EXPO 02, Piazza Pinocchio: Monitoring visitor’s live loads

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ABSTRACT

Once every generation, Switzerland treats itself to a National Exhibition commissioned by the Swiss Confederation. Expo 02 was spread out in five “Arteplage” over a whole region: the land of the three lakes, on the shores of the lakes of Biel, Murten and Neuchâtel, which are located in the northwest of Switzerland. Each “Arteplage” relates to a theme, which is reflected in its architectures and exhibitions. The “Arteplage” of Neuchâtel was related to “Nature and Artificiality”; A big steel-wood whale eating a village represents the fairy tale named “Pinocchio” from the Italian writer Collodi. The “Piazza Pinocchio” was built together with other exposition buildings on one large artificial peninsula.

The belly of the whale holds the exposition dedicated to robotic and artificial intelligence, while the rest of the village was developed on two floors with steel piles / beams and wood walls and floors.

A fiber optic sensor system was commissioned to monitor the visitor’s loads over the whole “Piazza Pinocchio”. The main requirements were: real-time computer-screen figure-form results of the live loads during 18 hours a day, automatic thermal-induced strain compensation, real-time warnings and pre-warnings for each single pile, automatic phone call advises when reaching warning thresholds and remote monitoring for complete management of the monitoring system. The SOFO system based on low coherence fiber optic deformation sensors was selected to carry out the requirements.

The aim of this paper is to present an overview of the project, the installation solution, the results, and data analysis of the installed monitoring system.

Keywords: Fiber Optical Sensors, live loads, on-line structural monitoring

1. INTRODUCTION

In order to grant structural safety and optimal serviceability during the opening and in-service of the Piazza Pinocchio at the National Exposition 2002 in Neuchâtel, Switzerland, a real-time optical fiber monitoring system was selected and commissioned to SMARTEC SA, Switzerland.

One peninsula, comprehending Piazza Pinocchio and other five exposition structures was built on piles about 50 meters far from the shore and 5 meters above the lake water level. The global view of Expo 02 in Neuchâtel, Switzerland is shown in Figure 1.

These piles were installed with the aim to support the peninsula and the structural loads; a differentiated support settlement or just the loads due to visitors would have meant redistribution of forces in the hyperstatic steel structure. Moreover, the thermal-induced strains would have caused the same effect and a numeric emulation would have been too laborious without giving an indisputable real-time feedback on structural behavior.

One of the architects’ aim was to allow visitors to walk over the two exposition floors without restrictions.

Since it was not possible to forecast visitor’s behavior easily the EXPO 02 committee decided to monitor the Piazza Pinocchio. The SOFO monitoring system was selected because of its high resolution, the real-time computer screen representation and automated alert on warnings.

The monitoring aims were: real time visitor’s live loads monitoring, computer screen representation, complete remote control, alert on warnings by using screen indicators, sonorous devices and automatic phone calls.

To reach these aims; 31 SOFO sensors, 31 thermocouples and one central measurement point were installed.

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2. INTRODUCTION TO SOFO SYSTEM

The monitoring system selected for this project is SOFO (French acronym for Surveillance d’Ouvrages par Fibres Optiques – Structural Monitoring using Optical Fibers), it is based on low-coherence interferometry in optical fiber sensors. The functioning principle of the SOFO system is presented in Figure 2. The SOFO system consists of sensors, a reading unit and data acquisition and analysis software. The sensor consists of two optical fibers called the measurement fiber and the reference fiber, both contained in the same protection tube. The measurement fiber is coupled with the host structure and follows the deformations of the structure. In order to measure shortening as well as elongation, the measurement fiber is prestressed to 0.5%. The reference fiber is loose and therefore independent of the structure’s deformations; its purpose is to compensate thermal influences to the sensor. The optical signal (light) is sent from the reading unit through a coupler to the sensor, where it reflects off mirrors placed at the end of each fiber and returns to the reading unit where it is demodulated by a matching pair of fibers. The returned light contains information concerning the deformations of the structure, which is decoded in the reading unit and visualized using a portable PC. Typical sensor length (gage-length) ranges from 250 mm to 10 m, while the resolution reaches 2 micrometers (2/1000 mm) independent of the gage-length and with an accuracy of 0.2%. The dynamic range of the sensors is 0.5% in compression and +1.0% in elongation.

