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Application of terrestrial laser scanning TLS to control deformation of tanks for liquid substances

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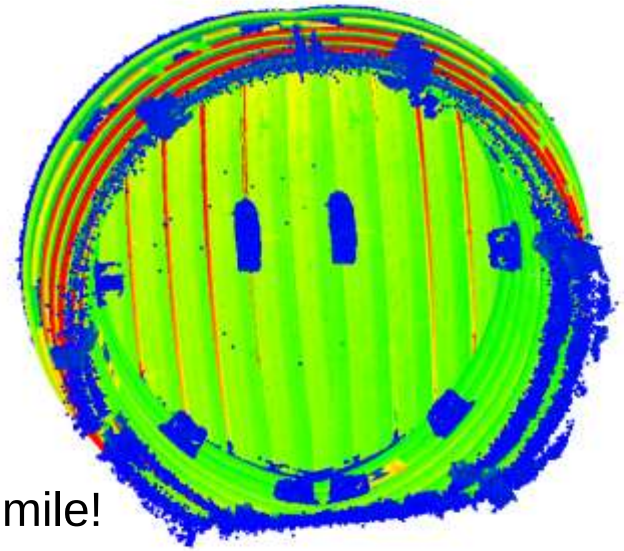
PLAN

1. Research Facility and instruments
2. Development of TLS data
3. Surface flatness
4. Results of the control measurements of the tank
5. Conclusions (1)
6. Spatial projection of a point cloud to the lateral of the cylinder
7. Expansion of tank/tunnel surface into a plane
8. Conclusions (2)



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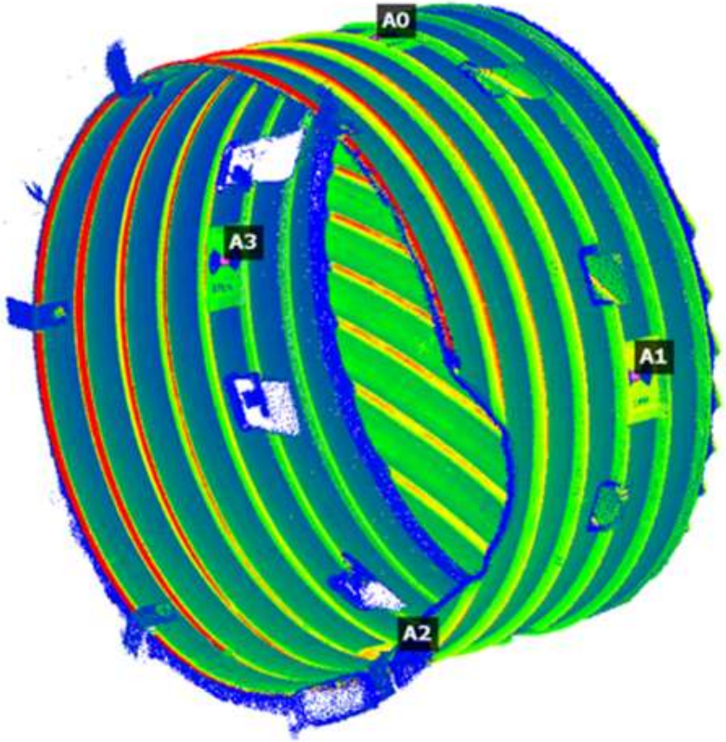
Research facility: underground tank for liquids made of pvc plastic

Measurements were taken with a Z+F Imager 5006d laser scanner, which has a scanning speed of up to 2 million points/sec, a declared scanning resolution of 6 mm at 10m, an angular accuracy of 18", a distance measurement accuracy of 1mm+10ppm, and a 3D point position accuracy of 2 mm (at 10m) and 3 mm (at 20m).



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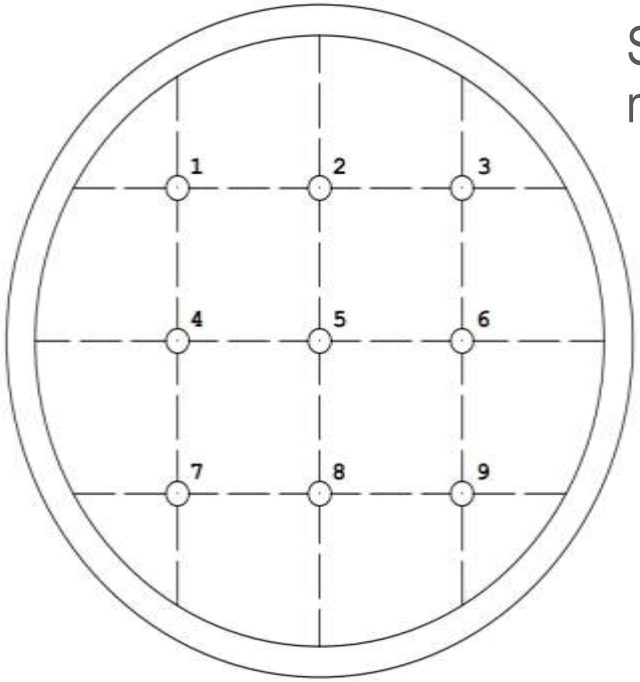
Purpose of the tests:

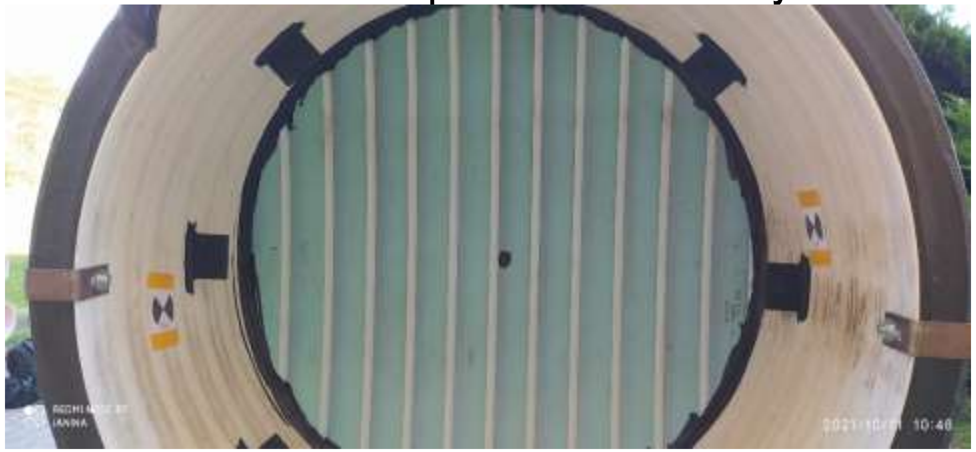
Determination of deformation of structural elements of the test tank using terrestrial laser scanning (TLS)

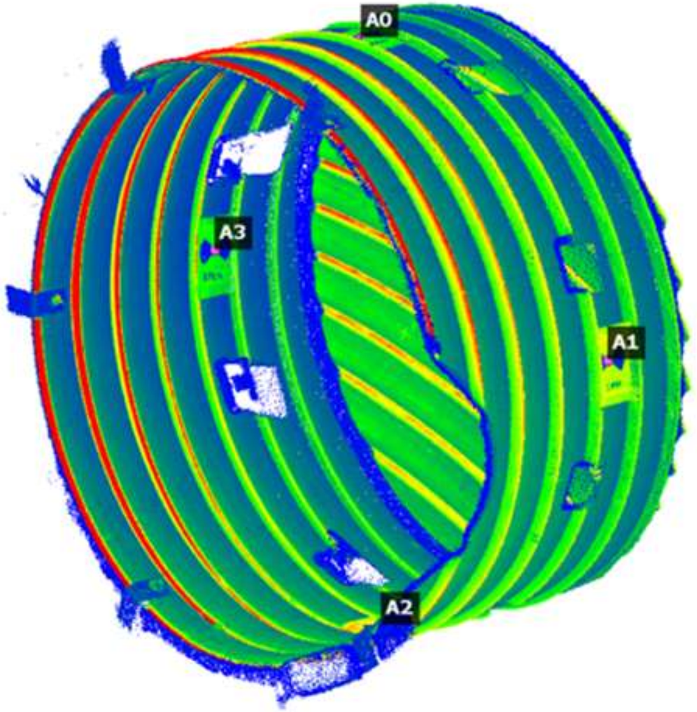


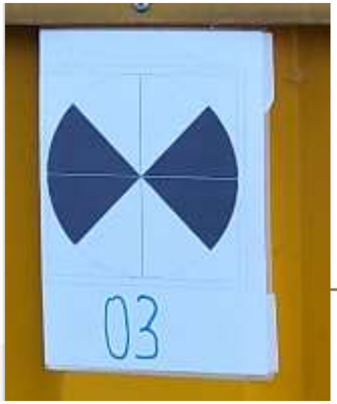
Schematic of tank bottom with numbering of control points

Development of TLS data

The point cloud orientation process was performed using Leica Cyclone Register360 software. The mutual orientation of the acquired point clouds was performed on the basis of automatic detection of the object’s features, while the external orientation of the entire object to the local state space reference system was performed on the basis of known target coordinates.







