Hydrostatic Leveling Systems: Measuring at the System Limits

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Key words: high-precision ground deformation, long-term stability, hydrostatic leveling system, vertical displacement, synchrotron, power dam, bridge control, Earth tide

SUMMARY

Three hydrostatic displacement monitoring system applications in Switzerland are discussed; the first concerns experience gained monitoring the foundation of the Albigna dam, the second relating to the underground stability of the Swiss Light Source synchrotron and the third concerning the deformation of a bridge near the city of Lucerne. Two different principles were applied, the Hydrostatic Leveling System (HLS) using the "half-filled pipe principle" which was developed for the Paul Scherrer Institute (PSI) and the Large Area Settlement System (LAS) using the "differential pressure principle". With both principles deformations down to ground deformations induced by tidal forces can be seen. However, high accuracy of single sensors is not sufficient. A well-considered configuration of the complete system is equally important. On the other hand there are also limits given by the feasible installation or by the environmental conditions. Such an example is shown in the measurement task of the bridge, where the acceleration along the bridge due to the pass over of heavy trucks is limiting the feasibility of hydrostatic leveling measurements.

ZUSAMMENFASSUNG

Dieser Beitrag beschreibt drei Anwendungsbeispiele hydrostatischer Messsysteme für grossräumige Deformationsmessung: Das Hydrostatic Leveling System (HLS), welches für das neue Synchrotron am Paul Scherrer Institut PSI entwickelt wurde, sowie das kompakte und sehr einfach einzusetzende Large Area Settlement System (LAS), welches für die Untergrundüberwachung der Bewegungen in einer Staumauer und bei der Überwachung einer Brücke zur Anwendung kam. Beide Systeme sind so empfindlich, dass durch Erdgezeiten bewirkte Verformungen gemessen werden können. Die hohe Messempfindlichkeit der Sensoren allein ist jedoch nicht ausreichend. Einerseits ist ein durchdachter Aufbau des Gesamtsystems und die einfache, zuverlässige Installation ausschlaggebend für die Brauchbarkeit einer Messung. Andererseits werden auch die Grenzen der Machbarkeit mit hydrostatischen Messsystemen aufgezeigt, die insbesondere am Beispiel der dynamischen Brückenüberwachung verdeutlicht werden.

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1. INTRODUCTION

Since ancient times the surface of fluids has been used as a reference tool to determine precise level differences. Nowadays, the hydrostatic measuring principle is more often applied, when visual observation is not possible or disturbances such as air turbulence prevent optical measurements. The advantages of hydrostatic measuring systems are their high accuracy and resolution. With regard to this aspect, these systems are far superior to modern geodetic instruments such as tachymeters and digital leveling devices. Due to their simple and robust configuration, hydrostatic measuring systems are well-suited for permanent all-season monitoring, combined with remote control systems and automated data acquisition. All hydrostatic measuring systems work on the fundamental principle stating that a water surface which is under the influence of a gravitational field and free to move, orientates towards a certain level surface. Measuring pots, which are connected to each other, obey the law of the communicating vessels and therefore the water surface represents a stable, reliable and very accurate reference for leveling purposes. The fundamental layouts and the calculation of hydrostatic measuring systems have been described in 1998 at the XXI Congress of the International Federation of Surveyors in Brighton [1]. The various hydrostatic measuring systems can be divided into three groups according to the operational method:
- Half-filled pipe (open surface)
- Hydrostatic level
- Pressure measuring system

With half-filled pipes as well as with hydrostatic levels the changing fluid-levels are measured. According to the demands on precision of hydrostatic levels, different methods of fluid-level sensing are applied. The pressure measuring system differs basically from the first two designs, as no (or very little) fluid flow occurs. Inductive, capacitive or piezoresistive sensors are used for pressure measurements in either differential or absolute pressure transducers, respectively, depending on the task. At present the highest accuracies are obtained by capacitive pressure transducers.

The advantage of hydrostatic leveling systems is the high resolution of static and dynamic deformations. Therefore, hydrostatic systems are used in large research facilities such as linear and ring accelerators, as well as for monitoring settlements and tilts, movements of buildings and dams, landslides and rock avalanches. All applications have two essential aims:

- To control predicted deformations
- To serve as early-warning system in case of unexpected movements of the observed objects.

Hydrostatic leveling systems are not only used for permanent monitoring. They also allow detecting the behavior of buildings during specific events, such as release from snow loads, bending due to wind exposure or vibrations caused by trucks passing over a bridge.
In complex buildings, in which hydrostatic leveling systems with consistent water level are not continuously applicable, the system can be disrupted and vertically displaced. Thus this requires high precision in data logging, because measuring errors cumulate with several lateral offsets.

