Geodetic Monitoring and Deformation Analysis of a Vertical Lift Bridge

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Key words: engineering surveying, deformation analysis, bridge monitoring system

SUMMARY

A structure is subject to a continuous aging process due to acting loads. By monitoring this process, the engineering surveyor has an essential contribution to the short-term assessment of its functionality and safety. However, usually the monitoring activity starts after first damages have already occurred. Therefore, the properties of the structure before the damage took place are unknown. Such an unfavorable situation was prevented in the presented project by measuring and modeling the deformations due to regular influences. The object of interest was an old vertical lift bridge that will be replaced in near future by a new bridge, situated closely. Thus it will be possible to identify the additional influences of the construction works on the old structure and to assess its stability and functionality.

The monitored object is a steel bridge situated in the harbor of Hamburg. It plays a major role in the road, rail and shipping traffic of the harbor. For this reason its functionality has to be guaranteed until the new bridge will be build up. Therefore, the monitoring activity was focused on the two towers and the superstructure, the most exposed components of the bridge, and aimed to measure and model their deformation due to temperature, tide, wind and traffic.

In order to monitor long-term effects measurements were conducted for several weeks using GPS and inclinometers. All data was directly transmitted to a central PC deploying WLan. Thus, the modern concept of a wireless monitoring system was realized and implemented. For acquiring short-term deformations induced by vehicles and trains high frequency measurements were performed using a laser scanner set in profiler modus, inclinometers. Due to the fast observed effects the sensors needed to be synchronized.

The recorded deformations were related to the acting influences within a dynamic model using a system theoretical approach. The behavior of the structure is described by weighting functions in the time domain and transfer functions in the frequency domain with tools of time series analysis. The deflections due to traffic measured with the various sensors are compared with each other and related to the specific traffic loads. Finally, all results are compared with planned values.

This project was accomplished with students in the final semester of the Geodesy and Geoinformatics course of studies at the University of Hanover and is part of the curriculum.

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1. INTRODUCTION

The Rethe vertical lift bridge (Figure 1), built in 1934, is one of the most important links between the container and oil terminals of the port of Hamburg and the surrounding mainland. Due to increasing road, rail and shipping traffic its condition has been deteriorating over the last few decades. Additionally, today's large sized container ships are not able to pass the bridge because height and width were originally constructed for ships of the 1930s. Therefore the construction of a completely new bridge next to the current location was scheduled to begin in 2007. In order to guarantee the functionality of the Rethe vertical lift bridge while the new bridge will be under construction, a monitoring of the structure's deformations had to be carried out. The campaign's aim was to determine the impact of current periodical influences like temperature and tide and non-periodical influences like traffic on the bridge. Thus the usual deformations had to be modeled deploying various sensors and analysis techniques.

Fig.1: The Rethe vertical lift bridge while road and rail traffic crossing the bridge

These results, displaying the usual movements of the bridge, will be compared to deformations of the structure due to the building process of the new bridge. It will be possible to give warnings to the Hamburg Port Authority (HPA) as soon as the deformations exceed certain thresholds. False alarms will be prevented resulting in a save and effective traffic flow.

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[1] This project was accomplished at the Geodetic Institute, University of Hanover.

2. DESCRIPTION OF THE RETHE VERTICAL LIFT BRIDGE

Whereas the towers' foundations are made of concrete, the entire superstructure of the bridge is built of steel. The superstructure consists of two 62 m high towers and a 74 m long and 15 m wide lift section. Both heavy rail and truck traffic use the bridge as a gateway to the inner part of the port. However, it is not possible to have trains and trucks cross the bridge at the same time because the train tracks intersect with the road. Hence the road traffic, limited to 30 km/h, is shut down any time a train needs to cross the bridge. Several trucks breaking at the same time on the lift section in front of the traffic lights have a severe effect on the deformation of the bridge. Additionally, about 300 ships pass the Rethe vertical lift bridge every month resulting in lifting operations of the mid section. Prior to each lift the road and rail traffic has to be shut down. The actual lifting height depends on the height of the ship that needs to pass. The highest lift, however, is 48 m which delays road and rail traffic for approximately five minutes. All lifting operations are executed by the technician who is in charge of the bridge. Two precisely synchronized electric engines, one on each of the towers, run the lift section. The lift section is fixed to steel cables with counter weights on the opposite end. When open to traffic the lift section is fixed with a bolt to both the northern and the southern foundation of the towers if road or rail traffic crosses the bridge. As soon as a lifting operation is conducted both bolts are driven back into the foundations and the lift section is no longer fixed to the foundations. Furthermore, the lift section runs on vertical rails up the northern tower. These rails keep the lift section fixed to the northern tower lengthways and transverse. The lift section is fixed to the southern tower only transverse to allow for small movements. Thus cant of the lift section between both towers may usually be prevented. However, a cant of the lift section has happened before. Therefore one major goal was the monitoring and modeling of the towers' tilt.

3. MONITORING SYSTEM LAYOUT

In order to uncover deformations due to the construction of the new bridge, a precise monitoring of the usual behavior of the Rethe vertical lift bridge has to be conducted. This monitoring must be carried out while usual influences like temperature and tide have effects on the deformations of the bridge. The determined deformations will furthermore be compared to the bridge's behavior during the construction process of the new bridge. The model layout chosen in this project will describe deformations in a temporal context due to acting forces on the bridge (Pelzer, 1988).

