

Geodetic Techniques for the Navigation, Guidance and Control of Construction Processes

NIEMEIER, Wolfgang
Institute of Geodesy and Photogrammetry
Technical University Braunschweig, Germany
Email : w.niemeier@tu-braunschweig.de

Abstract: One of the main objectives in engineering geodesy is a stronger integration into the construction processes of large scale structures. Nowadays it seems to be possible to come closer to this target, due to the development of powerful new sensors, adequate communication links and the ability of real time processing of the observations. At first general requirements for a more intensive participation in construction processes are outlined. Then the potential of modern geodetic techniques and new concepts for a real integration are presented and typical examples for already existing solutions are given: Steering for compaction control, guidance for tunnelling, understanding tunnelling as a combined system and geometric aspects of adjustments during the construction of large bridges.

1 TERMINOLOGY

Since several years in the geodetic literature papers are found on the navigation of construction machinery. The geodesy-related industry has developed systems for machine guidance and control and they seem to be quite successful or at least optimistic. Here we want to discuss and - to a certain extend - answer the question : What can be the potential of geodetic techniques for navigation, guidance and control of construction processes, where are their limitations and what can be done in the future ?

To clarify terminology, at first we want to define the frequently used term “*Navigation*”: Navigation is a purely geometrically defined expression, it is information and action required to come from A to B. Navigation of machinery therefore asks for geometric information on the actual position and orientation of the machine and where it has to go. In this understanding navigation includes the technical process of steering a machine to its final position, too.

“*Guidance*” is the look at this process from a different point of view, mainly the view of the driver of the machine: To achieve the best/optimal path from A to B, he needs external geometrical information on the (route). With this information for him the steering is possible.

Most complex is the challenge of “*Control*” , where the objective is to determine and realise the “best way”, which can be defined in terms of length, time or effort. Adequate actions or adjustments have to be initiated, if the optimal path is not followed. To realise an optimal control system, a well defined interaction has to be established between the individual sensors, who determine the actual path and the mechanical, hydraulic and electrical actors, who bring the machine back into its ideal path. Here the main problem is to know precisely, by which action of the steering system which geometric movement can be achieved.

A principally different and complex area, which has an important impact in practise are errors during the construction process and effects of external forces, like wind loading, temperature,

temporal loading, etc. In terms of system theory, for a complete guidance and control problem a system identification has to be performed, taking into account all these effects.

2 GEOMETRIC REQUIREMENTS FROM THE CONSTRUCTION PROCESS

To define the requirements of construction processes and the geodetic possibilities for navigation, guidance and control, at first the temporal development of construction projects will be outlined. Classical phases of the life-cycle of structures are given in Table 1. At the end of its life a complete demolition and/or a new construction follows, starting with phase 1 again.

In this table the usually required information from the area of geodesy and geoinformatics is summarised, too. In general, in every step of the construction progress some geodetic information is required, but it differs in quality, actuality and completeness.

<i>Life-Cycle Phases in Construction</i>	<i>Deliverables from Geodesy/Geoinformatics</i>
1. <i>Idea/ Feasibility study</i>	<= <i>Maps, Geoinformation</i>
2. <i>General Planning / Architectural Design</i>	<= <i>Detailed Geoinformation, Cadastral Aspects</i>
3. <i>Constructional Design / Detailed Planning</i>	<= <i>Coordinate References, Main Axes</i>
4. <i>Realisation Phase / Construction</i>	<= <i>Stacking-Out, Quality Control and Monitoring</i>
5. <i>Utilisation Phase / Reconstructions / ...</i>	<= <i>As-Built Documentation and Monitoring</i>

Table 1: Actual services from Geodesy and Geoinformation during the construction phases

What is pointed out in this table is a *one-way-delivery*, i.e. the information from geodesy and geoinformatics has to be provided to the construction office. It has to be establishment in time and responsibility independently from the construction progress itself. The geodetic engineer gets his tasks and time schedule from the central construction office, but he is – normally – not part of this team !

In the time domain critical tasks are surveying jobs during the realisation phase. Here e.g. for the construction of high buildings precise position of form-works, quality of surfaces, verticality of walls or correct position of pillars between different floors have to be determined. The time-span for these surveying tasks should be as short as possible, best would be a solution, where no time-delay is related to the surveying work.

Due to the tremendous progress in sensor developments in geodesy, made during the last years and the advent of modern communication and real-time processing capabilities for geodetic data, a much more rapid geodetic information can be achieved. An outline of the relevant geodetic concepts are given in the next section.

On the other hand, the following requirements from the construction site exist, which have to be fulfilled, before the geodetic engineer is attractive enough to become part of the team. The requirements can be formulated as follows :

- i. *Development of measuring techniques to determine geometry of arbitrary forms and structures without targets, but with sufficient precision and reliability*
- ii. *Real-time processing techniques to compute each geometric form and the derivation from a design model*
- iii. *Set-up of a communication and data structure for perfect interaction with information systems used in construction*

Only if these requirements are fulfilled, the position of the geodetic engineer on a construction site will be improved. It should be possible that he becomes responsible for all geometric aspects during the planning and realisation phase.

3 POTENTIAL OF GEODETIC TECHNIQUES TO FULFILL THE CONSTRUCTION REQUIREMENTS

The classical activities of the surveying engineer during a construction process itself are staking out and quality control. The requirements in terms of precision, actuality and completeness of the geometric information are derived from the design of the structure and the construction technology itself by the site manager or his management team, mainly without real cooperation with the geodetic engineer.

With the advent of new sensors, modern communication and efficient processing concepts this situation can be changed completely. It is important to point out the real advantages of modern geodetic techniques. Best would be to estimate the shortening of the construction time and the reduction of the construction costs due to adequate geodetic integration, see the example in section 6. Further advantages are to avoid (geometrical) conflicts before they become critical and to improve the final quality of the structure/building.

3.1 Modern Sensor Systems

Well established in geodesy but not sufficiently applied in construction are modern satellite positioning systems, like GPS, GALILEO and GLONASS. For navigation of construction machines for earth work these systems are already in use, see Table 1 and section 4. But there is a much higher potential within these systems, as they provide real-time information with high accuracy and this is needed in further construction areas as well.

