DEVELOPMENT OF CROSS SECTION MANAGEMENT SYSTEM IN TUNNEL USING TERRESTRIAL LASER SCANNING TECHNIQUE

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WG V/3 Terrestrial Laser Scanning.

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ABSTRACT

Laser scanning technology with high positional accuracy and high density will be widely applied in vast range of fields including geomatics. Especially, the development of laser scanning technology enabling long range information extraction is increasing its full use in civil engineering. This study taps into the strengths of a terrestrial laser scanning technique to develop a tunnel cross-section management system that can be practically employed for determining the cross-section of tunnels more promptly and accurately.First, high-density three-dimensional data was obtained in a prompt and accurate manner using a terrestrial laser scanner. Data processing was then conducted to promptly determine arbitrary cross-sections at 0.1-, 0.5-, and 1-meter intervals.A laser scanning technique was also used to quickly and accurately calculate the overbreak and underbreak of each cross-section and from the entire tunnel length. As the developed system utilizes vast amounts of data, it was possible to promptly determine the shape of arbitrary cross-sections and to calculate the overbreak and underbreak more accurately with higher area precision.A economic analysis of various techniques for determining the tunnel cross-section revealed that this measurement system is also outstanding from an economical perspective. It is expected, therefore, that the system will not only enable more efficient and cost-effective tunnel drilling management and monitoring but also will provide a basis for future construction and management of tunnel cross-sections.

1. INTRODUCTION

Although many capitals are invested for the development of tunnel and underground space due to the geographical condition that over 70 % of national land is formed by the mountains and the congested district of city is the majority in our nation, the efficiency of measuring works is practically decreased as obtaining the location information with the existing traditional measurements from the works before starting construction. Recently many studies on the determination of tunnel internal cross section using the Digital Photogrammetry, the Non Prism Totalstation, etc are being tried. But, in case of the Digital Photogrammetry, there are many cases that it is difficult to discriminate the subjects for photography because of the restricted sources of light from the poor measuring environments and working conditions in the tunnel and it is very difficult to abstract the characteristic from the character of irregular tunnel internal cross section. And the

Non Prism Totalstation using the noncontact-type measuring method can efficiently obtain the 3-dimensional location information of the cross section as compared with the existing measuring method but requires many times for calculating the determination of exact cross section and the outbreak quantity, etc.

But, if the 3-dimensional laser scanner making it possible to obtain high-accuracy data and high location precision even

under those disadvantageous conditions is used, the huge quantities of data about tunnel internal cross section can be obtained and more exact outbreak quantity and underbreak quantity can be calculated.

Regarding to the laser scanning technology, the scope of the utilization was further varied by the spread of the high-precision 3-dimensional laser scanners for the middle and long distance in the early 2000's and the study on this technology is continuously performed in the areas of engineering works, the road and the cultural properties, etc also (Lee et al., 2003; Son et al.,2003; Lee, 2005; Yunet al., 2006; Jang et al., 2006; kim et al., 2006; Kim, 2007).

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By the way, seeing the trends of overseas studies related to this study, the cliffs at south beach of San Francisco where the geographical activities are comparatively active was monitored as using the 3-dimensional laser scanner and the safety was predicted, which was proved to be used as the data for preparing the countermeasures against the later stormwind. And as modeling the perforated slope with the 3-dimensional scanning scheme, the possibility and the problem of the utilization of ground laser scanner were presented.

And there was the study to interpret the transform of the cross section in the tunnel with ground laser scanning technology, the utilization of ground laser scanning technology in the analysis of geometric error in the tunnel structure was used to be presented (Gosliga et al., 2006;Lam, 2006).

Accordingly, this study is purported to determine more exact internal cross section of tunnel with the enormous quantities of point data obtained by ground laser scanning scheme and to develop the cross section management system in the tunnel which can utilize it at the actual practices. And the flowchart of study is like Figure 1.
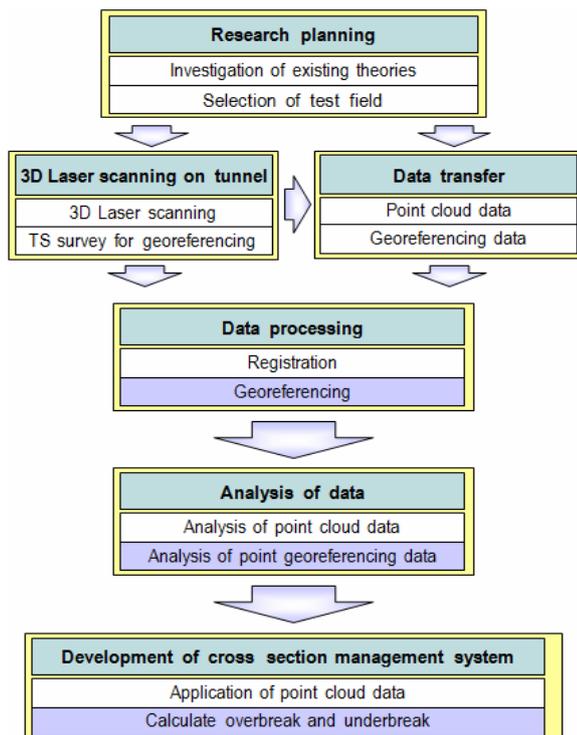

