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MONITORING OF KRK BRIDGE COLUMNS WITH INTERFEROMETRIC FIBRE OPTIC SENSORS

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Abstract: *Maintenance and repair of the reinforced concrete structures becomes a very important field of activity in civil engineering works. In order to guarantee safety and to minimize repair costs it is important in every moment to know condition of structure. The continuous measurement of strains represents an important part of structural monitoring systems. Monitoring of structural properties with conventional methods with usage of strain gauges is complex, time consumpting and requires intervention of specialized operators. Conventional measurement systems are sensitive to exterior influences such as vibrations, temperature changes, chemical aggression and haven't got long term stability. Fibre optical sensor systems show many advantages, such as stability practically during whole service age of construction, high accuracy, they are immune to environmental influences, they have possibility for embedment into structure and there is no need for calibration.*

Low coherence interferometric fibre optic system embedded into columns of Krk Bridge before few years shown all these advantages. For application on Krk Bridge, long gauge fibre optic sensors are selected to insure measurement of average deformation avoiding influence of local deformation changes. Paper gives deformation measurement results and proposes possibilities for future measurements by measurement system centralization and automation.

1. INTRODUCTION

The Krk Bridge was built 1980. with the largest reinforced concrete arch span (390m) in the word. Bridge is situated in a aggressive maritime environment. Salinity of sea of about 3,5% in combination with strong wind Bora cause salted water spraying on the bridge structure, which governed by mechanisms of Cl^- diffusion through thick protective coat caused reinforcement corrosion. As a consequence of corrosion, spalling and deterioration of concrete cover occurred. For construction load bearing capacity chlorides induced pitting corrosion which is invisible for outside is much more dangerous.

During last years an extensive repair works was conducted, consisting of hydrodemolition of chloride contaminated protective layer of 3 cm thick from columns, reinforcement cleaning, and application of new protective coating - reprofilation (shotcrete + protective coating) and new concrete layer (with steel fibres + impregnation) with thicknes of about 8 cm. Concrete was mixed with the addition of new generation of super plastificizer for self compacting, silica fume and 50 kg of steel fibres per cubic meter[1]. World experiences is that about a half of repair works were poorly performed, from which 75% repairs is attributed to poor durability properties, and 25% to structural failures.

So, during the repair work design some important questions and open issues arouse: the stress increase rate in the rest of the concrete after hydrodemolition of the concrete cover, the rate of elastic deformation and plastic creeping caused by disburdening of column S26, the rate of influence of the new concrete shrinkage on additional longitudinal loading and how the new layers (of repairing concrete) affect loading capacity of the repaired columns - when and in which rate will new concrete participate in useful freight bearing.

In order to find out what really happens during repair phases and afterwards, during further exploitation of the bridge columns, it was decided to perform deformation measurement on two characteristic columns S20 and S26. Different deformation measurement techniques was considered, among that monitoring with interferometric fibre optic sensors was selected as the most appropriate measurement method.

2. CHARACTERISTICS OF USED FIBRE OPTICAL SENSORS

Among several different commercially available fibre optical sensors (FOS) which is based on different principles[2], interferometric FOS are chosen as the most suitable measurement technique. Used sensors characterise long measurement base of 2 m, which enable averaged deformation measurement without influence of local phenomena as a cracking and concrete nonhomogenity. Another advantage of used FOS is possibility of embedding into concrete which makes sensors insensitive to mechanical influences during operation, unlike conventional extensometers. FOS is insensitive to temperature changes, chemical influences, and to electrical fields. Measurement stability is estimated to about 20 years.

Table 1 shows main characteristics of used fibre optical sensors.

Measurement base	2 m
Resolution	2μm
Working temperature range	-50°C to +110°C (sensor) -40°C to +80°C (optical cable) 20°C to +60°C (measurement device))
Linearity, accuracy	< 0,002 % of measured deformation
Maximal length of optical connection between sensor and measuring unit	5 km

Table 1: Characteristics of used fibre optical sensors

3. OPERATING PRINCIPLE OF USED FIBRE OPTICAL SENSORS

Sensors used for Krk bridge monitoring are based on Michelson interferometric technique. Sensor consist of two fibres, measuring fibre and a reference fibre as shown in figure 1. The measuring fibre is attached on the construction whose deformation is measured, and the reference fibre is free. Input light is divided into two rays and, after passing through the reference and measuring fibres, rays are coupled together and transmitted to the detector. As structure deformation occurs and as, consequently, the length of measuring fibre changes so do the optical length of light passing through the fibre. The coupled light rays interfere constructively or destructively depending on the deformation of the measuring fibre. Constructive interference occurs for phase shift, $\Delta\phi=2m$ (m=integer) giving maximum of intensity at the sensor output, and destructive interference occurs for phase shift $\Delta\phi=(2m+1)$, giving minimum of intensity. With deformation of structure phase shift is changing, which change interference conditions, i.e. at the sensor output light intensity changes at a cyclic way, measured by a photodiode.

