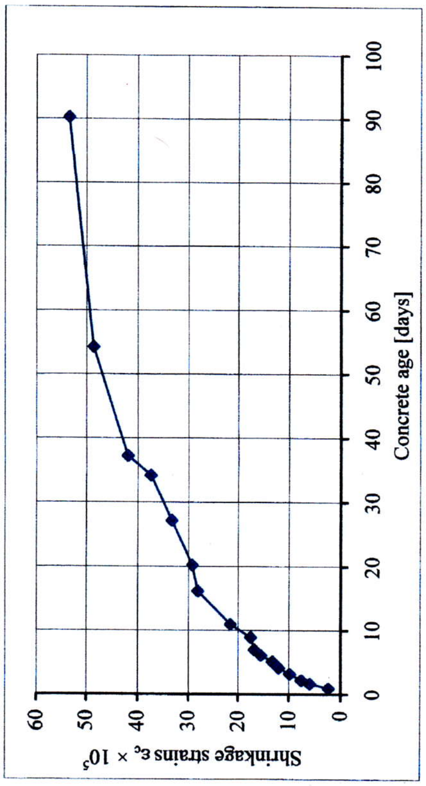
The following variables were monitoring during the load time:



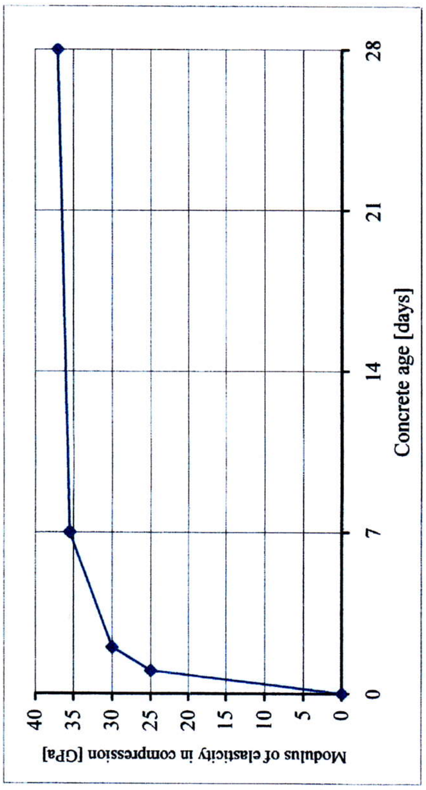
***Graph 1** Development of compressive strength in day-time*



***Graph 2** Development of tensile strength in day-time*



***Graph 3** Development of shrinkage strains in day-time*



***Graph 4** Development of modulus of elasticity in day-time*

- prestressing forces in tendons,
- concrete strains and temperature development at three levels of midspan cross-section: 20 mm above the bottom surface, middepth of slab and 20 mm under the top surface,
- concrete strains on the top concrete surface in three lines in the longitudinal direction,
- slab contraction at the level of prestressing tendons (inductive 10 mm displacement transducers).

The prestressing force has been released at 28 days after concreting but the monitoring has been conducted for several days yet. The initial and final forces as well as the prestressing losses values are presented in Table 2. P_0 denotes the initial force in the tendons, and P_t denotes the forces in the tendons 20 hours later and 28 days from the time of prestressing. The prestressing tendons were situated in cross-section with eccentricity equal to 10 mm (Fig. 2 and 3).

The compressive strength of concrete at the first stage of prestressing was equal to 18,2 MPa (cylindrical samples) and at the second (final) stage of prestressing was equal to 26,9 MPa (cylindrical samples). The modulus of rupture of concrete was equal to 3,3 MPa at first and 4,4 MPa at second stage of prestressing. The secant modulus of elasticity of concrete was equal to 23 GPa, 28 GPa and 37,5 GPa after 24 hours, 48 hours and 28 days respectively.

