

# **AUTOMATED ANALYSIS OF SEGMENTAL RING OVALITY IN TBM TUNNELS**

T.Langar & P.Matter

*Amberg Engineering a.s., Amberg Technologies AG*

L.Hannan

*Amberg Technologies AG*

**ABSTRACT:** At present, several hundred Tunnel Boring Machines (TBMs) are in operation worldwide for the construction of infrastructure projects. Approximately 70% of these machines excavate tunnels with precast segmental lining, where assessment of geometric quality—particularly ring ovality, inter-ring transitions, and ring rotation—is essential. Traditional methods for measuring and evaluating these parameters are time-consuming and typically involve the use of multiple software tools combined with manual processing steps. This paper presents a new fully automated method for the analysis of segmental ring ovality based on 3D laser scanning data. The method was successfully applied on the Eglinton Crosstown West Extension project in Toronto, where a total of 1,488 rings were analyzed in accordance with the recommendations of the International Tunnelling Association (ITA), resulting in the saving of hundreds of working hours. The automated workflow includes profile extraction from point clouds, detection and removal of outliers, ellipse fitting, and the computation of all required parameters, including internal diameters and deviations from the theoretical tunnel axis. The results are presented through clear graphical outputs and exported into standardized formats for further use.

## **1. NORMATIVE REQUIREMENTS AND STANDARDS**

Several national and international regulations define permissible geometric tolerances for segmental lining rings. The following sections summarize selected standards commonly applied in practice.

### **1.1 BRITISH TUNNELLING SOCIETY**

According to the BTS, the maximum and minimum measured diameters of each ring shall lie within 1% of the theoretical design diameter of the ring, measured after completion of ring production and grouting, or within any other tolerances specified in the project documentation.

### **1.2 INTERNATIONAL TUNNELING ASSOCIATION**

The ITA defines construction tolerances for ring shape (ovality) ranging from  $\pm 0.25\%$  to  $\pm 0.5\%$  of the internal diameter, depending on ring size and the number of segments per ring.

### **1.3 SINGAPORE LAND TRANSPORT AUTHORITY**

According to Singapore specifications, the center of a segmental ring may not deviate from its design position by more than 42.5 mm, and each internal diameter may not differ from the design diameter by more than 25 mm.

### **1.4 NORTH AMERICAN PROJECT SPECIFICATIONS**

North American projects often require measurement of horizontal deviations from the theoretical axis to the inner surface of the tunnel, vertical deviations of the crown and invert measured from the theoretical axis, and horizontal stationing of the points at which the measurements are taken.

### **1.5 FORMULAS FOR OVALITY CALCULATION**

Various formulas exist for the calculation and presentation of ovality, differing according to methodology and project requirements. To evaluate all the specifications mentioned above, a measured profile of each ring is required. A typical ring width ranges from 1.5 to 1.8 m. In a 6.4 km long segmentally lined tunnel, approximately 4,200 rings must be measured, analyzed, and processed.

### 1.5.1 Standard Ovality Formula

This formula calculates the percentage deviation based on the maximum and minimum internal diameters of the tunnel ring: (1):

$$\theta = \frac{D_{max} - D_{min}}{D_{nominal}} * 100\% \quad (1)$$

Where  $D_{max}$  is the maximum measured internal diameter,  $D_{min}$  is the minimum measured internal diameter, and  $D_{nominal}$  is the design or nominal internal diameter.

### 1.5.2 ITA Formula for Maximum and Minimum Percentage Deviation

The International Tunnelling Association uses a method to express the percentage deviation from the design diameter, accounting for both expansion and compression effects (2):

$$\theta = \frac{D_{AbsMax}}{D_{nominal}} * 100\% \quad (2)$$

Where  $D_{absMax}$  represents the absolute maximum deviation from the nominal diameter.

### 1.5.3 Ellipse-Based Formula

This method uses the major and minor axes of a fitted ellipse to determine ovality (3):

$$\theta = \frac{a - b}{D_{nominal}} * 100\% \quad (3)$$

Where  $a$  is the length of the major axis and  $b$  is the length of the minor axis of the fitted ellipse.

### 1.5.4 Maximum Diameter Difference

This method calculates the maximum deviation from the design diameter in absolute units rather than percentage (4):

$$\theta = D_{AbsMax} - D_{nominal} \quad (3)$$

Where  $D_{absMax}$  is the diameter with the largest absolute deviation from the nominal diameter.

