Monitoring the behaviour of the Traneberg Bridge during retrofitting

M. Enckell

Royal Institute of Technology, KTH, 11820 Stockholm, Sweden

Berg Bygg Konsult AB, Ankdammsgatan 20, 171 43 Solna, Sweden

H. Larsson

SL Infrateknik AB, 12189 Stockholm

ABSTRACT: Monitoring structures under retrofitting and strengthening is an ideal way to verify and control their behaviour and also to confirm and calibrate the calculation models. The Traneberg Bridge is a combined road and suburban railway bridge. The retrofitting and strengthening of the bridge started in 1999 in order to accommodate the increasing traffic and the need for heavy vehicles. It is a concrete bridge where only the deck support girders are made of steel. The main span is 191 meters and at the time of its completion in 1934 was the longest concrete arch bridge in the world. The vertical clearance is 26 meters. The old concrete arches seemed to be in good condition and the concrete samples taken confirmed high values of Young's modulus. It was decided that the old arch would be kept but the pillars and the deck were to be reconstructed. Monitoring the old arch during the retrofitting was significant in order to control the behaviour of the arch during demolition and reconstruction. The monitoring system consisted of seven fibre optic SOFO sensors and five thermocouples. The monitoring started in November 2003 and was completed in February 2005. The bridge was checked on a weekly and monthly basis and the modelling of the construction steps was compared to real values from measurements. This paper presents the results during reconstruction and highlights the benefits of the monitoring project when reconstructing the old structure.

1 INTRODUCTION

Several bridges in Sweden that were built in the 1930's need repairing or replacing. To maintain these structures in operation as long as possible is of great economic concern. It is even more important to guarantee the safe use of them as long as they are under operation and this is where monitoring becomes useful. When structures are finally replaced or retrofitted it is excellent if some parts of structures can be reused from the point of view of time saving and economics. Time saving might be the most beneficial in cases where the traffic is massive and cannot be rerouted.

The Traneberg Bridge consisted of two arch bridges beside each other built in1934, one for vehicles and one for subway. While retrofitting and constructing, the first step was to build a third bridge in order to upgrade for the needs of increasing traffic and heavier loads. The old bridges were retrofitted by keeping the arches and reconstructing the pillars and the deck. The unique solution for traffic arrangements appeared in (www.tranebergsbron.nu, 2005) when the first old bridge, the road bridge was retrofitted. The subway traffic was removed temporary to the road bridge while retrofitting the suburban railway bridge. The whole project was able to be completed without disturbing the road or railway traffic and all the three bridges are now in use (Figure 1) and are able to support the new traffic demands.

Figure 1 A clear winter day in March 2005

This paper highlights the retrofitting of the Traneberg suburban railway bridge. In order to control the behaviour of the arch SL Infrateknik AB ordered a monitoring system for the bridge from Berg Bygg Konsult AB. The old arch of the bridge was continuously monitored during retrofitting using 7 fibre optic sensors and 5 thermocouples. The monitoring equipment is permanently installed on the bridge.

The measurements were carried out during reconstruction and the system can be utilized in the future if the need to control the structure appears. The data logger was connected to the office via a modem connection. Automatic measurement was done and the data was downloaded to the office on a weekly basis. The data was briefly analysed and then sent for SL Infrateknik for verification. The Finite Element Models used in the structural design were compared with the measured values. The models can be calibrated later on and increase our knowledge when maintaining and retrofitting the old structures.

2 THE TRANEBERG SUBURBAN BRIDGE

The Traneberg suburban bridge (Figure 2) is a reinforced concrete structure. Only the girders supporting the floor structure are made of steel (Nilsson E., 1938). The arch was, at the time of its completion, the largest and longest ever built. The main span is 191 meters and the vertical clearance is 26 meters. The arch is 9 meter wide and the height is 3 meters at the crown and 5 meters at the abutments. The arch is hollow and provided with three cavities (Figure 3). It is fixed in the abutments and there is no hinge in the crown. The reinforced concrete floor structure rests on plate shaped pillars by means of welded plate girders. The floor structure lies above the crown over the length of 54 meters. The mean thickness of the track slab is 0.22 meters.