Modern sensors like *Automated Total Stations*, *Laserscanners* and *Lasertrackers*, see Fig. 1, are best suited to fulfil the first requirement, mentioned above, i.e. to determine the geometry of arbitrary forms and structures without any physical targets. With these measuring systems a complete determination of geometric forms can be achieved, therefore these systems can be used for tasks which are characterized as being “*Continuous in Space*”.

In Figure 1 the main concepts for these polar sensor systems are depicted, where the observations are the polar coordinates “horizontal direction”, “vertical angle” and “slope distance”. With these instruments an almost arbitrarily dense capture of geometric objects even without physically marked targets is possible. While a Lasertracker can only be used with additional tooling to be in touch with the surface, the other systems are developed for remote data capture. In terms of precision the Lasertracker gives a standard deviation in the range of 0.1 mm or better, the Automated Total Station of about 1 mm and the Laserscanner up to how in the range of about 5 mm for single shot.

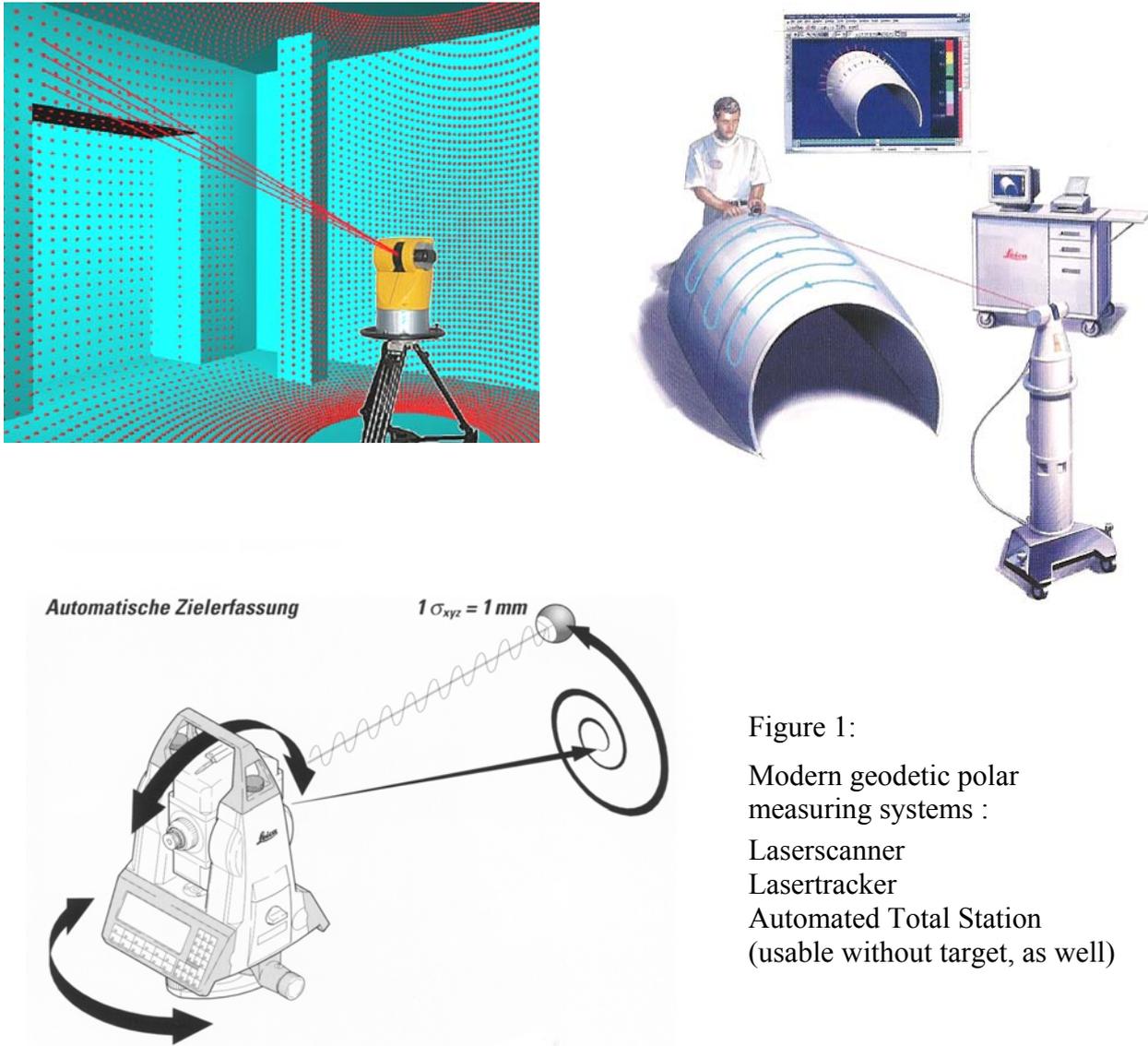


Figure 1:
Modern geodetic polar
measuring systems :
Laserscanner
Lasertracker
Automated Total Station
(usable without target, as well)

It is obvious, that not all geometric problems can be solved with these mainly geodetic techniques alone, but that further systems like optical sensors, inclinometers, pendulums and others have to be taken into account to find the best suited solution. It is an absolute “must”, that at in the definition phase of a project all disciplines have to discuss as a team, what are the normal requirements and what are the critical phases during the construction process. The complete measuring concept has to be set-up to find the best measuring solution for all these phases, see Kovari/Bosshard (2003).

3.2 Real-Time Processing

Real-Time in this concept means “the geometric information (form of an object, derivation from the design model) has to be available, before the next user needs it”. This practical definition of real-time leads to time discreet determinations, which are much easier to handle than a continuous real-time description of the structural behaviour and the construction phases.

The main difference in relation to well-known surveying techniques is the much more complex data processing : As result of data capture without targets in general one achieves a point cloud with numerous single points, which represent the object and not a coordinate set for a well defined single point. Sophisticated and efficient software is required to derive the final

geometric information out of these data and at the moment intensive research activities are focused to derive and realise the optimum concepts for the geometry extraction out of these point clouds, see Niemeier (2005).

A second challenge for research is the development of strategies and procedures for an integrity check of the observations and results. This starts with adequate estimates for the precision and reliability of the observations but includes on-line calibration procedures and self-checking of the devices, which often have to be used independently for a longer time span on a construction site.