Tab. 2 *Initial, final forces and prestressing losses values*

Number of slab	I stage of loading			II stage of loading		
	Start (20h)	End (40h)	Force loss	Start (40h)	End (28 days)	Force loss
	P_0 [kN]	P_t [kN]	ΔP [%]	P_0 [kN]	P_t [kN]	ΔP [%]
Slab 1	100,1	98,9	1,3	189,9	183,3	3,5
Slab 2	99,0	96,7	2,3	189,4	182,9	3,4

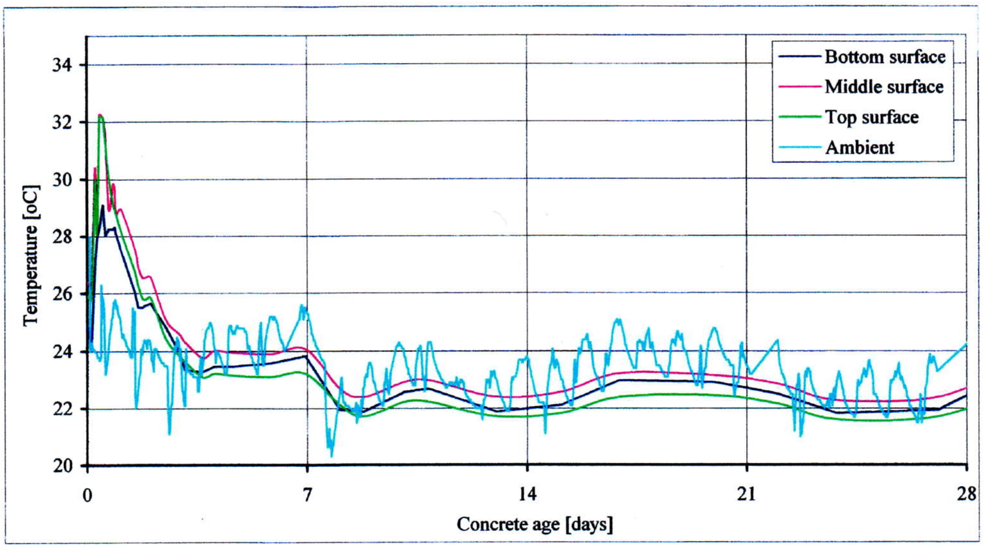
3 RESULTS DISCUSION AND CONCLUSIONS

In Graph 5 the concrete temperature development recorded on the three depth of the midspan and the air temperature have been plotted. The highest concrete temperature was registered after 12 hours from casting at the middepth of cross-section and it was 32,2°C.

