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Comparisons of Surveying with Terrestrial Laser Scanner and Total Station for Volume Determination of Overburden and Coal Excavations in Large Open-Pit Mine

B. Keawaram, P. Dumrongchai

***Abstract*—**The volume of overburden and coal excavations in open-pit mine is generally determined by conventional survey such as total station. This study aimed to evaluate the accuracy of terrestrial laser scanner (TLS) used to measure overburden and coal excavations, and to compare TLS survey data sets with the data of the total station. Results revealed that, the reference points measured with the total station showed 0.2 mm precision for both horizontal and vertical coordinates. When using TLS on the same points, the standard deviations of 4.93 cm and 0.53 cm for horizontal and vertical coordinates, respectively, were achieved. For volume measurements covering the mining areas of 79,844 m^2, TLS yielded the mean difference of about 1% and the surface error margin of 6 cm at the 95% confidence level when compared to the volume obtained by total station.

***Keywords*—**Mine, survey, terrestrial laser scanner, total station.

I. Introduction

ELECTRICITY Generating Authority of Thailand (EGAT) Mae Moh Mine is responsible for overburden and coal excavation to provide Mae Moh Power Plant which produces approximately 2,400 MW per year. About 100 megatons of overburden and coal have been excavated. EGAT Mae Moh [1]. Mine has signed contracts with contractors for the excavation and defined to use the conventional survey with total station for excavation volume and its expense determination. However, Mae Moh Mine has planned to expand the operation area to be about 4 km wide and 7 km long, and 300 m deeper than the existing depth of mine by 2019 [2]. This will make surveying more difficult to operate with the existing survey instruments that require a number of operating staff. Therefore, the study aimed to adjust or change the survey technique to improve efficiency and also use less members of staff by using TLS was initiated. This study was conducted to analyze the differences of the results and evaluate whether the new instrument is able to replace the conventional method.

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II. Approaches

This research used three survey approaches to measure the volume excavation of overburden and coal excavation; A. the conventional survey using total station, B. TLS, and C. Global Navigation Satellite System (GNSS) technology with Real Time Kinematic (RTK) method as the following.

A. Total Station

The survey technique using total station provides horizontal and vertical coordinates, and three-dimensional coordinates (x,y,z). This technique has been widely used for volume determination due to its high accuracy result [3].

B. Terrestrial Laser Scanner

This study used a pulse-based TLS to measure surface objects. The observations made consist of the range, r, the horizontal angle, α, and the vertical angle, β. Then, the coordinates (x,y,z) of points were obtained by conversion from the observational quantities [4].

C. GNSS with RTK Method

This survey technique requires at least two satellite signal receivers. One was located on the known coordinate point and the other was on the interested points. Moreover, both receivers must receive navigation satellite signals from at least five mutual satellites, and also be able to connect with radio transmission or internet signal in order to receive the adjusted value of coordinates (x,y,z) [5].

III. Instruments

The study used total station Leica TPS1205 and TLSI-site 8820 to measure the surface area for volume determination and GNSS Trimble R8 with RTK method to position the location of the total station and TLS, as a reference point. The instrument pictures and their specifications are shown in Fig. 1 and Table I to III, respectively.

TABLE I
PERFORMANCE OF TOTAL STATION LEICA TPS1205 [6]

Accuracy Horizontal & Vertical	5 seconds
Distance measurement	1,800meters
Distance accuracy	1mm+1.5ppm
Measure time	2.4s / point

TABLE II
PERFORMANCE OF TLS I SITE8820 [7]

Integrated digital camera	70 mega pixel
Maximum range	2000 m
Minimum range	2.5m
Range accuracy	6 mm
Repeatability	±6mm

TABLE III
PERFORMANCE OF GNSS TRIMBLE R8 [8]

Static Accuracy of Horizontal	±5+0.5 ppm
Static Accuracy of Vertical	±5+1 ppm
RTK Accuracy of Horizontal	±10+1 ppm
RTK Accuracy of Vertical	±20+1 ppm

(a) (b) (c)

Fig. 1 (a) total station Leica TPS1205; (b) TLS Maptek I-site 8820; (c) GNSS Trimble R8

IV. METHODOLOGY

This research focused on the controlled testing area and field testing area. The controlled test was aimed to evaluate accuracy in the position of each particular instrument. On another hand, the field test in the mining area is aimed to evaluate the result of excavation volume using each particular instrument. The research process is shown in Fig. 2.