Figure 1. Flow chart of study process

2. TERRESTRIAL LASER SCANNING TECHNOLOGY

The advantages of laser scanning compared to existing techniques systems from the high rate-of-capture and density of three dimensional data (Boehler et al. 2001). The greatest

difference between Laser scanning technology and photogrammetry is each technology adopts active sensor and passive sensor. Different sensors support different way of getting and processing information as well as the form of information. TLSs allows a large amount of three-dimensional data including colors and intensity information and their rapid process.

TLSs operate on one of three principles: time-of-flight, phase shift, or triangulation. A proper scanner for general use of large scale applications is time-of-flight or phase shift methods using timed pulse (Mills and Barber 2004). Triangulation scanners are mainly used to close scan for cultural property restoration, inspection, and reverse engineering fields.

Since this study has selected longitudinally long range highway as a target, time-of-flight type scanners with relatively long observation length were used. The Transmitted and received signals are shown in Figure 2.
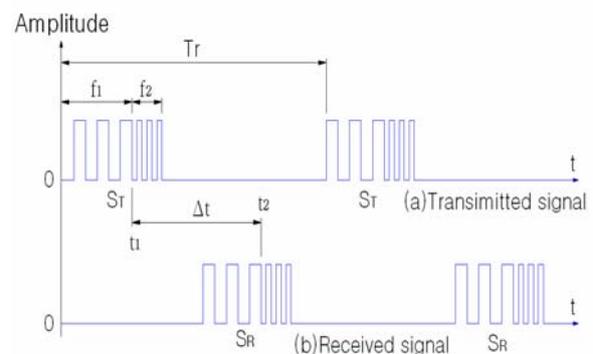

Figure 2. Principle of distance survey using transmitted and received signals in the TOF method

As shown in Figure 3, registration is a process that calculates point clouds from different positions, which is calculating relative positions that makes the gap between configurationally common parts close to zero theoretically.
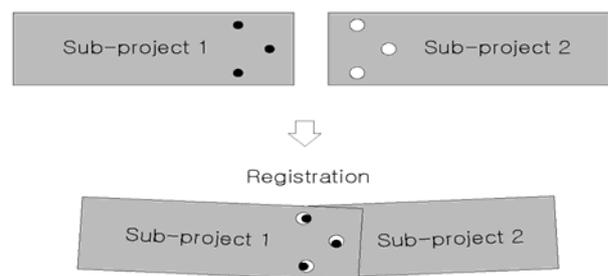

Figure 3. Principle of registrating point clouds data measured from different locations

This is the procedure of point clouds' coordinate conversion to form the same coordinate system, and it is determined by movement and rotation elements in three-dimensional space. The point clouds that have formed the same coordinate system through registration is converted to target's absolute coordinate merging with control point by georeferencing as shown in Figure 4.
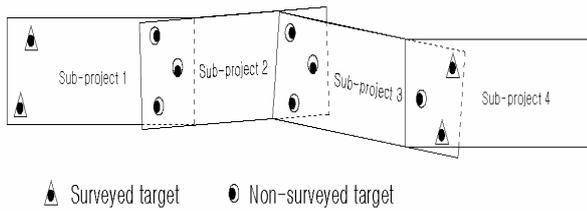
Figure 4. Principle of geo-referencing point clouds data passed through a registration process

3. MEASUREMENT AND ANALYSIS OF RESULTS

3.1 An outline of measurement

As the region to be studied, ○○ tunnel section, located at Namyangjoo City, Gyunggi-Do, among the highway sections by the private capital between Seoul and Chuncheon, was selected. And the satellite pictures on the region to be studies are like Figure5.

