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Monitoring of Long-Term Effects on Concrete Bridge Realised by Balanced Cantilever Method

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Abstract- Balanced cantilever method a common method for the construction of concrete monolithic bridges. Generally non-homogenous concrete structures with changing the structural system during its erection are sensitive to predict the deformation and stress distribution in time. Long-term monitoring system has has become very important tool that enable to obtain information about stress and deformation prediction in time. It can capture the other influences such as temperature effects also which can affect the later complex structural behaviour. Bridge designers do not have enough information about these influences within the structure erection in time. Underestimating such mentioned effects often causes that predicted values of stresses or deformation does not corresponded with the reality. In boundary cases unexpected excessive deformations or crack opening due to the stresses distribution may lead to the serviceability problems, deterioration of aesthetics, and even early reconstruction of the bridge eventually.

In this paper we would like to present some experiences with the long-term monitoring of bridge structure and performed structural analysis considering the real load history and structural scheme changing. Recorded strains development was compared with the numerical model results based on the expected behaviour of prestressed concrete structure according to the European standard models.

***Keywords*:** Concrete Bridge Monitoring, Creep, Shrinkage Effect Prediction,

1. Introduction

Balanced cantilever method being generally used for long span concrete bridges over 60m in the cases where the other technology cannot to be used for the sake of inaccessible terrain or other similar problems. Cast in-situ segments are realized by the step by step method and each segment being a different age and different property of concrete basically. Rheological effects like a differential shrinkage, creep and thermal effect have a significant impact on a stress distribution along the cross-section and along the span particularly in cases where the structural scheme has been changed. Deformation behavior and stresses status of structure in the service life depends on accurate long-term effect prediction, respectively. Structural design or reliability assessment of long span bridges need to adopt a range of input assumptions due to the entire structural behavior during the construction especially the load history. In these cases the long-term monitoring has great significance. It can enable to work with the real stress level along the span and the cross-sections too over a certain time. Two important outputs of the bridge monitoring we can define. The first one concerns the bridge design feedback and the preferable structural modelling from the stress and deformation prediction in time point of view. The second one concerns the fact we can perform the bridge analysis based on the real level of stresses distribution along the structure in the future. If so required by technical condition to realize the structural analysis the bridge administrator will have relevant information about the structure.

Therefore one representative of the long span bridge type constructed by the balanced cantilever method in Slovakia on the highway D1 has been chosen. That is bridge No. 205 that was recently built (in 2014) in northern part of Slovakia, near the city Zilina. University of Zilina and the contractor company Vahostav-Sk, have been cooperated on that research work. Whole experimental program has been proposed in order to obtain the real structural behavior of the bridge over the time from the construction stages to the service. In-situ recorded data from the monitoring system have been compared with the theoretical one based on well-known prediction theories based on the Eurocode 2 rheological models and the Model Code 2010 too. Also several numerical time dependent FEM models have been applied to consider the concrete long-term effects.

2. Bridge and Monitoring System Description

Prestressed concrete bridge No. 205 has five spans (75,0m + 120,0m + 75,0m + 53,0m + 37,0m), with total length 362,0m. The main span (120,0m) bridging the river Vah had been cast by the balanced cantilever method and other spans on the stabile scaffolding, see Fig. 1. Length of each cantilever is 49,0m and consists of 11 segments with length 5,0m. The cross-section is a typical single box girder. Width of the top slab is 13,65m and the bottom slab is 7,0m. The cross-section height is variable, from 2,85m in the middle to 6,5m above the support. Thickness of the webs varies from 450mm (middle of span) to 800mm (above the supports). The top slab has a constant width 300mm, the bottom slab varies from 240mm (middle of span) to 920mm (above the supports).

The concrete has been designed C40/50 and prestressed tendons with characteristic strength 1860MPa. The cables consist of 15 or 18 tendons with profile 15,7mm.