## 2. TRADITIONAL APPROACH TO RING PROFILE ACQUISITION

Data collection using a total station is a labor-intensive process in which an operator measures 8–16 evenly distributed points on each ring. This is followed by a manual workflow to determine ovality using several different software tools.

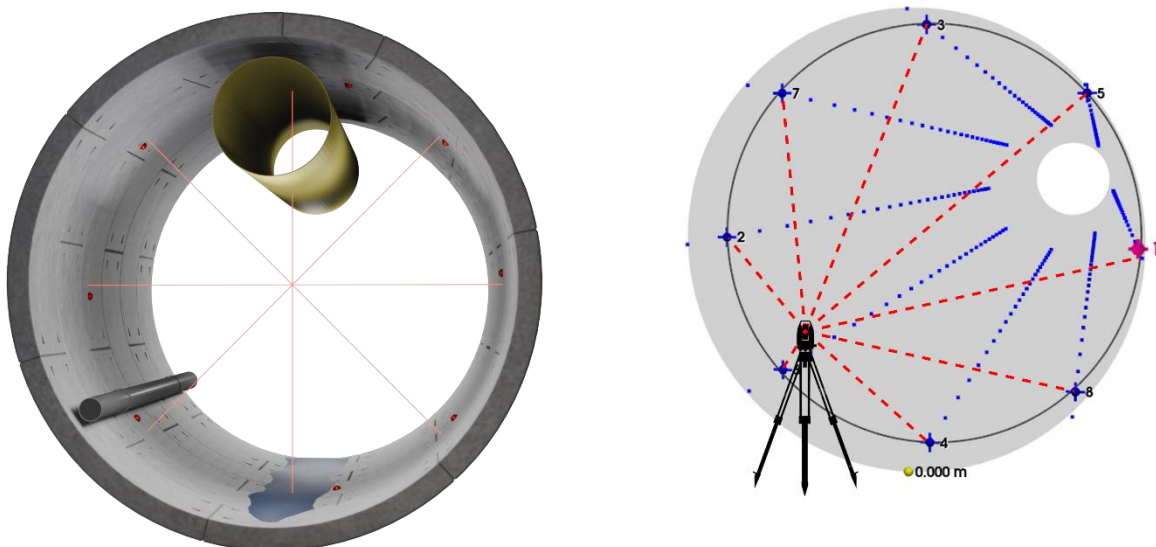


Figure 1: Typical distribution of 8–16 measured points per ring

The analysis of measured profiles—determining the major and minor axes of the ellipse to obtain the as-built axis (LSP) and the actual center point of the ring—requires fitting a radius through the measured points, typically performed in CAD software. This process is time-consuming and must be repeated for the required number of rings. In the next step, the values are manually analyzed in spreadsheet software, often taking weeks or even months depending on tunnel length and ring count.