Only if these problems are solved, real-time processing techniques can be established to compute each required information out of the geodetic data. Finally for the control of the construction and a necessary adjustment procedure the deviation between a design model, i.e. the theoretical structure, and the reality on the construction site has to be derived in real-time, too.

3.3 Communication and Data Structure

A further problem is the set-up of powerful communication links between the sensors and central processing offices, which can be on the site and far away, e.g. in another city. The set-up of the communication is a really interdisciplinary approach, as these links have to be valid between the different groups on the construction site and the site management, as well.

A general requirement is a common data-structure for observations and the designed and computed geometry in all steps of the process. Here “common” means that all groups on the construction site and in external planning and evaluation offices have to use this structure. One possibility to set-up such a system is the use of internationally accepted standards for the representation of geometry, like Industry Foundation Classes (IFC) or Geography Markup Language (GML). Gielsdorf (2004) has analysed and compared these standards and came to the conclusion that both are not ideally suited for the here mentioned purposes. His own new concept, based primarily on the topology of the structures, seems to bring real progress.

Once the data structure is defined, one has to establish intelligent, i.e. error redundant and stable communication links on the construction site. To achieve this the maximum data rates, possible disturbances e.g. by the concrete masses, temporary machine positions and material transport, power failure and many other effects have to be taken into account. Here electrical engineers are the specialists and finally they should set up the communication system.

Finally a readable or understandable presentation of the results in attractive graphical form has to be established. This helps the communication between the groups and is an important prerequisite, if problems arise and have to be discussed with external experts or the customer.

4 COMPACTION CONTROL

Due to the wide range of construction projects the methodology, sensors, data structure and processes may differ to a large extent, but the basic ideas are similar. As examples here the potential and impact of modern geodetic concepts on typical large scale projects are outlined.

4.1 Objectives for Compaction Control

Well established are methodologies for the navigation of construction machines for earth work. Retscher (2002) gave an overview on applications on different types of construction machines and compared the specifications, see Table 2.

	Dozer	Grader	Road paving machine	Slipform paving machine
Major application field	Bulk earthworks and earthmoving	Fine grading, sideslop work	Asphalt surface for highways, concrete surface for runways	Concrete surface for highways, high speed railways, runways
Precision requirements	up to ± 2 cm	up to ± 5 mm	up to ± 5 mm in plane ± 3 mm in height	up to ± 5 mm in plane ± 2 mm in height
Guidance systeme	3-D systems: GPS or total station	Laser systems 3-D systems: total station	String lines or stakes Laser systems 3-D systems: total station	String lines or stakes Laser systems 3-D systems: total station

Table 2 : Comparison of different types of construction machines (Retscher 2002)



Sensor on top of compactor

- a) D-GPS
- b) Azimuth Sensor
- c) 2 -Axis Inclinometer

Figure 2: Compactor on a landfill with sensor head

Presented here will be project of our institute, the use of geometric real-time information for the steering and control of *compaction machines*, which are used in landfill work. The objectives of this project are :

Volume accounting :

- Daily, monthly and/or yearly determination of the actual volume of the landfill body
- Control of the emplacement process : Estimation of the remaining volume within the permitted dimensions of a landfill site.

Optimization of the emplacement technology :

- Estimation of the achieved density of the compaction process
- Guiding the efficient use of the compaction machinery, i.e. limitation of the crossings to a minimum

4.2 Technical Realisation

The technical realisation is a sensor head mounted on top of the compactor, see Fig. 2, which consists of a real-time differential GPS-system, an azimuth sensor and a dual-axis inclinometer. The data acquisition and the processing steps are depicted in Fig. 3. By numerical coupling of different sensor data and after some filtering and smoothing routines the resulting surface observations are available and are imported into a rastered GIS-model, where the actual change of the surface geometry is computed in real-time. To do this the local geometry of the machine has to be known, as the GIS is representing the surface of the landfill, and the comparison has to be independent from the orientation and tilt of the compactor.

