7th Research/Expert Conference with International Participations
"QUALITY 2011", Neum, B&H, June 01 – 04, 2011

DEVELOPING MEASUREMENT TECHNOLOGIES FOR IMPROVING THE QUALITY OF CONSTRUCTION

Andrej Štrukelj
University of Maribor, Faculty of Civil Engineering
Maribor
Slovenia

ABSRACT
Civil engineering objects are exposed to different loading cases, which can have an important influence on structure functionality, safety and durability as well as on the safety of their users. To assure the quality of construction process as well as full functionality of structures through their entire life cycle it is of great importance that we have enough possibilities to follow their behavior and response to different types of loadings. The first step to make this possible is to establish a stable and reliable monitoring system consisting of robust and cost effective sensors which are applied on all important places of the structure especially at difficult or even impossible accesses after the construction works are finished. In order to follow this concept, very efficient sensors for strain measurements inside the concrete structures were developed. They are based on strain gage technology and are cheap and easy to build into structures. It is very important that the positioning of sensors at the chosen measuring points does not disturb the construction process and the measurement results can be continuously obtained from the early construction stages to the end of the structure life cycle. Finally, some very successful examples of practical use of such monitoring system will be presented in my paper.

Keywords: quality of construction, monitoring, construction phases, structure performance

1. INTRODUCTION

The idea of developing the efficient monitoring system arose in 1998 when more than fifty bridges, overpasses and viaducts in Slovenia were investigated. Some of them needed additional strengthening, some of them had to be totally reconstructed. The reason for that was that the Nuclear power plant in Krško needed new steam generators. They were transported by a ship from Spain to Koper. However, the transport of two compositions from Koper to Krško, that weighted more than 800 tons, used the road infrastructure system. In some cases, the weight of this transport several times exceeded the project loading and sometimes also the additional loading effects were caused due to inconvenient load distribution on bridging structures. The design engineers responsible for the strengthening and reconstruction of bridges had to establish their present bearing capacity to find the optimal way for making them capable to carry the heavy transport. In most cases, the existing project documentation was the basis for strengthening and retrofitting projects but still there remained the question if this was enough since no one could determine the degree of degradation of structures older than 30 years with certainty. Therefore, all accessible vital parts of structures were carefully examined and sometimes also the loading tests were performed. A big amount of examined important structure parts could be reached only by specially made scaffolds or with the help of special trained stuff that used alpine climbing equipment. Hence, it would be very convenient to have a monitoring system consisting of sensors already installed on such difficult reachable points which could provide data about the behaviour of structure and the condition of its vital parts.

Nowadays many types of sensors are developed so that they can be built into structure body (temperature and moisture sensors, sensors for measuring the corrosion level, etc.). In the present paper the main attention is focused on the development and usage of strain sensors that proved themselves very reliable and applicable.

2. THE DEVELOPMENT OF SENSORS

The strains of concrete structure elements are usually measured on its surface. For the surface strain measurement on concrete elements, which should be at least 100 mm long, strain gages have to be applied directly to the concrete surface. Since the concrete surface is not smooth, it should be grinded as much as possible in order to be suitable for strain gage application. The smoothing of the surface therefore produces a lot of dust which could influence a quality of adhesion. Another problem is that the whole process of strain gages application and wiring takes a lot of time and disturbs a normal working process on a construction site. The measurement points and connection wires are usually exposed to rough conditions in the sense of temperature changes, precipitations and several possibilities of damage. This may cause disturbances in measurement signal especially when the period of measurement is very long. Last but not least, sometimes very important events that should be followed by strain measurements appear when the concrete is still in formwork and the places where the strain gages should be applied cannot be reached or the surface of observed concrete element may be too wet. To avoid the majority of these problems the other concept for preparation of measuring points can be used. The idea is to build a complete strain sensor for a single measurement point with all layers of protection coatings and wiring. Such sensors can be placed to desired positions in a very short time. They are insensible for moisture and dust and their vital parts are very well protected against mechanical damage. The basis for such sensors is a standard reinforcement bar of length about 150 cm and diameter 16 mm. In the middle of the reinforcement bar its surface is grinded on both opposite sides. Strain gages can be connected in full, half or double quarter Wheatstone bridge. The connecting cable is protected by a PE tube and fixed to the reinforcement bar as seen in Figure 1.

