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Full Length Research Paper

Close range photogrammetry and robotic total station in volume calculation

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Nowadays, volume calculations are been used in many engineering studies such as road project, mining enterprise, geological works and building applications. In many volume calculations, some approaches such as number of lorry computation instead of mathematical calculation are used because of lack of adequate technical knowledge or insufficiency of software and hardware. Particularly, the difficulties of measurement processes in mine areas, even owing to impossibility of it in some cases, have obliged this kind of solutions. However it is reality that this process does not give volume value at adequate accuracy. In this case, important economic losses have been revealed in many applications. Volume computations can be carried out not only by geodetic measurement but also by photogrammetry and laser scanning technologies. Particularly, in the areas where reaching is risky and difficult, it is more convenient that the calculations should be performed by means of the photograph taken or scanning images of the object rather than land studying. The developments in software and hardware technologies, makes the processes in engineering studies easier and rapid as soon as possible. In this study, the performance of photogrammetry and laser scanning method on volume computation was investigated. For that in an excavation site, the volume computations were performed in both methods. The methods were compared from point of view of accuracy, time and cost. It is concluded that the both methods can be used on account of volume calculations.

Key words: Volume calculation, laser scanning, close range photogrammetry.

INTRODUCTION

Generally, during the studies related to land of engineering projects (road, building, mine, etc.), calculations of land volumes that will be excavated and filled in order to perform cost accounts is needed. The volume calculations are carried and out and to benefit from intersections, prisms, dimensions of surface levelling and the contour.

Nowadays the alternative studies to these methods have been carried out. The base points of these studies are to collect the points that appropriate distribution and density. But this method needs more counting process. These mathematical processes take more time and boring even though it is not complicated. On the other hand these difficulties have been overcome by developments in computer technologies. For this reason, digital land model method have been considered as important, thus it has being the most frequent method used in volume computation. The basic principle of the theory here is to base on X, Y and Z coordinates defining the land perfectly. Each point is connected to the next adjacent point, thus triangle prisms are formed covering all land surfaces. The total volumes of triangle prisms, give volume quantity of whole surface from a certain reference surface. The results of investigation have been increased to the level that will perform volume counting between two complex surfaces. In these days, the studies have been focused directly on volume counting of 3D (three dimensional) surfaces. The recent developments in computer technologies have brought about innovations continuously on 3D measuring technology (Atkinson, 1996). Close range photogrammetry and laser measuring techniques are two technologies affected from these developments. The total stations having Robotic scanner being as effective measuring technology for 3D

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modelling have been developed rapidly as an alternative or rival to present systems. The total stations having Robotic scanner can be obtained by 3D coordinates of hundreds of points. Robotic laser scanners can be used in classic mapping processes. In addition, it broadens new horizons on measurement by means of laser technology having non-contacting measuring ability and application fields that have increased at the same rate, too. The regions where measuring is risky, its advantage to other classic instruments, is increased twice. To become automatic of some processes by the new method in addition to possibilities provided as technological is the other advantage. The measuring processes, whether can not be measured or measured hardly by geodetic methods can now be completed easily by this kind of technique.

The other method attracting attention in 3D measuring technologies is technique of close range photogrammetry. Close range photogrammetry when compared to classic measuring methods is more productive and speedy; it reduces the required time meaningfully to data acquisition on land. The data collected in ten days by classical methods are collected in three days by this method. Each one of measuring point can be obtained physically as non-contacting. It is a quite reliable method (Carbonell, 1989; Kraus, 2007).

In recent years, one of the important reasons for increasing usage regions of close range picture photogrammetry is that, when the objects are measured accurately from classical photographs or from over digital images captured by close distance/range with camera and evaluated, the desired accuracy can be obtained (Atkinson, 1996; Carbonell, 1989). The photogrammetric method is 21.89% faster, 12.83 % more accurate, and its cost is 33.33% less, on the average, compared to the classical method (Yilmaz and Yakar, 2008).

There are some advantages of the close range photogrammetry when compared to the traditional measurement techniques. These are effective and fast to reduce time for collecting field data, safe and reliable in terms of the employees, because measurements are accomplished from remote (Kraus, 2007, 1992).The most accurate volume on irregular surfaces is obtained from the surface, which can be defined as the most accurate. There is a close relationship between the definition of the surface and the scanning interval (Yakar, 2009).

All studies in photogrammetric technique can be completed by only using photographs; this is a noncontact technology. For this reason, the photogrammetric method can be considered particularly for high risk places. It can also be considered useful in the surveying of objects that cannot be physically measured (Yakar, 2009).

In this project, the usefulness and performance of digital close photogrammetry and the total stations with Robotic laser scanner on volume computations have been investigated. For this purpose, an excavating area was selected in a business enterprise where real production is carried out in land, the volumes of excavating area were calculated from data obtained with photogrammetric method and also laser measuring method. The time and cost accounts were executed in land and evaluation studies performed by each method.

MATERIALS AND METHODS

In this study, close range photogrammetry and robotic laser scanning methods were used for volume computation. The details about these methods are given as following.

Close range photogrammetry

Digital close range photogrammetry is a technique for accurately measuring objects directly from photographs or digital images captured with a camera at close range. Multiple overlapping images taken from different perspectives, produces measurements that can be used to create accurate 3D models of objects (Kraus, 1992, 2007; Wolf and Dewitt, 2000; Cooper and Robson, 1996). Knowing the position of camera is not necessary because the geometry of the object is established directly from the images.

Photogrammetry techniques allow you to convert images of an object into a 3D model. Using a digital camera with known characteristic (lens focal length, imager size and number of pixels), you need a minimum of two pictures of an object. If you can indicate the same three object points in the two images and you can indicate a known dimension, you can determine other 3D points in the images.

The photogrammetric 3D coordinate determination is based on the co-linearity equation which simply states that object point, camera projective centre and image point lie on a straight line. The determination of the 3D coordinates from a definite point is achieved through the intersection of two or more straight lines. Therefore, each point of interest should appear in at least two photographs (Kraus, 1992) then, coordinates are measured from 3D model which is constituted by photogrammetric software.

