Summary of calculation methods of engineering earthwork

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Abstract. Earthwork calculation occupies an important position in all aspects of engineering construction, and its calculation accuracy and efficiency will have a significant impact on engineering construction. This article analyzes and summarizes the calculation results of various methods and software used in calculating earthwork; points out the shortcomings of the existing earthwork calculation methods; discusses the future development direction of earthwork calculation, which requires not only high accuracy, but also Faster and smarter information feedback provides timely and effective reference and guidance for project construction.

1. Conventional earthwork calculation method

1.1. Section method

The cross-section method is to divide the site at a certain interval according to the scope of earthwork calculation on the topographic map or the plan view of the broken part, and divide the site into several parallel cross sections; it is composed of the design elevation and the ground line Cross-sectional view, calculate the area enclosed by each cross-section line; multiply the average of the area of two adjacent cross-sections by the equal interval to obtain the volume between each two adjacent cross-sections; add the volumes of each adjacent cross-section , Find the total volume, this method is called section method, as shown in Figure 1.

Multiply the average of the fill and excavation area of two adjacent design sections by the distance between the two sections to obtain the number of excavated and filled earth and rocks between the two adjacent cross sections.

\[ V = \frac{(A_1 + A_2)L}{2} \quad (1) \]

In the formula, \( A_1, A_2 \) are the excavation or filling area of two adjacent transverse sections; \( L \) is the distance between two adjacent transverse sections, which is generally selected according to needs, and the area \( A_1, A_2 \) are adopted according to the measurement data of the transverse sections [1]
1.2. Grid method

The principle of the square grid method is to divide the site into a number of square grids, interpolate to find the elevations of the four vertices of each grid, and calculate the depth and amount of filling for each grid based on the measured elevation and the design elevation. The total amount of filling and excavation of the grid and the amount of slope earthwork are summarized, namely the total amount of earthwork of the site [1].

It is necessary to determine the zero point and zero line when calculating the grid. The zero line is the intersection of the fill area and the excavation area. On this line, the construction height and the amount of fill and excavation are both zero. The zero line is connected by the zero points. The zero point diagram method is shown in Figure 2. The formula for calculating the zero point is as follows:

\[ x_1 = \frac{h_1}{h_1 + h_2} \times a, \quad x_2 = \frac{h_2}{h_1 + h_2} \times a \]  

(2)

In the formula, \( x_1, x_2 \) is the distance from the grid to the zero point, \( m \); \( h_1, h_2 \) are the absolute value of the construction height at the two ends of the grid, \( m \); \( a \) is the actual side length of the grid, \( m \).

In actual work, the graphic method is often used to draw the zero line directly. The method is: mark the value with the same ratio at the adjacent corner points, connect the two ends and cross the grid edge to get the position of the zero point, as shown in Figure 2.
1.3. Contour method

The calculation principle of the contour method is to divide the topographic map into several parts with contour lines. First, measure the area enclosed by each contour line. The volume of each layer is calculated according to the area formula of the platform and the truncated cone. Add the volume of each layer to get the total earthwork, as shown in Figure 3.

When the two contour lines are approximately a platform, the volume formula is:

\[ V_i = \frac{1}{2} h_i (S_{i-1} + S_i) \]  

(3)

When the two contour lines are approximately a truncated cone, the volume formula is:

\[ V_i = \frac{1}{3} h_i (h_{i-1} - h_i) \left( S_{i-1} + S_i + \sqrt{S_{i-1} S_i} \right) \]  

(4)

In the formula, \( S_{i-1}, S_i \) are the area of the ground above and below the number \( i \) layer, and \( h \) is the corresponding equal height distance.

![Figure 3. Contour method](image)

1.4. DEM method

Digital Terrain Model (DTM) is a way to describe the shape of the ground surface with the plane coordinates and elevation of a group of ground points. Any feature content of the surface, such as soil type, vegetation, elevation, etc., can be used as the feature value of DTM. DTM with elevation as its characteristic value is also called Digital Elevation Model (DEM) [2].

The earthwork calculated by the DEM model is based on the ground point coordinates (X, Y, Z) measured on the spot and the design elevation. A triangulation network is generated to calculate the amount of filling and excavation of each triangular prism, and finally the accumulation of the filling and the specified range Excavation dividing line [3, 4], as shown in the figure.

