Determination of Deformations of a High-Capacity Tank Using the Technology of Terrestrial Laser Scanning

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Abstract

The paper deals with the use of terrestrial laser scanning for a special industrial application, namely the determination of a deformation extent of high-capacity tank. Due to the fact that this technology can be characterized by a high speed of spatial data collection and high accuracy, we used it to determine deformations of the high-capacity tank of aromatics – oil, which was damaged in premises of the refinery in Eastern Slovakia. Calculations of deformation were performed using the CloudCompare software.

Keywords: terrestrial laser scanning, deformation analysis, high-capacity tank

1. Introduction

Storage tanks are a part of our daily lives although we do not encounter them directly. Their use is associated with every refueling of motor vehicles. A direct connection with the environment is the reason why the emphasis is placed on checking the tank, since any small leaks or penetration of hazardous substance into soil can cause huge environmental disaster with consequences for many organisms. For this reasons, the emphasis is placed on the execution of inspections during manufacture and operation of tanks [9].

An accurate geodetic survey of deviations of body shapes and deviations of their spatial position is performed by surveying methods, mainly by surveying using electronic total stations [7], but also by photogrammetry and terrestrial laser scanning.

2. The Subject of Survey

In the complex of Východoslovenskárafinéria, s.r.o., (distillation unit Senné) the survey of deformation extent was realized in June 2013. In order to change stored media, the tank was filled with hot water to a height of 2 meters in 2012. The main objective was the removal of sediments and residues of aromatics in the storage unit. After filling, the tank was hermetically sealed while there was a decrease of pressure due to condensation, leading to a collapse – the implosion of the tank caused by a violation of technological procedure. The tank was filled with water to a height of about 4 meters. The Fig. 1 and 2 shows the state of the tank after filling with water and places of water leak through cracks, incurred by the weakening of plastically deformed material, and are clearly visible.

By a subsequent control, also the anchorage of tank was documented and it was found that rips at three places were caused by the implosion. Material of the inner wall is damaged, but welded joints do not show damage. During the visual inspection of the tank in September 2012, the sample for metallographic study was taken and an ultrasonic thickness measurement was performed together with marking points of measurement. We have found the state of corrosion loss, which is not higher than 2%.

3. Geodetic Survey of the High-Capacity Tank Deformation

Geodetic survey of the tank deformation was realized in June 2013 by terrestrial laser scanning using the Leica ScanStation C10 (Fig. 3, Tab. 2), that is a high-speed, full-panoramic pulse scanner. Because the tank deformation had to be measured from its interior, the spatial position of points was determined in a local coordinate system, with the origin at the center of the scanner at the first scanning station. For their calculation, the following equations (1, 2, 3) [6, 10] were used, where d is a slope distance, ω is a horizontal angle and ζ is a zenithal distance. The Leica ScanStation C10 can described as a pulse full panoramic long-range scanner with the mean error of position determination 6 mm and distance measurement 4 mm. Density of the scanning grid was set to 2x2 mm so that the measured data represent the scanned surface as accurately as possible [3, 4].

Spatial coordinates of surveyed points were calculated on the basis of mathematical relations (1) to (3) in the Fig. 4, where ω is the measured horizontal angle, ζ is the measured vertical angle of single point and d is the measured slope distance [6,8,10].

$$x= d.\cos(\omega).\sin(\zeta) \quad (1)$$
$$y= d.\sin(\omega).\sin(\zeta) \quad (2)$$
$$z= d.\cos(\zeta) \quad (3)$$

The real errors of measurement ε can be determined based on the following relations [1,5,8,11]:

$$\varepsilon_x = \cos(\omega) * \sin(\zeta) * \varepsilon_d - d * \sin(\omega) * \sin(\zeta) * \varepsilon_\omega + d * cos(\omega) * \cos(\zeta) * \varepsilon_\zeta \quad (4)$$
$$\varepsilon_y = \sin(\omega) * \sin(\zeta) * \varepsilon_d + d * \cos(\omega) * \sin(\zeta) * \varepsilon_x + d * sin(\omega) * \cos(\zeta) * \varepsilon_\zeta \quad (5)$$
$$\varepsilon_z = \cos(x) * \varepsilon_d - d * sin \cos(\zeta) * \varepsilon_\zeta \quad (6)$$

The surroundings of damaged tank, which does not enter the processing, was also surveyed for the needs of visualization (Fig. 5).

Approximately 54,157 mil. points, which were used in processing, were obtained by field survey from two survey station inside the tank (Fig. 6). The object was scanned with a density 2x2 mm, in order to capture all deformations of the inner wall of tank to the maximum possible extent (Fig. 5 and 6). The resulting surveyed deformations are shown in the Fig. 7 and 8.