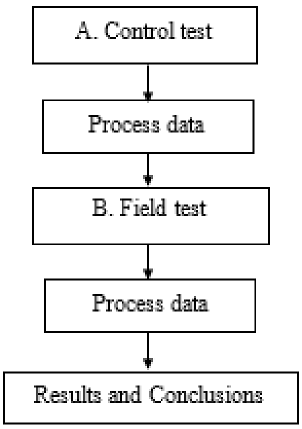


Fig. 2 Research methodology

A. Control Test

The controlled test for evaluating the positioning accuracy of each particular instrument was processed in the clear and uncovered area 50 m x 50 m, chosen to get strong GNSS signal to avoid the effect of multipath. The instruments were calibrated before the examination to ensure that they were in a good condition to get accurate and reliable results. Five reference points were appointed (HPC01-HPC05) to install total station and TLS. Sixteen points (CH01-CH16) were tested using GNSS with static survey for an hour long per point. Data was analyzed by Trimble Business Center commercial software, which yielded the positioning precision of about 0.1cm – 0.3 cm. Total station survey was setup at HPC01 with HPC02 as a back sight target. All points were observed 10 times per point, as shown in Fig. 3.

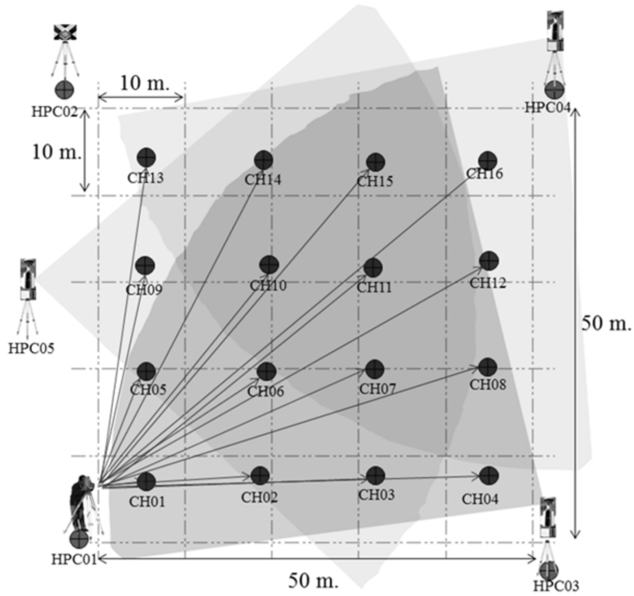


Fig. 3 Controlled test

We considered TLS at HPC03 for scanning the same area, then moved it to HPC04 and HPC05, respectively. The selected scanning data to be used for analysis were from the point clouds, close to the positions, measured by the total station. Controlled test evaluation used standard deviation (SD) to evaluate the precision value of measurements as in (1) and root mean square error (RMSE) to evaluate accuracy of positioning as in (2) [9].

$$SD(P) = \sqrt{\sum_{i=1}^{n} \frac{(\overline{P} - P_i)^2}{n-1}} \quad (1)$$

$$RMSE(P) = \sqrt{\sum_{i=1}^{n} \frac{(\hat{P} - P_i)^2}{n}} \quad (2)$$

where, $\overline{P}$ is the average of (X,Y,Z), $\hat{P}$ is the correct coordinate, P_i is the coordinates from point i to n, and n is number of measured values.

B. Field Test

The field test in the pitch mine was aimed to evaluate the results of excavation volume using each particular instrument. The test operated in six areas by using three different excavator machines which can operate at different heights of wall, as shown in Fig. 4, such as backhoe excavator at 4 m high wall, shovel excavator at 7 m high wall, and bucket wheel excavator at 12 m high wall with not less than 10,000 m^2 area per field.

The surveying process began with the reference points for total station and TLS using RTK having the positioning accuracy at the range of 0.1 cm – 0.5 cm. By using TLS, the operator chose three locations to install TLS which covered the testing field, as shown in Fig. 5.