The first step is to determine characteristic points of the object which are crucial for its functionality. All parts playing major roles for the bridge's safety particularly while running the lift section are of interest. Absolute movements of the entire object are not as crucial for its safety as relative deformations of e.g. the two towers. The next step is to gather all possible deformations that might occur at any of the bridge sections. Influences that could probably result in movements of the towers, the foundations or the lift section are listed. Deformations of interest at the Rethe vertical lift bridge are tilt and torsion of both towers, movements of the foundations and the deformation of the lift section due to traffic. These deformations can be divided up into short term and long term deformations. Short term deformations are initiated by short term causal variables like road traffic. Long periodic deformations are e.g. due to temperature changes. The final step at this stage is to discuss and determine appropriate sensors to measure the important deformations as well as the corresponding causal variables. In order to guarantee a homogeneous dataset and enable online analysis of all sensor data, the implementation of a central database is necessary.

In cooperation with the Hamburg Port Authority (HPA), the responsible agency for all maintenance work at the Rethe vertical lift bridge, the final monitoring layout was decided. A monitoring session for two weeks was found appropriate for the determination of long periodic deformations. Thereafter, short periodic deformations would be measured during a field campaign for three days.

A monitoring software for data collection, recording and maintenance was implemented especially for this project. A homogenous data set was achieved while all data could be stored simultaneously. However, all GPS data was stored within the corresponding GPS receivers and downloaded every three days.

3.1 Monitoring Software

The software system was used in order to facilitate the efficient data storage of temperature, wind and the tilt of the towers. The implementation of the monitoring software, named *Projekt Suite*, was conducted deploying the object oriented programming language *C#* within *Microsoft Visual Studio .NET 2005*. The layout of the software system is modular in order to enhance flexibility. Additionally, the modular layout enables the integration of further sensors via serial RS-232 interfaces.

After starting the software a connection to the database has to be established and the data storage interval of the database must be set. All data is collected within monitoring software until it is synchronized with the database. The measuring interval of the sensors must also be set in the software. During the registration of the sensor data all current values may be viewed in the corresponding windows of the sensors. For both the temperature and the tilt sensors a graphical display of the data was implemented.

3.2 Database

All data is stored within a *MySQL* database. There are two ways to gain access to this database. The first way is to use the monitoring software; the second is to run a web browser. However, the IP-address of the database server has to be known in order to run the web browser. The communication between the monitoring software and the database is enabled by the *MySQL ODBC 3.51 Driver*. Database and monitoring software may be run on two different computers which enhances the overall flexibility of the monitoring system. Besides the advantage of accessing the database via the internet, this database also facilitates fast search operations. Elimination of data due to overwriting is not possible, too.

3.3 Sensor communication

Another specialty of this monitoring system and the monitoring software is the possibility of integrating wireless sensor communication. This wireless communication is enabled by the implementation of a converter from the wireless local area network (WLan) to RS-232. Integrated in this converter is a *Lantronix WiPort*. The converter may easily be configured via an integrated web server. Hence all controlling operations and data collecting of the sensors on both towers may be conducted wireless with only one computer (Figure 2). However, this computer also has to be fitted with an Access Point and a WLan-card. In order to enhance the radio communication between the *WiPort* on the northern tower and the Access Point on the southern tower a special WLan-antenna was build at the University of Hanover.

Three *Quat*-thermometers and one *Schaevitz* tilt sensor were installed on the southern tower and directly connected to the central computer via RS-232. The same set of sensors was installed on the northern tower and connected to the *WiPort*. All data from the northern tower was sent to the southern tower using the *WiPort*. It was received by the Access Point and then stored in the database.

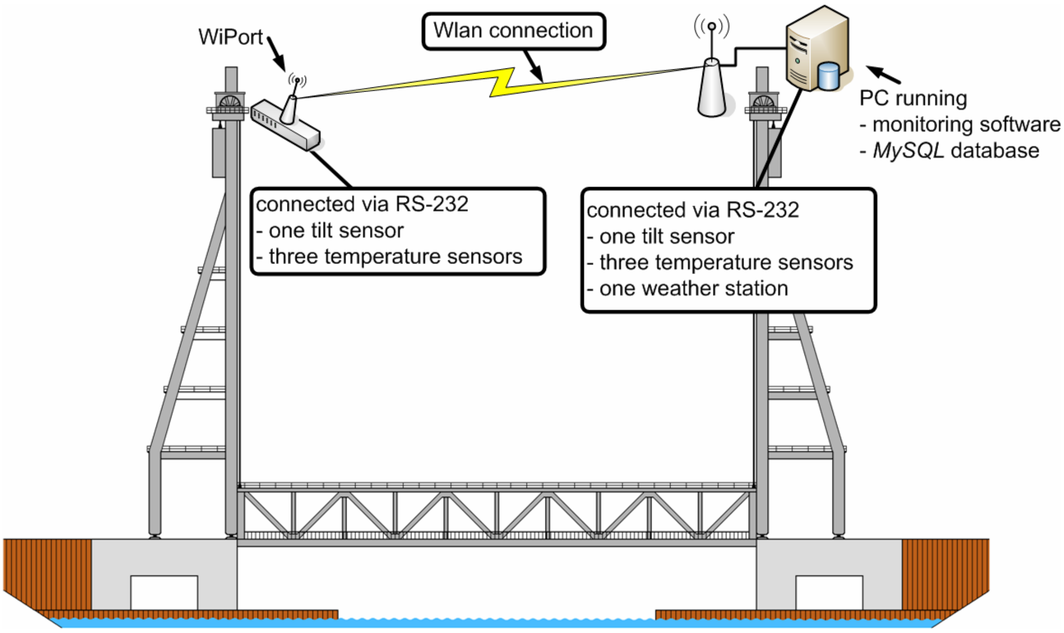

Fig. 2: Sensor communication

4. APPLICATION OF THE MONITORING SYSTEM

The registration of all long periodic deformations was conducted with the previously described monitoring system. GPS, tilt, temperature and wind sensors were installed on both towers for two weeks. All captured data, except GPS measurements, was stored within the database.