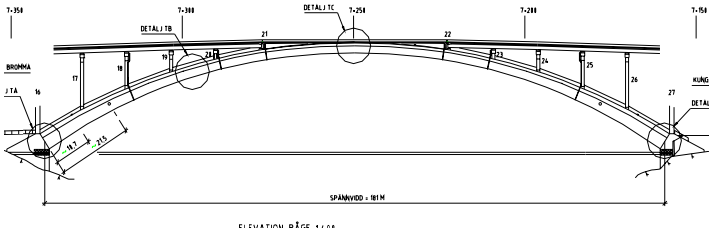

Figure 2 Side view of the Traneberg Bridge.

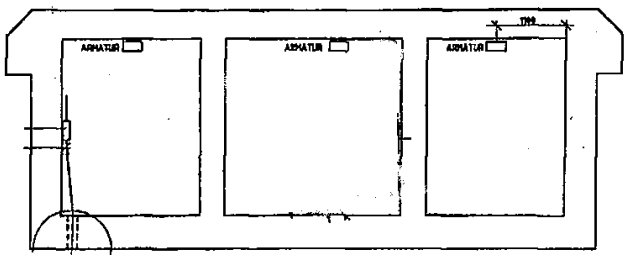

Figure 3 A cross section of the arch.

Civil Engineer David Anger (Anger D., 1935) describes the construction project in his report "Tranebersbro". During its construction in the 1930's, the structure was considered complicated to build and therefore several monitoring activities took place during construction. When planning this statically indeterminate structure the engineers wanted to have a good control of the shrinkage and several series of tests were performed and monitored. These activities in turn provided good information when choosing the cement type and quality, gravel etc. 4 electrical tension transducers type "Carlson, Oakland, California" were embedded in the concrete in the abutments and measured during critical stages of the construction e.g. when removing the scaffolding. It was desirable to avoid construction joints in the pillars and therefore additional measurements were done for control of pressure on formworks. This was done by measuring the traction force in stay bolts using manometers.

3 THE RETROFITTING

The demolition work (Figure 4) started at the beginning of November 2003 and was finished in January 2004. The track slab and steel girders were removed first and followed by the demolition of the pillars. The work was done symmetrically from both sides starting from the east side. Then the new pillars and the crown were concreted in similar way with symmetrical castings starting from the crown. This work started in the beginning of March 2004 and was finished in the beginning of July 2004. Afterwards, the steel girders were mounted and the track slabs was cast on them under July 2004. Finally, in the beginning of October the macadam was spread out on the bridge and two tracks for the train traffic were mounted and the rails were adjusted. The railway traffic was recommenced on the bridge in the beginning of 2005.

Figure 4 Removing the floor structure

4 INSTALLATION AND DATA ACQUISITION

An inspection was done at the end of October 2003 in order to see the conditions inside the arch where the sensors were to be installed. Peab Ab, the contractor was contacted and they started the preparatory work such as cleaning the surfaces and building scaffolding. The installation started in November 2003. The fibre optic sensors, so-called SOFO-system by SMARTEC SA, Switzerland was used. Traditional thermocouples were used and they were also delivered by SMARTEC SA: Four sections of the arch were installed, abutments (Sections A, west & section D, east), west quarter point (Section B) and the crown (Section C). See for sensor names and locations.

Table 1 Location and number of sensors

NAME & LOCATIONS	MEASURES	PLACEMENT
TA1	Strain	West abutment, roof
TA2	Strain	West abutment, floor
TAT1	Temperature	West abutment, roof
TAT2	Temperature	West abutment, floor
TB1	Strain	Quarter point, west, roof
TB2	Strain	Quarter point, west, floor
TBT1	Temperature	Quarter point, west, roof
TBT2	Temperature	Quarter point, west, floor
TC1	Strain	Crown, floor
TCT1	Temperature	Crown, floor
TD1	Strain	East abutment, roof
TD2	Strain	East abutment, floor

All the sensors were installed in the longitudinal direction (Figure 5) in the central cavity of the arch. The length of the sensors is 4 meters and they are installed on the concrete surface with L-brackets. The sensors positioned on the floor are covered with steel beams in order to prevent damage.

