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MEASUREMENT OF STRAINS IN CONCRETE BY INTERFEROMETRIC FIBRE OPTIC SENSORS

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Abstract: *In recent years, fiber-optic technology appeared in measurement technology and sensors. The great advantage of fiber-optic technology is lifespan and measurement which is not influenced by electromagnetic fields. Therefore, the large cable length can be used. For the same reasons, the optic fibers are used in computer networks. A number of physical principles can be used for measuring. In the case of measuring strains in the concrete, a relatively simple and economically favorable principle of low-coherence interferometer can be used. These interferometric extensometers were used to measure strains in the pre-stressed concrete railway sleepers stored in the laboratory. Thus, effects of creep and shrinkage of concrete were monitored. The experiment was supplemented by tests on the accompanying specimens, i.e., the concrete strength, modulus of elasticity and shrinkage and creep measurements. Experimentally obtained data was compared with standard assumptions for the design of concrete structures EN 1992-1-1.*

Keywords: ***Fiber-optic sensor, concrete, strain, shrinkage, creep.***

1. Introduction

The appearance, quality, durability and safety of constructions are the most important parameters for design process in the civil engineering. The structural monitoring during construction and monitoring of reliability and durability of structure use different methods of watching its "health" and their goal is to provide accurate and "in-time" information about structure status. The most frequently monitored parameters in concrete structures are strain, vibration, temperature, displacement and deformation, humidity, cracks opening, etc.

During the life of concrete structures, creep and shrinkage are caused by influences of several processes in material, external loading and environmental condition. These two parameters are variable over time and can significantly influence the final value of the strain. Creep and shrinkage of structures can be calculated through a variety of methods based on evaluations of similar parameters (material properties and surroundings conditions) with different importance. Therefore, it is necessary to choose a suitable prediction method of creep and shrinkage behavior for structure design spatially in case of pre-stressed concrete structure such as a bridge build by cantilever method.

For this reason, displacement and deformation are the most watched parameters in the structures. The monitoring of these parameters can be performed in the short term, middle term, long term or during the whole lifespan of the structures. The whole range of conventional sensors (i.e. strain gauge, videoextensometer etc.) is used for strain monitoring in structures. Selection of appropriate conventional method depends on the application, the measurement range to the desired accuracy and other parameters.

In the last few years, the field of structure monitoring of bridges, tunnels, dams, power stations, stadiums, historic buildings, as well as piping systems, etc., is increasingly utilizing systems based on fiber-optic technologies. Compared to traditional methods, the fiber-optic technology exhibit many advantages such as higher quality measurements, higher reliability, easier installation and

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maintenance, insensitivity to the environment (mainly to the electromagnetic field), corrosion resistance, safety in explosive and flammable environments, the possibility of long-term monitoring and lower cost per lifetime. There is a large variety of fiber-optic sensors working on different physical principles. Results in this article were obtained by fiber-optic sensors working on principle of low-coherence interferometer.

2. Theoretical background

The total strain in concrete structure ε_c consists of strain due to stress ε_σ, shrinkage ε_{SH}, creep ε_d and strain caused by temperature ε_T (1). Strain due to creep and shrinkage is dominant is strain monitoring of pre-stressed structure, therefore, the evaluation of these structure measuring shall take into account these phenomena and the entire job is more complicated. The experimental results led to a number of standards, recommendations and models for calculating the coefficient or creep. The model according to EN 1992-1-1 was chosen for strain course calculation by reason of simple application, adequate accuracy and sufficient number of important parameters.

$$\varepsilon_c = \varepsilon_\sigma + \varepsilon_d + \varepsilon_{SH} + \varepsilon_T \qquad (1)$$

Total strain calculated according to model EN 1992-1-1 was compared with experimental data of total strain obtained on monitoring structure. Total strain of monitored pre-stressed sleeper was measured by long-gauge optical fibers SOFO. This type of sensors was chosen by reason of possibility installation them into body of the structure, adequate accuracy and mainly ability of strain measurement along the structure, not only at local point. The SOFO sensor can be used for the whole lifespan structure monitoring without continuous data recording; it is one of their advantages. The SOFO interferometric sensor was developed at the Swiss Federal Institute of Technology in Lausanne and now are manufactured by SMARTEC.

SOFO sensor consists of a measurement fiber and reference fiber installed in the structure. The total strain of the structure is then result in a change of the length difference between these fibers. The low-coherence double Michelson interferometer is used to make an absolute measurement. The first interferometer is made of the PA tube with measurement and reference fibers and the second low-coherence interferometer with mobile mirror is placed into the portable reading unit (Glišić & Inaudi, 2007), Figure 1.