Robotic Total Station

These days, laser measuring concepts are applied in many technical fields by different instruments and methods. Generally, the meaning of non-contacting measuring an object is to execute processes in computer environment using the data obtained as cloud of points. Also, the meaning of 3D scanning process is to obtain the real coordinates of an object as three-dimensional (Kraus, 1992).

The measurement principle of Laser instrument is to calculate the time taken between transmitting and receiving movements of distance signal when laser pulse is sent to object. This principle is known well from electronic tachometers. In this instrument, the light signal is sent to a prism and it is recorded as period of time of the light that is going-coming. Whereas, in laser measuring instruments, since there is no reflecting prism on object measured, the light reflecting from object itself is used (Lichti et al., 2000).

3D laser scanner combines non-cooperation laser range finder and angle measure system. This makes us create dense digital surface model quickly and effectively. The principle of 3D laser scanner is: emit laser and reflected when touching the object, gain distance S, horizontal angle α and vertical scanning angle (θ). Generally, ground 3D laser scanner uses instrument coordinate system: X is in landscape orientation scanning cover, Y is vertical to X in the landscape orientation scanning cover and Z is vertical to landscape orientation scanning cover (Figure 1). Then the point coordinates can be calculated from equation (1) (Lichti et al., 2002).

$$X = S.Cos\ \theta.Cos\ \alpha\ ;\ Y = S.Cos\ \theta.Sin\ \alpha\ ;$$
$$Z = S.Sin\ \theta$$

3D laser scanning technology can measure 3D coordinates point on object surface. Therefore, it belongs to three-dimensional measurement technology. Compared with the traditional surveying method, laser scanning technology has particular superiority as follows: is a sort of untouched measure system,gain the 3D coordinates, reflecting intensity etc. on object surface, rapidity of data acquisition, great quantity of data and high accuracy, work under all kinds of environments and extensive application.

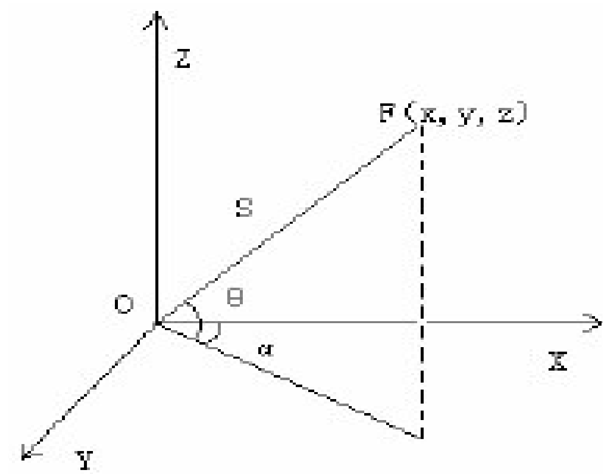


Figure 1. Principle of 3D laser scanning.

FIELD STUDIES

A sand pit 20 m in length, 14 m in depth and 5 m in width was selected for volume calculation (Figure 2). The volume calculations were performed with two methods: photogrammetric method and robotic laser scanning method. The sand excavation in excavating area was carried out by two dump lorry (Figure 3), the dimensions and volume of its trailer are measured respectively as 2.20 x 5.00 x 1.55 m and 17.03 m^3. A sample was taken from sand source in excavation area and pressure rate of this material was calculated as 6% in the laboratory. The amount of sand excavating from sand pit was calculated as.

34.10 -34.10 x 0.06 = 32.054m^3

This value was considered as real volume rate.

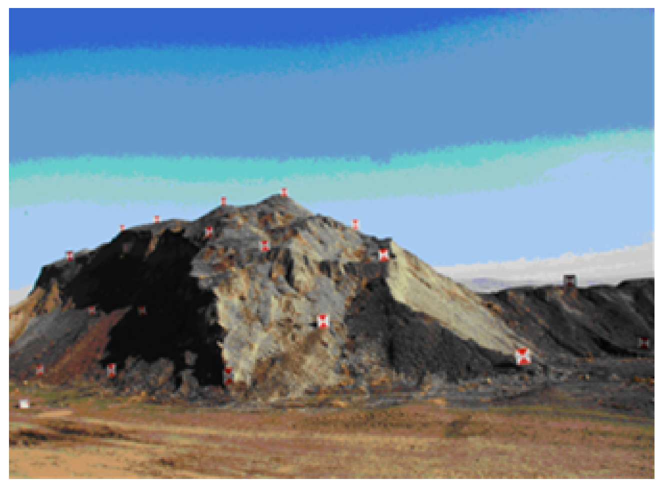


Figure 2. Working land

VOLUME CALCULATION

The volume calculations in this project were performed by three different methods as revealed before. In measurements carried out by these methods, the data required for time, cost and accuracy analysis were also recorded. In volume calculations, the situations before and after excavation were evaluated separately and the volumes were calculated from the difference between both surfaces by using software Surfer 8.0.[10] In the excavation area, a local geodetic network was constituted and formed from three points. Total coordination processes were built based on these points. The studies for volume calculations were explained in detail in the following parts.

Figure 3. A view of working land.

