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GIS in Excavation Volume estimations for Intake Structures: An Industrial Approach

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Abstract

Estimating excavation quantity for construction in a challenging terrain surface is quite complicate. Thus, modelling the natural terrain from survey data and excavation profile from excavation plan in GIS (Geographical Information System) helps to estimate the quantity of soil to be excavated and filled with better accuracy. Also, it is possible to visualize the exact 3D model of excavation profile with respect to the natural terrain. In this study, excavation quantity for an intake structure was estimated using ArcGIS Pro software. Triangulated Irregular network (TIN) was created for pre and post cut/fill scenarios using appropriate GIS tools. Surfaces were created using the TIN of same cell size for calculation. The Cut Fill tool of ArcGIS software calculates the volume using the formulae, Volume = (cell area)*ΔZ, Where the cell area is the spatial resolution of the DEM used and ΔZ is the difference in z value between the pixels of two surfaces at that location. This tool was used for volume calculations for excavation/filling. This method takes very less time and cost than any manual or software computations. This enables contractors to decide on the precise volume for costing.

Keywords: GIS, Excavation, 3D Models

Introduction

The computation of volume is an essential engineering application used in several fields, such as evaluating mine reserves and determining excavation and earth fill for sites such as motorways, tunnels, and airports. Other applications include evaluating the size of a mine's reserves and determining the size of an excavation. Volume calculation is an important application for any construction activity. For large construction activities like water Intake structures, a huge amount of earthwork is required, which involves a huge cost. Thus, estimating the cutting and filling volume prior in the planning stage will result in better cost management.

The 2D approaches, such as the average-end method, prismoid formula, and other models developed based on them, are not precise in principle but are realistically employed in engineering. (Ragab, 2015).

The 3D concept developed a digital Elevation Model (DEM) for the surface, a Triangular Irregular Network (TIN), and earthwork amounts by comparing the TIN of the original terrain to that of the final project (Du and Teng 2007; Bao, 2011; Kerry et al. 2012; Bhatla et al.,2012). The provision of Geographic Information System (GIS) assistance for the development of a three-dimensional representation of the current ground surface and the excavated surface in accordance with the excavation plan. ArcGIS Pro software has many geoprocessing tools to calculate the cutting and filling quantity from the existing and after excavation surfaces. The representation of the current ground, the final as-built surfaces, and the design, all of which may be layered and differentiated such that the Geographic Information System can be used to determine volume. In the ArcGIS pro program, there are many tools that may be used to compute the volume of earthwork in three dimensions based on TIN or grids sets that include data, or by interpolating data from cross sections. No data is collected in locations where surveyors are unable to access, reducing the quality and richness of the data obtained. The quality of data collected by Total Station and GPS technology varies from user to user because it is based on the user's judgement, experience, and intuition. In this study, excavation quantities required for the construction of an intake structure was arrived using ArcGIS Pro software.

Materials and Methods

This study involves the following procedures (1) Collection of survey data (levels) for natural ground level (NGL) (2) Collection of excavation plan data as per the Intake design (3) Creation of TIN from NGL and excavation profile (4) Creation of DEM from TIN for before and after excavation (5) Quantity estimation using Cut Fill geoprocessing tool (6) 3D multipatch creation of exact excavation profile.

Study Area

The region of this study is situated along the Ban Sagar Lake in Shahdol district of Madhya Pradesh. It is the largest manmade lake in India. The study area lies between 24 ° 5’ 33” - 24° 5’ 37” north latitudes and 81° 0’ 21” – 81° 0’ 27” east longitudes (figure 1).

A water intake structure was planned to be constructed at this location as a part of Satna water supply system project of Madhya Pradesh. Thus, an excavation plan was prepared for the construction activity of this site is shown in the figure 2. A lot of analyses are realized easily with the help of DTM which has been produced by using GIS which has been realized with the development of information technology (Gumus et al, 2003). For modelling of Cutting and Filling and estimation, ArcGIS Pro 2.8 software was used.

