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AUTOMATIC MONITORING OF THE RIDDES BRIDGES USING ELECTRONIC INCLINOMETERS

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Abstract. *The paper presents an innovative method of measurement of long-term deformations of bridges. The use of high precision electronic inclinometers permits an efficient and cost-effective automatic monitoring of bridge deformations. The system is easily applicable to structures subjected to intense traffic loads and is able to follow accurately the movements of the bridge during daily and seasonal temperature variations.*

The system has been in operation in the Riddes viaduct in Western Switzerland for over a year, and has provided valuable information on the behavior of the bridge under service condition. The aim of the measurements is to provide the owner with accurate information on the on the possible downward tendency of the main span. Because of extreme temperature movements, which occasionally exceed 50 mm within a single day, classical methods of measurements are inapplicable, or would at least require a very long period of observation. The system has been able to quantify that tendency within less than tree years of measurement. Preliminary results indicate that previous interventions on the bridge have mainly stabilized the downward deflection behavior.

1. INTRODUCTION

The paper presents the results of measurements made on the Riddes twin bridges starting in late 1999. The purpose of the measurements was to assist the owner in the decision process concerning a possible retrofitting of the bridges, which, as several other but similar bridges, exhibit an apparently non-stabilizing increase of their mid-span deflections. The necessity to predict long-term deflections based on a relatively short period of measurements has led to the choice of a combination of measurement techniques : a proven hydrostatic leveling system combined with automatic measurements using electronic inclinometers, with in addition a series of temperature measurements[1,2,3].

2. CHARACTERISTICS OF THE RIDDES BRIDGES

The twin Riddes Bridges are located on the highway that crosses the Canton Valais in Western Switzerland. They allow the highway to cross the Rhône River at a very sharp angle (fig. 1). Build in the late 1980's by the balanced cantilever method for the main span over the river, the bridges have a very special shape, that reminds of present-time extradossed bridges. That shape allows the crossing of the Rhone river without having to significantly raise the level of the roadway.

Figure 1: General view of the two Riddes bridges

The two bridges are identical, with two approach spans of 55 m and a central span of 143 m, with a hinge at mid-span. Because of that hinge, long-term deflections cannot induce positive moments at mid-span and thus mobilize the stiffness that a continuous bridge would have.

As other bridges with a hinge at mid-span[5,6,7,4], the Riddes bridges have exhibited over the years deflections that were not stabilizing as anticipated by the designers. Figure 2 shows the increase in mid-span deflections over the years. By the late 1990's, it was decided to take opportunity that two post-tensioning ducts remained empty in the structure to add some post-tensioning to the bridges. As it appears from fig. 2, this intervention had the effect of lifting the mid-span by about 60 mm. But further measurements seemed to indicate that the downward descending rate of the bridges was not significantly altered. This type of behavior had already been observed in the South Lutrive Viaduct some years earlier, so it was decided to monitor more closely the two bridges, in order to provide more information on the actual behavior of the bridges and, in case this would become necessary, to help in the conception of the retrofitting. The figure 2 shows also the measurement made by the authors after the reinforcement (end of the year 1999 - 2001).

