11TH INTERNATIONAL SYMPOSIUM FIELD MONITORING IN GEOMECHANICS

Challenges to monitoring during construction of two inner city railway infrastructure projects

Holger Wörsching[1], Robert Schneider[1], Marcel Hubrig[1], Markus Stolz[1], Muhammed Celik[1]
[1]Solexperts AG, Mönchaltorf, Switzerland

Abstract

To improve railway infrastructure many construction projects are currently running in Europe. Two major projects in the centre of Europe are the "Zukunft Bahnhof Bern" where the main station of Bern / Switzerland is extended with 4 new tracks underneath the existing infrastructure. A second large project is "2. S-Bahn Stammstrecke" in Munich / Germany where a new suburban railway line is constructed tunnelling in a depth of approx. 40 m under the city centre. Both projects are very challenging in their construction method and in monitoring of the existing structures as well as in the new constructed components.

In Bern the new RBS station is being built partly directly underneath an office building which is founded on 4 columns in the area of influence of the future station caverns. Due to the excavation of the caverns, the columns will lose their load-bearing capacity. Hence the support of the columns will be provided by two new concrete girders based on 36 micro-piles each. All these new elements are constructed underground with very limited space in the tunnels. The girders are built in several sections and after construction put into operation by stepwise prestressing. At the same time the load will be diverted onto the micro-piles by means of safety nut jacks. An extensive control and monitoring system including fibre-optic strain measurements and displacement measurement is in operation.

In Munich an over 40 m deep construction pit in the city centre is being constructed in heterogeneous ground. It serves as a start pit for the tunnel constructions and will be established as a station and access building in future. The deep excavations are monitored by means of long extensometers and vertical ReverseHead-Extensometers (90 m deep). In the diaphragm walls high precision IPIs (Bivec) with automated reversal measurements are used, among others.

Keywords: suburban railway, FO strain measurements, Bivec, SAA, RH-Extensometer, combined IPI/Extensometer, tailor-made systems

1. Introduction

Growing metropolitan regions demand for higher public transport capacities. Due to this in many cities large railway infrastructure projects are ongoing. In city centres, where space is limited, the only option to extend railway capacities is going underground next to existing traffic junctions and stations. Therefore, the construction methods are very complex and demanding, as existing infrastructure must stay in operation continuously. During all construction processes of the special foundation and tunnelling an intensive monitoring is required to minimize risks and early detect any irregular situations or evaluate design approaches.

Solexperts is strongly involved in two projects for new railway stations in Munich / Germany and Berne Switzerland.

In the Munich project a 40 m deep excavation pit next to existing underground railway stations and in direct neighbourhood to the most significant city heritages is required to start the tunnelling underneath all currently existing structures. After the installation of an intensive geotechnical monitoring the excavation has being started in February 2022. The monitoring includes a system for the existing railway tunnel and inclinometers / extensometers and Strain Gauges in the diaphragm walls and the future supports of the pit cover. Some instruments are based 90 m below the ground level.

In Berne an existing end point of a railway line will be moved and extended underneath the existing main railway line station with tall buildings above. Here one of the major challenges before the excavation of tunnels has been started, was to transfer the loads of the Post Parc building on girders which were built in small caverns and successively loaded. Here the strains in the girders and in micro-piles are monitored with fibre optics. Due to a complex construction process the installation of the monitoring was challenging in many aspects.

2. München Marienhof

2.1 The Project "2. Stammstrecke"

The Munich S-Bahn already transports around 840,000 passengers a day. This makes it one of the largest S-Bahn systems in Germany. However, the system is reaching the limits of its capacity, even as the population continues to grow.

The new 2nd main line tunnel passes over the three new underground stations at Hauptbahnhof, Marienhof (see Figure 1) and Ostbahnhof. Because several underground lines have to be crossed, the Hauptbahnhof and Marienhof stations are located at a depth of about 40 metres and the Ostbahnhof station at a depth of 16 metres. At all stations there will be underground crossings to the stations of the underground lines and the already existing suburban railway line network.

