Design of vertical levelling using CAD and GIS

Djumanov Jamolzhon Khudaykulovich , Khaitov Bafo Usmanovich

DSc, Professor, Head of the Department of Computer Systems, Tashkent University of Information Technologies named after Muhammad al-Khwarizmi, 100084. RUz. Tashkent city, Amir Temur Avenue, 108
PhD, Associate Professor of the Department of Descriptive Geometry and Engineering Graphics of the Bukhara Engineering and Technological Institute, 200100. RUz. Bukhara, st. Kayum Murtazaev, 15

ABSTRACT: A technique is proposed for constructing a design surface of a vertical leveling on the basis of graphic-analytical methods for determining the line of the average slope of a flat curve, which are the lines of the profile and cross-section of the relief. On the basis of the lines (straight lines) of the average slope of the plane curves of the longitudinal and cross-section of the relief, an inclined plane of the vertical leveling is constructed. The initial data for modeling the design surface are determined using the Google Earth program with open Internet access.

KEYWORDS: design surface, vertical leveling, initial data, plane of relief, line of average slope of a flat curve.

I. INTRODUCTION

The development of a project in real time is in demand in the practice of engineering design, in particular in the development of projects for the vertical leveling [1,2,3]. It is also important to conduct a preliminary analysis of the area to determine the acceptability of the project in the area [4,5]. The purpose of the experimental studies was to develop a methodology for a vertical leveling project using publicly available software tools in real time. As a publicly available software, a GIS program was chosen - Google Earth with open access to the Internet for collecting initial data on the terrain, as well as AutoCAD for processing initial data and drawing up a vertical planning project taking into account the balance of earthworks. The practical application of the Google Earth application program in various problems of engineering analysis and scientific research is also known. [6,7].
The dimensions of the experimental field of the "Khursanbibi" farm were chosen 285 × 145 m. Location: 40° 9'56.15"N 64°26'55"E (figure 1).
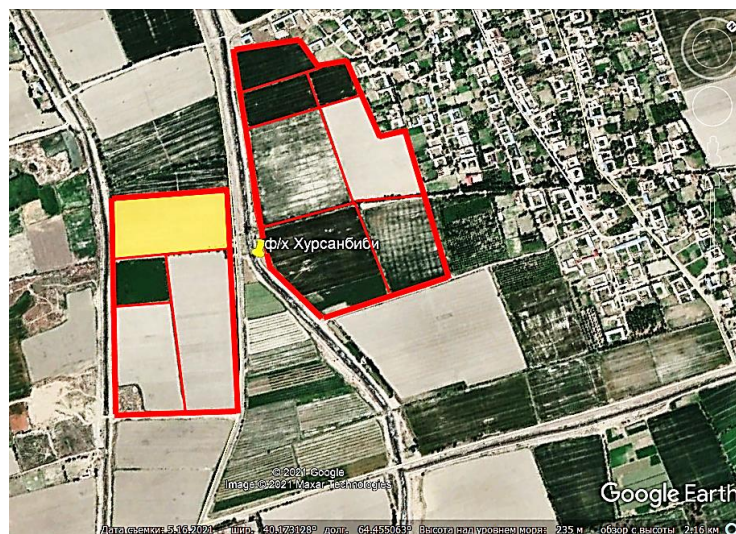

Figure 1. Location of the farm "Khursanbibi", Bukhara region of the Republic of Uzbekistan

II.   MATERIALS AND METHODS

Data collection. The original field data was collected from a regular rectangular grid in Google Earth. The parameters of the regular network were the field perimeter 285×145 m, which were rounded at 280×140 m with an alternation of 20 m nodes. The dimension of the regular network m $\times$ n was $15 \times 8 = 120$ nodes.

The rectangular regular grid was drawn in CAD AutoCAD with subsequent conversion to png (or jpg) file. This file served as a background for overlaying in Google Earth using the "Add Image Overlay" tool (Fig. 2).
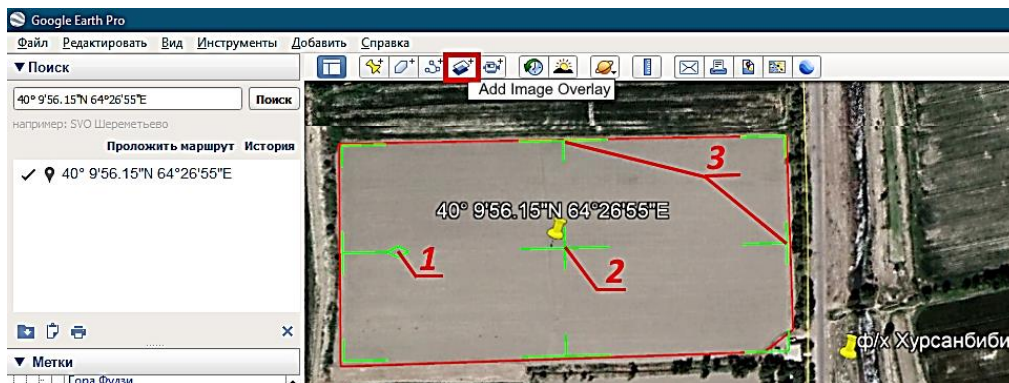

