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A digital twin based integrated sustainability and quality assurance concept for subway constructions

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ABSTRACT: In regard to subway structures, non-destructive testing and structural health monitoring techniques are beneficial for construction and operation, which require an integrated quality control and sustainability concept. Such an integrated concept is presented, focusing on two main tasks. Inspection during construction will lead to a better quality of the components and structures. Proper data can be integrated into a building information model (BIM). The conceptual design should, however, anticipate later impacts and possible deteriorations at critical parts. The building information model could then be continued (updated) in the form of structural health monitoring (SHM) to make (visual) maintenance of subway structures more efficient, resulting in fewer disruptions (fewer closures, less downtime) and lower costs. It can also contain sensors at non-visible or non-assessible locations. Recording impacts on the structure (e.g. loads, vibrations, chlorides) enables a digital model as a so-called digital twin and the calculation of the remaining service life. Such a concept is presented for a new subway station in Munich.

KEY WORDS: Digital model; BIM; Subway station; Monitoring.

1 MOTIVATION

In order to minimize the carbon footprint of constructions over their life cycle, it is necessary to maximize their service life. In addition, operational disruptions or breakdowns must be kept to a minimum in terms of number and duration to avoid "switching effects" to private transport. Up to now, quality control during construction has mainly been carried out visually. Conformity with the approved and released execution documents is examined, representative random samples of the building materials to be installed are taken, and compatibility with subsequent components and equipment elements is checked. However, as soon as a component or construction section has been concreted, quality control is essentially only carried out on the surfaces (e.g. gravel pockets, cracks, etc.).

During the operation of the construction, inspection of infrastructure in Germany is carried out based on the German standard DIN 1076, establishing an inspection cycle of 6 years for so-called “major structural inspections” (German: Hauptprüfung). So-called "minor inspections" (German Nebenprüfung) with a reduced scope must be carried out every adjacent 3rd year.

2 STRATEGY FOR NOVEL QUALITY INSURANCE

2.1 New constructions

A customized selection and combination of BIM (Building Information Modelling), non-destructive testing (NDT) inspection techniques, and monitoring procedures can improve quality assurance during the construction phase and make condition monitoring and maintenance easier and more competent during operation. The first step would be categorizing all structural components with regard to their importance for stability, traffic safety, and durability. This can be done based on a Building Information Modeling (BIM) approach. The BIM model can be the basis for a digital model (sometimes referred to as a *Digital Twin*) containing physical or chemical material parameters for each structural component. To derive the resistivities of the materials, the monitoring of exogenous impacts can lead to a better understanding of material degradation. Proper monitoring techniques have the capability to measure such impacts as well as physicochemical conditions of the material in near real-time to update the digital model. Such a model is often called *Digital Shadow*, which always represents the actual state of the construction.

2.2 Existing structures

Such implementations are most efficient if they are implemented during the construction of the structure. However, there is also considerable potential for such a monitoring approach to increase resilience, durability, and, therefore, sustainability of existing structures from the perspective of retrofitting during operation. Such techniques can be combined with conventional visual inspection during certain intervals (as mentioned above), but can contribute information from the interior of the structures and from structural parts that are inaccessible.

Figure 1. BIM model of a new subway station.

3 COMBINED APPROACH

To exemplify the above-given strategy, a novel monitoring concept is illustrated for a new subway station to be built (see

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a BIM model in Fig. 1). Assuming that the station has a total length of 400 m, such an underground structure is typically built in the so-called "cut-and-cover" technique ("Deckelbauweise" or "Schlitzwand-Deckel", see the example in Fig. 2). The outer walls are first inserted into the ground as diaphragm walls. The reinforced concrete cover is then produced in a shallow cover construction pit. Under the protection of the already constructed diaphragm walls and the tunnel cover, the ground is excavated up to the lower edge of the floor slab. The floor slab, the inner shell, the mezzanine floors, and the platforms are then constructed from bottom to top using solid construction methods. This construction process considerably limits the traffic restrictions caused by the construction work as well as the dirt and noise emissions. The subway station significantly impacts the groundwater, which is why all external components must be designed as watertight concrete structures and complex culvert structures are required.

