TIN MODELING OF CURRENT EARTHWORK VOLUMES DURING EXCAVATION PIT CONSTRUCTION FOR DEFENCE PROTECTIVE STRUCTURE

Ivan Openko[1], Olesia Huretska[1], Oleg Tsvyakh[1], Oleksandr Shevchenko[1], Ruslan Tykhenko[1], Nataliia Kolesnik[1], Viktoriia Paschenko[2]
[1]National University of Life and Environmental Sciences of Ukraine, Ukraine;
[2]Bogomolets National Medical University, Ukraine
ivan_openko@ukr.net, gurlesa1308@gmail.com, 2231738@i.ua, shevchenko_ov90@ukr.net, rvtyhenko@ukr.net, kolesnik.n@nubip.edu.ua, vikaoverchenko8@gmail.com

Abstract. The article considers the use of TIN modeling technology in Autodesk AutoCAD Civil 3D software environment to determine the current volume of earthworks during the construction of a civil defence excavation. Field measurements were performed on the basis of the created geodetic marking network, formed by the GNSS method using GPS points fixed by the Alpha-GEO NetBOX receiver. The main axes of the building were drawn in accordance with the requirements of DBN V.1.3-2:2010 using the Alpha-GEO X (2″) electronic total station, the technical characteristics of which ensured the necessary accuracy of engineering and geodetic works. The removal of marks of the external geodetic network was performed from three standing stations using the circular methods, and the orientation of the total station was carried out using the inverted linear-angular serif method using three coordinated GPS points. To determine the initial topographic surface, a detailed survey of the construction site was carried out after dismantling the landscaping elements on the territory of lyceum No. 183 “Fortuna”, which allowed us to correctly take into account the actual relief before the start of excavation work. Office data processing was carried out in Civil 3D by constructing TIN surfaces based on the results of surveys before and after the excavation. The calculation of soil volumes was carried out using the square method by dividing the territory into a uniform grid and determining the average heights within each square. The calculations reflect the volumes in the dense stage without taking into account the soil loosening coefficient. The results obtained are presented in the form of a cartogram of volumes, which allowed us to assess the accuracy of the work performed and confirmed the effectiveness of TIN modeling for monitoring the current volumes of earth masses during the construction of civil defence protective structures.

Keywords: TIN modelling, earthwork volumes, civil protection shelter, GNSS surveying, total station measurements, digital terrain model.

Introduction

In the current conditions of the martial law and constant rocket attacks in Ukraine, the construction of civil defence facilities that ensure safe functioning of social infrastructure facilities, in particular educational institutions, is of particular importance. The complex of engineering and geodetic works in the construction of such shelters is a key stage, since the accuracy of determining the geometric parameters of the excavation and the volume of earthworks directly affects the reliability and safety of the future structure. In this context, digital terrain modelling, in particular the construction of TIN surfaces using Autodesk AutoCAD Civil 3D, is an effective tool for analysing the actual state of the territory and controlling the process of excavation for such civil defence facilities [1-6].

In this article, we carried out a full cycle of engineering and geodetic works and performed TIN modelling necessary to determine the current volumes of earth masses during the construction of a civil defence protective structure excavation.

Among the current studies in the field of TIN modeling and determination of excavation volumes, it is worth noting the study by Wen et al. [7] who investigated the accuracy of calculating volumes based on TIN models and the influence of the density of the source data on the result. At the same time, Vasic et al. [8] compared different approaches to calculating volumes based on digital terrain models, and Slattery et al. [9] substantiated the effectiveness of using laser scanning to increase the accuracy of calculations. Hadi and Alhaydary [10] demonstrated the capabilities of Civil 3D in the tasks of quantitative determination of earth masses. Ansari and Agrawal [11] analyzed the effectiveness of different methods for calculating volumes. Unlike the aforementioned works, our study focuses on the applied aspect of controlling the current volumes of excavation for civil defence structures, with a combination of TIN modeling, cartographic method, and accuracy assessment, which determines the scientific novelty and practical significance of the results obtained.