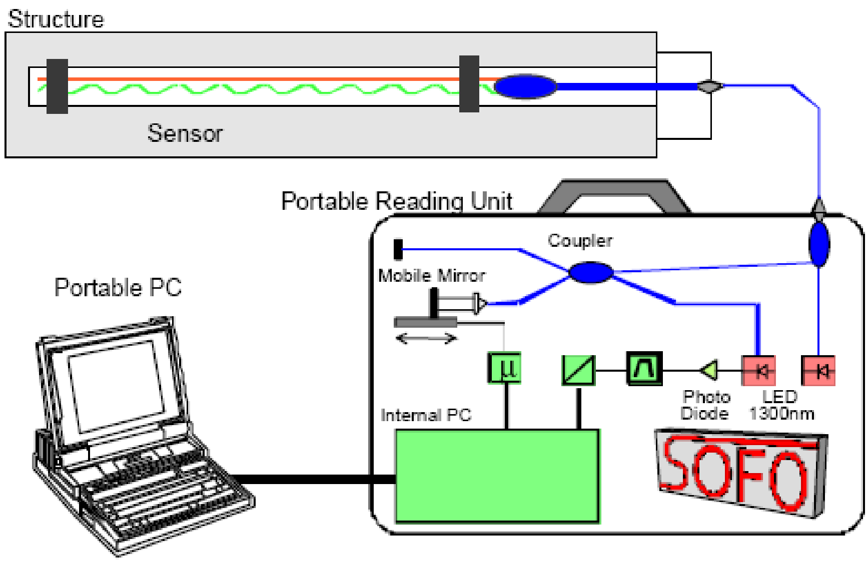

Fig. 1: Setup of the SOFO interferometric sensor system (Inaudi (2004))

3. Experimental

SOFO interferometric extensometers were used to measure strains in the pre-stressed concrete railway sleepers stored in the laboratory conditions. Thus, effects of creep and shrinkage of concrete were monitored. Concreting of two reinforced concrete sleepers B91 S were conducted by the ŽPSV a.s. company in Nové Hrady on September 20, 2010. The fiber-optic extensometers were installed on steel reinforcement of sleepers before casting of concrete. Four fiber-optic extensometers with active length 0,5 m marked with serial number (9088, 9089, 9090 and 9091) were installed on the pre-stressing wires at the center span of sleeper – two extensometers on each sleeper. Location of extensometers is shown on scheme in Figure 2. In addition, two temperature sensors Ni 1000 (see Figure 2) marked with serial number 0301 and the 0302 were also installed. These two pre-stressed concrete railway sleepers were monitoring for 467 days in laboratory of Klokner Institute. Thus, obtained data of total strain was compared with theoretical prediction of total strain calculated according to EN 1992-1-1.

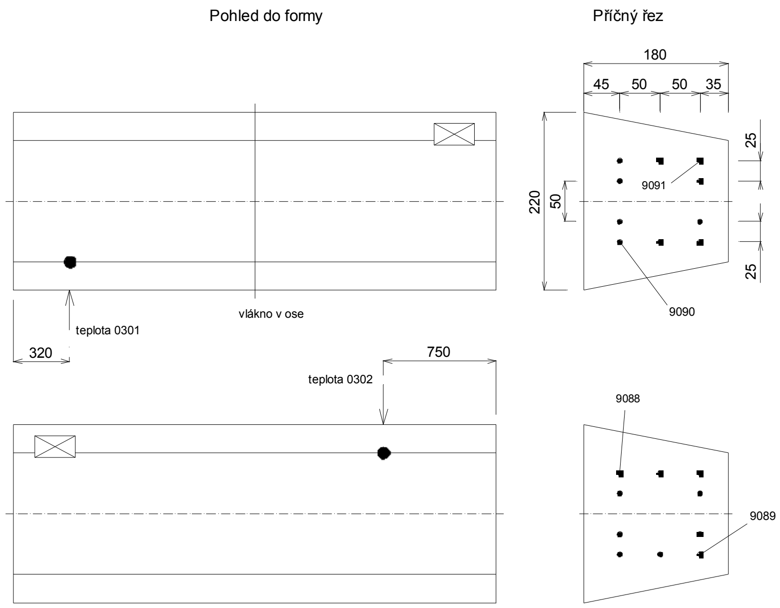

Fig. 2: Location of SOFO fiber-optic extensometers on reinforced concrete sleepers B91 S.

