

Experimental Investigation of Young Concrete Properties Needed for Proper Analysis of Concrete Pavements Behavior During the Hardening Process

Andrzej Seruga, Mariusz Zych and Wojciech Politalski¹

Abstract

In this paper there are presented results of experimental investigation of young concrete properties. During design process of concrete structures there is used number of mechanical properties of concrete that are not normally part of the concrete specifications. Desirable values are often related to primary parameter of concrete – mean concrete compressive strength. Some of them are poorly or even not at all described at the very beginning of concrete maturing. This paper describes results obtained from common mechanical test of compressive and tensile strength, shrinkage strain and two author's test dealing with creep under constant compressive and tensile stresses of young concrete and also temperature development in quasi-adiabatic conditions.

Introduction

Directly after execution each RC construction not only the strength of concrete increases but also the amount of emitted heat of hydration (Guo 2006). In most cases the significantly heat emission is hardly noticeable. So, the influence of temperature on strains in the cross-section is very small.

However the problem occurs not only in case of massive structures or semi-massive structures (Guo 2006), which due to their volume and geometry have ability to store up greater amount of produced heat, but also in constructions which are subjected to high temperature changes i.e. influence of solar radiation or rapid cooling at night (Rilem Report 15 1998; Schutter 1999). Moreover the strains caused by this temperature are almost fully restrained. So, the pavement is this kind of the structure, which owing to big surfaces could in short time yield to rapid heating and cooling. Moreover there are partially restrained on the whole bottom surfaces. Therefore in this case we have to construct dilatation. Present work is merely fragment of work effort on analysis of constructions which are subjected to early age cracking during maturing of concrete (Zych 2011). Temperature development in this construction due to hydration and ambient temperature conditions can cause tensile stresses which may exceed the tensile strength of concrete. The basis aim of these works is to test and present young concrete properties, which will be later described using suitable models to an analysis of the development of thermal stresses and cracking at early age concrete. Furthermore this model allows ability to optimize the solutions in case of such constructions. The examples of models used by authors, based on real structures in which appeared early age cracking, were presented in following papers (Seruga and Zych 2008; Zych 2008).

¹ Andrzej Seruga, Professor PhD. Civ. Eng. aseruga@imikb.wil.pk.edu.pl,
Mariusz Zych, PhD. Civ. Eng. mmzych@interia.pl,
Wojciech Politalski, M.Sc. Civ. Eng., wpolitalski@pk.edu.pl,
Cracow University of Technology, Civil Engineering Faculty, Institute of Building
Materials and Structures, Warszawska 24, 31-155 Kraków, phone: +48 12 6282027

To find solution in each individual example it is required to create advanced model which will take into consideration the development of heat of hydration and describe the relationships between $\sigma(t)$ - $\varepsilon(t)$ in period of hardening concrete. So, presented in this work researches take into account: test of concrete compressive and tensile strength, test of shrinkage strain, test of concrete creep under constant tensile and compressive stresses during maturing of concrete, and test of temperature development during hardening process in quasi-adiabatic conditions. The tests of temperature development allows to assume correct function of temperature development, in which amount and speed of heat increasing will be dependent on current temperature and degree of hydration (Shimomura 2008). This function allows ability to describe the temperature development in construction with any geometry and volume. The creep test allows to find correct parameters for instance to viscoelastic model to analysis of temperature stresses.

Since 1995 year in Poland it was started the construction of concrete pavements. According to polish regulation all road structures must be constructed using concrete mix with portland cement CEM I only. In 2010 year during the construction one of these main roads in Kraków, it was performed experimental investigation on short section 3,5x20 m (11.5x65.6 ft). After construction the concrete slab was post-tensioned in both directions [Seruga, Szydłowski 2012]. During construction this main road the concrete samples were taken to test the concrete properties. The commonly used air-entrained concrete mixture for concrete pavement has been used portland cement CEM I type 42,5 (28 days cement paste compressive strength in MPa) in quantity 380 kg for 1 m³ (641 lb/yd³) concrete mix was used (fly ash content 0 %) and water to cement ration was equal to 0,41. Granit aggregate 2-8 and 8-16 mm has been used.

The aim of this paper is presentation of investigation results obtained from common mechanical test of compressive and tensile strength, shrinkage strain and two author's test dealing with creep under constant compressive and tensile stresses of young concrete and also temperature development in quasi-adiabatic conditions.

Research conducted during maturing of young concrete

Compressive and tensile strength test. To obtain information about concrete strength development there were conducted several tests. Compressive strength testing included: cylinder strength measured by loading cylindrical specimens (150 x 300 mm) and cube strength measured by loading 150 mm cubes. Tensile strength testing was done by means of flexural test conducted on beams (150 x 150 x 600 mm) and splitting test carried through 150 mm cubes. Gathered results were presented in figures 1 and 2.

