Quick method of the grunt prisms gravity centers’ exact compliance with vertical area planning

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Abstract. The article discusses the methods for improving the accuracy of calculating the soil movement distances along the vertical layout of areas, which is one of the first works for leveling the construction site surface [3, 5, 6, 14]. This work is usually performed using the earth-moving machines [12, 17, 19, 20]. Norms of time for their work are given in Unified Standards and Prices Е2-1 [13] with gradation of the soil movement distances of 100 and 10 m. When vertical planning is required on the large areas with the soil movement over the distances of several hundred meters and with large working elevations, the options for using faster motor vehicles are possible [1, 2, 10, 11]. However, not all standards indicate between which points and how to set these distances. We believe that it is advisable to install them using the positions of the soil bodies’ gravity centers instead of the commonly used centers’ positions of their areas [9, 18]. This will increase the reliability level of the soil movement distance to establish the appropriate costs of computer time [7, 8]. The formulas for determining the positions of the gravity centers of bodies (BGC) are given in the reference book [9] and in other sources.

Introduction
In a vertical layout, it is taken into account that the vertical faces and projected surfaces in soil prisms and pyramids are flat, and natural surfaces are often random. But to determine the volumes of soil bodies, they are considered to be conditionally flat, which allows us to consider them with sufficient accuracy as “correct” prisms, pyramids, wedges and establish the BGC positions in them [15].

BGC homogeneous prisms’ provisions can be installed at the intersections of the lines drawn through BGC their opposite lateral faces, representing generally trapeziums. In heterogeneous prisms BGC can be installed in the parts of the excavation and embankment, divided into pyramids.

No positioning required BGC maps, if it is allocated for soil dumping by the dump trucks from the temporary earthen structures, but its boundary can be precisely set according to the methodology in work [4].

Planning planes are usually designed with small slopes, so they are not taken into account in calculating the soil bodies’ volume and the soil movement routes lengths.

Results
For quick and accurate BGC positioning a side face of the prism a table has been developed [18], which indicates the distance from the node with a larger working elevation to BGC lateral face, taking into account the prism square size and the ratio of work marks on the verge of lesser to greater.

**Table 1.** On determining the position of the prism lateral face gravity center

| \( h_p^{\text{min}} \) | \( h_p^{\text{max}} \) | The distance from the node with a larger working elevation, m, to the prism lateral face gravity center with its length, m, on scales, m |
|-----------------|-----------------|----------------------------------------------------------------------------------|
| \( m \) | 100 | 90 | 80 | 70 | 60 | 50 | 40 | 30 | 20 |
| 0   | 33.3 | 30.0 | 26.7 | 23.3 | 20.0 | 16.7 | 13.3 | 10.0 | 6.7 |
| 0.05 | 34.9 | 31.4 | 27.9 | 24.4 | 21.0 | 17.5 | 14.0 | 10.5 | 7.0 |
| 0.10 | 36.4 | 32.7 | 29.1 | 25.4 | 21.8 | 18.2 | 14.5 | 10.9 | 7.3 |
| 0.15 | 37.7 | 33.9 | 30.1 | 26.4 | 22.6 | 18.8 | 15.1 | 11.3 | 7.5 |
| 0.20 | 38.9 | 35.0 | 31.1 | 27.2 | 23.3 | 19.4 | 15.6 | 11.7 | 7.8 |
| 0.25 | 40.0 | 36.0 | 32.0 | 28.0 | 24.0 | 20.0 | 16.0 | 12.0 | 8.0 |
| 0.30 | 41.0 | 36.9 | 32.8 | 28.7 | 24.6 | 20.5 | 16.4 | 12.3 | 8.2 |
| 0.35 | 42.0 | 37.8 | 33.6 | 29.4 | 25.2 | 21.0 | 16.8 | 12.6 | 8.4 |
| 0.40 | 42.9 | 38.6 | 34.3 | 30.0 | 25.7 | 21.4 | 17.1 | 12.9 | 8.6 |
| 0.45 | 43.7 | 39.3 | 34.9 | 30.6 | 26.2 | 21.8 | 17.5 | 13.1 | 8.7 |
| 0.50 | 44.4 | 40.0 | 35.6 | 31.1 | 26.7 | 22.2 | 17.8 | 13.3 | 8.9 |
| 0.55 | 45.2 | 40.6 | 36.1 | 31.6 | 27.1 | 22.6 | 18.1 | 13.5 | 9.0 |
| 0.60 | 45.8 | 41.2 | 36.7 | 32.1 | 27.5 | 22.9 | 18.3 | 13.7 | 9.2 |
| 0.65 | 46.5 | 41.8 | 37.2 | 32.5 | 27.9 | 23.2 | 18.6 | 13.9 | 9.3 |
| 0.70 | 47.1 | 42.4 | 37.6 | 32.9 | 28.2 | 23.5 | 18.8 | 14.1 | 9.4 |
| 0.75 | 47.6 | 42.9 | 38.1 | 33.3 | 28.6 | 23.8 | 19.0 | 14.3 | 9.5 |
| 0.80 | 48.1 | 43.3 | 38.5 | 33.7 | 28.9 | 24.1 | 19.3 | 14.4 | 9.6 |
| 0.85 | 48.7 | 43.8 | 38.9 | 34.1 | 29.2 | 24.3 | 19.5 | 14.6 | 9.7 |
| 0.90 | 49.1 | 44.2 | 39.3 | 34.4 | 29.5 | 24.6 | 19.6 | 14.7 | 9.8 |
| 0.95 | 49.6 | 44.6 | 39.6 | 34.7 | 29.7 | 24.8 | 19.8 | 14.9 | 9.9 |
| 1    | 50.0 | 45.0 | 40.0 | 35.0 | 30.0 | 25.0 | 20.0 | 15.0 | 10.0 |
\[ h_{p}^{\text{min}}, h_{p}^{\text{max}} \] – are the smaller and larger working marks in the prism accordingly

To determine the rationale BGC heterogeneous prisms, they should first be divided into the triangular pyramids in terms of which their volumes and BGC positions are clearly established.