2. ALBIGNA POWER DAM MONITORING USING LAS SYSTEM

The LAS-meter was developed at ETH Zurich in co-operation with the company Edi Meier + Partner AG, Winterthur, Switzerland. The Multipoint LAS-meter described here uses the pressure difference between two liquid columns (Fig. 1).

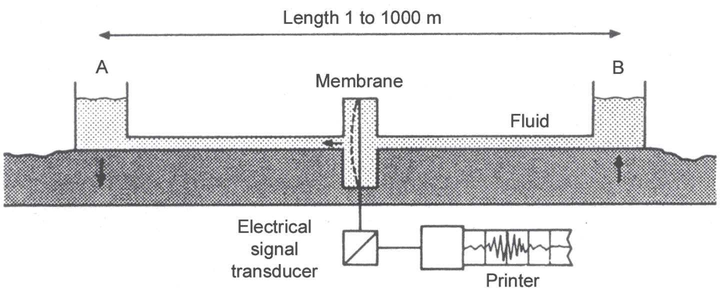

Fig. 1): Measuring principle of the LAS-meter. As a result of the pressure differences between two fluid columns, the diaphragm becomes arched. The deformation of the diaphragm is transformed into an electric signal proportional to the elevation difference.

In the middle of the tubes a diaphragm is inserted which deforms according to the equalization of the liquid. As a result of pressure differences between the liquid columns, the diaphragm is deflected. The movement of this diaphragm is transformed to an electrical signal, which is a measure for the level difference between the ‘chambers’ at the end of the tube.

Fig. 2a shows the auto-calibration setup of the Albigna instrument. The normal measurement cycle shown in Fig. 2b indicates a change in height of about 1 mm over the whole measuring period in 1997, which agrees well with the expected dependence on the lake level. An auto-calibration cycle is carried out periodically to correct the sensor drift. The inverse measurement is symmetric in relation to the zero line and gives an idea of the inherent accuracy of the system [2].

The provision for mechanical switching of the individual measuring points makes it possible to determine and eliminate the systematic effects of a hydrostatic measuring system. On the other hand, the loss of liquid in the vessels and tubes as a result of evaporation cannot be neglected when the system is running for a long-term measurement.

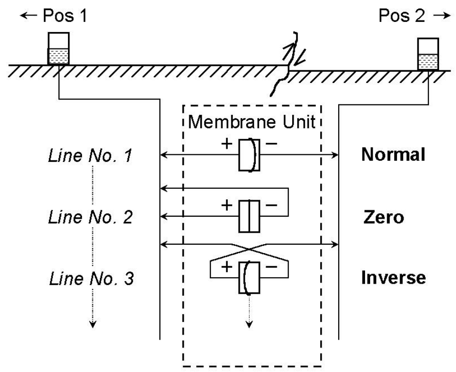

Fig. 2a): The principle of the auto-calibration procedure performed periodically at the Albigna instrument for elimination of the membrane drift. There are three calibration cycles which carry out normal, zero and inverse measurements.

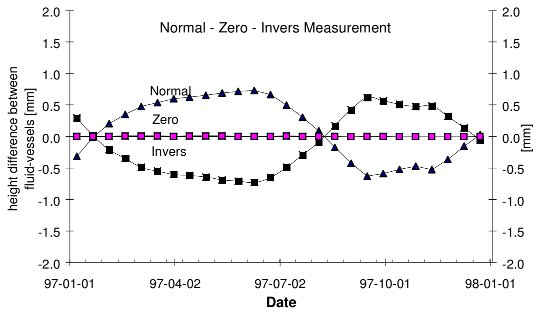

Fig. 2b): The results of the system calibration during 1997. Note the inverse measurement is symmetrical in relation to the zero line.

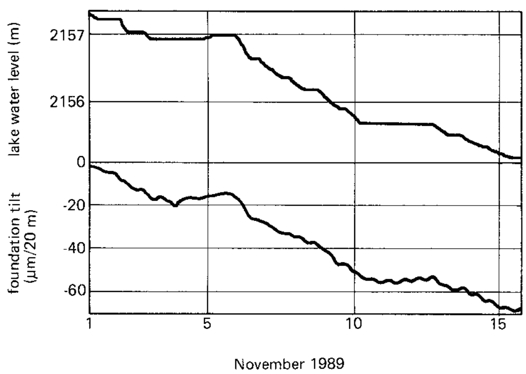

Fig. 3a): Water level of the Albigna-reservoir between November 1 and 16, 1989. The upper line represents the water level (in meters above sea level). The comparison with the tilt of the dam foundation during the same period (lower line) shows the influence of the water level fluctuation on the tilt changes of the dam foundation.