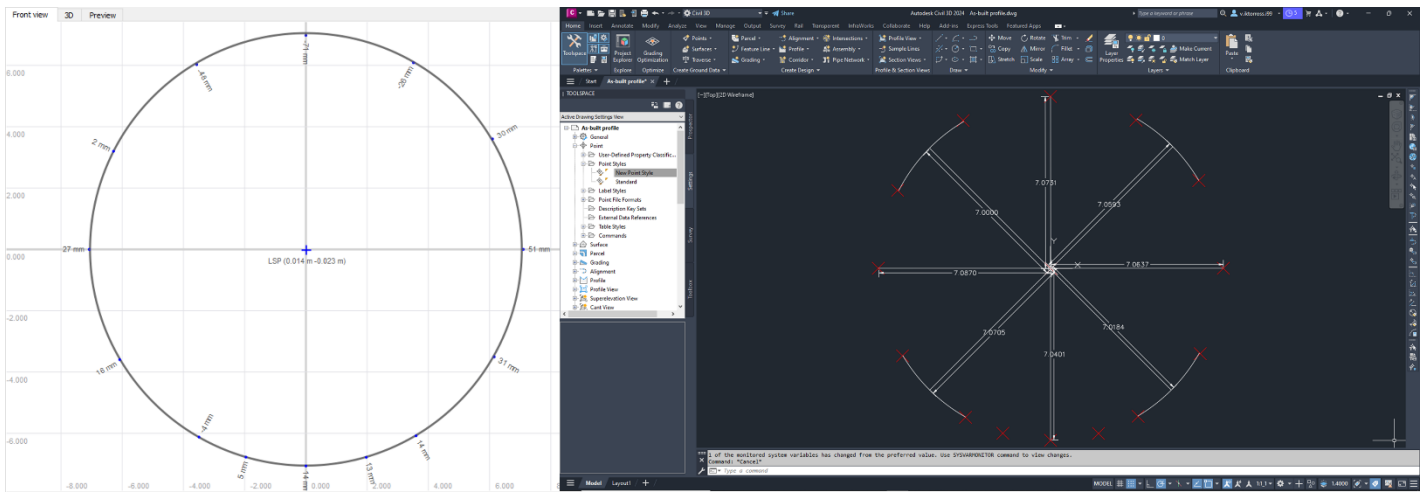


Figure 2: Example of measured points and CAD processing

Ring	Stationing	D_min	D_max	D_nom.	0°	22.5°	45°	67.5°	90°	112.5°	135°	157.5°	0°	22.5°	45°	67.5°	90°	112.5°	135°	157.5°	Max	Result	
2	320	10,064.876	6,946	7,011	7,000	6,946	6,989	7,011	7,053	7,047	7,018	6,978	6,952	90%	19%	35%	88%	78%	30%	36%	80%	OK	
3	330	10,078.402	6,988	7,015	7,000	7,013	7,015	7,005	7,002	6,989	6,988	6,993	6,997	22%	25%	8%	3%	19%	21%	12%	6%	23%	OK
4	340	10,093.431	6,988	7,012	7,000	6,996	6,997	7,004	7,008	7,012	6,998	6,994	6,988	7%	4%	7%	14%	20%	3%	11%	20%	20%	OK
5	350	10,108.461	6,991	7,008	7,000	7,008	7,006	6,997	6,991	6,993	6,996	7,002	13%	9%	5%	15%	12%	11%	6%	3%	15%	OK	
6	360	10,123.489	6,988	7,015	7,000	6,988	6,994	7,001	7,011	7,015	7,009	6,993	6,992	19%	10%	2%	19%	25%	15%	12%	13%	25%	OK
7	370	10,138.503	6,984	7,015	7,000	6,984	6,988	6,989	7,002	7,015	7,012	7,006	6,992	27%	24%	19%	4%	25%	20%	11%	13%	27%	OK
8	380	10,153.523	6,983	7,008	7,000	7,008	6,999	6,993	6,983	6,991	7,001	7,003	7,005	13%	1%	12%	28%	15%	2%	6%	8%	28%	OK
9	390	10,168.556	6,994	7,014	7,000	7,014	7,009	6,999	6,994	6,996	6,997	6,995	7,007	22%	15%	2%	10%	7%	4%	8%	12%	23%	OK
10	400	10,183.577	6,990	7,010	7,000	7,004	7,001	6,994	6,990	6,990	7,000	7,003	7,010	7%	2%	10%	17%	18%	1%	5%	16%	18%	OK
11	410	10,198.598	6,980	7,010	7,000	7,010	7,010	6,997	6,988	6,980	6,992	7,002	7,007	17%	16%	5%	20%	33%	14%	3%	12%	OK	
12	420	10,213.627	6,985	7,009	7,000	7,009	7,002	6,991	6,985	6,994	6,998	7,009	7,009	14%	4%	15%	25%	11%	3%	15%	15%	23%	OK
13	430	10,228.650	6,989	7,012	7,000	7,012	7,006	6,999	6,995	6,989	6,997	6,998	7,011	21%	10%	3%	8%	18%	5%	3%	18%	21%	OK
14	440	10,243.172	6,995	7,004	7,000	7,004	7,003	7,001	6,997	7,000	6,995	6,997	7,003	6%	0%	1%	5%	1%	9%	6%	6%	OK	
15	450	10,258.205	6,995	7,021	7,000	7,019	7,012	7,002	6,998	6,995	6,996	7,005	7,021	32%	20%	4%	4%	9%	6%	8%	34%	OK	
16	460	10,273.731	7,003	7,012	7,000	7,012	7,005	7,003	7,003	7,003	7,006	7,009	20%	9%	6%	6%	14%	4%	10%	14%	20%	OK	
17	470	10,288.754	6,984	7,024	7,000	7,024	7,018	7,001	6,993	6,984	6,994	7,005	7,022	39%	30%	1%	12%	27%	11%	9%	37%	OK	
18	480	10,303.777	6,993	7,010	7,000	7,006	7,009	7,010	7,002	7,005	7,001	6,993	6,996	10%	10%	17%	4%	8%	1%	12%	6%	17%	OK
19	490	10,318.798	6,988	7,009	7,000	7,009	7,007	6,999	6,991	6,989	6,997	7,005	15%	11%	3%	15%	18%	20%	5%	8%	20%	OK	
20	500	10,333.821	7,001	7,012	7,000	7,012	7,012	7,011	7,001	7,001	7,005	7,001	7,011	20%	19%	18%	2%	1%	8%	1%	18%	20%	OK
21	510	10,348.851	6,976	7,014	7,000	7,014	7,014	6,999	6,992	6,976	6,992	6,997	7,005	24%	24%	1%	13%	40%	14%	4%	9%	OK	
22	520	10,363.869	6,990	7,018	7,000	7,018	7,015	6,996	6,991	6,990	6,995	7,002	7,014	30%	25%	6%	16%	16%	8%	3%	24%	OK	
23	530	10,378.890	6,987	7,017	7,000	7,017	7,017	6,997	6,994	6,987	6,996	7,000	7,013	29%	28%	6%	10%	21%	7%	0%	22%	OK	