It is known that BGC pyramids are located on the straight lines, lowered from their vertices to GC bases and 1/4 of the bases’ height.

Let us consider an example of positioning the BGC pyramids of an inhomogeneous prism according to Figure 1. According to it and in the subsequent figures, the letter symbols mean the following:

O₁, O₂ – are the zero points; A, B, C, D – are the tops of angles (nodes) in prisms and pyramids; ±H – defines working marks (with or without the numerical values).

**Figure 1.** Schemes of an inhomogeneous prism (exaggerated scales)

- a - side face AB; b - prism plan; in - side face CD; 1 - gravity centers of the prism trapezoidal lateral faces; 2 - gravity centers of pyramids with one zero point; 3 - gravity centers of pyramids with two zero points

In the pyramids, the vertices should be installed at the points according to one of the working marks that differ from the other two in particular. For example, in pyramids with two zero points (O₁BO₂ and O₁O₂D) the vertices are set at the points with working marks +0.600 (point B) and -1.620 (point D). Their bases are the planning planes.

In pyramids with one zero-point ABO₁ and CDO₂ vertices are set at zero points. Their bases are the corresponding lateral faces of the prism; therefore, they can be called the “lying” pyramids.

GC bases provisions in these pyramids are set differently. For example, in the lying pyramids GC grounds on the area plan are established in relation to the working marks according to the Table. In the pyramid ABO₁ on the brink AB in relation to working marks (see Fig. 1) 0.540/0.600=0.900 and the length of the face 100 m, the distance from the node with a larger working mark (0.600) to GC will be 49.1 m (point 1). In a similar pyramid CDO₂ with the ratio of working marks (-0.180) / (-1.620) = 0.111, the required distance is 36.7 m.

BGC of these pyramids are located, as indicated above, at a distance of 1/4 of their height from the bases and are indicated by points 2.

In pyramids with two zero points the BGC position is set according to the following calculation and graphic scheme (Fig. 2 - exaggerated non-scale scheme) using the example of a pyramid BO₁O₂ (see Fig. 1). Its BB’ height corresponds to the working mark. To determine the GC pyramids position first its foundations’ GC position is set - at the intersection of medians B’T₁ (the main, dividing in half
a piece of the zero-work line $O_1O_2$ and $O_2T_2$ in the point $M$. On a straight line from the top of the GC pyramid tits founding $BM$ long $K$ for $1/4$ its height at a point $H$ of the GC pyramid body is located. With the length of the main median $X$, it is easy to prove (see Fig. 2): the pyramid $BGC$ is projected in the middle of the main median - to the point $H'$.

![Figure 2. Definition Scheme of the GCT pyramid with two zero-point](image)

Sometimes it is advisable to establish the positions in an inhomogeneous prism $GC$: general - according to the pyramids of the excavation and general - according to the pyramids of the embankment. To do this, it is possible to apply the method of static moments or the graphical method (Fig. 3), which consists in the following:

- straight lines connecting $BGC$ excavations $(1;1)$ and embankments $(2;2)$;
- straight lines connecting $GC$ opposite triangular lateral faces of the prism parts - notches $KK'$ and mounds $MM'$.

At the intersections of these lines $GC$ parts of the notch (point 3) and the $GC$ parts of the embankment (point 4). For comparison, the figure shows the $GC$ parts of the excavation and embankment over their areas with the numbers 5 and 6.

![Figure 3. Positioning Scheme GCT heterogeneous prism separately for the excavation and embankment parts](image)
Discussion
The vertical layout of the areas is carried out, as is known, according to square grids with the squares sides sizes, depending on the terrain nature, the construction conditions of the object, etc. Design planes are set at the levels that mainly meet the requirements of the construction object operation [16]. The volume of soil planning dredging and embankments is established on them.

To determine labor costs and machine time on a vertical layout, it is known that, in addition to the excavations and embankments volume, it is also necessary to establish the distances of the soil movement from the excavation prism to the embankment prism.

In many cases, the basis for calculating the costs of computer time is the soil movement distance from the planning ditches to the planning embankments in the centers of their areas. But this principle can lead to a result markedly different from the real one. To find its significance, let us consider an example with the prisms measuring 60x60 m in plan. GC of their area will be located at a distance of 30 m from any face. If these prisms have two zero marks on one side, then their GC will be located at a distance of 20 m from the edge opposite the zero marks.

If another prism similar to it is located “mirror” on the opposite side of the zero work line, then the distance between their GC will change by (10 + 10) 20 m compared to the distances between GC of their area, which is 2 times greater than the gradation of distances to determine the time norm - 10 m for earth moving vehicles in Unified Standards and Prices E2-1.

With the increase in the square prisms’ size, the discrepancies in the distances between BGC and GC areas will increase and with a size of 100x100 m the squares will amount to 16.6 m. Therefore, the use of BGC prisms provisions is appropriate.

Summary
Use of BGC prisms provisions when planning soil movement will eliminate the irrational (intersecting) routes.

To determine the sufficiently accurate distances of soil movement along the prisms with their establishment at the gravity centers of their areas, the squares of the site should not exceed 40-50 m.

With a calm relief of the site for construction, the squares’ sizes of the prism splitting can be quite large (up to 80 ... 100 m), but reliable when establishing the lengths of the soil movement routes between the gravity centers of their bodies.

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