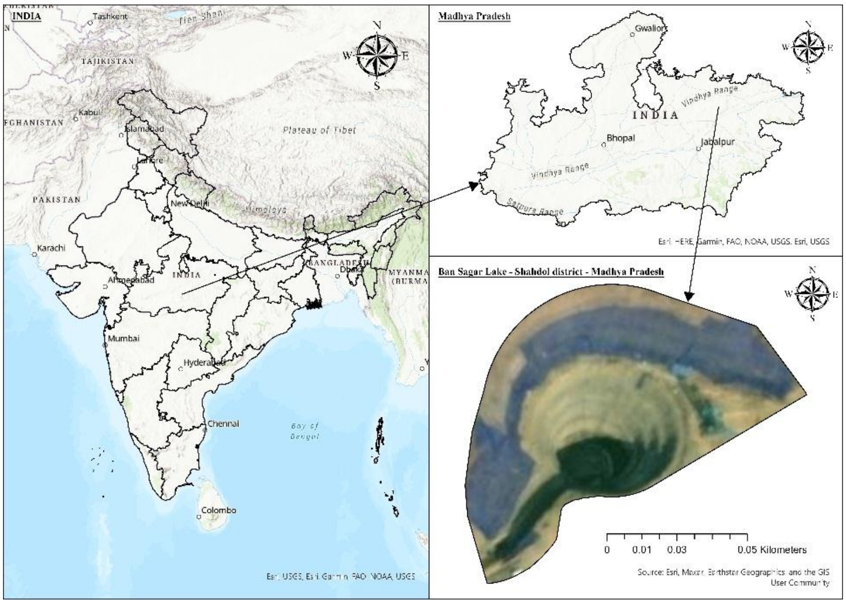

Figure 1. Study Area

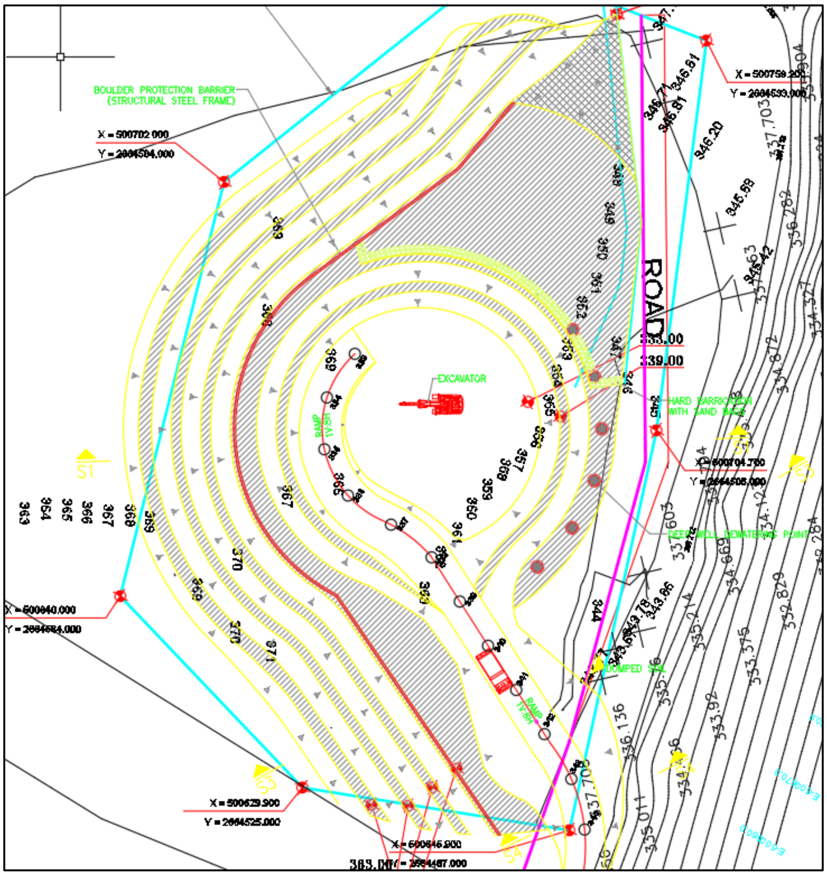

Figure 2. Excavation Plan

Creation of Natural Ground DEM

A total station survey was conducted for the area under study to collect the elevation points of the existing ground. DEM of 0.1 m resolution was created from the level points (figure 3). Topo to Raster method was used for creating DEM as it found to be the best method with higher accuracy rate (Ragab,2015). An interpolation approach that was developed expressly for the purpose of producing hydrologically corrected digital elevation models (DEMs) is called the Topo to Raster tool. It is based on the ANUDEM software, which was created by Michael Hutchinson (1988, 1989, 1996, 2000, 2011) and may be found on the website of the Australian National University's Digital Elevation Model. TIN created for the natural ground level for 3D modelling is shown in figure 4.