Figure 5. Location of test-field in a satellite image

This studied tunnel, as the NATM tunnel, is 1,355m (up=665m and down=690m) as total length and 2-way road with 11.573m as the width and 6.59m as the radius of tunnel as the specification.

And like Figure 6, as the tunnel of which the shortcrete casting process on the excavating surface after Supex-cut is finished, outbreak quantity by each section can be calculated as comparing the sections by the obtained scan data with the excavating line planned in designing.

Figure 6. View of the object tunnel

The studied tunnel in this study, as the tunnel where up line and down line were divided, had 2 reference points respectively at the starting and finishing point of tunnel by each direction and

the measurement on total 8 ground reference points was executed. To measure ground reference points, the model named as SET2$_{30RK3}$ manufactured by SOKKIA was used and this equipment was the Totalstation making the observation in prism/no-prism method possible and the specifications of equipment are like the below Table 1.

Model	SET30RK3
Laser class	Class 3R laser product
Laser output	Reflectorless mode : class 3R
	Prism/Sheet mode : class 1
Measuring range	1.3 to 500m (with reflective sheet target) 1.3 to 5,000m (with AP prism)
Accuracy	±(3+2ppm×D)mm (with reflective sheet target) ±(2+2ppm×D)mm (with AP prism)

Table 1. Specification of SET2$_{30RK3}$

And, the 3-dimensional laser scanner used in this study, as GS 200 model manufactured by Trimble company, uses TOF measuring method and can measure the objects with 18% of reflection intensity to about 200m distance. And due that it uses the laser in the area of luminous energy of 532nm wave range, the acquisition of color information is possible. The specifications of GS200 model are like the Table 2.

Model		GS 200
General	instrument type	long range laser mapping system
	metrology method	time of flight
Specification	laser	pulsed 532nm, green
		class 3R (IEC 60825-1)
		class 2 (21CER 1041.1D)
	field of view	360°×60° continous single scan
Performance	range	standard 200m
	scanning speed	up to 5,000 points/second
	standard deviation	1.4mm@≤ 50m 2.5mm@≤100m 3.6mm@≤150m 6.5mm@≤200m
	single point accuracy	position 12mm@100m distance 7mm@100m
	scan resolution	spot size : 3mm

Table 2. Specification of GS 200

The tunnel for this study is the tunnel of which the up-line and the down-line are divided. Accordingly, like Figure 7, the

scanning was performed by each direction and total 35 scanning data(17 up-lines and 18 down-lines) were scanned as moving in order for the gap of each scanning data to be about 40m.
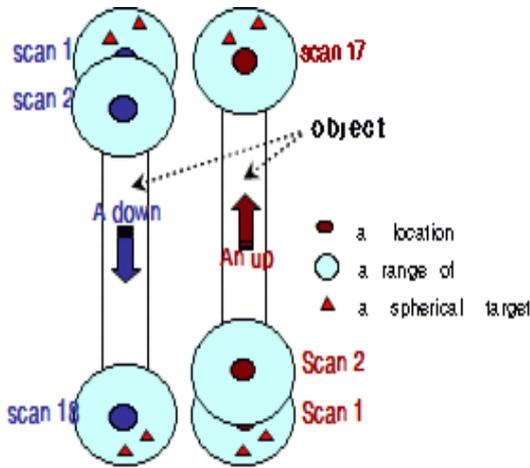

Figure 7. Constituent diagram of laser scanning for registration and georeferencing in the object tunnel.

And the ground reference points were facilitated at the starting part and the ending to convert the multi scanning data into the absolute coordinates. 3 round-type targets were facilitated at the repeated location like Figure8 for the conformation of sequent multi scanning data and precisely scanned in the process of each sub project work.

Figure 8. Plan view of spherical target arrangement for the registration of continuous scanning data.

At 2 ground reference points facilitated at each starting point and ending point, the round-type targets with the high reflection powerfulness were facilitated and the precise scanning was performed to achieve the conversion into the absolute coordinates. The photograph which automatically mosaicked the snap photographies obtained while the laser scanner was rounded 360° in the horizontal direction within the concerned tunnel is like Figure 9.
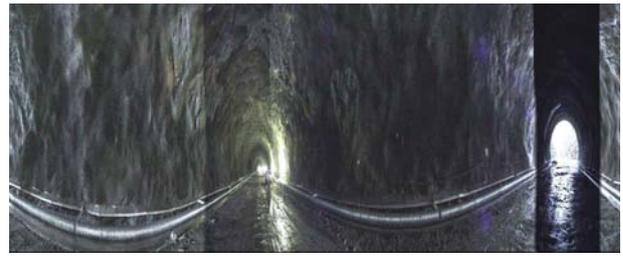

Figure 9. Panoramic view of a sub-sections

The data obtained in the process of a sub-project included the 3 dimensional location information, RGB information and reflection powerfulness information and the primitive data of a sub-project were appeared like Figure10 and Table 3.

