Experiences resulted from construction of two-way posttensioned concrete pavement

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Abstract

In this paper there are presented results of experimental investigation and preliminary conclusions dealing with the efficiency of early posttensioning concrete pavement. Short section of concrete pavement 3.5 by 20.0 m (11.5 by 65.6 ft) thickness 0.23 m (9 in.) was posttensioned in longitudinal and transverse direction. The total prestressing was realized in one stage after 48 hours from concreting. The unbonded tendons 7ϕ5 mm (0.6 in.) were tensioned with 200 kN (45 kip) force in both direction. The aim of investigation was the experimental evaluation of temperature and concrete strains distributions during the process of pavement concrete hardening for different environmental condition for period of 13 months. Values of prestressing force distribution were monitoring for 26 days period. For this reason, unbonded tendons were equipped with vibrating wire force transducer Geokon type. The concrete strains as well as temperature changes were recorded with Geokon vibrating wire sensors localized at three levels of the slab thickness in four vertical cross-section.

Introduction

Concrete pavement are widely used in highway, airport as well as in industrial construction works because of their high resistance against abrasive stresses and high loadings. Besides live loads, concrete pavements are normally exposed to severe weather conditions. As a consequence of great changes of the ambient temperature as wall as the relative humidity, the concrete pavement is subjected to significant temperature and moisture gradients. Moreover, the moisture gradients are increased by bedewing the slabs underneath. These gradients cause large deformations. In spite of many the experimental investigations have been done, the resulting stresses and strains as well as the combination of thermal and hygral loads with the live loads are not sufficiently considered in the design process of concrete slabs.

In general, the factors that have the greatest influence on the design of prestressed concrete pavement are the same factors that affect the design conventional pavements. These factors include the effect of traffic loads, environmental conditions, concrete temperature and temperature gradient, and friction resistance caused by the slab supporting layer. In addition to these factors, the design of PCP has to account for the effect of prestress and slab movement. All these factors must be considered in the design of PCP to ensure that the final product will meet the expectations of a high-performance

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concrete pavement. Research is needed to better understand how cracks influence the long-term performance of concrete pavements and structures.

Previous experimental investigations in the Institute of Building Materials and Structures

Three large-size concrete slabs measuring 3.6×1.0×0.16 m (11.81×3.28×0.53 ft) were tested in the Laboratory at steady-state temperature and moisture conditions. The results obtained from these investigations including the 56 days term variation of concrete strains on the top surface, the development of concrete strains at the three levels of the middle span cross-section, contraction of the slabs in longitudinal direction and the changes of prestressing force in the tendons, have been presented (Seruga, et al. 2006) at the 10th International Symposium on Concrete Roads in Belgium. The special air-entrained concrete mixture designed for prestressed concrete structures has been used. Portland cement CEM I type 42.5 (28 days cement paste compressive strength in MPa) in quantity 440 kg for 1 cu.m (742 lb/yd^3) concrete mix was used, and water to cement ratio was equal to 0.37 (fly ash content 0 %). Basalt aggregate has been used because of necessity of improving the concrete modulus of elasticity. The aim of investigation was to evaluate the strain and stress state in concrete slab of cross section 0.16×1.0 m (0.53×3.28 ft) under different stage of prestressing. Three concrete slabs were constructed. Anchorage steel plates has been stabilized on the front surfaces of tested elements instead of normal reinforcement in anchorage zone. To minimize the friction forces two layers of polyethylene between slab and base have been used. Two of three slabs have been prestressed by unbonded steel tendons 7ϕ5 mm (0.6 in.) in longitudinal direction. Slab 1 was prestressed by two tendons applied at the ends of slab in the distance 0.5 m (1.64 ft). In case of slab 2 four post-tensioning tendons were applied in the distance 0.25 m (0.82 ft). Slab 3 was nonprestressed, for monitoring shrinkage, thermal strains and friction resistance what has allowed to separate the creep strains from the results obtained in slab 2. The prestressing was realized in two stages. I stage – about 50 % of total prestressing force was applied 20 hours after casting, II stage – the prestressing force was improved to final value 40 hours after casting.

Present experimental investigation

Using the portland cement concrete mix, a 3.5 by 20.0 meter (11.5 by 65.6 ft) thickness 0.23 m (9 in.) test slab was constructed at 21 of July 2010. Twenty four days of curing was executed by watering the burlap covered slab to keep the slab wet.

Exactly 48 hours after construction the concrete slab was posttensioned in both directions. The unbonded steel strands 7ϕ5 mm (0.6 in.) type (f_{pk} = 1860 MPa, 270 ksi) have been used. Each tendons was tensioned with 200 kN (45 kip) force. General view of tested slab and tendons layout are presented in Figure 1. This slab is the portion of the test pavement. The second part was constructed as jointed plain concrete pavement and general view as well as the longitudinal cross section are presented in Figure 2. Both elements are used as the bus stop at two lane way in Kraków. Because of the ground configuration, the pavement is deflected at B-B cross section (Fig. 1). The slope of posttensioned concrete slab is equal to 2.5% and the slope of jointed plain concrete pavement is equal to 6% (Fig. 2).