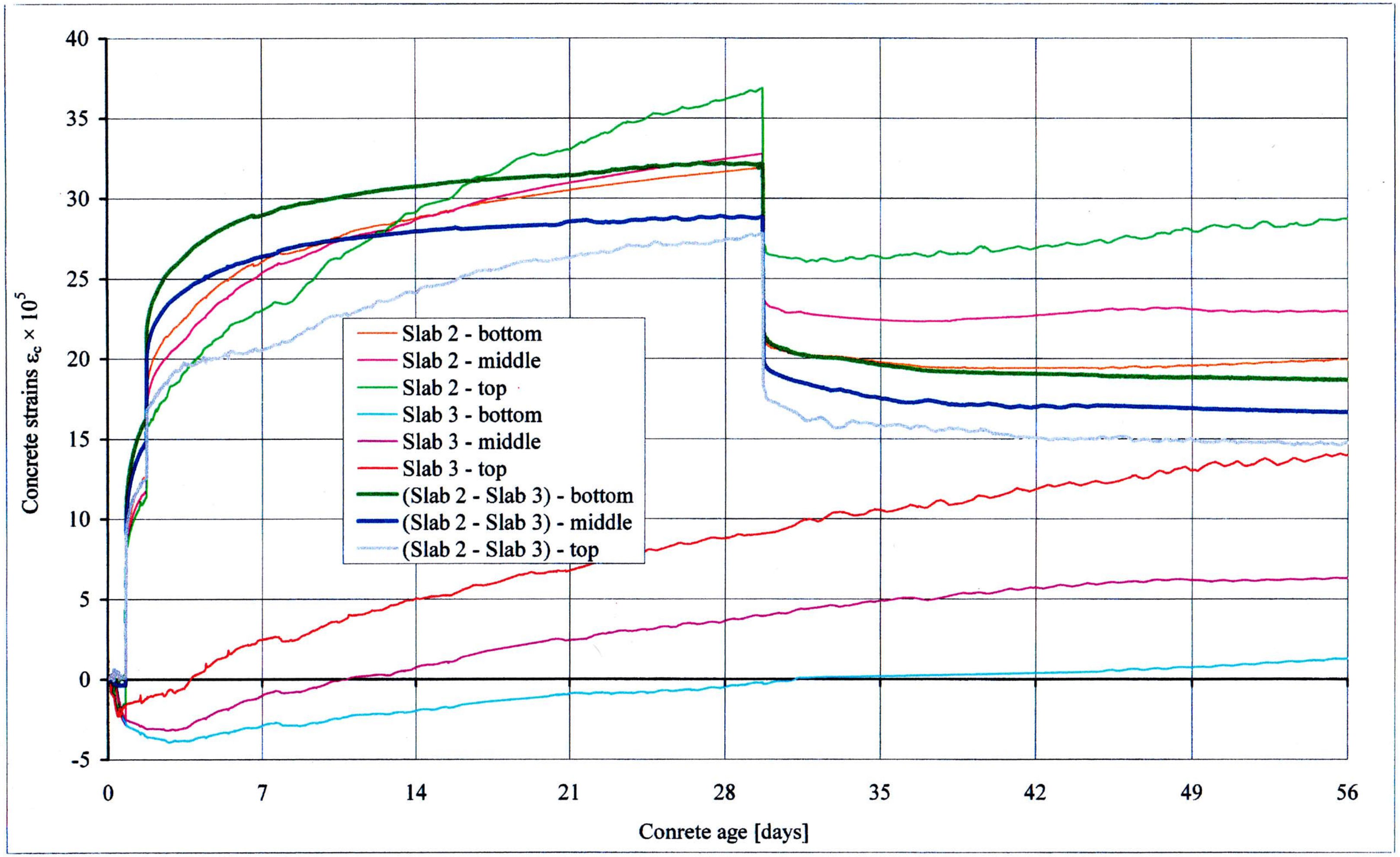
The distributions of shrinkage and thermal strains measured at three levels of midspan cross-section: 20 mm above the bottom surface, middepth of slab and 20 mm under the top surface (monitoring only on the Slab 3) are presented at the lower part of Graph 6. However, the complete concrete strains including the thermal, shrinkage and creep strains are presented at the upper part of Graph 6 (Slab 2). This Figure also presents only creep strains, calculated from deduction the mentioned above results (thicker lines).

The strains values of concrete at the three levels on cross-section of slab 2 and slab 3 measured during the investigation (Graph 6) are listed in Table 3. Based on these values the distributions of concrete strains (instantaneous and time-dependent) recorded in each stage of prestressing and between them in cross-section are presented on Fig. 3.

The creep coefficient ϕ (equation (1)) depends on the moisture content that is different at the top and the bottom surfaces. Unfortunately, it was impossible to measure these parameters to calculate sustained modulus. As described in



Graph 5 *Temperature development monitored during the investigations*



Graph 5 *Development of concrete strains at three levels of midspan cross-section*

the preceding paragraph 1 the sustained modulus values may be obtained from the known stresses (from prestressing) and the observed deformations at any time.

Taking into consideration the concrete stress equal to 2,96 MPa and concrete strains (after 28 days) equal to 28,7 × 10^{-5} (Fig. 3) at the top surface, it has calculated sustained modulus equal to 10,3 GPa. Similarly, from concrete stress equal to 6,61 MPa and concrete strains equal to 31,0 × 10^{-5} at the bottom surface, it has received sustained modulus equal to 21,3 GPa. Obtained values of sustained modulus are lower than ones suggested by ACI Committee 325 for determination the cross-section distribution of long time stresses due to prestressing and warping in the design of prestressed pavements. It should be emphasis that in laboratory testing there are no environmental conditions.