The type TES/5.5/T embedment vibrating wire strain gauges for concrete in the decisive cross-sections in the first segment (L1) and (L2) near the supports of the cantilever and in the middle cross-section (UL) have been installed, see Fig. 2. There were monitored the strains and temperature in certain fibres of concrete cross-sections continually. Concreting traveller started casting of the first (V1) cantilever. There was time difference around 140 days between the cantilever V1 and V2 erecting. Both of the cantilevers joining occurred after around 380 days.

Fig. 1. View on the bridge No. 205 - final construction stage for the left cantilever – V1

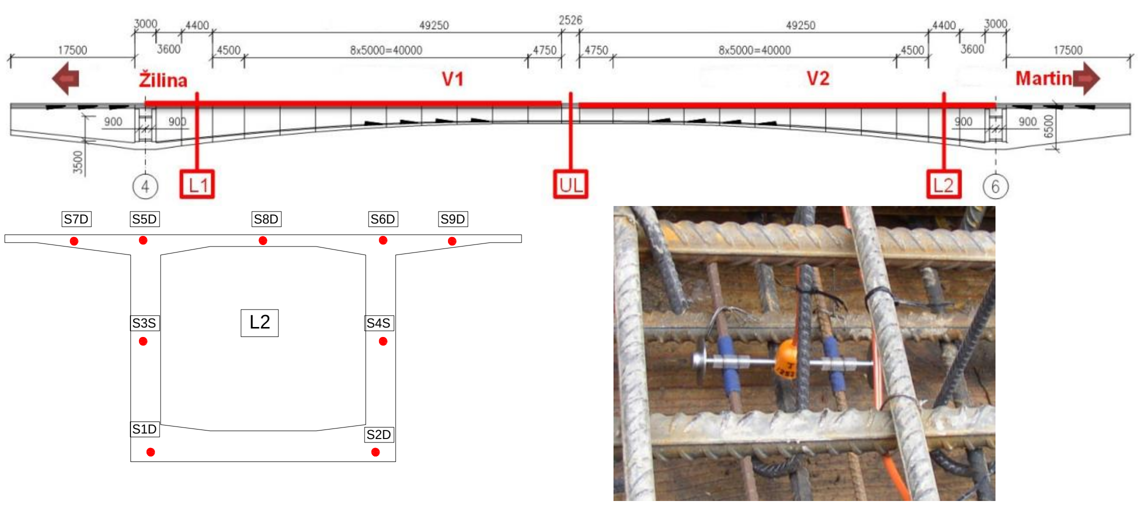


Fig. 2. Sensors arrangement on the bridge No. 205

3. Structural Model of the Bridge

The numerical analysis of the bridge was performed in the MIDAS Civil system with the basic concrete creep and shrinkage prediction model parameters setting according to the Eurocode 2 standard especially (STN EN 1992-1-1 and STN EN 1992-2). Own prediction model have been based on acquired concrete parameters from experimental observing in the lab. Bearing structure was modelled using linear beam 1D elements as a time dependent analysis using the time step by step method and real load history considering, see Fig. 3.

The concrete shrinkage along the cross-section was modelled using uniform function as the first approach. The second one more precise model was based on the differential shrinkage principle. The cross-section of each segment was divided into three parts according to the real time steps, see Fig. 3. For that reason the time dependent effects was acting exactly by course of each construction stage according to above mentioned standard approaches and real measured parameters. The recorded temperatures in each parts of cross-section, was applied as a nonlinear temperature gradient, see Fig. 4. 2D model for simulation of that problem had also been prepared, as for example at the (Halvonik,J at al. 2007).

Within the first segment (L1) casting the highest temperature of concrete was observed in the web, smaller in the top slab and the lowest in the bottom slab due to the fact that this part of cross-section was casted earlier than the other ones. After some days the temperature of both of slabs became approximately unified, see Fig. 4. But the temperature of the webs remained significantly higher longer. But over the time the temperatures produced by the hydration process in concrete became declined and they were affected by the ambient temperatures and gradually unified. Very different climatic conditions were recorded within both of cantilever concreting. The first one (L1) was casting over the winter condition with temperature (-6 ≈ +11ºC) and the second one (L2) over the summer time (+15 ≈ +28ºC) basically. Relative humidity reached the different values too, on the L1 it was around 70-90% and on the L2 around 40-60%.