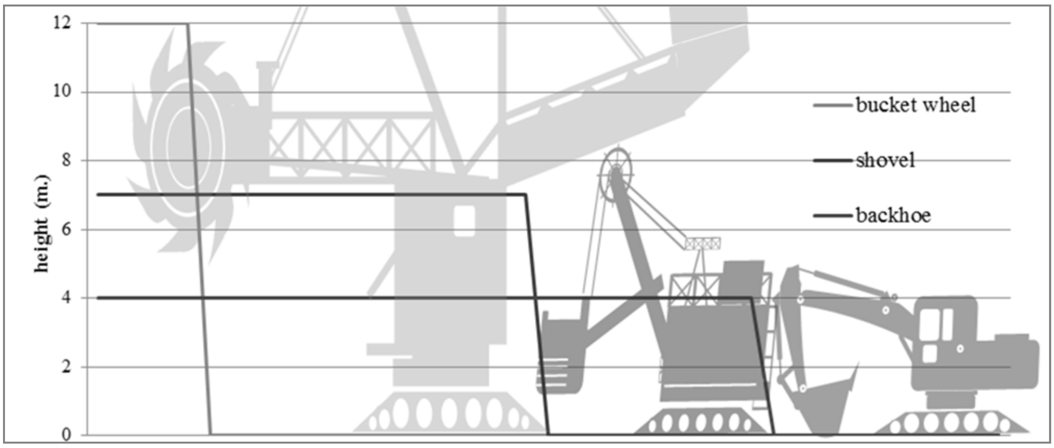


Fig. 4 The wall height of each excavator

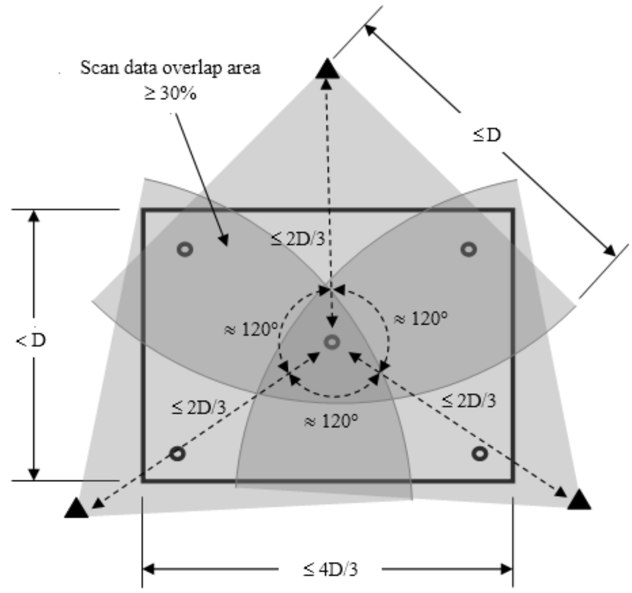


Fig. 5 The chart of reference points for setting TLS [2]

The data from the total station in 3D coordinate format were directly used for volume calculation, whereas the data from TLS had to be evaluated in the I-Site Studio program to convert point cloud data into triangulated irregular network (TIN) surface. Then, the Mine Sight commercial program [10], which is mostly used and reliable in the mining engineering, was used to calculate the excavation volume. Finally, the margins of error or "E" from both methods with respect to different types of excavators were determined as in (4) [11].

Difference of volume/Volume of total station x 100 (3)

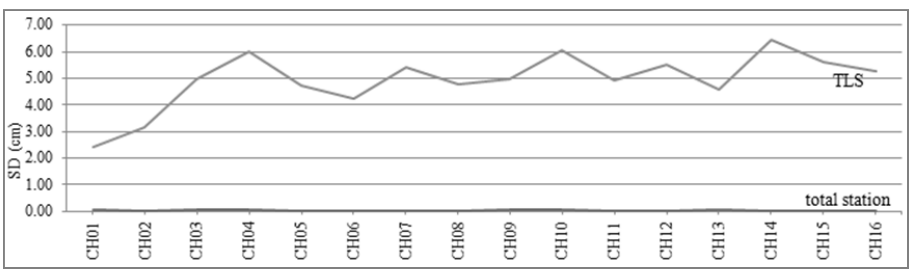
$$E = t_{\frac{a}{2},df} \times \frac{\sigma}{\sqrt{n}} \tag{4}$$

where σ is standard deviation, n is the number of measured value; $t_{\frac{a}{2},df}$ is critical value with the n-1 degree of freedom.

V. Results

A. Control Test

From the controlled test, the statistic results are shown in Fig. 6 and listed in Table IV.