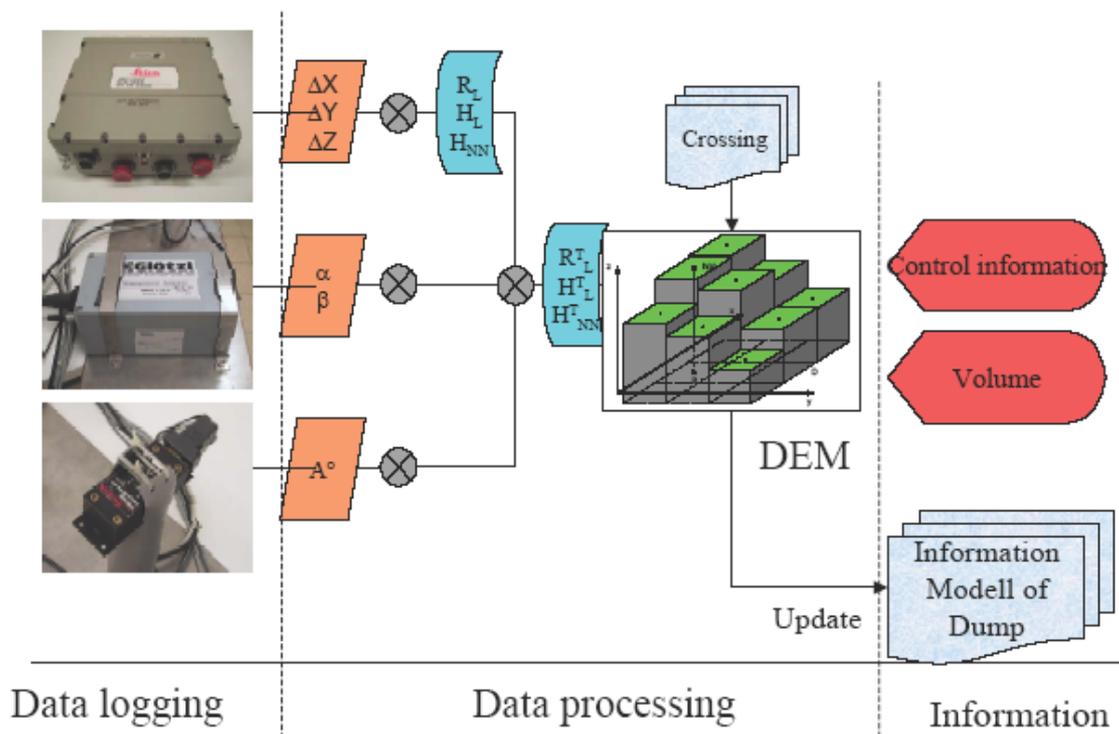


Figure 3: Management of measuring and processing of data for compaction control

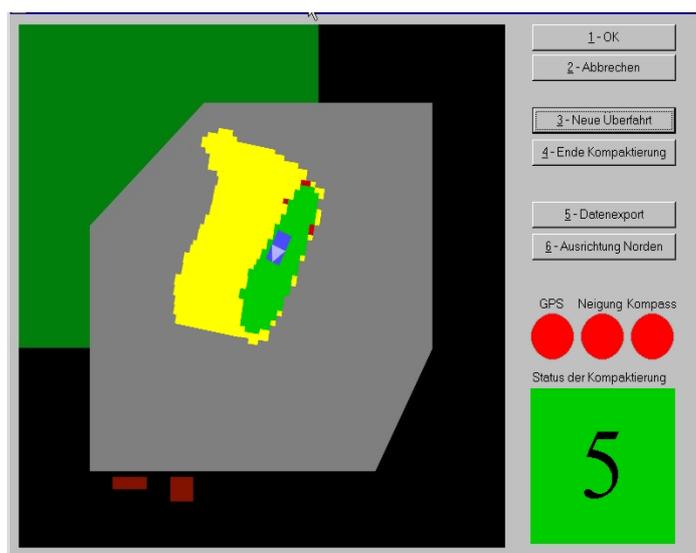


Figure 4: Guidance information for driver: - **Green** : Final compaction achieved
- **Yellow** : More crossings required

4.3 Steering information for the driver

As final step the compaction progress is visualised to the driver of the compactor by a little screen in his cabin, see Fig. 4. Here the border lines of the actual compaction field are given as outer limits of the working area and the colour indicates, whether or not a further crossing over the brought-in material is meaningful. If the screen appears to be green, the job of the driver is finished. Computational basis for this steering information is the gain in compaction, computed after every crossing by comparing the two surface models of the landfill section und discussion.

This compaction result is computed in real-time and is used primarily for the steering process, but at the end of the day the final surface, determined by the compactor can be used for daily accounting of the volume, as well.

5 TUNNELING

Within this classical type of projects the participation of geodetic engineers always was well-respected. The set-up of the *surface geodetic network* to give the outer geometric frame, as well as the continuously observed and extended *underground control network*, used to give the steering information for the construction work, are key issues for the successful realisation of each tunnelling project.

But even in tunnelling in recent years important changes can be observed, some of them will be discussed here.

5.1 Geodetic Control and Guidance

The realization of the surface geodetic network, often separated into a horizontal and a vertical part, has to be ready some time in advance to the construction phase. Therefore this is a real deliverable to the other disciplines. As main information the starting positions and starting bearings for the construction have to be given in the field (Schäfer&Weithe 2004).

The realization of the underground control network is a process, which is going on during the complete construction phase. Here geodetic techniques are able to control the construction progress and to give information on possible deviations and by this are used for a correction of the alignment.

Due to modern geodetic sensors and processing techniques nowadays direct guidance information e.g. for Tunnel Boring Machines (TBM) are given by a geodesy-based system. For *Pipe Jacking*, a fairly automated construction principle, which is used more and more in soft soil, the principle set-up of such a real-time guidance system is depicted in Fig. 5.

Main geodetic component is an automated total station (Laser Station) with a specially adopted diode laser to focus to the active target station (ELS). An automatic positioning process makes the observations to the different targets in the back (rear reference object) and aside (survey prisms). Important is the self-levelling tripod, as in pipe jacking rolling effects of the complete pipe are quite normal. This concept allows an automatic positioning and orientation of the total station.

The ELS-unit, see Fig. 6a, is attached to the rear of the TBM in line of sight to the laser station and has two build-in inclinometers to amount for the actual orientation of the machine. On a screen, see Fig 6b, the position and orientation of the machine, derived completely from this measuring system, is displayed by two circles, the first circle gives the position of the front, the second of the rear of the machine, i.e. the actual tilt is displayed to the driver of the

TBM. The designed tunnel axis is visualised as centre of the screen and therefore the total offset of the machine is given on this screen in a very clear form.

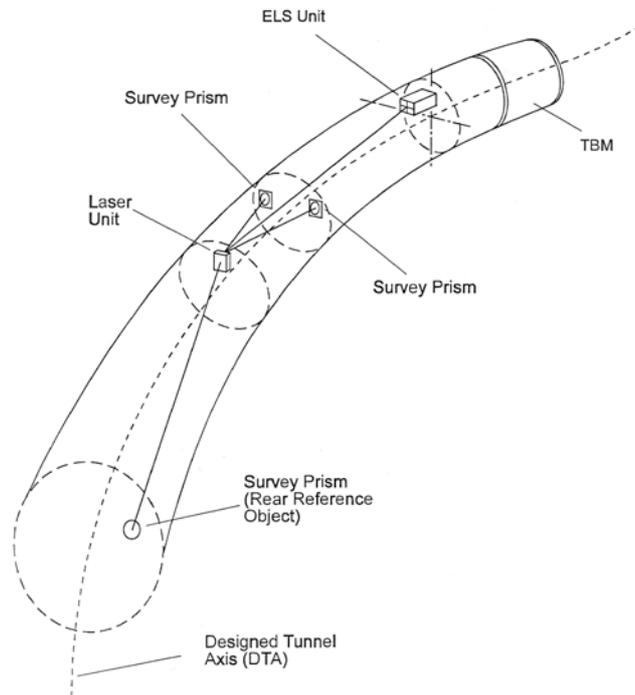


Figure 5: Derivation of guidance information for Pipe Jacking (VMT 2002)

The speciality of this system is its referencing : In Fig 5 two survey prisms relatively close to the laser station and just one rear reference prism are used to maintain the coordinate system. The rear survey prism has an additional inclinometer to amount for the rolling effect of the complete pipe. The theoretical concept behind this measuring equipment is the “*invariance of the existing pipe sections*”, what means, this steering principle assumes that the pipe is moving forward only within the narrow existing tube through the soil.

