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The High Speed Railway Hub of Florence: 4D-Monitoring – Innovation in Data acquisition and Data Management for Tunneling Projects in Sensitive Urban Areas

C. Meyer(1), P. Cucino(2), G. Eccher(3), D. Ulrich(1)

(1) *terra international ltd., Monitoring department, Othmarsingen, Switzerland*

(2)*SWS engineering, Geotechnical department, Trento, Italy*

(3)*SWS engineering, Monitoring department, Trento, Italy*

ABSTRACT: Main Construction works for „Nodo di Firenze“ started 2010. The TBM pathway runs through very variable geological conditions where excavation along the overall length is beneath the water level. The 6.5 km of underground line are crossing below critical infrastructure and sensible historical buildings. Due to geological complexity following the excavation settlements are expected. Hence this urban tunneling project has a special requirement for supervisory measures. It is necessary to identify potential hazards at a very early stage and mitigate their impact. Especially during TBM advance the client demands comprehensive presentation of all monitoring data at short notice. This includes online post-processing and interpretation for all automated and manual measurements. These challenges could be achieved by using well-proven swissMon core technology for web-based monitoring. This paper shows how the workflow for the manual measurements could be optimized by introducing the innovative tManual software. It enables field workers to safely upload their validated measurements to swissMon at any place and time. Following the workflow, the focus will be on the data management, necessary to make data available for online post-processing services. Together, real time measurement data and post-processing procedures (described in a second paper), enable project engineers to take well founded decisions.

1 Introduction

As a part of the new Italian and European high speed rail network, a high speed railway hub is under construction in Florence, including a new station and a twin single-track tunnel to underpass the city.

Tunneling projects within urban areas have a special requirement for supervisory measurements. Where construction works are near to existing critical infrastructure, including residential and commercial sites, any kind of incident can have a profound impact on building structures, human safety and commercial logistics, such as traffic flows. Special challenge in Florence arises from the complex underground condition (extreme spatial variability of soils) as well as from the building and monumental patrimony, said to be among the greatest in the world.

Built to fulfill the challenging monitoring task, the “Associazione temporanea di Impresa” (ATI) consortium designed and implemented a comprehensive monitoring system. Terra international ltd. provides a wide variety of geodetic and geotechnical sensors for automatic and manual measurements, embedded in the well-proven swissMon monitoring platform.

This paper gives an overview on the dimension of the used monitoring system highlighting the innovations in data acquisition and management which are necessary to meet the project requirements. A special focus lies on the optimized workflow of the integration of manual measurements and of virtual values, calculated by online post-processing services, into the system.

2 Project Overview

Italferr, member of the Italian railway group and responsible for planning and controlling the completion of infrastructure and technological works, started works on the Florence Hub in 2004. The Florence Hub is one of the major railway facilities on the high speed / high capacity (HS/HC) Milan-Rome Main line. Beside of its nationwide importance, this facility also is the major gathering point for central Tuscan area regional lines. It constitutes the core of the Metropolitan Regional Railway System (Italferr 2012).

Thanks to the work on the HS/HC line, for High Speed trains, S. M. Novella head station will extended by new through station at Belfiore. This will make it possible to reduce train stop-times conflicts between the various types of traffic. Furthermore, the new line will provide a significant recovery of capacity on the existing railway line, to be used to develop regional and metropolitan traffic.