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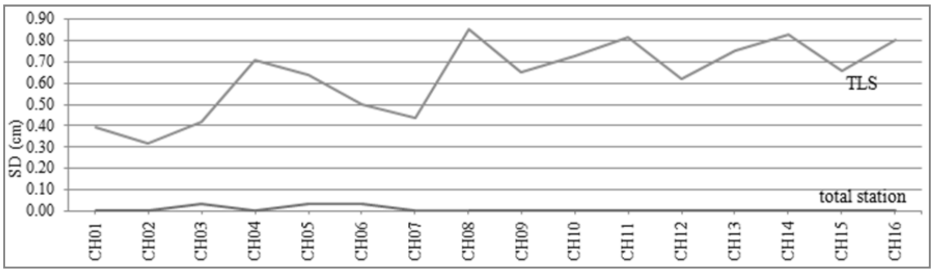

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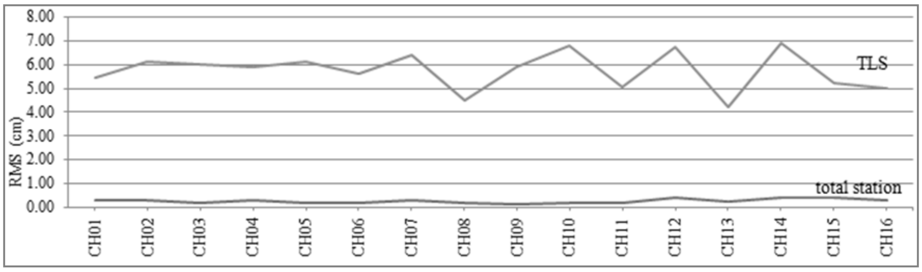

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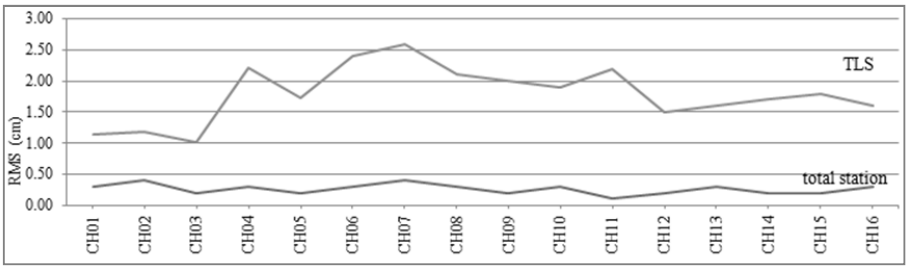


(d)

Fig. 6 (a) SD of horizontal (b) SD of vertical (c) RMSE of horizontal (d) RMSE of vertical

TABLE IV
RESULT OF CONTROL TASTE

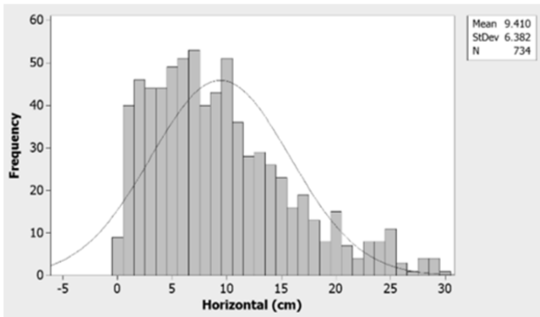
Instrument	Average of SD (cm.)		Average of RMS (cm.)	
	H	V	H	V
total station	0.02	0.01	0.02	0.03
TLS	4.93	0.83	5.75	2.10

According to the results of the controlled test, SD and RMSE values showed that TLS survey method provides less accuracy than total station in both the horizontal and vertical coordinate. It can be explained that TLS is unable to select specific points, unlike the total station in which the operator can specify where to stick the prism pole.

B. Field Test

From the field test areas of 79,844 m^2, the comparisons of the results from TLS and total station yield 734 points from TLS were close to the points from the total station.

Fig. 7 shows the difference between both instruments in horizon and vertical coordinates. The horizontal differences are from 0.1 cm to 29.8 cm with the average of 9.4 cm. The vertical differences are from 0 cm to 9.5 cm with the average 1.8 cm. The horizontal and vertical SD are 6.38 cm and 1.48 cm, respectively.



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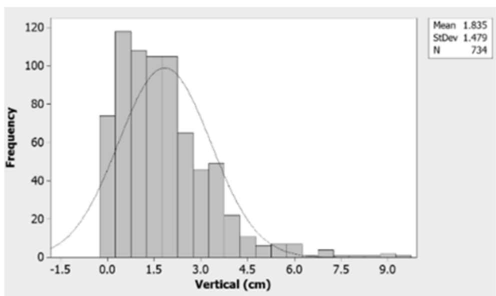