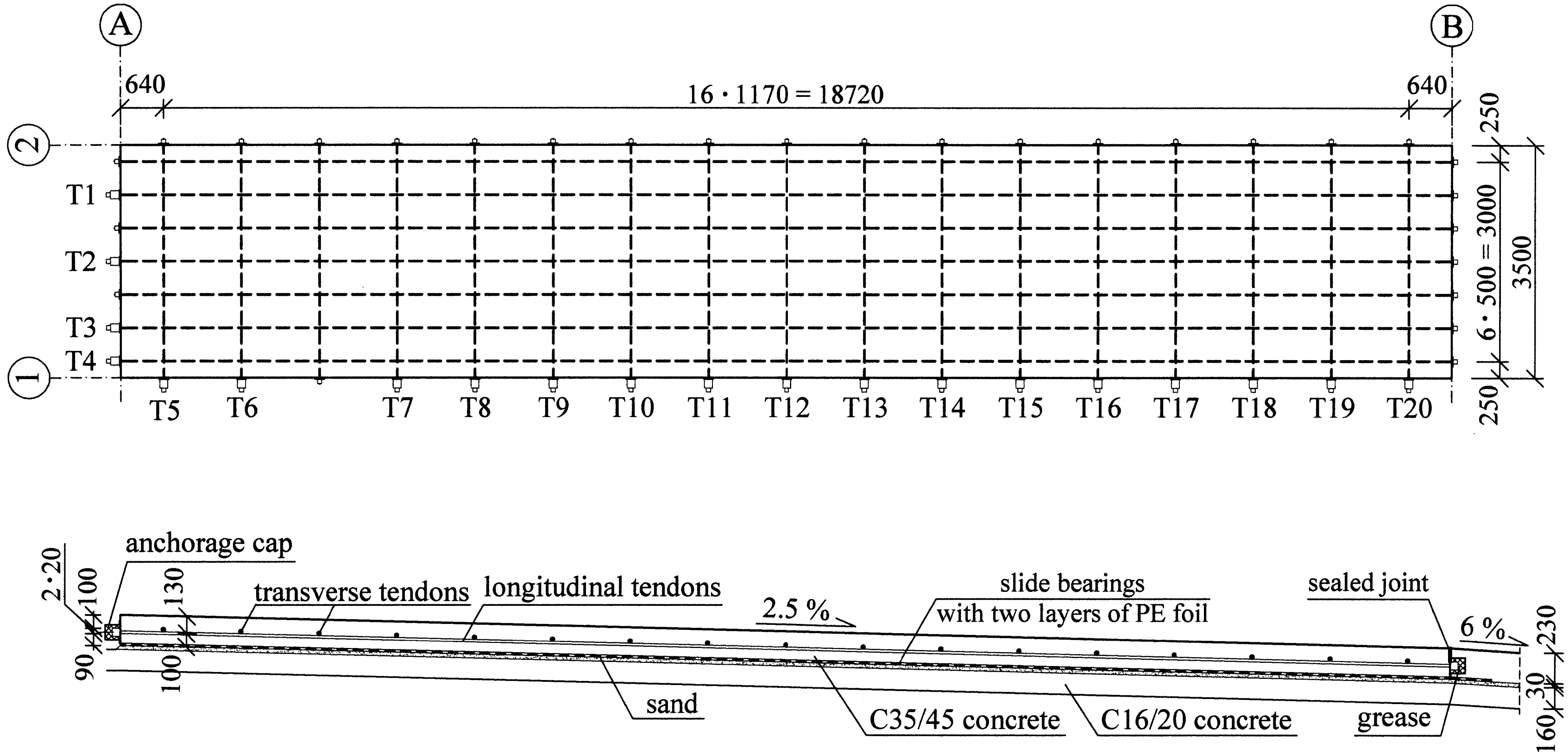

Figure 1. Tendons layout in posttensioned concrete pavement.

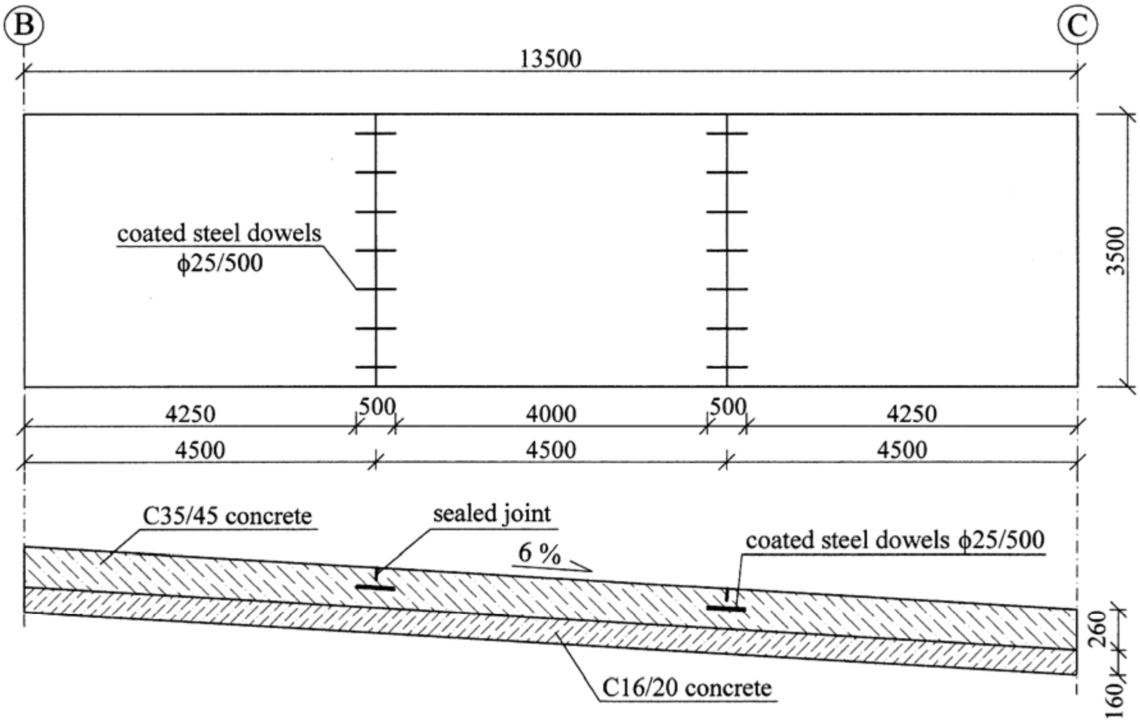

Figure 2. Horizontal and vertical cross section of jointed plain concrete pavement.

No special junction of this two part was constructed. The joint was sealed with flexible putty. Coated steel dowels 25 mm (1 in.) diameter were used to other joints.
One month after posttensioned slab was executed static load tests up 28840 kg (63500 lbs) were conducted to measure the displacements and strains of the slab as well as the force in posttensioned tendons.

After the load tests were finished on August 18, 2010, the vibrating wire force transducers were removed individually. Each tendon, after detensioned, was again tensioned with force 200 kN (45 kip) and new anchorage was used. Then construction of jointed concrete pavement was continued.