Both towers were equipped with two GPS antennas, one tilt sensor and three temperature sensors. Additionally, wind magnitude and wind direction were captured on the southern tower. However, wind was found to have no significant impact on the bridge's deformations and was therefore not included in further deformation analyses. A GPS reference station was established on a building located closely to the bridge to allow for Precise Differential GPS (PDGPS). Each tilt sensor of make *Schaevitz* was installed in the machine room on the tower's top platform. Both tilt sensors were oriented lengthways towards the bridge. The steel temperature, the major causal variable for the towers' deformations, was measured at three different locations on the top platform. Much attention was paid to prevent direct solar radiation. Hence all temperature sensors were installed at shadowy locations and insulated towards the open air (see Figure 3 for sensor types and positions). Another causal variable for various deformations is lifting operations. The caretaker of the Rethe vertical lift bridge assigned responsible for recording all start times, ending times and lifting heights of the lift section. All necessary tide data, the water level and the corresponding times, was provided by the HPA. Two leveling campaigns were performed, one in spring and one in summer, to take seasonal changes of the foundations' heights into account.

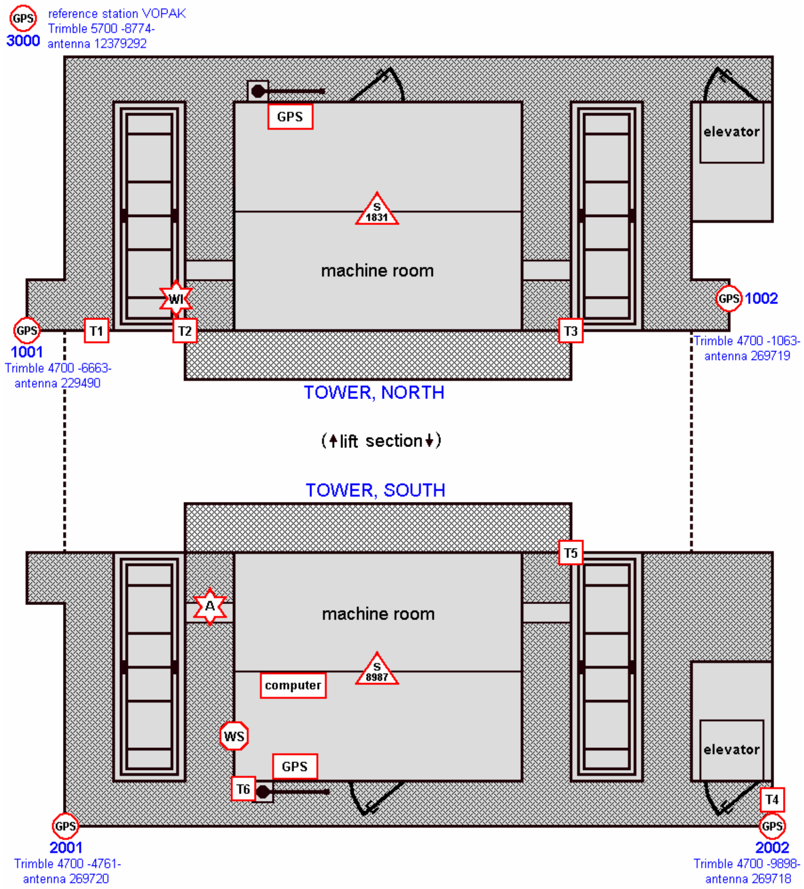

Fig. 3: Sensor positions on both towers

T : temperature sensor
WS : weather station
WI : *WiPort*
S : tilt sensor of make *Schaevitz*
GPS : GPS antenna
A : External WLan antenna

A three days long measurement campaign was accomplished after two weeks of long term measurements in order to detect short term deformations. The aim of this campaign was to measure deformations of both towers due to lifting operations using high frequency PDGPS. Additionally, the deformation of the lift section caused by traffic was of particular interest. A laserscanner in combination with tilt sensors was deployed in order measure short deformations.

5. LONG TERM MEASUREMENTS

First a common time reference was introduced to all data. Thus, the application of various time series analysis tools was enabled. The causal variables temperature, tide and wind were recorded with an interval of 300 seconds and stored within the database. The long periodic deformations of the Rethe vertical lift bridge were measured by GPS and tilt sensors.

5.1 Analysis of tilt measurements

Figure 4 shows an overview of the northern tower's tilt measurement. Displayed superimposed are lifting operations. The clipping of the registration in figure 5 shows that in most cases the lifting operation is overlapping with large peaks. The first step in analysis of the tilt measurement was to remove the effect of the lifting operations. 69 lifting operations were recorded in total during the analysis epoch from 27.03.2006 – 12.04.2006. Figure 5 indicates that no systematic coherence between the maximum tilt and the height of the lifting operation does exist. Besides its height, a lifting operation is also characterized by its duration. Times and heights were noted by the bridge's caretaker. However, an offset between the noted time and the time of the registered tilt measurement could not be estimated.