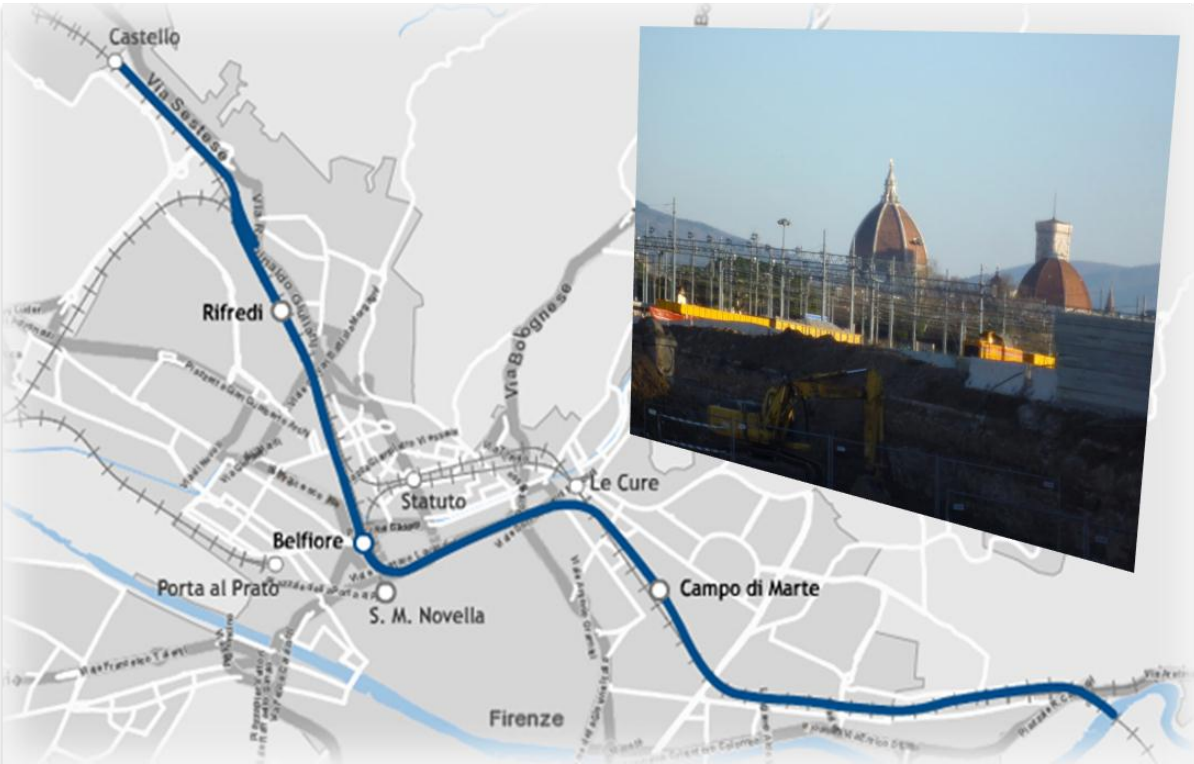

Figure 1. Nodo di Firenze – Florence HS Hub Project Overview (Italferr 2012)

Basically the project is devided in two major sub-projects:

- Tunneling Works "Passante AV"
- Underground Station "Firenze Belfiore"

Tunneling works for "Passante AV" start at existing Campo di Marte station. From there, the tracks will continue into the underground proceeding to new Belfiore underground station, located way north of the city main station, S. M. Novella. From Belfiore the tunnel runs to the north reaching the northern entrance near Rifredi station (see Figure 1).

The tunnel sections have a total length of about 6.5 km and will be built as a 9.4 m diameter TBM-driven twin tunnel (circular section), each of them hosting a single rail track. The tunnels are located at a depth from ground level varying in the range of 10 m to 27 m and should be put into service in 2015.

The new Belfiore station, designed by Norman Foster and engineered by Arup, will be built 25 m below ground inside a 454 m long and 52 m wide box of reinforced concrete diaphragm walls. The station's roof consists of a 450m long steel structure defined by a cylindrical surface formed by a steel diagrid structure. The whole structure will be built in a top-down technique in order to meet environmental requirements (Raschillà et al 2012). Construction works for the station are scheduled until 2016.

As pointed out by Raschillà et al (2012), the first half of the tunnel is expected to be the most critical part of the work. TBM will run in an urban area, underpassing a bridge, the railway line to Milano and many structures, including hospitals, public buildings and famous monuments like "Fortezza da Basso", a Renaissance fortress built between 1534 and 1537.

Passive and active protection measures have been designed to guard existing buildings, bridges and rails. In particular, compensation grouting has been foreseen in the southern part of the tunnel where two buildings are going to be under passed with a cover between 5 m to 10 m, and also at about 3 km in the north of the southern portal to protect the ancient Fortezza Da Basso.

More detailed information related to construction methodology and project management for the construction works at the high speed railway hub of Florence can be found in the paper presented by Raschillà, A. and Severi, M. at WTC 2012 session.

Figure 2. TBM, ready to start at the South Entrance Campo di Marte

3 "Nodo di Firenze" Monitoring

3.1 Ojectives

Tunnelling projects within urban areas have a special requirement for supervisory measures. The supervision tasks are:

- To observe the situation and keep it under systematic review
- To conserve evidence
- To avoid damages on Infrastructure / Buildings / Environment
- To identify potential hazards at a very early stage and to mitigate their impact
- To optimise building techniques

To work on these tasks, it is necessary to execute an integrated monitoring program merging sensors and technologies of different areas of expertise including geotechnical, geodetic, environmental (chemical) and geophysical methods.

