RESEARCH PAPER

Optimizing the desktop processing of the terrestrial laser scanning data in assessing the stress-strain state of tanks

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ARTICLE INFO

Received: *12 February 2019*
Accepted: *22 May 2019*

ABSTRACT

The paper deals with optimizing the desktop processing of the tanks' terrestrial laser scanning data in assessing their stress-strain state (SSS). The basic concepts to optimize the desktop processing are established and analyzed, thus providing the means to reduce the spent resources and time of PC work without losses to the final result of the tanks' SSS assessment.

Key words: vertical steel tank (VST), terrestrial laser scanning, stress-strain state (SSS).

INTRODUCTION

When determining the residual service life of the tank, strength analysis of its structural elements is performed. Such analysis is recommended to be carried out by 3D-simulation using software products that use the finite element method [1, 2]. In order to improve the monitoring efficiency of engineering structures' technical condition, the terrestrial laser scanning technology is used for more than 12 years in domestic and international practice [1].

The terrestrial laser scanning is a logical continuation of the electronic tacheometer's development and enables the operator to obtain in the automated mode the complete information about the surface of the scanned object [2, 3]. By their main purpose, terrestrial laser scanners are purely topographic devices. However, the accuracy of the point coordinates measurement and the high resolution of the latest generations of terrestrial laser scanners open the potential for their wide application as inspection instruments in assessing the technical condition of storage tanks for oil and petroleum products [3, 4].

The data obtained as a result of the terrestrial laser scanning (hereinafter – laser scanning), generate the basis for constructing the 3D model of the tank surface, with regard to its real geometric shape, suitable for the analysis of its stress-strain state (SSS) using specialized software packages employing the finite element method [4]. The results of such analysis reflect the real picture of the tank's SSS, since the original 3D model is constructed with regard to the actual geometric shape and spatial position of the tank [5-8].

At the same time, optimization of methods for desktop processing of the tank laser scanning data to obtain its 3D model becomes actual. This is explained by the need to allocate significant resources and time of the personal computer, spent on the desktop processing of the entire array of data obtained by laser scanning of the tank. Thus, depending on the selected method of scanning and the resolution of the laser scanner, the total point cloud of the 20,000 m^3 tank surface may consist of more than 20 million points. Moreover, higher laser scanning resolution multiplies the arrayed data and necessitates the use of much more powerful personal computers [5].

In order to solve the issue of optimizing the desktop processing method of tanks' laser scanning data, it is necessary to review the main steps of the tank point model

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http://doi.org/10.28999/2514-541X-2019-3-2-112-117

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[2] RD-23.020.00-KTN-141-16. 'Trunk pipeline transportation of oil and petroleum products. Rules of tanks inspection'.
[3] RD-23.020.00-KTN-017-15. 'Trunk pipeline transportation of oil and petroleum products. Laser scanning of tanks. General provisions'.
[4] OR-23.020.00-KTN-065-16. 'Trunk pipeline transportation of oil and petroleum products. JSC 'AK Transneft' technique of monitoring the geometrical parameters of the tanks using the method of terrestrial 3D laser scanning in the construction and repair'.

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Tank	Triangle height *h*, mm	Triangle area, mm^2	Required number of triangles
VSTP-20000 D=45 600 mm H=12 000 mm	15	129.9	13227159
	25	361	4759579
	50	1443	1190719
	100	5773	297628
	150	12990	132272
	200	23094	74401
VSTPA-50000 D=60 700 mm H=18 000 mm	15	129.9	26410808
	25	361	9503501
	50	1443	2377522
	100	5773	594277
	150	12990	264108
	200	23094	148557

Table 1. *Data for work in Geomagic Studio.*

Tank	Belt #	Actual plate thickness, mm	Height of belts, m	Tank innage level, m	Roof weight, kg	Product density, kg/m^3	Steel density, kg/m^3
VSTP-20000	1	12.3	1.5	11.4	109000	900	7850
	2	10.4					
	3	10.4					
	4	10.3					
	5	10.4					
	6	10.4					
	7	10.3					
	8	10.5					
VSTPA-50000	1	27.5	2.25	16.974	90000		
	2	24.0					
	3	20.0					
	4	18.0					
	5	18.0					
	6	16.2					
	7	16.0					
	8	14.0					