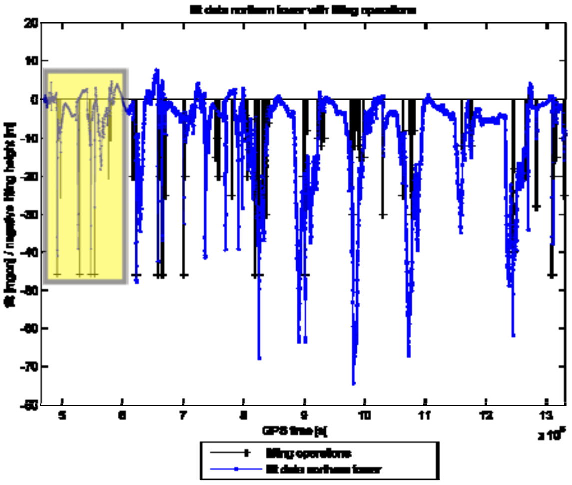

Fig. 4: Analysis of the tilt measurements on the northern tower - overview

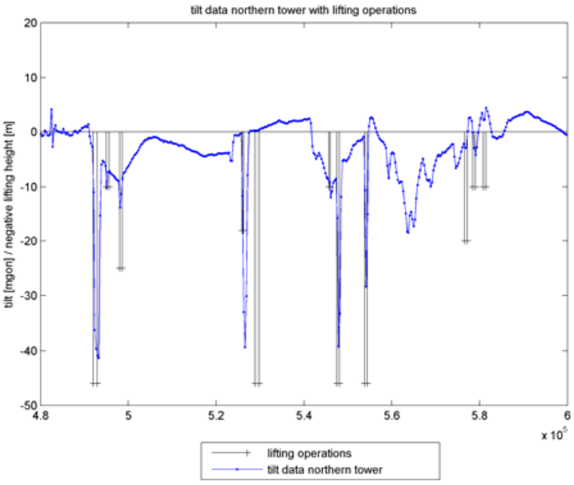

Fig. 5 Analysis of the tilt measurements on the northern tower - clipping

As can be seen from figure 4 the recorded time series are not stationary due to the effects of the lifting section. Stationarity of the time series must be guaranteed for the following frequency analyses. In this case numerous large peaks are disturbing the stationarity. Hence, an adequate modeling of the lifting operations is necessary. The most favorable way is to use a physical model for the elimination of such peaks. However, comprehensive information about acting forces during the lifting operation is essential in order to deploy such a physical model. Due to the lack of this knowledge the modeling was done mathematically. For mathematical modeling a functional context is required to describe the lifting operations exactly. Figure 6 displays that the tilt measurement during the lifting operation can be described by the Gaussian function. This function is characterized by a scaling parameter which produces a steep graph for a small value and a flat one for a high value. In this case the mean is the middle time of the lifting operation. The scaling parameter accounts for the duration of the operation. In order to facilitate effective modeling an additional parameter was introduced. This parameter specified the camber which compensated the flat graph in case of large scales.

