

High-end laser scanning under the Elbe River

by Konrad Saal

One of the most important components of northern Europe's infrastructure lies about 28 metres (92 feet) below the surface of the Elbe River: the Elbe Tunnel in Hamburg. As part of the A7 Autobahn, it connects the southern and northern portions of the Hanseatic city of Hamburg and the Scandinavian countries with Europe's metropolises. It is about 3.3 kilometres (1.9 miles) in length, with some 1,000 metres (3,280 feet) passing under the riverbed. At peak periods, up to 145,000 cars and trucks pass through the tunnel's four tubes each day. To ensure the future safety of this important traffic route, the three older tunnel tubes were renovated between 2009 and 2013 in accordance with the updated guidelines for facilities and operations of highway tunnels. The state geoinformation and survey office commissioned the Hamburg based company Dr. Hesse und Partner Ingenieure (dhp:i) with the documentation of every tunnel tube by kinematic 3D laser scanning. The objective was to make current,

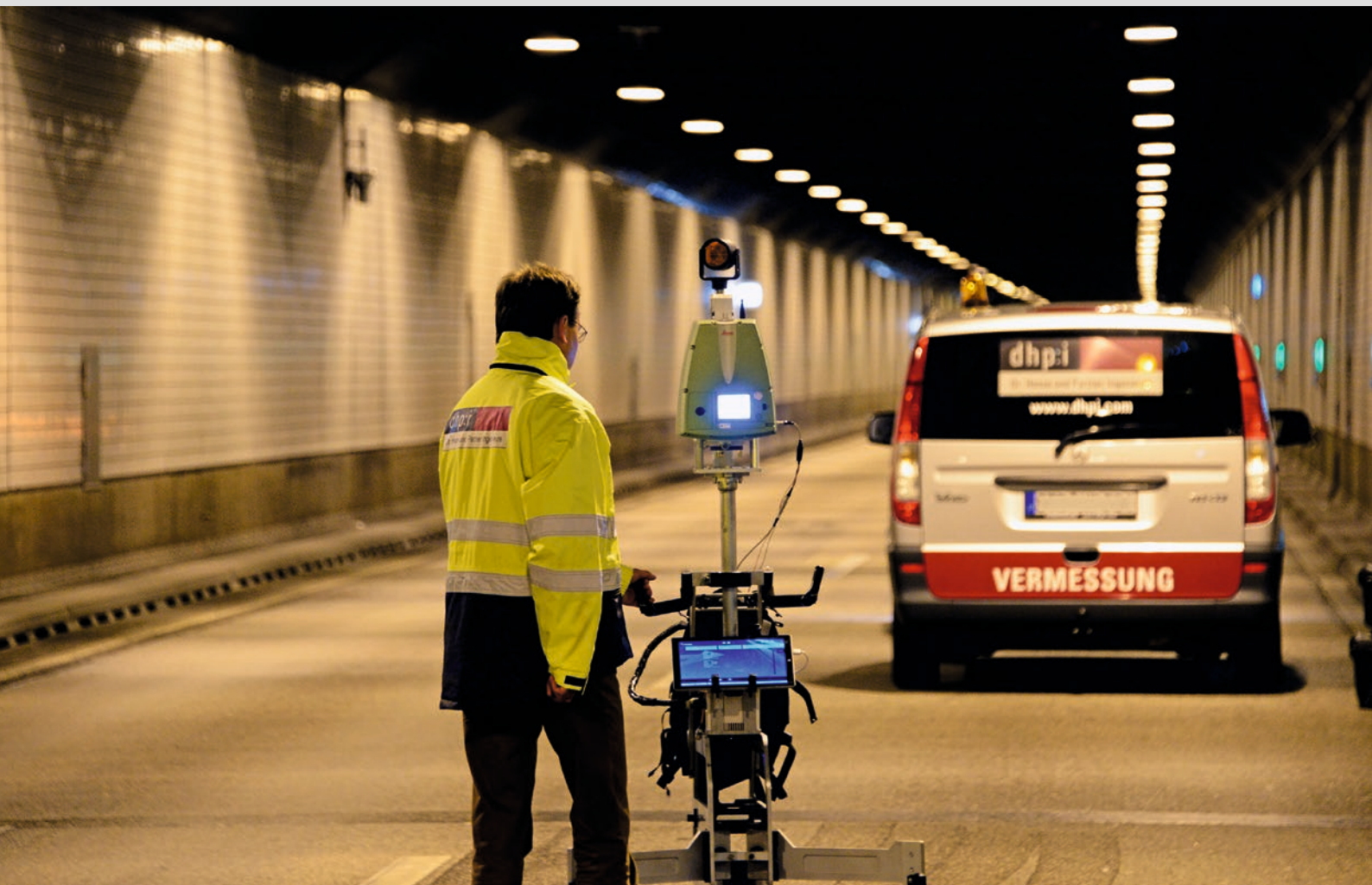
accurate inventory documentation available to the Elbe Tunnel operator (LSBG, state office for roads, bridges and waters).