Figure 1: Example of processing in MS Excel

A fully automated solution for ovality calculation is now available. The following sections describe how this new method was successfully implemented, saving hundreds of working hours on a real project.

### 3. EGLINTON CROSSTOWN WEST EXTENSION PROJECT, TORONTO

The West End Connector project in Toronto provides insight into the automated workflow.

#### 3.1 PROJECT DESCRIPTION

The Eglinton Crosstown West Extension (ECWE) Advance Tunnel project represents the first phase of works on the 9.2 km extension of the Eglinton Crosstown LRT (future TTC Line 5). The extension runs predominantly underground. A pair of 6.2 km long tunnels was excavated and lined with precast segments. Each ring consists of seven segments with an internal diameter of 5.75 m.



Figure 2: Eglinton Crosstown West Extension

### 3.2 PROJECT SPECIFICITATION

Upon project completion, the contractor was required to deliver the analysis in accordance with ITA standards. The automated as-built analysis of the TBM segmental rings was based on fully registered 3D scans of both tunnel tubes. In total,  $2 \times 6.2$  km of tunnel was scanned, corresponding to 3,720 constructed rings with a width of 1.7 m. According to the specification, only every fifth ring had to be processed, resulting in a total of 1,488 analyzed rings ( $2 \times 744$ ).

## 4. AUTOMATED WORKFLOW

The new method consists of several fully automated steps that significantly reduce the time required for analysis.

### 4.1 AUTOMATED EXTRACTION OF RING PROFILES FROM 3D POINT CLOUDS

The first step involves extracting profiles directly from the 3D point cloud without prior cleaning. The software automatically identifies individual rings based on their position and width.