In order to determine the size of tank deformation, it was necessary to determine dimensions of the reference undamaged object. Since there were not available accurate manufacturing parameters of the tank, we obtained them graphically by modelling the top and bottom centering, for which we did not expect statistically significant deformations. At the top and bottom centering, we took the point cloud in the cross-section with a thickness of 10 cm, through which we fitted the cylindrical body by approximation.

4. Calculation of the Deformation Size

The final graphic interpretation to determine the extent of deformation due to the implosion was done in a graphical environment of the CloudCompare software. Displayed deformation significantly exceeded the visible extent of deformation from the preliminary inspection and it is graphically and numerically shown on the Fig. 9 and in the Tab. 3.

The extreme deviation reached the value of ± 0.147 m, with the hypsometric distribution (Fig. 9). A positive direction of deformation represents the shift towards the inside of the tank (red color display), negative direction of deformation represents the bulge of the tank outwards from the reference object (blue color).

5. Conclusion

In the case of determining deformations of tanks in mechanical engineering, using the methodology of terrestrial laser scanning is innovative, since previously the method of non-prism surveying using electronic total stations was widely used for this type of tasks. Not only the demonstration of position and extent of deformation, but also its numerical expression of shift or bulge of the steel casing represents an important contribution. In the case of massive gaps in the casing, the subsequent localization of the extent as well as identifying errors of welded joints is relatively easy.

Fig. 1: The High-Capacity Tank in the VýchodoslovenskáRafinéria, s.r.o.

Tab. 1: Basic Technical Information about the Tank

The owner	Východoslovenskárafinéria,s.r.o., (distillation unit Senné)
Type of the unit	Tank for a production material
The manufacturer	NAFTA, a.s. GBELY manufactory ÚD
Year of build	1997
Serial number	1386
Operating parameters:	
Maximum operating pressure	0,05 MPa
Maximum test overpressure	0,6379 MPa
Maximum operating temperature	40°C
Capacity	250 000 L
Working substance	AROMATY 60/90

a) b)

Fig. 2: A) View of Places with the Largest Deformations; B) Display of Rips of the Tank Anchorage

Fig. 3: Terrestrial Laser Scanner Leica ScanStationC10

Tab. 2: Technical specification of Leica ScanStation C10

Technical specification of the laser scanner	
Accuracy of single measurement	
Position/Distance	6 mm/4 mm
Angle precision	
Horizontal/Vertical	12″ / 12″
Modelled surface precision	2 mm
Range	300 m @ 90%; 134 m @ 18%
Minimal step of scanning	1 mm
Scan rate	50 000/sec.
Laser class	3R, green (λ = 532 nm)
Spot size	0-50 m ≈ 4,5 mm
Field of view	
Vertical/Horizontal	270°/360°

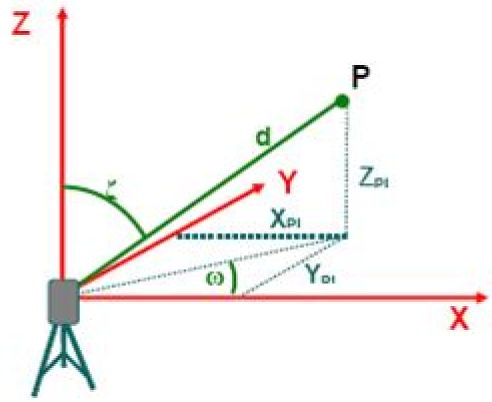

Fig. 4: The Principle of Spatial Polar Method [8,5]