Figure 2. Varying the dynamic mesh for the image matte: 1 – rotation; 2 – moving; 3 – change perimeter.

Selecting the "Show ruler" tool and going to the "Path" tab sets the trajectory of one profile section by indicating the first and last node of one line of the regular grid. On the "Path" tab, the "Show Elevation Profile" switch is turned on (Fig. 3).
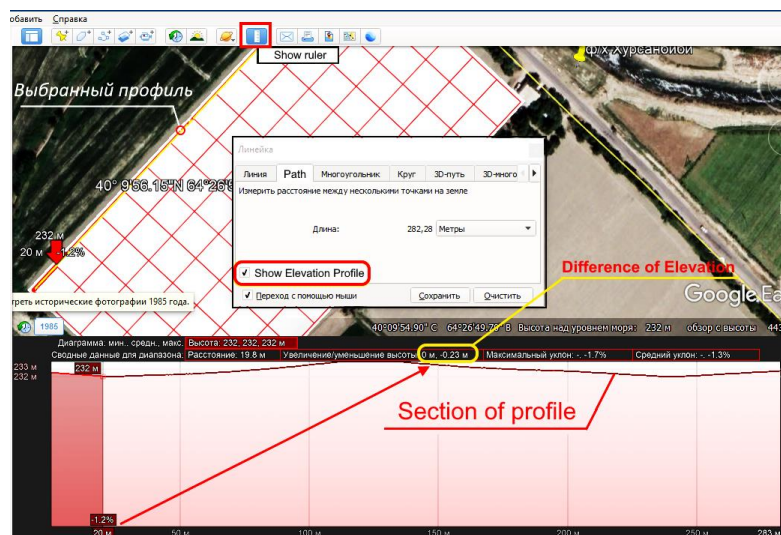

Figure 3. Determination of the heights of the profile section of the relief

By moving the cursor along the profile section, you can determine the value of the height in this interval in the form of the difference in heights relative to the beginning of the area under consideration (see Fig. 3). All data should be consistently recorded (for example, in Microsoft Excel). By repeating the selection of the "Path" tool, the trajectory of the next profile section is set and the values of all subsequent values of the heights of the grid nodes are also determined. The operation is repeated until the last profile section of the substrate. All fixed data of elevation values form a table of initial data (table 1).

Table 1. Table of elevation values determined by Google Earth

Zmn	Z_{n1}	Z_{n2}	Z_{n3}	Z_{n4}	Z_{n5}	Z_{n6}	Z_{n7}	Z_{n8}	Z_{n9}	Z_{n10}	Z_{n11}	Z_{n12}	Z_{n13}	Z_{n14}	Z_{n15}	ΔZm
ΔX=ΔY=20 m. Columns-n=15, Rows-m=8.																
Z_{m1}	0,28	0,00	0,11	0,33	0,54	0,85	1,05	0,99	0,71	0,54	0,46	0,26	0,07	0,27	0,47	0,46
Z_{m2}	0,03	0,18	0,42	0,67	0,88	1,01	1,01	1,01	0,93	0,76	0,56	0,36	0,16	0,04	0,37	0,56
Z_{m3}	0,11	0,27	0,44	0,60	0,77	0,92	0,92	0,92	0,92	0,84	0,64	0,44	0,25	0,26	0,35	0,58
Z_{m4}	0,11	0,29	0,55	0,83	1,00	1,04	1,04	1,04	1,04	1,04	1,03	0,83	0,76	0,86	0,96	0,83
Z_{m5}	0,04	0,21	0,54	0,80	0,96	1,04	1,04	1,04	1,04	1,04	1,04	0,94	0,87	0,90	1,00	0,83
Z_{m6}	0,07	0,30	0,63	0,88	1,04	1,07	1,07	1,07	1,07	1,07	1,07	1,07	1,03	1,06	1,17	0,91
Z_{m7}	0,32	0,44	0,56	0,69	0,69	0,69	0,69	0,69	0,69	0,69	0,69	0,69	0,69	0,86	1,06	0,68
Z_{m8}	0,58	0,69	0,81	0,81	0,81	0,81	0,81	0,81	0,81	0,81	0,81	0,81	0,81	0,81	1,01	0,80
ΔZn	0,19	0,30	0,51	0,70	0,84	0,93	0,95	0,95	0,90	0,85	0,79	0,68	0,58	0,63	0,80	ΔZ= 0,705