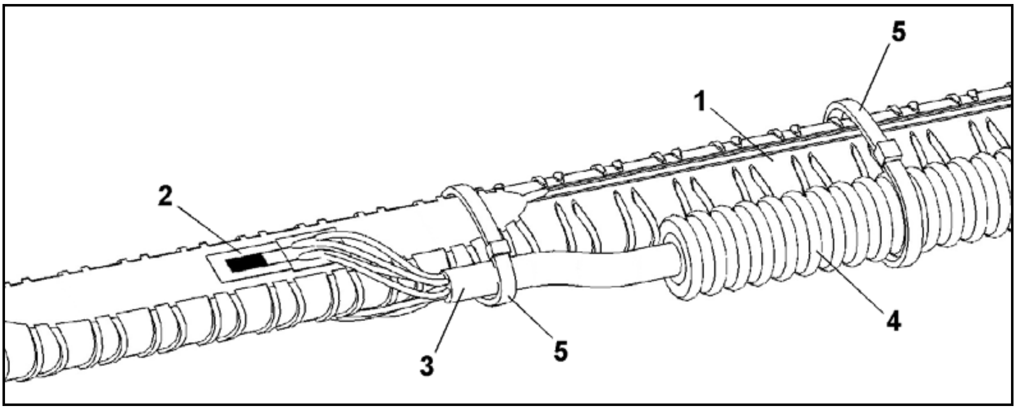

Figure 1: The measurement area of the strain sensor before application of protection coatings: 1 - reinforcement bar; 2 - strain gage with solder points; 3 - connection cable; 4 - PE tube for cable protection; 5 - PE binding element used to fix the cable to the reinforcement bar

The protection coatings consist of two layers of PU warmish, a layer of special silicone putty and a layer of permanently plastic sealant putty coated by aluminium foil. This combination of protection was tested and remained waterproof even at 30 m under the water surface. The final layer represents the physical protection and can be made of PE tube (Figure 2) when the dimensions of the measured concrete elements are not too small to be significally weakened by the built in sensor. Otherwise the physical protection of measurement area can be made of cement mortar with addition of acrylic emulsion as shown in Figure 3. This type of strain sensors proved very reliable, easy to build and cost effective.

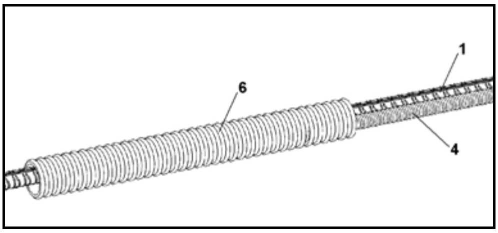

Figure 2: The final look of the strain sensor after application of protection coatings and physical protection of measurement area made of PE tube: 1 - reinforcement bar; 4 - PE tube for cable protection; 6 - PE protection tube of inner diameter 40mm for protection of measurement area

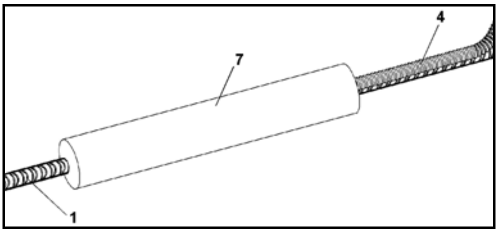

Figure 3: The final look of the strain sensor after application of protection coatings and physical protection of measurement area made of cement mortar: 1 - reinforcement bar; 4 - PE tube for cable protection; 7 – cylindrical shaped protection of measurement area made of cement mortar with the addition of acrylic emulsion

3. EXAMPLES AND RESULTS OF STRUCTURE MONITORING

3.1. Investigations of deep foundations

Foundations of bridging structures are frequently laid on soils of unfavourable geological composition which leads to decision to lay foundations on pilots or wells. In spite of an extremely sophisticated and expensive realization of these foundation structures, in most cases no activities are run during the construction and exploitation phase that would provide a designer with a feedback about the outcome of the foundation design or the effect of the selected foundation laying method on the behaviour of the whole structure as a result of soil-structure interaction. To verify the numerical simulations of pile behaviour, the described sensor systems were used to investigate the bearing capacity and shaft resistance of pile structures. These were embedded into some pilots and tested for their performance and sensitivity to mechanical damage as well as different embedment techniques (Štrukelj et al. 2005). The analysis of the obtained results showed that our endeavours are sensible since these systems would allow not only to monitor the pilot foundations but also to determine the extent of deformations transmitted to the soil with friction via the pilot coating and the extent of deformations transmitted to the pilot footing. This means that the whole mechanical soil–structure interaction could be monitored. It would be possible to analyze the pilot behaviour at vertical and horizontal loading. These systems would be especially effective if loading tests were used to determine the load-bearing capacity of pilots. Considering a great number of measuring results along the total pilot axis at different regimes and intensity of static and dynamic loads, designers could obtain a complete image of the testing pilot behaviour and its interaction with the soil. The results obtained in this way would also allow improvement of mathematical models and the realization of quality computer software to simulate the behaviour of foundations as well as the structure as a whole. The Figure 4 presents time history of normal strains measured along the test pile axis during the statical loading test of a pile. Because of graphical limitations only four curves are shown. On the basis of measured results the average pile shaft resistance has been estimated. The same situation was simulated by 3D computer analysis. After improving the soil model based on measured results the measured and calculated results showed very good agreement.