Using the same concrete mix C35/45 (according to EC2 code: cylindrical/cubic 28 days characteristic compressive strength), 3.5 by 13.5 meter (11.5 by 44.3 ft) slab was constructed at the beginning of October, 2010. After 12 hours the concrete surface was cut at the distance of 4.5 m (14.7 ft) as it is presented in Figure 2. Several days later, all joints were filled with flexible putty.
The aim of investigation was to evaluate:

- the strain and stress state in concrete slab in both direction under different stage of prestressing,
- the distribution of horizontal displacement of concrete slab during the process of posttensioning and in 28 days period after construction,
- the temperature distribution at the slab thickness in time.

A 0.23 m (9 in.) thick, 3.5 by 20.0 m (11.5 by 65.6 ft) slab was built on the base 0.16 m (6.3 in.) constructed with C16/20 concrete. Under the 0.23 m slab slide bearings with two layers of PE foil was located on 30 mm (1.2 in.) friction reducing sand layer (Figure 1).

The special air-entrained concrete mix (air content was 4%) designed for concrete pavement has been used. Portland cement 42.5 in quantity 380 kg for 1 cu.m (641 lb/yd^3) concrete mix with water to cement ratio equal to 0.41 was used (fly ash content 0 %). Granite aggregate in two fractions 2÷8 and 8÷16 mm was chosen.

Because of short straight prestressing transverse tendons the specially solved system of tendons anchorage was applied to minimize the slip in anchorage wedge.
Average concrete compressive strength tested on cylindrical specimens (150×300 mm) after 2 and 28 days was accordingly equal to 19.8 MPa (2,870 psi) and 40.8 MPa (5920 psi). Modulus of elasticity at compression was accordingly equal to 18000 MPa (2613 ksi) and 27000 MPa (3919 ksi). Average concrete flexural strength tested on beams (150×150×600 mm) after 2 and 28 days was accordingly equal to 3.05 MPa (440 psi) and 4.48 MPa (650 psi).

Instrumentation of tested concrete slab

Plan and elevation views of the tested slab as well as layout of prestressing tendons are presented in Figure 1. For simplified the slab construction process steel anchor bearing plates were stabilized at the external surface of concrete slab instead of steel reinforcement in anchorage zone (Figure 3). Twenty vibrating wire force transducers were stabilized between steel anchor bearing plate and anchorage. Four (numbered from T1 to T4) at longitudinal tendons and 16 (numbered from T5 to T20) at transverse tendons. The longitudinal tendons were installed on the steel chairs 90 mm (3.5 in.) from sliding layers and transverse tendons were stabilized on the longitudinal tendons at the level 100 mm (3.9 in.). It means that prestressing force in longitudinal direction is applied at the level 100 mm and in lateral direction at the level 120 mm (4.7 in.). Longitudinal tendons were tensioned in first stage. Total process of posttensioning took 4 hours.

Set of temperature sensors were placed at three depths within the slab thickness in the left part of the tested slab. Geokon sensors in points 1÷4 (Figure 4) were stabilized at the distance 20 mm (0.8 in.) from the top and the bottom surface. Thermocouple sensors in points 5÷8 (Figure 5) were stabilized at the distance 10 mm (0.4 in.) from both surfaces. The third sensor was stabilized accurate in the middle of slab thickness. The ambient temperature sensors were stabilized above the concrete slab.

The concrete strains were measured with the Geokon vibrating wire sensors localized in points 1÷4 at longitudinal direction. All sensors under the variation of the

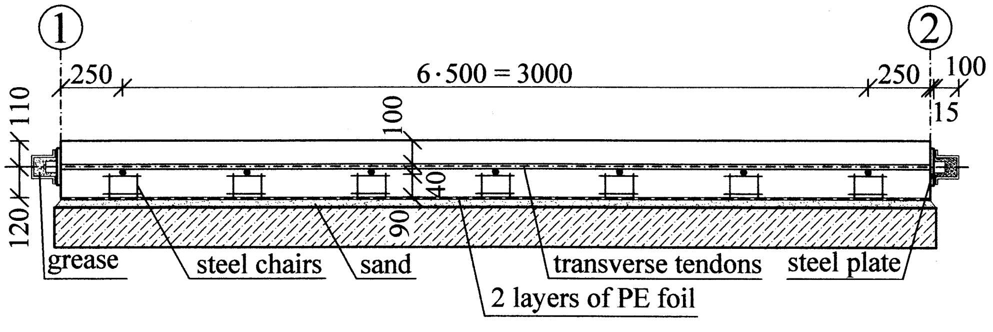

Figure 3. Transverse cross section of posttensioned concrete pavement.

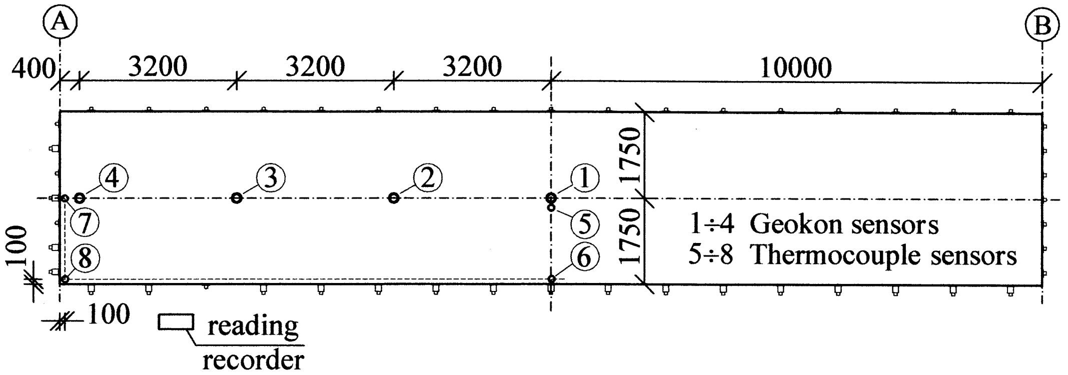

Figure 4. Heat sensors localization.