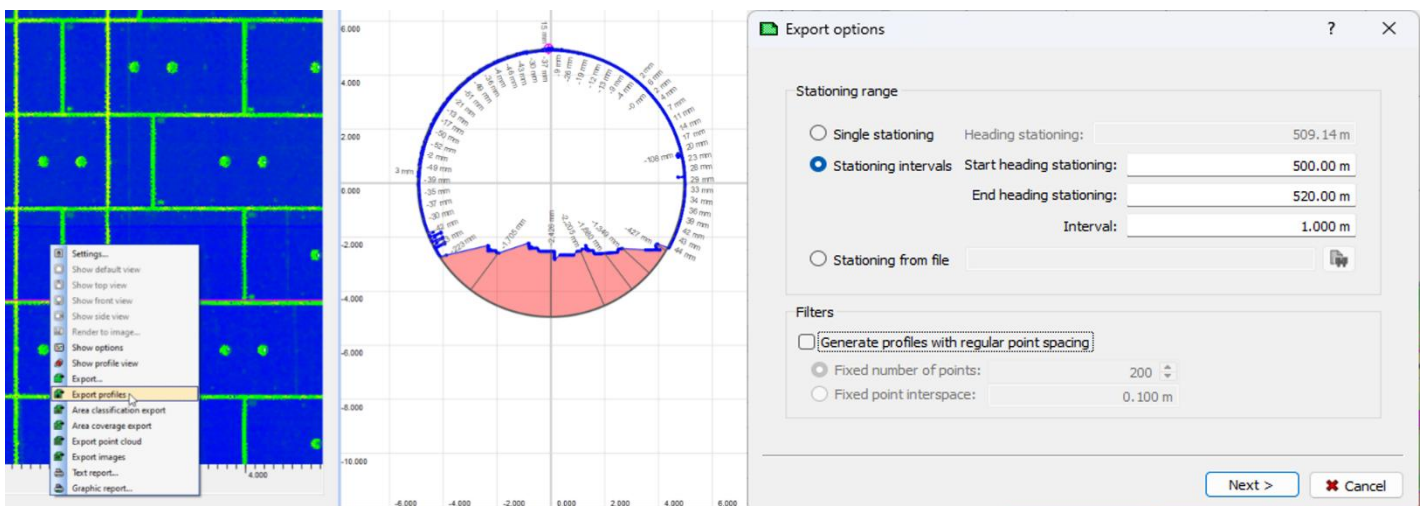


Figure 3: Profile extraction from point cloud

## 4.2 EXECUTION OF AUTOMATED ANALYSIS

The automated analysis includes calculation of the actual ring center (LSP), automatic detection and removal of outliers (noise), and automatic ellipse fitting. It also involves automatic calculation of all internal diameters and determination of the elevations of the tunnel crown and invert.

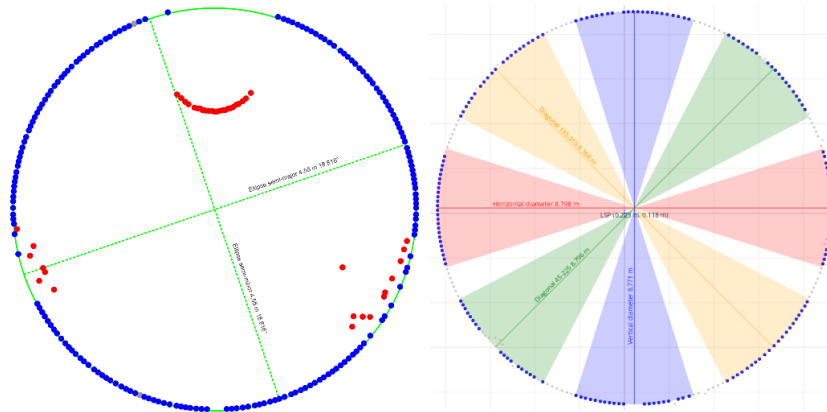


Figure 4: Automated processing of individual profiles

## 4.3 ASSIGNMENT OF RELEVANT SPECIFICATIONS

Based on the computed values, all parameters required by the project specifications are automatically derived, including deviations from the theoretical axis, ovality according to different formulas, and additional geometric characteristics.

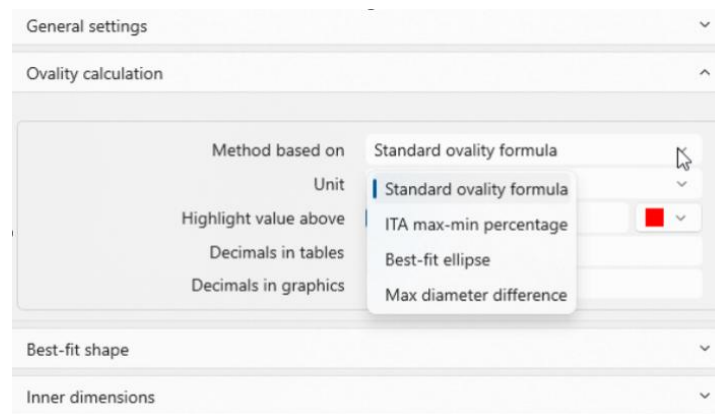


Figure 5: Selection of calculation method

## 4.4 VIZUALIZACE VÝSLEDKŮ

Results are presented using clear graphical outputs showing ellipse orientation, horizontal and vertical deviations, and lengths of the major and minor ellipse axes for each analyzed ring.