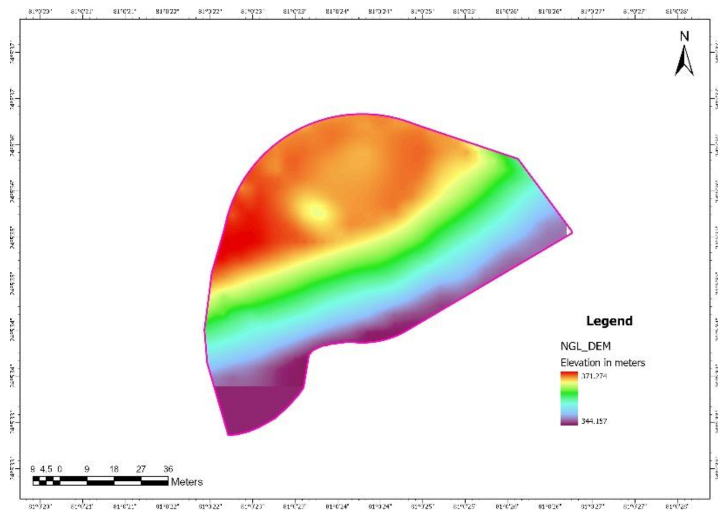

Figure 3. DEM of Natural Ground

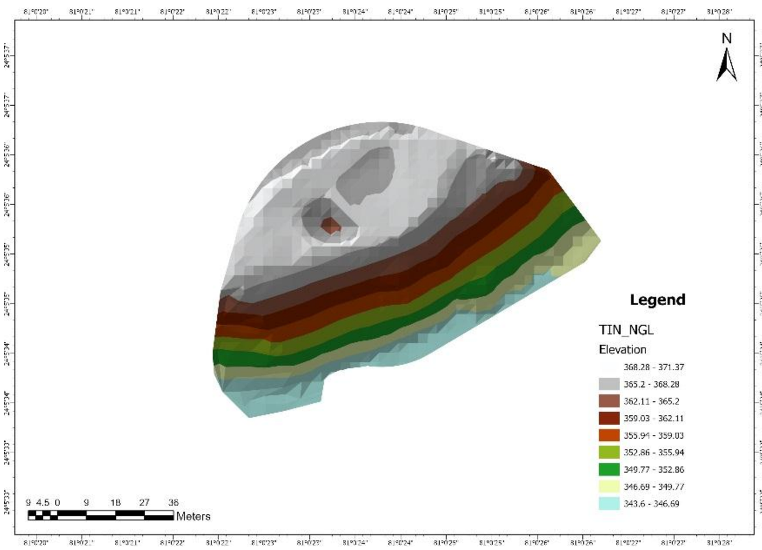

Figure 4. TIN of Natural Ground

Creation of Excavation Profile

Elevation fields were added to each line as From_Elevation and To_elevation and the respective elevation as per the excavation plan was updated. These lines were converted to 3D using Feature to 3D by attribute geoprocessing tools. These lines were densified using densify tool to improve the accuracy of interpolation while creating the TIN surface. For the outer line, the z values were updated from the natural ground level DEM using interpolate shape tool. The 3D Excavation profile lines derived from excavation plan are shown in the figures 5 and 6.