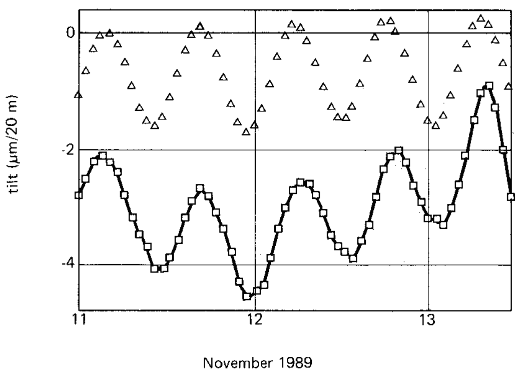

Fig. 3b): Tilt measurements at the Albigna dam. There was almost no fluctuation of the reservoir water level. The lower curve shows the residual tilt changes. The upper curve shows the calculated tilt changes of the Earth tides due to gravitational forces between moon, sun and Earth (by D. Emter, Black Forest Observatory).

3. THE HLS AT THE SWISS LIGHT SOURCE SYNCHROTRON (SLS)

For monitoring the underground of the new built storage ring of the Swiss Light Source (SLS) at the Paul Scherrer Institute (PSI), Switzerland, highest resolution and long-term stability over more than 10 years was required. As liquid loss over such long periods cannot be eliminated, the use of a differential pressure system was not suitable. Thus, the principle of the half-filled pipes was chosen, where a slow liquid loss is irrelevant. The HLS installed at the SLS was designed to meet the following specifications: measuring range 14 mm, resolution 0.0005 mm, accuracy better than 0.01 mm. The storage ring of the synchrotron (Fig. 4a) is subdivided into 12 sectors, each containing four girders on which the focusing electromagnets are mounted. Every girder is monitored by four installed level sensors (LS) (Fig. 4b). This leads to a total amount of 192 LS, which are linked together by half-full steel pipes with a total length of 450 m.

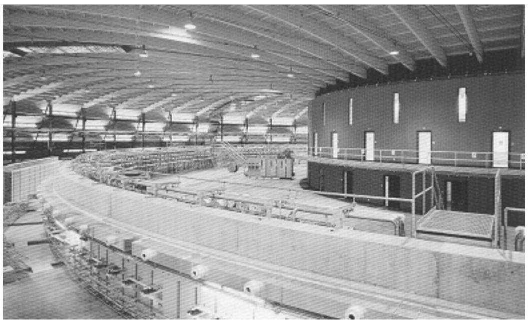

Fig. 4a): Storage ring of the SLS.

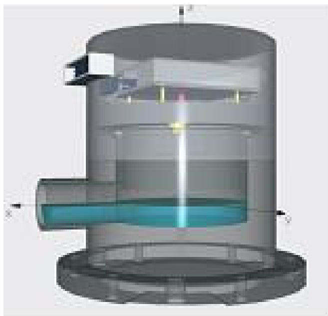

Fig.4b): HLS level sensor.

The fill level is determined capacitively, where the fluid surface and the electrode act each as a capacitor plate. Thus, there are no mechanical parts which can wear out, such as a pressure membrane. In order to avoid condensation water at the electrode, the LS has an integrated heating device. In the case of fluid touching the electrode, a specially designed ring ensures a quick and complete run off [3]. As a special feature, each LS is equipped with a touch point. The touch point is located near the electrode. This allows a calibration of the zero-level at any time during the HLS operation within the demanded accuracy. The calibration is done by raising the fluid level slowly until the touch point is reached. After a couple of months, it is necessary to compensate the fluid level for natural evaporation. At the SLS, the HLS can be refilled (or emptied) entirely by remote control over the internet. Thus, no interruption of the SLS operation is needed in order to control or recalibrate the HLS.
The influence of the Earth tides is clearly visible on quiet days. Fig. 5a shows the average values of all sectors in the four main cardinal points during a lunar eclipse [4]. To illustrate the symmetry the signals were adjusted with an offset value so that opposed signals can be compared. The single signals of the first sensor on each girder are not as quiet as the average value of the sector (Fig. 5b). Apparently, there are small local signal differences. Fig. 6a shows the absolute values of the north sector and the average value of all 192 signals. In the average value no tides are visible, as the signals of the opposite sensors are cancelled out. Yet a daily cycle can be observed, presumably due to the daily variability in temperature. In

addition, a slow liquid loss of about 5 µm during this period is detected. Both, daily cycle and liquid loss do not generate an error in measurement, since only the signals relative to the average value are analyzed. The long-term stability of the measurements is shown in Fig. 6b. Equal sensors are compared with the same offset after 5 years. The ground is slightly more unstable and the south sector is seeing a small trend, though the signals provide quite the same values after 5 years. These results indicate the stability of the ground on which the synchrotron was built.