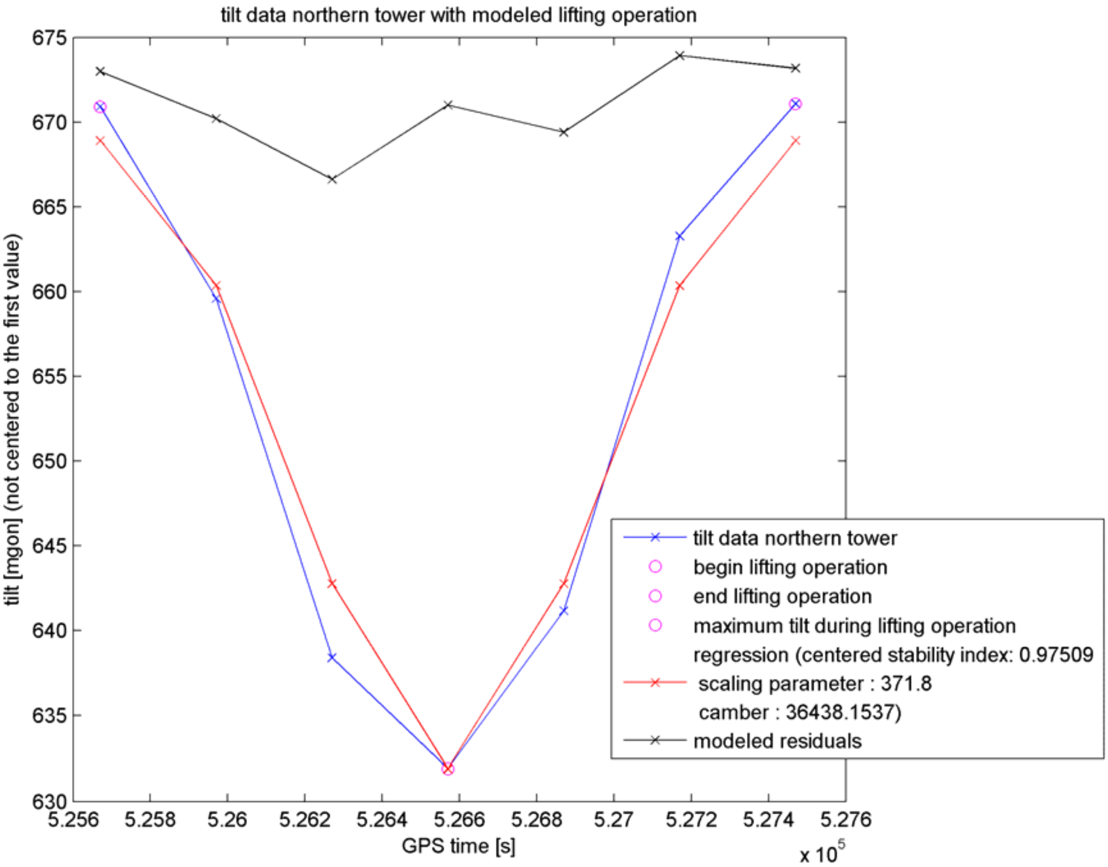

Fig. 6: Example for the approximation of a lifting operation with the Gaussian function

Different durations of lifting operations could be approximated by varying the corresponding scaling parameter. This process was repeated iteratively until the stop criterion given through the centered stability index was reached. The fact that there is no systematic coherence between the maximum tilt and the lift height was once more confirmed. In conclusion, deploying this functional approach for mathematical modeling provides sufficient results for most of the 69 lifting operations. The effect of the lifting operations may now be removed from the tilt measurements by replacing the large effects with the. All data can be analyzed in the frequency domain. The dominant frequencies were estimated from a periodogram of the tilt measurements. The frequency $f_T = 1.1366 \cdot 10^{-5}$ Hz was assigned to the daily period due to temperature changes. The frequency $f_{HM} = 2.2732 \cdot 10^{-5}$ Hz was assigned to the half day main moon tide. On this basis a cross correlation between the deformation and the cause variable was determined in order to estimate the reaction of the structure to temperature loads. The resulting cross correlation coefficients were found to be $k_{Temp} = 0.49$ for the temperature and $k_{Tide} = 0.13$ for the tide. Thus, tide was indicated to have no significant impact on the towers' tilt. However, the temperature was indicated as an essential cause variable. Relating the temperature and tilts in a linear model (Kuhlmann, 1996), accounting for phase shifts, a significant gradient of $b_1 = 3.1124$ mgon/°C was estimated. According to our project partners of the HPA this value is plausible for the Rethe vertical lift bridge. The positive sign indicates a southwards inclination of the northern tower with increasing temperature. This may be unusual but can be explained by the action of the support behind the structure.

5.2 Analysis of GPS measurements

Five GPS receivers with five antennas were installed in total. Four GPS receivers *Trimble 4700* with antennas *Trimble Micro-Centered L1/L2* were mounted at the south eastern (1002 (Figure 7), 2002) and south western (1001, 2001) handrails of the top platforms of the towers, two on each tower. One reference station (3000) with a *Trimble R8* receiver and a *Trimble Zephyr Geodetic* antenna was established on the roof of a building located closely (Figure 8). The receivers were set to a data capturing interval of 15 seconds.

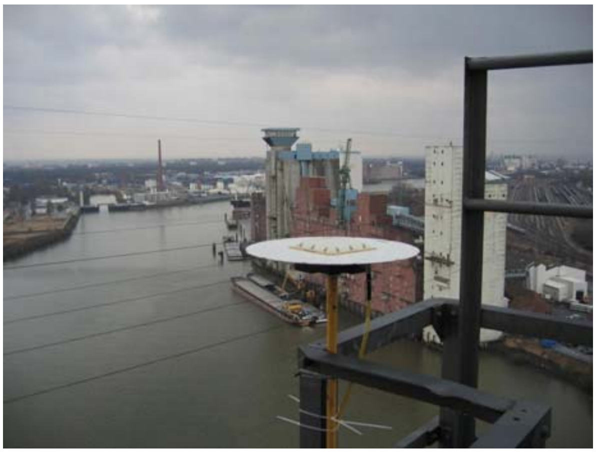

Fig. 7: GPS antenna 1002 above the river Rethe on the eastern side of the northern tower

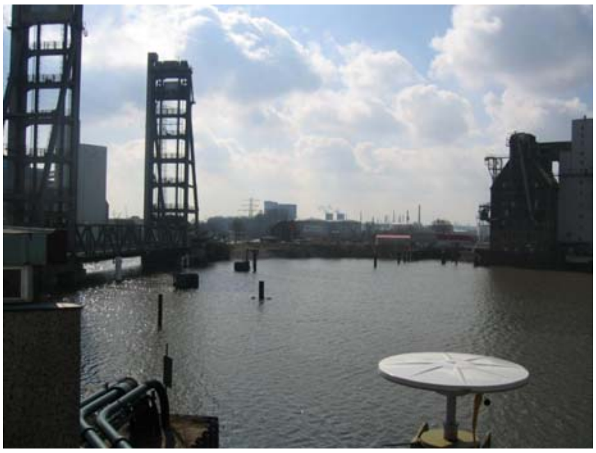

Fig. 8: GPS reference antenna 3000 in front of the Rethe vertical lift bridge

A relatively poor multipath environment on top of the towers could not be avoided although all GPS antenna sites were chosen carefully. A lift core was shadowing the north eastern sky section of both antennas on the eastern side of the towers leading to outliers of several meters. Although various filter techniques were applied to the data both antenna sites could not be included in further investigations. However, the antenna on the south western handrail of the northern tower and the antenna on the south western handrail of the southern tower captured good quality data. The two antenna locations will be referred to as 1001 and 2001 respectively.

