Application of quantitative structural geology using Terrestrial Laser Scanning (TLS) for the stabilisation of the ‘Doggerwerk’ tunnel system in Happurg (Franconia, Germany)

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At the slopes of the ‘Hersbrucker Alb’ nearby Happurg in Franconia (Germany), the so-called ‘Doggerwerk’ has been projected as huge subsurface armaments factory (mainly for assembling aircraft engines). The name ‘Doggerwerk’ originated from the bedrock ‘Doggersandstein’, from what the tunnels have been excavated. The ‘Doggersandstein’ belongs to the geological stratigraphic formation ‘Eisensandstein’ (Dogger Beta, Middle Jurassic). The tunnel system has been realized only partly (around 3.9 km) until the late phase of the Second World War in 1944/45. The production of engines did never start at all. To date, only one of the originally eight entrances into the tunnel system, which are located at the steep, forested slope of the so-called ‘Houbirg’ mountain is accessible. The raw state of most of the tunnels - without a supporting inner shell - favoured the steady proceeding disintegration. Thus, the stability of most of the ‘Doggerwerk’ is not given. Consequently, the stabilisation of the tunnels in danger of ‘imminent collapse’ has been projected, resulting in several recovery measures since the beginning of the 1990th. The current stabilisation of overall 1.2 km long tunnels started in 2014 and was finalised in 2019.

After the evaluation of several technical approaches (securing by fencing, blasting etc.) and considering nature conservation guidelines, the gradually backfilling (single sections separated by brick-built walls) of the tunnels with cement suspension was favoured. The used filler (suspension of mainly cement, bentonite, slag sand and water) was specifically developed and certified for this project because of special requirements on viscosity (pumping distance of around 1.6 km), hardening and compressive strength (circa 1,6 N/mm²), as well as of the required environmental compatibility. For the estimation of the needed volume of filler and its potential loss in the fractures, faults and joints, the tunnel system was surveyed by using a quantitative visual application - the terrestrial laser scanning (TLS). Based on the laser scanning, a theoretical filling volume of around 12.918 m³ has been calculated for the 1.2 km long tunnels. Considering, however, the predominantly bad ground conditions, a volume of around 15.000 m³ was estimated. Additionally, the joint system was mapped classically. The joint system shows two general strikes, the Hercynian (110° - 157°) and the Rhenish (18° - 27°). The inclination of the joints is predominantly steep (circa 80°, ± vertical) and the bedding is mainly horizontal. Resulting from the laser scanning and the mapping, sections featuring particularly critical stability issues have been designated. Following the statically demands, these sections with critical ground conditions have
been supported with a reinforced (two layers) shotcrete lining (minimum 20 cm thick) to guarantee the underground construction site safety during preparatory works before starting the backfilling.

The stabilisation of the whole ‘Doggerwerk’ tunnel system by gradually backfilling was successfully carried out by using in total 17,360 m$^3$ cement suspension. A potential outflow of filler at the surface was monitored by verifying the actual injection volume with the calculated volume and visually also by the help of installed cameras. An outflow, however, has not been observed.