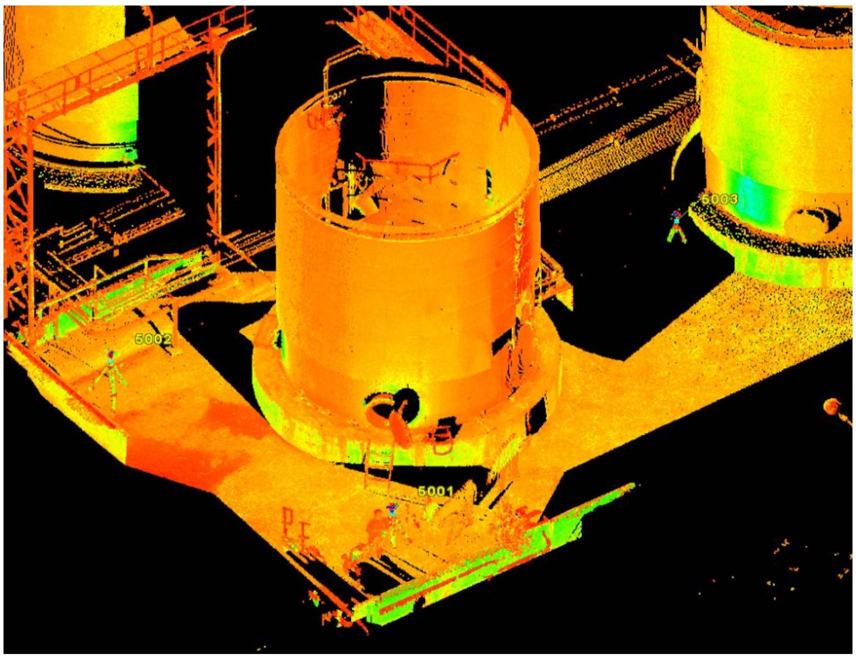

Fig. 5: Point Cloud of the Scanned Tank

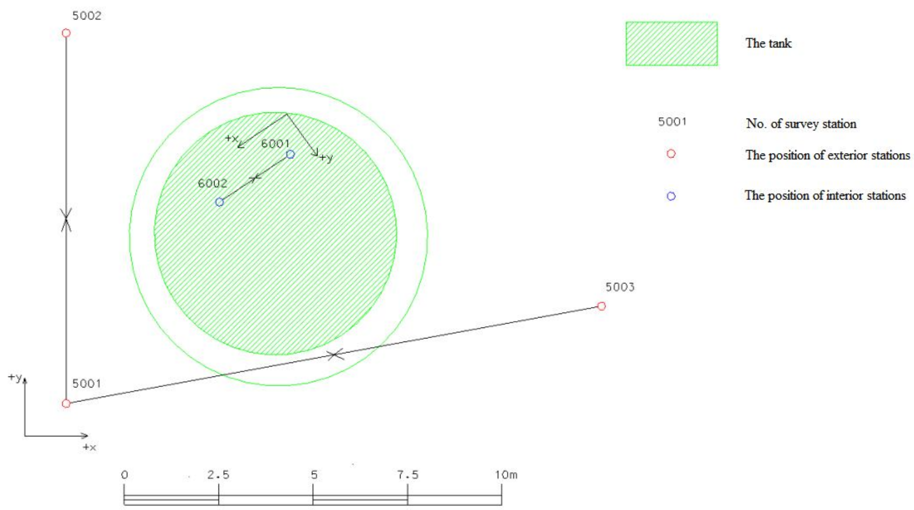

Fig. 6: Situation of the Field Survey

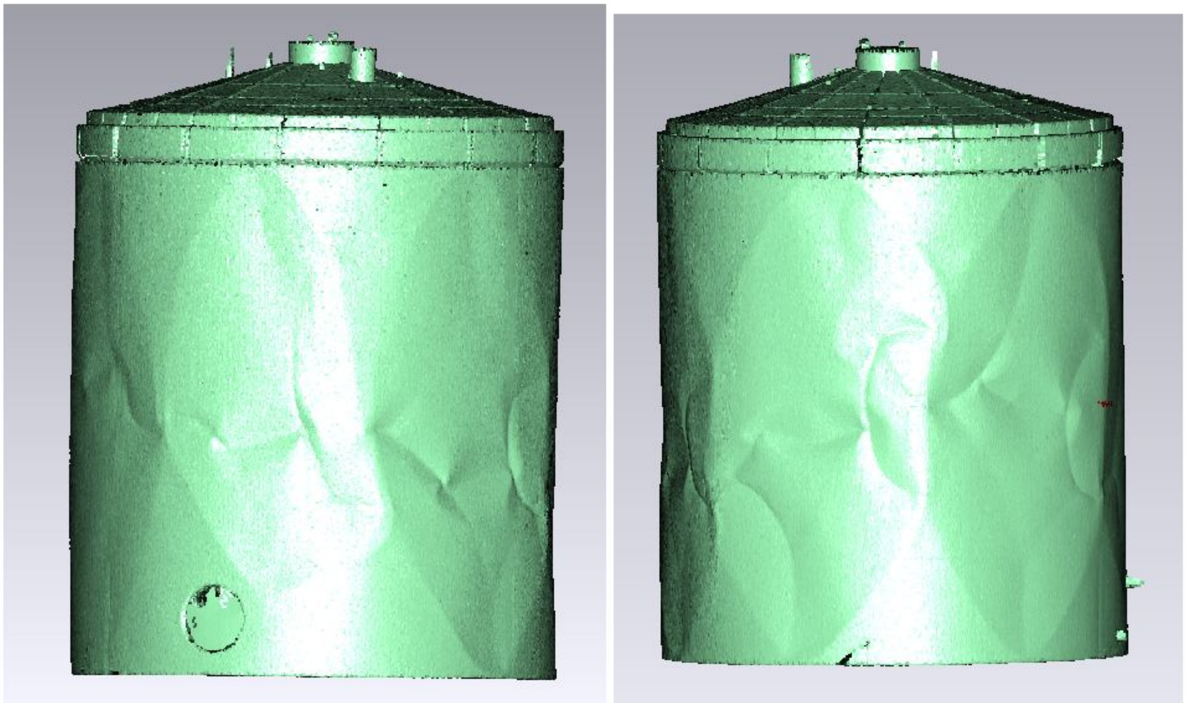

Fig. 7: Point Cloud of the Surveyed Inner wall of the Damaged Tank

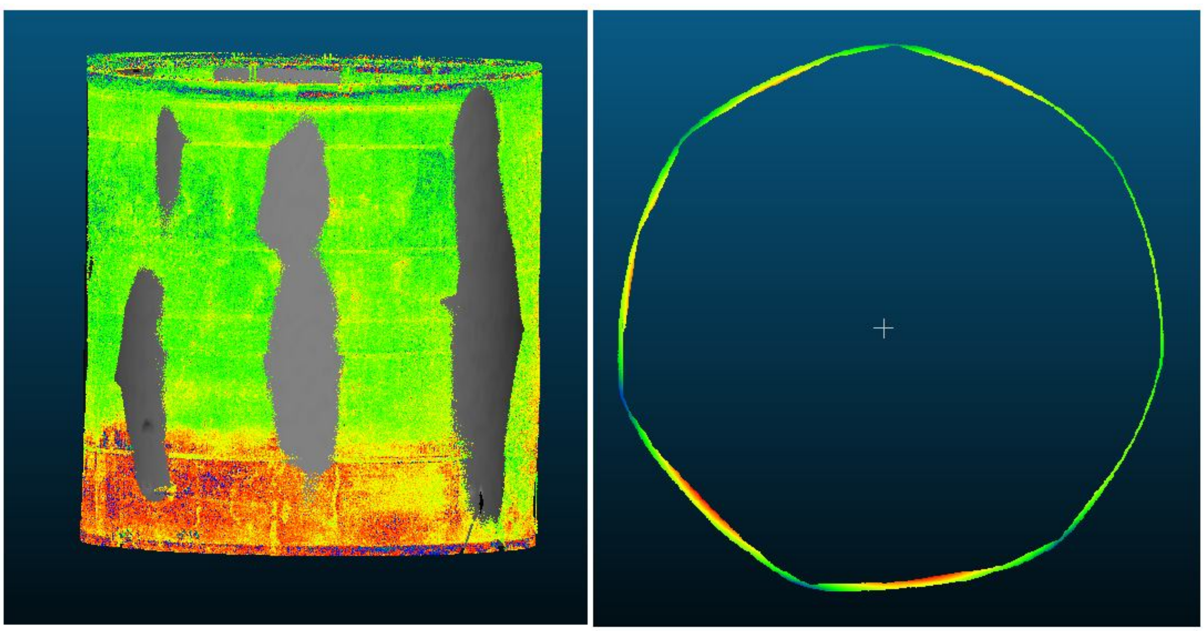