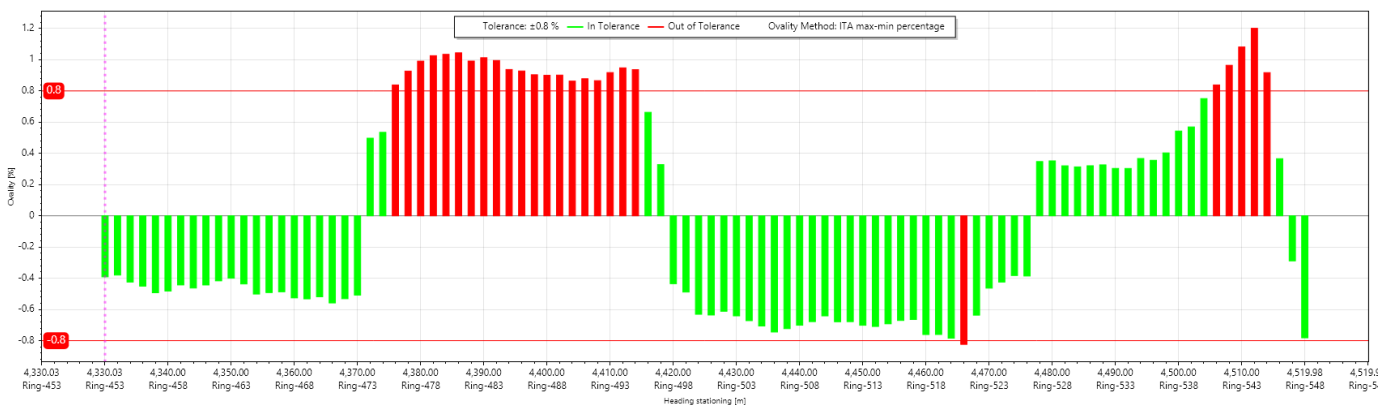


Figure 6: Overview of calculated ovality values per ring

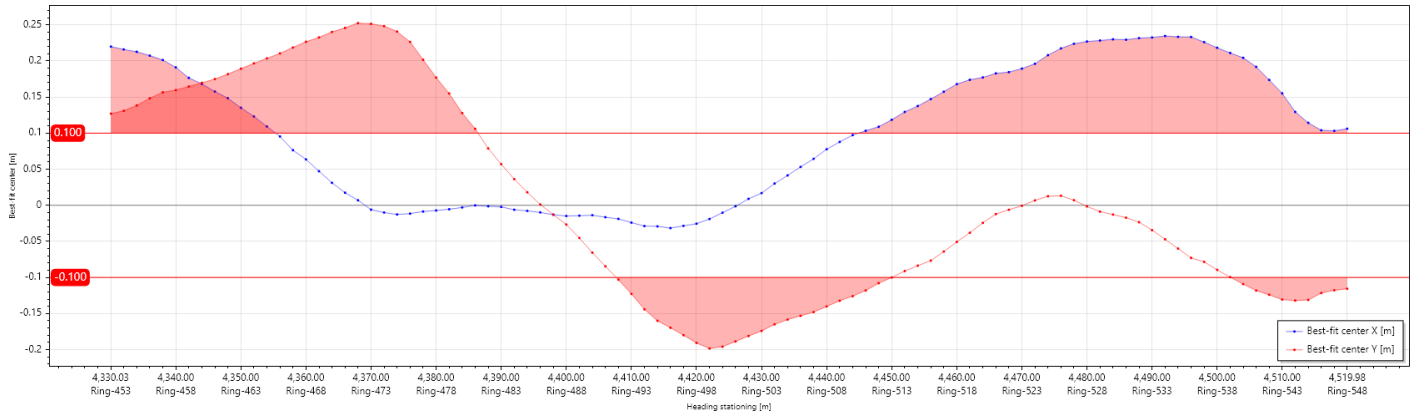


Figure 7: Overview of calculated ring centers relative to design values

## 4.5 SUMMARY REPORT

The automatically generated report provides a complete overview of all analyzed rings, including graphical representations and tabulated results.

