SHIP CRASH INTO THE RIVER DANUBE RAILWAY BRIDGE IN KREMS – MONITORING AND ALARMING SYSTEM FOR THE DAMAGED STRUCTURE

Peter Furtner
VCE, Austria

Helmut Wenzel
VCE, Austria

Abstract

In the early morning of 17 December 2005 a ship loaded with more than 3500 tons iron ore traveling upstream the Danube River crashed into the center pier of the railway-bridge in Krems - Austria. The pier was sheared off above the water surface and moved 2.17 meters upstream (Figure 1).

The temporary stability of the damaged pier was checked by dynamic measurements. Furthermore a monitoring and alarming system based on vibration monitoring was installed on the bridge to observe the behavior of the damaged bridge for two months until the lifting of the superstructure. Because the shipping traffic under the bridge should not be interrupted, the system was designed to warn ships as well as workers on the structure early enough in advance to a collapse.

This paper describes the layout and the function of the monitoring and alarming system including the real time data analysis and the results for the whole monitoring period.

INTRODUCTION AND SCOPE OF WORK

The submerged part of the pier stub was checked by divers. They noticed numerous cracks at the pier stub. Due to the check results failure mechanisms were assumed. First: Failure of the substructure which is announced by an inclination. Second: Brittle fracture of the remaining pier shaft due to the loads from the structure.

For a better understanding of the situation measurements were performed to be able to check the stability of the damaged pier. A monitoring system based on vibration and inclination measurements was installed for the permanent monitoring of the damaged pier and the supported superstructures in order to be able to detect critical situations at an early stage. For the permanent monitoring two different situations had to be taken into consideration:

Non-working phases: During the non-working phases the bridge was monitored in a completely automated way without any personnel. For the case that previously defined threshold values should have been exceeded, a defined group of persons would have been automatically alarmed via SMS.

Securing works: The automated alarming was de-activated during the working phases. In order to be able to identify critical situations on time and to warn the workers on time, the measuring devices were supervised by engineers on site.

Figure 1: Damaged pier

STABILITY CHECK OF THE DAMAGED PIER

Measurements

The measurements on the stability check were carried out on 21 December 2005. Two mobile measurement devices of the type BRIMOS-Recorder 800 were used. Each of these units has two highly sensitive 3d-acceleration sensors for vibration measurement at structures especially under ambient conditions.

Measurements were performed at the damaged pier 5, the undamaged pier 4 and at both superstructures supported by pier 5. During the measurements the BRIMOS-Recorder was always located at the pier and the external sensor at the superstructure.

Evaluation of the Measurement Data

The evaluation of all measurement data was performed by means of the software BRIMOS 9.03. The evaluation procedure took place automatically in several steps, which are shortly described below.

– Conversion of the acceleration signals of V into g, depending on the respective sensor.

– Establishment of a signal window, where the x–axis describes the length of the file and the y-axis is scaled automatically. These specifications are adopted by the printing illustrations.

– Elimination of interfering signals or of signal areas disturbed by exterior influences.

– Evaluation of the vibration displacements by numeric double integration

– Evaluation of single-channel spectra and of ANPSD (Averaged normalized power spectra density).

– Determination of the damping values by means of RDT (Random Decrement Technique) for all eigenfrequencies and sensors.

The operations carried out in the individual evaluation steps are not commented in detail in this contribution. For more details, please refer to [1].

Results of the Stability Check

The dynamic parameters for the damaged pier 5 and the undamaged pier 4 were determined by the evaluation of the measuring data in the frequency and the time range. From a comparison of the values conclusions could be drawn on the condition of the damaged pier.

The great mass of the superstructures influenced the dynamic behaviour of both piers. For both piers the same eigenfrequencies were identified in cross direction (normal to the flowing direction). This can be attributed to a reciprocal transmission of the vibration behaviour of the piers by the superstructures. This behaviour indicates that the damaged pier was held in its position by the supported superstructures because of constraining forces introduce by the displacement and distortion of the structures during the ship crash. The test also assessed the monolithic behaviour of the displaced pier shaft. From the measuring results no signs of an imminent brittle fracture can be seen.

PERMANENT MONITORING AND ALARMING SYSTEM

The permanent monitoring unit with alarm system was installed by the VCE measuring team on 22 December 2005. The measuring system was in permanent operation up to its removal on 16 February 2006. The system is based on the assumption that critical situations are recognized due to deformations of the pier or the structures.