Table 1: Concrete strength determine according to EN 12390

Specimen No.	Specimen diameter [mm]	Specimen high [mm]	Weight [g]	Bulk density [kg·m^{-3}]	Load [kN]	Cylinder strenght f_{cm} [MPa]
Date of the test: 29.9. 2010 – 9 days						
1	149,6	301,0	12979	2453	901	51,3
2	149,4	301,3	12983	2458	1231	70,2
3	150,3	301,5	13011	2432	1193	67,2
Average value:				**2450**		**63,0**
Date of the test: 18.10. 2010 – 28 days						
4	151,3	301,5	13169	2431	701	39,0
5	150,5	301,5	13137	2449	1413	79,4
6	150,0	302,0	13032	2444	1156	65,5
Average value:				**2440**		**61,5**

The parameters of model EN 1992-1-1 for strain prediction were obtained by experiments carried out on fundamental concrete elements (cylinder samples) made from same concrete recipe as monitored structure. Additional necessary experiments were tests of concrete strength, modulus of elasticity tests, shrinkage and creep measurements. Concrete strength was determined according to

EN 12390 on six test specimens at the age 9 days (three test specimens) and 28 days (three test specimens). Test specimens were made from same concrete recipe as the monitored pre-stressed railway sleepers in the same day. Results of concrete strength are shown in Table 1. Next important material parameter is modulus of elasticity. This parameter was determined according to ISO 6784 on the same test specimens as concrete strength. Values of elasticity modulus are stated in Table 2. Average concrete strength and elasticity modulus at the age 28 days were used in creep and shrinkage model according to EN 1992-1-1.

Table 2: Elasticity modulus determine according to ISO 6784

Specimen No.	Specimen diameter [mm]	Stress in cross-section [MPa]			Strain [10^{-3}]			Elasticity modulus E_{cm} [GPa]
		Lower level σ_d	Upper level σ_h	$\Delta\sigma$	$\Delta\varepsilon_1$	$\Delta\varepsilon_2$	$\varnothing\ \Delta\varepsilon$	
Date of the test: 29.9. 2010 – 9 days								
1	149,6	0,5	22,5	21,96	0,535	0,403	0,469	46,8
2	149,4	0,5	22,5	22,02	0,612	0,659	0,636	34,6
3	150,3	0,5	22,3	21,76	0,490	0,598	0,544	40,0
Average value:								**40,5**
Date of the test: 18.10. 2010 – 28 days								
4	151,3	0,5	25,6	25,10	0,599	0,617	0,608	41,3
5	150,5	0,5	22,5	21,98	0,566	0,505	0,536	41,0
6	150,0	0,5	26,0	25,54	0,541	0,706	0,624	41,0
Average value:								**41,0**

One component of total strain is shrinkage. For this reason, the shrinkage measuring was conducted on three test specimens 100 x 100 x 500 mm made from same concrete recipe as the monitored pre-stressed railway sleepers. Results from these experiments are shown in Figure 3. Average values of experimental data were compared with shrinkage calculated according to EN 1992-1-1 (see Figure 3). There is shown relative good agreement between experimental dates of shrinkage and calculated values.