Anyway, the position and orientation information out of this system is available almost continuously, and normally after a progress in piping of 0,5 m a new position is requested by the machine operator. This information is available in the central management office, too.

Summarizing this is a completely integrated guidance system with a predefined measuring process, stable communication links, established data processing and is working in real-time.

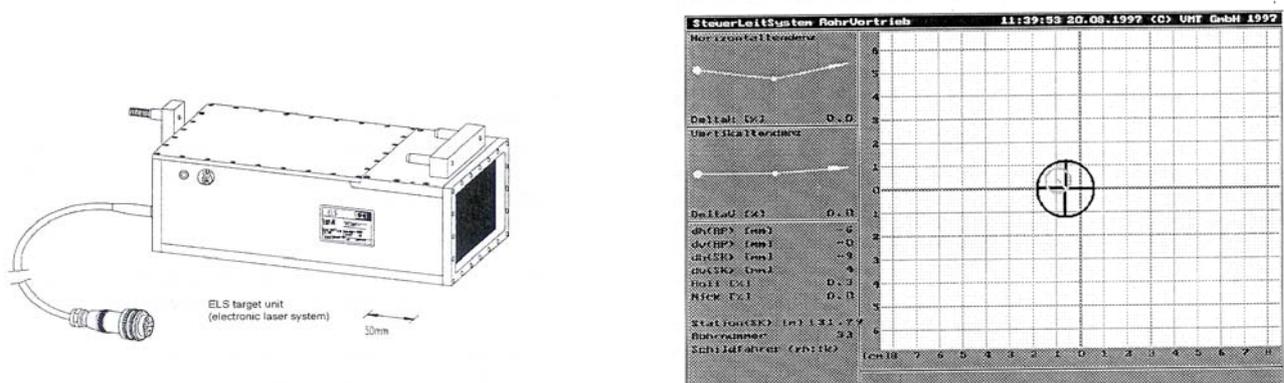


Figure 6: The target unit ELS and the screen with guidance information (VMT 2002)

5.2 System Tunnel

More and more tunnel constructions worldwide are located in metropolitan areas to account for the growing traffic demands of the increasing population in these areas. Here one of the most important requirements for tunnelling is to avoid any construction-induced damages to the existing valuable and/or historic buildings. If these areas have a soft or even very soft soil (Amsterdam) and the overburden is close to a minimum, as greater depths are significantly more expensive, then possible effects of tunnelling on existing structures are really critical.

Deformations in tunnelling are caused by changes of the initial state of stress in the ground. For TBM techniques three phases for the occurrence of deformations can be identified (Frenzel & Rehm 2005):

- *Ahead of the TBM* : If the support pressure to the tunnel face does not match the initial stress, then horizontal deformations of the tunnel face will cause mainly vertical deformations at the effected area.
- *During the TBM passthrough* : Usually the excavation diameter is not equal to the shield of the TBM. This is necessary to improve the steerability, but results in greater soil settlements.
- *After the passthrough of the TBM* : Main factor is the grouting of the annular void of the shield. If that space is not filled properly, the ground loss may cause severe deformations at the surface. Additionally some long-term deformations may be due to consolidation of the soil and the segmental lining.

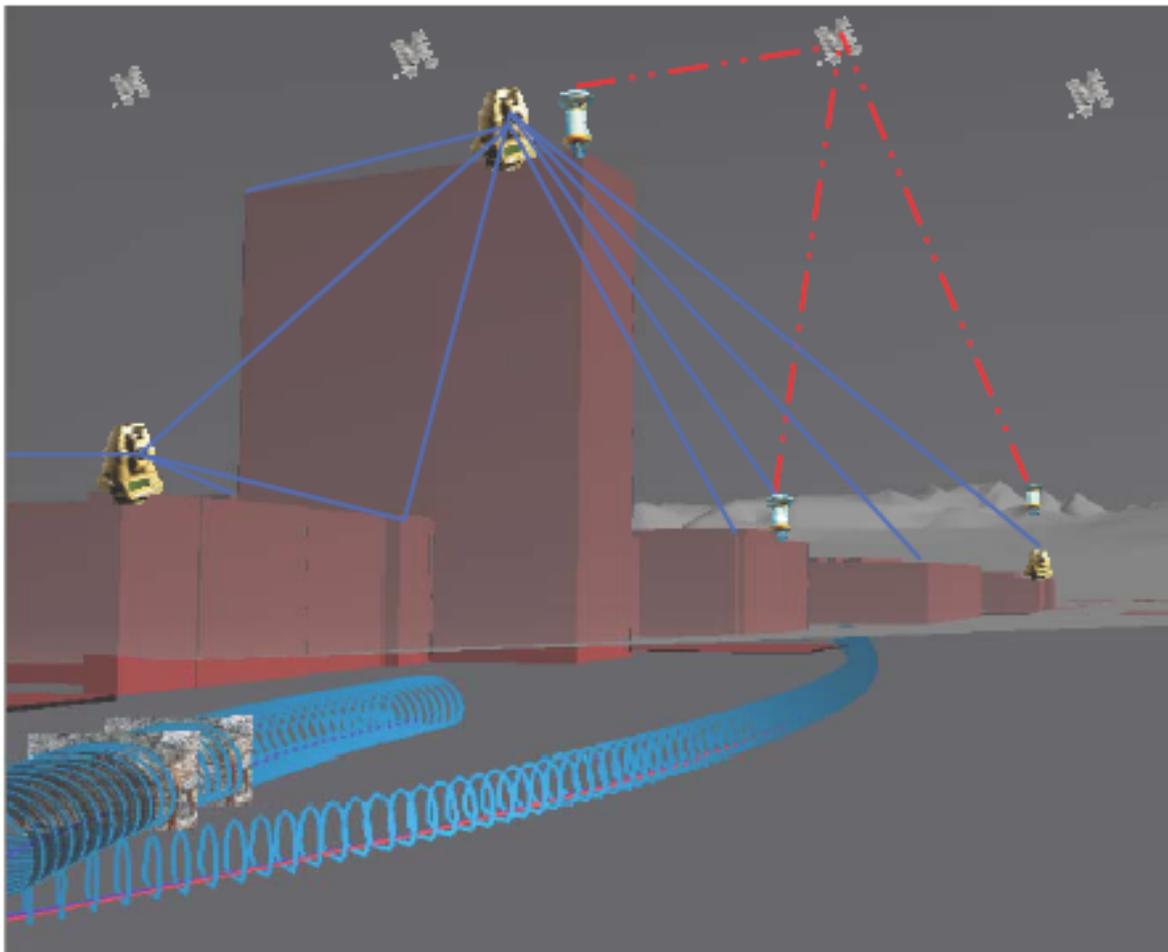


Figure 7: Online-Monitoring-System for surface deformations, caused by shallow tunneling

Various techniques exist or under development to account for these deformations. The classical civil engineering approach is geotechnical data collection and interpretation and a most complete finite modelling to predict the impact of the construction of the tunnel on the surface buildings. In an iterative process then the final construction scheme is developed.