The upper surface of the triangular prism is fitted with an inclined plane, and the lower surface is a horizontal plane or reference plane. The calculation formula is:

\[ V_i = \frac{1}{3} \left( H_{i-1} + H_i + H_{i+1} \right) \cdot S \]  

(5)
In the formula, $H_1$, $H_2$, $H_3$ are the height difference of the corners of the triangle; $S$ is the area of the base of the triangular prism.

**Figure 4. DEM method**

1.5. *The scope of application and accuracy analysis of the four methods*

The earthwork calculation under complex mountain terrain conditions is suitable for the DEM method; the earthwork calculation under the flat terrain conditions is suitable for the square grid method; the contour method is suitable for the estimation of the volume of the mountain; roads, rivers and other narrow belt-shaped areas. The section method can be used to calculate the square quantity. [5-7]

The earthwork calculated by the DEM method and the square grid method is closer to the equilibrium value, and the cross-section method and the contour method have greater errors in the earthwork calculation; the square grid method and the cross-section method have different sampling intervals, the sample spacing. The smaller the value, the higher the accuracy of the calculation results of the two methods, and the smaller the fill-excavation difference. Although the results calculated by the grid method under different sampling intervals have errors, the calculation results are more stable than the section method [8-10].

2. *Improved earthwork calculation method and examples*

2.1. *Theoretical improvement*

Changshun Liu [12] applied the basic principle of double integration to propose a method for determining project earthwork based on different resolutions of DEM. Taking the Qingliangjiang Project in Nangong City, Hebei Province as an example, the calculation and analysis were carried out, and the calculation results were compared with the calculation results of related literatures. It shows that this method is feasible to calculate the earthwork. Guanghui Zhang [13] adopted the method of directly measuring the feature point coordinates from the topographic map or the plan view measured by the fragments without drawing the cross-sectional view, and then calculating the cross-sectional area and volume. This method was successively used in the second phase of the Qinshan Nuclear Power Plant. It has been used and verified in many projects such as the Yihuang Expressway and the Three Gorges Project in Hubei Province, and has met the design requirements. Jianying Liu [14] proposed a calculation method for the corresponding earthwork, taking full account of the impact of the site and other environmental factors for artificial landforms with large elevation changes. After many inspections and verifications, the elevation measurement and earthwork calculation were carried out in strict accordance with the requirements of the internal and external industries. The result was slightly different from the actual filling and excavation amount, meeting the requirements of the specification, and was highly evaluated. Shufang Zhang et al. [15] introduced a square grid calculation method based on the design surface triangulation in order to solve the problem of earthwork calculation in irregular design surface landscape river engineering. The engineering case shows that it has good application in solving the irregular area earthwork calculation. Sex and universality. Jian Luo [16] studied the different types of earthwork excavation, and discussed the calculation method of the foundation pit earthwork quantity, put forward a formula that can be easier to understand to achieve the purpose of convenient memory, and introduced the need in calculating the quantity Attention to detail
2.2. Program realization
Qiqing Duan [17] used the principle of linear interpolation to form DTM according to the principle of filling and digging balance to design the program of earth and stone calculation and put it into use at a construction site to improve work efficiency. Weimin Li [18] developed the DTM-VOL earthwork calculation software by using the digital ground model automatically established by the digital mapping software, which realized the fully automatic process of earthwork integration of internal and external operations. Jiahua Chen and Youtang Hong [19] realized the program design of regular grid earthwork calculation based on the scattered point data measured in the field. Yuzhen Zuo and Yongqiang Yan [20] developed an "interpolation method" to calculate the earthwork in the process of optimizing the ArcGis software based on the DEM method. The test in the county’s shallow hilly area puts forward the application of the two methods, which provides a reference for the development of earthwork calculation software for land development and consolidation. Long Ma [21] used four different DEM interpolation methods to establish DEM, and evaluated the established DEM accuracy using the error accuracy model. The results proved that the kriging method is the most suitable method for calculating earthwork in the experimental area.