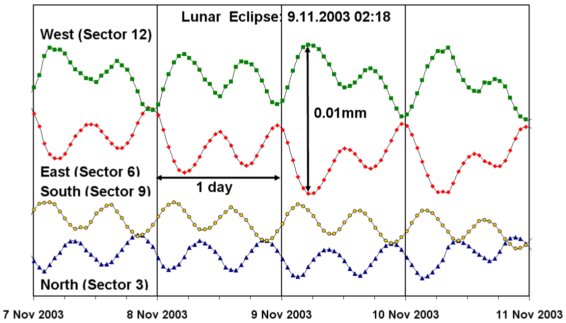

Fig. 5a): A four day period of the year 2003 with a time resolution of 1 hour. The influence of the Earth tides with 2 periods a day is clearly visible. Note the high amplitude difference between East and West during the eclipse of the moon.

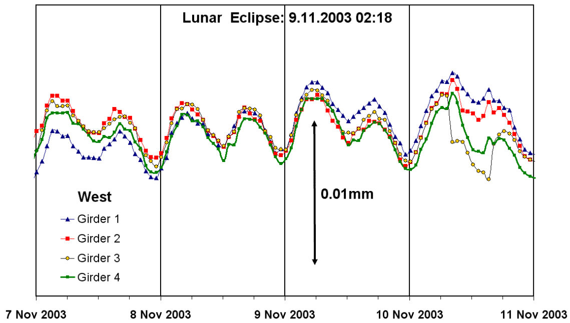

Fig. 5b): Variation of single signals in sector west. Signals of the first HLS sensor on each girder are plotted.

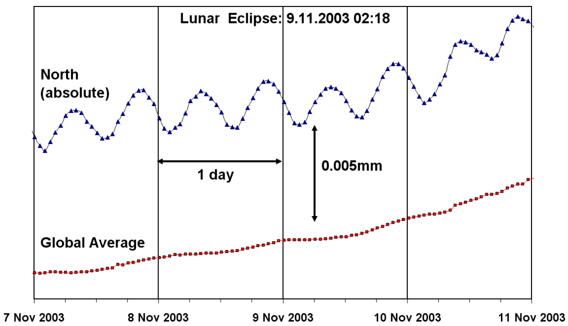

Fig. 6a): Average of the absolute values of sector north und and the average value of all 192 signals, which is subtracted to balance the liquid loss.

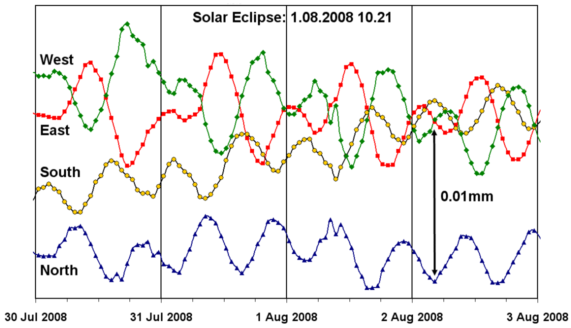

Fig. 6b): Same sensors as in Fig. 5a during a solar eclipse 5 years later. The signals are slightly more unstable, but they show good long-time stability.

4. DYNAMIC BRIDGE MONITORING

A highway bridge over the Reuss River near the city of Lucerne was broadened and strengthened (Fig. 7). The static calculations concerning this modification predicted deflections and settlings of up to 27 mm. Fiber-optic strain sensors and hydrostatic measurement systems were installed in order to monitor and control the predictions over 5 years, with the following objectives:

- Verification of the considerations concerning the dimensioning of the structure
- Monitoring and recording of the structures behaviour during rehabilitation and operating conditions
- Release of alarms in case of exceeding the notification and alarm values

Fig. 7a): Highway bridge near Lucerne after enlarging during construction phase.