No	X	Y	Z	R	G	B	Intensity
1	6.036	3.203	-1.715	158	181	144	25
2	9.522	4.235	-0.915	213	116	253	64
3	11.265	3.563	0.236	161	153	151	30

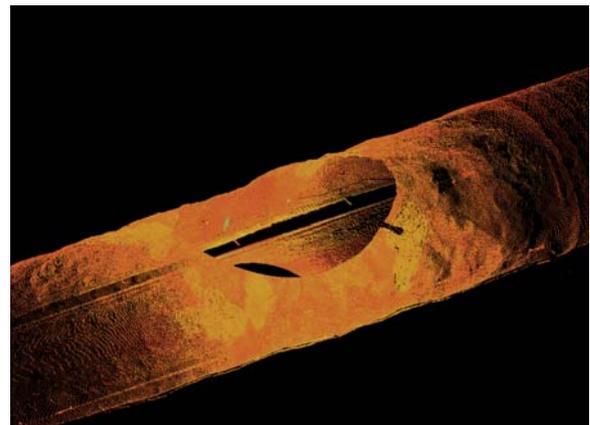Table 3. Raw point clouds data including various informations

Figure 10. Illustration of raw point clouds data obtained from a sub-sections

3.2 Results of measurement

The transmitted data were treated by RealWorks Survey developed by Trimble company. At the step of treatment, the registration and the geo-referencing were performed and finally the accuracy of treated data was analyzed. And for the registration, 3 round-type targets were facilitated at the repeated locations in the process of the sequent sub-project and precisely scanned in the process of each sub-project work. The round-type targets were facilitated like Figure 11 and the figures of the targets precisely scanned at the sequent prior and post sub-project are as per Figure 12 and 13.

Figure 11. View of arranging spherical target for registration
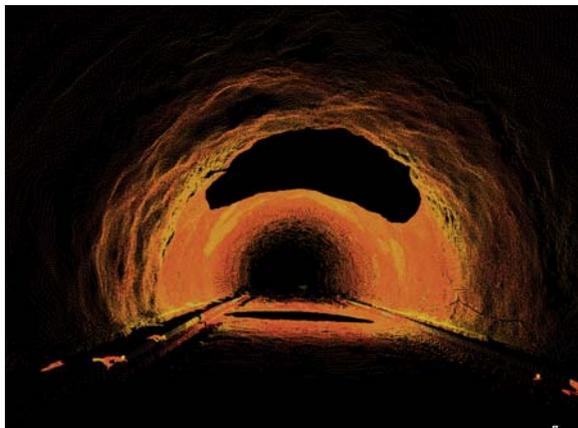

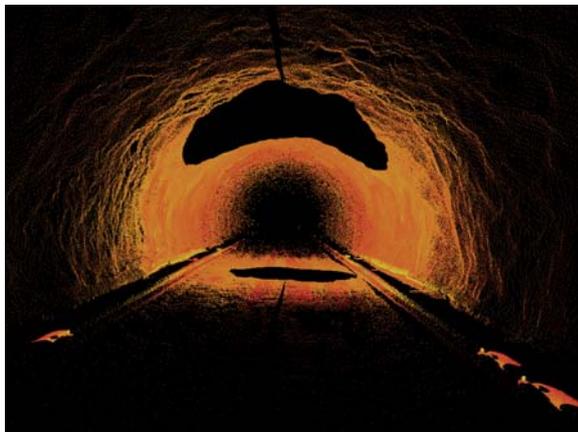Figure 12. Continuous point clouds data(before)

Figure 13. Continuous point clouds data(after)

From the data of round-type targets precisely scanned, the centers of targets are automatically determined like Figure 14 and as using 3 centers of targets determined like that, the relative location conformation among the sequent sub-project is achieved. The results of the registration of obtained 3 sequent scan data were appeared like Figure 15.