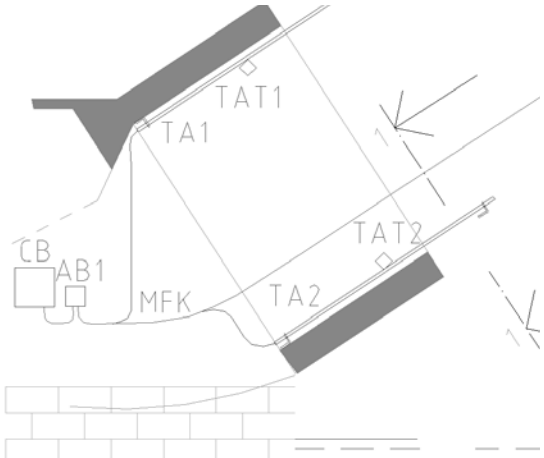

Figure 5, Sensors and thermocouples in section A, the west abutment. CB stands for the Central Connection Cabinet and AB1 is the connection box for all sensors and thermocouple devices. MFK is the multi fibre cables from the other sections.

Sections A and B were contacted at once to the data logger and measured continuously. Sections C was connected a few days later and meanwhile some manual measurements were performed in section D since connection cables were missing for this section. The multi-fibre cables were delivered at the beginning of December, the thermocouples were installed and the Central Connection Cabinet where all the sensors were connected was set up. The modem connection was also set up and tested. Automatic measurements started for the whole system and control and downloading took place from the office.

The behaviour of the bridge was reported to SL Infrateknik AB on a weekly and monthly basis. Peab AB continuously reported activities from the building site to Berg Bygg Konsult AB and these activities were included in these reports. SL Infrateknik AB checked the reports and verified these real values with the results from modelling.

Some problems appeared in data communications and the loss of electricity caused some interruptions in measurements and the modem connection also broke down a few times. In these cases the data was collected manually from the bridge and the modem connection was re-activated.

5 RESULTS

Some typical results are reported here, partly during demolition, without load and during reloading. The measurements shown here started on November 2003 and were carried out until the end of February, 2005.The unloading procedure for sensors TA1, TA2, TB1 and TB2 which are located in west abutment and the west quarter point are shown in Figure 6. At the time of these measurements the thermocouples were not installed and therefore some compensation for strain because of temperature has not been performed.

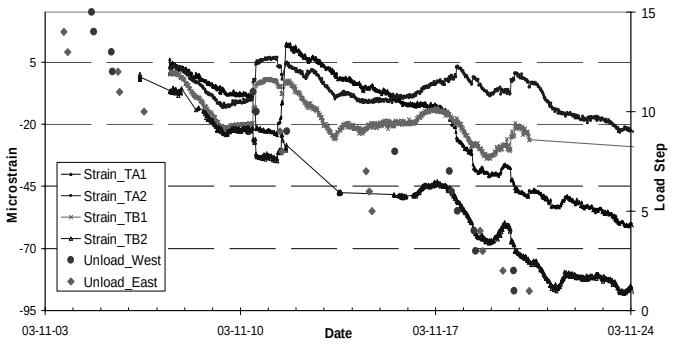

Figure 6, Unloading steps for west and east sides and strain changes for sections A and B.

Figure 7 shows the changes in strain for these sensors during a few days while unloading both in

west and east sides. It clearly illustrates the effects of unloading in more detail. Sensor TB2 had unfortunately some problem in the temporary connection cable and some data was lost for a short period.