Table 2. *Data for estimation in Ansys.*

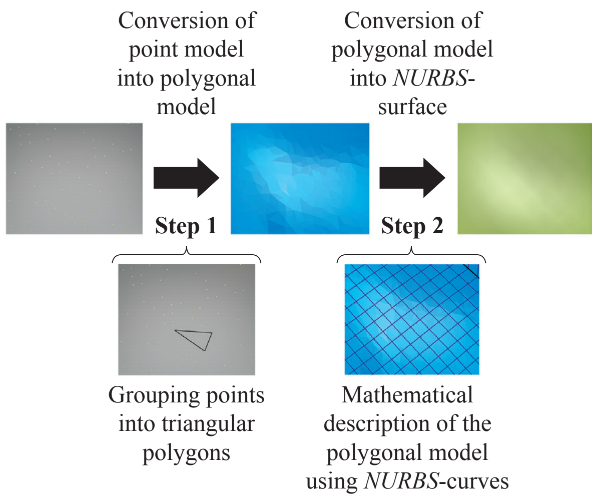

***Figure 1.** The procedure of converting a point model into a 3D mathematical model.*

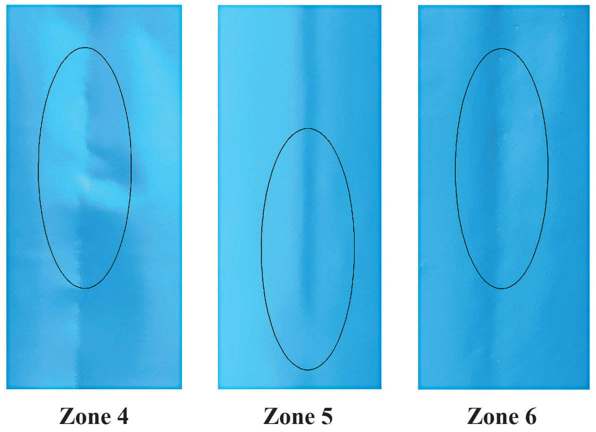

***Figure 2.** Zones selected for the analysis of changes in surface equivalent stress of VSTP-20000 tank.*

(as the initial result of laser scanning) conversion into a 3D model suitable for the analysis of SSS in specialized software packages. In general case, two main steps of this conversion may be identified (Fig. 1) [9]:

1. Conversion of the tank point model into 3D polygon model. At this step, the points forming the surface of the tank are combined into a polygonal network consisting of flat triangular polygons. At the same time, only a part of the available points can be used to form a polygonal model. The resulting polygonal model of the reservoir is not yet suitable for further assessment of its SSS, because it has a non-organic shape (with sharp edges);
2. Conversion of the polygonal model to a *NURBS*-surface (*Non-Uniform Rational B-Splines*). At this step, the polygonal model of the tank surface is described mathematically using a set of NURBS-curves (inhomogeneous rational *B*-splines), the population of which forms the *NURBS*-surface. The resulting *NURBS*-surface is a 3D shell model suitable for export to specialized software packages in order to assess the tank's SSS.

Analysis of the steps in the initial tank point model's conversion process indicates that the desktop processing optimization is possible at the step of converting the point model of the tank surface into the polygonal model. Using only a part of the points in the point model to obtain a polygonal model (i.e., using smaller number of triangular polygons to build a polygonal model than their theoretically possible number) will enable the operator to reduce the further volume of the processed data, time and resources spent on desktop processing. At the same time, such a step can lead to significant distortions of the actual geometric shape of the tank surface and, as a consequence, distortions to the results of its SSS assessment.

So, the issue of maximum reduction of the processed dataset volume at the step of the point model conversion into the polygonal model with no critical damage for the end result of the tank SSS assessment becomes important. This paper covers the solution to this issue.

Initial concepts and data for simulation

To evaluate the number of triangle polygons (hereinafter – triangles) needed for polygonal approximation of the tank wall surface point model without 'damage' to final results of SSS assessment, the concept was accepted that the point model can be approximated by the identical equilateral triangles. The height of triangles *h* was considered as the evaluation factor of their size (and, as a consequence, of their number).

This height *h* also enables to judge on the minimum necessary resolution of the tank surface laser scanning for its SSS assessment. Potentially, this will not only optimize the process of desktop data processing, but also can reduce the time of field work when scanning the tank surface.

Surface modeling and further estimation of SSS were carried out at different values of the approximating triangles height *h* (*h* = 15, 25, 50, 100, 150, 200 mm) for the walls of two tanks: VSTP-20000 with significant geometric defects, and VSTPA-50000, without significant geometric defects. For the example considered in this paper, the terrestrial laser scanning results were desktop-processed using the non-commercial version of the *Geomagic Studio* software package (it is possible to use other similar software, such as *Geomagic Design X, 3DReshaper, Trimble RealWorks*, etc.), and the tank SSS assessment was performed in the non-commercial version of *Ansys* software package.

Initial data (the required number of approximating triangles) to work with the tank point models in Geomagic Studio software are shown in Table 1.

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The initial data for tanks SSS calculation in *Ansys* software are shown in the Table 2.

Simulation in *Geomagic Studio* software

At all steps of simulation, point models of the tanks VSTP-20000 and VSTPA-50000 surfaces were subjected to the same desktop processing.