The multi scan data forming the same coordinates series over through such data conformation process are combined with ground reference points through the process of geo-referencing

to be converted into the absolute coordinates of objects. Figure 16 shows the result that 17 multi scan data obtained at the up line section of the length of 665m were done by registration and finally by geo-referencing.
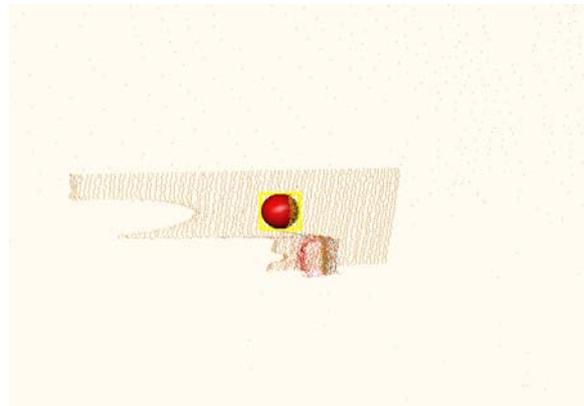

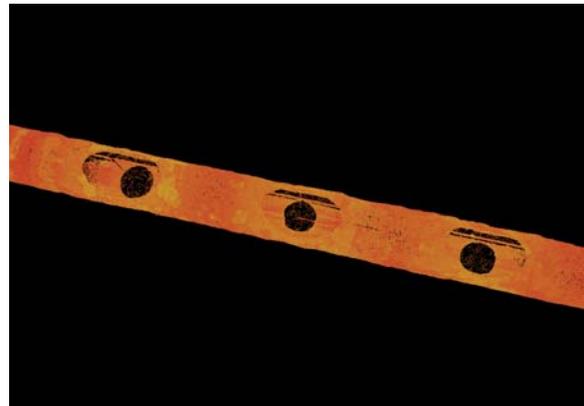Figure 14. View of automatically recognizing spherical target

Figure 15. Result of registration

Figure 16. Result of georeferencing for a line

The scan data passing through the final treatment step is used to determine the cross sections of tunnel at 1.0m intervals by profile/cross-section tool. Firstly, the center line data of road in the tunnel are overlapped on the scan data and the point data concerned to the cross section with 1.0m gap away from the

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center line of road are automatically abstracted. The point data of the cross section abstracted like that are linked with the lowest square line by the principle of the lowest square and Figure 17 shows the figures which automatically abstracted the cross section of concerned tunnel at intervals of 1.0m

The cross sections abstracted like that are converted into DXF format to be stored like Figure 18 and the final cross section is determined after passing through the correction step under the CAD environment. Figure 19. shows the random cross section of the tunnel passing through the final correction step.
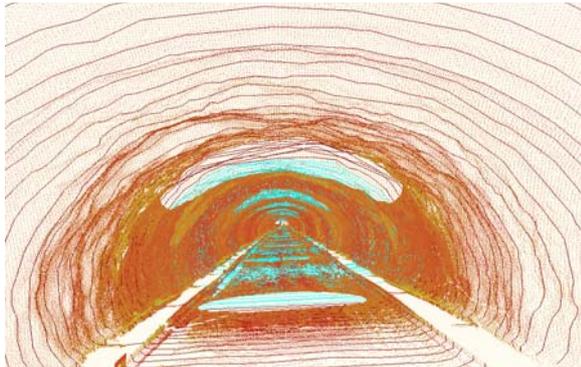

Figure 17. View of extracting cross section at intervals of 1m by profile/cross section tool
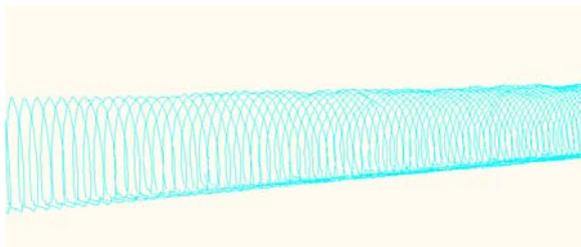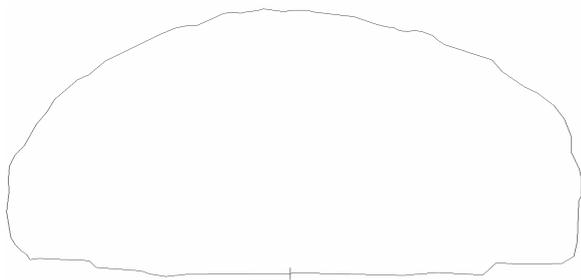