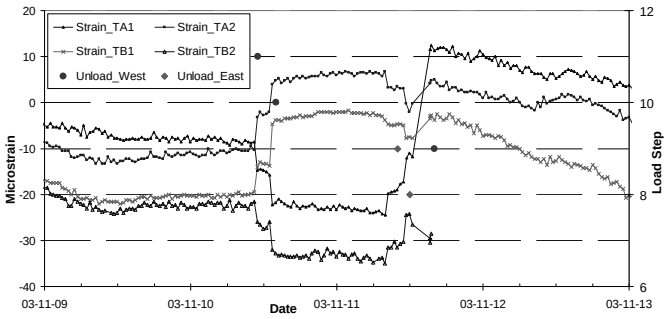

Figure 7 Detailed changes in strain for sections A and B

Figure 8 shows strain and temperature variation during the period of time when the arch was unloaded and the new activities had not yet started.

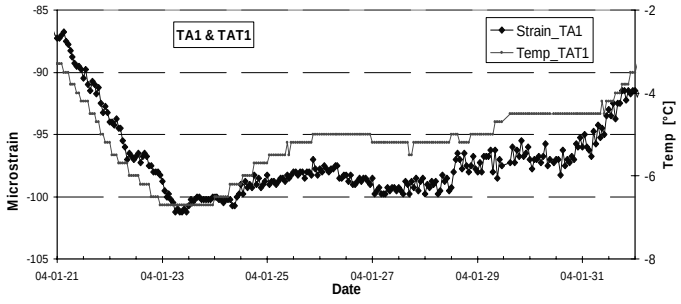

Figure 8 Strain changes related to temperature after unloading

Temperature compensation was done by taking the thermal expansion into consideration and strain profiles were corrected. However, this is a very simplified assumption and needs to be verified in more detail in the future. Figure 9 and Figure 10 show these profiles for all sensors and are shown in the same figure with different load steps. Load step 1 consists of casting the pillars and the crown and load step 2 of casting the floor structure on steel girders. Unfortunately the electrical cable was stolen under the summer vacation and a lot of data was lost during this period of time.

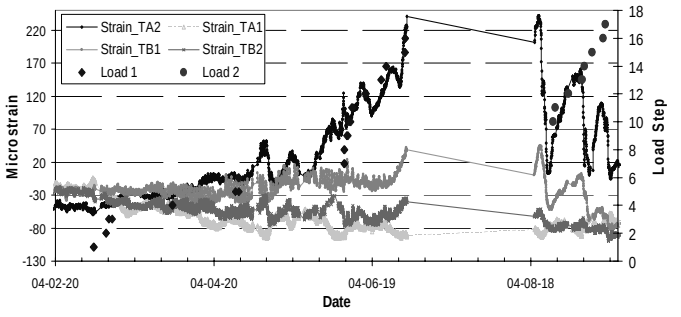

Figure 9, Load steps and strain diagram for sensor TA1, TA2 TB1 and TB2

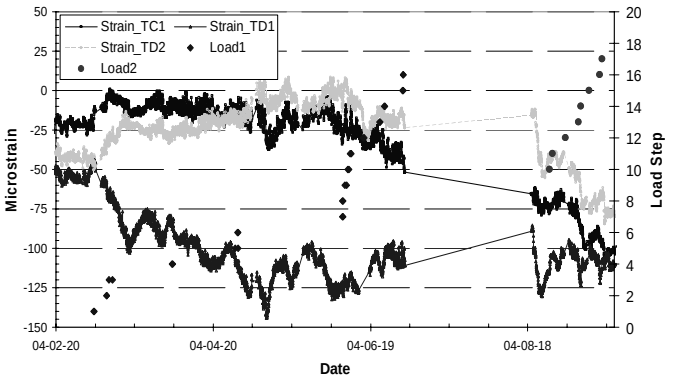

Figure 10 Load steps and strain diagram for sensor TC1, TD1 and TD2

The placement of the macadam started from the east side and progressed towards the west of the bridge. This loading process is shown in Figure 11 in terms of the arising related strain profiles. These measurements are not temperature compensated