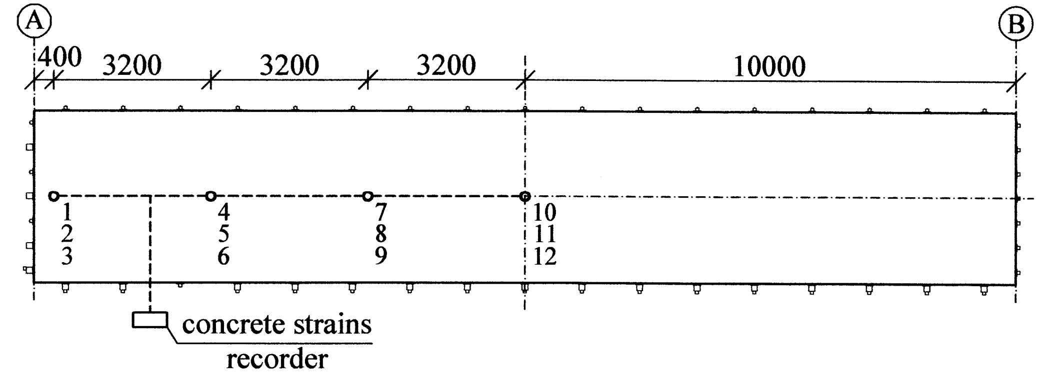

Figure 5. Concrete strain transducers arrangement at the height of prestressed concrete slab.

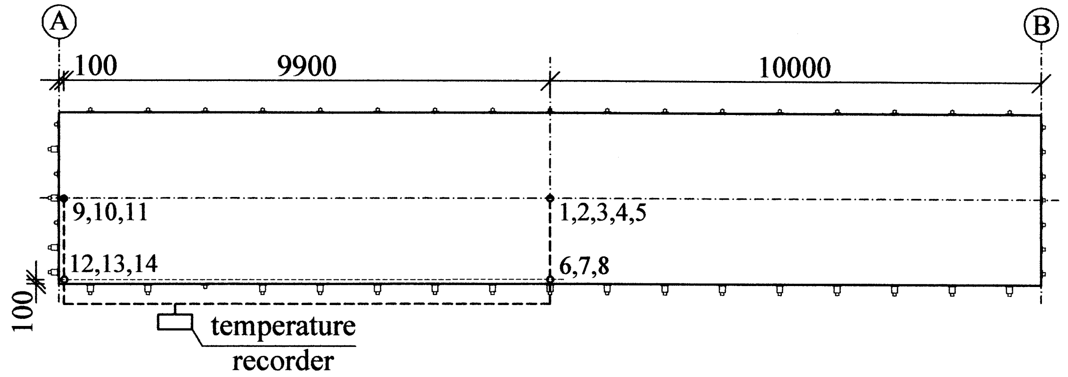

Figure 6. Heat sensors arrangement at the height of prestressed concrete slab.

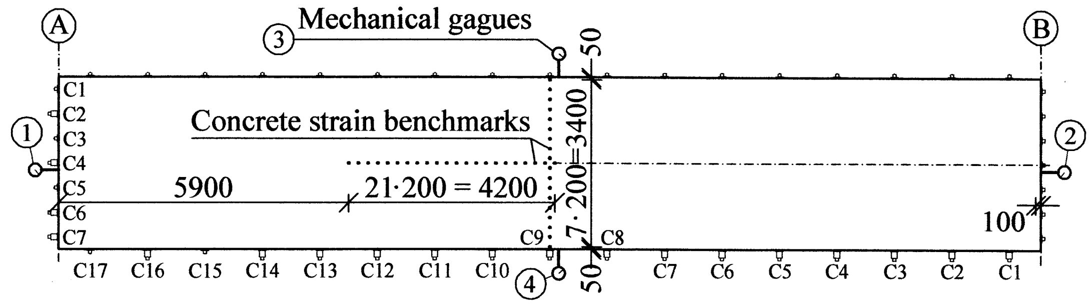

Figure 7. Slab contraction gauges and strain benchmarks arrangement.

real outdoor environment were continuously monitored in the special box situated outside the concrete slab. Moreover the top concrete strains in the longitudinal and transverse directions have been recorded. The measuring points (strain benchmarks) were stabilized in the distance equal to 200 mm (8 in.) along the center lines in both directions, on the top surface of tested slab (Figure 7). The concrete strains were recorded with mechanical strain gauge DEMEC type. First readings were taken before start to posttensing the slab. Additionally four horizontal displacement mechanical gauges were installed at the center line in both directions, in the middle of slab thickness (Figure 7). After 28 days monitoring all of them were removed.

Some obtained results and conclusions

The force distributions in longitudinal tendons are presented in Figure 8. However all of them were tensioned with force equal to 200 kN (45 kip) the initial values for tendons T1, T2, T3 and T4 recorded with sensors are accordingly 197.0; 188.0; 194.4 and 194.2 kN. Taking into consideration the losses of prestressing force due to the concrete elastic shortening and the tendon slip in anchorage registered during the process of tensioning the calculated values are as follow: 197.5; 188.7; 194.6 and 194.6 kN. The final values of tensioning force after 26 days monitoring are equal to: 184.7; 176.5; 182.6 and 179.1 kN. The average decrease of tensioning force due to concrete creep and shrinkage as well as prestressing steel relaxation are equal to 6.5%.

The similarly force distributions in transverse tendons are presented in Figure 9. The initial values of tensioning force for tendons from T5 to T20 are gathered in range from 187.1 to 170.7 kN. It should be noted a good agreement to analytical values obtained taking into calculation measured tendon slip in anchorage (from 1.5 to 3.5 mm) and concrete elastic shortening. The average decrease of tensioning force due to rheology effects are equal to 5.75%.

The time histories of the temperature recorded in the measuring point No 3 (Fig. 4), are presented in Figures 10 and 11. It can be seen the clear peak temperatures in the second day from casting the concrete slab. Exactly 24 hours from the time of concrete slab construction it is at 1 p.m it was recorded the highest concrete temperature: T_t = 50.2°C, T_m = 49.4°C and T_b = 49.1°C. Afterwards the concrete temperature in the slab started to decrease simultaneously with the decrease of ambient temperature. The minus temperatures in concrete slab were registered from November 2010 to March 2011 (Figure 11). The lowest of ambient temperature minus 16.2°C was attained at 6 in the morning in 18 of December 2010 but the concrete temperatures measured at the top sensors in measuring point No 3 were equal to T_t = -8.0°C, T_m = -4.6°C and T_b = 4.0°C.