3. Earthwork calculation software
With the development of computer technology, various software capable of calculating earthwork are emerging in an endless stream, and are more and more widely used in various engineering constructions. They are mainly divided into the following categories: GIS series (ArcGIS, Arc view, MAPGIS, Autodesk Map), AutoCAD series (HTCAD, Southern CASS, Civil3D, Fischer, ZDM), remote sensing series (ERDAS) and BIM series (Revit), the following is an introduction to some of the frequently used software and its calculation effects [22]

3.1. GIS series
GIS series software is the most used in calculating earthwork. Many researchers have used GIS series software to calculate earthwork, and ArcGIS is the most used. Chen Yong [23] used ArcGIS geostatistical analysis module to calculate the amount of earthwork for land leveling; Hongfei Pan and Cuiwei Zhao [24], Chunmei Li and Haitao Jing [25] and others based on the TIN form of DEM, using the Cut in the ArcGIS 3D Analys module The /Fill tool calculated the amount of earthwork; Changshun Liu and Lijuan Du [26] used Arcview to calculate the amount of earthwork for land consolidation projects; Zhang Xinhai et al. [27] discussed the application of MAPGIS in the calculation of earthwork; Zhigang Xu [28]The amount of earthwork was calculated by AutoDesk Map 3D software. In addition, Po Yang and Baoxia Fan [29] used a three-dimensional laser scanning technology based stone monitoring program to compare and analyze the data through a monitoring and analysis system implemented by the secondary development design of Arc Engine, and obtained valuable analysis results. From the perspective of usage, ArcGIS is the most used, followed by MAPGIS, and finally Arcview and AutoDesk Map 3D; from the calculation results, the calculation results of ArcGIS and Arcview are very close; from the perspective of operating efficiency, the calculation speed of ArcGIS and Arcview is faster Slow, MAPGIS is faster.

3.2. AutoCAD series
The Southern CASS software of the AutoCAD series is also a commonly used software for calculating the volume. It can use DEM models, cross-sections, square grids, contours and other methods for earthwork calculations; in recent years, Hangzhou Jiayuan Technology Co., Ltd. has also launched HTCAD, Provides a variety of earthwork calculation methods for various complex terrain conditions; Civil3D is a 3D design software launched by Autodesk in the civil engineering industry, which can create 3D terrain and calculate earthwork. Quansheng Zhang, Xinjiao Wang [30] used the Southern CASS software to compare the characteristics of the DEM method and the square grid method; Wang Kai, Shimin Guo [31] carried out the DEM method, DTM method and grid method in the Southern CASS software and ArcMap software Feng Qin [32] introduced several typical applications of Civil 3D
in earthwork calculation in earthwork, and proved that Civil3D is a powerful and very applicable civil engineering software. Yanping Bai [33] used the Feishida earthwork calculation software and Casio 9860 calculator to solve the problem of inaccurate stakeout and earthwork calculation; other related software includes ZDM, etc. [34].

3.3. Remote sensing series
The ERDAS IMAGINE software in the remote sensing series is a remote sensing image processing system developed by the US ERDAS company. It can be combined with traditional grid method and DEM method for earthwork calculation [35], but it is not used much at present.

3.4. BIM series
BIM technology has developed rapidly in recent years, and its applications in construction engineering technology are increasing. Some researchers are trying to apply it to earthwork [36, 37], and found that the calculation effect of earthwork is good and the result is more accurate. But in general, the BIM software supports a small spatial range and cannot carry a large amount of terrain data. Therefore, it can only calculate the amount of earthwork in a small area, which needs further study.

4. Prospects of Earthwork Calculation Research
With the continuous development of science and technology, drone aerial survey technology and ground 3D laser scanning technology, as a new type of measurement method, have played an important role in different measurement fields. They have the advantages of fast measurement speed, high accuracy, and easy operation. The development of technology is relatively short, there are still problems such as high cost, insufficient data analysis system, and unstable equipment operation. We believe that with the development of time, mankind will conduct in-depth research on new measurement technology, its performance will become more perfect, the construction cost will be cheaper, and it will have a better use effect in engineering measurement.

5. Conclusion
The calculation of engineering earthwork plays an important role in the planning of the entire project. It is related to the budget of the project cost and the preparation of the specific construction plan. The accurate result of the calculation can make the construction plan reasonable, convenient and quick to construct, and improve the project schedule. At present, there are various calculation methods and means of earthwork, and it is indeed possible to calculate earthwork effectively in the planning and design stage. However, in the actual project, we still need to analyze the specific conditions, fully understand the development status of the earthwork calculation industry, and choose the calculation methods and measurement methods suitable for the project.

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