Using the methods and the technical options, the monitoring system addresses two essential aims:

1. Impact-Monitoring: Observing, warning and conserving evidence. Results are used to confine responsabilities, identify possible causes for claims and identify remaining risks.

2. Design-Monitoring: Optimisation of methods and processes by measuring important indicators according to EC7.

Today monitoring systems must handle huge amounts of data that have to be processed and visualised for different stakeholders and purposes in near real-time. At the same time the monitoring systems automatically process data, compare the measurements and (post processed) deducted values to thresholds and triggers informing stakeholders in time where they have to pay attention or take further action.

As a state of the art instrument, web-based monitoring platforms are used in major projects to cope with these challenges. It is an essential requirement for these platforms that they work in a robust way no matter how many measurements are executed or how many sensors are connected.

3.2 Requirements

As one of the passive protection measures, a broad monitoring system using state of the art sensors and digital data communication is being installed and operating along the whole construction area of the Railway Hub.

An overview on the sensors and requirements for monitoring system in use in Florence is given in Table 1.

Table 1. Requirements for the monitoring system

<table>
<tr><td colspan="2">Measurement systems</td></tr>
<tr><td>Automatic Measurements</td><td>Manual Measurements</td></tr>
<tr><td>27 Total Stations covering >3000 targets
400 hydrostatic Leveling Cells and Inclinometers
66 Extensometers
54 Piezometers
75 Load Cells
60 Fissurometers
>1100 Strain Gauges</td><td>2100 levelling points
2000 measuring points for manual 3D measurements
59 vertical inclinometer measuring points
28 convercence measurement points
Various ground water measurement points</td></tr>
<tr><td colspan="2">Boundary Conditions</td></tr>
<tr><td>Frequency of measurement: 10 to 120 min
Operating time: 365 days per year, 24 hours
Project duration: 4 years
Online access to measurement data to be assured continuously
Processing of >270’000 datasets daily</td><td>Frequency of measurement:
According to the monitoring plans

Online access to measurement data to be assured within 24 hours</td></tr>
</table>

In addition to these requirements the online calculation of derived values from the measured values was requested. In total about 150’000 measurement values per day, gained manually and automatically, and about 120’000 derived parameters are produced. Thus, 270’000 parameters have to be checked daily against threshold exceedance.

To meet the above-mentioned requirements the well-proven swissMon monitoring system, developed by terra, came into operation, enhanced with functionalities to efficiently integrate manual readings and calculation processes.

3.3 swissMon - 4D-Monitoring

This chapter introduces swissMon, the web-based monitoring platform, deployed throughout the project to automatically gather, analyse and display thousands of datasets generated both manually and automatically by geotechnical and geodetical sensors every day.

The system is running since 2010 and will be applied along the whole alignment. Measurements will be taken both underground (e.g. convergency measurements) and on the surface, where a total of about 150 buildings is planned to be put under monitoring. Defined cross-sections are subject to measurements before, during and after the TBM passage, depending on the actual TBM location.

The structure of *swissMon* is completely modular and can therefore be scaled to every kind of project and project size. It provides interfaces for all important geodetic and geotechnical sensors. Due to its modern architecture, any sensor can easily be integrated as long as an interface is available.

The SwissMon Monitoring-System is divided into three basic units:

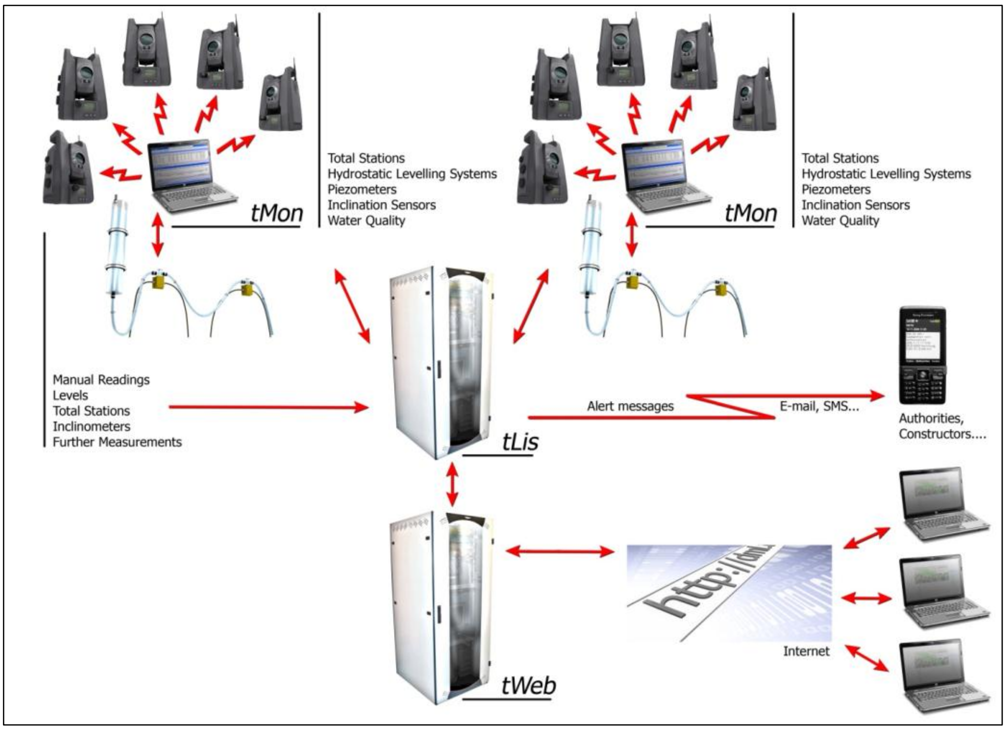

Figure 3. Modular Architecture of swissMon

Sensor Unit (tMon)

All on-site sensors which perform automatic measurements are connected to a node computer. The nodes are strategically placed near the sensors in order to reach as many of them as possible. The nodes take control of the sensors, automatically making the measurements within defined time periods and analysing the field data. The validated datasets are temporarily stored on the tMon node and are regularly transmitted to the database unit via internet or internal network connection. Internet connection can be established either by telephone earth line or in special cases through a mobile telephone network with a high bandwidth. tMon already provides basic alarming features by performing simple trigger tests. This makes it possible to provide near real-time alarming on the site using sirens or flashlights.

Figure 4. Total Stations and Hydrostatic Leveling Systems at the Site of the Belfiore Station.

Database Unit (tLis)

This unit stores all datasets measured within the project. Datasets can also be updated with additional information and manually measured datasets. This unit is able to perform complex triggering tests, which can be individually adapted to project requirements. In the event of a trigger level exceedance, tLis can automatically issue alarms to single persons or groups of persons through email messages, SMS, facsimiles, pager calls or voice calls. It can also confirm whether an alarm message reached the required recipients. The database unit runs on a server which is located outside the project vicinity. It is continuously backed up to ensure data security. It also features a watchdog functionality to automatically check if all attached tMon nodes are still working.

Visualisation Unit (tWeb)

All data are presented to the online user in a numerical or graphical format. All stakeholders can access data at any time and place by using their preferred web browser both on computers and mobile devices. With their personal login they have access to all necessary information to make important decisions. tWeb features the following functionality:

- Visualisation of data as time plots, profiles, cross sections, surface plots etc.
- Visualisation of trigger breaches.
- Storage and access to Team Documents.
- Direct access to Webcams on site.
- Quick search of single measuring points
- Selecting of targets by sections, subsections or trigger-status.
- PDF or CSV download of all data available
- Data protection through secure personalised logins

In order for site engineers and site management staff to be able to address the vast amount of data arriving from the manifold monitoring sensors each day (270'000 datasets in this project) tWeb is designed to provide information in a suitable and comprehensive way, allowing the ability to focus on the critical tasks in order to make decisions at the right time.