A modern approach is to consider the tunnel, the build infrastructure and the in between lying soil as a *combined system*, where the interaction between the different components have to be studied and adequate action has to be taken, if critical values are achieved (Herbschleb & de Wit 2003). The range of impact can be assessed using the *observational method*: By means of an extensive online monitoring programme the movements of the surrounding buildings and by this the deformations due to the construction process are measured directly, see Fig. 8. This monitoring will be used for back analyses resulting in more precise predictions and allowing adjustments in the construction progress and technology, if necessary. Possible back-up measures are previously designed, using the results of the parametric studies.

For this online monitoring task in principle geodetic and geotechnical instruments can be used, which fulfil the requirements of section 3, i.e. which have the ability to perform continuous observations, and where a stable data transfer with real-time processing is possible. Additionally they should not be influenced by external forces or these influences have to be known to a high level.

In Fig. 7 a concept for such an online-monitoring system is depicted, using a combination of total stations and permanent GPS-receivers. From each total station a tremendous number of individual points and by this buildings can be monitored with an accuracy in the range of mm.

A second possibility, mainly applied for individual buildings, not for complete urban zones, is the installation of a gauge system (Jacob 2006), which consists of several sensors to detect vertical deformation even of parts of the building. If the information is available in real-time, required guidance information for the construction process can be derived from this system. Main advantage of a gauge system is the even more precise determination of vertical movements in the range of 1/10 mm, one disadvantage is the laborious installation, which includes the drilling through walls and the attachment of sensors and cables in a lot of rooms.

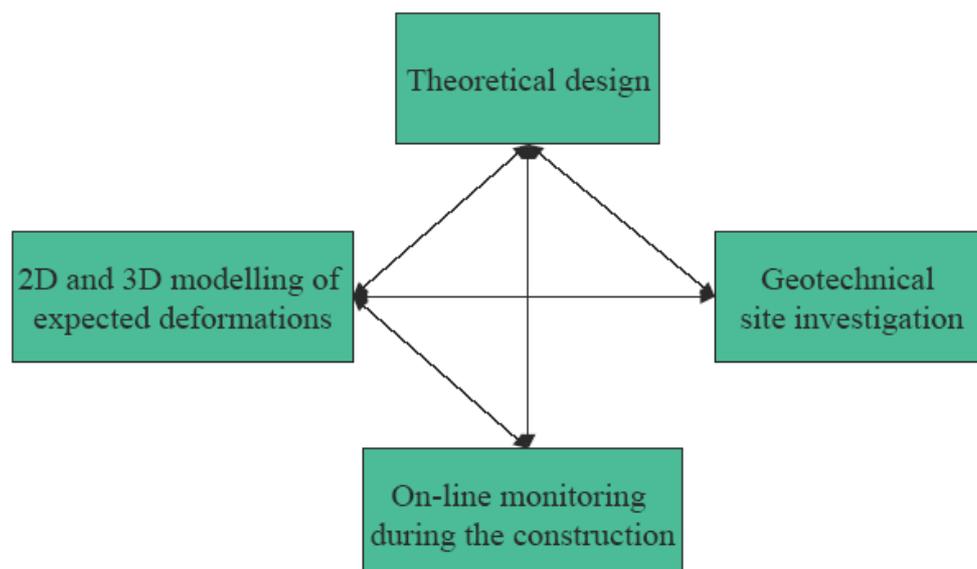


Figure 8: “System Tunnel”: Interaction between theoretical design, geotechnical site investigation, parametric/mechanical modelling and real-time geodetic monitoring (after Herbschleb & de Wit 2003)

In this “*System Tunnel*” the surface deformations are used as control information for the construction process itself. Possible reactions of the construction team to surface-displacements could be a reduction the velocity of the TBM passing through the soil, an increase of the support pressure to the tunnel face, an improvement of the grouting process, etc.

6 CONSTRUCTION OF BRIDGES

6.1 General

Very impressive large scale structures are bridges, which are constructed today with extreme dimensions to cross valleys and rivers or to connect islands with the mainland. The width of these structures, normally designed as suspension bridges, is increasing more and more.

The basic tasks for engineering geodesy for the construction of a bridge are :

- *Geodetic basic network* : Establishment and maintenance of the basic control network; today combined networks with GPS and terrestrial techniques are most effective solutions
- *Staking out for the main pylons* : Depending on the depth of water these can be laborious tasks. If main parts of the construction, e.g. soil reinforcement and realisation of the foundation are performed under water, then the coordinate system has to be kept available continuously in real-time. Here a dense network of permanent GPS-receivers and reliable communication links could be the best solution.
- *Quality control for the pre-fabricated elements* : The normal procedure is the use of pre-fabricated steel and concrete segments, which have to be checked in their dimensions. The required geometric quality for these precasted elements is in the range of mm or even higher.
- *Assembling the pre-fabricated elements* : The individual segments have to be transported to their final location. By use of a continuous GPS-Array it is possible to navigate the floating cranes into the correct position and to erect their loads, so that the new segments can be assembled to the existing parts.
- *Adjustments during the construction* : This is the most critical part during the complete construction phase. An interdisciplinary approach for this adjustment with strong participation of geodetic knowledge is outlined in the following subsection.

6.2 Geodetic Techniques for the Adjustment of the Rion-Antirion Bridge

Marchetti et. al. (2004) report on the adjustment concept and its technical realisation for the Rion-Antirion cable-stayed bridge, crossing the Gulf of Corinth in Greece. Some impressions from this structure are given in Fig. 9 and 10.