The georeferenced information obtained will be needed for maintenance and repair support of Elbe Tunnel planning, design, construction and administration processes and as a basis for future Building Information Modelling (BIM), among other uses.

In addition to the tunnel geometry, all other objects and equipment in the tunnel also had to be recorded for this purpose within an accuracy of a few centimetres. This includes supply and safety installations, such as transport equipment, emergency exits, escape route signage, emergency phone and operations alcoves, fire protection systems, ventilation shafts, lighting systems, cameras, loudspeakers, and sensors for traffic telematics and operating technology, totalling more than 200 different 3D objects.

Selecting the appropriate procedure

Because of the Elbe Tunnel's critical importance for traffic in and around Hamburg, the survey could only



result in minimal blocking periods. It was, therefore, clear from the outset that the activities would have to take place in the low traffic period between 10 p.m. to 5 a.m., and only one tunnel tube could be blocked at a time.

The client's invitation to bid explicitly specified surveying by means of kinematic laser scanning. In the course of the tendering procedure, several vehicle-based and mobile scanning systems from different bidders were evaluated. At the end of the selection process, the decision was made in favour of the ProScan T-Series system from p3d systems GmbH. In addition to other features, easy integration of the Leica ScanStation P15, high acquisition speeds and extremely accurate object recording were persuasive.

"The kinematic scanning system used by dhp:i not only guarantees us maximum precision but also a complete recording of the entire tunnel structure. We have the confidence of being able to rely on the data quality and, at the same time, minimise the blocking periods for this important tunnel," says

Bernhard Cieslik, engineer and manager of municipal surveying at the state geoinformation and survey office responsible for the project.

The kinematic ProScan T-Series system – the T stands for tracking by means of total stations – is a manually guided, mobile laser scanning system. An inertial measuring unit (IMU) and a standard laser scanner, such as the Leica ScanStation P15, are adapted to a trolley. In addition, there is the tablet PC for data acquisition and control. Precise positioning in this project was ensured by Leica TS30 and Leica Viva TS15i total stations, which tracked the prism mounted on the system with around eight measurements per second.

One of the advantages of this acquisition method is direct system referencing through tracking with the total stations. This eliminates the laying out of control points that vehicle-based systems require. Secondly, the high accuracy of the point cloud, combined with very high resolution, and the opportunity to process and check the data shortly after measurement directly "on site" is impressive.



The first forecasts revealed that it would be possible to record one tunnel tube per night in high resolution with this solution.

The measurement – one tunnel per night

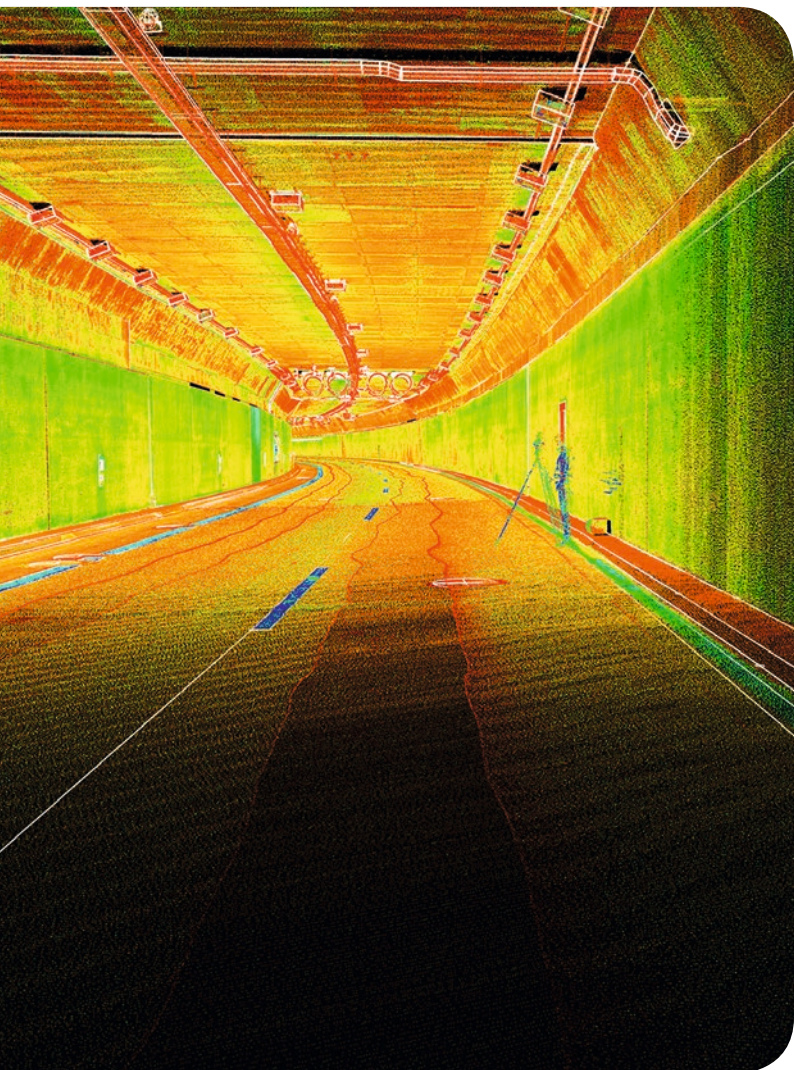
The survey of four tunnel tubes took place in four night-time operations. The intensive preplanning and detailed measuring concept ensured a smooth operation for both data acquisition and evaluation. It was possible to significantly improve on the target duration of nine hours per surveyed tunnel tube from the first measurements.