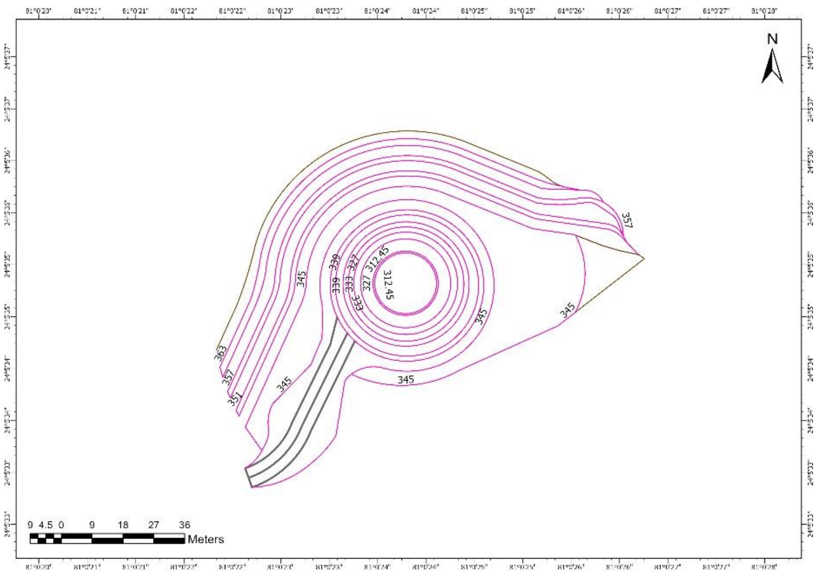

Figure 5. Excavation Plan in GIS

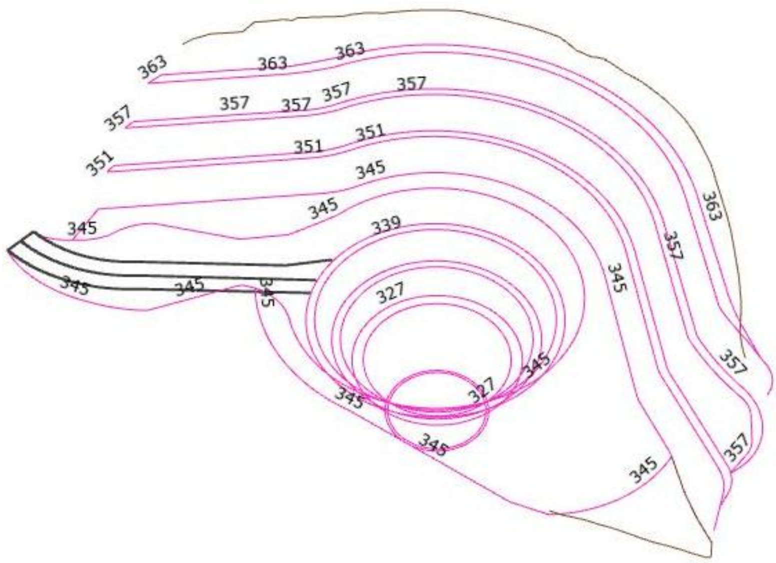

Figure 6. 3D Excavation Plan in GIS

Creation of Excavation profile DEM

TIN was created using the excavation profile lines as input feature classes using create TIN tool (figure 7). Excavation DEM was then prepared as raster from TIN with the cell size of 0.1m and linear interpolation. The DEM is clipped to required boundary (figure 8). The variation of levels is from 312.45 m to 371 m in the boundary which is considered for excavation.