Data transformation. In AutoCAD, vertical lines are placed at the nodes of a regular grid by elevation values. Using the command "spline", we sequentially interpolate the end nodes of the height values along the rows and columns of the regular grid, forming a wireframe model of the relief surface. As you know, surfaces have "Forming" and "Guides". If longitudinal sections of the relief are selected as forming, then cross sections are selected as guides. In AutoCAD, the formation of surfaces taking into account forming and guides is performed by the command "Loft". By selecting the command "Loft", the longitudinal sections of relief are indicated in ascending order (see Fig. 4-a). The selection is completed by the command "Enter", and then the cross-sections are indicated sequentially in ascending order (see Fig. 4-b). The command "Enter" completes the construction of the surface.
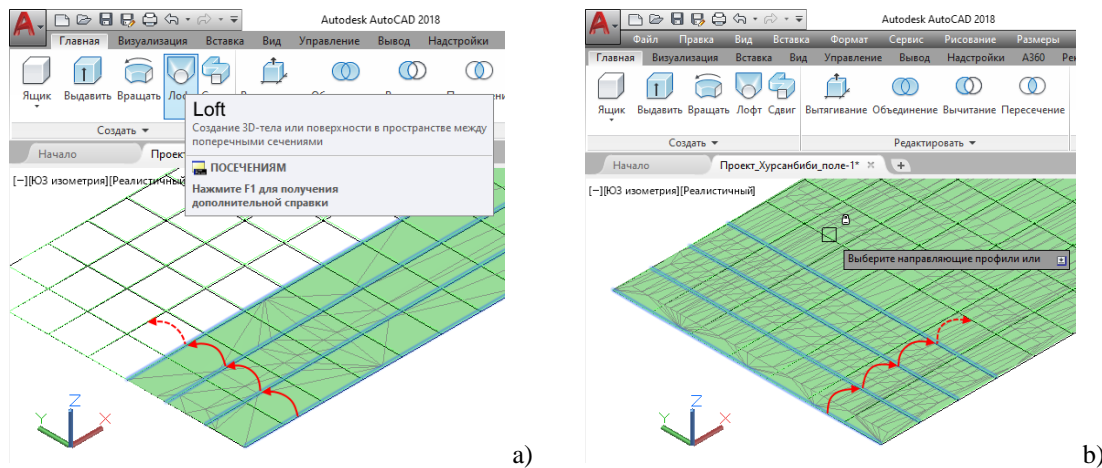

a)   b)

Figure 4. Formations of the relief surface in AutoCAD: a) selection of longitudinal sections; b) selection of cross-sections.

To carry out the design surface (inclined plane) of the vertical leveling, we present the following definitions and the methods for determining a straight line drawn from the average values of the initial data by a flat curve using a graphic-analytical method.

Definition-1. The straight line drawn by the mean values of the flat curve will be called the "the line of average slope" [8].

Since the initial data are selected discretely, it is possible to solve the problem of determining the line of average slope by the method of finite differences.

If we have a matrix of height values of some surface:

$$A \equiv \begin{pmatrix} Z_{11} & Z_{12} & \cdots & Z_{1n-1} & Z_{1n} \\ Z_{21} & Z_{22} & \cdots & Z_{2n-1} & Z_{2n} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ Z_{m-11} & Z_{m-12} & \cdots & Z_{m-1n-1} & Z_{m-1n} \\ Z_{m1} & Z_{m2} & \cdots & Z_{mn-1} & Z_{mn} \end{pmatrix} \equiv (Z_{ij}) \qquad (1)$$

where each row or column of the matrix is one flat curve - a longitudinal or cross-section of the relief, then the average value of heights - δZ_{1j} of the line of average slope of the one row will be [8]:

$$\delta Z_{1j} = \frac{Z_{11} + Z_{12} + \dots + Z_{1n-1} + Z_{1n}}{n} = \frac{\sum_{k=1}^{n} Z_{1k}}{n}; \qquad (2)$$