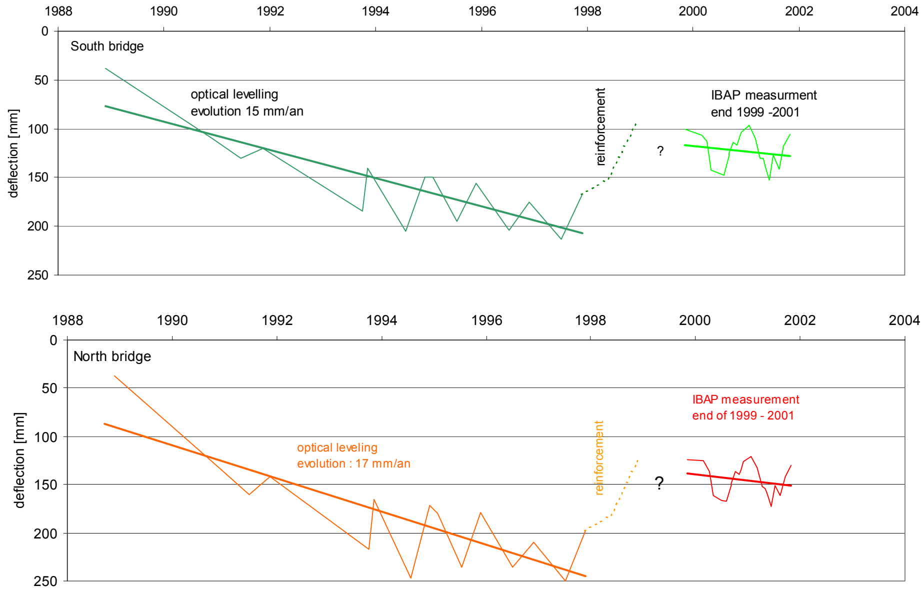

Figure 2: Deflections at mid-span of the two Riddes bridges since completion

3. INSTRUMENTATION

The two bridges were instrumented starting in late 1999 with a complete network of hydrostatic leveling devices. These simple devices, already widely used to follow the long-term deflections of large structure, are very easy and inexpensive to install and operate. Because the measurements are not automatic, however, they only provide punctual information. In order to increase the accuracy and to better follow the bridges over the years, it was decided to perform monthly measurements of the bridges, instead of the more common quarterly measurements. As figure 3 shows, this density of the measurements gives a good idea of the behavior of the bridges.

It was observed very early in the process – and this had been noticed before by the surveyors in charge of the early monitoring phase – that the Riddes bridges are very sensitive to temperature, both seasonal effects, as can be seen from fig. 3. It was therefore decided to install an automatic measurement system in the bridge. This system consists for each bridge in a network of 7 electronic inclinometers, connected to a central computer located under the bridge (fig. 4). This system is complemented by a series of 20 thermocouples that follow the bridge's temperature as well as the ambient temperature (fig. 5). Measurements are taken every minute and stored on the local computer. The results are manually transferred to a laptop during site visits that are coordinated with the monthly hydrostatic measurements. The system has exhibited a very good reliability, with only a few interruptions of service, most notably in October 2000 during an inundation that left most of Valais inaccessible for a couple days. The material losses were very limited at that occasion, however.

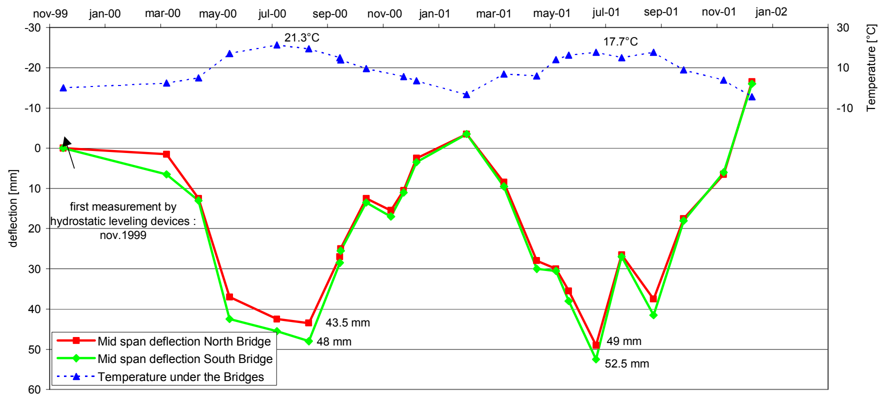

Figure 3: Measurements by hydrostatic levelling since 1999

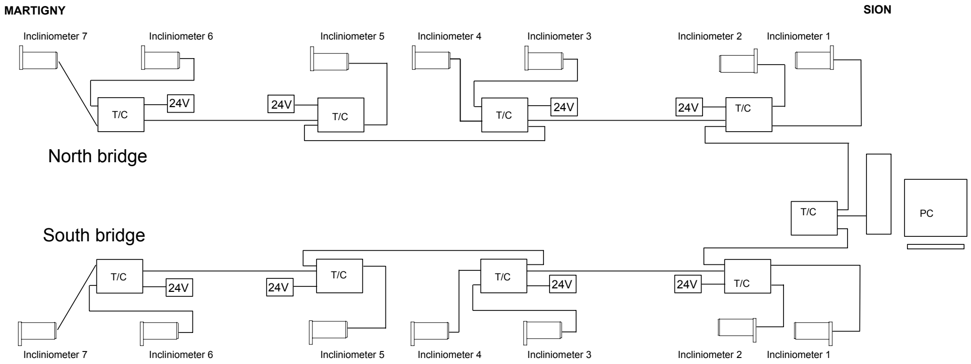

Figure 4: Schematic view of the network of electronic inclinometers in the two Riddes bridges