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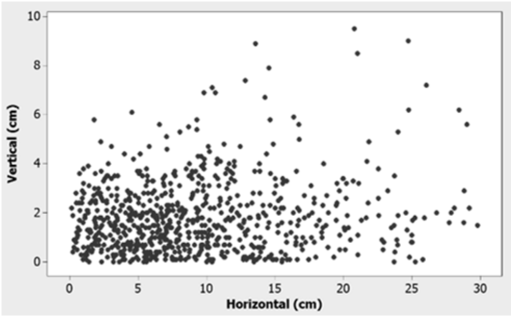


(c)

Fig. 7 (a) Histogram with normal curve of horizontal; (b) Histogram with normal curve of vertical; (c) Scatter plot of vertical and horizontal

The cause of difference is, due to the fineness levels of TLS, used in the test. In this study, we defined three levels. For instance, the medium level makes point cloud to fall off from the points from total station. To get more reliable results, the higher fineness level should be selected (no results in this study). However, it would take more time to get signal response, as shown in Table V.

TABLE V
LEVEL DENSITY OF SCANNING

Level of density	1	2	3	4	5
Time (min)	2.07	3.28	11.34	34.58	183.00

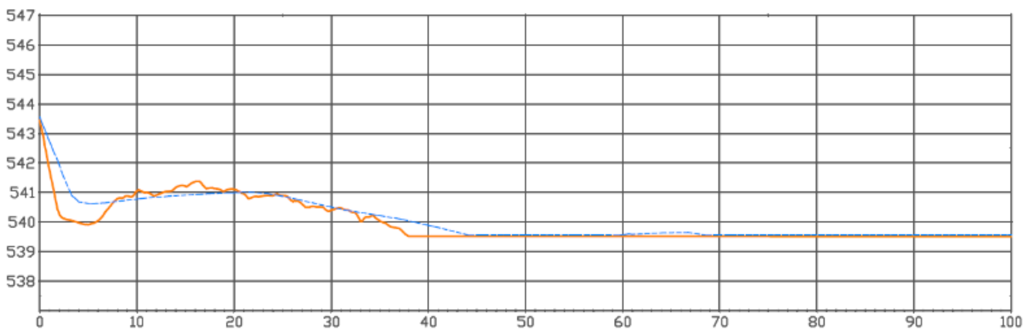
After consideration, using TLS with high fineness level is not practical to be used for measuring the excavation in this pitch mine because of its immense size. Nevertheless, choosing level three fineness is tended to be the most appropriate choice because the measuring time used by TLS is likely to coincide with the time, used by total station.

From the field test, the results of volume are shown in Table VI. According to the table, the difference of volume between both instruments was 1.03%. This is due to different measuring spacing between both--TINs which was generated from different instruments and may have difference surfaces. TINs from total station had about 10 m spacing between each measured points, whereas TINs from TLS had only 10 cm. The results in wall area case yielded large differences because total station could not measure every inch of the wall but TLS could, as shown in cross-section as in Fig. 8. Moreover, this study found that the characteristic of field of each excavator machine affected the result of each instrument. The comparative results of surveying volume, as shown in Table VI, revealed that the field with more wall area provides more different results. This is because TLS measured details of the wall area unlike total station, which, in practical working, could not thoroughly measure the wall area, as shown in Fig. 9

Working time of TLS, exclude traveling and setup time, is around 11 minutes each field divided into 3 setting up locations cover all of the area.

TABLE VI
RESULT OF FIELD TEST

area test	area size	plain area (m^2)	wall area	Volume (m^3)		difference TLS–total station			working time (min)	
				Total station	TLS	Volume (m^3)	%	Height (m.)	Total station	TLS
1.BHE1	12,999	12,381	618	55,304	55,614	310	0.56	0.024	33	35
2.BHE2	14,268	13,777	491	51,608	51,728	120	0.23	0.008	46	35
3.SVE1	13,826	12,233	1,593	90,170	90,664	494	0.55	0.036	41	35
4.SVE2	12,940	11,605	1,335	83,552	84,293	741	0.89	0.057	30	35
5.BWE1	13,105	11,446	1,659	104,777	106,447	1,670	1.59	0.127	35	35
6.BWE2	12,706	11,534	1,172	107,036	108,794	1,758	1.64	0.138	32	35
Summary	79,844	72,976	6,868	492,447	497,540	5,093	1.03	0.064	217	210
average	13,307			82,075	82,923					
SD								0.055		