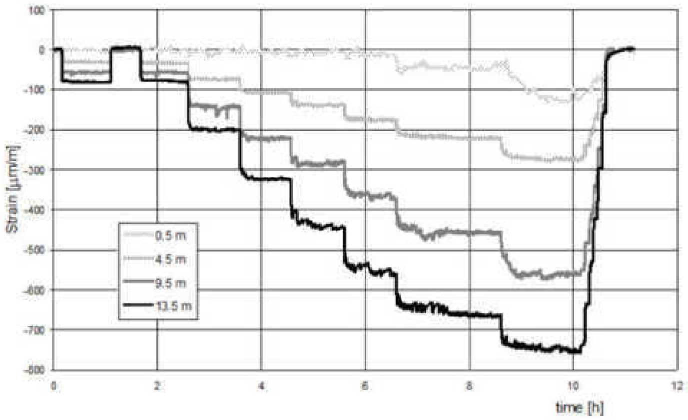

Figure 4: Time history of the measured normal strains along the test pile axis through all loading stages

3.2. Monitoring of bridging structures during construction

A new viaduct "Peračica" was built in 2007 on the highway Ljubljana – Jesenice. The spans situated on both ends of the viaduct are 73.50 m and the both middle spans are 110.00 m. The heights of three piers are 27.00 m, 50.00 m and 56.00 m. For the construction, the balanced cantilever technology was chosen. The building of the bridge deck started from each pier where the base segment had length of 7.50 m, the length of first segment on both sides of each pier was 4.00 m and all other segments except the last (middle) one were 5.00 m long. The disposition of the viaduct is shown in Figure 6. This was the first large viaduct where the efficiency of new developed monitoring system was tested. During the construction, 72 strain sensors were put in all important parts of the structure including foundations, piers and important places in bridge deck. Strains were measured in all measurement points and they were compared to the results of computer simulations. Due to graphical limitations, there will be only the presentation of measurement results from the measuring points placed in the corners of the section between the first and the second segment of the deck structure seen from the highest pier in western direction. The section where the results are presented is also signed with A-A in the Figure 5.

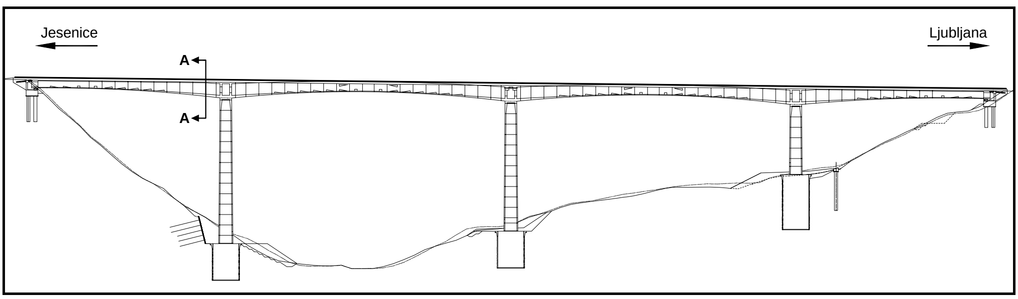

Figure 5: The longitudinal section of the Viaduct "Peračica"

In Figures 6, 7 and 8 the strains caused by three characteristical events during the building of one segment of viaduct are presented: In Figure 6 the strains during concreting of the third

CONTENTS
AUTHORS

segment are shown, in Figure 7 the strains during prestressing of the same segment can be seen and in Figure 8 the strains caused by moving of the erection gantry from the second to the third segment are displayed.

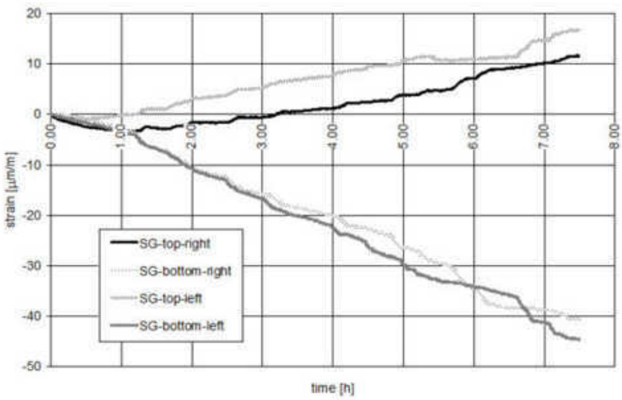

Figure 6: Strains in the corners of section A-A during the concreting of the third segment