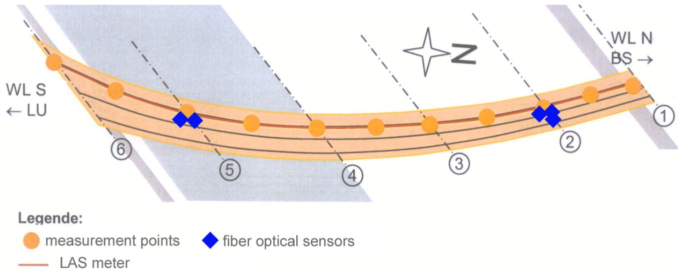

Fig. 7b): Instrumentation with fiber-optical strain sensors and LAS-meter [5].

The tasks of the hydrostatic measurement system consisted in monitoring the long-term stability of the structure with millimeter accuracy and documenting dynamic movements with periods down to 1 s. These movements are produced by heavy trucks passing the bridge at about 80 km/h. During the evaluation of the measurement systems, the highly accurate HLS system with 20 leveling sensors was considered first. For financial reasons however, the less expensive LAS system with 10 single channels and without automatic calibration was finally used, even if possible air pockets can lead to erroneous measurements. In order to correct such errors, a yearly control of zero-point and fluid-level was scheduled. The accuracy of the fluid-level controls is +/- 1 mm. The dimensioning of the individual LAS-meter was evaluated in order to achieve a response time of below 1 s.

The 10 separated LAS-meter systems were placed upstream along the western longitudinal girder of the bridge, at the inner wall of the box girder. For each field of the bridge, separated by two pylons, two independent LAS systems were installed. For each of the two systems, one fluid vessel was mounted in the center between two pylons, and the second vessel was installed near the pivot (pylon). This yields two opposite signals from the two systems. Heights are computed by summing the signals from all LAS systems (Fig. 8).The predicted values in Table 1 are only comparable at a limited extend to the deformation values shown in Fig. 8, due to the complex load history.

Building element	Point	Predicted value	Reported value	Alarm value
		[mm]	[mm]	[mm]
Abutment north (Pivot 1)	LAS 1	0	- 10	- 15
Field 1	LAS 1 / LAS 2	-15	- 20	- 38
Pylon 2 (Pivot 2)	LAS 2 / LAS 3	-5	- 10	- 15
Field 2	LAS 3 / LAS 4	-15	- 20	- 35
Pylon 3 (Pivot 3)	LAS 4 / LAS 5	-5	- 10	- 15
Field 3	LAS 5 / LAS 6	-13	- 18	- 34
Pylon 4 (Pivot 4)	LAS 6 / LAS 7	0	- 10	- 15
Field 4	LAS 7 / LAS 8	-16	- 24	- 48
Pylon 5 (Pivot 5)	LAS 8 / LAS 9	0	- 10	- 15
Field 5	LAS 9 / LAS 10	-27	- 40	- 50
Abutment south (Pivot 6)	LAS 10	0	- 10	- 15

Tab. 1): Predicted, reported and alarm values

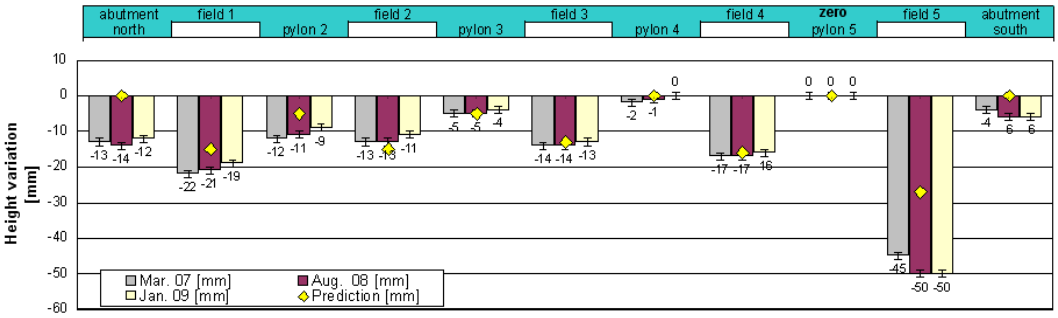

Fig. 8): Predicted and measured long-term deformations since the start of construction works in 2006. Pylon No. 5 was used as reference.

A functional test was made in order to check if the measurement facility meets the required specifications. For this purpose, the fluid level was raised by 5 mm. The resulting signal (Fig. 9) shows the expected transient oscillation curve with a response time of 0.9 s, meaning that the specifications are achieved. The amplitude of an oscillation with duration of 0.9 s is only reproduced to 63%, while faster movements are attenuated even more.