The amount of raw data in a column or row of a matrix can be even or odd. It was found that the graphic-analytical determination of the line of the average slope of a flat curve for an even and an odd amount of initial data is different. If, in equation (2) n is even, then it is enough to determine the position of one more point N (or M) belonging to the line of average slope (Fig. 5), since a straight line can be drawn through two points.
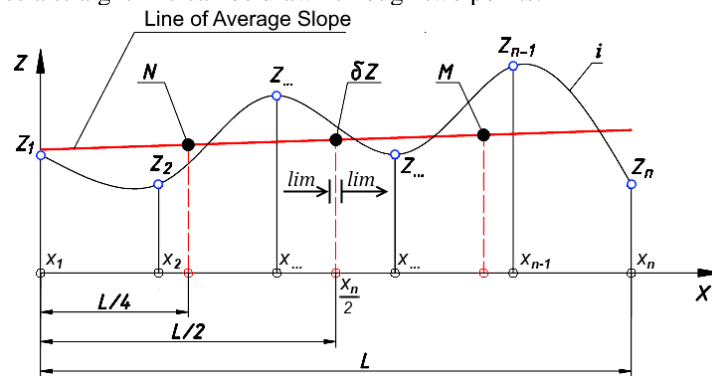

Figure 5. Line of average slope of a curve with an even amount of data

The next point N (or M) of the general slope line with an even amount of initial data n will be (see Fig. 5) [8]:

$$N = \frac{Z_{11} + Z_{12} + \dots + \lim \, \delta Z}{n/2}; \quad \text{or } M = \frac{\lim \delta Z + \dots + Z_{1n-1} + Z_{1n}}{n/2}; \qquad (3)$$

here $\lim \delta Z$ is the condition for the summation limit of the amount of Z from x_1 to $x_n / 2$ (or after $x_n / 2$ to x_n), while the value of δZ itself is not taken into account at $x_n / 2$.

If, in equation (2) n is odd then the position of the point N (or M) of the line of general slope (Fig. 6) will be [8]:

$$N = \frac{Z_1 + Z_2 + \dots + \delta Z_k}{(n+1)/2}; \quad \text{or } M = \frac{\delta Z_k + \dots + Z_{n-1} + Z_n}{(n+1)/2}. \qquad (4)$$

here

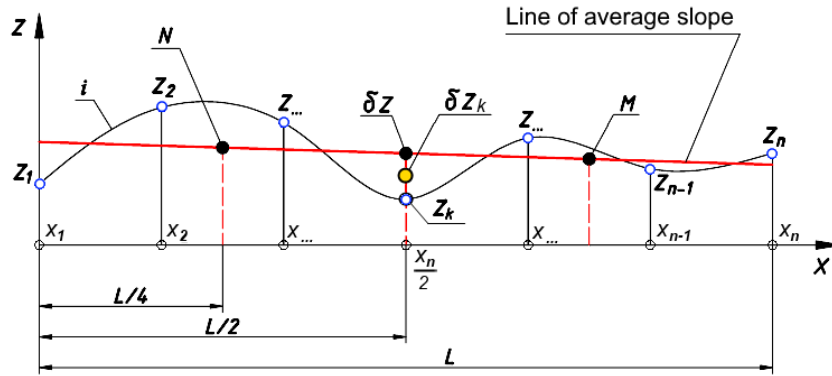$$\delta Z_k = \frac{\delta Z + Z_k}{2} \qquad (5)$$

Figure 6. Line of general slope of a curve with an odd amount of data

By inserting (5) into equation (4) and performing transformations, we finally have:

$$N = \frac{2(Z_1 + Z_2 + \cdots) + \delta Z + Z_k}{n+1}; \text{ or } M = \frac{\delta Z + Z_k + 2(\ldots + Z_{n-1} + Z_n)}{n+1}. \qquad (6)$$

Definition - 2. The plane drawn according to the average values of the elevation points of the relief surface will be called the "Plane of Relief" (the plane of average slope) [9,10].

The plane of relief contributes to the optimal conduct of design surface, taking into account the natural slope of the entire territory, minimal transformation and anthropogenic impact on the biobalance of the environment, the greatest preservation of the fertile soil layer.

To determine the geometric position of the plane of relief, two mutually intersecting straight lines should be determined, which are the lines of average slope of the longitudinal and cross sections of the relief.