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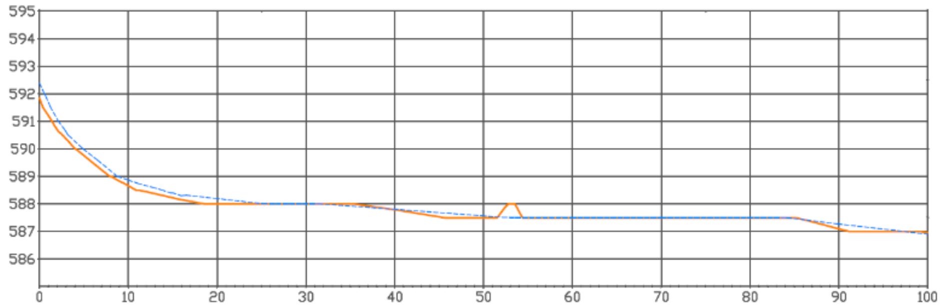
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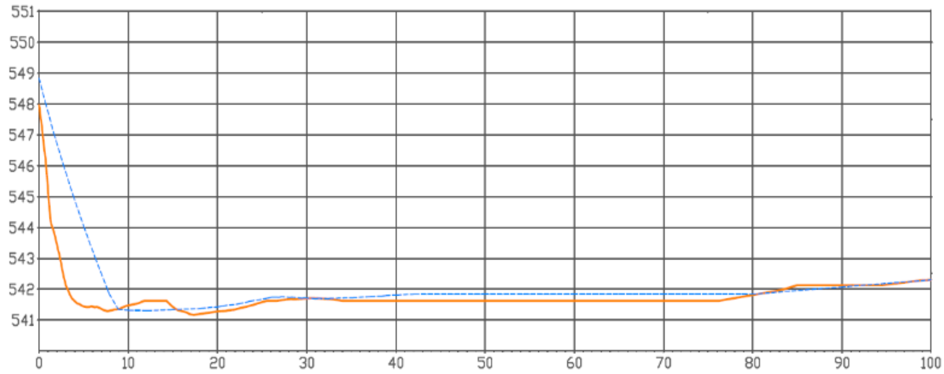
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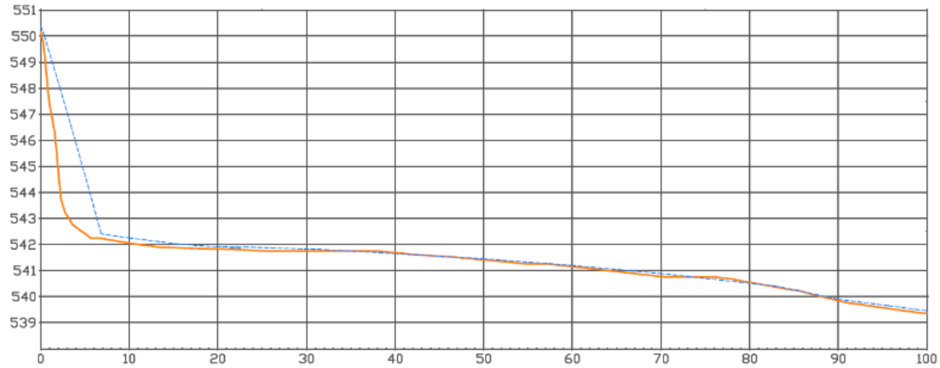
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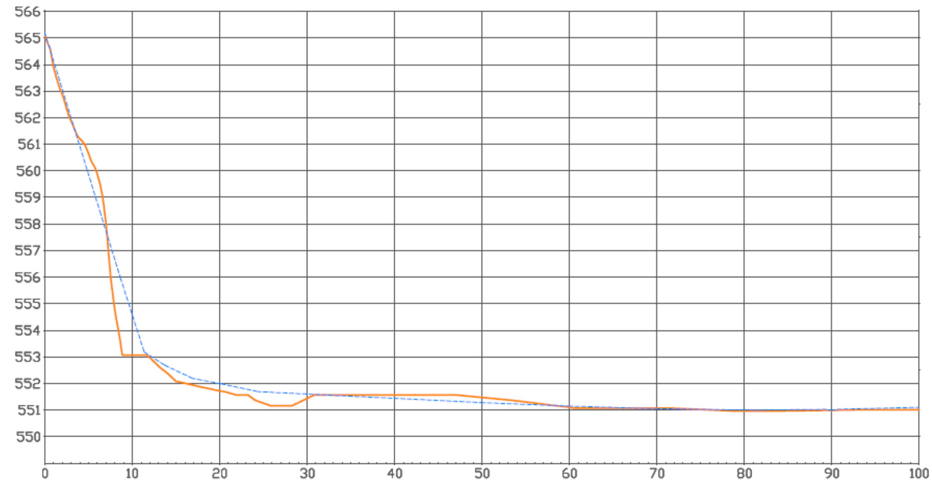
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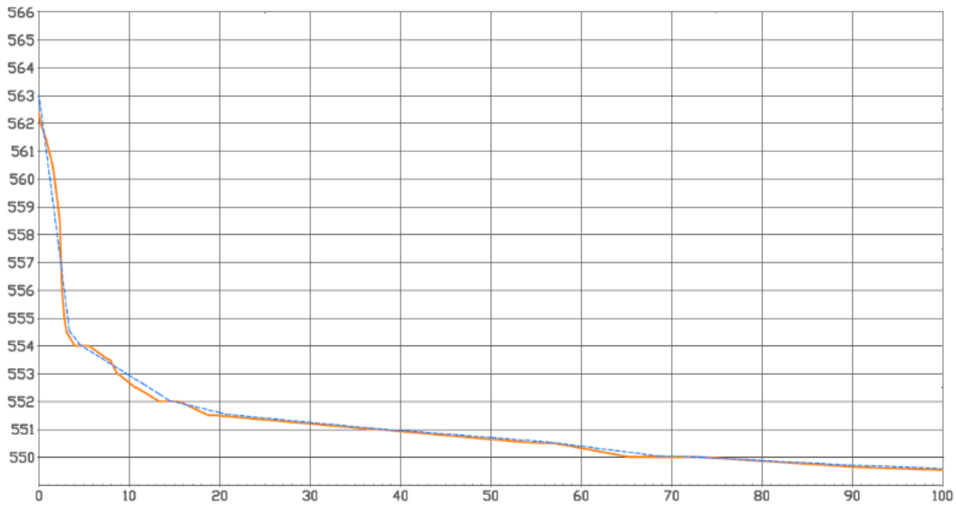
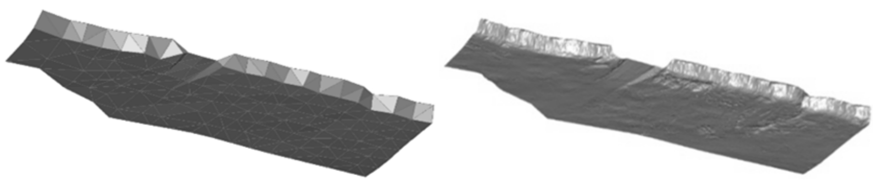