2.2 Munich's underground

Munich's city centre is crisscrossed underground by many pipes and tubes. Not only do the supply lines for district heating and cooling, electricity and the sewage system run under the buildings. The existing main line and the underground lines also need to be considered in the construction.

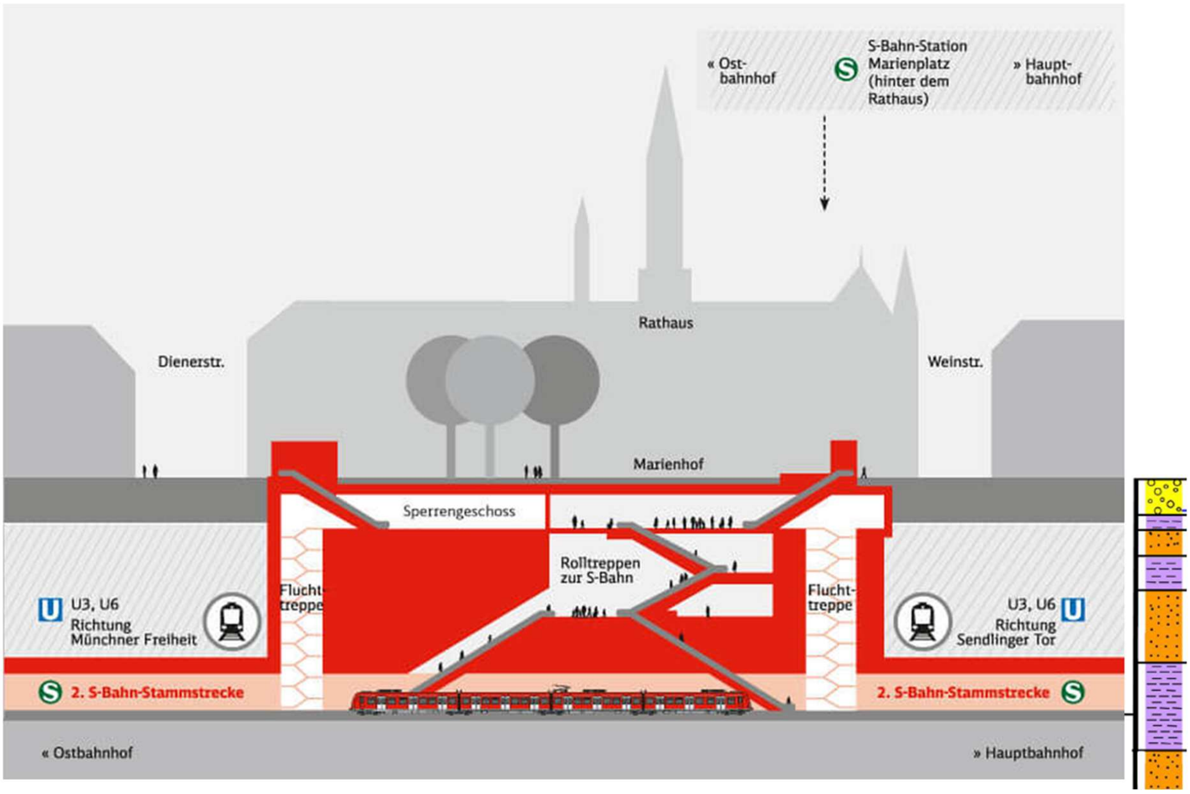

Figure 1: Schematic sketch of the new Marienhof station in Munich with the underground lines, the neighbourhood buildings and a typical soil profile (Source: https://www.2.stammstrecke-muenchen.de/marienhof.html, modified)

Ground investigations identified the geology of the subsoil. It has a heterogeneous structure, i.e. there are alternating layers of gravel, sand, clay, silt and, to a lesser extent, gravel. In some areas, the soils are consolidated by lime to form solid rock. Typically, in Munich the alternating soil layers are traversed by various interconnected "groundwater storeys".

The results of the investigations were used to determine the construction methods and materials to be used as well as the necessary safety measures for the ground and the existing buildings. Due to the rather large depth of the tunnel and the underground stations, a large pressure must also be considered.