Set the average value for each rows and columns of the matrix (1), we form two flat curves c and d (Fig. 7):

$$\begin{cases} c = (\Delta Z_{1k} & \Delta Z_{2k} & \ldots & \Delta Z_{m-1k} & \Delta Z_{mk}) \\ d = (\Delta Z_{n1} & \Delta Z_{n2} & \ldots & \Delta Z_{ni-1} & \Delta Z_{ni}) \end{cases} \qquad (7)$$
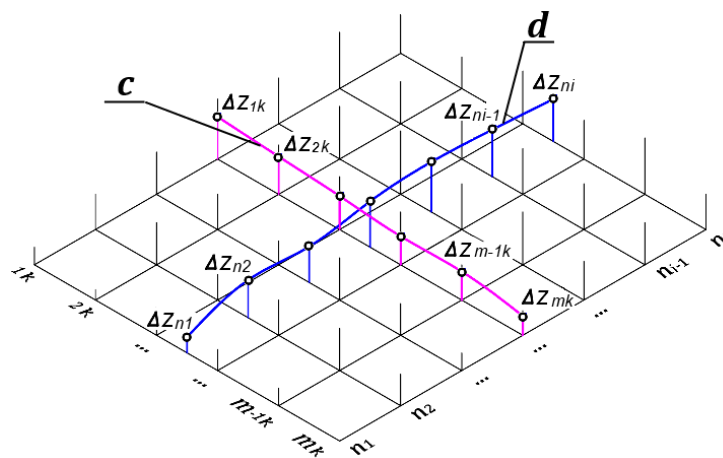

Figure 7. Formation of gentle curves by the average values of rows and columns of the elevation matrix

Sequentially applying equations 2 - 6, taking into account the even and odd initial data of the columns and rows of the matrix (1), the lines of average slope of two plane curves c_i and d_i are determined [8-10] (Fig. 8). It is characteristic that

two lines of average slope mutually intersect and have a common point ΔZ, which is also the mean point of the initial data of the matrix (1) and determines the plane.
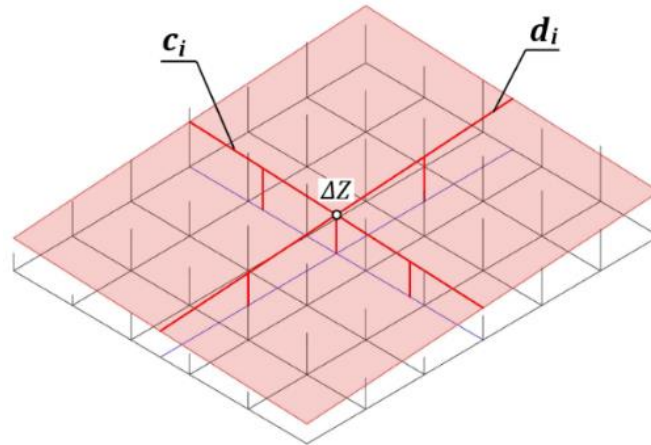

Figure 8. Plane of relief

III. SIMULATION&RESULTS

To determine the plane of relief, the following are required: the average value of all initial data - ΔZ, the average value for the rows - ΔZm, the average value for the columns - ΔZn. Table-1 they are already given in the form of ΔZ, ΔZm and ΔZn values.

Project development. On the basis of the ΔZm values, the average cross-section of the relief is determined in the form of a flat curve, and on the basis of the ΔZn values, the average longitudinal section of the relief is determined also in the form of a flat curve (see Fig. 7).

The intersecting straight lines are determined by the graphic-analytical method for determining the line of the average slope, taking into account the evenness and oddness of the amount of initial data. Copying the straight lines of the average slope of the longitudinal and cross sections by the center, we rearrange them to the ends of the straight longitudinal and cross sections, forming a rectangle (Fig. 9). By means of the command "Flat" (AutoCAD) we successively indicate the edges of the relief plane and the rectangle is transformed into a plane.
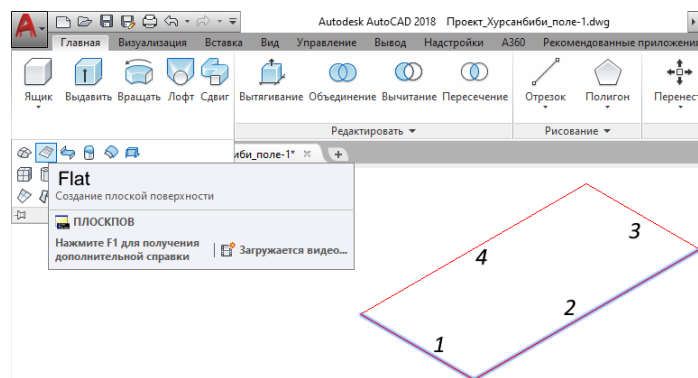

Figure 9. Converting the rectangle to the plane

The mutual intersection of the surface and the plane given an idea of the unevenness of the relief (Fig. 10).
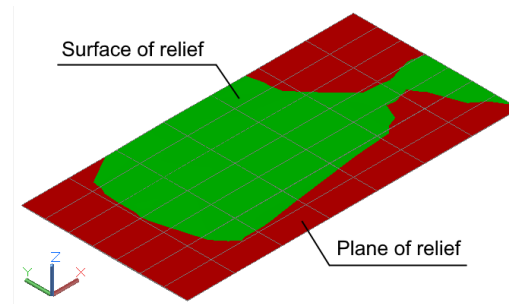
Figure 10. Mutual intersection of the surface and the plane of relief.