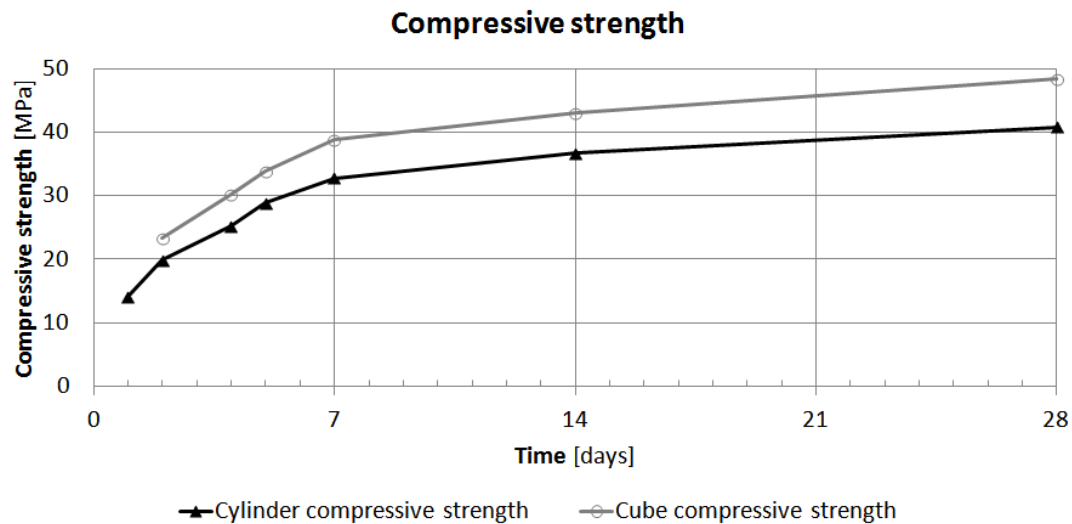


Figure 1. Compressive strength of concrete

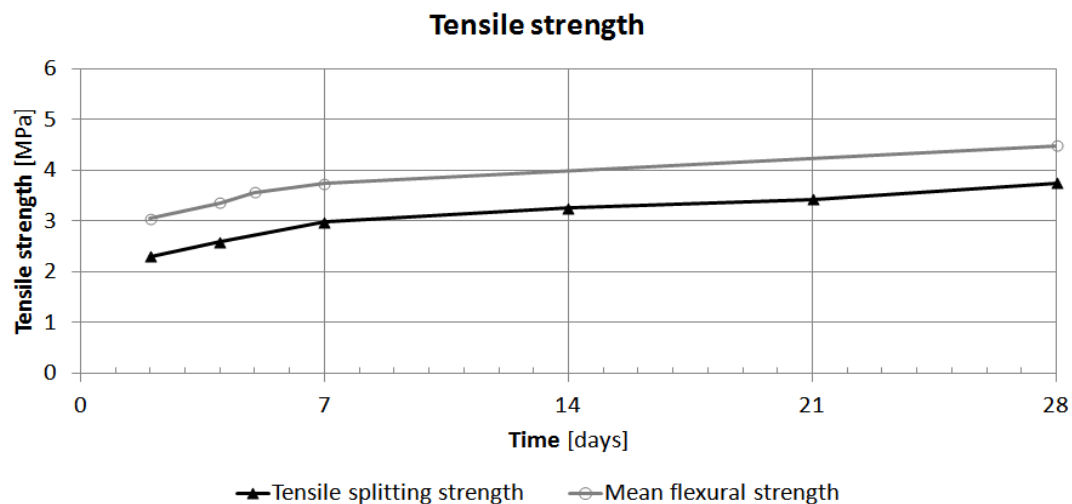


Figure 2. Tensile strength of concrete

Shrinkage test. This test were conducted on 6 specimens (100 x 100 x 500 mm). To obtain medium strain changes there were measured strains on each side of the specimen. Test results were shown in figure 3 and compared to EC2 standard recommendations for calculating autogenous and drying shrinkage making assumptions that relative humidity (RH) was equal to 45%, type of Portland cement 42,5 was Class R, notional size of element $h_0 = 50$ mm and the age of the concrete at the beginning of drying shrinkage $t_s = 12$ hours. It is worth to emphasize that research data is very close to theoretical calculations. Additionally, in the graph there are shown ambient temperature variations during first month of concrete hardening from 23rd of July to 21st of August.

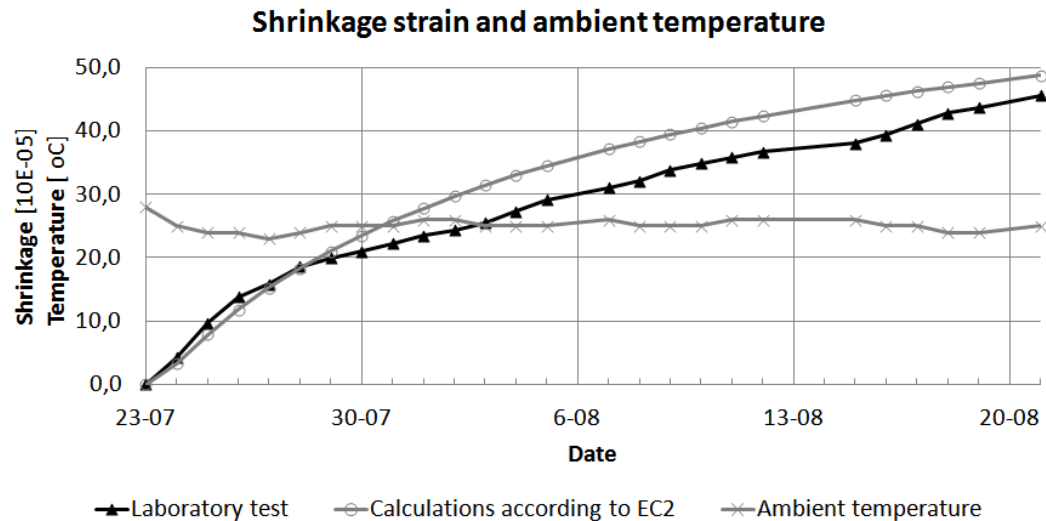


Figure 3. Shrinkage strain of concrete and ambient temperature

The test of temperature development in quasi-adiabatic conditions. The test of temperature development during hydration process was performed on cylindrical concrete elements. Tested element were covered from each side, from pouring of concrete (the concrete was poured in this form), by polystyrene – thickness 30 cm from sides and top and 35 cm from the bottom. These forms were made from hard polystyrene. The dimensions were $H=130\text{cm}$, $\Phi_o=120\text{cm}$, $\Phi_i=60\text{cm}$ (height, outside and inside diameter). These forms were gripped by tightened belts which usage allowed to keep tightness and constant shape during concreting (figure 4).



Figure 4. The polystyrene forms used during the tests of heat development in maturing concrete.

The concrete cylinders, in which the tests were executed, have dimensions $H=65\text{cm}$, $\Phi=60\text{cm}$. According to literature's information the conditions similar to adiabatic could be obtained inside uncovered cube which has dimensions $1\text{m}\times 1\text{m}\times 1\text{m}$. However assumed solution according to earlier numerical optimization of polystyrene in relation to the diameter of concrete cylinder seems to be much more accurate.

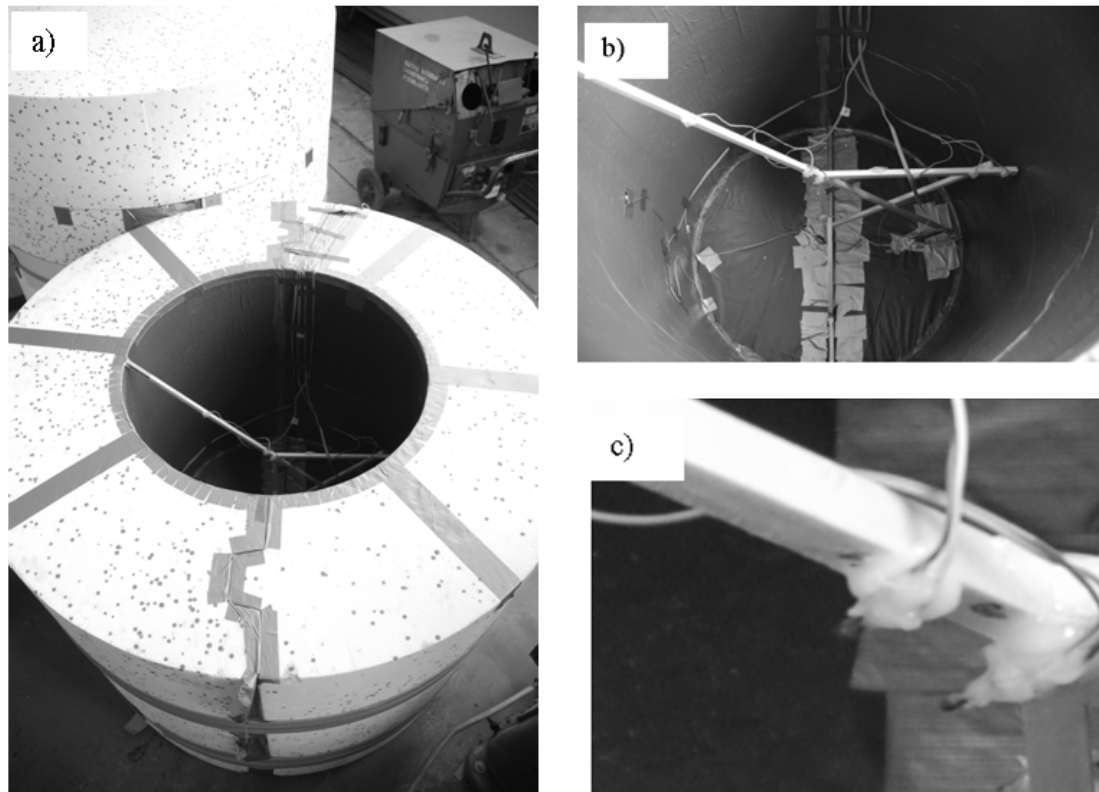


Figure 5. a) The polystyrene form used in the test of heat development during concrete maturing process b) wooden construction c) temperature gauges (Zych 2011).