Tab. 3 *Instantaneous and time-dependent concrete strains* $\varepsilon_c \times 10^5$

Sample number - depth	Loading I stage		Time-dependent I stage		Loading II stage		Time-dependent II stage		Unloading	
	start	end	start	end	start	end	start	end	start	end
Slab 2 -bottom	-2,4	7,6		12,7		18		31,9		21,3
Slab 2 - middle	-2,8	7,1		11,8		16,9		32,7		23,8
Slab 2 - top	-1,5	7,1		11,4		15,7		37,1		27,3
Slab 3 - bottom	-2,7			-3,6				-0,2		
Slab 3 - middle	-2,5			-3,1				3,9		
Slab 3 - top	-1,6			-1,2				9,2		

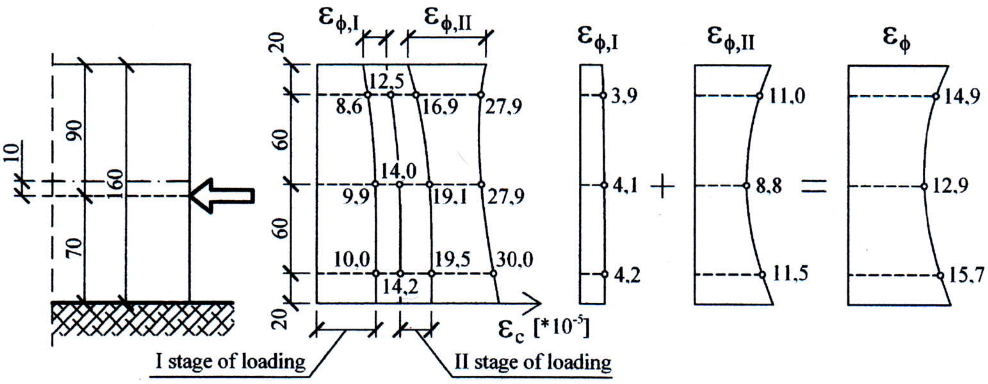
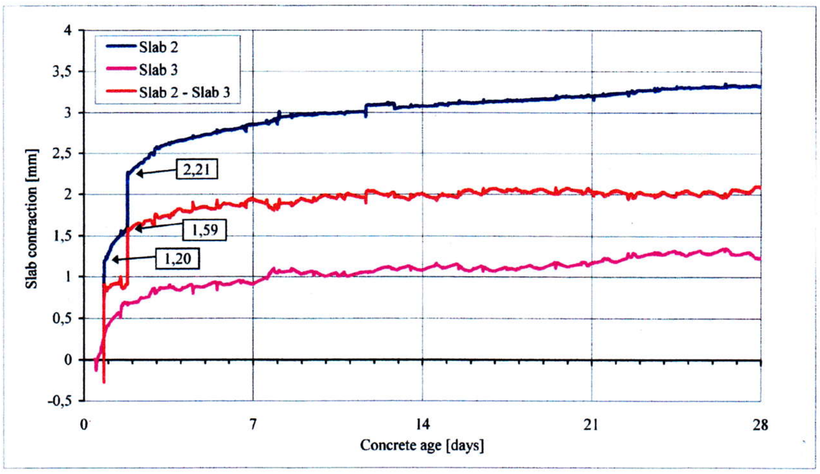


Fig.3 *Instantaneous and creep strains due to prestressing of Slab 2*



Graph 7 *Contraction of slab 2 and slab 3*

These investigations have shown that it is possible to post-tension the concrete pavements after 20 hours from casting. In spite of so early tensioning in case of concrete with high secant modulus of elasticity, it is possible to sustain small instantaneous concrete deformations. In this case for slab 2 it was 1,2 mm in the first stage and 0,62 mm in the second stage of prestressing (Graph 7).

The values of prestressing losses for the full forces were 3,5 % and 3,4 % for slab 1 and slab 2 respectively (Table 2). It can be concluded that the value of prestressing losses is independenced of the level of concrete compressive stress (for these assumed in this investigation). Based on this results, author of this work is convinced of the stability of value of prestressing force in time if the similar prestressing program and concrete stresses level will be used in practice.

Further investigations in situ are needs to evaluate the influence of curling, moisture and thermal effects as well as the influence of two-directional post-tensioning on time-dependent strains and prestressing losses.

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