Figure 18. View of DXF format at CAD interface

Figure 19. Final result of a cross section

3.3 Analysis of results

Prior to determining the internal corss section as using the scan data treated over the whole cross sections, the accuracy of dimensions by the number of measuring points for determining the section was analyzed. The laser scanning scheme used in this study can observe over minimal 500 measuring points at the random cross sections. Accordingly, the sectional

dimensions determined by 15~25 and 50 measuring points which are generally applied for the sectional measurement of tunnel and the sectional dimensions by the laser scanning scheme were compared. The Table 5 is to compare the sectional dimensions of each cross section and the average sectional dimensions by the number of measuring point at the sectional intervals of 1.0m at STA.17+800～STA.17+810.

points STA.	Area of a cross section (m^2)			
	> 500	50	25	15
17+800	88.96	88.76	86.15	85.75
17+801	87.05	86.67	85.68	85.24
17+802	88.25	87.74	86.87	86.05
17+803	88.54	88.15	87.56	87.01
17+804	88.78	87.87	87.12	86.88
17+805	89.87	89.35	88.89	87.89
17+806	89.25	88.74	88.51	87.78
17+807	89.58	88.94	88.48	87.89
17+808	89.28	88.87	87.92	87.18
17+809	88.85	88.25	87.70	87.08
17+810	89.35	88.77	88.05	87.43
Average	88.89	88.37	87.54	86.93

Table 5. Area of a cross section classified the number of points

Comparing these results with the standard sectional dimensions of 91.58m^2 is like Figure 20. In the case by the laser scanning scheme, there was the smallest difference of about 2.9% from the standard sectional dimensions. In case that 15 measuring points were applied, there was the biggest difference of about 5.1%. Like the above, in case of determining the random section as using the laser scanning scheme, the accuracy of dimensions was appeared to be improved by 0.6%, 1.1% and 2.2%, respectively as compared with the section determined by the number of measuring points of 50, 25 and 15. This, although there is the smallest difference in a section, means that there is very big difference in considering the whole length.
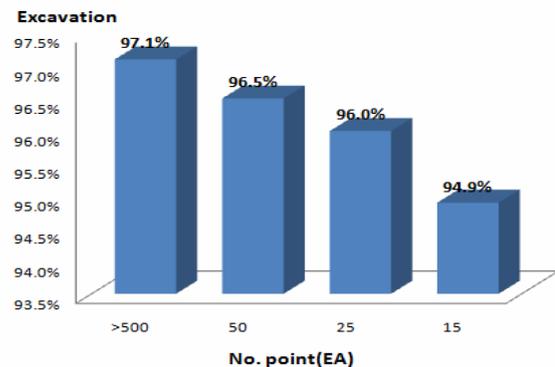

Figure 20. Distribution chart of each excavation classified the number of points

The results comparing outbreak quantity and underbreak quantity by the interval of random cross section showed the distribution like Figure 21. In the excavation of tunnel, the underbreaks have many effects on the constructing period as

compared with the outbreaks and generally the construction is performed not to generate them as long as possible to ensure the lining sections, but in this study, the underbreak quantity by the interval of cross section was somehow largely determined on the whole. This is judged to be occurred due that the underbreak of lower part of tunnel in the construction is removed away by the trench process at the final step. And there was the tendency that the outbreak quantity and the underbreak quantity were decreased as the interval of section becomes large and the case of 20m interval showed further large difference as compared with the value determined by the short interval.
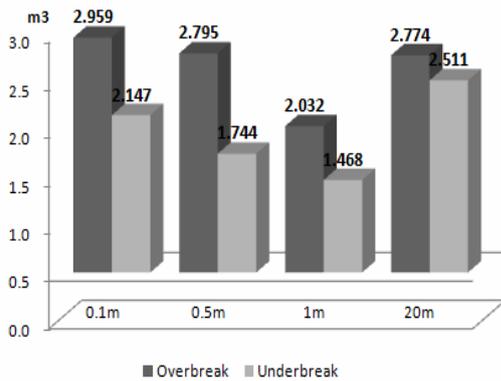

Figure 21. Distribution chart of overbreak and underbreak classified an interval of cross section