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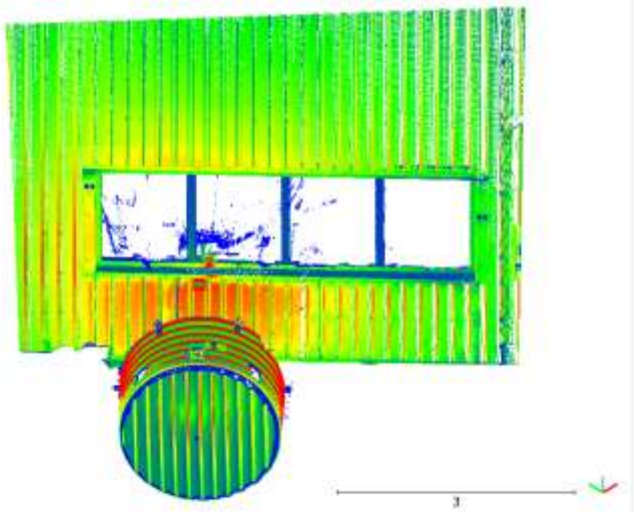
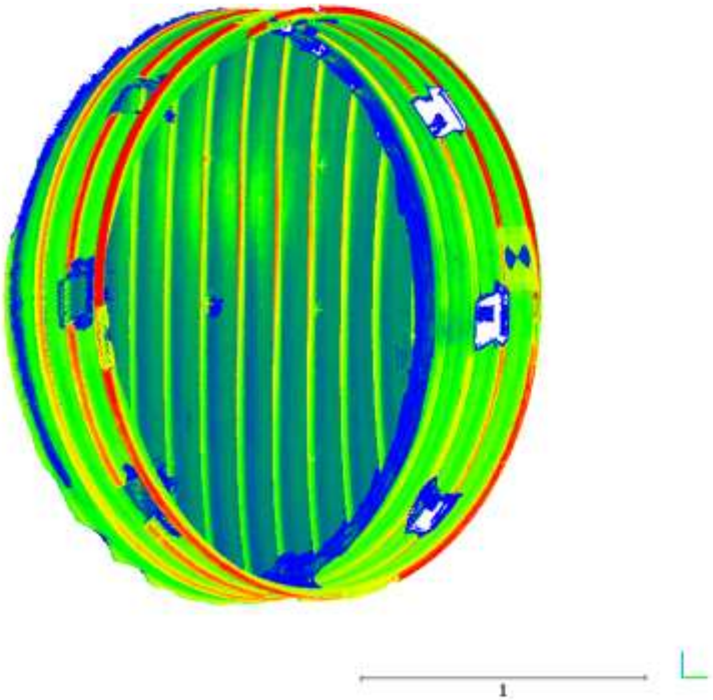
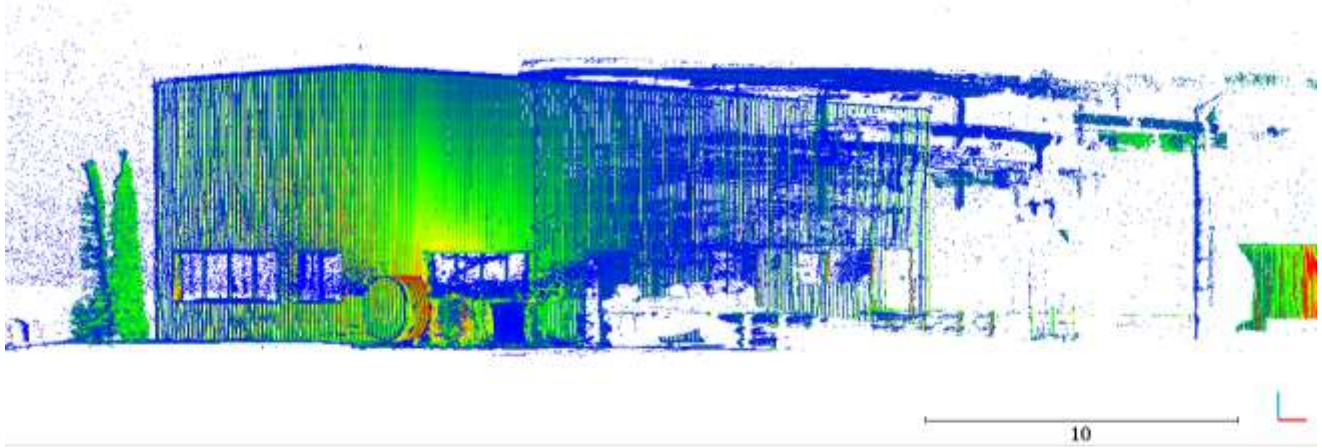
Noise reduction and point cloud filtering







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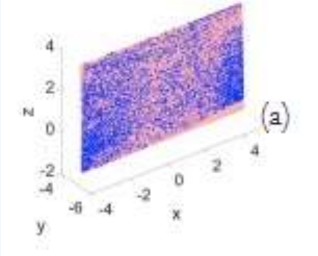
Surface flatness

Reliably fitting a plane to a point cloud requires an assessment of the accuracy of the fit.