2.3 Station construction: the diaphragm wall covers construction method

The diaphragm wall/cut-and-cover construction method is being used in the design resp. construction of all three new stations. For the station Marienhof the ARGE VE41, a joint venture among Implenia and Hochtief won the tender.

At Marienhof (Figure 2) the diaphragm walls made of reinforced concrete reach a depth of 55m excavation. Inside the future pit the support columns were also installed in advance. These reach depths of 65m. The lower part is constructed as a drill borehole pile, the part in the future station is a pure steel construction. Then, after the placing of the top concrete deck at surface level the excavation work takes place underneath this concrete deck. More layers of soil are gradually dug out from under the deck and more concrete slabs installed at specific intervals. These form the mezzanine levels and also reinforce the excavation pit. A small opening in the deck serves to supply and remove materials. Dewatering or groundwater lowering measures prevent the ingress of groundwater during the construction phase and reduce pressure on the structure.

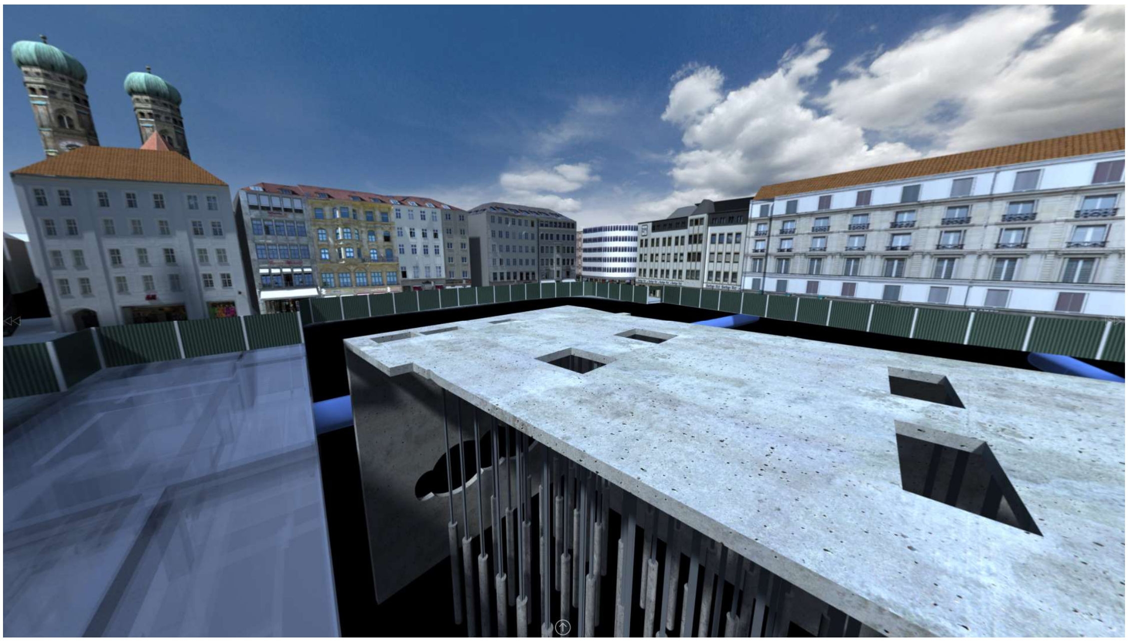

Figure 2: Marienhof station- diaphragm wall / cut and cover construction method with temporary supports (Source: https://tour.stammstrecke-muenchen.de/)

2.4 Geotechnical instrumentation

Besides the standard surveying and levelling of all structures in the area of influence, the construction process demands for an intensive monitoring of the existing underground line tunnels in short distance to the diaphragm walls and the excavation pit. Furthermore, the existing underground station and stair cases have to be monitored. On the surface the existing buildings have to be observed with hydrostatic levels. These also in perspective of future works in soil heave when excavation and tunnelling are ongoing. Around the pit there are several inclinometer/extensometers along defined cross sections in close distance to the already existing underground objects. Intensive monitoring is demanded for the diaphragm walls, as their deformation is one of the key parameters during the construction process.