The highest minus concrete temperatures were measured the 6th January 2011 at 9 in the morning: T_t = -10.1°C, T_m = -7.9°C and T_b = -7.6°C. The ambient temperature was equal to -13.0°C. The concrete temperatures measured at the bottom and in the middle point are similar. The distribution of temperature differences T_t -T_m, T_t -T_b and T_m -T_b are presented also in Figure 11. The maximal value T_t -T_b recorded in 13 months period of monitoring are equal to 8.9°C (7 of July 2011). It means that real difference between top and bottom surfaces of tested slab could attain even 10°C. It is very important information for analytical calculation.

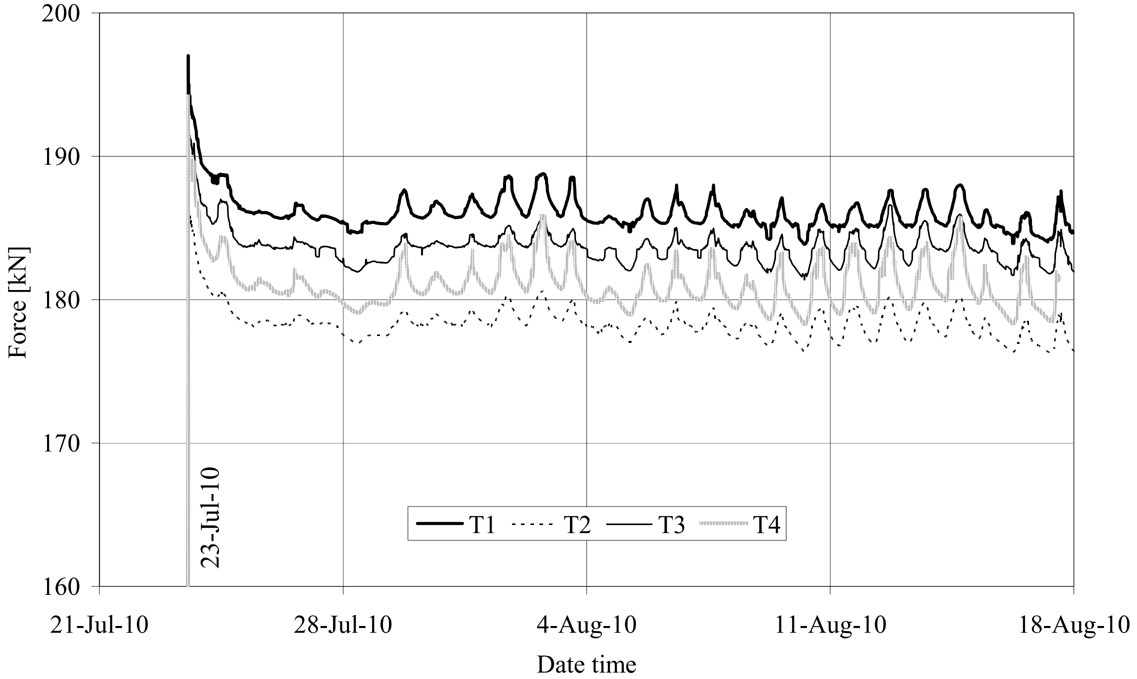

Figure 8. Posttensioning force distributions in longitudinal tendons (1 kip = 4,45 kN).

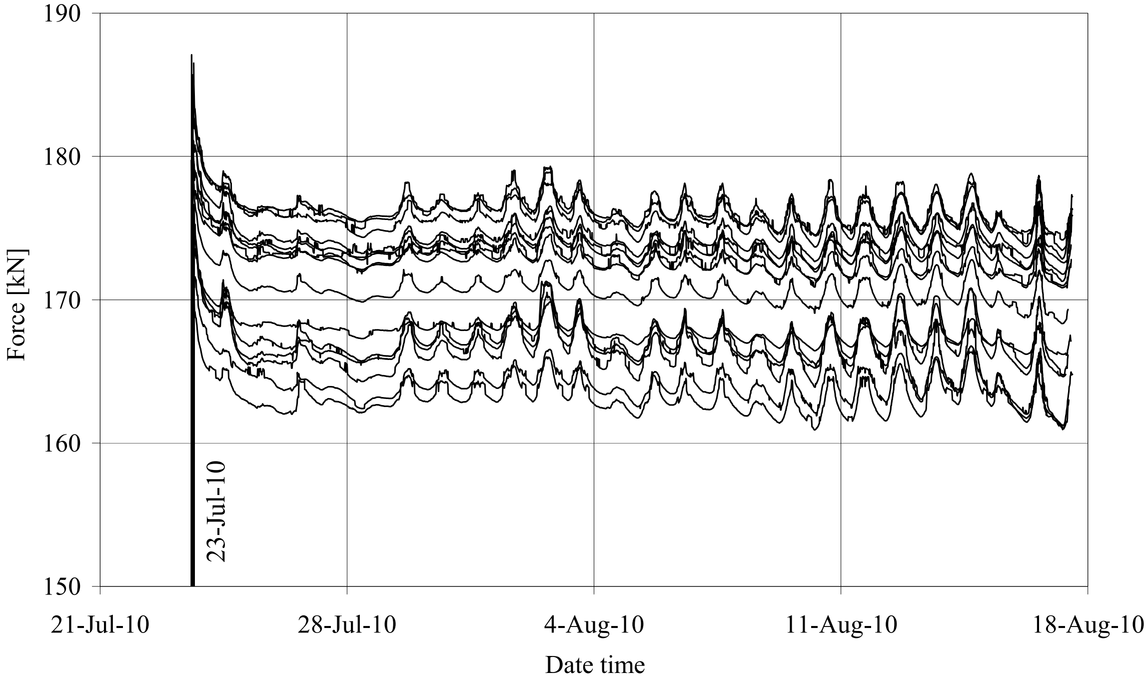

Figure 9. Posttensioning force distributions in transverse tendons (1 kip= 4,45 kN).