	Plane fit
Diagram	
Equation (vector form)	(p-p_0)*n=0, where n=(nx, ny, nz) is the normal vector of the plane, p_0=(x_0, y_0, z_0) is a point on the plane, p=(x, y, z) is a point in the point cloud
Equation (Cartesian form)	Ax+By+Cz+D=0

Parameters for fitting a plane to a point cloud Ye et al., 2014, 2018)

Evaluation of the accuracy and quality of the fit can be made based on the global plane fitting error - e_a (1). For an extracted plane containing M data points, the plane-fitting error is given by:

$$e_a = \sqrt{\frac{\sum_{i=1}^{M} d_i^2}{M}} \qquad (1)$$

where d_i is the distance from the i^{th} data point to the plane.

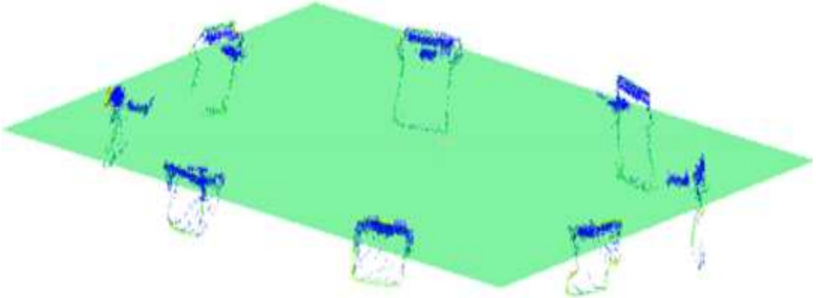
One publication also proposes evaluating the accuracy of the plane fit based on the formula for the distance of a point from the plane (2).

$$e = \frac{Ax_i+By_i+Cz_i+D}{\sqrt{A^2+B^2+C^2}} \qquad (2)$$

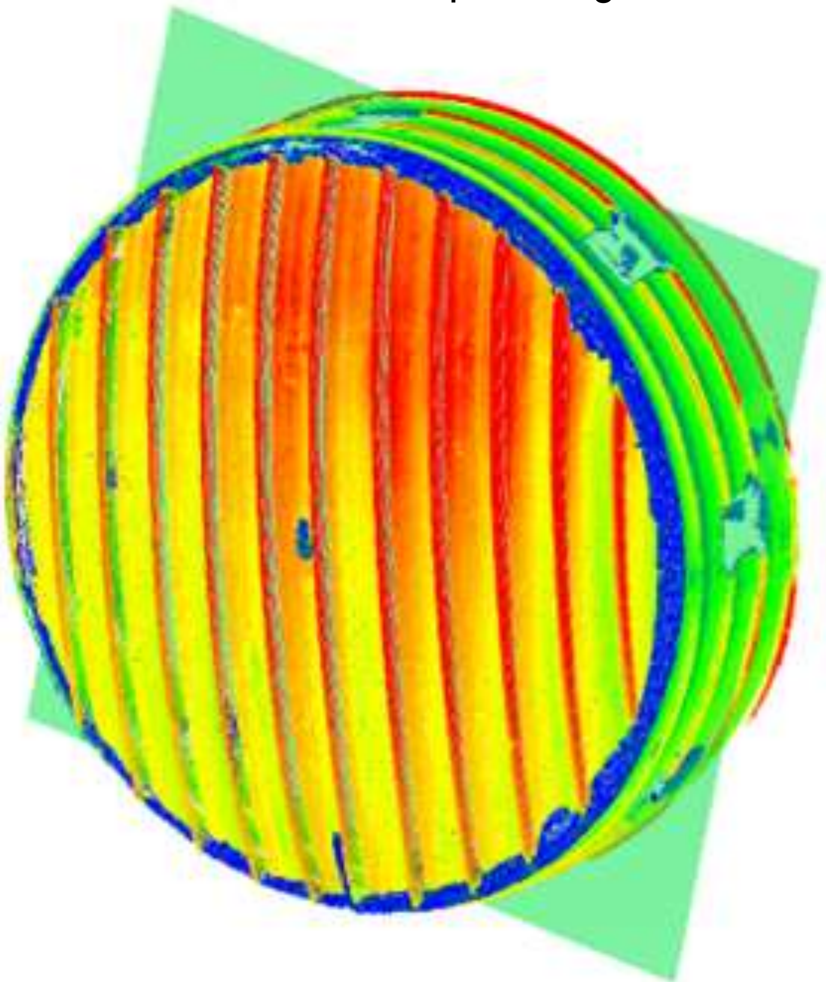
where e – point position error
A, B, C, D - parameters of the plane equation in Cartesian notation
x_i , y_i, z_i - point in the point cloud