To confirm among other things correctness assumed way of test, the temperature gauges were distributed not only inside the concrete samples, but also in some distance from surface of the sample and at the inside surface of the polystyrene forms. To avoid possible thermal bridges the gauges were stick to wooden constructions (figure 5b). To avoid the humidity absorption and disturbance in amount of water needed to hydration, all wooden surfaces were painted by varnish. Moreover, at all inside surfaces of the forms the foil was stuck to avoid humidity flow from inside into surrounding area. Right before closing the forms the connections under the covers were sealed using polyurethane foam.

The tests were performed for three concrete samples. The accurate scheme of temperature sensors distribution was presented in the figure 6. The measuring points were distributed also at the outside surfaces of polystyrene. This will allow to take into consideration (in later calculation), directly measuring values in boundary conditions. The measured points nr 1,2,3 were distributed at the outside surface i.e. top, bottom and side.

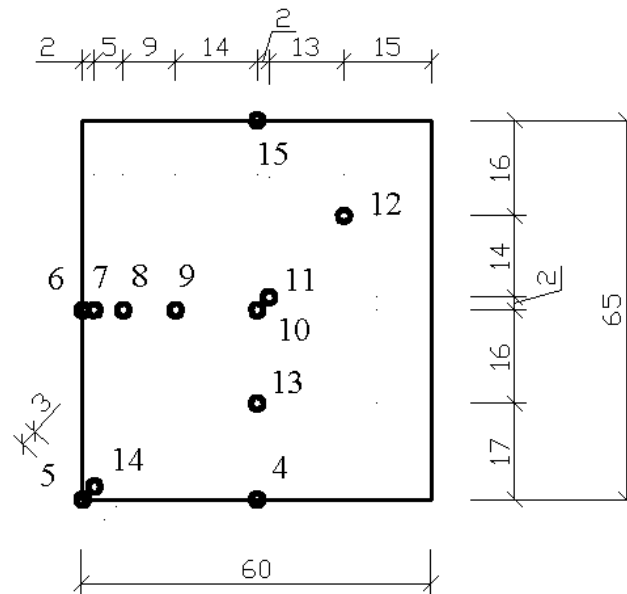


Figure 6. The distribution of temperature gauges during the test (Zych 2011).

In performed experiment including two samples, achieved results were compatible with initial assumptions. Directly after pouring and in later time there weren't any leakages through the forms. So, the forms were fully water tightness. It was also confirmed by results of temperature development (figures 7 and 8), at which for samples nr 1 and 2 (up to time 72 hours) have nearly identical temperature development (from sample nr 2 the cover was removed). At the each figure the development of temperature for all gauges which were inside the sample were presented. The temperature changes in each points are almost identical, independent whether it is inside the concrete or at the inside surface of the form. Therefore presented temperature development for such distributed temperature gauges confirmed early assumption about quasi-adiabatic conditions. Because the temperature development in samples nr 1 and 2 were almost identical the cover from sample nr 2 was removed three days after pouring. This sample was treated as a additional information about temperature distributions in case of another boundary conditions.

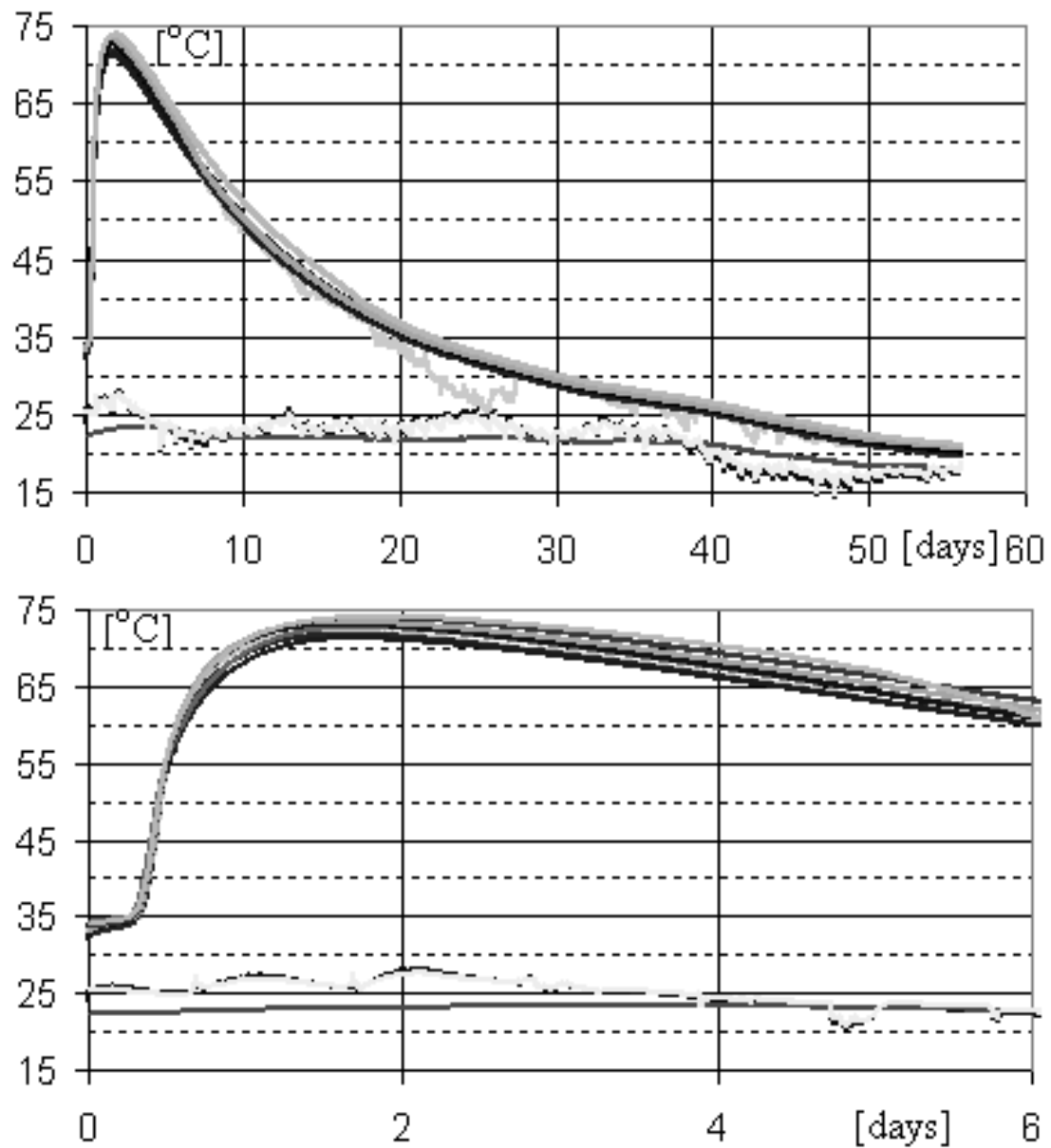


Figure 7. The temperature development during heating process in sample nr 1: a) in the whole cycle of measurement b) in first 6 days