System Description and Instrumentation

The permanent monitoring system is based on the BRIMOS technology in its composition and its function. Four highly sensitive acceleration sensors are used, which enabled very precise inclination measurements with an accuracy of <0.001°. The sensors were installed at the following points:

– Damaged pier, upstream (Figure 2).
– Damaged pier, downstream.
– At both superstructures supported by pier 5 at a distance of approx. 20 m of the pier.

Figure 2: Sensor on the damaged pier

The measurement unit consisting of uninterruptible power supply, cabling, data logger, PC and modem was accommodated in a heated container at the left shore directly beside the bridge.

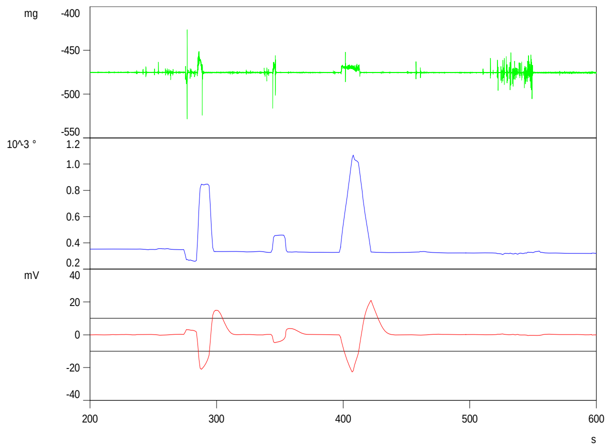

Figure 3: Test of the monitoring system

After installation the proper function of the system was tested by manual inclination of the sensors. Figure 3 shows the results of this test:

- The raw signal
- The inclination
- The trigger criterion with the threshold values

Evaluation and Alarming

The evaluation of all measuring data and the checking for fixed threshold values was performed by software specially created for this purpose on site in real time. The permissible deformation was established by the soil expert on site at 1 cm. Due to the geometry a threshold value of 0.1° was determined for alarming.

The “normal“ inclination curve over the day due to temperature fluctuations and solar radiation had to be considered. From the observation over 2 days, from 22 to 23 December 2005, this inclination curve caused by temperature expansions was determined. For monitoring and alarming two different situations had to be taken into consideration:

Non-working phases: During the non-working phases the bridge was monitored in a completely automated way without any personnel. For the case that previously defined threshold values should have been exceeded, a defined group of persons would have been automatically alarmed via SMS.

Securing works: During the securing works interruption of the highly sensitive acceleration sensors was to be feared. This could have led to the exceeding of the threshold values and the triggering of false alarms. Therefore the automated alarming was de-activated during the working phases. In order to be able to identify critical situations on time and to warn the project engineers on time, the measuring devices were monitored by engineers on site.

For the monitoring system a permanent function control was established. For any malfunction, like for example power failure, an automatic alarming of an available measurement engineer was planned via SMS. For the bridging of short-term power failures a UPS (= uninterruptible power supply) was installed.

Results of the Permanent Monitoring

All recorded measuring data were saved on site and subsequently evaluated and graphically processed. Figure 4 shows typical results of permanent monitoring. The influence of insolation on temperature expansion and the pier inclination influenced by it can be clearly recognized.

In Figure 5 the slight movement caused by the loosening of the rail fastenings and the cutting of the rails can be seen.

On 31 January a sensor was knocked over during the cutting of the cable trough. This led to an exceeding of all threshold values. The slight change in position of the sensor during the resetting was expressed by a displacement in the measurement record.