Volume calculation by photogrammetry method

In photogrammetric method, the close range photogrammetry method was used for evaluating the photographs. Before taking photographs, the metal targets were placed in studying area. The metal targets were manufactured from metal plates in dimensions of 20 x 20 cm (Figure 4). Before and after excavation number of 19 control point targets were placed on the land surface, the coordinates of these targets were measured by geodetic measuring instrument. The placing of control points were taken 20 min, while the measuring of coordinates were executed 24 min. While the targets were distributed over the land, they were placed on the areas that do not affect excavation. These points placed as their coordinates are known, that is to say designing to control point about to use photogrammetric evaluating. After the targets were placed on the land, the photographs were taken by digital camera (NIKKON D200-digital SLR) to be suitable to photogrammetric principles, it took 20 min. The photographs were evaluated in the photogrammetric software (Photomodeler 5.0) (Photomodeler 5.0

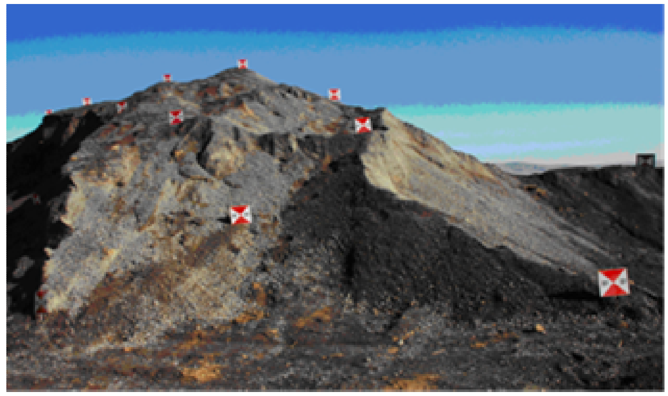


Figure 4. Distribution of targets in working area

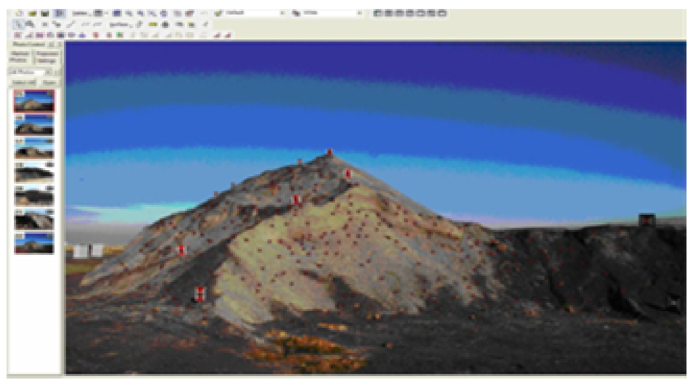


Figure 5. Photogrammetric evaluation.

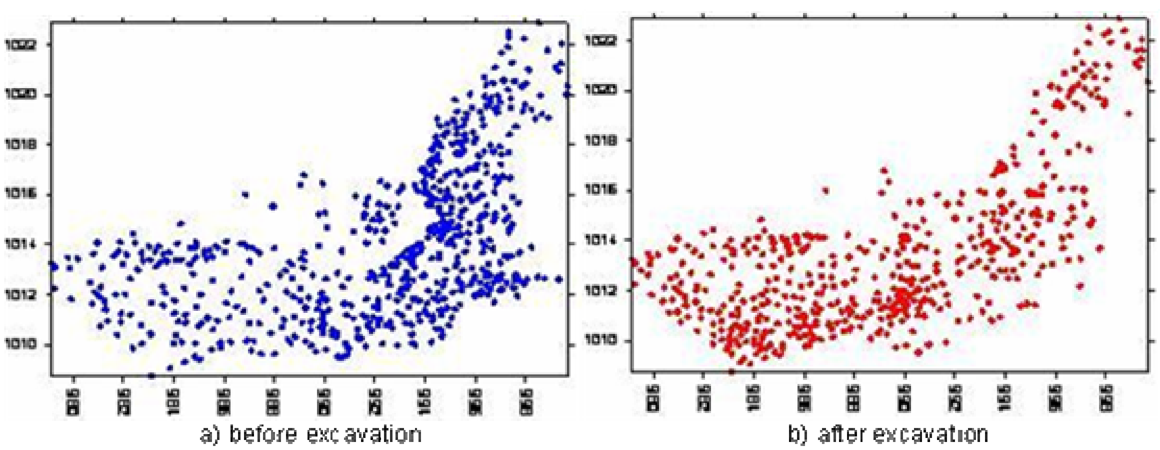


Figure 6. Point distribution before and after excavation.

Software, 2006), (Figure 5). At the end of the photogrammetric evaluation, it was measured 595 points before excavation, 476 points after excavation. The evaluation process was performed 115 and 95 min before and after excavation respectively. The point coordinates belonging to both conditions were transferred to the program (Surfer 8.0) (Surfer 8.0 Software, 2006), and the surfaces were obtained for both condition. The excavation volume was calculated as 30.012 m^3 from difference of two surfaces. The images belong to work done in photogrammetry method as shown in Figures 6 - 9.

Volume computing by robotic laser scanner

In this work, the coordinates of points at determined distances on the land have been measured in laser scanning method. Scanning

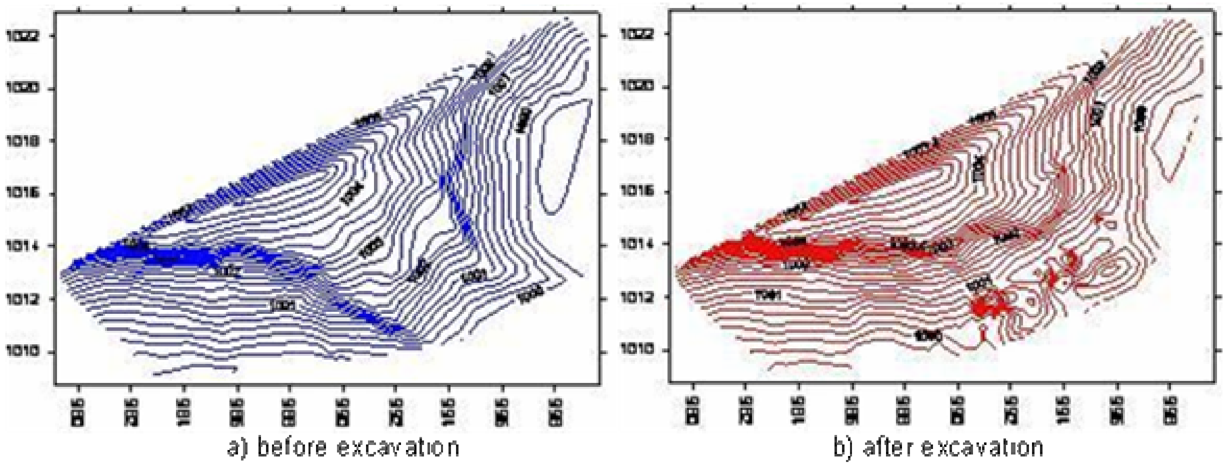


Figure 7. Contour map before and after excavation.