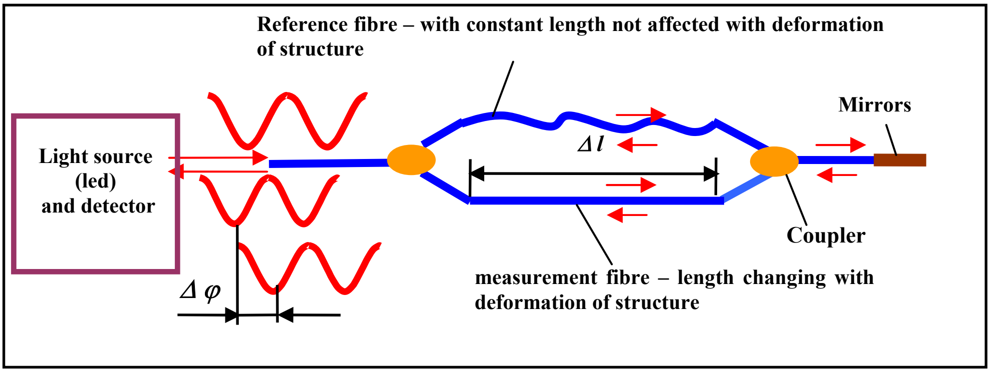

Figure 1: Basic principle of interferometric fiber optic sensor

Dinaudi D. And collaborators[3] constructed equipment based on this principle. Sensor has the ability to measure absolute deformation, which has been achieved by using of two interferometers in tandem and low coherent light source (LED). First interferometer is measuring interferometer, made of optical fibres which is attached or embedded into structure, and second interferometer is analysing interferometer incorporated into portable reading unit. Light signal from a LED splits by optical coupler into two components, each travelling one sensor fibre, reflected on the mirrors at the fibre end. Reflected light wave splits into two components by an optical coupler. One component is reflected in the portable unit by fixed mirror and other component is reflected by movable mirror. The movable mirror scans along the measuring range and as a results three peaks occurs. Difference between peaks is proportional to the measuring fibre deformation, i.e. to the deformation of the structure.

4. INSTALLATION PROCEDURES

During repair work into the columns S20 and S26 of Krk Bridge eight fibre optical sensors are embedded. Positions of sensors are indicated in figures 2 and 3.

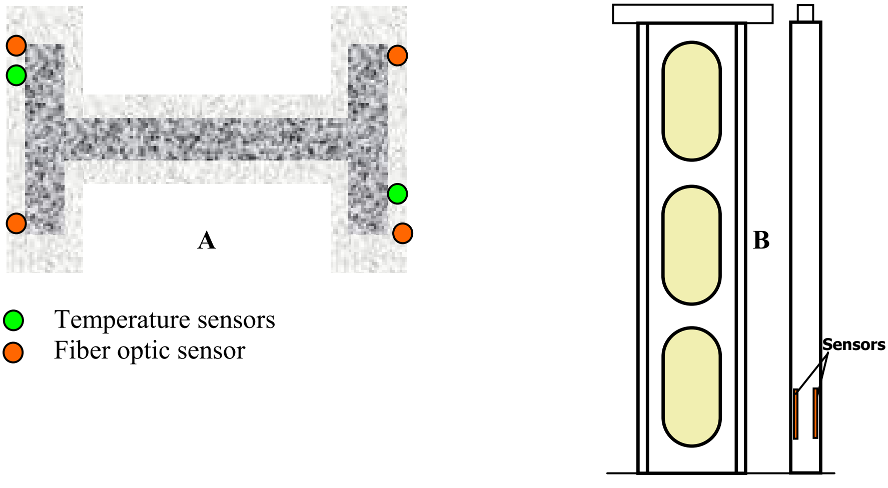

Figure 2: Sensor position on the bridge columns – A - cross section, B - Front and side view

Prior sensor installation a part of old protective coat sufficient for sensor installing, next to the reinforcement is removed by hydrodemolition technique as shown in figure 3. Surface for sensor mounting was flattened by electric hammer as shown in figure 4. After that sensor holders are fixed, at distance of 200 mm by inox bolts. Sensor is attached to the holders as shown in figure 5, then prestressing of sensors for 2,0 mm, necessary for measurement ability in both directions (column elongation and compression) is carried out. Finally, sensors are temporary protected in tin housing, which was remain until a new protective coat application.
Immediately before formwork mounting, protective sensor housing was removed, and sensors was embedded into concrete layer. This is the most sensitive phase for sensors, and subsequent inspection of sensors shows that seven of eight sensors survive concrete casting, which is acceptable result.