Inside the pit there are 4 RH-extensometers (chain-extensometers) with a length of 90 m. These will be shortened during the excavation of the pit. The intact part below the shortening will stay in operation and give valuable information on soil heave and settlements. Along the temporary supports and in the bore piles further extensometer systems and strain gauges were installed during their construction process. These were requested to investigate the behaviour of the supports and to control deformation, which may interact with the cover.

Piezometers have been installed already during the preliminary geological explorations.

Once the tunnelling will start under compressed air drivage further systems in the tunnel support (e.g. horizontal IPIs, strain gauges etc.) will be required.

In the tender phase monitoring of the underground lines were planned with traditional total stations. For the diaphragm walls and the area around the pit Trivec systems with very high accuracy were tendered. The demands for very precise deformation measurements are very high.

Due to the high frequency of underground trains and due to the occupation of the (relatively small) pit area for public roads, access roads to the pit and other usage Solexperts, together with the monitoring partner Geo-Instruments and the construction contractor proposed alternative systems with higher performance resp. less requirements to the available space.

In the underground tunnel instead of automated geodetic surveying, a combination of hydrostatic levels, fissuremeters, tilt sensors on railway beams and Measurand Shape Array for convergence measurements and settlements of the railway line along the track were installed.

Instead of Trivec systems with manual measurements at extremely high precision 12-fold borehole extensometer combined with high precision BIVEC-IPIs were proposed. The Bivec IPIs are equipped with MEMS accelerometer, which are internally reversed by 180° degrees during the measurement. With this principle a high accuracy and long-term stability can be achieved.

In Table 1 a list of all instruments and systems from the ARGE Monitoring (Solexperts and Geo-Instruments) is given.

	Quantity	**Length (system)**	**Range**	**Accuracy**	**Number of data channels**
Underground railway tunnel					
Fissuremeter /2D	72	0.3m	100mm	±0.01 mm	216
Tilt sensor on railway beam	70	0.5m	±10°	±0.03mm/m	70
SAAX on track	6	33m	±30° with respect to horizontal	±0.01 mm/m	780
SAAV Convergence at tunnel crest	34	7.5m	±60°with respect to vertical	±0.01 mm/m	2088
Hydrostatic level	233			±0.1mm	
Surrounding of the construction pit					
IPI / Extensometer	9	66m	±30°/ 100mm	±0.03mm/m / ±0.01 mm	1890
IPI / Extensometer	5	34m	±30°/ 100mm	±0.03mm/m / ±0.01 mm	552
Extensometer	9	24m	100m	±0,2% FS	44
Hydrostatic level	713			±0.1mm	
Construction pit					
RH-Extensometer	4	90m	100mm	±0,2% FS	80
Extensometer in temporary supports	15	40m	100mm	±0,2% FS	90
IPI / Extensometer in Diaphragm wall shoring	12	64m	±30°/ 100mm	±0.03mm/m / ±0,2% FS	2364
Extensometer in temporary supports and piles	78	0.153m	3000 µe	±0.5% F.S.	78
Total	340		-	-	8252

Table 1: List of current monitoring installations in and around the Marienhof station