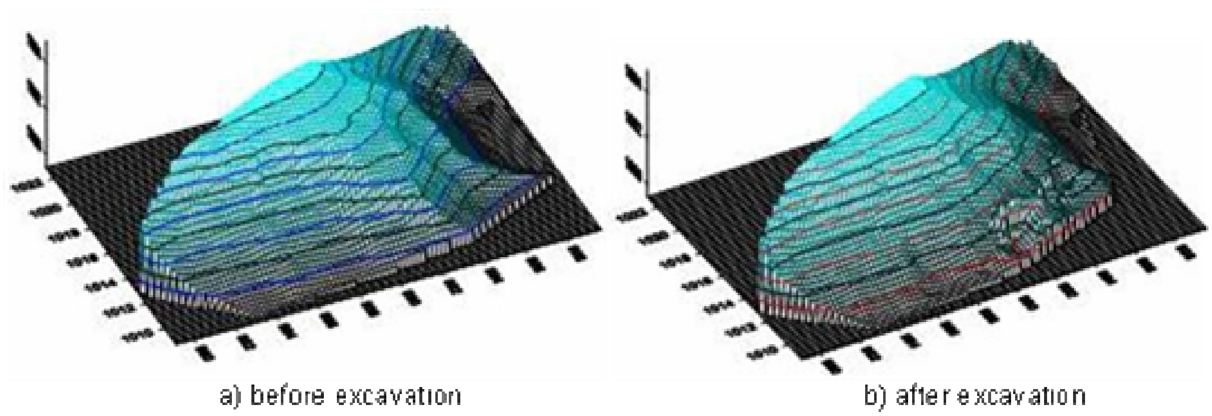


Figure 8. Wire frame map before and after excavation.

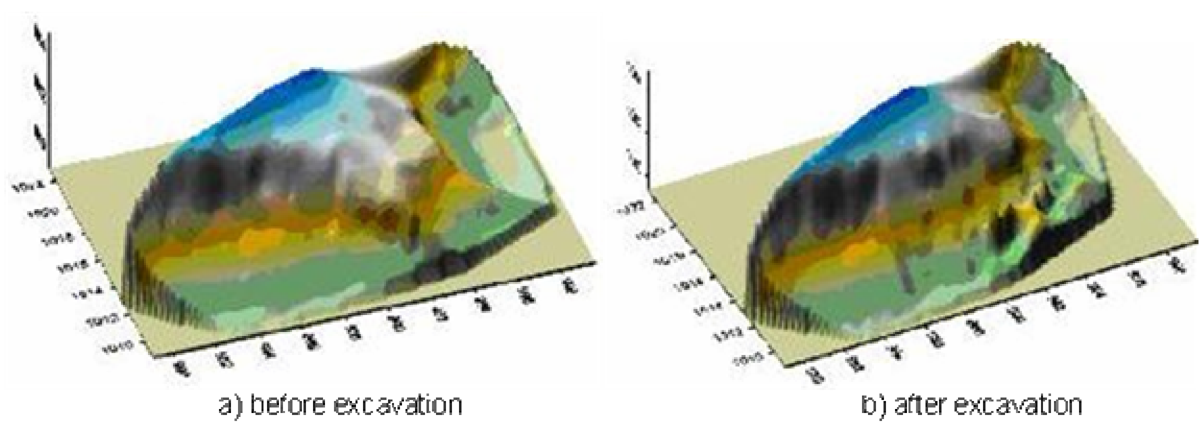
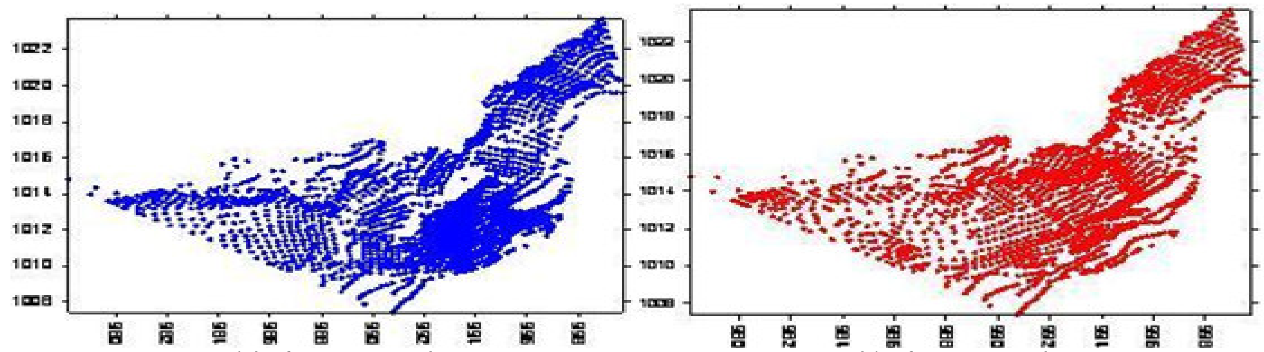


Figure 9. 3D model before and after excavation.

spaces were selected as 20, 40 and 100 cm respectively. The volume calculations were performed using the points obtained at the scanning spaces.