Materials and methods

The reference geodetic network of the construction site in the territory of the construction of civil defence facilities near the educational complex No. 183 “Fortuna” (5 Yunosti St., Kyiv) was created and fixed in the form of four geodetic marks. The marks were marked films with a reflective surface on an adhesive base, and two additional characteristic points of the terrain were also included in the network. The basis for building the network was the reference points coordinated with the help of GNSS, obtained using the GNSS receiver Alpha-GEO NetBOX, which provided the necessary accuracy and stability of the position of the starting points. The geodetic marks laid under the external geodetic network were taken from three standing stations by an electronic total station using the circular reception method. The orientation of the Alpha-GEO X (2″) total station was carried out by the method of inverted linear-angular serif from the points of the network (Fig. 1).

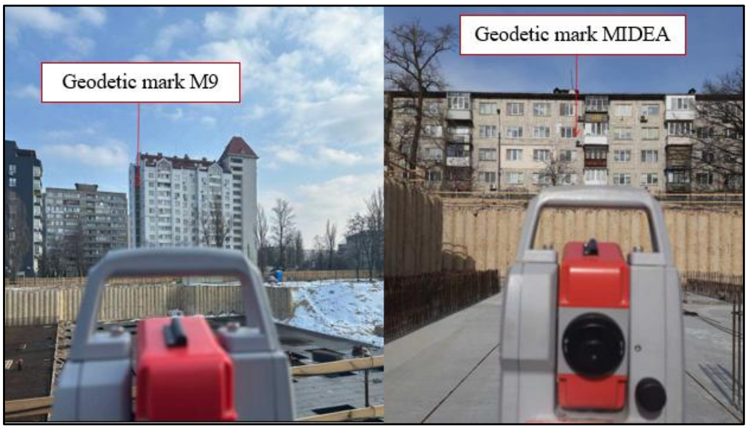

Fig. 1. **Location of reference marks**

The choice of a total station with an angular accuracy of 2″ met the requirements of DBN V.1.3-2:2010 “Geodetic works in construction”, according to which the accuracy of marking and observation works is determined by the class and complexity of the structure. The technical characteristics of the geodetic equipment fully satisfied the conditions for performing geodetic control and monitoring of the parameters of the excavation [2].

At the same time, the definition of excavation works is regulated by the requirements of DSTU-N B V.2.1-32:2014 “Guidelines for the design of excavations for the arrangement of foundations and buried structures”. Excavation works are the forced movement of earth masses in order to prepare the base for the arrangement of foundations and foundation-basement parts of buildings and structures, including the development of excavations and pits, vertical planning, construction of embankments, backfilling [1].

The complex of geodetic works at this stage of construction begins with the performance of topographic surveying before the start of the construction work. On the example of the experimental object of construction of the shelter, topographic surveying to establish the initial surface before the start of work was carried out after dismantling the elements of the former landscaping on the territory of Lyceum No.183 “Fortuna”, in particular reinforced concrete slabs and asphalt pavement, in order to separate the area of these coatings in advance from the process of calculating the volume of earthworks. The second stage in determining the volume of earthworks is the direct performance of excavation after soil removal. The process of excavation was carried out mechanized using medium-sized excavators. The purpose of excavation is to achieve the design bottom mark. The vertical boundaries in this case are the pile field that limits the excavation (Fig. 2).

Coordination was performed in the state coordinate system USK-2000 using the Baltic Height System of 1977. Point heights were determined as orthometric, the transition from ellipsoidal GNSS heights was carried out taking into account the geoid model. Detailed surveying was performed taking into account the characteristic structural lines of the relief: the edges of the excavation, the sole, the boundaries of the pile field and other fault lines were recorded. The average density of points was 1-2 points per 10 m^2 with thickening in areas of sharp relief changes.

Fig. 2. **Process of excavation development**

The office processing of the survey results was performed in Autodesk AutoCAD Civil 3D software. The principle of calculating the volume of earthworks was based on comparing surfaces constructed on the basis of the topographic survey before the start of work and the survey after removing soil from the pit [7-11].

The surfaces were displayed using the TIN modeling method, which is based on the Delaunay triangulation principle. This method involves dividing the surface into a set of non-overlapping triangles, which ensures accurate reproduction of the relief. Fig. 3 shows the view of the survey performed after the completion of the work, which is transformed into a TIN model with drawn contours [7-11].