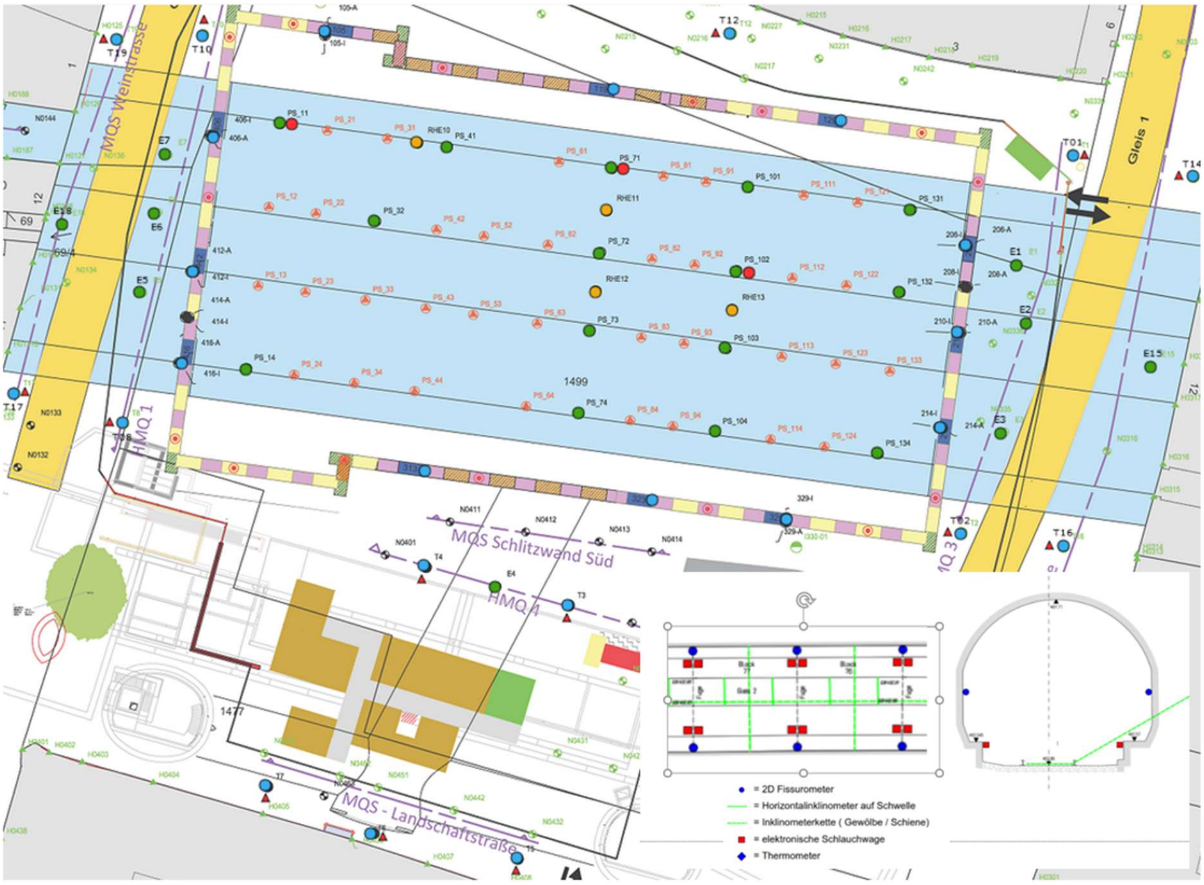

Figure 3:

Large view: Top view on pit with instrumented points in cross sections, diaphragm wall and temporary supports inside. Small view: Scheme of the instrumentation in the underground line tunnels

For the monitoring of the pit at the Hauptbahnhof (Munich main railway station) the originally tendered Trivec systems were applied.

3. Berne main station - "Zukunft Bahnhof Bern"

3.1 Project Outline

The main station of Berne is the second largest railway station in Switzerland with 330 000 users per day. To extend its capacity and improve space and quality to commuters the terminal of the RBS line (Regional Bahn Solothurn) will be moved in a newly built cavern underneath the existing railway station and the building structure above. Furthermore, public areas to change between platforms and for shops and convenience will be extended.

As a key element in the project the new RBS train station is being partially built directly under the "Postparc Mitte" building (opened in 2016) and the railway tracks, which are in service. With very limited space in the station areas and high demands on the running train service some special solutions in construction methods and logistic have to be realized.

3.2 Foundation of the Postparc Building

Four major supports of the up to 25 m high office centre are between the existing railway tracks and lie in the impact area of the future station caverns. The supports are built into old lift shafts and have a dimension of 8m to 2 m in a distance of 2 to 4 m to the new cavern. The foundation loads of these bearings into the molasse ground are up to 29 MN. Calculation showed that differential settlements of up to 20 mm do not affect the structural safety of the building and structures above.