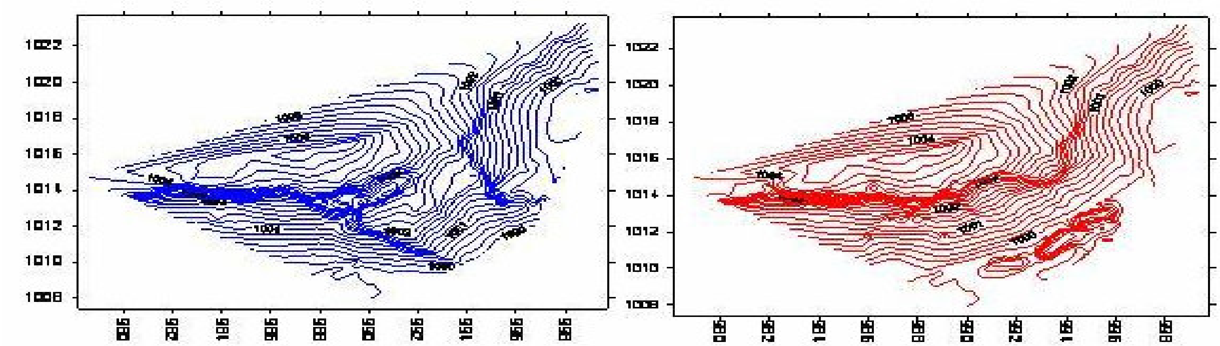
Volume computing by 20 cm scanning interval

Before excavation, the land surface was scanned at 20 cm spaces



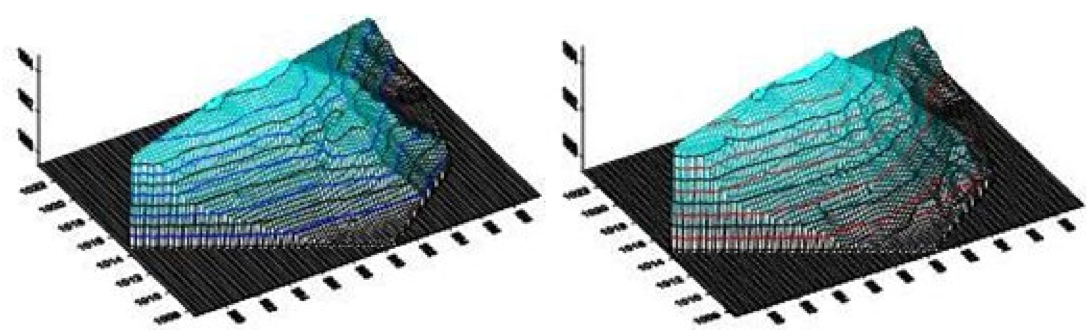
a) before excavation b) after excavation

Figure 10. Point distribution before and after excavation.



a) before excavation b) after excavation

Figure 11. Contour map before and after excavation.



a) before excavation b) after excavation

Figure 12. Wire frame map before and after excavation

and 1949 points were measured in 126 min. After excavation, the land surface was scanned in horizontal and vertical position at 20 cm spaces and 1779 points were measured in 120 min. The coordinates obtained were transferred to the program Surfer 8.0. After the surfaces of the land before and after excavation were obtained, the volume of excavation area was calculated as 30.883 m^3 from difference of two surfaces. In this scanning the images belong to land surface are shown in Figures 10 -13.

Volume computing by 40 cm scanning interval

Before excavation, the land surface was scanned at 40 cm spaces and 979 points were measured in 68 min. After excavation, the land surface was scanned in horizontal and vertical position at 40 cm spaces and 890 points were measured in 63 min and the coordinates were also transferred to the program. In the same way mentioned above, the volume of excavation area was calculated as

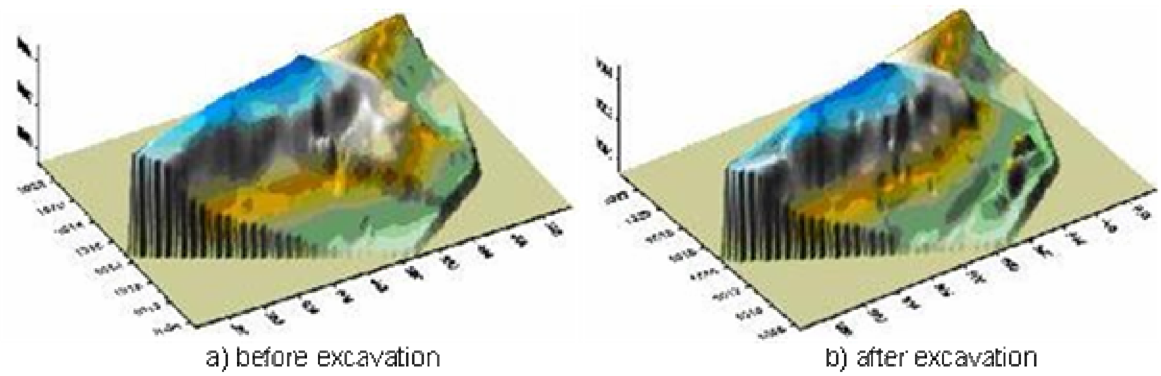


Figure 13. 3D model before and after excavation.

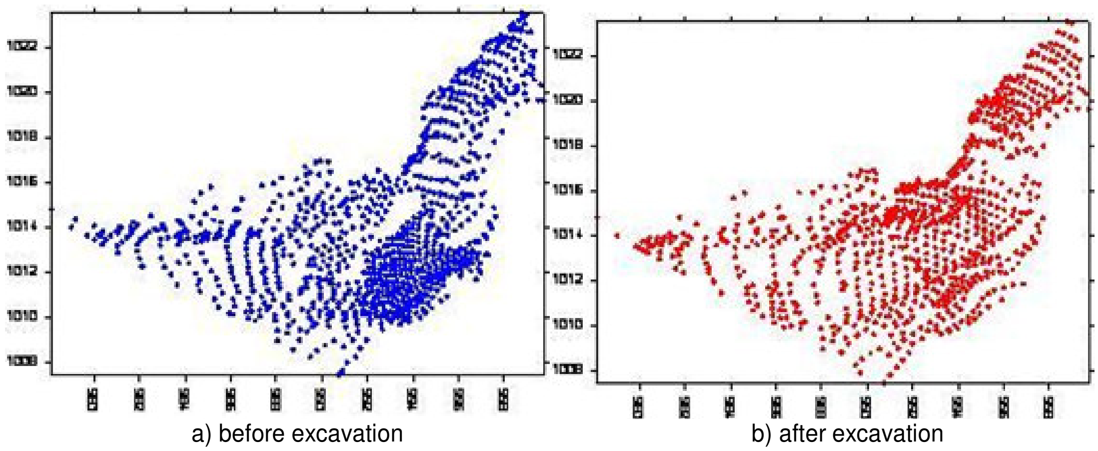


Figure 14. Point distribution before and after excavation.