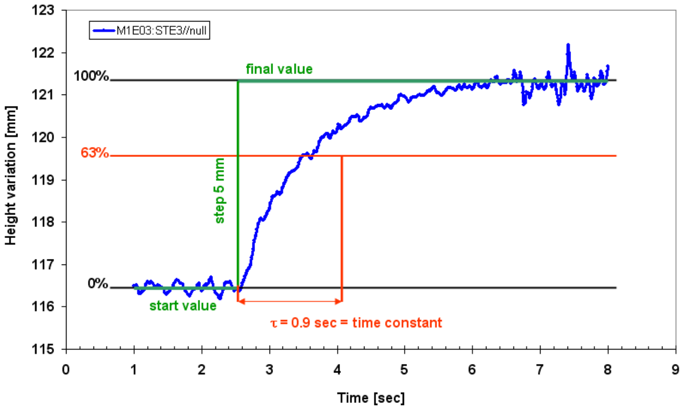

Fig. 9): In-situ functional test for determination of the time constant at LAS No. 3 by increasing the fluid-level.

For the long-term observations, mean values over 10 minutes were computed. According to the task definition, the monitoring system should also allow detecting fast deformations produced by heavy trucks. Based on the experience gained from the dam observations (Fig. 3), no problems were expected in this domain with the LAS system.

Fig. 10 shows the results of LAS-meter No. 3, which should represent the height variations between pivot 2 (pylon 2) and the field 2 of the bridge. However, the conversion from the observed pressure differences to height differences yields values that are clearly too high.

The fiber-optic observations (Fig. 11) do not show comparable oscillations. The fiber-optic string covers 5 m on each side of pivot 2, and hence covers the first 5 m of the range of the LAS-meter to the center of field 2. Similar movements in the signals from both systems are to be expected.

To investigate this phenomenon, acceleration and magnetic field observations were carried out. The sensors were installed 20 cm below the LAS-meter No. 3. This means that the observed accelerations represent events occurring in the first quarter of the bridge field. The comparison of the observed accelerations and the LAS measurements (Fig. 12) reveals a correlation between the two signals. The passing of vehicles is detected by the magnetic field observations (Fig. 13). Obviously, heavy bridge oscillations are produced by consecutive vehicles passing the bridge and yielding large accelerations. The frequency of these resonance oscillations is 2.5 – 3 Hz.

The high correlation between the accelerations and the oversized dynamic LAS measurement values lead the following conclusion: In contrast to the dam observations, the individual LAS systems in the bridge configuration are altogether in motion. Hence, the LAS sensors are not only measuring the pressure difference yielded by the fluid level difference and the gravitational acceleration g, but also by the acceleration of the complete system. If the system is e.g. subject to an additional horizontal acceleration $a(t)$, measurement errors of the height difference dH in the order of $dH \sim l\ (a/g)$ are induced, where l is the horizontal distance between the two fluid vessels. Fortunately, the measurements errors of a LAS system in motion can be eliminated if the interfering frequency is sufficiently distinct from the useful frequency. Since the LAS-meter has a response time of 0.9 s, movements with duration of 0.9 s are only reproduced to 63% (Fig. 9), while faster movements are attenuated even more.

Due to the high resonance frequency of 2.5 – 3 Hz, these disturbing signals can be eliminated by low-pass filtering, since such fast vertical movements are only partly reproduced by the LAS-meter. Hence, it is legitimate to eliminate these high frequencies by low-pass filtering. The remaining low-pass filtered signal is shown in Fig. 14. It is much closer to the values expected for dynamic conditions. Obviously, the signals of the two LAS-meters 3 and 4 are not exactly opposite. This can be explained by differential movements within a bridge field.