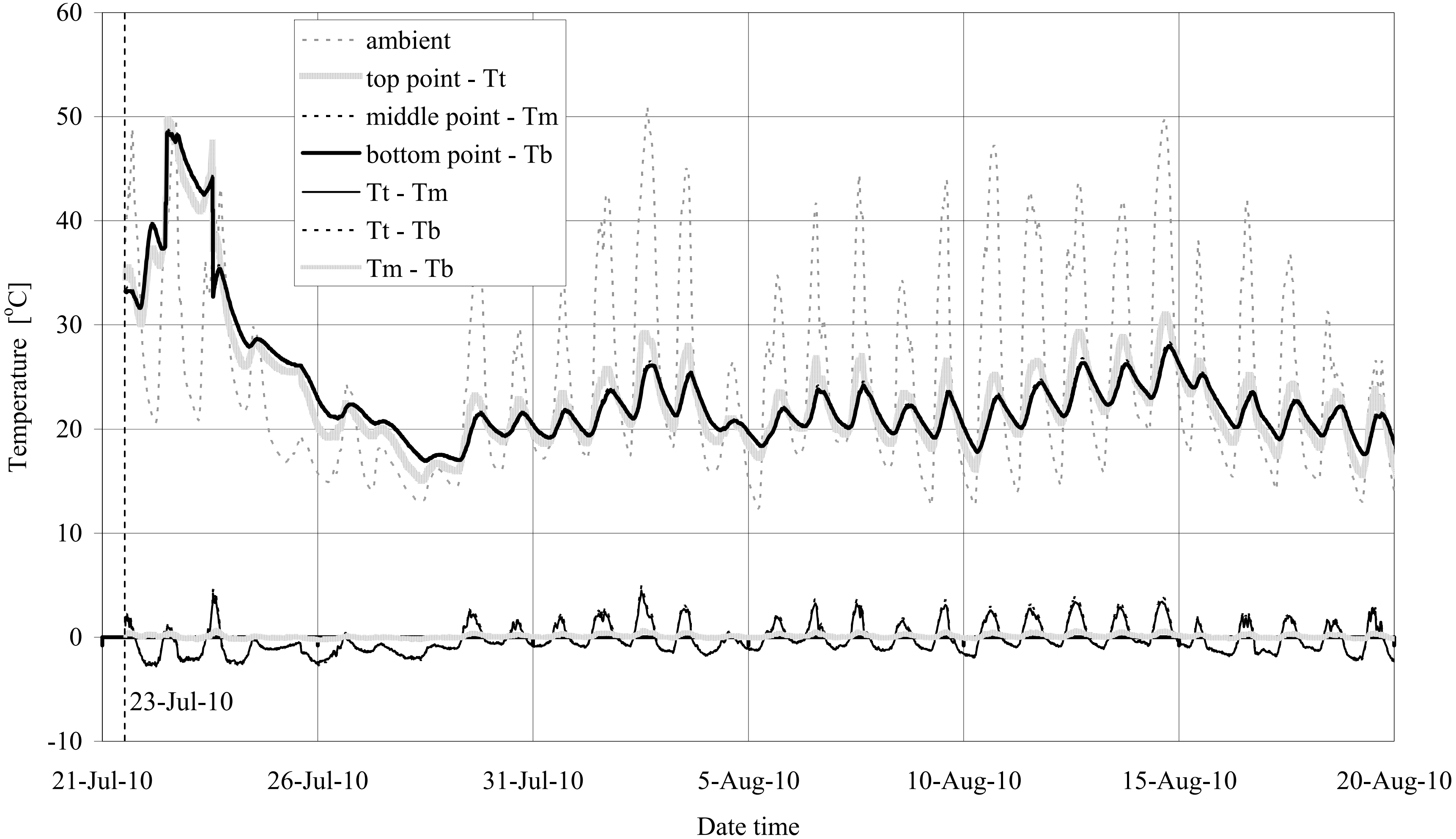

Figure 10. Temperature and temperature differences distributions at the height of slab.