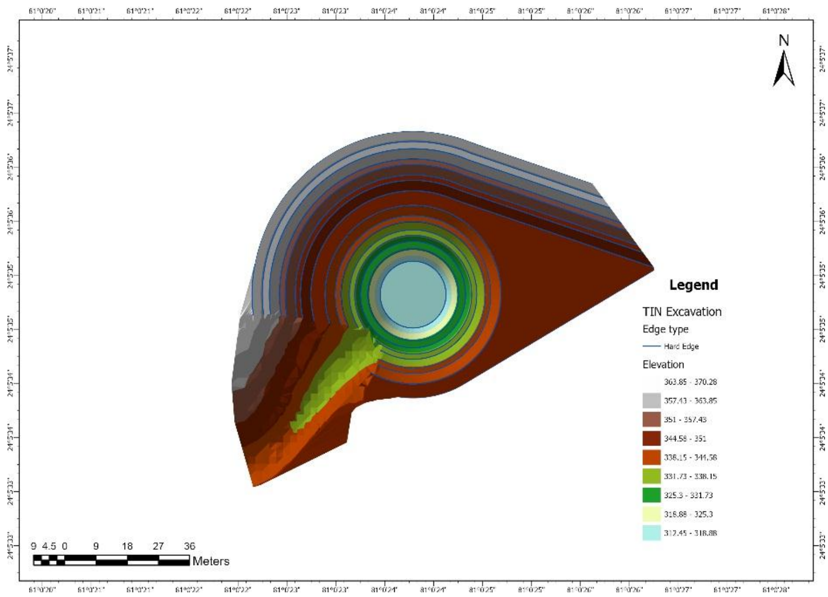

Figure 7. TIN of Excavation Plan

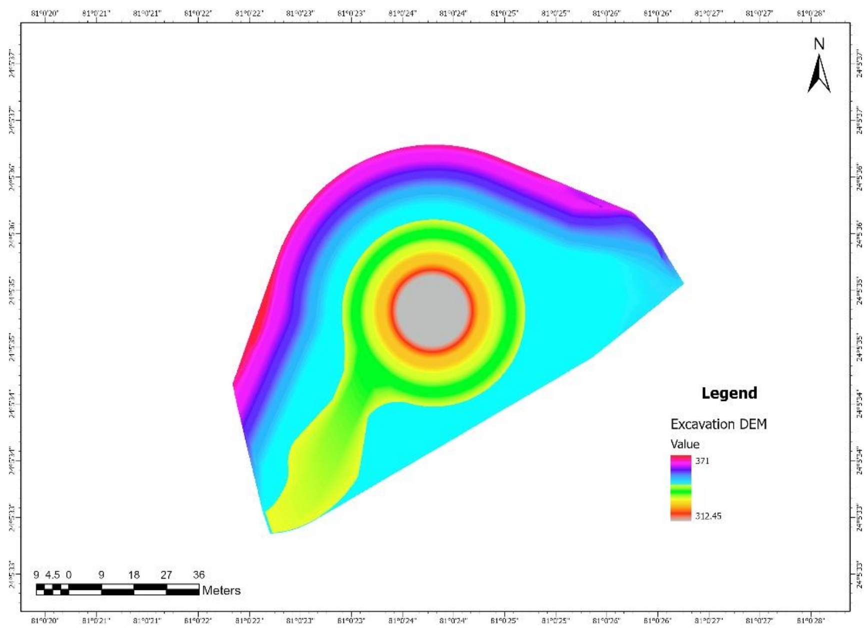

Figure 8. DEM of Excavation Plan

Estimation of Cutting

ArcGIS Pro's Cut Fill tool makes it possible to generate a map based on two input surfaces—a "before" surface and a "after" surface—that displays the areas and volumes of surface materials that have been transformed as a result of the removal or addition of surface material. This map may be created by comparing the two surfaces. If you want precise results, you need make sure that the z-units are the same as the ground units (x, y). This guarantees that the resultant volumes can be accurately measured using cubic units of some kind. The changes in the surface volumes that occurred as a result of the cut-and-fill operation are detailed in the attribute table of the output raster. Regions of the surface shown by the before raster that have had positive values for the volume difference indicate that they have had material removed from them. The presence of negative numbers indicates the presence of material that has been added to a region. Cut, Fill, and (3D Analyst).