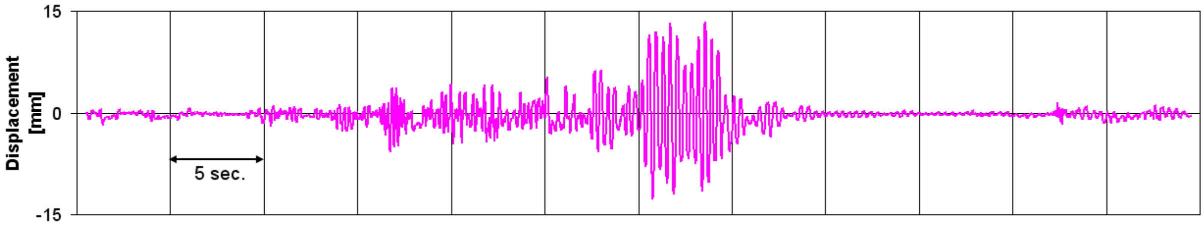

Fig. 10): Raw data of LAS-meter No. 3 from pylon 2 to the middle of field 2

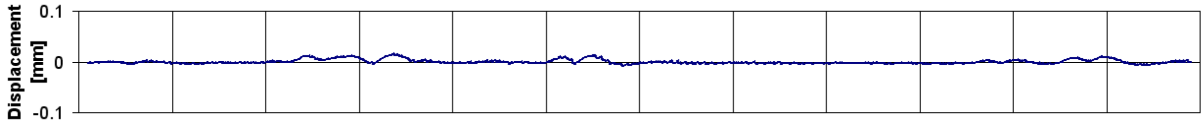

Fig. 11): Fiber-optical measurements +/- 5 m on each side of pivot 2

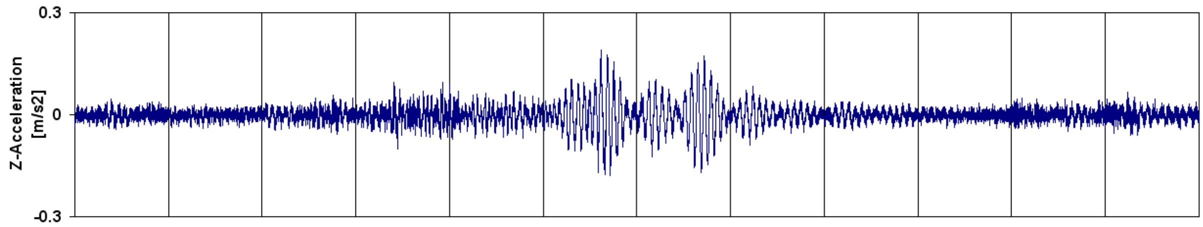

Fig. 12): Acceleration at LAS-meter No. 3 at ¼ of field 2

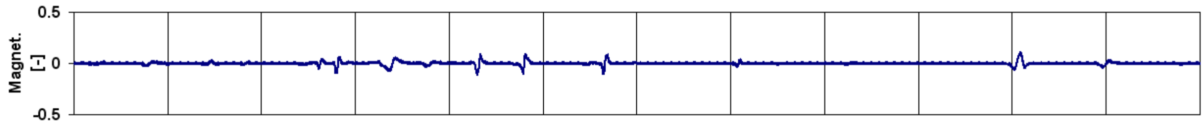

Fig. 13): Magnetic field observations for detection of vehicles passing the bridge.

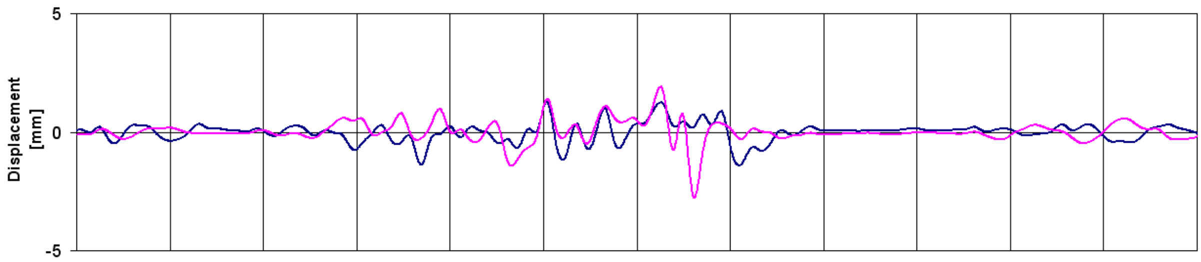

Fig. 14): Remaining signal from LAS-meter No. 3 and 4 after 0.9 s low-pass filtering.

CONCLUSIONS

High resolution down to Earth tide level can be achieved with both, the half-filled pipe hydrostatic system (HLS) and the differential pressure measuring hydrostatic system (LAS). However, if a high long-term stability is required, the half-filled pipe system must be used, since, due to the differentiation, a liquid loss is not causing errors. A slow liquid loss is even beneficial, since it is observed at all sensors at hence shows the correct functioning of the individual sensors. Financial issues are often the reason for switching to the less expensive differential pressure system. Even if the drift of the LAS-meter sensor is eliminated during the calibration cycle (Fig. 2a), liquid loss and blistering can produce hardly detectable measurement errors.

An additional error source occurs in the case of differential pressure systems in motion: if the entire system experiences acceleration along the measurement tube, this acceleration overlays the wanted signal and feigns a height variation of the liquid vessel. If the frequency of the acceleration is clearly higher than the one of the wanted signal, the LAS system can nevertheless be used. Two sets of information can even be obtained from the same instrument if the disturbed LAS signal is both low- and high-pass filtered: low-pass filtering of the raw signal yields the vertical movement, while high-pass filtering gives the longitudinal acceleration.