Fig. 8: Identified Point Clouds of the deformed wall and the Reference Surface

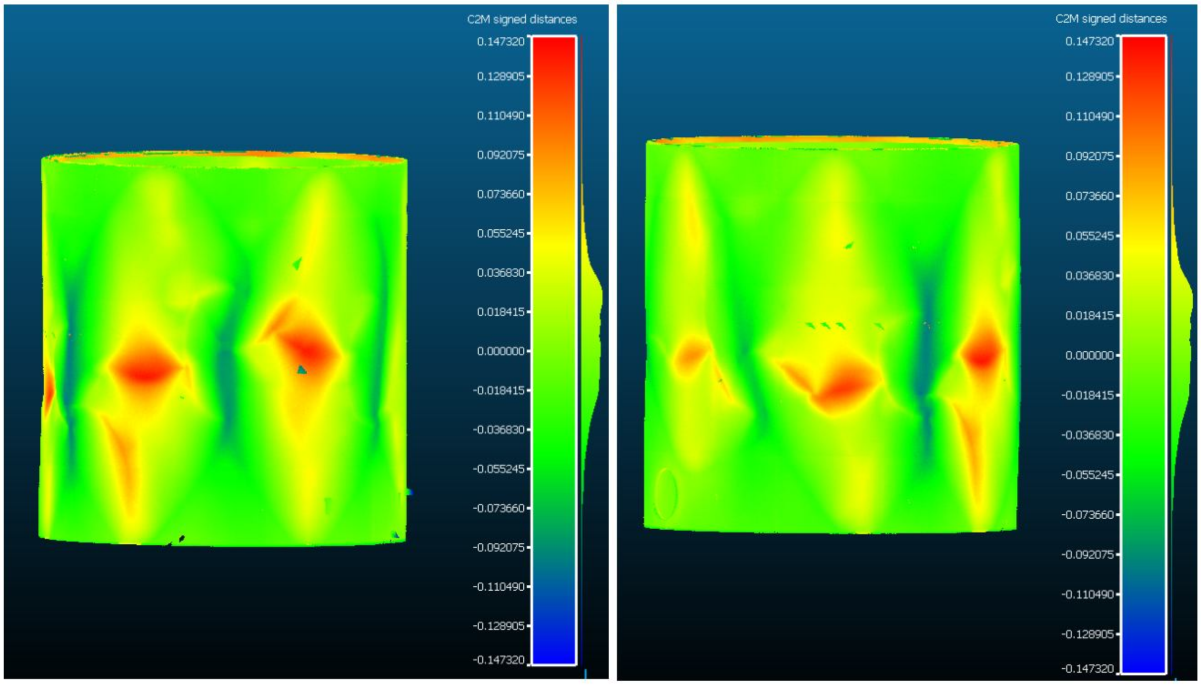

Fig. 9: Graphical Representation of Determined Deformations in the CloudCompare Software

Tab. 3: The Numerical Representation of the Tank Deformation

Peak No.	Height of the cross-section from the bottom [m]	Direction of the deformation	Graphically determined deviation in the CloudCompare [m]