The Cut Fill tool of ArcGIS software calculates volume using the formulae,

$$Volume = (cell\ area)*\Delta Z,$$

where

cell area is the spatial resolution of the DEM used

ΔZ is the difference in $|Z|$ value between the pixels of two surfaces at that location

Cutting and Filling Map (figure 9) was generated using the Cut Fill geoprocessing tool with NGL DEM and Excavation DEM as before and after raster respectively. This tool creates a raster map of net gain, net loss and unchanged pixels and the attribute table of the raster map gives the volume of net gain (filling) and net loss (cutting) of earthwork. The excavation volume required as per Cut Fill geoprocessing tools for this study are as follows:

Area studied	: 7358 square meters
Excavation volume	: 107287 cubic meters
Excavation area	: 6831 square meters

Multipatch of the excavation profile along with the coffer dam and ramp was created using Interpolate polygon to Multipatch geoprocessing tool Figure 10 shows the multipatch of excavation profile.

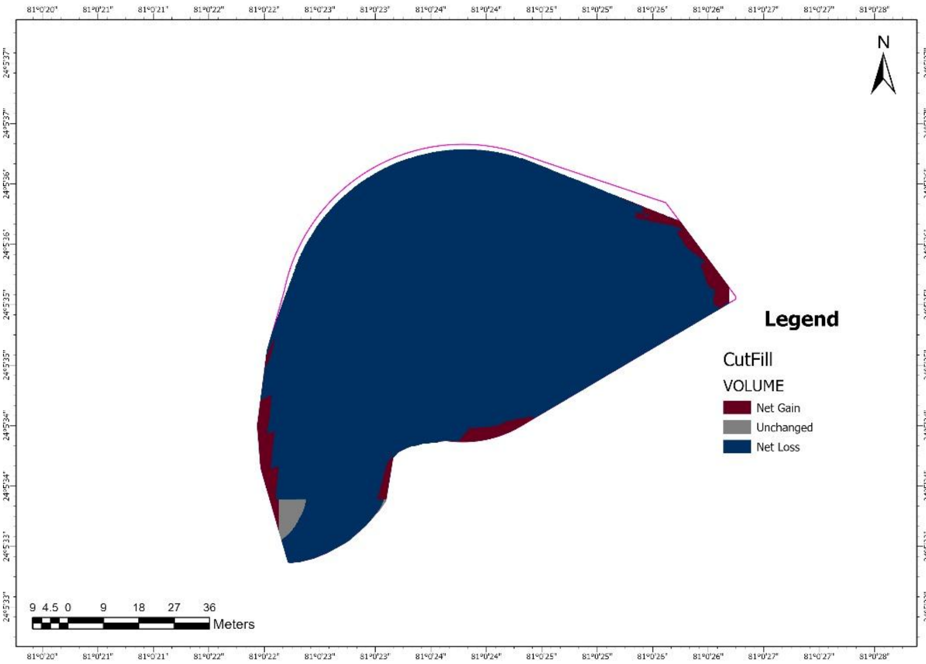

Figure 9. Cut and Fill Map

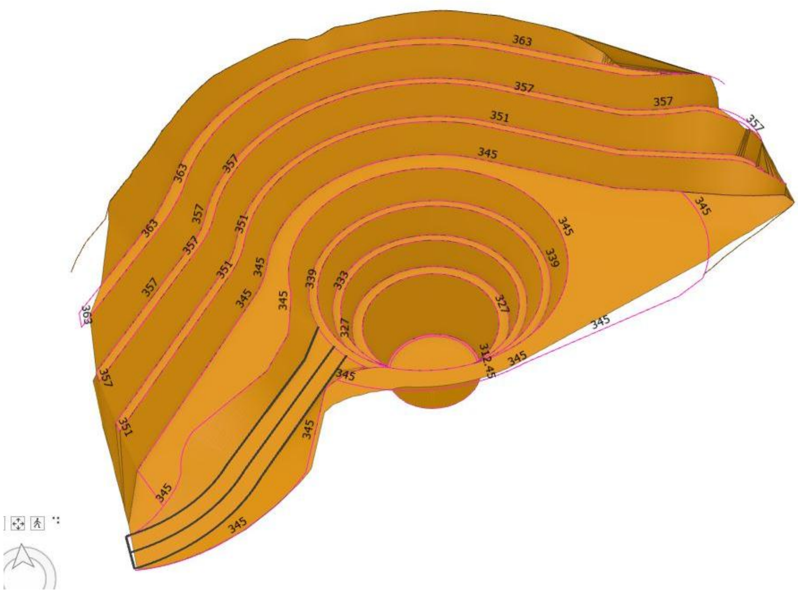

Figure 10. 3D Multipatch of cutting and filling.

Results and Discussion

The cross section of the natural ground level is shown in figure 11 varying from 344.6m to 369.5m above MSL (Mean Sea Level). The terrain has steep slope as there is a level variation of 24.9 m within 70 m horizontal distance and consisting mostly of hard rocks.

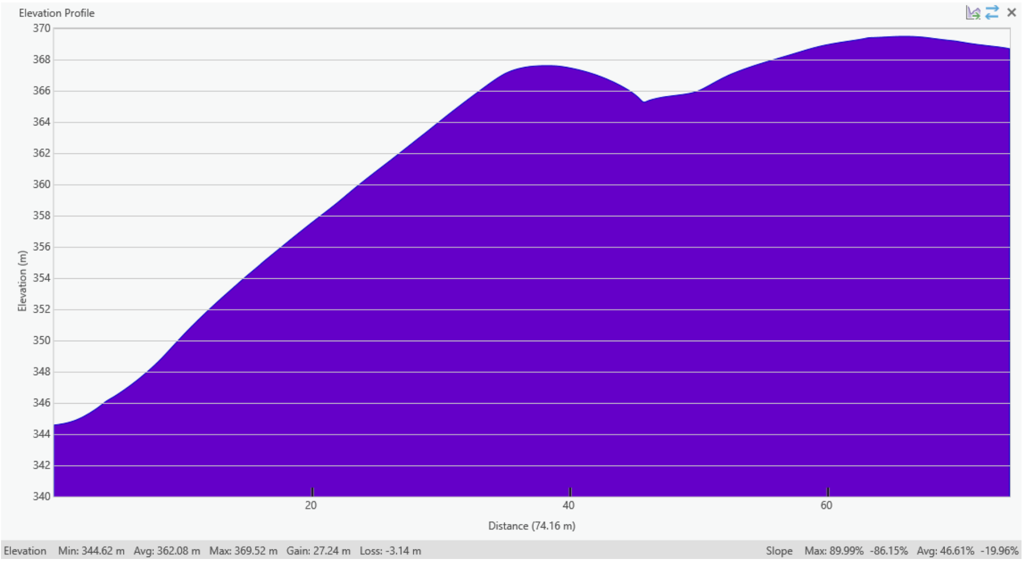

Figure 11. Natural Profile of the Study Area

The cross section of the intake excavation is generated using Profile tool is shown in the figure 11. This cross section is used to verify the dimensions of the excavation plan and section. The cross section varies from 312.45 m to 366.8 m above MSL. The berms are provided at every 6 m from 327 m to 363 m with the slope of 1:2 to maintain the stability and considering the operations of water intake structure.