Fig. 3. Numerical model of the cantilever – model for the differential shrinkage effect analysis

The concrete age of each member were measured from the real time schedule of concrete casting and prestressing. Each segment has an appropriate compressive strength and modulus of elasticity at construction stage depends on the verified values in laboratory. The general incremental step-by-step method was applied to perform that analysis. For the stress analysis of such non-homogenous structures where the basic concrete properties and the structural scheme vary on the structure within the time (e.g. cantilever construction method) is particularly recommended Annex KK.101, of the Eurocode 2 approach.

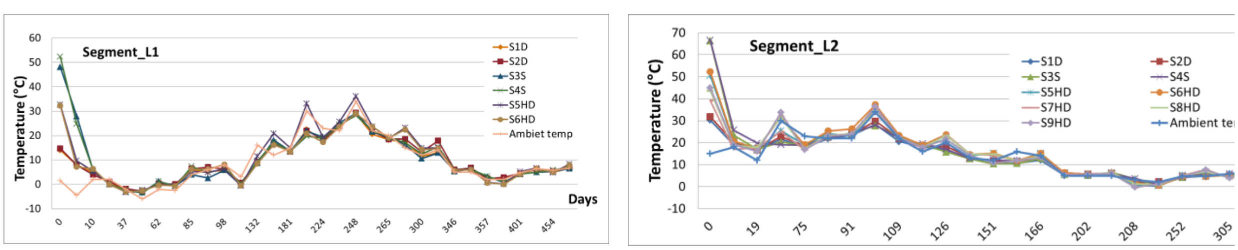


Fig. 4. Temperature in concrete and ambient temperature within the bridge construction

4. Some Results from the Bridge Monitoring

Experimental research was divided on the laboratory tests and continual in-situ bridge strains development monitoring. The main purpose of the laboratory tests performing was getting the real values of the concrete mechanical parameters and time dependent experimental curve of the creep and shrinkage. They were later used as an input data for the theoretical model.

4. 1. Laboratory Tests

We have token 3 concrete specimens (cube and cylinder) from each segment during the casting to get real values of the concrete strength and modulus of elasticity. Parameters were assessed for 7, 14 and 28 days. Mechanical strain gauge was used for the strain recoding. The long-term strains development over the time due to the concrete creep and shrinkage effects was continuously investigated on the 9 prism specimens. The theoretical curves based on the concrete creep and shrinkage prediction model according to the (STN EN 1992-1-1, STN EN 1992-2), (Model Code 2010) and the Model B3 with the experimental data have been compared, see Fig 5.

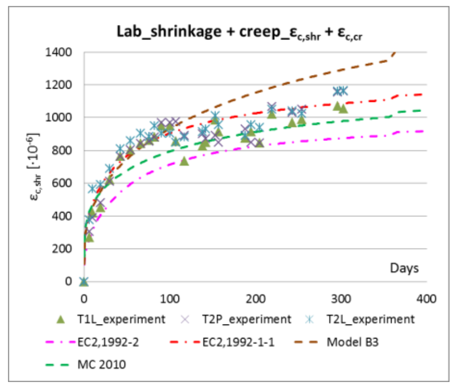
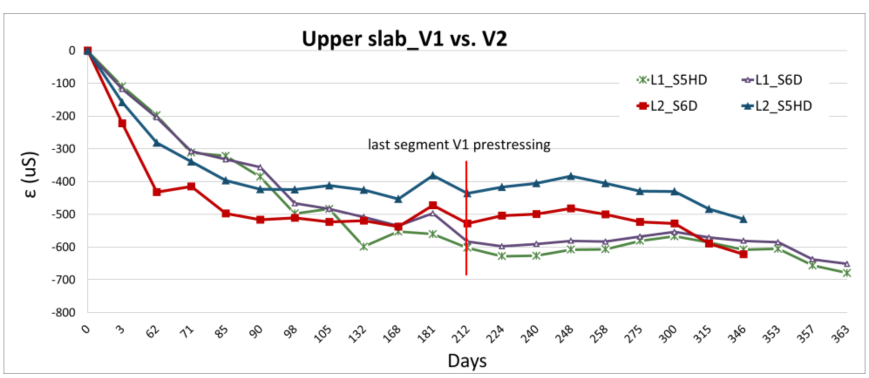