(f)

Fig. 8 Cross-section of 6 fields test. (a) SVE01; (b) SVE02; (c) BHE01; (d) BHE02; (e) BWE01; (f) BWE02.
Total station, TLS



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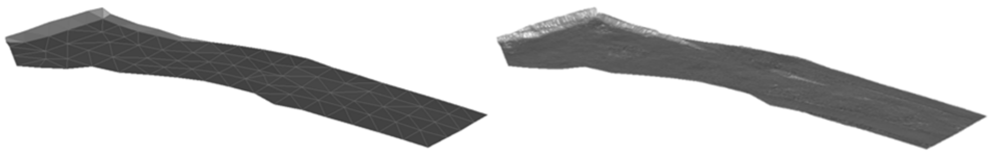

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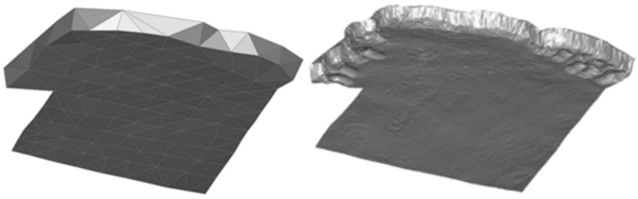

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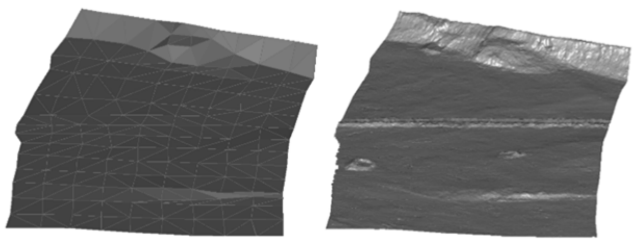

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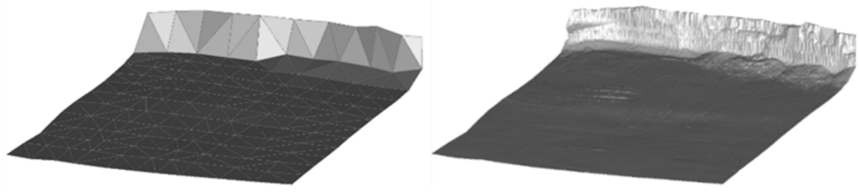