Methodology proposed for determining the distance of points from the fitted plane

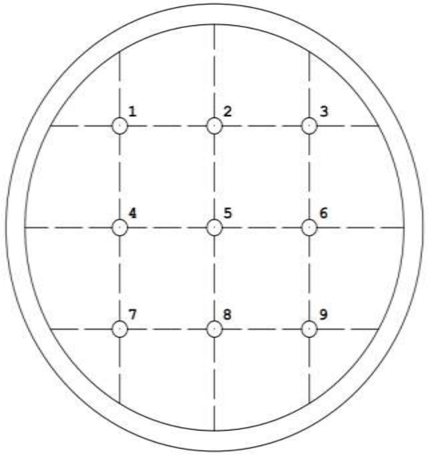
View of the fitted plane on the basis of the bottom elements (handles)



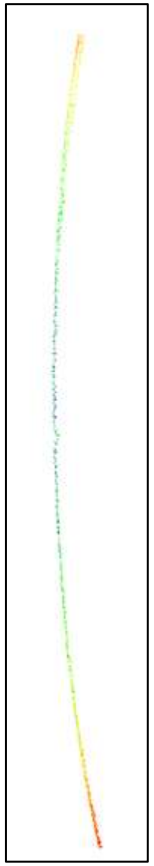
Side view of the fitted plane against the tank bottom



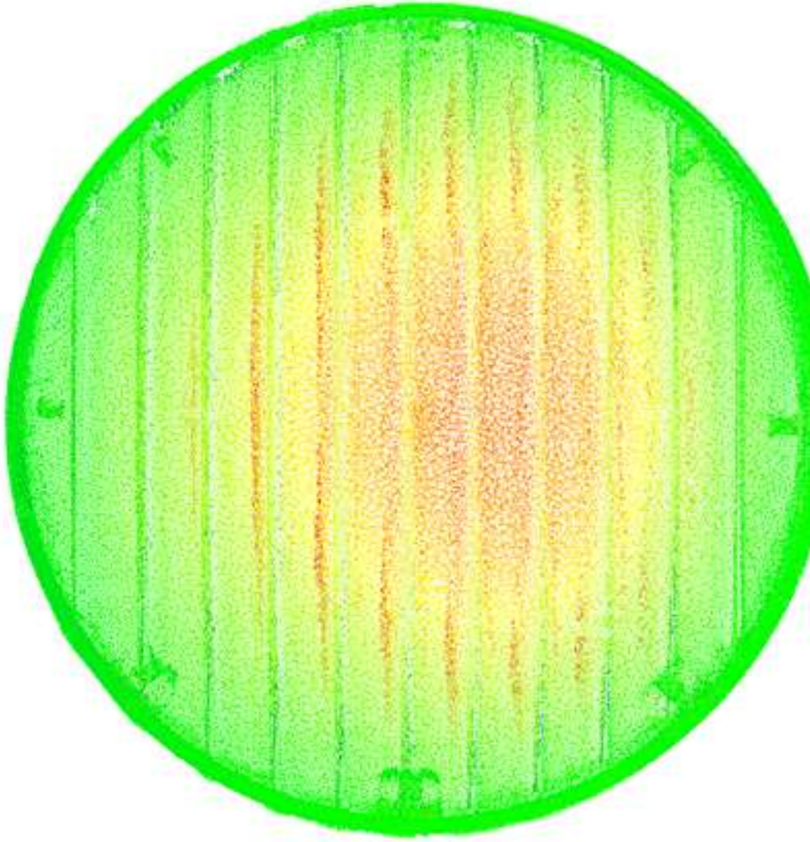
Results: Numerical values of changes



Tank bottom		Distances of points from the plane [m]		Changes in the distance between states [m]
		"1"	"2"	"1-2"
Number points	1	0,4320	0,4582	**0,0262**
	2	0,4405	0,4909	**0,0504**
	3	0,4049	0,4488	**0,0439**
	4	0,4665	0,5052	**0,0387**
	5	0,4558	0,5283	**0,0725**
	6	0,4280	0,4894	**0,0614**
	7	0,4564	0,4798	**0,0234**
	8	0,4664	0,5129	**0,0465**
	9	0,4455	0,4805	**0,0350**
	10	0,3540	0,3677	**0,0137**
	11	0,4288	0,4294	**0,0006**
	12	0,4285	0,4343	**0,0058**
	13	0,3909	0,3949	**0,0040**