1	2.50	-	< –0.110, –0.128 >
2	2.20	+	< 0.128,0.147 >
3	3.03	-	< –0.128, –0.147 >
4	3.25	+	< 0.092,0.110 >
5	3.50	-	< –0.092, –0.110 >

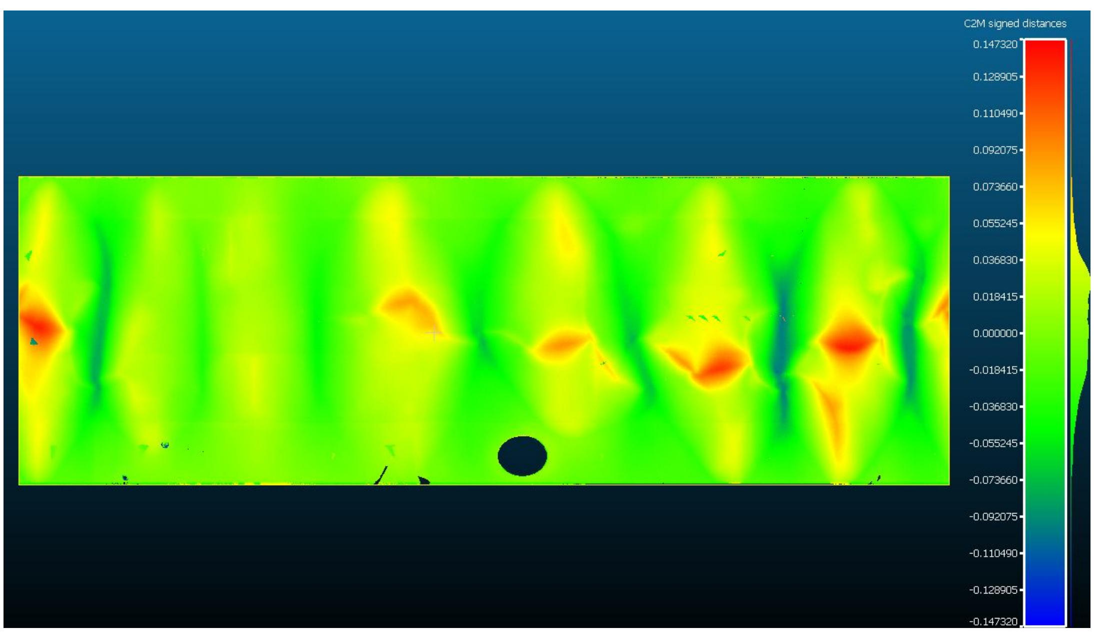

Fig. 10: Unrolling the Deformed Cylinder Surface to the Plane

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