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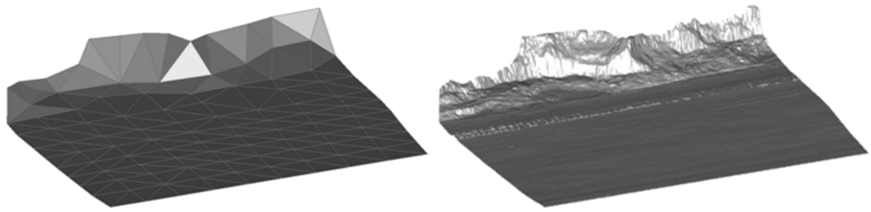

(f)

Fig. 9 TINs by total station and TLS of 6 fields test.(a) SVE01; (b) SVE02; (c) BHE01; (d) BHE02; (e) BWE01; (f) BWE02. Left (total station), Right (TLS)

TABLE VIII
THE DIFFERENCE OF ERRORING VOLUME BETWEEN TLS AND TOTAL STATION COMPARED TO THE ERRORING VOLUME BY USING MARGIN OF ERROR

Field of total 6	TLS	total station	TLS- total station	Using margin of error
Volume (m^3)	497,540	492,447	5,093	5,101

The difference of volume between TLS and total station could be represented by the margin of error as:

$$E = \pm 2.5706 \times \frac{0.055}{\sqrt{6}} = \pm 0.058 \quad (7)$$

where, $t_{\frac{a}{2},df}$:±2.5706 from t-distribution with Degree of freedom =5 at 95 % confidence interval; σ = 0.055m.; n : 6, as listed in Table VI [12]

The margin of error was used to estimate the error of surveying volume [11] between TLS and total station by assuming that the area of rectangle representing all characteristic types of testing field.

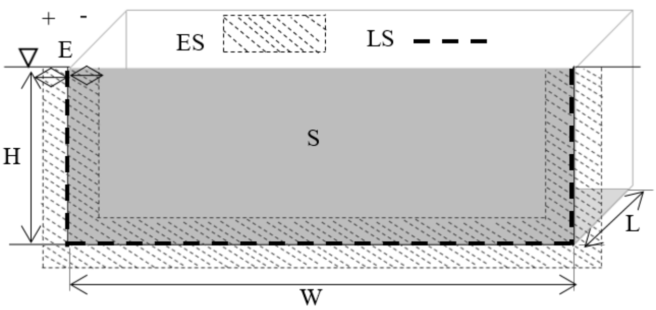

Fig.10 Rectangle representing all testing field [13]

Table VII shows the parameters that calculated by known volumes and areas. As a consequence, the error of sectional area is 7.37 m^2.

The difference of surveying volume between TLS and total station in any fields can be calculated by dividing the surveying volume of TLS by sectional area (S) of 718.84 m^2, to get length (L), and multiplying L by the error of section areas (ES) to estimate error of volume between both methods. Therefore, the volume error of surveying by TLS calculation using the error margin is 5,101 m^3, whereas the difference between TLS and total station volume is 5,093 m^3, which is 8.07 m^3 difference, as shown in Table VIII. The difference is so small that sectional area (S), 718.84 m^2, and error of section areas (ES), ±7.37 m, can be used to estimate the difference between surveying by TLS and total station in any field.

TABLE VII
RESULT OF CONTROL TASTE

volume(V)	82,923	m^3
area(A) = W x L	13,307	m^2
width(W),length(L)	115.36	m.
height(H)	6.23	m.
sectional area(S)	718.84	m^2
length of section(LS) = W+(2H)	127.82	m.
error of section areas(ES) = (LS x E)	7.37	m^2

VI. CONCLUSION

According to the research results, total station and TLS provide different results. Total station is more accurate in terms of positioning due to a capability to specific point, unlike TLS. However, TLS provides more details which yield more accurate results in terms of spatial areas. Moreover, the characteristic areas of the field test also affect the result in the case of on the wall area, which is much different. TLS requires a fewer number of operational staff, and closely consumes the period of time for operational process. However, it consumes more time in analysis process, besides the requirement of experience analysts to use TLS data-processing program. Based on these comparative results, this study reveals the possibility of using TLS for overburden and coal excavation in the large open-pit mine.

ACKNOWLEDGMENT

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