4. DEVELOPMENT OF CROSS SECTION MANAGEMENT SYSTEM IN TUNNEL

4.1 Characteristic of System

For the plan of tunnel, the safe construction and the future maintenance and management, the cross section management system in tunnel was developed. As the important characteristics of cross section management system in tunnel, like Figure22, first, it is composed to make it possible to check the real time constructing states and perform monitoring because it links the parts on the drawing management such as the planning plane figure, vertical cross section and horizontal cross section, etc for the construction of tunnel with this system. Secondly, as calculating the outbreak quantity and the underbreak quantity, etc of tunnel as the excavating quantity in the construction of tunnel, it can provide the foundation data for the state and the plan of construction in future. Thirdly, as using the characteristic information and the space information of topography space, it was constructed to be applied to the efficient maintenance and management on the tunnel.
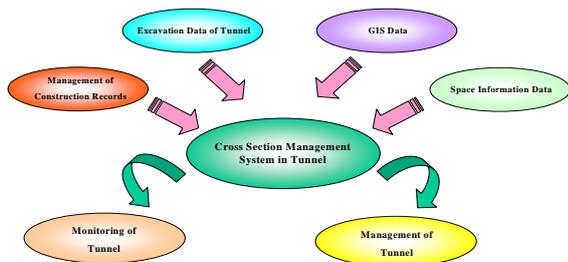

Figure 22. Characteristics of cross section management system in tunnel

4.2 Cross section management system in tunnel

The composition of cross section management system in the tunnel can be largely classified into 2 kinds of important parts like Figure 23. The first part was composed as the part related to the construction and the use of space information of tunnel and the second part was as the part related to the excavated cross section of tunnel.

First of all, the first part was constructed to be more convenient to maintain and manage the tunnel as making it possible to display the planning plane figure and the vertical cross section together and especially, to be more adaptable to the management of present constructing state and construction as making it possible to show before and after the execution of excavation and the excavation-executing parts in the real time.

The second part was constructed to perform data management on the excavated cross section of tunnel in priority. Especially, it was constructed to make it possible to see the outbreak quantity, the underbreak quantity and total excavation quantity, etc of excavated cross section along with the neighboring cross section to the excavated cross section.
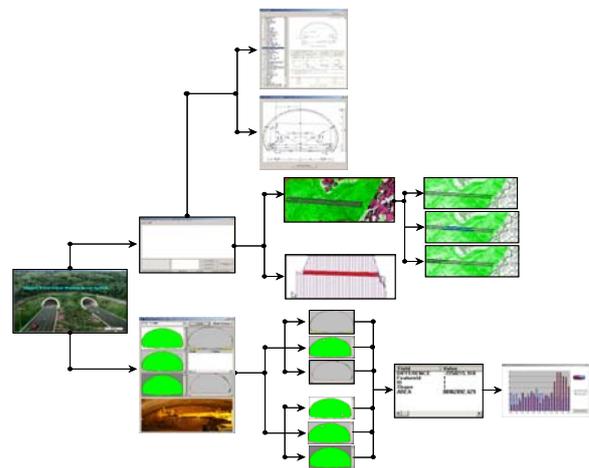

Figure 23. Configuration of cross section management system in tunnel

Regarding to the calculating principle of tunnel excavation quantity, the calculating formula that if the standard horizontal cross section and the excavated cross section are compared, the excavation quantity of excavated cross section is calculated, if the difference of outbreak quantity and underbreak quantity is calculated from the above excavation quantity, the outbreak quantity and the underbreak quantity are calculated and the sum of outbreak quantity and underbreak quantity should be equal to the difference of the standard horizontal cross section and the excavated cross section was used.

The flowchart of calculation is as per Figure24 and the results that this calculating formula was applied to the excavated cross section of tunnel were appeared like Figure25.

And it was constructed to perform more efficient maintenance and management as showing such results on the excavating quantity as the graph like Figure26.

The outbreak quantity and the underbreak quantity at intervals of 1.0m determined like that are used to calculate total outbreak quantity and underbreak quantity at the up line and down line sections by total both cross section average method and are as per the Table 6.
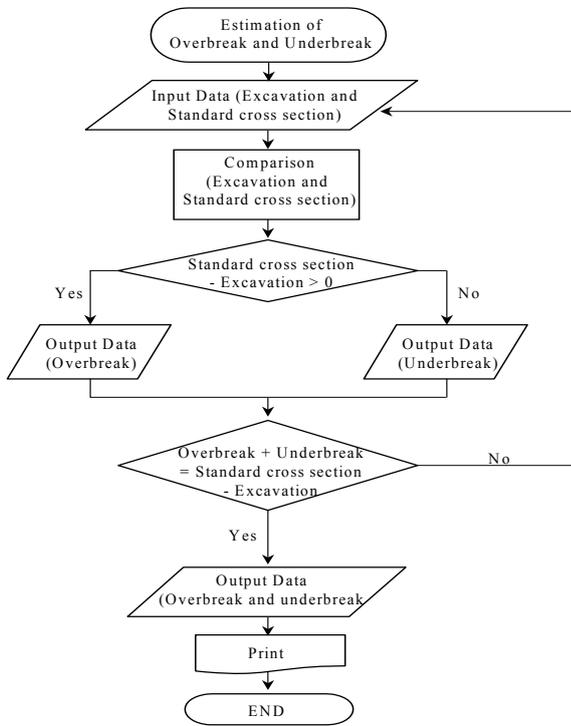