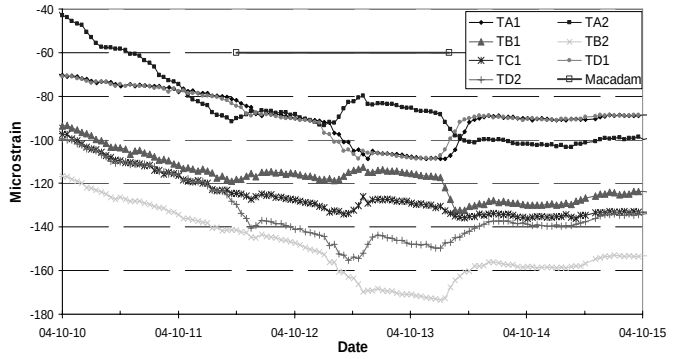

Figure 11 Strain profiles that follow placement of the macadam onto the bridge

Lastly, Figure 12 shows the last month of this project when the trains are already running on the bridge. Sensor TA1 which is located on the roof of the west abutment is the most sensitive to these movements and strains up to 10 micro strains occur during these passages.

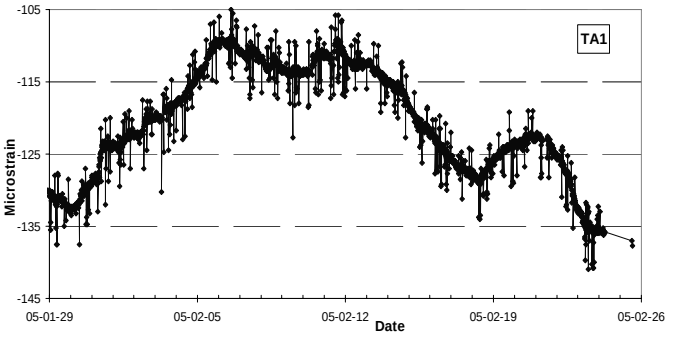

Figure 12 Strain profile for sensor TA1 under operation

6 CONCLUSION

The Traneberg Bridge is again in service with both road and railway traffic running normally. This paper gives an overall description of the monitoring while retrofitting the old structure. During the construction work, a lot of data was collected, briefly analysed and the real values were verified with theoretical models. Monitoring during retrofitting provided confirmation of the expected behaviour of the structure and of the quality of the materials. The concrete structure like Traneberg Bridge that is 70 years old might have some unconsidered properties. The effects that might not be taken in consideration while planning and modelling can be captured by monitoring. It might be complicated to find necessary tools in handbooks for long-term behaviour like the fatigue, changes in static and dynamic properties, shrinkage, creep etc.

Some discontinuity in the measuring appeared because of the lack of electrical power and interruption in power delivery. The cables were stolen or damaged several times at the building site and the personal needed to visit the bridge in order to solve the problem. Fortunately, Peab AB, the contractor was very co-operative and helped the monitoring staff to control the function of electricity in order to keep measurements continuous. Also the problems with the modem connection caused some lost of data and the possibility for remote control disappeared when the system was closed down and had to be re-started from site.

The monitoring project is completed in its present state; however, the system remains on the bridge and is able to measure any time if required. It is recommendable to make at least one measuring campaign per year in order to control the long term behaviour of the arch and to learn about old concrete structures. In this way it will be possible to give advice for future projects in similar matters. It should also be of great interest to compare the calculations and modelling in a more detailed manner with measured values and behaviour. This should increase the knowledge both from a material and a structural point of view.

As mentioned earlier, when constructing the bridge in the 1930's some kind of short term monitoring during construction was performed. These monitoring activities verified the uncertainties in design and helped the engineers to make decisions concerning material properties and construction techniques. This in turn resulted in the most economic solution and the cost of the bridge was reduced from a calculated 4.8 million Swedish crowns to 4.0 millions. Monitoring was used to increase the understanding that was needed in order to build a bridge with the quality that still stands today and can be reused. After retrofitting, the service life of the structure is extended and this is a great economic benefit for the society and a confirmation of the exceptionally good engineering work from 1934.

REFERENCES

Anger D., 1935, *"Tranebergbron"*, Offprint from Cement and Betong 1932-1934, Tryckeri Aktiebolaget Thule, 341092, Stockholm.

Nilsson E., 1938, *"Modern Bridges in Stockholm"*, technical notices from the harbour board of Stockholm, 1938:1

www.tranbergbron.nu, 2005. Website visited 2005-05-20.