As new support the four columns were newly founded with the aid of two new transfer girders and 36 lateral micropiles each (see Figure 4). The 24 m long micropiles are next to the future caverns in a fan-shaped arrangement. Due to space restrictions in the existing service tunnels, only 1 m long pile sections can be built in. In the section between the future caverns very high accuracy on the boreholes and their surveys were requested, because the micropiles cross each other in close distance. In narrow working space the transfer girders were built in 9 and 8 sections, respectively. For each section a small cavern was driven directly underneath the train platforms and then heavily reinforced and concreted. In both girders 48 cables for prestressing were installed into. To take the load the transfer girders were pretensioned in 7 to 8 stages. At the same time hydraulic presses on the pile heads were loaded to transfer all bearing loads on the micropiles.

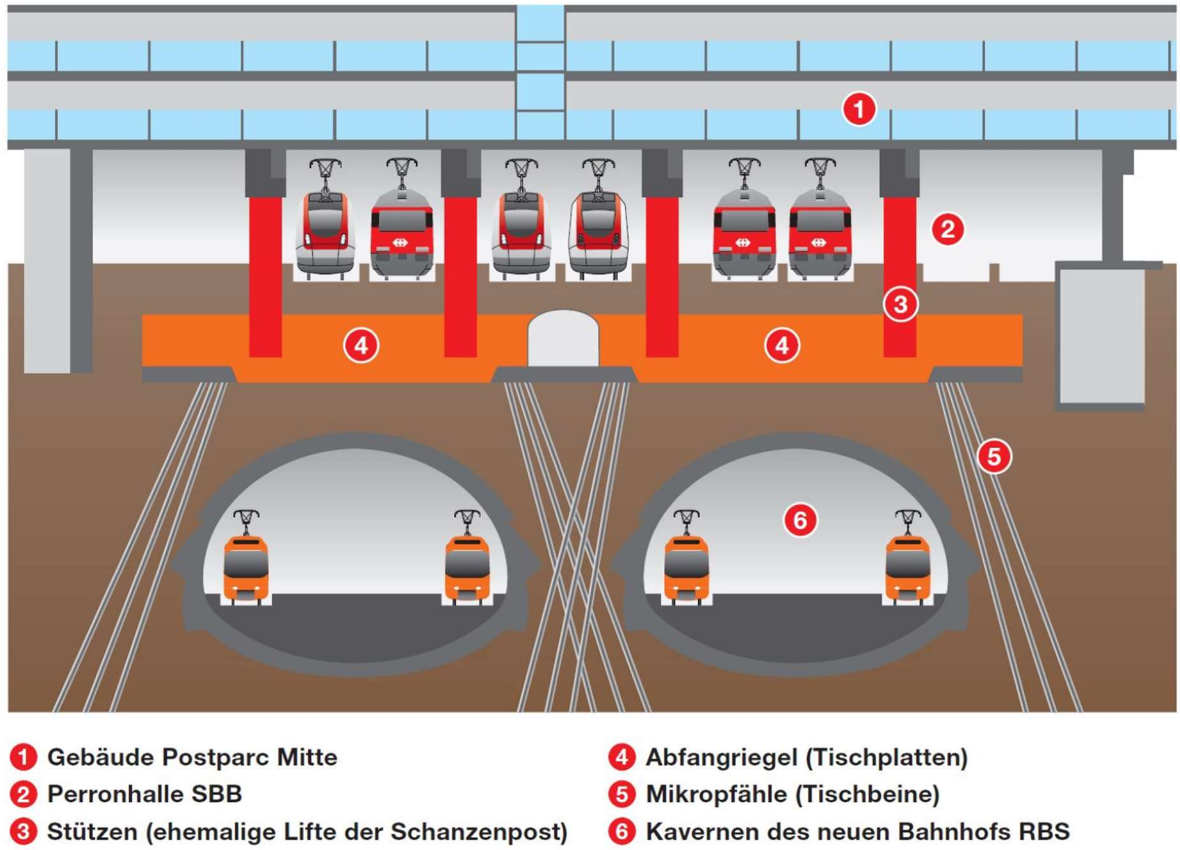

Figure 4: Designed situation with the new foundation of the Postparc building and the new caverns (source: https://www.zukunftbahnhofbern.ch)

Differential settlements of 10 to 15 mm are expected by numerical models. In order to have complete control over the settlements and to cover all uncertainties, the hydraulic presses can be re-activated for mechanical compensation of settlements. High attention was paid to the referring monitoring system.