All GPS raw data was analyzed with the software *Trimble Total Control (TTC)* at the Geodetic Institute of the University of Hanover. Three different solutions were determined: a static solution for the entire measurement period, a static solution for each day and a cinematic solution for each interval. In the following only the cinematic solution will further be described since it is the most important one for the deformation modeling of both towers. The baselines from the reference station to 1001 and 2001 had to be calculated and equalized within *TTC*. The resulting positioning solutions were then transformed to topocentric system. This transformation facilitated the interpretability of the data because the Rethe vertical lift bridge is directed in north south direction. Hence, the northing was interpreted as a movement of the tower lengthways to the bridge. The height component was evaluated as height deformation and the easting was related to transverse movements. Furthermore, the residuals for each position were calculated to detect deformations easier.

Time series with equidistant intervals of 15 seconds, without gaps and without linear trends were processed in order to account for further analysis tools. Additionally, all time series were low pass filtered with a mean filter ranging over three hours to reduce high frequency noise. Periodograms for all six smoothed time series could be determined. However, the focus was on the northing component. The northing component was expected to change with a daily period due to temperature changes. The daily period could be proved with the corresponding periodogram (Figure 9). Due to a not purely sine function of the northing component harmonics appear.

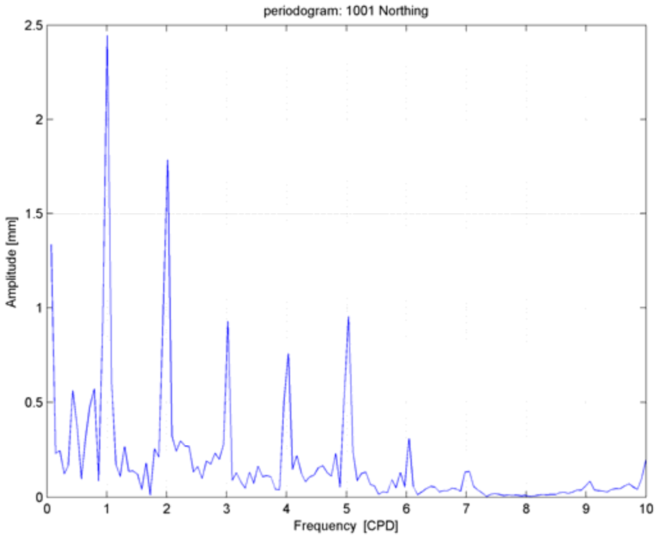

Fig. 9: The periodogram of the northing of 1001 shows both a daily and half day period

5.3 Leveling

The level *Zeiss DiNi11* was used to determine the heights of four points on each foundation. Points 101, 102, 103 and 104 were measured on the southern foundation while points 105, 106, 107 and 108 were measured on the northern foundation (Figure 10). Two leveling campaigns were run, one in spring at 7°C and one in summer at 20°C.

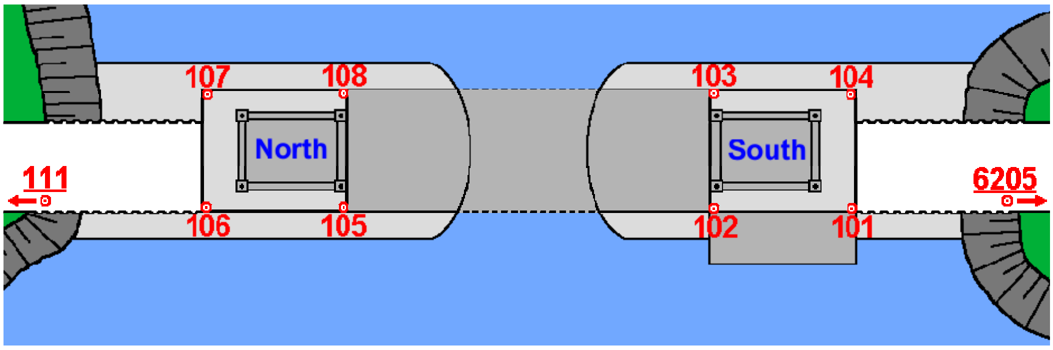

Fig. 10: Site plan of the Rethe vertical lift bridge with four levelling points at each foundation and the benchmarks 111 on the northern side and 6205 on the southern side

Both level runs were conducted at low tide in order to achieve maximum positive correlation between both runs. The outcomes of both leveling campaigns were compared to detect seasonal height changes of the foundations. Both foundations were found to be slightly higher in summer than in spring. The southern foundation had been uplifted approximately three millimeters. The northern side was found about two millimeters higher in summer than in spring. This significant uplift of both foundations may be due to the Elbe flood during the measurement campaign in spring. Much more water results in higher weight on the foundations and thus lower heights in spring. Additionally, rising temperatures have resulted in the expansion of the concrete foundations. In conclusion, this uplift is not regarded crucial since the relative height change between both foundations of about one millimeter is tolerable.

6. SHORT TERM MEASUREMENTS

Three different sensors were used in order to capture short term deformations of the lift section. The laserscanner *Leica HDS 4500* was deployed in combination with the already introduced tilt sensors of make *Schaevitz*. Additionally, a GPS session with a one second data capturing interval was run.