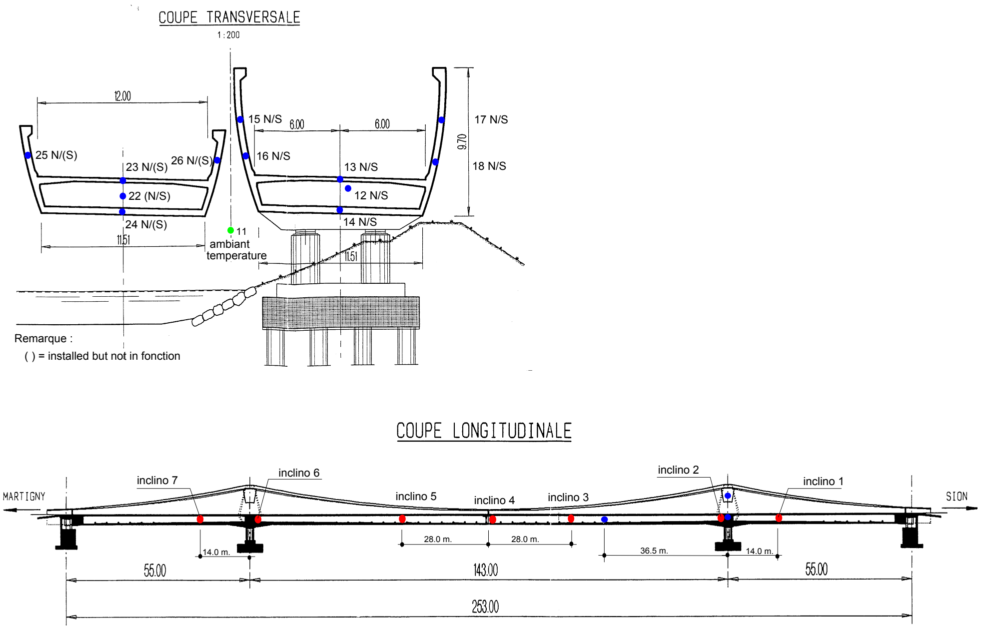

Figure 5: Instrumentation of the Riddes bridges : inclinometers ● and thermocouples ● ●

4. PRELIMINARY RESULTS

The monitoring has started in late 1999 and early 2000. The results presented here are only preliminary, but are certainly representative of the behavior of the bridges. The bridges' deflections have been reconstructed from the angular measurements of the inclinometers, leading to probable deflected shapes. Several algorithms have been used to that effect. In some cases, it is best to use a linear combination of deflected shapes, pre-computed using a realistic model of the structure. In the case of the Riddes bridges, however, it has been found that a simple fitting of a polynomial through the measured angles, followed by an integration of the polynomial is sufficient to achieve a good accuracy.

Figure 6 shows the deflected shape of the Riddes bridge relative to is position at it maximum elevation, at 9AM. Figure 7 shows the reconstructed mid-span deflection of the bridge over a single day, compared with measurements made by the hydrostatic leveling system. The concordance of both methods is good. Notice that the daily amplitude of displacements exceeds 40 mm. In some cases, even higher daily amplitudes have been observed. This illustrates why manual monitoring the this type of bridge is difficult. A slight change in the time the measurement is made, or a change in ambient temperature can lead to substantially different results.

Figure 8 shows the deflected shape of the South Riddes bridge since the start of the measurements. The dots indicate the measurements made by the hydrostatic leveling system. The long-term reliability of the inclinometers is good, but, in order to improve the accuracy, the system was reset to the value given by the hydrostatic leveling system at several occasions, indicated by dark dots in the figure. The wide scatter in the figure is the sole result fo thermal effects, as the signal given by the inclinometers permits an efficient filtering of the results, thus eliminating the effect of traffic loads on the measurements. Again, the large influence of the thermal effects complicates the interpretation of the results, making a prediction of the trend in the deflections difficult.