The difference was only in the number of triangles used in the polygonal approximation of tank surfaces point models that was taken according to Table 1.

Parameters of additional processing of tanks' polygonal models and also the parameters of polygonal model's transformation into shell surfaces (*NURBS*-surfaces) are presented in the Table 3 in a sequence of the processing performed.

The resulting shell models of tank surfaces were exported to *Ansys* software in the *.igs* format. The selection of this format for export is due to the fact that it was specifically designed to exchange 3D-models between various *CAD/CAE* – systems and is the most common [5].

Simulation in *Ansys software*

Ansys Workbench software was used to calculate SSS.

Additional processing of tank models in *Ansys* was not carried out, except for the walls breakdown into rings. When calculating the wall's SSS, the following loads were considered (Table 2):

- the hydrostatic pressure of the product;
- the net weight of the wall (using the actually measured thicknesses according to the results of technical inspection);
- the roof weight (the weight of the roof was transferred to the wall in the form of a distributed load; the roof is not shown in the figures for clarity).

Shell 181 was used as the finite element (maximum size of the finite elements is 10 cm). The thrust block was considered as an anchorage, and 20x20 cm square beam was used as a stiffness element to simulate the work of the upper part of the wall [10].

SSS estimation was performed in the non-linear geometric setting.

Criteria for comparison and analysis of the simulation results

The main evaluation criterion for comparison and analysis of the simulation results for 3D models of tank surfaces with different number of triangles used in the polygonal approximation of point models was the nature and magnitude of changes in SSS of tanks.

Comparison of the simulation results and analysis of the changes in SSS of the tank wall was carried out for midplane and surface equivalent (von Mises) stresses compared to the surface model at *h* = 15 mm, with regard to:

- changes in the overall picture of the effective stress distribution in the wall of tanks at various *h*;
- changes of the effective midplane and surface stresses in selected zones (three zones were considered for each type of stress: zones 1–3 and 4–6 in VSTP-20000 for midplane and surface stresses; zones 7–9 and 10–12 in VSTPA-50000, respectively).

The choice of equivalent von Mises stress as a criterion for analysis of changes in tank's SSS is explained by the fact that this stress is the most suitable for the assessment of complex stress state of the tank wall with regard to the deviations of its geometry from cylindrical shape (in the form of dents, bulges, angularity) and the deviation of its spatial position from the design. In this case, the equivalent von Mises stresses are determined by the formula:

$$\sigma_M = \sqrt{\frac{1}{2}\left(\left(\sigma_1 - \sigma_2\right)^2 + \left(\sigma_2 - \sigma_3\right)^2 + \left(\sigma_3 - \sigma_1\right)^2\right)}, \qquad (1)$$

where $\sigma_1, \sigma_3, \sigma_3$ – principal stresses.

The selection of individual zones to analyze changes in the effective midplane and surface stresses at different heights *h* of the approximating triangles was carried out on the basis of the following criteria:

- the maximum stress of this type is acting in the zone at *h* = 15 mm;
- there are major tank geometry defects in the zone (dents, bulges, angularity, etc.).

In particular, Fig. 2 shows zones 4, 5 and 6 of VSTP-20000 tank selected for the analysis of changes in surface equivalent stress. These areas correspond to the maximum local deviations of the tank surface from the correct geometric shape.

Simulation results

An example of the results for midplane equivalent stress evaluation in VSTP-20000 tank wall at *h* = 15 mm and *h* = 200 mm is shown in Fig. 3 and 4.

As a result of the simulation, it was found that the increase in the size of the triangles used in the polygonal approximation of the tank point model (decrease in the number of triangles) leads to the following:

1. Gradual decrease in the overall level of the midplane and surface stress acting in the tank wall, which is explained by the model's geometry gradual approaching to the cylindrical shape as and when the number of approximating triangles decreases. This can be seen in zones 1, 3, 7, 8 (Fig. 5) and 5, 6, 10, 11, 12 (Fig. 6);
2. Gradual increase of the maximum stress zone size in the tank first-ring wall is explained not only by a

[5] ASTM E2807-11 Standard Specification for 3D Imaging Data Exchange.