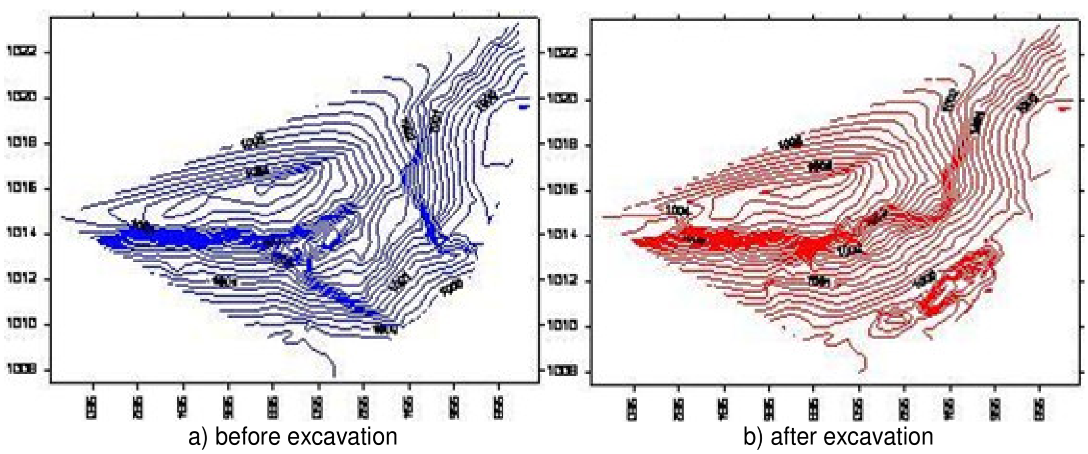


Figure 15. Contour map before and after excavation.

30.025 m^3. The images belong to the land surface as shown in Figure 14 - 17.

Volume computing by 100 cm scanning interval

Before excavation, the land surface was scanned horizontally and vertically at 100 cm spaces and 410 points were measured in 30 min. After excavation the land surface was scanned in horizontal and vertical position at 100 cm spaces and 368 points were measured in 27 min and the coordinates were again transferred to the program. In the same way the volume of excavation area were calculated as 35.141 m^3. The images belong to the land surface are

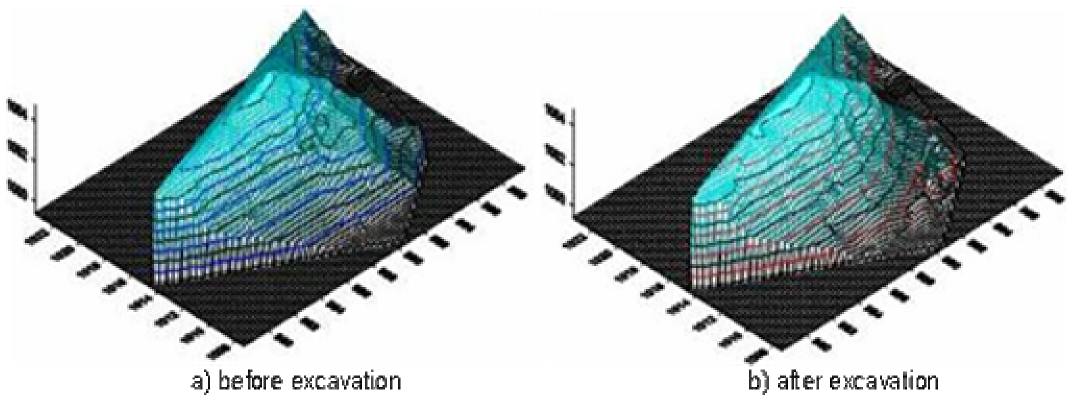


Figure 16. Wire frame map before and after excavation.