To determine the volume and balance of earth masses, you need to build a parallelepiped (3D solid) based on the edges of the surface or the plane of the relief. The parallelepiped parameters are chosen $280 \times 140 \times h$.

$$h > (Z_{max} - Z_{min}) \tag{8}$$

The height - h of the parallelepiped should be sufficient for variation when crossing the surface in order to balance the volumes of the two truncated parts of the parallelepiped (in our case, h = 10 m was chosen). The volume of the parallelepiped is preliminarily determined (V = 392000 m3). The parallelepiped from the center of gravity snaps to the center of the regular grid so that the surface of the relief and the plane of the relief pass along the center of the height of the box. The intersection of the parallelepiped with a relief surface is reproduced using the command "Edit / 3D Operations / Section". To determine the volumes of the two truncated parts of the parallelepiped, select the "Measurement Tools / Volume" command and specify the 3D object to determine the volumes of the truncated parts of the parallelepiped (Fig. 11):

$$V_{об.1}^1 = 167316,3332 \text{ м}^3; \quad V_{об.2}^1 = 224683,7261 \text{ м}^3; \quad \text{at} \quad Z_1 = 0 \tag{9}$$

here $V_{ob.1}$ is the upper part of the truncated parallelepiped; $V_{ob.2}$ - the lower part of the truncated parallelepiped.
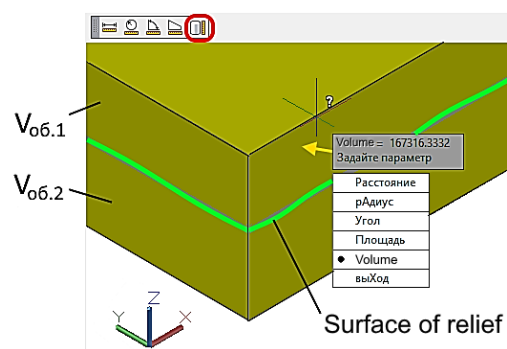

Figure 11. Determination of the volume of the truncated part of the parallelepiped

Both truncated parts of the parallelepiped are merged. The parallelepiped is displacing along the Z axis within Zmax ÷ Zmin (in our case, by 1 m). Having carried out the mutual intersection of the relief surface with the parallelepiped again, the volumes of the two truncated parts are compared:

$$V_{об.1}^2 = 206516,2855; \quad V_{об.2}^2 = 185483,7618; \quad \text{at} \quad Z_2 = 1 \tag{10}$$

Both truncated pieces of the parallelepiped are merged and returned to their original position. To balance the volumes of the two parts of the truncated parallelepiped, a nomogram is constructed (Fig. 12) taking into account the scale of the ratio of quantities and the displacement value is determined - Z_{bal} (in our case, $Z_{bal} \approx 0.7317$).

The parallelepiped is displaced in the Z direction by a new value Zbal and the mutual intersection of the parallelepiped with the relief surface is repeated. The volumes of the two parts of the parallelepiped are balanced:

$$V_{об.1}^3 \approx 196000; \quad V_{об.2}^3 \approx 196000; \quad \text{at} \ Z_{бал} = 0{,}7317 \tag{11}$$
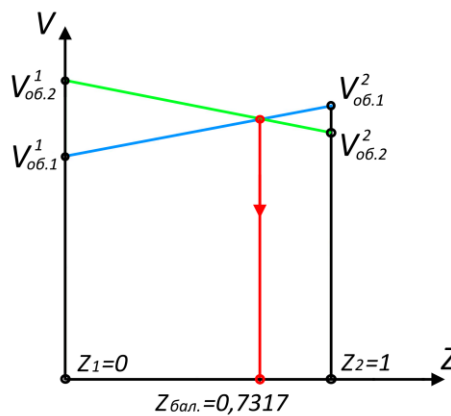

Figure 12. Nomogram for determining the balance of volumes

Next, you should determine the volume of the cut and embankment after the intersection of the truncated parts of the parallelepiped with the relief plane. It should be noted that the volumes of the embankment and cut after intersections with the relief plane will be inside the truncated parts of the parallelepiped. Consequently, after the mutual intersection of the truncated parts of the parallelepiped with the relief plane, the residual volumes of both parts of the parallelepiped are determined without taking into account the volumes of the embankment and cut.

$$V_{ос.1}^1 \approx 191851{,}2818; \quad V_{ос.2}^1 \approx 190836{,}1537; \quad \text{at} \ Z_{пл.1} = 0 \tag{12}$$

here $V_{ос.1}$ - the upper residual part of the truncated parallelepiped; $V_{ос.2}$ - the lower residual part of the truncated parallelepiped.