The SOFO system was developed in early 1990’s and since 1995 it has been commercialized and applied to the monitoring of a wide range of civil structures, such as geotechnical structures, bridges, dams, residential and industrial buildings. The system is insensitive to temperature changes, EM fields, humidity and corrosion, and immune from drift for at least 6 years (after the first installation), making it ideal for both short- and long-term monitoring (estimated long-term stability is up to 20 years). Sensor can be both directly embedded into the fresh concrete or surface mounted using the particularly designed L-brackets which permit easy installation; require no calibration and feature high survival rate (more than 95% for correct concrete embedding in normal conditions). The long gage-length makes them more reliable and accurate than traditional strain sensors, averaging the strain over long bases and not being influenced by local defects in material such as cracks and air pockets. More information on the SOFO system and its applications and references can be found in the web site www.smartec.ch
3. BUILDING CHARACTERISTICS

The Piazza Pinocchio building consisted of two levels with steel piles / beams, wood walls and floors. The design of the building represents the whale of the fairy tale named “The adventures of Pinocchio” from the Italian writer “ColloDi”. The main floor (inside the whale belly) comprehends two expositions regarding “Artificial Intelligence” and “Robotic Systems”, while the rest of the village (mainly on the firsts floor) was developed on the whale’s back as shown in Figures 3a and 3b. A large textile membrane was used to cover “Piazza Pinocchio”. After closing Expo 02 the structure as well as the monitoring system were dismantled.

Figures 3a and 3b: Different sights of the whale
4. MONITORING CONCEPT

The sensor monitoring concept was developed together with: structural engineers for the technical part, with architects to decide on the aesthetic and logistic and together with the Expo 02 Security Department to develop warnings procedures.

Technical aims were to grant detection of small load changes, to identify thermal-induced strains and to detect bending on representative piles.

The resolution of the SOFO System is 2 micrometers regardless of the sensor gage length; to grant the detection of the weight caused by 10 people (700 kg) carried by one pile (which corresponded to about 20 kg/m²!) sensors with a length of 1m were selected.

The Calculus of the minimal detectable weight changes is presented in Equation 1.

\[ F = \frac{\Delta L [mm]}{L [mm]} \cdot E [kN/mm^2] \cdot A [mm^2] = [kN] \]  

(1)

Where \( \Delta L = 0.002 \) [mm] SOFO system resolution, \( E = 210 \) [kN/mm²], \( A = 7680 \) [mm²] (Piles type HEA 240, profile surface), \( L = 1000 \) [mm] (SOFO sensor gage length).

The resolution in terms of load is presented in Equation 2.

\[ F = \frac{0.002 \text{ mm}}{1000 \text{ mm}} \cdot 210 \frac{kN}{mm^2} \cdot 7680 \text{ mm}^2 = 3.22 \frac{kN}{mm^2} = 320 \frac{kg}{mm^2} \]  

(2)

The increase of minimal load detection would have been possible using longer SOFO sensors, but 1 meter-long sensors were finally selected to facilitate installation.

To detect bending moment effects, four SOFO sensors were installed at the edges of one representative pile. With that lineup it was possible to detect bending moments (caused mainly by the hyperstaticity) with respect to two axes.

To isolate thermal-induced strains one thermocouple per pile was installed. The monitoring concept is schematically represented in Figure 4.

![Figure 4: monitoring concept scheme](image)

Continuous measurements by means of SOFO sensors were carried out over five months during the daily opening hours (about 18 hours a day). In the morning, before visitors were on site, the zero measurements were launched. This measurement was useful for comparing the measurements without live loads. Approximately 6 minutes were necessary to read all sensors. After each measurement session the computer screen was automatically updated and if warning threshold reached, the alert status was activated.
5. SOFO SYSTEM INSTALLATION

The sensors installation was carried out step by step. To help building enterprise to maintain the construction work schedule, the sensor active parts were installed on piles during construction while the connecting cables were installed at a later time inside the 1st floor wood pavement. The central measurement point consisted of one reading unit, one optical channel switch and one computer connected to the phone line. The central measurement point was installed in the control room (on the first floor) together with other devices used to manage and control the Piazza Pinocchio’s shows and performances. The photography of installation are presented in Figures 5a–5d.

Since some sensors were installed in rooms accessible to visitors, it was necessary to cover them in order to grant good aesthetical impact and protection. Moreover, in certain piles (HEA 240 profile), neon lamps were installed, so protection against unintentional accident was necessary. For these reasons the architects decided to protect the pile by using an aluminum grating. The presence of neon lights was considered non intrusive (in order to isolate thermal-induced strains) since neon lights were alight during the whole monitoring time. Thus, as the emitted heat was constant it didn’t affect the measurements.