Fig. 5. Concrete creep and shrinkage prediction models verifying

4. 2. Some Results of the Bridge in-Situ Monitoring

The long-term strains in concrete in characteristic cross-sections of the bridge are presented at the follow graphs, see Fig. 6. Only the decisive strains in upper and bottom fibres and in the web ones have been presented.

Quite good coincidence between the monitored values of the strains in slabs and webs of the cross-section has been achieved, see Fig. 6. But noticeable deviations mainly between strains in webs and bottom slab being demonstrate the effects of concrete non-homogeneity from the various temperature and humidity influences point of view. More massive parts of the c ross-section are more sensitive to above mentioned effects. Thinner upper slab showed quite integrated strains courses on both of cantilevers.



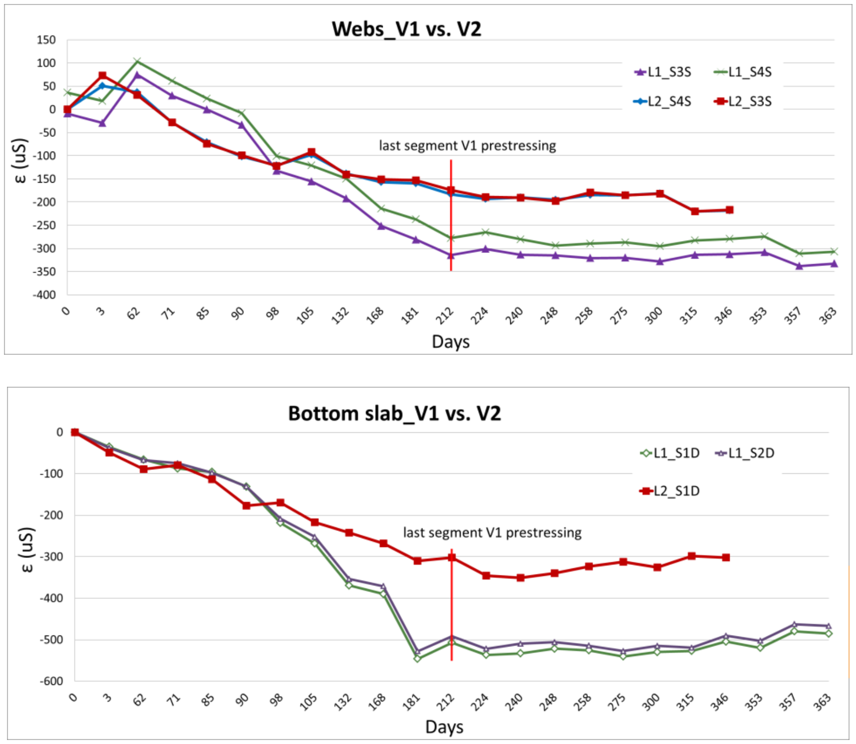
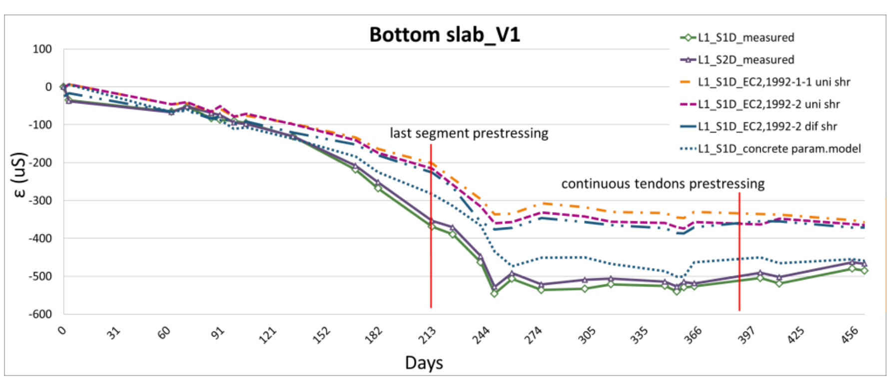