OUTLOOK

The measurements described above are a first attempt to qualitatively assess the errors sources of hydrostatic measurement systems in motion. To be able to draw also quantitative conclusions, additional measurements with multiple comparative systems, such as high-resolution acceleration sensors and Broad-Band Seismometers, are necessary.

REFERENCES

[1] Meier, E., Ingensand, H (1998): A multipoint hydrostatic system for permanent deformation monitoring, International Federation of Surveyors, XXI Congress Brighton, Commision 5, p. 369 –381, ISBN 0-85406-901-1.

[2] Meier, E., Huggenberger, P., Ingensand, H (1998): Precision monitoring of displacement over large areas, Hydropower & Dams, Commision 5, Issue Six, p. 77 – 88.

[3] Ingensand, H., Meier, E.(2001): Neuere Entwicklungen von hydrostatischen Messsystemen für permanente Überwachungsmessung. 11. Internationale Geodätische Woche, 18.-24.2.2001, Obergurgl, in Proceedings des Instituts für Geodäsie, Insbruck: Institutsmittteilungen Heft 19, 191-194.

[4] Wei, F.Q., Meier, E., Rivkin, L., Wrulich, A., (2004): Data analysis of SLS hydrostatic levelling system in 2003, PSI Scientific and Technical Reports 2003, vol. 6, ISSN 1423-7350, p. 26 – 27.

[5] Steiger,A., Licht, H., Zwyssig, R. (2009): Nationalstrasse A2/3 – Lärmschutz und Instandstellung Riffig-Reussegg, Auswertung der Kontrollmessungen, Bericht Nr. 10.106-018, Ingenieurgemeinschaft Kompetenz Emmen.

BIOGRAPHICAL NOTES

Edi Meier, is managing director of the engineering company Edi Meier + Partner AG, Winterthur, Switzerland. He studied Geophysics at ETH Zurich. Subsequently he worked as a manufacturer of seismic instruments (Streckeisen Switzerland) for six years and founded his own engineering company in 1987. Since 1995 the company is collaborating in research and development of new instruments with the Institute of Geodesy and Photogrammetry of ETH Zurich.

Alain Geiger, Diploma in Physics in 1979, ETH Zurich. In 1980 he joint the institute of geodesy and photogrammetry. PhD thesis in gravity field determination in 1991. Presently he is professor in satellite geodesy and precise navigation at the geodesy and geodynamics lab. He works on precise Kinematic GPS, airborne Laser technique and GPS based landing approaches, geodynamic interpretation of GPS measurements, and 4-dimensional modelling of atmospheric refractivity. He is a fellow of the International Association of Geodesy and serves as president of the Swiss Geodetic Commission of the Swiss Academy of Sciences.

Hilmar Ingensand is a full professor at the ETH Zurich since 1993, holding the Chair of Geodetic Metrology and Engineering Geodesy at the Institute of Geodesy and Photogrammetry. His main research activities at the ETH Zurich are geodetic metrology, sensor technology and engineering geodesy. He is the author or co-author of more than 170 publications, and FIG member in Commissions 5 and 6.

Philippe Limpach studied Geomatics Engineering at EPFL Lausanne, Switzerland. He received his Ph.D. in Geodesy at ETH Zurich, Switzerland, in 2009 and is currently working as Post-Doc at the Geodesy and Geodynamics Lab at ETH Zurich.

Hans Licht is since 2003 an employee of Andreas Steiger & Partner AG. He studied civil engineering at the TU Darmstadt. He is working on inspection, rehabilitation and monitoring of concrete constructions.

Andreas Steiger is managing director of the engineering consultant company Andreas Steiger & Partner AG, Lucerne, Switzerland. He studied Civil Engineering at ETH Zurich. Subsequently he worked as project engineer with engineering consultant companies in geotechnics and water construction and founded his own engineering consulting company in 1990. Andreas Steiger & Partner AG is focussed on assessment, monitoring and rehabilitation of existing structures as roads, bridges and tunnels. Non distructive investigation techniques for existing structures are an important topic of the company.

Roger Zwyssig is a project- and site manager as well as a member of the executive board of Emch+Berger WSB AG, one of the leading civil engineering companies in central Switzerland. In 1998 he graduated in civil engineering at ETH Zurich and post graduated in industrial engineering. His fields of specification are maintenance, enlargement and reinforcement of bridges, in particular of high-performanced roads.

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