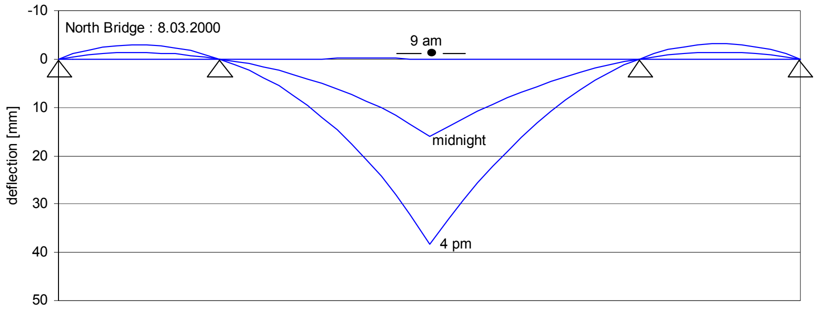

Figure 6: Longitudinal view of the deflections of the South Bridge relative to its position at 9AM on March 8th, 2000

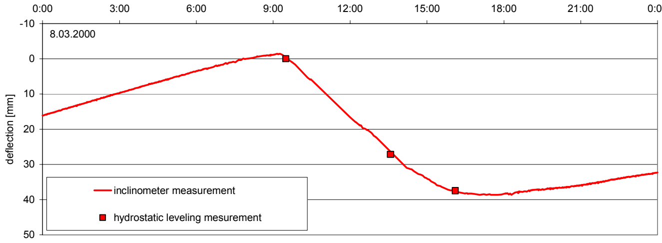

Figure 7: Reconstructed deflected shape of the South Riddes bridge over 24 hours on March 8th, 2000

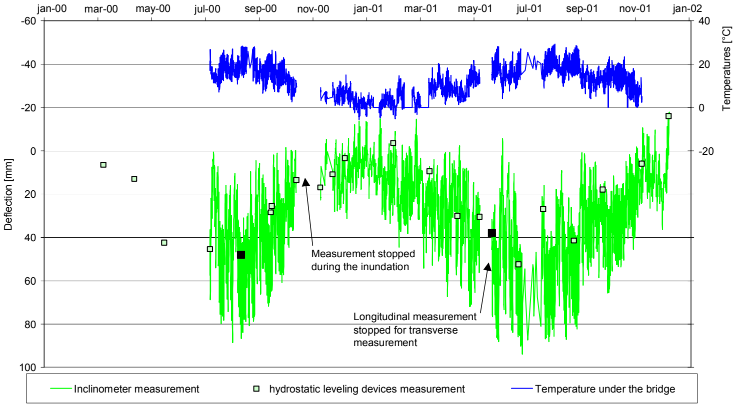

Figure 8: Probable deflected shape of the South Riddes bridge over the period of monitoring

The results from the monitoring shown in figure 8 are very difficult to interpret. There seem to be a small downward difference between the measurements from 2000 and 2001, but this value is likely to be much small than the average 15 mm a year observed before the retrofitting (see also fig. 2). But there is also a small difference in the temperature profiles of the two consecutive years. Figure 9 shows the very linear relationship between the position of each bridge and the ambient temperature. A linear regression made separately for the results of the years 2000 and 2001 shows, however, that for a same temperature, both bridges are somewhat lower in 2001 than in 2000.

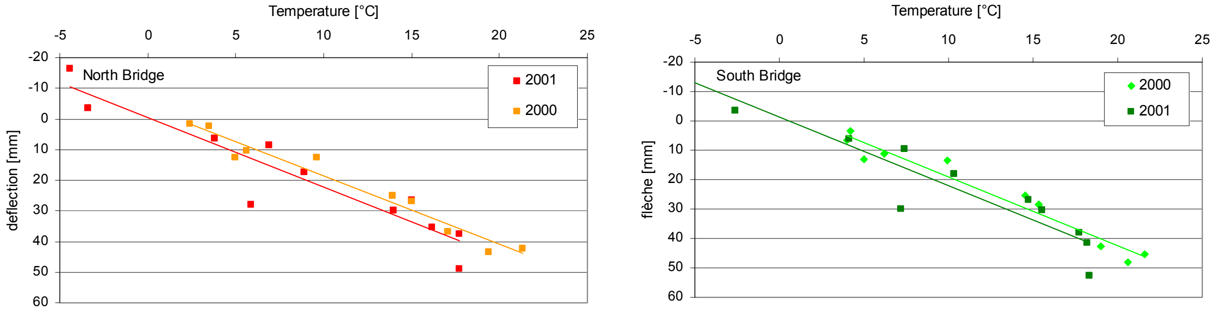

Figure 9: Relationship between deflection and temperature for the years 2000 & 2001