	Triangle height *h*, mm	Triangle area, mm²
1. Noise reduction	Form	Free form shapes
	Smoothness level	Maximum
	Deviation limit	0.003 mm
2. *Wrap*	Number of triangles	Per Table 1
3. Smoothing	Smoothness level	8
	Force	8
	Priority of curvature	2
4. Carcass defects removal	-	-
5. *AutoSurface*	Geometry type	Organic
	Surface detail	Maximum
	Custom tolerance	0.001 mm

Table 3. *Additional models processing in Geomagic Studio package.*

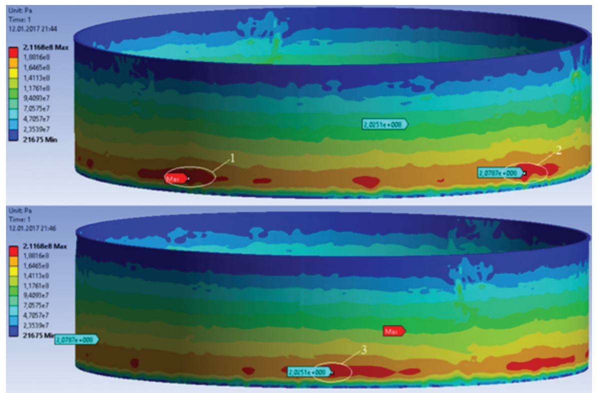

Figure 3. *Midplane equivalent stress in VSTP-20000 tank wall at h = 15.*

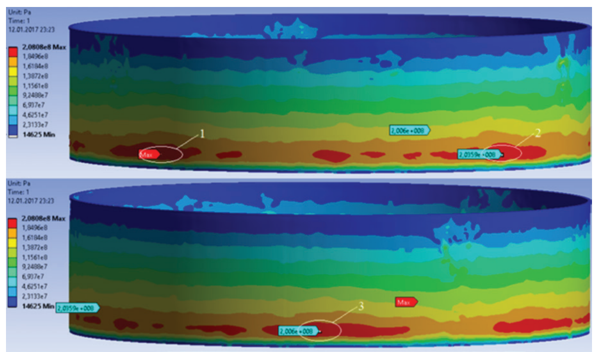

Figure 4. *Midplane equivalent stress in VSTP-20000 tank wall at h = 200 mm.*

decrease in the values limiting the zone of maximum stress (visual component of the simulation results presentation), but also by a slight increase of stress in certain zones compared to the initial values. Thus, at h = 200 mm the action point of the maximum midplane stress shifts to a new region and the stress increases by 4 MPa in VSTPA-50000 tank;

3. Local features of the tank wall surface geometry cease to have a significant impact on the change of SSS pattern at h = 100 mm and more. Only the largest defects with complex geometry (zones 2, 7 in Fig. 5 and zones 4, 5, 7 in Fig. 6) have an impact on a significant change in SSS pattern);
4. Change in the size of the approximating triangles has a negligible impact on variations of the median equivalent stress (stress decrease does not exceed 5%). However, the change in the size of the approximating triangles has a significant impact on variations of surface equivalent stresses (stress decrease attains 20% at h = 200 mm) in the areas with the largest defects of geometry, as can be seen in the example of zones in Fig. 6. Moreover, in some cases there are fluctuating surface equivalent stresses for defects with complex geometry (zone 4).

Findings

Based on the results of the simulation, the following conclusions can be drawn:

1. When passing from the point model to the polygonal approximation of the tank wall surface, the most optimal equilateral triangle, in terms of a personal computer resource and time of operation, has the height h from 50 to 100 mm.
2. The results of this study can be used to determine the dimensions of approximating surface elements in other software packages for processing the laser scanning results and preparing data to calculate SSS of civil engineering structures.

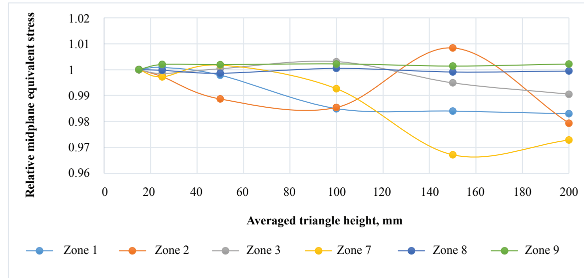

Figure 5. *Relative change of the midplane stress in the tank wall (stress at h = 15 mm is taken equal to 1).*

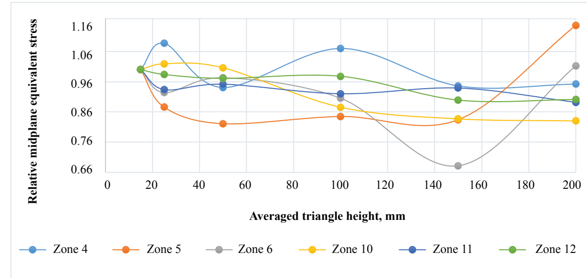

Figure 6. *Relative change of the surface stress in the tank wall (stress at h = 15 mm is taken equal to 1).*

Competing interests

The authors declare that there is no competing interest regarding the publication of this paper.

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To cite: G. G. Vasiliev, A. P. Salnikov, A. A. Katanov, M. V. Likhovtsev and E. G. Ilyin. Optimizing the desktop processing of the terrestrial laser scanning data in assessing the stress-strain state of tanks. *Pipeline Science and Technology*. 2019; 3(2): 112–117. http://doi.org/10.28999/2514-541X-2019-3-2-112-117