6.1 High frequency measurements at the lift section

The laserscanner *Leica HDS 4500* is enabled to measure profiles with 16.5 Hz because it is a continuous wave scanner. Hence, high speed profile laserscanning of the bottom side of the main steel beam of the lift section was accomplished. All laserscanner data was stored on a connected notebook which is also necessary for controlling the laserscanner. The laserscanner profiles were synchronized with the tilt observations. Both road and rail traffic were recorded on video tape in order to reference the lift section’s deformation magnitude to the corresponding traffic load.

Data analysis was done stepwise. Only those sections of the laserscanning profiles situated directly beneath the tilt sensors were of interest in order to compare both sensor types. Hence, these sections were selected from the profiles and further analyzed. The length of such sections was set to 0.5 m (see further details in Hesse et al. (2005)). Furthermore, the mean was calculated for every section in order to reduce noise. All tilt data could be transformed to vertical deformations in millimeters since the locations of the tilt sensors corresponding to the northern end of the lift section were carefully surveyed. In conclusion, two time series with direct vertical deformations in millimeters had been calculated. The next step was establishing equidistant time series with observations at exactly the same times. Hence the tilt data was interpolated to 16.5 Hz. In order to further reduce noise both time series were filtered with a low pass filter. Figure 11 and Figure 12 display a comparison of laserscanner and tilt sensor data. Obviously the blue laserscanning profiles show more sufficient results for the deformation of the lift section. The tilt data indicated in red shows more noise but proves the profile data. This noise mainly results from the tilt sensors’ sensitivity for accelerations. Figure 13 is a picture taken by the video camera at the time of interest. The offset can be explained by the different sensor positions. While the laserscanner was measuring to the bottom side of the steel beam the tilt sensor was installed on a grid above the beam.

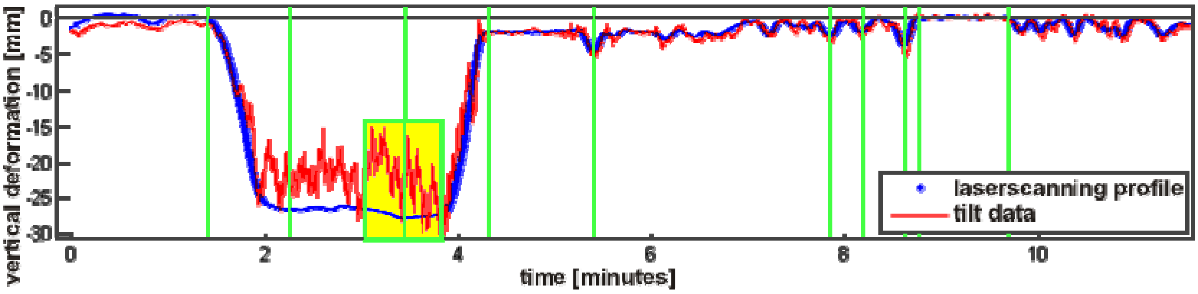

Fig. 11: Deformation magnitude of the lift section while a train is crossing - overview

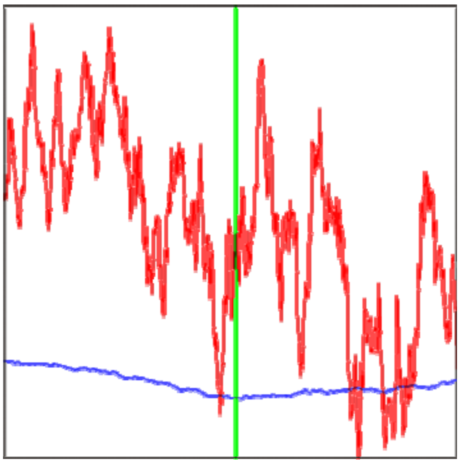

Fig. 12: Clipping of the deformation shown in yellow in Figure 11

Fig. 13: Video picture of the traffic situation at the time of the vertical green line in Figure 12

The vertical deformation of the lift section depends on the weight of the crossing traffic. Trucks usually cause deformations of approximately 6 mm. Trains cause deflections of about 3 cm. However, these values refer to the maximum deflection in the middle of the lift section. According to the project partners from the HPA this deflection is normal.

6.2 GPS short interval measurements on the lift section

A short term GPS campaign for three hours was accomplished on the lift section. Two *Trimble R8* receivers with *Trimble Zephyr Geodetic* antennas (4000 and 5000) were mounted on an eastern brace of the lift section above the road (Figure 12). Their data capture interval was set to one second to allow for the detection of short term deformations. Additionally, the data capture interval of antennas 1001 and 2001 on the towers was changed to one second. Once more rail and road traffic was recorded with a video camera to reference certain magnitudes of deformation to certain objects on the lift section. After the analysis of all data from the towers no deformations due to lifting operations could be detected in the GPS data of antennas 1001 and 2001.