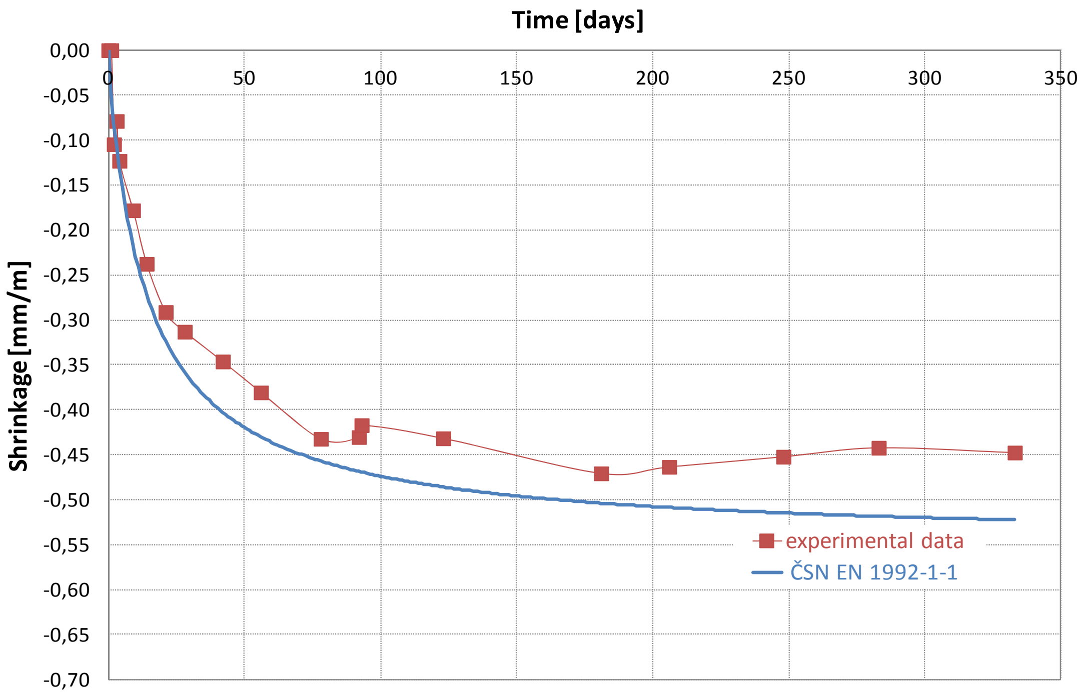

Fig. 3: Comparison of experimental shrinkage and calculated prediction of shrinkage according to EN 1992-1-1

All of these experimental data were used for prediction of total strain according to EN 1992-1-1. This prediction is shown in Figure 4. In Figure 4 are shown experimental data obtained from measuring of total strain in two pre-stressed concrete railway sleepers by four SOFO interferometric extensometers.

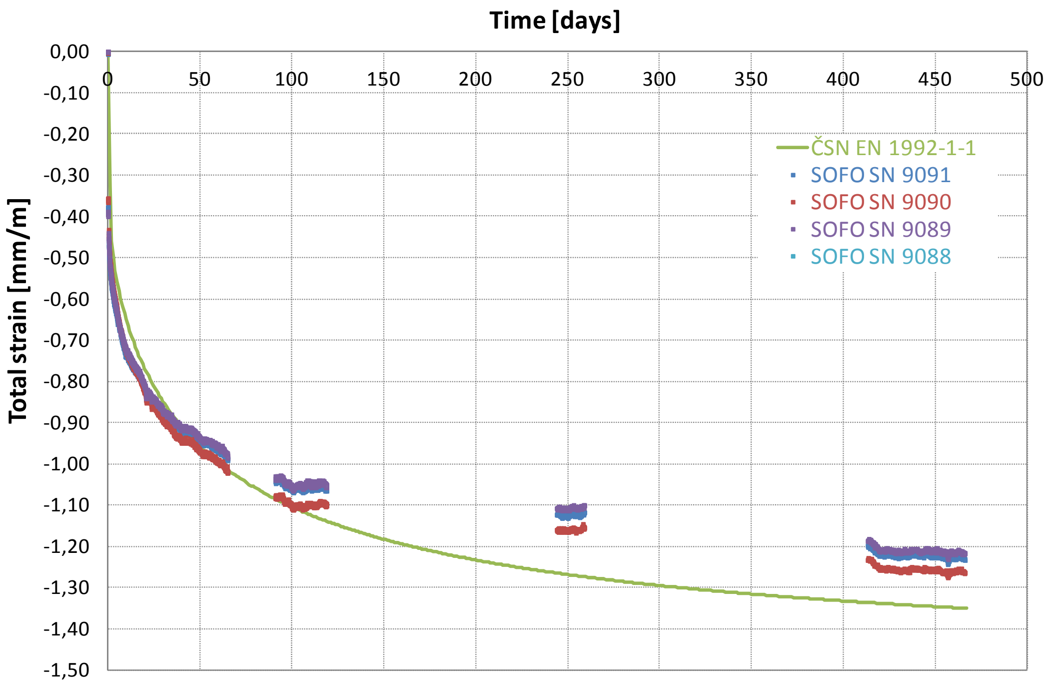

Fig. 4: Comparison of experimental total strain and calculated (EN 1992-1-1) prediction of total strain

4. Conclusions

The comparison of experiment and chosen model proved the applicability of this model EN 1992-1-1 with adequate accuracy for strain describing structures with same concrete recipe. Above mentioned mathematical model can be used for calculation other characteristics of pre-stressed reinforced concrete sleeper. Furthermore, this relatively simple experiment conducted on railway sleepers verified applicability of the fiber-optic extensometers for monitoring of pre-stressed concrete structures.

Acknowledgement

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