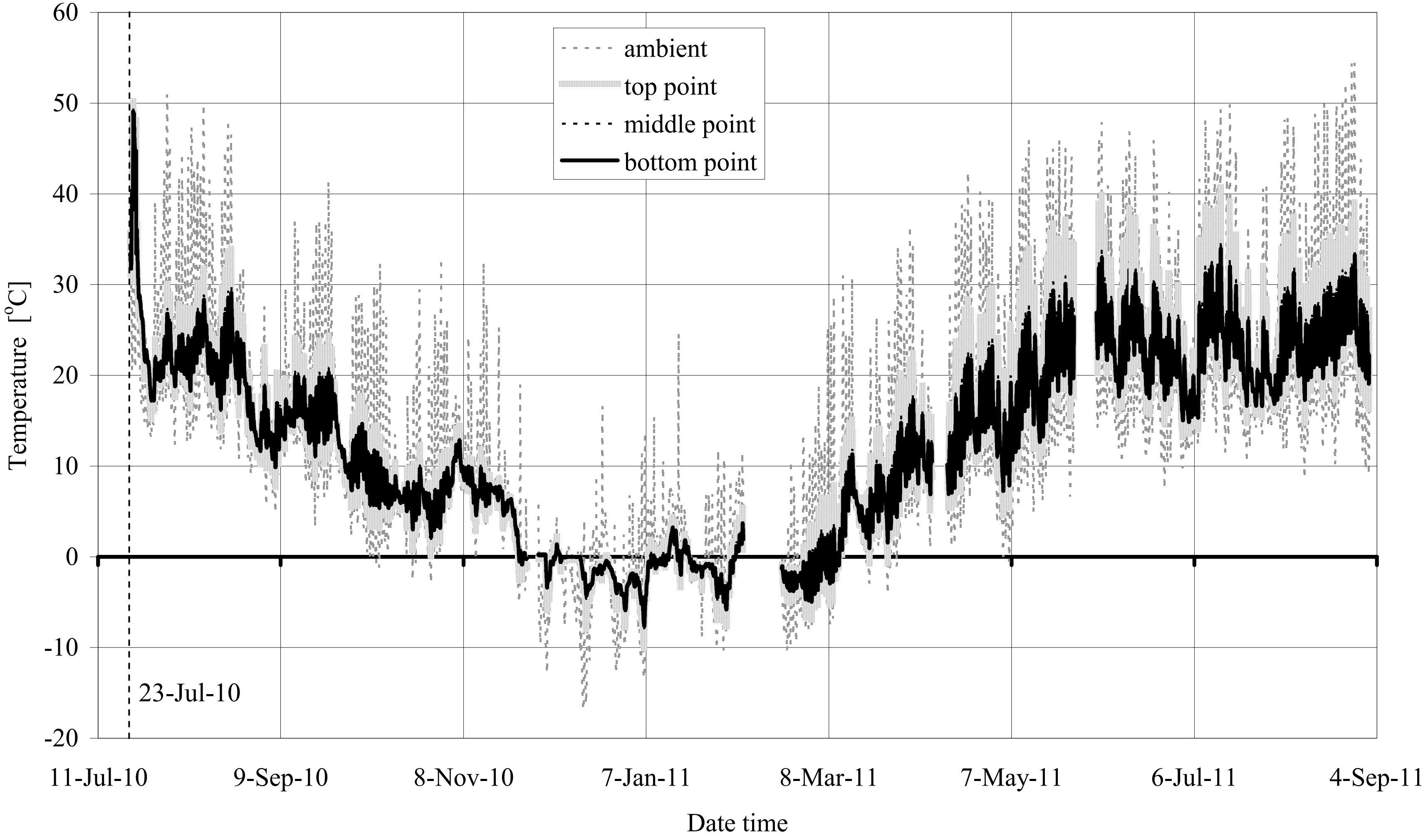

Figure 11. Ambient and concrete temperature distributions at the height of slabs.

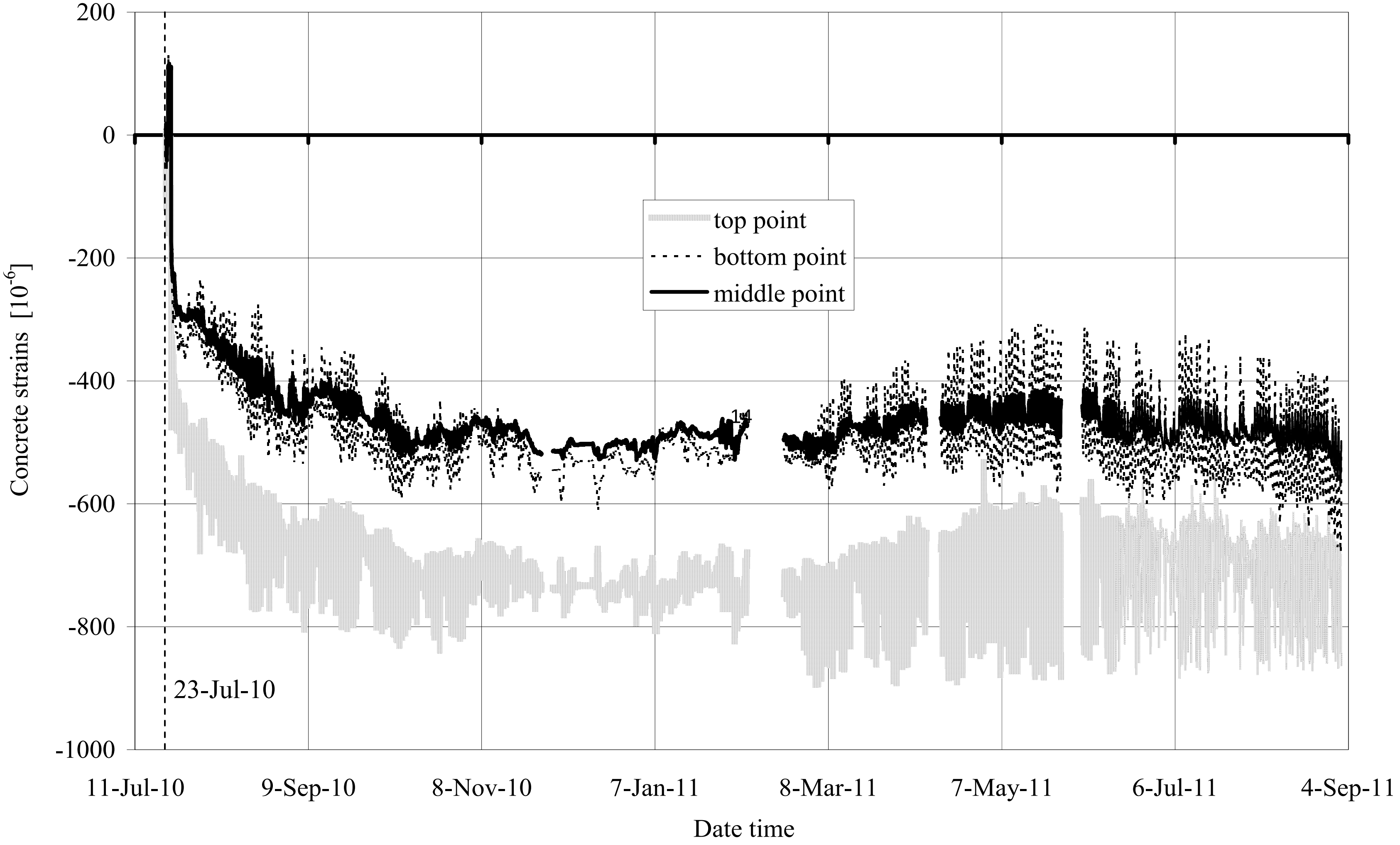

Figure 12. Concrete strains distributions at the height of slab in total period of investigations.