Since a strong correlation between the temperature profile of the bridge and its position has been observed, a cancellation of the temperature effects was attempted. The method applied was as follows : a set of cancellation constants relating the average yearly position of the bridge to the corresponding temperature measurements (ambient temperature, temperature in the box girder, thermal gradient at mid- and quarter-span) was calculated for a whole year. This set of constants was subsequently applied to the entire set of measurements, yielding the temperature-cancelled position of the bridge for the entire year. As can be readily observed, this operation essentially cancels most temperature effects on the bridge.

Consequently, it was concluded that, in its current condition, the bridge still deflects downwards, but only at a very reduced rate (3 to 5 mm a year), that does not require an intervention in the short term. Measurements will continue on the bridge for about one year, after what only the hydrostatic leveling system will be left in place for the routine long term monitoring.

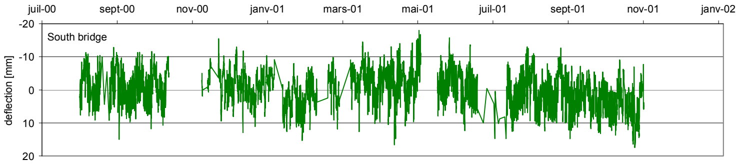

Figure 10: Deflection with temperature effect cancelled

5. CONCLUSIONS

The combined use of the proven method of hydrostatic leveling and high precision electronic inclinometers have allowed an efficient and relatively rapid diagnostic of the evolving condition of the Riddes Bridges. The fact that the inclinometers are temperature-corrected and insensitive to freezing conditions (contrary to the hydrostatic leveling system), that the effect of traffic can be easily detected and eliminated have allowed a very efficient use of the time available for measurements.

The algorithms used for the reconstruction of the deflected shape from the measured angles are robust and accurate. It was found necessary to also include temperature measurements to facilitate the interpretation of the results. Using a simple optimization technique, an efficient was found to cancel temperature effects on the bridge, allowing a direct prediction of the actual behavior of the bridge.

ACKNOWLEDGEMENTS

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REFERENCES

[1] **O.BURDET and J.-L. ZANELLA**, *Automatic Monitoring of Bridges using Electronic Inclinometers*, IABSE, Lucerne Congress Structural Engineering for Meeting Urban Transportation Challenges, pp. 398-399, Zürich, Switzerland, **2000**.

[2] **N. PERREGAUX, S. VURPILLOT, J.-S. TOSCO, D. INAUDI, O. BURDET**, *Vertical Displacement of Bridges Using the SOFO System: a Fiber Optic Monitoring Method for Structures*, ASCE-12th Engineering Mechanics Conference Procedings: A force for the 21st Century, 791-794, San Diego, Etats-Unis, **1998**.

[3] **O. BURDET, J.-L. ZANELLA**, *Long-Term Evaluation vs Short-Term Measurements : the Case of the Riddes Bridges*, ***fib*** Congress 2002, Osaka, Osaka, Japan, English, to be published, October **2002**.

[4] **A. PATRON-SOLARES, B. GODART, R. EYMARD**, *Etude des déformations différées du pont de Savines (Hautes-Alpes)*, Bulletin des Laboratoires des Ponts et Chaussées, 203, 91-103, Paris, France, **1996**.

[5] **O.BURDET**, *Load Testing and Monitoring of Swiss Bridges*, CEB Information Bulletin, Safety and Performance Concepts, 219, Lausanne, Switzerland, **1993**.

[6] **O.BURDET**, *Automatic Deflection and Temperature Monitoring of a Balanced Cantilever Concrete Bridge*, 5th International Conference of Short and Medium Span Bridges, Calgary, Canada, **1998**.

[7] **O. BURDET and M. BADOUX**, *Long-term deflection monitoring of prestressed concrete bridges retrofitted by external post-tensioning - examples from Switzerland*, IABSE Rio 1999, Rio de Janeiro, Brazil, **1999**.