Figure 3: Removing of protective coat

Figure 4: Flattening of concrete surface

Figure 5: Sensor fixing onto inox bolts

Figure 6: Mounted sensor

5. MEASUREMENT RESULTS

First trial measurement in a state before beginning of repair works shows extraordinary accuracy in which we can find out short term behaviour of the structure - relative deformation in a range of 0,002 mm/m corresponding to stress of 0,04 N/mm^2.

Short term measurement can show rates of several different load influences, such as: traffic load, wind load and temperature expansion, as shown in figure 7. Slope of overall curve represent thermal contraction due with concrete cooling during night, sharp peaks are caused by traffic, and larger oscillations in the morning are because of wind.

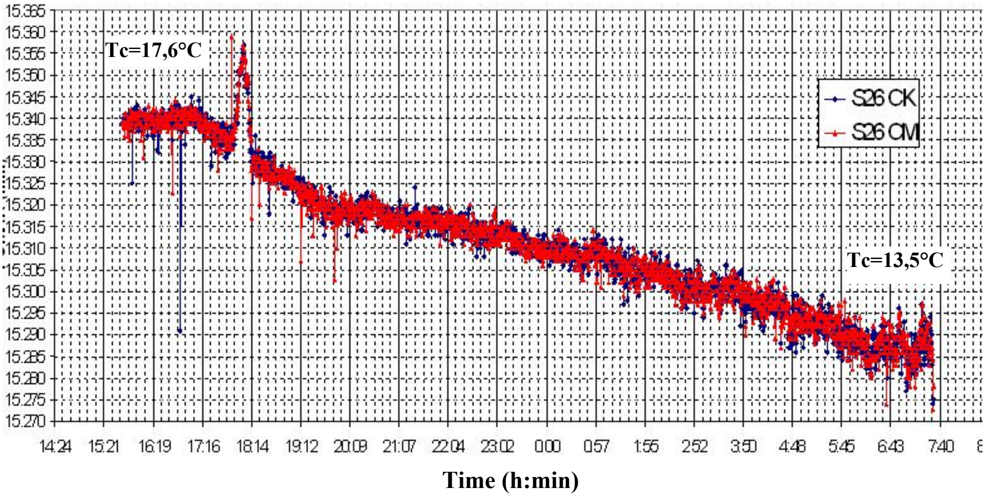

Figure 7: First trial measurements on column S 26

Figure 8 shows mounted sensors on the column S 26 before new protective layer application. Column S 26 above Small arch are disburdened during reparation by help of load bearing scaffolding and hydraulic presses, as shown in figure 9.