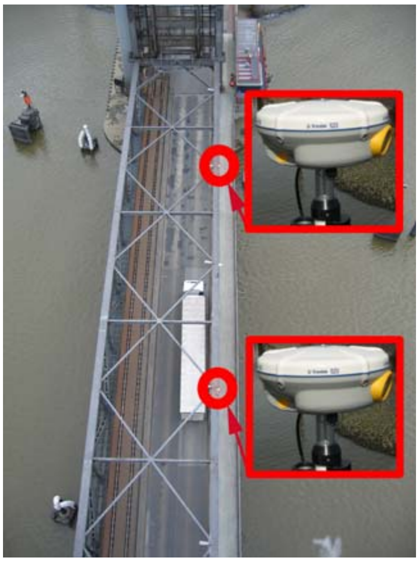

Fig. 12: Location of antennas 4000, 5000 on the lift section

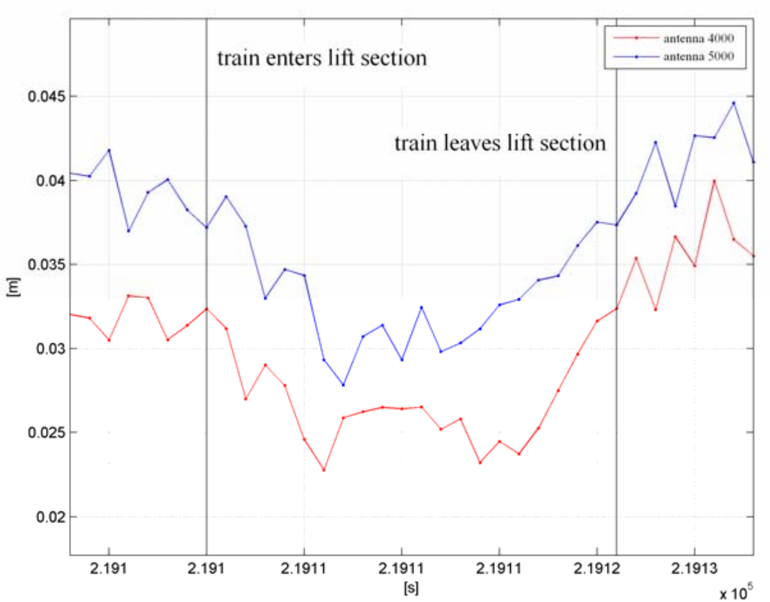

Fig. 13: Height variation of GPS antennas 4000 and 5000 for a train crossing the bridge from south to north

However, rail traffic could be detected in both antenna sites 4000 and 5000 on the lift section. Both antennas show height variations of approximately 1 cm (Figure 13). However, this result slightly differs from the combined laserscanner and tilt sensors' results. On the one hand the data capturing period was different. On the other hand the GPS antennas were mounted on a brace above the road while the tilt sensors had been installed on road level and the laserscanner was set up below the bridge. Truck traffic did not cause any significant deformations in GPS data.

7. SUMMARY AND OUTLOOK

The established monitoring system proved to be very successful in detecting deformations of the Rethe vertical lift bridge. By applying various sensor combinations for the capture of long periodic and short term effects, a continuous bridge deformation monitoring was achieved. The major contribution to this success was the implementation of wireless data transfer to an internet enabled database. Sensors may be moved as well as additional sensors may be integrated easily due to the systems wireless and modular layout. Financial efforts could be reduced by cutting costs for cables and the labor necessary to lay them. Excellent conditions were achieved for further data analysis:

- Remote access to all data in real time via the internet ,
- Performance of analysis algorithms online on an arbitrary, remote computer
- High speed information flow as soon as crucial deformations occur

Long periodic deformations of both towers were measured with PDGPS. For further implementations of this monitoring system the deployment of GPS choke antennas, which were not available for this project, is advised. Steel bridges provide a very poor multipath environment and thus special antennas will reduce noise and outliers significantly. The integration of GPS data storage in the central database would further improve the overall system. Deformations of the towers on millimeter level could be detected with the *Schaevitz* tilt sensors. The cause variables steel temperature and tide could be proved in both GPS and tilt time series. Further improvements would be the installation of a GPS antenna on the lift section in order to capture all lifting operations' times and heights precisely. The combined deformation capture with laserscanner and tilt sensor develops a completely new and promising tool for high speed deformations. The introduction of profile laserscanning to high frequency deformation analysis will prove to be a very important tool in the future. It may also be thought of detecting harmful vibrations with the laserscanner *Leica HDS 4500* because of its very high scanning rate of 16.5 Hz in profile modus. The implementation of water level gauges would make level runs superfluous. As a consequence, height data analysis would be enabled continuously, online and from a remote computer via the internet.

The result of this first campaign at the Rethe vertical lift bridge is a model of its usual deformation behavior. Changes to this behavior during the construction of the new bridge located closely may be detected fast and without false alarms. A continuous deformation monitoring with this system for the entire construction period is advised. The monitoring system proposed in this paper will be applicable to other types of bridges although small changes will have to be conducted.

REFERENCES

[Hesse et al. 2005] Hesse, C., Neuner, H., Kutterer, H.: Statistical analysis of kinematic laser scans., In: Grün, A., Kahmen, H. (Eds.):Optical 3-D Measurement Techniques VII, Vienna 2005.

[Kuhlmann 1996] Kuhlmann, H.: Ein Beitrag zur Überwachung von Brückenbauwerken mit kontinuierlich registrierten Messungen, Dissertation, 1996. - Wissenschaftliche Arbeiten der Fachrichtung Vermessungswesen der Universität Hannover, Nr. 218

[Pelzer 1988] Pelzer, H. (Eds.): Ingenieurvermessung: Deformationsmessungen; Massenberechnungen. Ergebnisse des Arbeitskreises 6 des Deutschen Vereins für Vermessungswesen (DVW) e.V. Vermessungswesen bei Konrad Wittwer, 1988

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