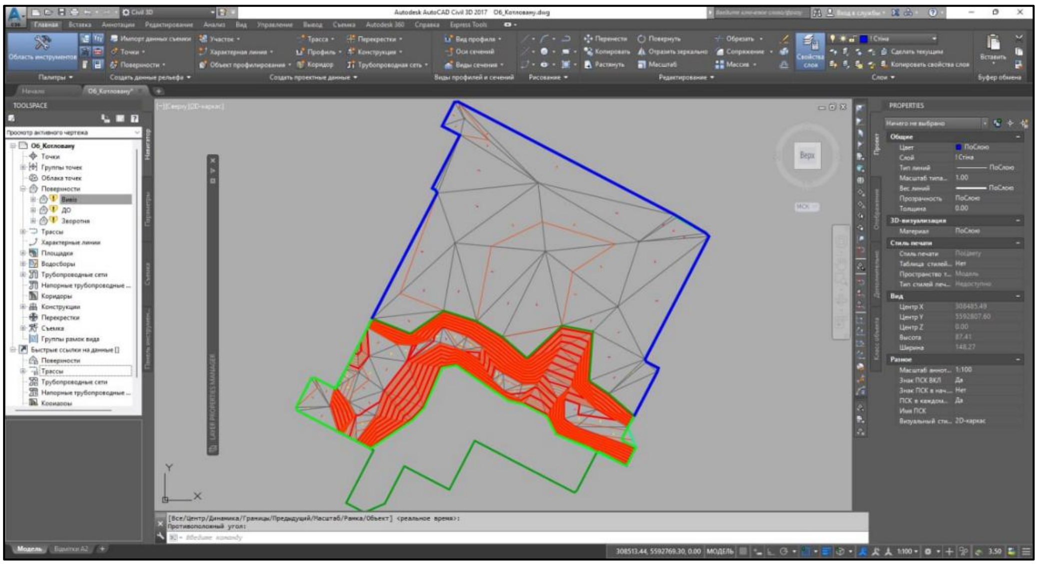

Fig. 3. **Result of TIN modeling in Autodesk AutoCAD Civil 3D**

In Civil 3D, a TIN surface was created based on survey points and structural lines with an outer boundary set along the contour of the excavation without triangulation smoothing. Horizontal lines for graphic materials were constructed with an interval of 0.5 m. A cartogram was formed using the square method with a cell size of 10×10 m. The average marks within the square were determined as the arithmetic mean values of the heights of its vertices.

Results and discussion

As a result of the office processing of the survey, we obtained a levelled digital surface model that accurately reflects the actual state of the excavation, preserving its geometric shapes, boundaries and main parameters.

In the future, the obtained surface will be compared with the initial one, created on the basis of the topographic survey performed before the start of the work. The comparison is carried out by the method of superimposing surfaces and analyzing changes relative to the surface before the excavation, which makes it possible to determine the volumes of selected and moved soil, assess the accuracy of the excavation work and make adjustments if necessary.

Fig. 4 shows a three-dimensional model of the excavation, at the bottom of which a residual layer of soil remains. This layer is intended for subsequent backfilling in the gaps between the piles and the concrete frame.

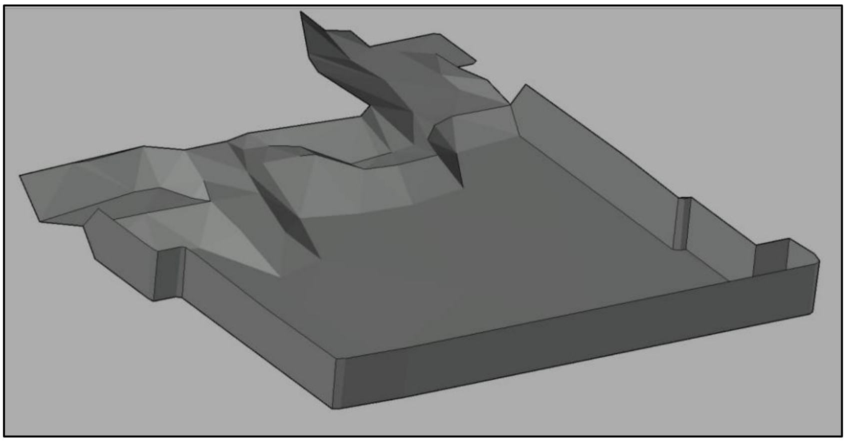

Fig. 4. **TIN model of a pit with residual soil for backfilling in Autodesk AutoCAD Civil 3D**