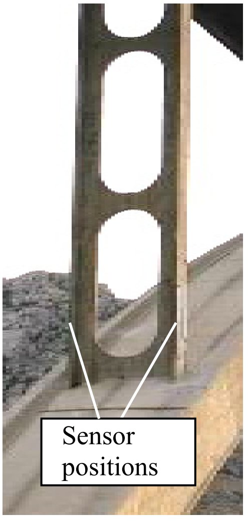

Figure 8: Mounted sensors

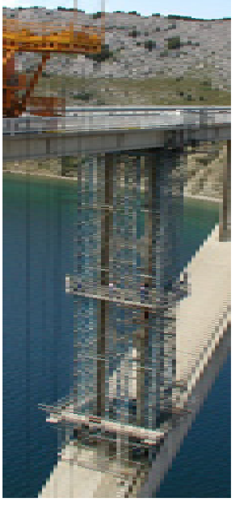

Figure 9: Disburdening of column S 26

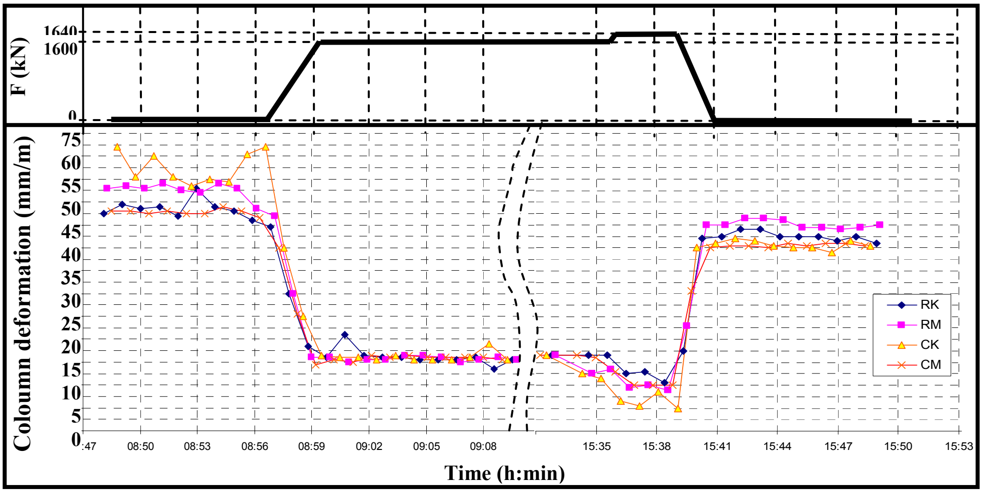

Figure 10: Measurement results for load application and load removal for column S 26 before new concrete layer application

Measurements with disburdened and loaded column was conducted, before and after new protective layer application.

Figure 10 shows measurement results for 4 sensors on a column S 26 before new concrete layer application. At the beginning of measurement session a column was loaded by road construction, and after that it was unloaded by reclining of road construction on scaffolding, by hydraulic presses. Pressure reading on hydraulic presses corresponded to 1600 kN at the beginning, and to 1640 kN at the end of measurement in unloaded state, which give column stress of 1,39 MPa and 1,43 MPa respectively. After unloaded phase column was loaded again.

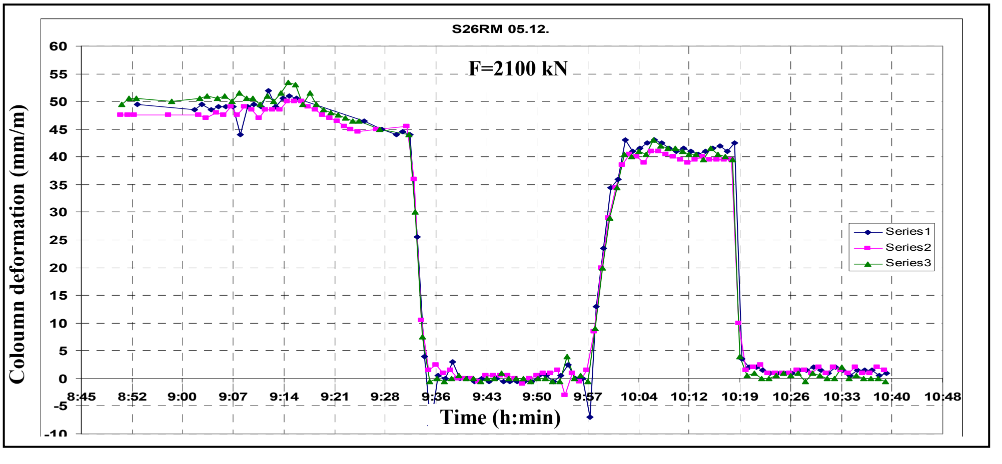

Figure 11: Measurement results for load application and load removal for column S 26 after new concrete layer application.

Few months later, after new concrete layer application, measurements were repeated, for the same states of loading and unloading, but this time column was more unloaded and force was 2100 kN. Taking into account larger force and larger column cross section due with thicker new concrete layer, column stress of 1,46 MPa was calculated. Obtained deformation measuring results exhibit similar relative deformations, as before refurbishment of columns, as shown in figure 11.

6. CONCLUSION

Measurement results give practical evidence of usability and advantages of fibre optical sensor measurement technique. Measurements after and before refurbishment of Krk bridge columns show similar deformations under load application, which leads to conclusion that concrete used for repair exhibit satisfactory mechanical properties and acts as a load bearing layer coupled with old concrete.

REFERENCES

[1] Würth D., Sekulić D. & Štemberga K. 2006. Properties of protective coating applied on concrete bridge. *Bridges - International conference proceedings, Dubrovnik.*

[2] Sekulić D., Bjegović D., Mikulić D. & Veža D. 2003. Corrosion Monitoring In Concrete Structures With Fibre Optical Sensors. 2003. *Int. Conference Structural Faults & Repair, "Extending the Life of Bridges, Concrete + Composites, Buildings, Masonry + Civil Structures", Commonwealth Institute, London, 1-3 July 2003* .

[3] Inaudi D., Elamari A., Pflug L., Gisin N., Breguet J. & Vurpillot S. 1994. Low-coherence deformation sensors for the monitoring of civil-engineering structures, *Sensor and Actuators A, Vol 44:* 125-130.