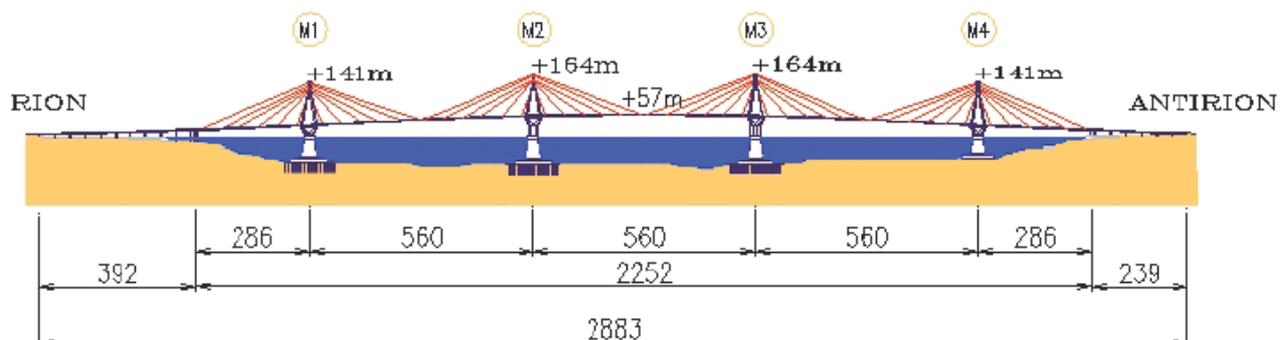


Figure 9: Basic construction and dimensions of the Rion-Antirion bridge, Greece (Marchetti et. al. 2004)

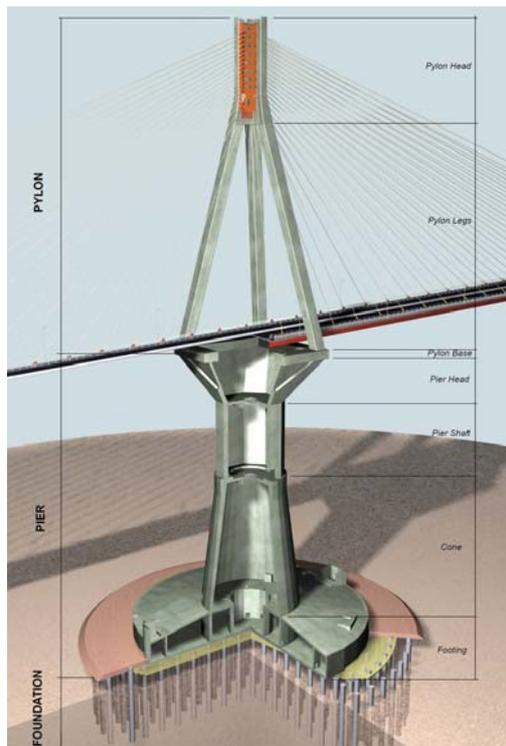


Figure 10 : Rion-Antirion Bridge in Greece
(Marchetti et.al. 2004)
- Basic construction of pylons
- Cantilever construction

In this paper the focus is laid on the adjustment of the bridge construction during the assembling of the segments. Due to the chosen cantilever technique the new segments have to be assembled precisely to the section of the deck already built and to maintain their position unchanged during the bolt tightening operation. The technical solution is a special equipment called Quick Connection Device and has been designed on the basis of a safe static scheme.

During this process, where the segments are alternately erected at both ends of the cantilever, the bridge deck is subject to large deformations, reaching an amplitude of 1,50 m in vertical direction when assembling the last segments. Additionally, the pylon is subjected to horizontal displacements up to 100 mm, which have to be observed, too. Finally, the effect of site loads and of thermal variations have to be estimated and corrected, too.

The objective of the bridge adjustment was to obtain a final deck profile and a force distribution in the complete structure, which strictly comply with the design definitions. According to the nowadays often recommended "observation method" the adjustment procedures are tightly connected to on-site operations. Their purpose is to specify to the production team quantitative instructions, i.e. precise geometric values. There are two main items that have to be considered, i.e. for which a solution in real-time has to be derived from measurements:

- Geometrical shape adjustment to be imposed to the deck during construction
- Adjustment of each stay being installed

Without going into detail of the complex operations and the static background, here the observation concept is outlined, as it gives valuable hints for the integration of geodetic techniques into the production process of structures :

Three coordinate systems are used :

- For the above mentioned alignment for new segments in a *local coordinate frame* a laser-beam-device is located on the already built part of the deck. With a target, similar to the ELS in section 5.1, the geometric displacement of the new segment relative to its design position can be observed with *some tenths of millimetres accuracy*.

- As the cantilever - suspended to a pylon - is built independently from the other cantilevers, for each pylon an *absolute pier frame* is defined, to determine the geometry of the deck and the pylon head. Here an accuracy of *one to two millimeter* has to be achieved.

- To guarantee the consistency between the different pier systems, a *bridge global coordinate frame* is established, used for stacking out the pier point positions and monitoring of the complete structure. The accuracy for this frame is in the range of *five millimetre*. Within this global frame regular surveys are performed to detect potential movements, as the Gulf of Corinth is in a tectonically very active zone.

The main instrument for the deck control is a motorized or automated total station, while the tilt or better the horizontal displacement of the pylon head is observed with the combination of an optical pendulum in the lower part and a mechanical pendulum in the upper part. For both devices optoelectronic receivers are developed to get readings automatically.

The collection of all data and their processing is done on-site by the adjustment team of the bridge construction, i.e. a separate group of specialists, being responsible for this task only. Besides, a specific software was developed for pre-processing and evaluation of the data, derivation of the adjustment instructions, and the final documentation of all steps.

As one example the adjustment of the deck geometry is discussed here, see Fig. 11: The so-called *pilot line* is defined as the profile that the deck would display, if it was built without any construction errors. In practise, this pilot line is a best-fit surface to a set of benchmarks, laid on actual concrete surface. The vertical offset η of these benchmarks from the pilot line indicate the construction errors.

The *vertical deck deflection* w , defined as difference between this pilot line and the theoretical project line, now is derived at any benchmark free from construction irregularities.

When a new segment is erected, it is positioned relatively to the deck end, using the section of the pilot line located on the last deck segment.