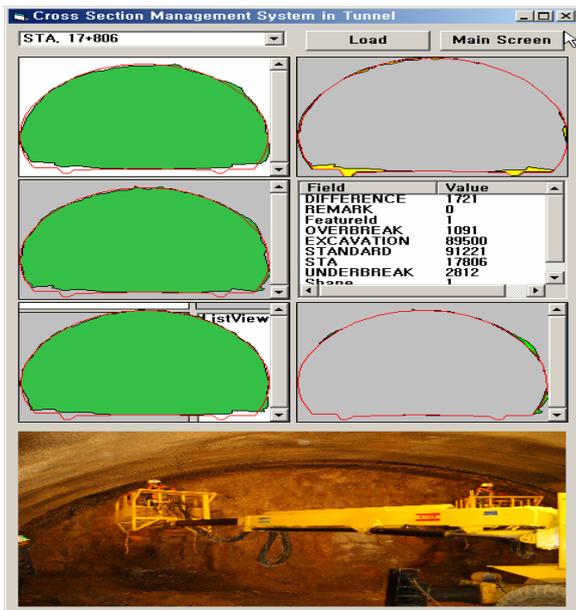Figure 24. Flowchart of estimation for excavation

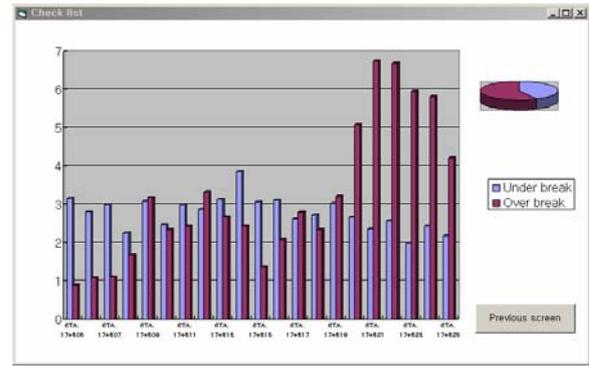Figure 25. Result of excavation cross section
(STA.17+805   STA.17+807)

Figure 26. Graphic of excavation cross section

Space	Overbreak(m^3)	Underbreak(m^3)
An up line	1,566.99	1,703.58
A down line	1,481.22	2,041.71

Table 6. Total underbreak and overbreak in the object tunnel

5. CONCLUSION

As the results that more precise tunnel internal cross section is determined as using the data obtained by ground laser scanning scheme in the tunnel and the cross section management system in the tunnel which is useful in the practical works is developed, the following conclusions are obtained.

First, as using ground laser scanner, 3 dimensional data with the high accuracy could be promptly and exactly obtained and the random cross section at intervals of 0.1m, 0.5m and 1.0m could be promptly determined as passing through the step of data treatment. And as utilizing laser scanning scheme, not only outbreak quantity and underbreak quantity of each cross section but also outbreak quantity and underbreak quantity occurred at total tunnel length could be promptly and exactly calculated.

Second, as the results of analyzing the accuracy of dimensions by the number of measuring point for determining internal cross section, the laser scanning scheme appeared about 2.9% difference from the standard cross section dimensions, which meaned about 2.2% improvement of dimensional accuracy as compared with cross section dimensions determined by 15 measuring points. This, although there is the minute difference in a cross section, means that there is very big difference from the pre-existing quantity in considering the length of whole tunnel. Accordingly, it shows that the utilization of laser scanning scheme makes it possible to calculate more precise outbreak quantity and underbreak quantity as compared with the existing measuring methods.

Third, the cross section management system in the tunnel making it possible to calculate more precise outbreak quantity and underbreak quantity at the step of tunnel excavation and monitor them was developed. The developed GUI program makes more efficient and economical tunnel excavation management and monitoring possible and is judged to contribute to providing and utilizing the important foundation data for the maintenance and the management of tunnel as abstracting the data of random cross section in future.

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