According to the clause N.1.4 DBN V.1.3-2:2010, periodic executive surveying is carried out in order to calculate the current volumes of earth masses [2]. The final office stage of processing and reporting form was the compilation of a cartogram of calculation of the volumes of soil removal and movement. The total volume of soil removal reaches 17827.03 m^3, from the total area of the excavation 3387.84 m^2.

The calculation of the soil volume was performed by the method of squares with the construction of a cartogram. This method involves dividing the studied surface into uniform squares with the subsequent determination of average heights. The cartogram was compiled without taking into account the type and group of soil, the volume is displayed with no loosening coefficient applied of the soil. This means that discrepancies may arise in mutual settlements for transportation, storage, or backfilling, since the actual volume of soil developed in a loose state is greater [3; 4].

An assessment of the accuracy of the excavation during the excavation work was performed. Topographical surveying of the surface before the start of construction and after the completion of the soil removal process was carried out with an estimated vertical accuracy of determining the marks of up to ± 3 cm. The total surface area is 3387.84 m^2, therefore, to calculate the possible volumetric deviation caused by the error in height measurement, the formula was applied (1) [8; 11]:

$$m_v = 2m_h \times S \tag{1}$$

$$m_v = (2 \times 0.03) \times 3387.84 = 203.27$$

where m_v – marginal error in calculating the soil volume excavation, m^3;
m_h – accuracy of determining the height of points during the survey, m;
S – surface area, m^2.

Considering that the total volume of developed soil during the construction of the excavation was 17827.03 m^3, we calculated the error in determining the volume of soil when calculating the cartogram using the formula (2):

$$m_{V\%} = (m_v / V_{soil}) \times 100 \tag{2}$$

$$m_{V\%} = (203.27/17827.03) \times 100 = 1.14\%$$

where V_{soil} – total volume of developed soil during excavation, m^3;
$m_{V\%}$ – error in determining the soil volume when calculating the cartogram, %.

Thus, the theoretical error based on the accuracy of performing the altitude survey to determine the soil volume is 1.14%.

The values obtained by the method of squares (10x10 m map) were compared with the results of the automated calculation of the volume between two TIN surfaces (the surface before development and the actual surface after excavation) in Civil 3D within the same closed polygon of the excavation contour. The discrepancy between the two methods was less than 1.5%, which confirms the consistency of the results.

Conclusions

1. As a result of processing the field measurements in Autodesk AutoCAD Civil 3D environment, an aligned digital TIN model of the actual surface of the excavation was obtained, which accurately reflects the geometry of its boundaries, depth and configuration of the trough part. The created surface made it possible to visualize the actual state of the excavation works and determine the preservation of the geometric characteristics of the excavation in accordance with the design solutions. Further analysis by comparing the obtained model with the initial surface before the excavation development provided the opportunity to establish the volumes of the selected and moved soil, as well as to trace the residual soil layer left for further backfilling between the piles and the concrete frame. Thus, the performed TIN modeling provided a comprehensive spatial understanding of the actual state of the excavation works and created the basis for the formation of a cartogram of soil volumes.
2. Calculation of the volumes of earth masses by the method of squares with the formation of a cartogram confirmed the volume of the selected soil at the level of 17827.03 m^3 with a total area of the excavation of 3387.84 m^2. The accuracy assessment showed that the permissible error in calculating the volume of soil, associated with the vertical accuracy of the survey, is approximately 203.27 m^3. This indicator indicates the high reliability of the office processing of the results and the accuracy of the volumes obtained, which confirms the effectiveness of using TIN modeling in Civil 3D for monitoring excavation work at civil defence facilities.
3. The proposed approach provides quantitatively confirmed accuracy in determining current excavation volumes (with an error estimate of 1.14%), demonstrates consistency between the TIN-to-TIN and cartographic method results, and justifies the modeling parameters, which increases the reliability and practical applicability of the calculations compared to existing studies.