3.3 Monitoring system

All micropiles boreholes were precisely surveyed in position. The piles were equipped with distributed Fibre Optic-sensing cables (FO) and VW strain gauges integrated. Between the girders and the pile heads, resp. between the girders and the molasses above the future cavern displacement measurements with special designed extensometers were requested. Pile heads and girder are instrumented with hydrostatic levels to observe all settlements and reference them outside the area of influence of the cavern excavation. Pressures in the hydraulic jacks and loads in the tension cables are monitored. The strains in the girders are measured with distributed FO. Starting from ground level (existing train platform) and from the existing post tunnels high precision IPIs (Bivec) combined with extensometers are installed to monitor the deformations in the adjacent subsoil of the bearing construction (girders / micropiles) and the cavern excavation.

Due to the complex construction situation and the limited space systems had to be adapted for the application in this project. All systems were integrated in a permanent monitoring system.

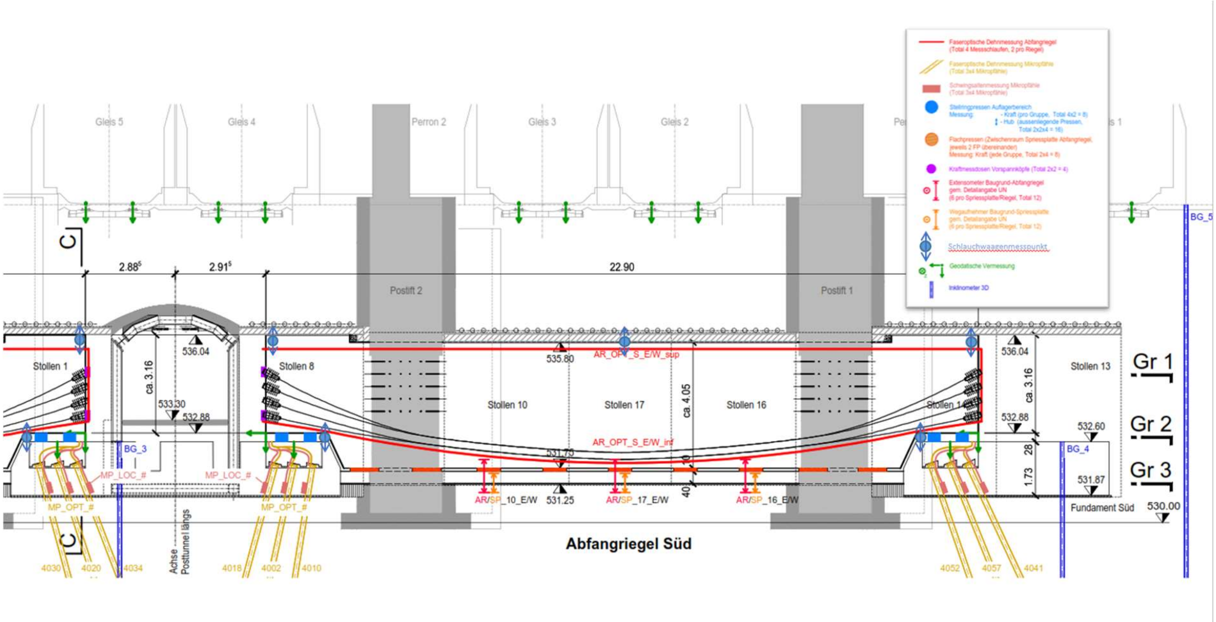

Figure 5: Overview on the installed monitoring devices on the south girder

3.4 Monitoring of the load transfer onto the girders and the first excavation process

In August 2020 (North) respectively December 2020 (South) the cables in the girder were stepwise tensioned and the presses loaded to transfer the load of the building and constructions onto the girders with the micropiles below. In figure 6 the stepwise loading can be distinguished at the piles and the girder.