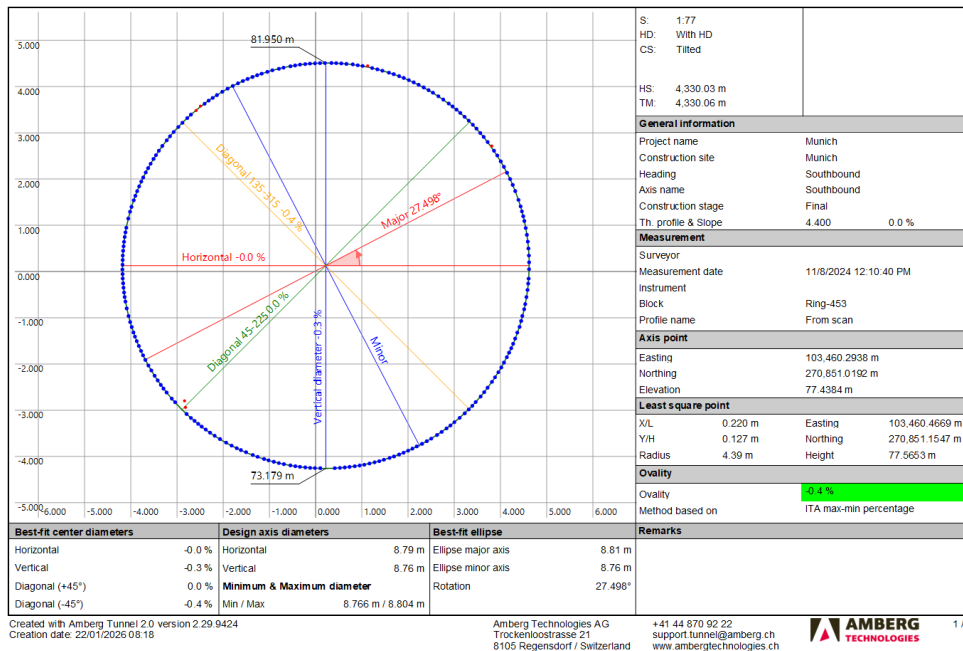


Figure 8: Example report

## 4.6 EXPORT OF RESULTS

The results can be exported as layered DXF files containing 2D profiles, as graphical profile reports in PDF format, to Excel with all calculated values and attribute information, and as measured profile points both with and without outliers.

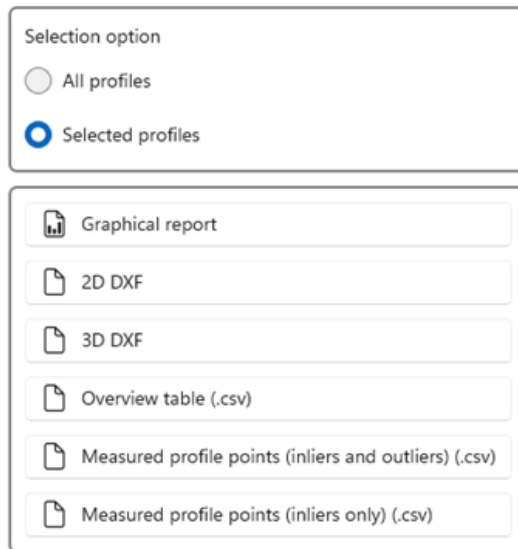


Figure 9: Export options

## 5. CONCLUSION

The newly developed method, combining best-fit calculations with advanced outlier detection, provides high accuracy while maintaining ease of use under a wide range of site conditions. Automatic outlier identification enables direct profile extraction from unfiltered point clouds, eliminating the need for preliminary data cleaning. The calculation of the as-built axis is fully automated and includes determination of both the major and minor ellipse semi-axes without manual intervention. Internal diameters are computed using the same approach, yielding stable and accurate results due to the exclusion of outliers. The entire process is unified within a single software platform, significantly simplifying the workflow and minimizing the risk of errors associated with data transfer between tools. Excluding outliers results in substantially improved accuracy. Moreover, the method dramatically reduces analysis and reporting time, allowing complete outputs to be generated within minutes. This ensures reliable, efficient, and user-friendly data processing while significantly reducing the probability of human error.

## 6. REFERENCES

- INTERNATIONAL TUNNELLING AND UNDERGROUND SPACE ASSOCIATION. Guidelines for the Design of Shield Tunnel Lining. Lausanne: ITA-AITES, 2000.
- BRITISH TUNNELLING SOCIETY. Specification for Tunnelling. London: BTS, 2010
- AMBERG TECHNOLOGIES. Tunnel Suite Software Documentation. Regensburg: Amberg Technologies, 2024.
- UNDERGROUND CONSTRUCTION TECHNOLOGY. TBM Market Analysis 2022–2030 [online]. 2023. <https://www.tunneltalk.com/>

**Ing. Tomáš Langar**  
**Amberg Engineering a.s.**  
**[tlangar@amberg.cz](mailto:tlangar@amberg.cz)**