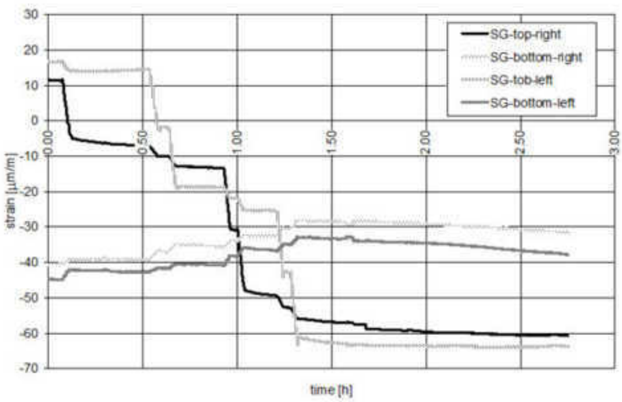

Figure 7: Strains in the corners of the section A-A during prestressing of the third segment

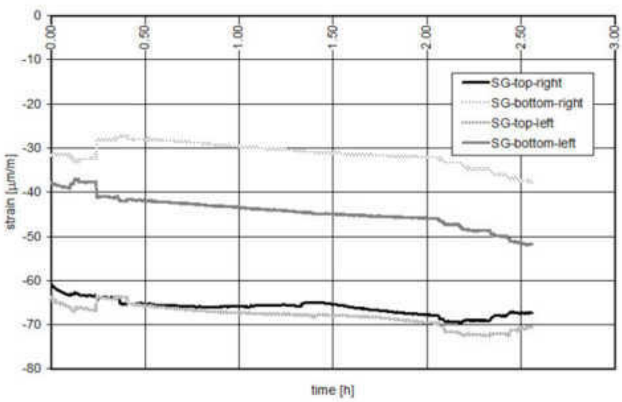

Figure 8: Strains during the moving of the erection gantry from the second to third segment

The described sensors were carefully tested before usage in the structure of viaduct "Peračica". They were first built into the body of deck structure of a small highway overpass near Maribor in October 2004. Until now all twenty sensors are in operation and all of them are working properly and stable. Since the cost of material needed to prepare a sensor does not exceed 110.00€ the price - performance ratio is very convenient. The price of monitoring depends on type of investigation needed to be performed. The simplest kind of monitoring is the measurements of structural response on expected events in a short period of time. The operator has to plug only the connection cables from sensors to the measuring equipment and perform the planned measurement. On the other hand, permanent monitoring can be the most complex and it demands the measuring device which is connected all the time. It needs the permanent reliable energy source and the computer with software which would/could control the measurement and save the measured results. If the computer has internet connection or remote access of any other possible ways, the presence of measuring stuff at the testing or in a construction site is no longer needed. The measurements can be manually (through the remote connection) or automatically triggered. Such complex type of measurement system can be used at the same time as a warning device which can set up an alarm when one or more measured values reach or exceed the limit values.

4. CONCLUSIONS

To sum up, during the construction works some very useful information about loading history, which are not available after finishing the structure, could be obtained with simultaneously performed monitoring of structure behaviour. Therefore, obtained data together with information gathered during the exploitation of the structure are very important, especially for later strengthening, reconstruction or even maintenance of structure. What is more, continuous monitoring throughout all important construction stages is of essential importance in the case of using the construction technologies if the loading intensity on some structure parts is much higher during the construction than during the exploitation period (for example the technology of balanced cantilever construction of bridging structures). This contributes essentially to higher level of quality and safety during the construction. With the use of measured data regularly obtained and analyzed during the exploitation period it would be also possible to create the criteria that could assure the optimal strategy of structure maintenance in order to keep the full functionality of structure through its entire lifecycle. Moreover, the analysis of the last stage in the structure life (eventual demolition) could be performed with such monitoring system. In that case the important information about the influence of local overloading and collapse on global stability and safety of structures, that are similar to observed one, could be obtained. On the basis of such results the quality and safety of similar buildings can be significantly improved.

5. REFERENCES

[1] Crowter, C. L. (1988), Load Testing of Deep Foundations: The Planning, Design and Conduct of Pile Load Tests.

[2] Hoffman K. (1996), Hinweise zum Applizieren von Dehnungsmeßstreifen (DMS), 4. erweiterte Fassung. Darmstadt: Hottinger Baldwin Messtechnik GmbH

[3] Ryall M. J., Parke G. A. R. and Harding J. E. (2000) Manual of bridge engineering. Bodmin: Thomas Telford Limited

[4] Štrukelj A., Škrabl S., Štern K. and Logar J. (2005) The assessment of pile shaft resistance based on axial strain measurements during the loading test. Acta Geotechnica Slovenica, 2005/2, pp.13-23.

[5] Štrukelj A. (2008) The sensor for strain measurements in civil engineering structures. Patent declaration No. P-200800063. Ljubljana: The Slovenian Intellectual Property Office