As part of the on-site scanning, both the tunnel walls and all installations, such as signs and ventilation systems, are recorded completely. For this purpose, the tunnel tubes were divided into approximately 300

metre-long (984 foot) sections that were scanned forward and backward within about 40 minutes.

Thanks to the double recording, all shadowing was eliminated. It was also established that the accuracy achieved in this project was better than 10 millimetres (0.4 inches).

To use the kinematic scan system as efficiently as possible, without interruption, the three on-site project employees' tasks were meticulously coordinated. One employee steadily moved the ProScan along the 300-metre (985-foot) tunnel section, while the other two employees ensured precise system target tracking with their two total stations. Thus, downtime only occurred at the beginning and end of measurement and when changing batteries.



Data provision in compliance with specified standards

Many federal states use standardised data models for infrastructure and other construction projects. Standardisation catalogues regulate the contents described therein, which should supply uniform data to every specialised field that works with this information.

Since 2008, the Hamburg standardisation catalogue has described a detailed standard for digital traffic planning databases. In particular, the catalogue regulates the data structure, data format and signatures. For example, the layer structure, layer names, line types and blocks or hatching and dimensioning are defined in this standard.

As an extension of the two-dimensional Hamburg standardisation catalogue, every CAD object to be modelled and the entire tunnel geometry were constructed in 3D in this project.

The horizontal and vertical fixed control points in the tunnel, which were established by the state's geo-information and survey office and normally used for audit surveys and building projects, could be used for positioning total stations.

The speed with which the measuring engineer moved the system through the tunnel was adjusted to the required object resolution. Due to the number of small objects on the tunnel walls, a measuring point distance of better than 2 centimetres (0.8 inches) had to be guaranteed, which resulted in a scanning speed of 0.5 metres/second (1.6 foot/second).

"Although we have already carried out projects in the double digits with this system, the acquisition speed with the Leica ScanStation P15, the Leica Geosystems total stations and the p3d ProScan is always impressive. A comparable object resolution using tripod mounted and, therefore, static laser scanning would have required at least three times as much time," summarises Dr. Christian Hesse, CEO of dhp:i.

Upon completion of the laser scan, the total station measurement data was imported from the memory card on-site and the automatic geo-referencing of the scan in p3d PCloud began.

The completed point clouds were imported into the Leica Cyclone 9, filtered and cleaned. To carry out the preparation of several thousand 3D objects efficiently, the Cyclone databases were integrated into AutoCAD with the help of Leica CloudWorx Plug-ins. The parallel modelling of required CAD objects and the entire tunnel geometry then took place.

The result was 13.5 kilometres (8.4 miles) of Autobahn tunnel recorded precisely at high resolution in four nights, a completely satisfied client, and the happy motorists who hardly noticed anything. ■

Dr. Hesse und Partner Ingenieure (dhp:i) is an internationally active survey office with headquarters in Hamburg and is among the leading firms in the field of 3D laser scanning.
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Elbe Tunnel construction and renovation

After a seven-year construction period, the first three Elbe Tunnel tubes were opened to traffic in 1975. Since the expansion in 2002, four tubes are available with a total of eight lanes. An extensive renovation of the first three tubes took place between 2009 and 2013. Under the name "A7 – Elbe Tunnel retrofit program," asbestos abatement, improvement of the ventilation system, fire protection, escape routes and technical facility modernisations were implemented.

These construction activities were necessary for the tunnel to comply with the "Guidelines for Facilities and Operation of Highway Tunnels" (RABT 2006) that were current at the time.

The Elbe Tunnel is operated by the Hamburg state office for roads, bridges and waters (LSBG).