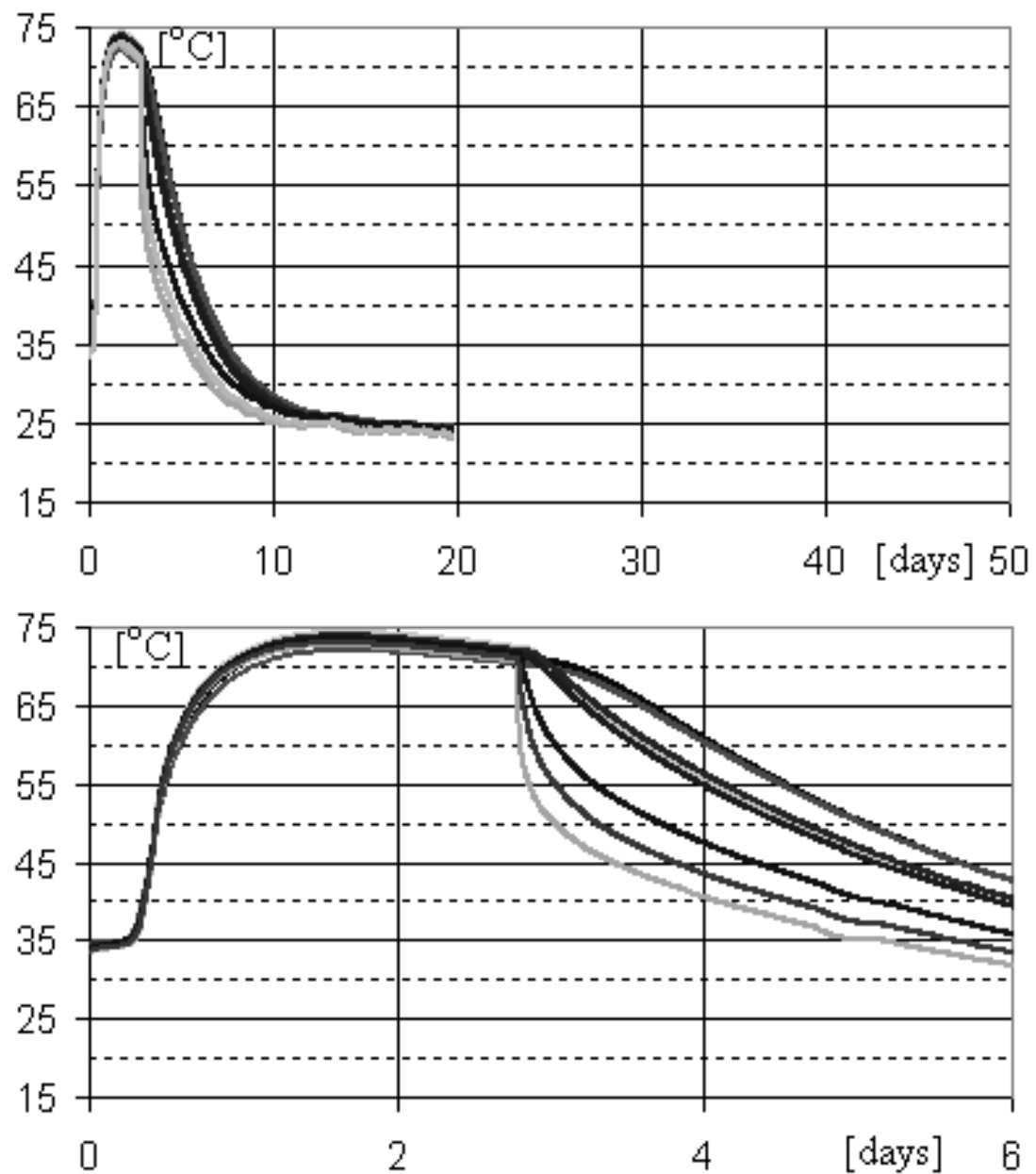


Figure 8. The temperature development during heating process in sample nr 2: a) in the whole cycle of measurement b) in first 6 days

The test of young concrete creep under constant tensile and compressive stresses.

The creep phenomenon is practically and universally described in design codes, but only for older concrete. In case of very young concrete this codes are helpless. Therefore to obtain necessary parameters of concrete which can be used to executed analyzed pavements the test of very young concrete under constant compressive and tensile stresses were performed. The very early time of specimen loading simulated early time of structure loading which was caused by the heating process. The compressive stresses appeared at the moment of temperature increase caused by heat of hydration, therefore it is in first day after pouring. The tensile stresses appeared when the temperature decreases significantly. And this is few days after pouring. The tests were performed on concrete samples of the length 120cm and diameter 15cm. The strain gauges were located inside the samples in the middle of the length. In this way we have one direction state of stresses (lack of boundary stresses influence).

The measurements were performed using vibrating wire gauges (Geokon system) which were concreted inside the elements (length 153mm). The edges of each gauge were completed in horizontal distances which assured that the gauge was always in vertical axis of the sample (figure 9a). Electronic registration of strains (figure 9b) was performed in basic step 15 min, however during loading the registration frequency was increased to 1 min. To achieve temperature changes in concrete similar to the temperature inside the construction during the test, the 15 cm polystyrene form was designed. Moreover, such warming assure relatively slowly temperature changes inside the element, uniform temperature in the cross-section of the sample and in significant degree smooth out changes caused by ambient temperature. To exclude moisture flow from tested samples, the foil was stick to the inside surface of the forms. Before the pouring the foil was smeared by grease.

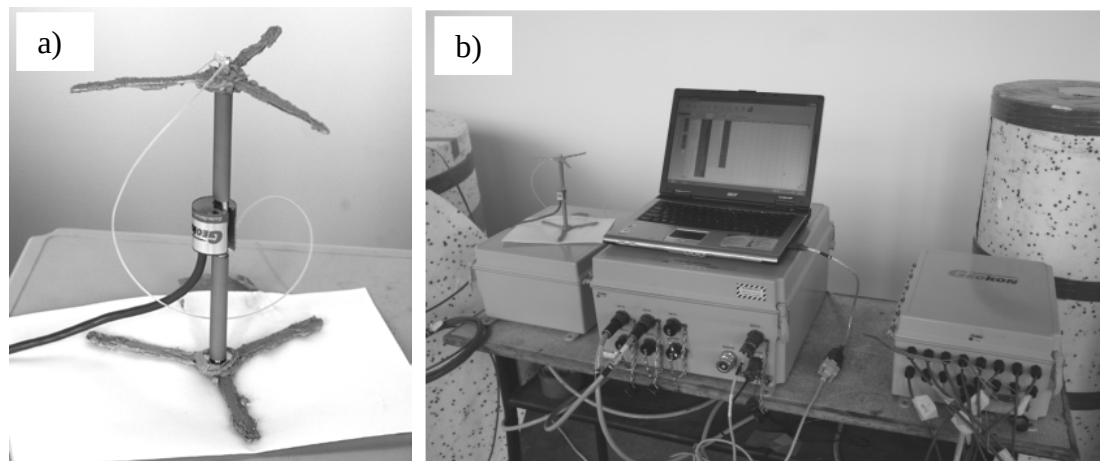


Figure 9. a) Strain vibrating wire gauges measuring strains inside the concrete, b) measurement station (Zych 2011).