Acknowledgements

This paper was supported by the project "Socio-economic challenges, implementation and improvement of Ukrainian legislation in the context of sustainable development" funded from the Ministry of Education and Science of Ukraine, approved by the resolution of the Cabinet of Ministers of Ukraine of July 10, 2019 No. 639, the order of the Ministry of Education and Science of Ukraine of April 16, 2021 No. 434.

Author contributions

Conceptualization, Ivan Openko and Olesia Huretska; methodology, Ivan Openko and Olesia Huretska; software, validation, Oleksandr Shevchenko, Nataliia Kolesnik and Viktoriia Paschenko; formal analysis, Olesia Huretska; investigation, Ivan Openko and Oleg Tsvyakh; data curation, Ivan Openko; writing original draft preparation, Ivan Openko and Ruslan Tykhenko; writing – review and editing, Ivan Openko and Olesia Huretska; visualization, Olesia Huretska; project administration, Ivan Openko; funding acquisition, Oleg Tsvyakh, Viktoriia Paschenko. All authors have read and agreed to the published version of the manuscript.

References

[1] DSTU-N B V.2.1-32:2014 – Guidelines for designing excavation pits for foundations and underground structures. Kyiv: Ministry of Regional Development of Ukraine, 2014, 98 p.
[2] DBN V.1.3-2:2010 – Geodetic works in construction. Unified State Electronic System in Construction. [online] [11.02.2026] Available at: https://e-construction.gov.ua/laws_detail/3199637436816688486?doc_type = 2

[3] Openko I., Tykhenko R., Shevchenko O., Tsvyakh O., Stepchuk Ya., Rokochinskiy A., Volk P. Mathematical modeling of economic losses caused by forest fire in Ukraine. 21st International Scientific Conference Engineering for Rural Development. 25-27.05.2022 Jelgava, LATVIA, 2022, pp. 22-27.

[4] Rokochinskiy A., Volk P., Frolenkova N., Tykhenko O., Shalai S., Tykhenko R., Openko I. Differentiation in the value of drained land in view of variable conditions of its use. Journal of Water and Land Development, No. 51 (X–XII), 2021, pp. 172-178. DOI: 10.24425/jwld.2021.

[5] Holian V., Marchuk Yu., Matrunchyk D., Karpuk A., Pohuliaiko Yu., Nedopad H. Financial and investment support for the development of innovative wood waste management infrastructure at the national, regional and local levels. Financial and Credit Activity Problems of Theory and Practice, vol. 1(60), 2025, pp. 490-510. DOI: 10.55643/fcaptp.1.60.2025.4696

[6] Tsvyakh O. M., Openko I. A. Industrial territories as a spatial basis for optimizing land use in the city of Kyiv. Land management, cadastre and land monitoring, No. 1, 2017, pp. 83-91.

[7] Wen Y., Yuan X., Yang X., Zhang H., Han Q. Research on earthwork calculation based on TIN model. E3S Web of Conferences, vol. 248, 2021, 03001. [online] [11.02.2026] Available at: https://www.researchgate.net/publication/350816172_Research_on_Earthwork_Calculation_Based_on_TIN_Model

[8] Vasic M., Janic N., Dukanovic M., Grujovic G., Dragomir. Earthwork volume calculation from digital terrain models. Journal of Industrial Design and Engineering Graphics, vol. 10, 2015, pp. 27-30.

[9] Slattery K. T., Slattery D. K., Peterson J. P. Road construction earthwork volume calculation using three-dimensional laser scanning. Journal of Surveying Engineering, vol. 138, No. 2, 2012, pp. 96-99. DOI: 10.1061/(ASCE)SU.1943-5428.0000073

[10] Hadi A. A. A.-J., Alhaydary M. M. Calculations of earthwork quantity by using Civil 3D. Journal of Engineering and Sustainable Development, vol. 22, no. 6, 2018, pp. 13-17. [online] [11.02.2026] Available at: https://jeasd.uomustansiriyah.edu.iq/index.php/jeasd/article/view/340/269

[11] Ansari A.A., Agrawal S. (2019). The study on efficiency analysis of calculating earthwork volume. Available at: Journal of Emerging Technologies and Innovative Research (JETIR), vol. 6, issue 5, pp. 607-613.