Very successful in this monitoring was that the different system showed redundant results. Compression of approx. 10 mm to 15 mm in the micropiles (mainly in the top area, distinguished by strain measurements) could also be observed with the hydrostatic levels and the extensometer systems between the pile heads and the girder.

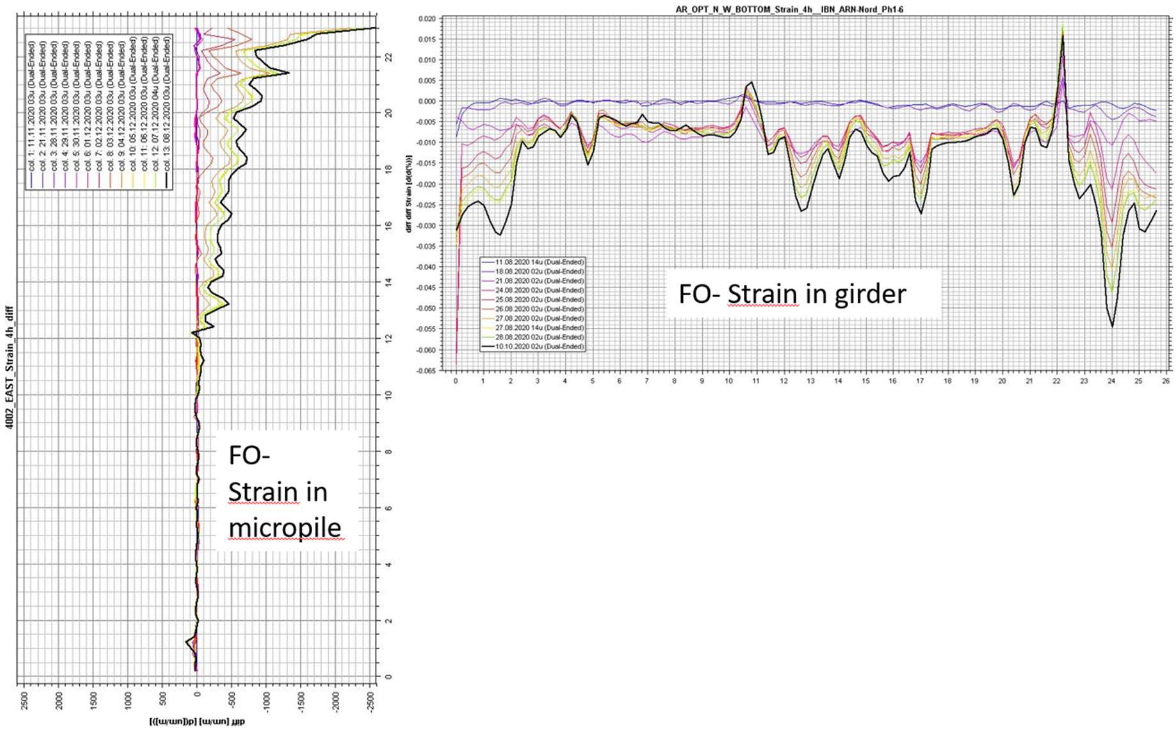

Figure 6: Stepwise tensioning of girders and load reaction (compression) of the micropiles

4. Conclusions

Inner city railway infrastructure projects often bear challenging requirements in construction methods as shown in examples from Munich and Berne. This again evokes high demands on surveys and in monitoring. Often standard systems cannot cover all these demands. The demonstrated examples show solutions which give extended benefit compared to tendered systems, resp. tailor-made solutions installed in very special conditions. With fibre optic measurements the transfer of a bearing into a new underground girder construction could be examined in detail and compared with other systems.

Acknowledgements

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