Having canceled the mutual intersection, the volumes of the truncated parts of the parallelepiped return to their original position. By shifting the relief plane to an arbitrary height relative to the Z axis (in our case, by 1 m) and re-intersecting the relief plane with the truncated parts of the parallelepiped, the volumes of the two residual parts of the parallelepiped are compared:

$$V_{ос.1}^2 \approx 157816{,}3658; \quad V_{ос.2}^2 \approx 195999{,}9828; \quad \text{at} \ Z_{пл.2} = 1 \tag{13}$$

Mutual intersection and movement of the relief plane along the Z axis are canceled and returned to the original position. To balance the volumes of the two residual parts of the parallelepiped, a nomogram similar to that shown in Fig.12 taking into account the scale of the ratio of quantities and the value of the displacement is determined $Z_{пл.бал}$ (in our case, $Z_{пл.бал} \approx 0.0259$ m).

The relief plane is shifted in the Z direction by a new value of $Z_{пл.бал}$ and the mutual intersection of the truncated parts of the parallelepiped with the relief plane is repeated. The volumes of the two residual parts of the parallelepiped, as well as the volumes of the cut and fill, are balanced:

$$V_{ос.1}^3 \approx 191378; \quad V_{ос.2}^3 \approx 191378; \quad \text{at} \ Z_{пл.бал} \approx 0{,}0259 \tag{14}$$

The total volume of the cut V_{cp} will be:

$$V_{\text{cp}} = V_{\text{об.1}}^3 - V_{\text{ос.1}}^3 = 196000 - 191378 = 4622 \ m^3 \tag{15}$$

The total volume of the embankment $V_{нас}$ will be:

$$V_{\text{нас}} = V_{\text{об.2}}^3 - V_{\text{ос.2}}^3 = 196000 - 191378 = 4622 \ m^3 \tag{16}$$

A complete representation of the result of visual design of vertical levelling in real time in AutoCAD can be seen in the form of technological layers in expanded form (Fig. 13).
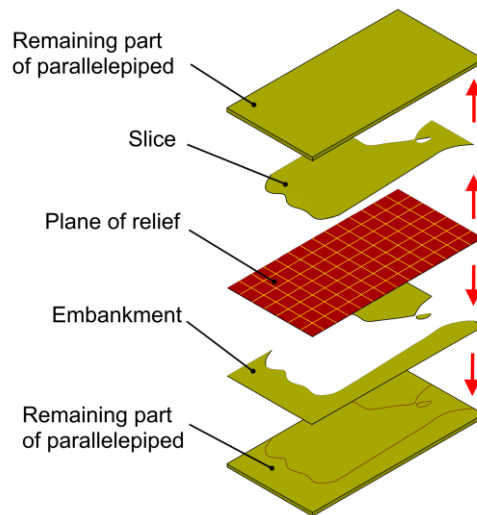

Figure 13. Project of vertical levelling in AutoCAD in expanded form

Next, you should determine the coordinates of the calculated elevations based on the plane of the relief. On the panel "CCS" (Custom Coordinate System) select the command "Object" and set the origin relative to the plane of the relief (Fig. 14). The points are placed at the mesh points of the relief plane.
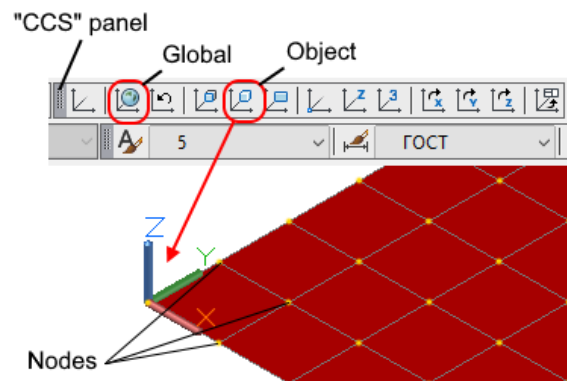