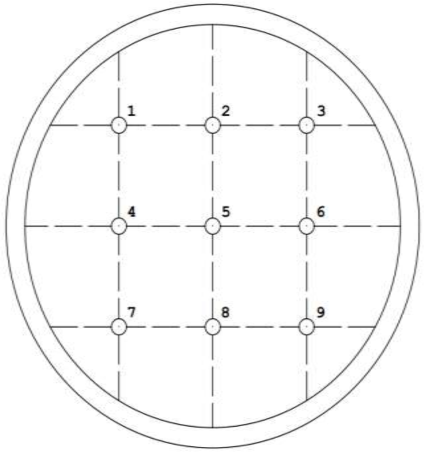
Vertical section



Colour difference map

Comparison results of measurements with terrestrial laser scanning and rangefinder

Tank bottom		Number points												
		1	2	3	4	5 /level	6	7	8	9	10	11	12	13
"1"	Scan	0,4320	0,4405	0,4049	0,4665	0,4558	0,4280	0,4564	0,4664	0,4455	0,3540	0,4288	0,4285	0,3909
	Rangefinder	0,4505	0,4739	0,4205	0,4389	0,4327	0,4095	0,4515	0,4759	0,4484	0,3298	0,3318	0,3379	0,3265
	Differences	-0,0185	-0,0334	-0,0156	0,0276	0,0231	0,0185	0,0049	-0,0095	-0,0029	0,0242	0,0970	0,0906	0,0644
"2"	Scan	0,4582	0,4909	0,4488	0,5052	0,5283	0,4894	0,4798	0,5129	0,4805	0,3677	0,4294	0,4343	0,3949
	Rangefinder	0,4852	0,5238	0,4601	0,4778	0,5022	0,4691	0,4753	0,5210	0,4734	0,3406	0,3363	0,3404	0,3299
	Differences	-0,0270	-0,0329	-0,0113	0,0274	0,0261	0,0203	0,0045	-0,0081	0,0071	0,0271	0,0931	0,0939	0,0650
zmiany „1-2"	Scan	0,0262	0,0504	0,0439	0,0387	0,0725	0,0614	0,0234	0,0465	0,0350	0,0137	0,0006	0,0058	0,0040
	Rangefinder	0,0347	0,0499	0,0396	0,0389	0,0695	0,0596	0,0238	0,0451	0,0250	0,0108	0,0045	0,0025	0,0034
	Differences	-0,0085	0,0005	0,0043	-0,0002	0,0030	0,0018	-0,0004	0,0014	0,0100	0,0029	-0,0039	0,0033	0,0006



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CONCLUSIONS (1)

- Verification of the predictions of the behavior of objects under a simulated load is often performed to select materials and geometric conditions of the objects
- A methodology is proposed for determining the deformation of the bottom of a prototype liquid tank using data from terrestrial laser scanning TLS

- Fitting the plane to all the measured points, according to the definition of the method of least squares, will minimize the distances of the points from the plane, and thus show the trend of changes, but not their actual values.

Spatial projection of a point cloud to the lateral of the cylinder

The function implemented in CloudCompare software was used, built on the basis of the Automatic RANSAC Shape Detection method with Schnabel's modifications (Schnabel et al., 2007).

5 basic parameters
the minimum number of points defining a given shape
the parameter e - the maximum distance of a point to the analyzed model
the parameter b - the resolution of the point cloud
the parameter a - the maximum deviation of the best fitted cylinder shape with respect to the normal vector (expressed in degrees)
the probability parameter

We performed a number of tests to select the most optimal parameter values = **the best-fitting cylinder model.**