The thermocouple heads were covered using pieces of polystyrene granting ambience thermal isolation.
Before the national exposition start the committee had planned a “warm-up” day where more than thousand people had been asked to freely visit the exposition (as shown in figure 6a and 6b) and to consent to trial load test where people had to stay very closely for few minutes. The aim was to compare the loads to the structure behaviors.

6. SOFTWARE DESCRIPTION

To ensure an active monitoring new applications were developed and integrated in standard SOFO system software. The aims of the software were to help detection of alteration in structural behavior in quasi-real-time environment, to visualize the automatic elaborations and at the same time to export daily measurements for a post-processing. The standard software (SOFO SDB) allows selection of sensors and monitoring periods to be analysed. It also allows simultaneous visualization of results obtained from selected sensors (not necessary all of them) over a selected period or after each measurement session in form of tables and diagrams or to visualize each single sessions directly on one selected picture of structure or on one technical drawing. The software was run in quasi-real-time in parallel with monitoring (each session of measurement is visualized immediately after the execution). Pre-warning and warning thresholds were set for each sensor, and if these values were reached or exceeded, appropriate software actions were executed in form of phone call to EXPO 02 Security Department.

New modules were developed making possible to combine real sensors using mathematical functions (e.g.: Sum, Product, Exponentials, Averages, Min, Max, …) in order to create more powerful and meaningful sensors. Using these powered SOFO sensors, called Macro-Sensors (MS), it is possible to extract in a real-time environment more information from the monitoring, calculating indirect parameters such as: loads, forces, stress, weights,… At the Expo 02 it was necessary to monitor continuously the live loads present on each pile and check constantly if the value exceeded the pre-warning and warning thresholds. To accomplish this operation, the macro-sensor “Sum” was used allowing calculus of linear combination of the sensors, as shown in Equation 3.

\[ F(s) = \sum_{i=1}^{n} k_i \cdot S_i \]  

(3)

For the purposes of EXPO it was necessary to express results in terms of live loads. The result (weight) applied to the single pile is calculated as a linear combination of the measurements obtained from SOFO and the thermocouples. For each pile, a MS has been created, as presented in Equation 4 in addition the pre-warning and warning thresholds were calculated and inserted in the software.

\[ F(s) = \frac{A \cdot E}{L} \Delta L - A \cdot E \alpha \cdot T \]  

(4)

A typical macro-sensor graph is shown in Figure 4. Pre-warning and warning thresholds together with loads evolutions during the day are also presented in Figure 7.

![Figure 7: A typical macro-sensor graph.](image-url)
The measurements management consists in sensors reading, alert threshold check and visualization of the results according to schedules. After the scan of the real sensors MSs values were calculated. During each session, all the real sensors (SOFO and thermocouples) were measured and the relative MS calculated. At the end of each session MS results were compared to relative thresholds to check the presence of alterations in structural behavior.

In Figure 8 weights (ton) measured on each pile are shown on the “Piazza Pinocchio” top view map. This output is updated automatically after each session of measurements.

Every day, at the closing time, the system automatically executed a backup of the database and generated an excel file (as official results document). After that, it prepared the new configuration file to be used the following morning and switched off.

![Image](image.png)

Figure 8. In this Figure are shown the forces measured on each pile. This output is updated after each session of measurements.

To grant the access to the monitoring system from different locations, the remote monitoring option was provided. Using a direct phone line it was possible to manage the whole monitoring system from SMARTEC’s office that is located in the South of Switzerland.

7. CONCLUSION

The Piazza Pinocchio of Expo 02 in Neuchâtel, Switzerland was monitored. The SOFO system based on low coherence fiber optic deformation sensors was selected to carry out the requirements. 31 SOFO sensors and 31 thermocouples were installed on steel piles to monitor real time visitor’s live loads. The main requirements were: real-time computer-screen figure-form results of the live loads during 18 hours a day, automatic thermal-induced strain compensation, real-time warnings and pre-warnings for each single pile, automatic phone call advises produced when reaching warning thresholds and remote monitoring for complete management of the monitoring system.
At the end of this experience it is possible to say that every step has been accomplished in a proper and useful way. During the five months opening of Expo 02 neither a warning nor a false alarm was generated. The monitoring system allowed not only to grant safety and deepen knowledge on structural behavior but also to exceed the load limits and restrictions recommended by the Swiss Construction Norms.

8. ACKNOWLEDGMENTS

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9. REFERENCES

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