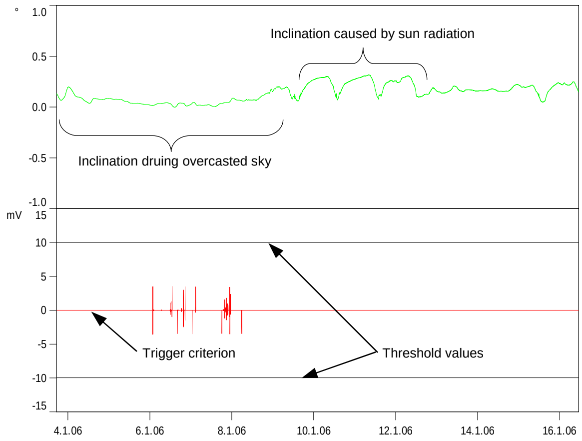

Figure 4: Typical monitoring results from the damaged pier

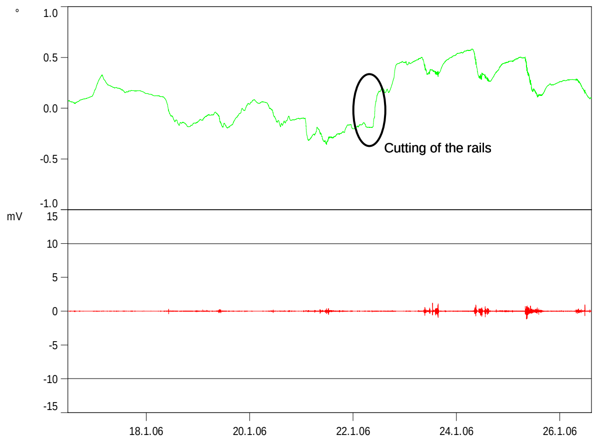

Figure 5: Inclination during cutting of the rails

ASSESSMENT OF THE SUPERSTRUCTURES

As already explained in detail earlier, statements on the actual load-bearing behaviour can be made by means of the determination of the dynamic characteristic – on the basis of vibration measurements under ambient conditions. Forecasts on the future development and residual life expectancy of structures become possible thanks to periodic measurements.

The monitoring and alarming system could be used for the determination of the dynamic characteristic of the railway bridge over the Danube in Krems. Two highly sensitive 3D-acceleration sensors of the measurement unit were placed at the two superstructures supported by the damaged pier at a distance of approx. 20 m of the pier. At both sensor positions the dynamic characteristic was determined based on the measurement data. The frequency spectra with the respective structural eigenfrequencies reflect the condition of the structure.

Any changes in the load-bearing behaviour are documented by a check after the re-mounting of the superstructures. This check can also serve as a basis for later condition assessments.

SUMMARY OF THE MEASUREMENT RESULTS

Results of the Stability Check

On 21 December 2005 the vibration characteristic of the damaged pier 5 and the undamaged pier 4 was measured by means of a mobile measurement unit. The evaluation of the measurement data in the frequency and time range and a comparison of the results enabled conclusions on the stability of the damaged pier.

The monolithic behaviour of the displaced pier shaft was assessed by the check. From the measurement results no signs for any brittle fracture could be recognized.

Results of the Permanent Monitoring

The permanent monitoring unit with alarm system was installed by the VCE measurement team on 22 December 2005. The measuring system was in permanent operation up to its removal on 16 February 2006.

The system is based on the assumption that critical situations are previously recognized due to deformations of the pier or the structures. Therefore both the damaged pier 5 and both structures supported by this pier were instrumented with highly sensitive sensors. From observation over two days, 22 and 23 December 2005, the “normal” inclination curve was determined over the day and subsequently threshold values were determined. For the case that threshold values should be exceeded, an automatic triggering of an alarm was established. Basically two situations could be distinguished:

First: Monitoring during the non-working phases up to the lifting of the structures. Second: Execution of securing and dismantling works at the structure.

In the whole monitoring period the threshold values were never exceeded during the non-working phases. During the works at the structure SMS alarming was de-activated. The monitoring of the works and the observation of the monitoring system was carried out by personnel on site.

Results of the Measurements at the Superstructures

Two 3d-acceleration sensors were mounted at the superstructures during the whole monitoring period. From the recorded measurement data the dynamic characteristic of the superstructures was established. The latter reflects the condition of the structure. Changes in the load-bearing behaviour can be documented by checks after the re-mounting of the structures.

FINAL COMMENTS

The monitoring system with SMS has proved a success in the configuration used. The measurement unit worked faultlessly and without any failures during the whole monitoring period. The additional presence of measurement personnel during the working phases at the structure (securing works, dismantling etc.) has proved appropriate and necessary as the trigger level for alarming was repeatedly exceeded by the works.

The system with the sensors installed directly at the pier and at the structures supplied accurate and reliable values.

In addition the measurement data recorded on the structures reflect the current condition of the structures before lifting. Any changes can be documented by a check after re-mounting.

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