Fig. 6. Strains development in time – cantilevers V1, V2

Time dependent analysis was applied for phased structural 1D model with the stress redistribution along the structure and along the cross section (3 parts) due to different concrete rheological processes acting. The influences of real temperature and humidity in the concrete still remain the problem how it takes into account in the practical analysis using a 1D numerical model. Some results of the decisive strains courses are presented in Fig. 7.

Good agreement between real monitored values and theoretical ones on the top and bottom slab of the cross-section were achieved, see Fig. 7. Two approaches of concrete creep and shrinkage prediction provided by Eurocode 2 and model based on measured concrete parameters had been used. In the case of strains in the web the 2D model had to be used again due to appropriate temperature effect and the shear deformation of web simulation. That caused the tension stresses in the webs at early stages, see Fig. 6. That effect being significant in the case of short cantilever phases that means the dimension of cross-section height is relatively the same as the longitudinal one.



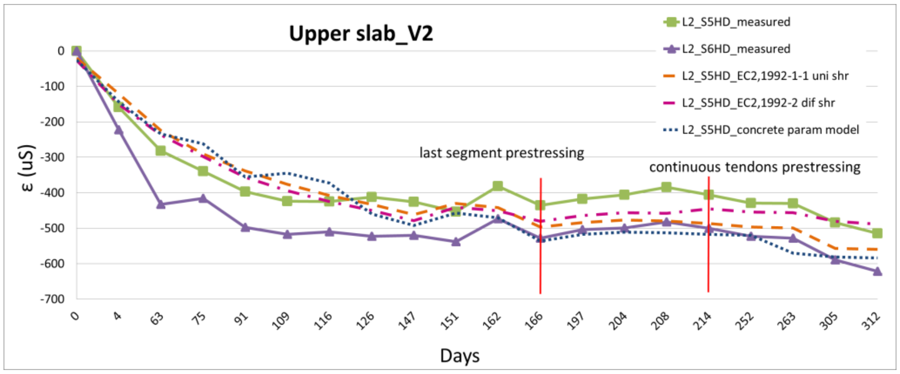


Fig. 7. Comparison - the measured strains and theoretical ones

5. Conclusion

Presented results are showed the possibility to analyze the long-term effects on complicated monolithic non-homogenous bridge structure characterized by the significant load history and structural changing influences using the continual monitoring system, laboratory experiments and appropriate numerical models. Good agreement between in-situ recorded strains in the characteristic fibers and the theoretical ones based on the rheological prediction models provided by Eurocode 2 and our parametric model were proved. In standard numerical model the shrinkage effect on the concrete box girder bridges has been usually assumed as the strains linearly distributed over the cross-section. But real structural behavior is more complicated. Effect of differential shrinkage causes the stress distribution in the longitudinal direction in such non-homogenous structure. In this case the 1D time dependent model with divided cross-section better reflect the reality. The underestimation of differential shrinkage effect can lead to the wrong assumptions for the future prediction of deformation and redistribution of the stresses in the structure. Temperature and relative humidity are important environmental factors which are affecting to the normal stresses distribution. Nonlinear temperature distribution along the cross-section height is very complicated problem for the 1D model. In that cases the 2D models can be successfully applied.

In spite of the complicated problems including a lot of environmental and structural influences our current experiences based on comparison of monitored bridge behaviour with the theoretical approaches can offer the new bridge design feedback and better understanding the non-homogenous structures behaviour generally. Long-term monitoring and analysis of current modern concrete structures has remarkable significance from having knowledge about stresses distribution state point of view. It can enable to perform future accurate structural analysis of bridges in service, as shown (Vican at al. 2008).

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