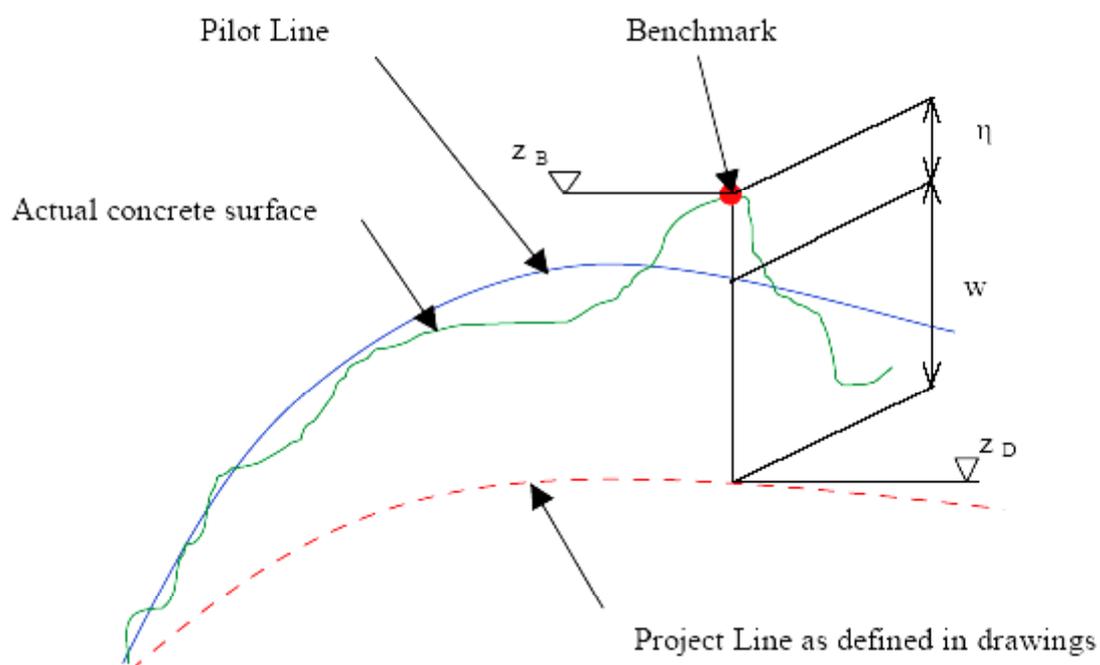


Figure 7: Pilot line with construction error η and vertical deck deflection w (Marchetti et. al. 2004)

7 CONCLUSION

For large scale structures the tendency goes to more complex construction techniques, where a better understanding and interaction between different disciplines is of increasing importance. To understand construction as a complex system with a lot of interactions emphasizes the online control during the construction process itself.

Nowadays the geometric behaviour of structures can be monitored by modern geodetic sensors and techniques, if these systems have the ability to observe continuously, provide results in real-time and are made available to the construction team in adequate form. Research and development has to follow this objective: The quality standards, the data communication and data processing have to be improved and developed further to fulfil these requirements.

Anyway, it seems to be possible that the geodetic engineer is much more integrated into the guidance and control of construction processes, if he is open-minded and brings in his knowledge into a team of several disciplines to develop an optimal solution.

8 REFERENCES

- GIELSDORF, F.: *Ausgleichsrechnung und raumbezogene Informationssysteme*. Habilitationsschrift, Tech. Universität Berlin, 2004
- FRENZEL C, REHM U. : *Controlled boring process (CBP) – a new approach to deformation-reduced tunneling in urban areas*. In : Yufin (ed.) : *Underground Space : Economy and Environment*. Moscow, Russia, 2005.
- JACOB M, KUMMERER C., MARCHIONI V. : *Der Einsatz eines hydrostatischen Schlauchwaagen-Messsystems unter extremen Temperaturbedingungen für die Steuerung einer Sicherungsmaßnahme*. In : *Messen in der Geotechnik 2006*, Inst. Grundbau u. Bodenmechanik, TU Braunschweig 2006.
- HERBSCHLEB J., DE WIT J.C.W.M. : *The use of models in the design of deep underground metro stations in Amsterdam*. In : Saveur (ed.) : *(Re)Claiming the Underground Space*. Swets&Zeitlinger, Lisse, Netherlands, 2003
- HEUNECKE O., NIEMEIER W. : *Paradigmenwechsel bei der Auswertung ingenieurgeodätischer Messungen*. In : *Ingenieurvermessung 2004*, ETH Zürich, Suisse, 2004
- KOVARI K., BOSSHARD M.: *Risks in Tunneling : Analysis and Procedures relating to the Zimmerberg Base Tunnel*, Tunnel, Heft 6, 2003, p. 3-23
- LEICA : *Leica Laser Tracker Systems*. Company Information, Leica, Suisse, 2000
- MARCHETTI M., BOUDON R., MONNERIE J.ET.AL.: *Adjustment of the Rion-Antirion Cable-Stayed Bridge : An innovative multidisciplinary response to a construction challenge*. Proc. 1st FIG Int. Symp. on Eng. Surveys for Constr. Works and Struct. Eng.; Nottingham UK, 2004
- NIEMEIER W. : *On the potential of geodetic techniques for the navigation of construction processes*. Proc. 1st FIG Int. Symp. Eng. Surveys for Constr. Works; Nottingham UK, 2004
- NIEMEIER W.: *Modellierung – Ableitung geometrischer Elemente aus Punktwolken*. 65. DVW-Seminar "Terrestrisches Laserscanning", Fulda 2005
- RETSCHER G.: *Multi-Sensor systems for Machine Guidance and Control*. Papers presented to XXII Int. Congress FIG 2002, Washington D.C., USA, April 2002
- SCHÄFER M., WEITHE G. : *Vermessungstechnische Lösungen auf den Baustellen North Downs Tunnel und Brücke Medway Crossing – Hochgeschwindigkeitstrasse von London zum Eurotunnel*. Bauingenieur, vol 78, June 2004
- SCHWARZ W. : *Geodätische Messtechniken für das Bauwesen*. DVW-Schriftenreihe, vol 43, Verlag Wittwer, Stuttgart 2002, p. 23-42.
- VMT, GESELLSCHAFT FÜR VERMESSUNGSTECHNIK GMBH : *Guidance System for Pipe Jacking SLS-RV*, Company Information, Ubstadt-Weiher, Germany, 2002