Figure 14. Coordinate system transformations in AutoCAD

The CCS object returns to its original position "Global". By indicating points on the plane of the relief, the heights of each anchor point are determined using the information panel "Properties" (Fig. 15).
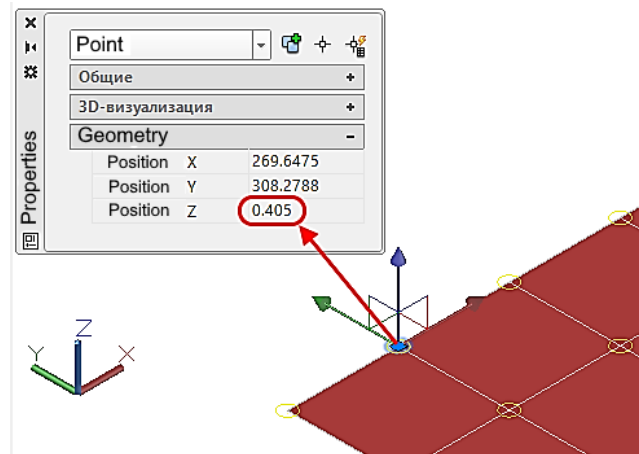
Figure 15. Determining the coordinates of point at the panel "Properties"

Based on the geometric properties of the nodal points of the relief plane, the height values of the design elevations are determined.

IV. RESULTS

On the basis of the presented methodology for the integrated application of GIS technologies and CAD, it is possible to visually design a project of vertical leveling of the terrain under an inclined plane for surface irrigation, preparation of the area for the construction of buildings, taking into account drainage, in general, in the tasks of engineering preparation of territories for various tasks of engineering design of earthworks.

REFERENCES

[1] Khaitov B.U. Digital terrain simulation for preliminary territory analysis. Herald of the Bauman Moscow State Technical University, Series Instrument Engineering, 2019, no. 3, pp. 64–76 (in Russ.). DOI: 10.18698/0236-3933-2019-3-64-76. http://vestnikprib.ru/catalog/icec/sysan/1153.html

[2] Khaitov B.U. Digital modeling of the relief for tasks of preliminary terrain analysis. ISSN 1609-364X. Geoinformatics: Scientific and technical journal. - Moscow, 2019. - No. 3. - P.34-41. https://www.elibrary.ru/item.asp?id=39584669&

[3] Khaitov B.U. Digital Modeling of Relief for Tasks of Preliminary Analysis. ISSN: 2350-0328. International Journal of Advanced Research in Science, Engineering and Technology (IJARSET). India. 2018. October. Volume-5, Issue-10. – P. 7027-7036. http://www.ijarset.com/upload/2018/october/10-IJARSET-Khaitov-xb75.pdf

[4] Khaitov B.U. Morphometric Indicators Analysis of Relief for the Engineering Design Problems. ISSN: 2643-6876. Current Trends in Civil & Structural Engineering (CTCSE). – San Francisco: Iris Publishers, USA. DOI: 10.33552/CTCSE.2019.02.000533. April, 2019. Volume-2, Issue-2. – P. 1-7. https://irispublishers.com/ctcse/pdf/CTCSE.MS.ID.000533.pdf

[5] Khaitov B.U. Review Analysis of Morphometric Indicators of Relief for Tasks of Engineering Preparation of Territories. ISSN: 2350-0328. International Journal of Advanced Research in Science, Engineering and Technology (IJARSET). – India. 2020. February. Volume-7, Issue-2. – P. 12744-12751. http://www.ijarset.com/upload/2020/february/06-xb75-01.pdf

[6] Rusli N., Majid M. Digital Elevation Model (DEM) Extraction from Google Earth: a Study in Sungai Muar Watershed. https://www.researchgate.net/publication/341078813_Digital_Elevation_Model_DEM_Extraction_from_Google_Earth_a_Study_in_Sungai_Muar_Watershed

[7] Safanelli J.L., Poppiel R.R., Chimelo Ruiz L.F., Bonfatti B.R., ets. Terrain Analysis in Google Earth Engine: A Method Adapted for High-Performance Global-Scale Analysis. International Journal Geo-Information. 2020. 9. https://www.mdpi.com/2220-9964/9/6/400

[8] Khaitov B. About one geometric method for determining the line of the general slope of a plane curve. Young Scientist: Monthly Scientific Journal. - Kazan, 2015. - №10(90). – pp.340-342. https://moluch.ru/archive/90/17360/

[9] Khaitov B. Graphic-analytical method for determining the plane of the relief in problems of vertical levelling. Development of science and technology: Scientific and technical journal. - Bukhara, 2019. - №3. – С.126-130. https://journal.bmti.uz/

[10] Khaitov B. Graphic-analytical method of relief plane definition. Landscape architecture and regional planning. – New York: Science Publishing Group, USA. 2016. DOI: 10.11648/j.larp.20160101.12. ISSN Online: 2637-4374. 2016. 1(1): 13-17. http://article.sciencepublishinggroup.com/html/10.11648.j.larp.20160101.12.html