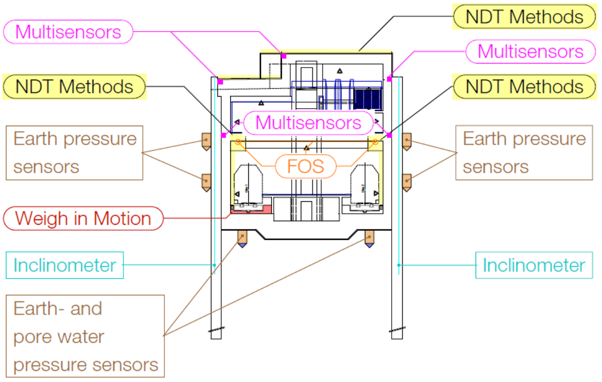

Figure 2. Cross-section of the BIM model in Fig. 1 of the subway station.

Fig. 2 provides, in addition, some elements of an integrated quality control concept, which is divided into measures for quality assurance during the construction phase and for structural maintenance during operation. Non-destructive testing methods such as endoscopy, ultrasound, radar, electromagnetic induction, etc., are primarily used. These are mainly operated right after the production of concrete components that are important, for example, in terms of structural design or for the tightness of the building. This is intended to rule out damage that is not visible on the surface, such as cavities, etc. Continuous monitoring methods such as fiber optic measuring methods are used in the construction phase, for example, for concrete parts with architecturally high-quality surface design to control the development of hydration heat and thus the early forced stresses in order to control the post-treatment and thus limit the formation of cracks.

Sensor systems and monitoring methods are also very important for repetitive structural testing and for structural maintenance during operation. For this reason, a new subway station can be equipped with a series of measuring devices for continuous monitoring of the structure: Earth pressure and pore water pressure sensors to record the load conditions, inclinometers to measure the structural deformations, multisensors, particularly in the area of component or structural joints, to detect the penetration of moisture and possible corrosion activity [1] (Fig. 3), fibre optic measuring systems to observe the stress conditions and possible load redistributions in the load-bearing components [2] and, last but not least, so-called "weigh in motion" systems for vibration measurements in the track bed. For more information on sensing systems for structural health monitoring it is to be referred to the literature [3].

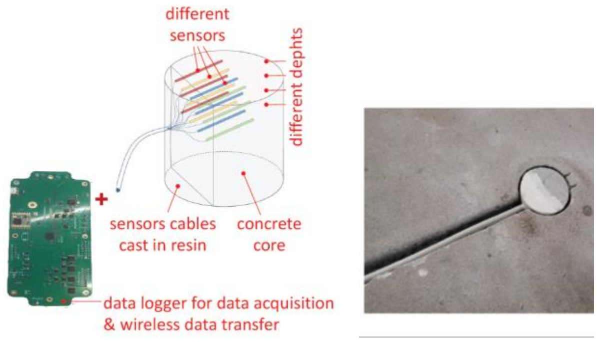

Figure 3. Multi-sensor system for corrosion monitoring [1] including different sensor modalities (left) and embedded into a concrete structure via a borehole (right).

4 CONCLUSIONS

Quality assurance for subway stations, as presented here, essentially consists of a combination of a digital model with modern measurement methods. This makes it possible to improve the quality achievable during the construction of the structure and to maintain the structure's condition at a high-quality level for a long time during operation. The structure's service life can be significantly extended, and the probability of occurrence and extent of operational disruptions minimized, as was shown earlier for wind turbines [4].

It is certainly true that the development of a digital twin and the installation and operation of inspection and continuous monitoring procedures are associated with costs. However, these costs are very low in relation to the structure's life cycle and the considerable monetary and environmental benefits associated with extending the service life.

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