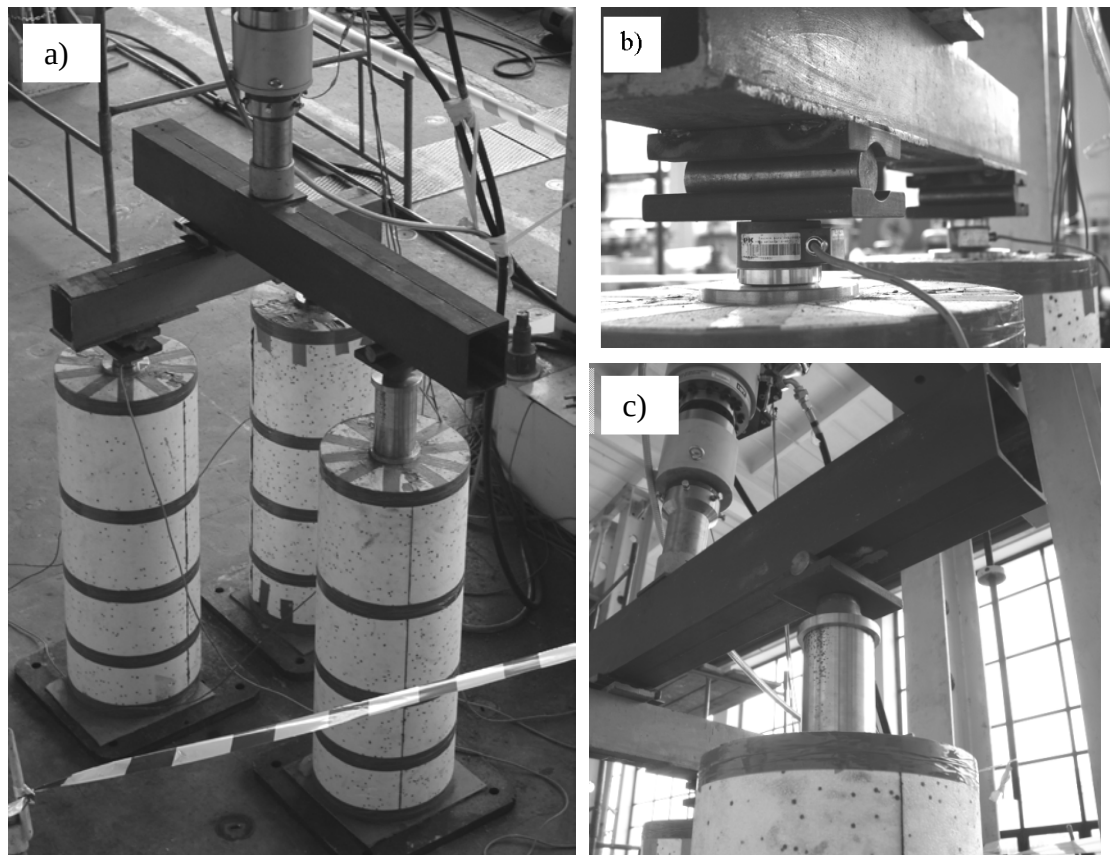


Figure 10. a) The stand for concrete creep test under constant compressive stresses
bc) the system of bearing and forces gauges (Zych 2011).

Finally nine concrete elements were executed. Three of them were designed for creep test under compression, three of them under tension and the last three like free samples. To perform creep test under constant compressed force the Schenck machine was used.

Thanks to transverse positioned of steel beam with additional bearing system and possibility of correction the position of tested elements, it was possible to obtain uniform loading on each element (figure 10a). During this test the acting forces on each sample were recorded by force gauges located at the top of the each sample (figure 10b).

The creep tests, under constant tensile stresses, is much rare executed because there are big technological problems, especially in case of young concrete. The samples were hanged to the steel frame (figure 11a) and constant tensile stresses were assured by hanged to them steel ballast (for that reason only few centimeters over the ground). Both bottom and upper surfaces of the elements were connected using hinge joints (figure 11b,c).