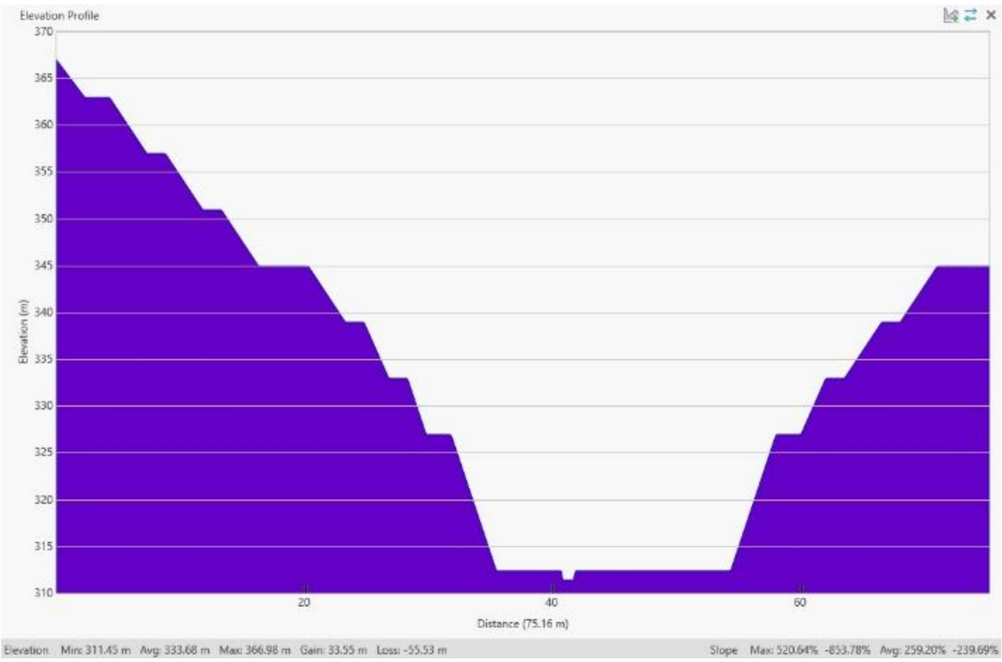

Figure 12. Profile of the Excavation Area

The excavation quantity calculated using ArcGIS, Civil 3D and manual methods for the study area of 7358 sq m are shown in table 1. The manual and Civil 3D calculations differ from the excavation estimate created using the specified GIS methodology by 2.38% and 0.8% respectively. Manual calculations differ from computerised calculations due to the multiple geometric assumptions and approximations that are needed because of the complexity of the terrain. There is a minimal variation of 0.8% between Civil 3D and ArcGIS estimation. GIS based estimation is quite simple and 3D visualization of it makes it better to understand the context and if any error in the plan can be identified easily and rectified before estimating.

Table 1. Excavation quantity

	GIS	Civil 3D	Manual Calculation
Area studied (sq m)	7358		
Excavation volume (cu m)	107287	108228	109904

As the surveying technology is improved in recent time, drone based lidar/ photogrammetry survey can be easily carried out and DEM can be generated at any time to visualize the progress and estimate the remaining excavation as per plan in GIS environment. Exact quantification will prevent excessive costs from being incurred because of approximation estimates for work orders to subcontractors.

Conclusion

Given the constraints of the BIM model and the difficulty of the cut and fill calculations, it is absolutely necessary to include GIS technology in the calculations. As a result of the continued development of GIS systems within the civil infrastructure sector, it is gaining increasing acceptance within the industry (Nassar et al. 2011). Cutting and filling estimated in GIS is accurate than the manual calculation. Computations before the construction activities will reduce the money and time spend on planning on a great scale (Gumus et al. 2003).

The method of computing cutting and filling using GIS helps to save the cost and time calculating the quantity. As 3D models are created for visualization and calculation, there are less chance of error. If any error is made, it will be reflected in the model and can be identified easily and sorted out.

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