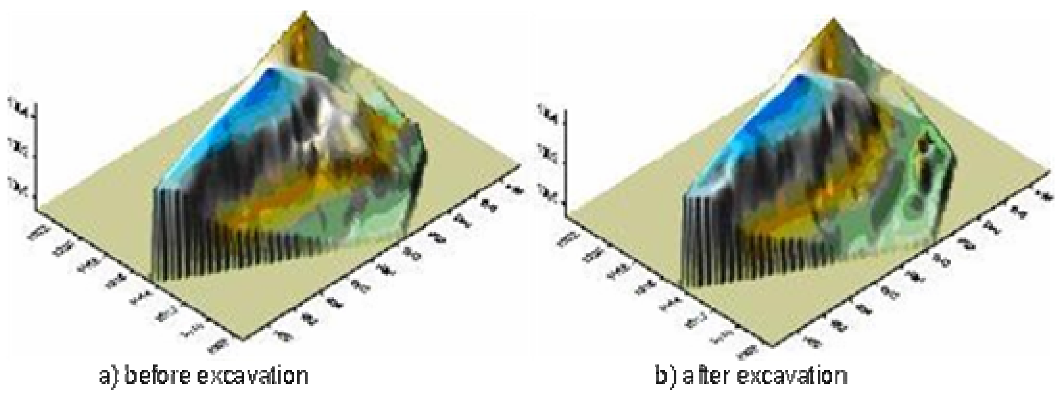


Figure 17. 3D model before and after excavation

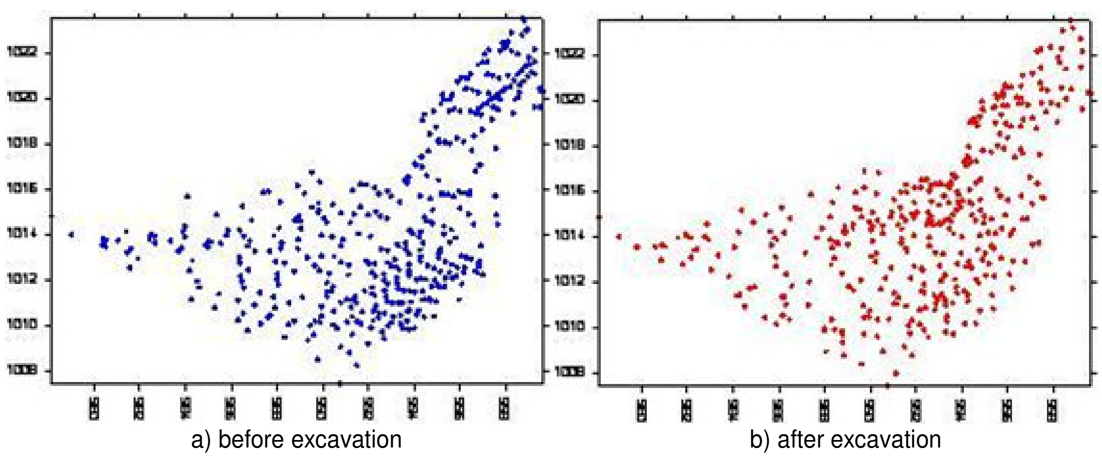


Figure 18. Point distribution before and after excavation.

shown in Figure 18 - 21.

Comparison of methods

Generally, volume calculations have been made from intersections, surface levelling measurements, plans with contour and digital elevation models. Recently, the volume calculations on land structures having complicated surface have been carried out whether from difference of defined two surfaces or differences between a defined surface and a reference surface. The required data in defining surface is the points that their coordinates are measured on surface in a coordinate system. In this experimental study, three different methods were used to obtain the points:

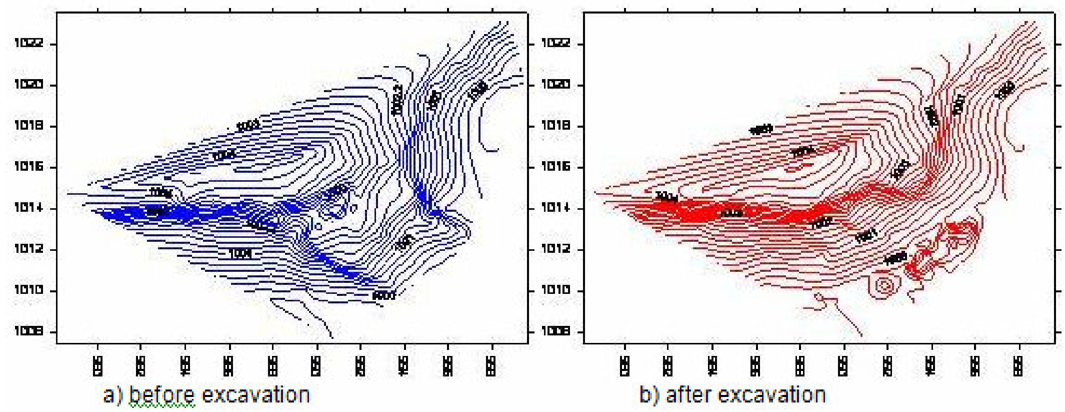


Figure 19. Contour map before and after excavation.

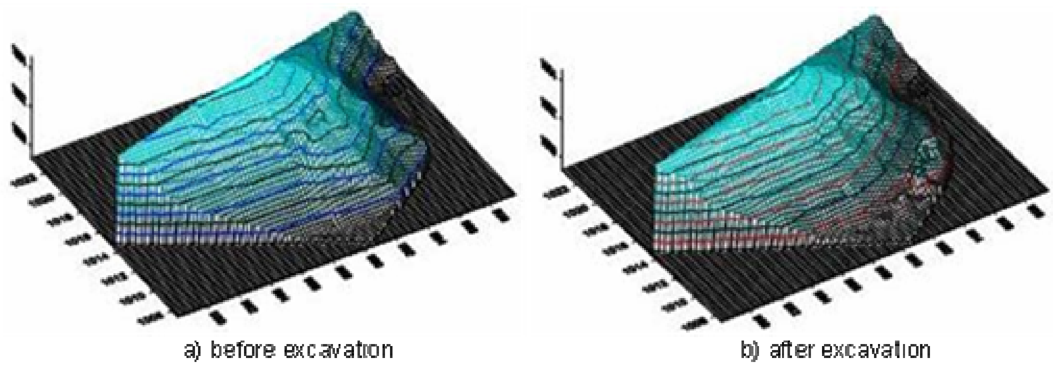


Figure 20. Wire frame map before and after excavation.