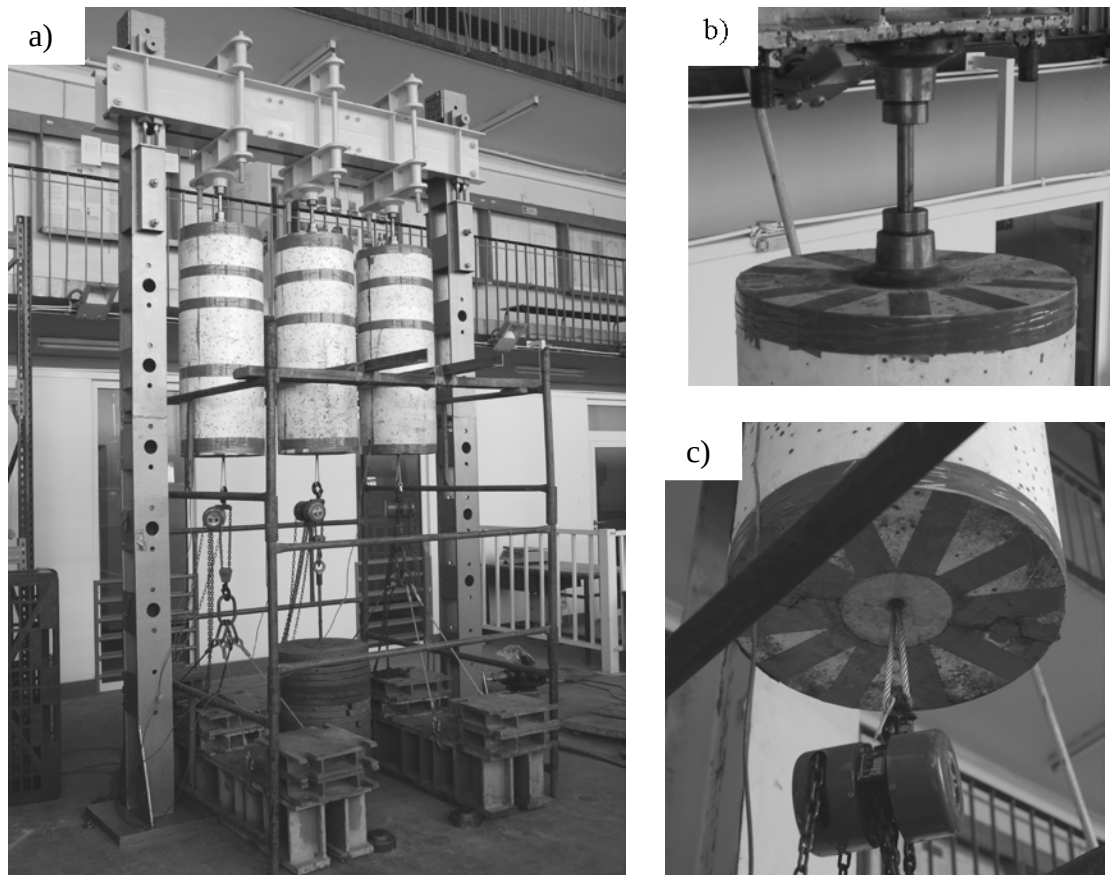
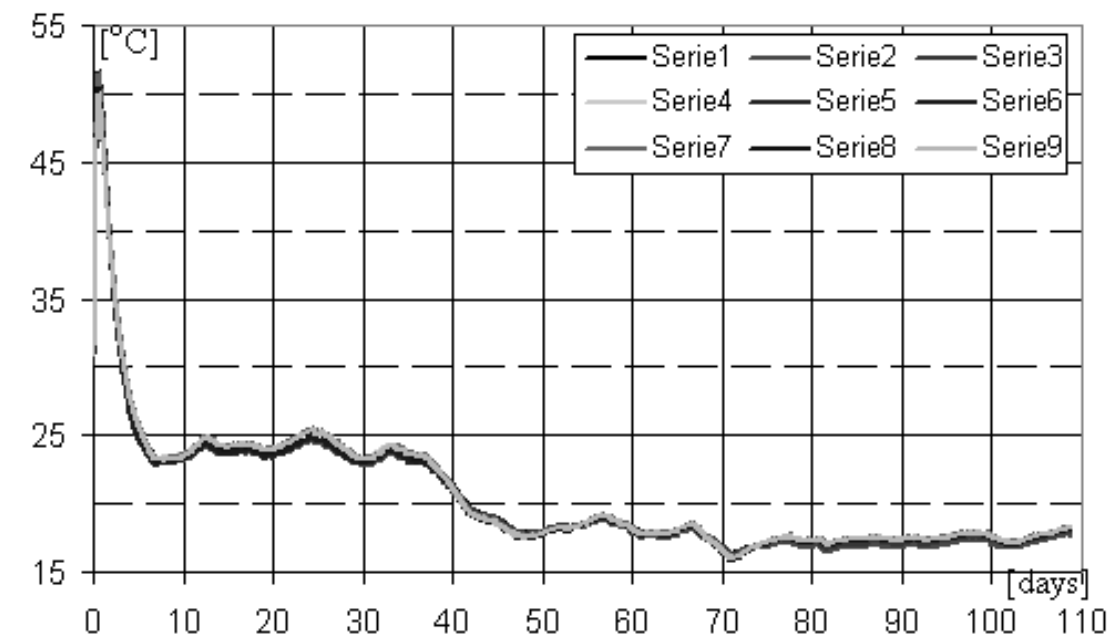
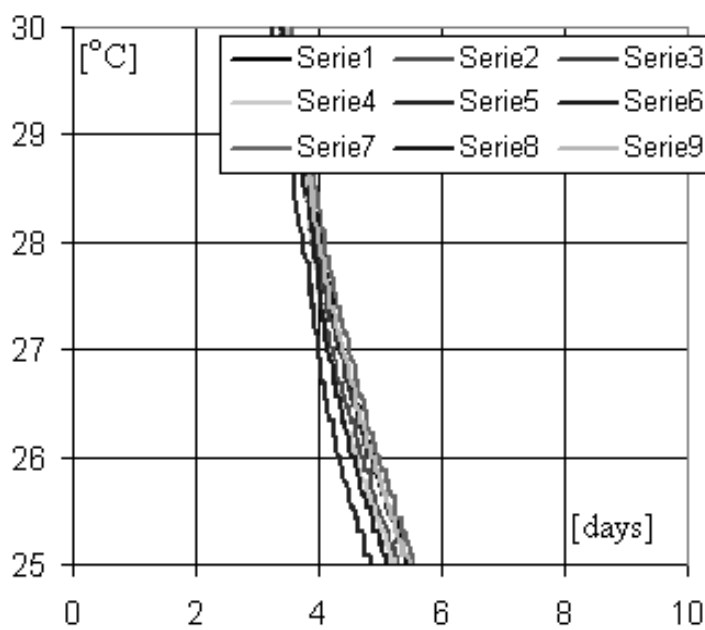


Figure 11. a) The stand for concrete creep test under constant tensile stresses, b) articulated connection at the top c) articulated connection at the bottom

During the whole cycle of research work i.e. from the moment of pouring until to the end of loading, the temperature was measured in all nine elements (figure 12a). The temperature was measured exactly in the middle of strain gauge. We can observe that temperature differences in whole cycle range about 1,5 °C (figure 12b). Surely, certain small influences on these differences have different boundary conditions for compressed, tensioned and free elements. If we take into consideration the error caused by precision of temperature gauges, we can say that this results are very good (all elements were concreted from one concrete mix). But it doesn't change the fact that even small temperature differences causes decrease of accurate in later received results.



a)



b)

Figure 12. a) The temperature changes in all nine elements, b) the temperature changes in selected range time

Three of these elements were tested under compressive stresses in very early age of concrete i.e. 24 hours after pouring. This elements were loading by compressed forces (at the stand presented at figure 10) which caused very small compressive stresses at the level equal to 3,93 MPa (sample nr 1,2) and 4,48 MPa (sample nr 3). Therefore very early moment of loading was caused by the time in which in real structures appeared compressive stresses. During this research work we have problems with constant work of the machine. Unfortunately, there appeared few brakes caused by lack of electricity. Therefore first brake was 20 hours after pouring. After this brakes this elements were again loading with a little higher force which caused stresses at the level equal to 6,3 and 7,2 MPa. The changes of measured strains in those elements are presented in figure 13 (3 curves in range minus). These results didn't take into consideration the compensation for temperature gauges and include all components of strains during maturing of concrete (i.e. shrinkage and temperature of concrete).