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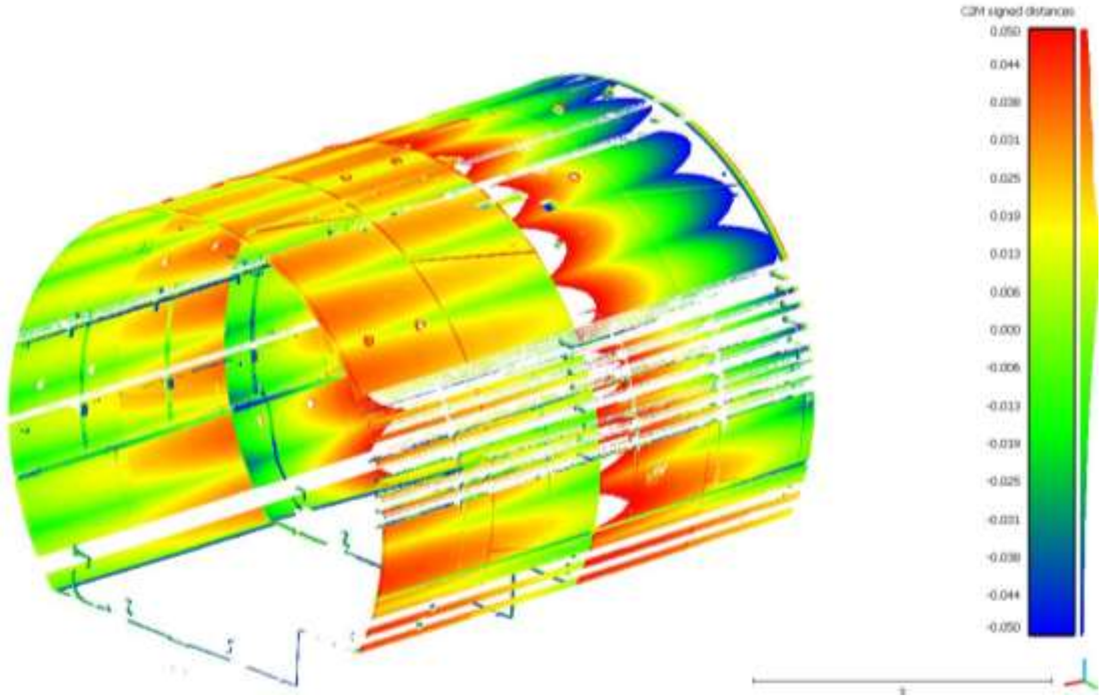
Relation of the initial point cloud to the cylinder model (C2M)



(Zaczek-Peplinska J., Kowalska M. et al., 2022)

The criteria for the selection of the best solution was to obtain the nominal value of the radius of the ttank casing - 2.7 meters, and to select the largest number of points for the fitting process.

Empirically determined parameters take the following values:

minimum number of points - 500 000,
e = 2cm,
b = 4cm,
a = 25^{o},
overlook probability = 3cm.

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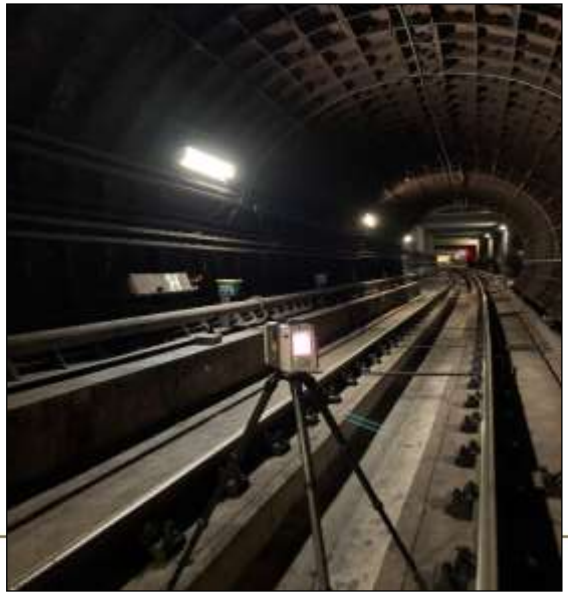
Expansion of the tank \ (or other eg.tunel) surface into a plane

In the next step, the point cloud representing the tank \ tunnel fragment was expanded onto a plane. For this purpose, the unroll function in CloudCompare software was used. Its parameters included:

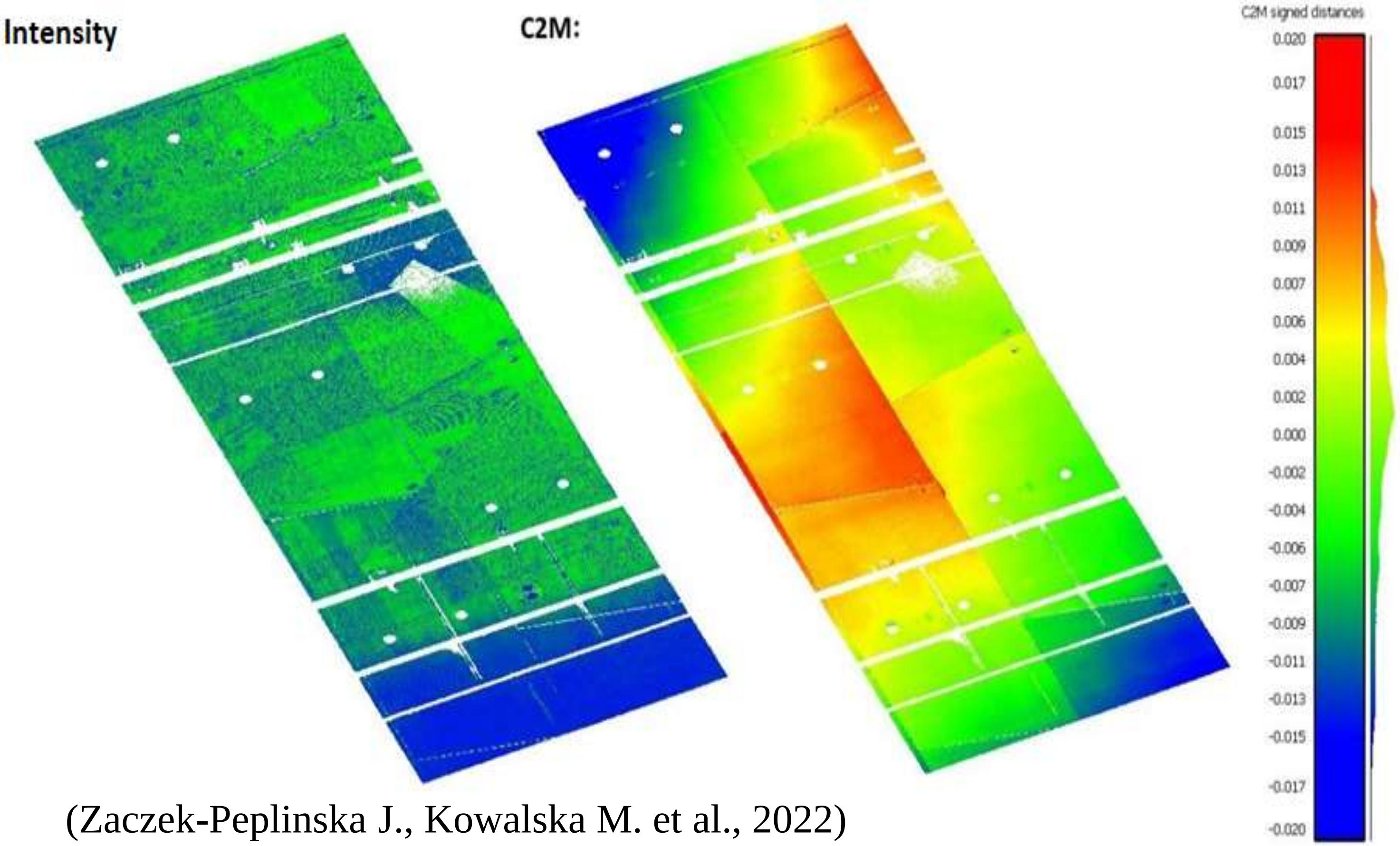
- expansion type,
- the parameter that defines the figure - in the case of a cylinder, it is the radius,
- axis - select the axis around which the expansion is performed,
- base point - which determines the position of the selected axis in space,
- the angle of expansion - determining what part of the cylinder is subject to expansion.

The parameters adopted for the development include the nominal radius value, the angle of development of the whole - from 0 to 360 degrees, and the base point defined as the center of gravity of the cylinder.



Expansion of the tank surface into a plane (as shown in the tunnel surface below)

Expansion results, on the left the expanded point cloud in intensity colors, on the right the analysis of the distance of the points (C2M algorithm) from the fitted plane based on the least squares method.



(Zaczek-Peplinska J., Kowalska M. et al., 2022)

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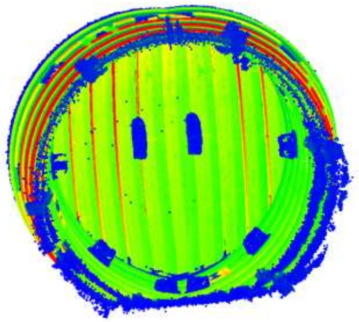
CONCLUSIONS (2)

The aspect concerned analysis of the surface deformation mapped with cylindrical unfolding of a tank / tunnel. We proposed to perform an expansion of the scanned surface into a plane so that it will be easier to represent the changes, and it will be possible to apply the conclusions drawn from the analysis of the plane.

The methods of flatness analysis and deformation assessment proposed are applicable to many tasks in the field of engineering geodesy performed at a construction site, with their results and interpretation having a real impact on the safety measures and construction works. In our opinion, increasing the reliability of analysis results is very important to ensure the different objects safety.



Thank you for your attention,
if you have questions please contact me:

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