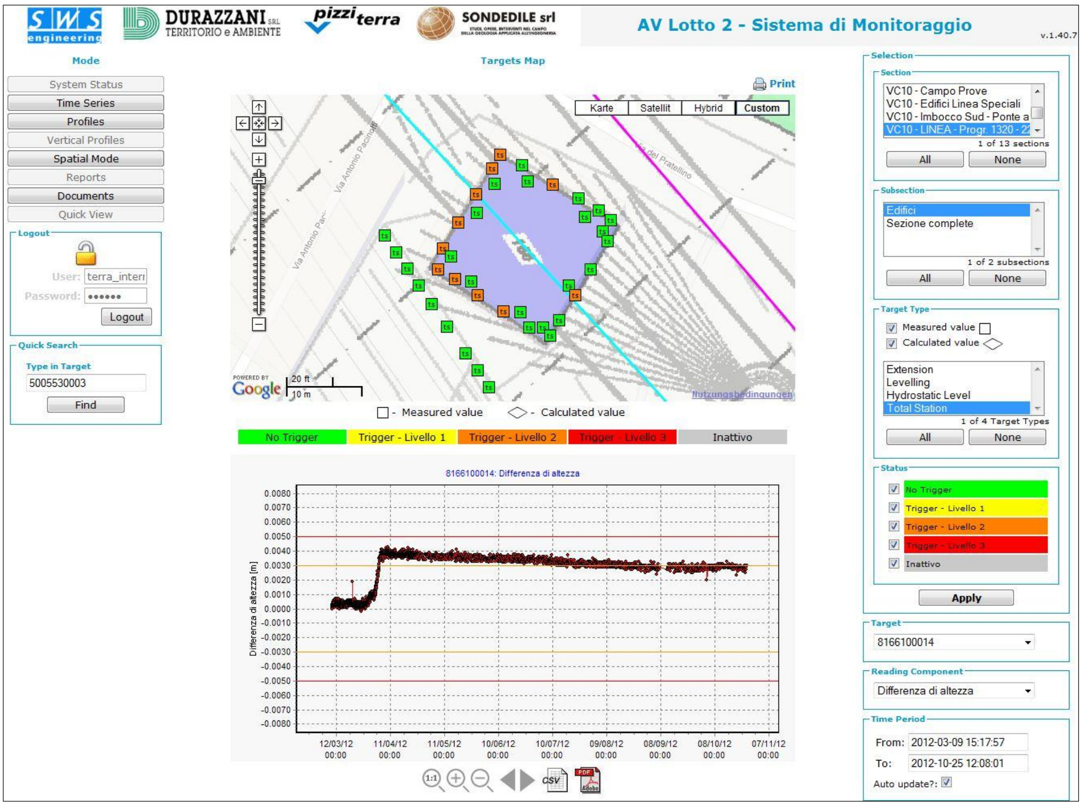

Figure 5. Time series of a Total Station Target shown in tWeb

3.4 Efficient integration of manual data

Formerly manual data used to be delivered to designated swissMon database administrators which directly inserted them into the system using SQL queries & scripts.

In order to guarantee a quick availability and an efficient integration of manual measurement data this workflow was shortened with the implementation of the web-based application "tManual". This tool comes with a graphical user interface. It is accessible over internet by means of a web browser and thus place and platform independent. It can be accessed either by a notebook computer, a tablet PC or any smartphone able to run a web-browser.

Managed through a user authentification system, it allows to be accessed by all involved consortium partners providing different functionality levels. The user (e.g. field service personnel) can in a simple way (by filling fields) define new targets with different trigger levels, insert his measurements into the database by either entering single values, pasting blocks of a spreadsheet or uploading whole text files.

In terms of quality assurance of the incoming data through this channel, limited input checks were implemented, such as the comparison with preceding values, selection lists and value ranges. After having passed the validation the new values are directly visible on the website, allowing an immediate visual plausibility check by the operator and instantaneous availability for decision makers.

With the direct access through the persons in charge for the manual measurements both time requirement and error rate for the upload process can be significantly minimised. Availability and quality requirements can thus be fulfilled.

Figure 6: tManual Screenshot highlighting a Selection of Sensors ready for Online Manual Data Input

3.5 Online Post-Processing Services

While geodetic and geotechnical monitoring systems in the past were usually limited to the delivery of validated data sets of direct measurements, and the derivation of additional information necessary for decision making was subject of the customer, this clear separation is more and more broken and the tasks of monitoring systems are gradually widened.

Actuated by the tasks postulated in the monitoring contract for the Railway Hub of Florence, the swissMon system underwent another innovative development step: The integration of online-post-processing services for the derivation of additional information from the given measurements. An interface has been opened in tLis in order to automatically deliver selected validated measurements to external calculation modules. In these modules individual parameters are calculated or complete data sets can be brought into a special context. The post-processing procedures applied in Florence are delineated in a separate paper.

The results from the post-processing procedures are automatically sent back to tLis as so called “Calculated Values” (CV), where they are automatically stored and compared to the predefined thresholds and triggers. In case of any trigger violation, tLis immediately starts the alerting procedures and integrates the process into the event- and alarm-management.