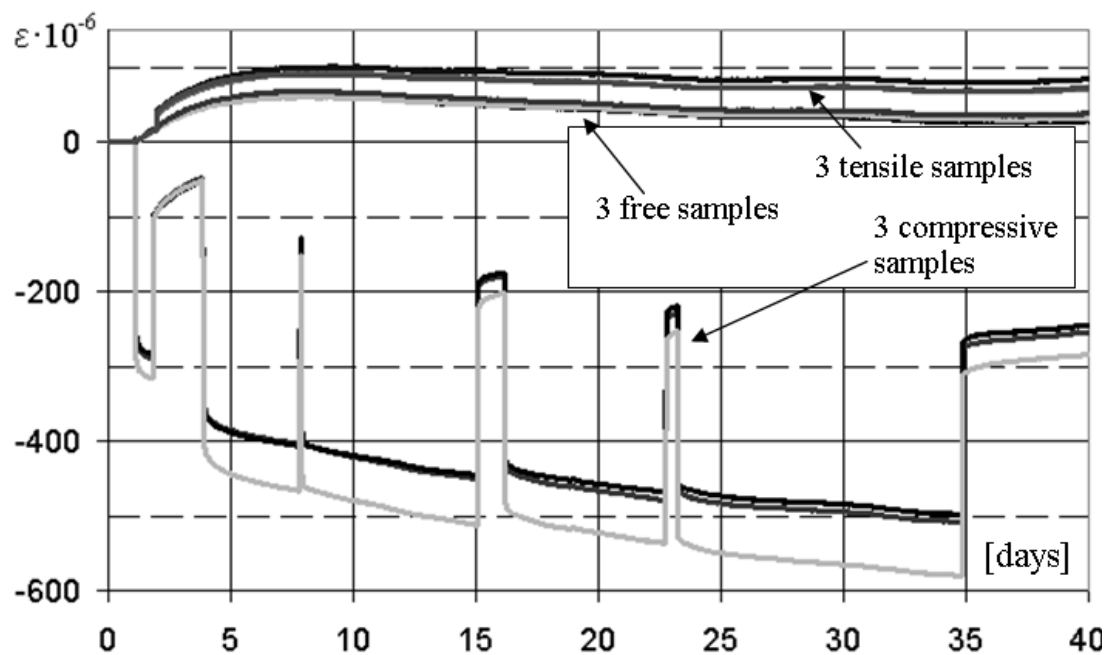


Figure 13. The increase of measured strains in compressed, tensile and free element

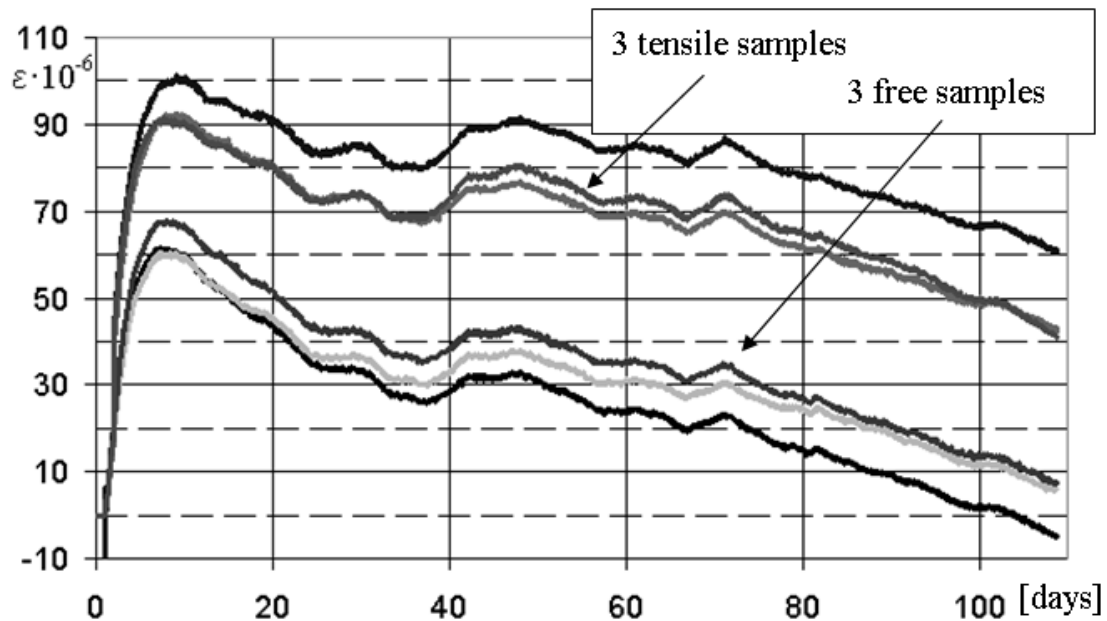


Figure 14. The increase of measured strains in tensile and free element

Three another samples were loaded by tensile stresses 2 days after pouring. The time of loading was caused by the moment at which the temperature in real structures decrease, but this temperature changes should be enough that causes tensile stresses. The level of loading was established to 0,56 MPa. Moreover, the way of testing was very risky. The changes of strains in three free samples (up to level 100 micro-strains) and changes of strains in three tensile samples are presented in figure 14.

After concreting elements, the concrete in each sample was vibrated. But vertical position of the gauges caused problems with stabilization of them because strains for each elements have very big differences. Therefore was assumed that the beginning of presented results, for all elements, will take place from the beginning of external loading. Therefore at the all figures we see strains equal to zero before the external load was acting. This assumption hasn't any influence on presented final measured results i.e. strains caused only by external tensile and compressive loads, what is the main assumption in presented work.

For such results the mean values from among 3 tensile, 3 free and 3 compressed elements were calculated (figure 15). Further the mean values between tensile and free also compressive and free strains were subtracted and in this way we received strains caused only by tensile and compressive loading (excluding temperature and shrinkage figure 16).

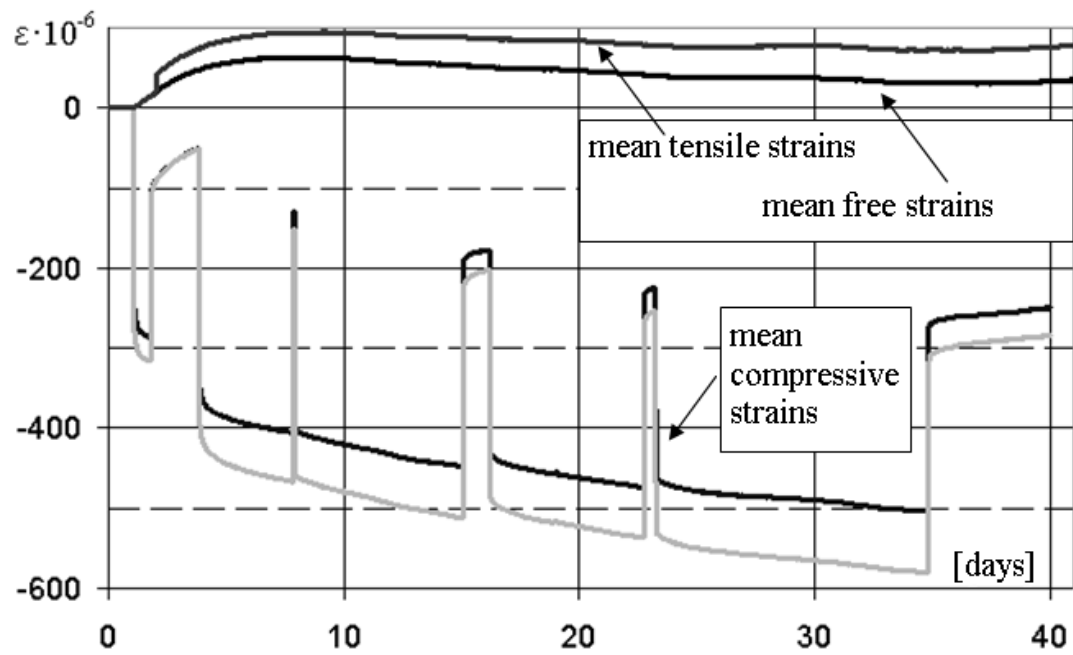


Figure 15. The increase of mean measured creep strains in compressive, tensile and free elements