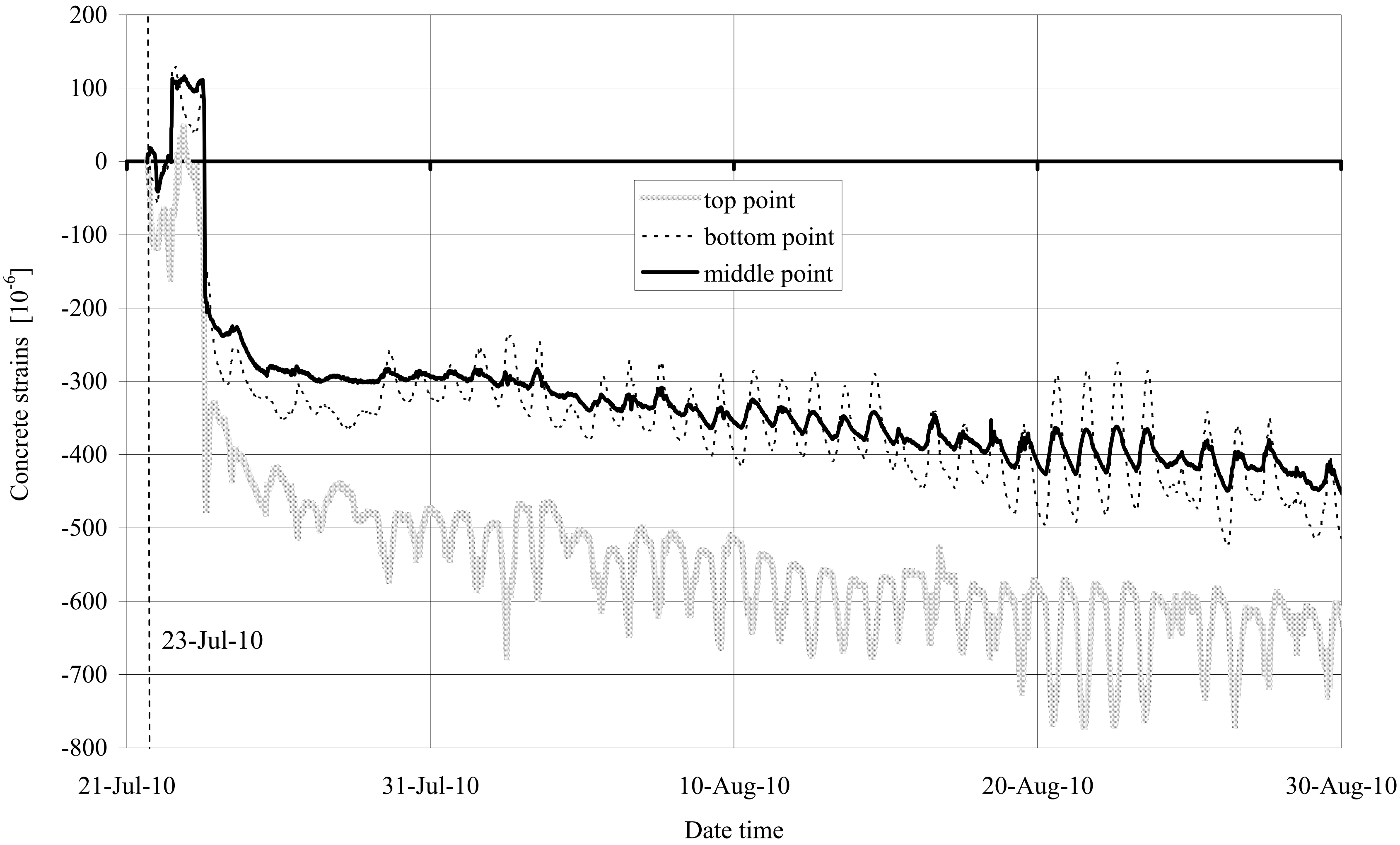

Figure 13. Concrete strains distributions at the height of slab in first month of investigations.

The concrete strains distribution at the height of slab recorded in measuring points No 3 in total period of investigations are presented in Figure 12. The most interesting is the early age concrete strains development to the time of concrete slab posttensioning (Figure 13). It can be observed the evolution of compressive concrete strains in the total section. Twelve hours (at the midnight) since the time of concreting, the concrete strains registered at the top, middle and bottom were accordingly equal to $-118.7\cdot10^{-6}$, $-41.0\cdot10^{-6}$ and $-58.8\cdot10^{-6}$ (minus signs the compressive strains). Twenty four hours from concreting, the concrete strains measured in analogous points were as follow: $-63.4\cdot10^{-6}$, $106.9\cdot10^{-6}$ and $129.1\cdot10^{-6}$ but after forty eight hours $-100.0\cdot10^{-6}$, $111.4\cdot10^{-6}$ and $100.8\cdot10^{-6}$ (just before posttensioning). When the process of prestressing was realized it is fifty two hours from concreting the concrete strains in measuring points were recorded at the following level: $-414.5\cdot10^{-6}$, $-203.4\cdot10^{-6}$ and $158.5\cdot10^{-6}$.

Compressive stresses in the bottom of the pavement tend to counteract tensile stresses due to friction between the slab and its base. The horizontal movement due to daily and seasonal temperature change create a frictional resistance between the bottom of the slab and the top surface of the base. Taking into consideration the results presented in Fig. 12 and 13 it can be concluded that in the measuring point No 3, the average difference concrete strains $\varepsilon_t - \varepsilon_b$ exceeds a value $200\cdot10^{-6}$. However it should be noted that total cross section of tested slab is under compression for 13 months.

The data received in the monitoring project show that maximum concrete slab temperature reached very high level also in polish condition, plus 40°C and minus 10°C. The real value over all cross sections are plus 40°C and minus 10°C even in concrete slab medium thickness. The test data also shows a significant values of measured concrete strains which should be analyzed in more detail include concrete creep and shrinkage investigated in Institute Materials and Building Structures.

Final remarks

Based on the analysis of obtained results the following conclusions have been drown:

- value of posttensioning force in each tendon and the tendons layout used in tested concrete pavement section are sufficient to counterbalance the tensile stresses coming due to concrete shrinkage and temperature effects,
- the tensile concrete strains have been recorded on the top surface of concrete pavement only for one day, before the posttensioning process,
- the average compressive concrete strains registered in the middle measuring point are similar to the average compressive concrete strains registered in the bottom point. However the scatter of the obtained results at the bottom of concrete slab is much higher.

Acknowledgements

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References

Szydłowski, R. (2006).
"Research of prestressed concrete plates for roads and airport pavements" (in Polish) *Zeszyty Naukowe Politechniki Śląskiej, Budownictwo*, 109, 395-402.

Seruga, A., Smaga, A., Szydłowski, R. (2006). "Prestressed concrete pavements" *Proc., 10th International Symposium on Concrete Roads*, Brussels.

Szydłowski, R. (2008). "Experimental research of early-age prestressed concrete for road and airport pavements" *Proc., 10th Professional Conference of Postgraduate Students*, Brno.

Seruga, A., Zych, M., Politalski, W. (2012). "Experimental investigation of young concrete properties needed to proper analysis of concrete pavements behavior during the hardening process" *Proc., 10th International Conference on Concrete Pavements*, Québec.