For the flexible integration of calculated values, tLis was enhanced by implementing dynamic sensor-datasets. With this feature it is now easily possible to create inside the database any kind of sensor type (i.e. volume loss, slope stability etc.) and allocate them a flexible kind and quantity of reading components (i.e. distance, settlement, stability ratio, failure probability etc.).

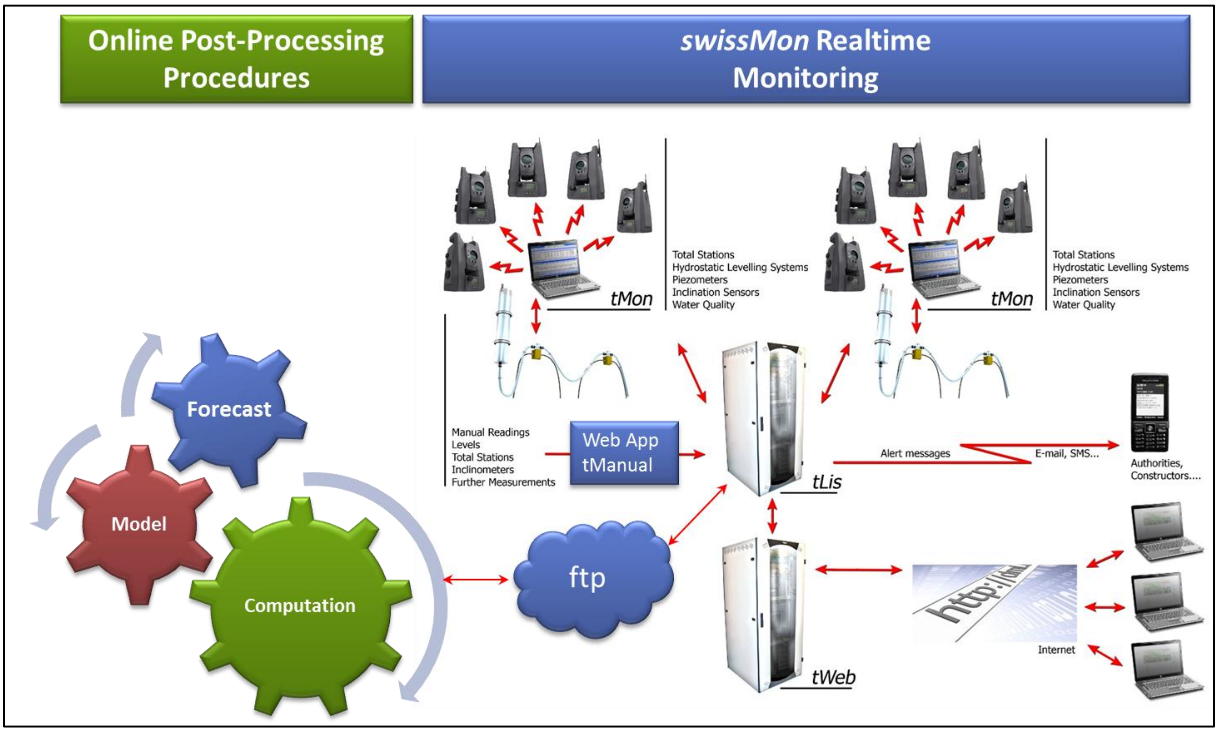

Figure 7. Enhanced swissMon Architecture developed for „Nodo di Firenze“ Monitoring

The procedures for online post-processing were deliberately not integrated into swissMon. This is to maintain the high degree of stability and availability that characterises swissMon and to enable flexible adaptation of post-processing procedures to every project.

For a clear differentiation between measured (realtime) information and calculated values (post-processed interpretation of measured data) items are clearly differentiated in the tWeb visualisation.

4 Conclusion

The large scale of the railway hub building project implies the generation of different measurement data every day to monitor the construction process. This requires an efficient and automated data management. The swissMon monitoring platform offers a powerful solution to carry out the complex monitoring tasks over this large scale and to assess the enormous amount of manual and automatic measurement data and calculated additional information.

The treatment of the considerable amount of manual data being produced by different players is successfully addressed by the introduction of tManual, turning out to be an efficient and time-saving method to make manual measurements accessible on one single platform. tManual gives more responsibility and independence to each person involved in the monitoring process by decentralizing the upload and verification process for manual measurements.

The integration of tManual and the post-processing procedures open new doors, as they offer a possibility to use a nearly unlimited number of data or sensor types within and beyond the geotechnical and geodetic field.

5 References

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