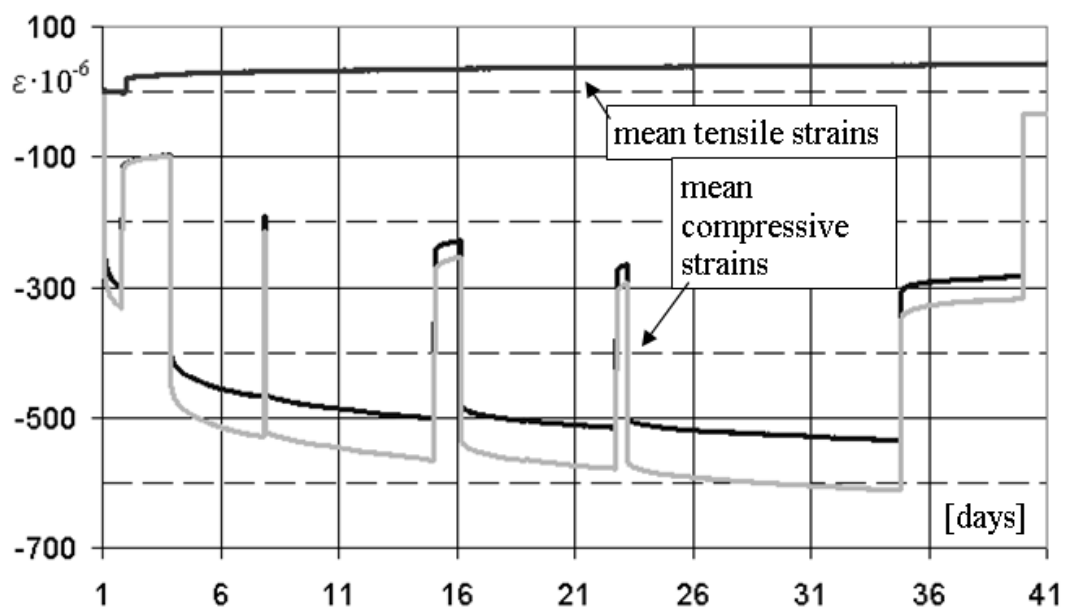


Figure 16. Strains in tensile and compressive elements caused only by external loading

The increase of creep strains in tensile elements caused only by external loading was presented in figure 17 (mean value).

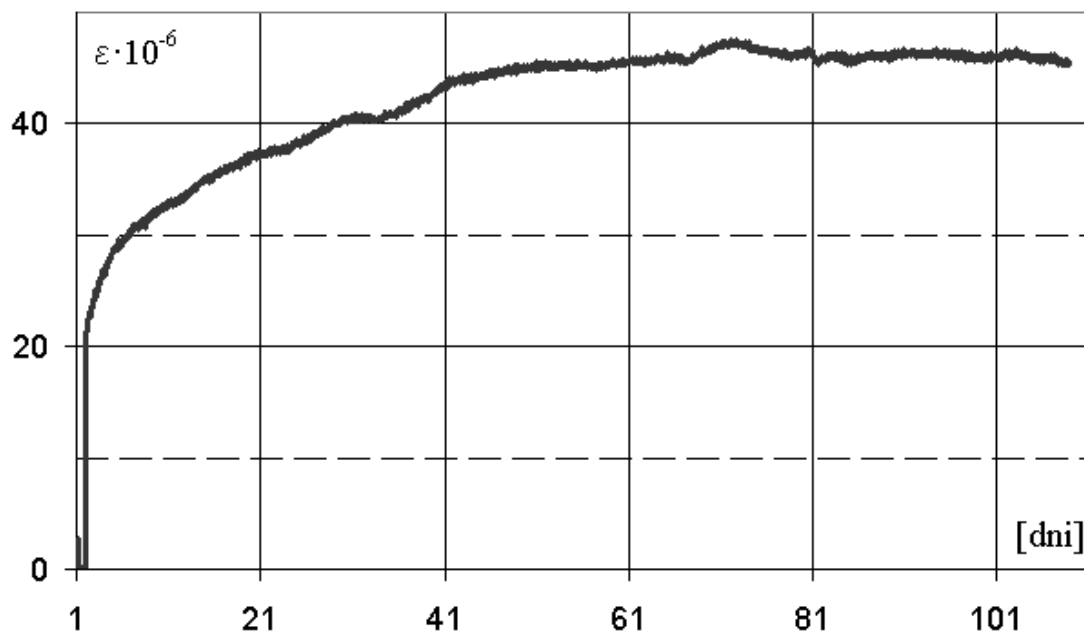


Figure 17. The increase of creep strains in tensile elements caused only by external loading

Conclusion.

Theoretical calculations according to EC2 and test data of shrinkage research has good convergence .

Assumed research manner of heat of hydration fulfilled assumption about a quasi-adiabatic conditions.

Prepared tests of creep taking into consideration kind of mould, fulfilled assumptions about the very good shape of concrete elements and about identical and stable developmental of temperature in each sample.

Designed stands and manner of load transfer ensured proper working during the test and equal forces in each element.

All measured properties and changes of these properties in time are the basis to describing and to finding parameters and materials models to describing tested concrete. This make possible to calculate real structure taking into consideration exactly tested properties.

References

E H. GUO (2006) *Fundamental modeling of curling response in concrete pavements*. 6th International DUT Workshop on Fundamental Modelling of Design and Performance of Concrete Pavements. September 15-16 2006, Belgium.

RILEM REPORT 15 (1998) *Prevention of Thermal Cracking in Concrete at Early Ages*. Edited by R. Springenschmid. London. 1998.

DE SCHUTTER G (1999) *Hydration and temperature development of concrete made with blast-furnace slag cement*. Cement and Concrete Research 29 (1999) 143-149.

SERUGA Andrzej, ZYCH Mariusz (2008) *The modeling of early age cracking in monolithic reinforced concrete rectangular tank wall*. The 6th Conference. Analytical Models and New Concepts in Concrete and Masonry Structures, Łódź-Poland 2008.

SHIMOMURA Taizo, NISHIZAWA Tatsuo, OZEKI Takato (2008) *Evaluation of thermal stress in airport concrete pavement slab by 3D-FEM analysis*. The 9th International Conference on Concrete Pavements. San Francisco, California, August 17-21, 2008.

ZYCH Mariusz (2008) *Numerical analysis of reinforcement stresses and stages of early age cracking in concrete tank's wall*. JUNIORSTAV, 23 January 2008, Brno.

ZYCH Mariusz (2008) *Phase analysis of young concrete cracking in FEM based on an example of rectangular RC tank (in polish version)*. Zeszyty Naukowe Politechniki Śląskiej, Seria: Budownictwo, z 113. 2008.

ZYCH Mariusz (2011) *„Analysis of RC tank walls during early hardening period of concrete, in water tightness aspect” (in polish version)*. Doctoral Thesis, Kraków February 2011.

SERUGA Andrzej, SZYDŁOWSKI Rafał (2012) *“Experiences resulted from construction of two-way pre-stressed concrete pavement”* ICCP10, 10th International Conference on Concrete Pavements.