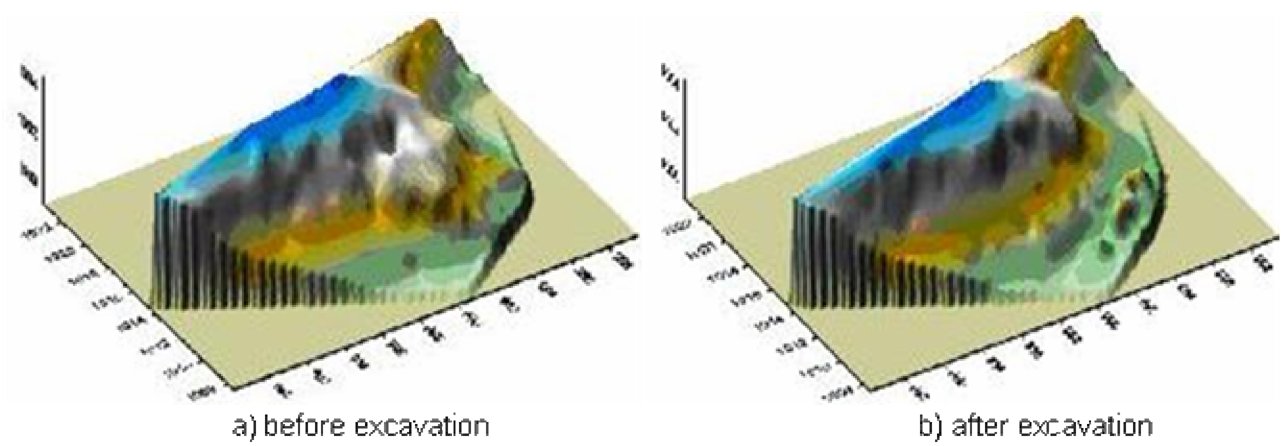


Figure 21. 3D model before and after excavation.

geodetic method, photogrammetric method and laser scanning method. By these methods, the volume of excavation rate executed in a digging area was calculated. The data related to these methods are given in Table 1.

In the study, an excavating area where reaching is possible has been selected. The sand rate dug from excavating land have been measured by a lorry with a known volume and this value has been compared with real value. Generally, It is seen that, it has been approached with 10% error to the reel volume by this method.

Nowadays, by using widely the geodetic measuring instruments capable of measuring in reflectorless reaching necessity to the points that will be measured have been removed. Being that the distance between measuring instrument and the object is more, it brings about difficulties in the selecting of characteristic points

Table 1. Obtained results from volume calculations according to the methods.

Method	Number of points		Spent time (min)		Volume (m^3)	Difference (m^3)	Accuracy (%)
	Before excavation	After excavation	Before excavation	After excavation			
Photogrammetric	595	476	100	85	30.012	-2.042	93.63
Laser 20 cm	1949	1779	126	120	30.883	-1.171	96.35
Laser 40 cm	979	890	68	63	30.025	-2.029	93.67
Laser 100 cm	410	368	30	27	35.141	3.087	91.22

defining the land on geodetic method. On the other hand, these problems have been eliminated with new developed automated laser point scanner instruments. In this process, the characteristic points representing the land is likely being out of scanning space defined in horizontal and vertical. This situation is eliminated by keeping scanning space smaller, but this scanning time is increased.

In order to be able to perform balancing/stabilizing processes in photogrammetric method, control points on surface is required. This control points, whether plates or targets are prepared in appropriate dimensions and shapes or on the points overlapped on surface, and can be seen in both pictures. The coordinates of points are determined by geodetic methods. Suitable results are taken from the point of view of accuracy with photogrammetric method. In this method, most of the time is spent for evaluation studies in office, whereas land studies take less time. Land studies in active business enterprises have been stopped in studying. Therefore the economical losses in business enterprises are increased. Photogrammetric method, by the reason not to obstruct land work, provides an important advantage. Laser point scanners have ability scanning land surfaces automatically in defined area and determined horizontally and vertically. When volume calculation is being discussed from defined surface differences, the most suitable measuring method is being performed by laser point scanner.

The most disadvantage of the method is that measuring time on land takes long time. The scanning space is smaller, while the scanning time is longer. In every method, the software defining surface and calculating volume from surface differences is required. In the event where geodetic measuring instruments are used to be able to measure without reflector, each method can also be executed by one person if required. More time is spent with photogrammetric and laser point scanning. When the number of points is more, the surface is defined perfectly and accuracy rate is increased. A photogrammetric evaluation software is also required in photogrammetric method in addition to required software for calculating human power and volume. When the costs are considered, a modern geodetic measuring instrument (capable of measuring without reflector) is approximately 20.000 Turkish Liras (TL). The necessary equipment in photogrammetric method is a camera for taking picture (≅ 1.000 TL), the software for photogrammetric evaluation (≅ 5.000 TL) and geodetic instrument to measure control points. It is not necessary that geodetic measuring instrument is a modern instrument. Consequently, the cost in photogrammetric method is 10.000 TL, approximately. In laser point scanning, a geodetic measuring instrument capable of performing laser point scanning is required. The current cost of this instrument is almost 70.000 TL. Photogrammetric method is seen more advantageous when it is considered from point of cost. Additionally, it is considered that laser scanning method which can detect thousands of points of which three dimensional coordinates are known in a short time with mm sensitivity is one of the most appropriate methods to obtain three dimensional models of objects with irregular surfaces, such as fairy chimney, and perform process in line with these measurements (Yilmaz et al 2009).

RESULTS

In engineering studies, volume calculations and exact volume rates are required. Depending on the characteristics of the studies performed, it is preferred that the volume values should be in optimum value when it is considered from the point of accuracy, cost and time. Depending also on expectation, method used in carrying out computing volume, is considered important. In this project, solutions to the questions mentioned above are searched for. For this, the sand rate dug in an excavation area was computed by geodetic, photogrammetric and laser point scanning methods, separately. Taken time, computing cost and accuracy rate for volume calculation, was obtained. The volume of sand rate dug was measured. After that the volume calculations were performed by three methods. The highest accuracy rate was obtained as 96.35% by laser point scanning. Nevertheless, much time was spent for this method. But in photogrammetric method, accuracy rate was obtained as 63.13% and 89.04% was obtained in geodetic method. In non-flat geometric surfaces, the determining sand rate that excavated, will be excavated and also will be loaded and cannot have accuracy of 100% in application. It is desired that, this value should be determined in optimum accuracy, in optimum cost and in less time. Generally the volume calculations can be carried out in 10% error limit by these methods.

As a result, it is brought up by the studies performed, that the volume calculations could be carried out by three methods, depending on the area where volume computing will be executed, to have expected accuracy, cost and time.

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