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Monitoring of rock surface shape using laser scanner

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ABSTRACT: Rock shape monitoring is one of the most important issues in geotechnical engineering. Rock slope failure and underbreak and overbreak in tunnels can be detected by observing the surface shape. Furthermore, the cutting shape of rock in waterjet aided tunneling is a key factor determining performance. 2-D laser scanners have been adopted to identify the surface shape of rock. Previous papers on waterjet cutting shape monitoring methods have reported that the effective factors of measurement using a laser scanner are laser distance, angle resolution, and surface shape. In this study, laser scanning speed and data averaging frequency are additionally considered as effective factors for laser scanner measurement in waterjet cutting shape monitoring. It is found that a wide opening of the free surface and at least 10 averaged data are necessary to guarantee accurate measurement.

1 INTRODUCTION

1.1 *Importance of rock shape*

Rock shape shows the status of a rock or rock formation in geotechnical engineering. Rock slope failure can be identified by continuous measurement of the rock slope surface. Overbreak and underbreak in tunneling are also measured by monitoring the surface of the tunnel wall compared with the planned tunnel line. Waterjet aided excavation is a rising technology for tunnel excavation. The shape of the rock surface cut by an abrasive waterjet is one of the key factors in determining the tunneling performance (Oh & Cho 2012).

1.2 *Applications of laser in geotechnical engineering*

Slope stability monitoring is performed using many sensors and devices such as strain gauges, tilt sensors, water content measurement sensors, photos, and a laser scanner. The laser scanner has the advantage that it does not have to be situated on the slope in question and can be used at a distance greater than 200 m (Kang 2007, Jung et al. 2012). Other researchers have studied the rock joint direction and its roughness using a laser scanner (Lee et al. 1999, Park & Park 2011, Feng 2001, Feng & Roshoff 2006, Lee et al. 2006, Oh et al. 2012).

Laser equipment is widely used in tunneling. 3D scanners are used for evaluating overbreak and underbreak (Kim & Lim 2007, Park et al. 2012). The rock shape cut by a waterjet, a rising technology in tunneling, is the most important factor for evaluating the excavation performance (Oh 2012). 2D laser scanners have be adopted to identify the rock shape cut by waterjet. Effective factors of measurement using a 2D laser scanner are laser distance, angle resolution, and surface shape (Oh et al. 2013, Hong et al. 2013).

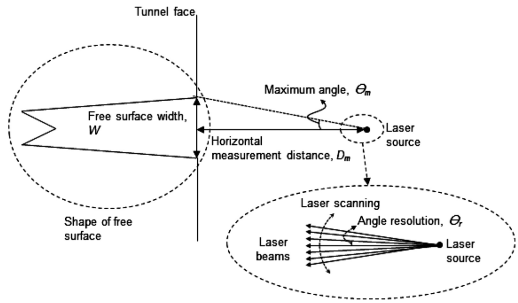

Figure 1. Definition of variables (After Oh et al. 2013).

1.3 *Goal of study*

In this study, we focus on the rock shape cut by waterjet. Additional factors that influence on the measurement are found and we suggest the guideline for the number of data averaged and the traverse speed.

2 EXPERIMENTAL PROGRAM

2.1 *Experimental variables*

Angle resolution, horizontal measurement distance, and shape of the free surface are identified as effective factors of measurement (Oh et al. 2013, Hong et al. 2013). The number of data averaged is additionally considered as an effective factor because it can help determine the maximum speed of movement of the laser scanner. The angle resolution is fixed as 0.25°, which is the maximum limit of the laser scanner. The definitions of the variables are presented in Figure 1.

Table 1. Specification of laser scanner.

Weight (dimensions):	1.1 kg (105 mm·102 mm·162 mm)
Light source:	Infrared (905 nm)
Field of view:	270°
Scanning frequency:	25 Hz/50 Hz
Response time:	40 ms/20 ms
Angle resolution:	0.25°, 0.5° adjustable
Operating range:	0.5–50 m (18 m at 10% reflectivity)
Operating temperature:	−30°C to +50°C
Statistical error:	±12 mm

2.2 *Specification of laser scanner*

Laser scanner should be light for field application and attachment on the movement equipment. Laser scanner is 1.1 kg without any line and more detailed specification of laser scanner is written on the Table 1. The laser scanner should be light for field application and attachment on the moving equipment. The laser scanner employed in this study is 1.1 kg without any line. More detailed specifications of the scanner are provided in Table 1.

2.3 *Preparation of specimen*

Shape of rock after cut using waterjet is generally classified with V and V-W shape (Oh & Cho 2012). V shape of specimen is more accurately measured using laser scanner (Oh et al. 2013).

The specimens used by Oh et al. (2013) have the depth less than 30 cm. Two specimens which have the cutting depth greater than 1 m that can simulate real field condition are prepared with different nozzle standoff distance (*SOD*) (Fig. 2).

(a) Small opening (20 mm)

(b) Large opening (80 mm)

Figure 2. Cutting shape of different nozzle *SOD*: (a) Nozzle *SOD* 50 mm (cutting depth: 1050 mm), (b) 400 mm (cutting depth: 1260 mm).

3 RESULTS AND ANALYSIS

3.1 *Effect of horizontal measurement distance*

The measurement accuracy of the laser scanner is proportional to the inverse of a cotangent function with horizontal measurement distance as a variable and proportional to the inverse function of a tangent with the size of the opening, or the cutting width (Oh et al. 2013). However, the results show that not all measured data fits the model suggested by Oh et al. (2013).

This is because of the irregularity of the specimen surface. Laser beam cannot reflect back due to irregular specimen surface. This can generate the measurement error. Relatively accurate measurement is obtained when the size of opening is larger (Figs 3 & 4). Dashed line in Figure 3 & 4 is real depth measured by mechanical method.

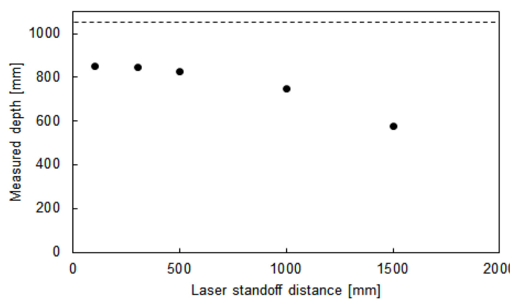

Figure 3. Measured depth in different laser standoff distance (number of data averaged: 50, Nozzle *SOD* 50 mm specimen).

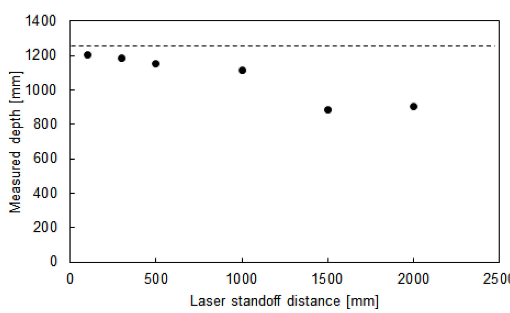

Figure 4. Measured depth in different laser standoff distance (number of data averaged: 50, Nozzle *SOD* 400 mm specimen).

3.2 *Effect of the number of data averaged*

It is obvious that the measurement accuracy increases with a larger number of data averaged. However, we

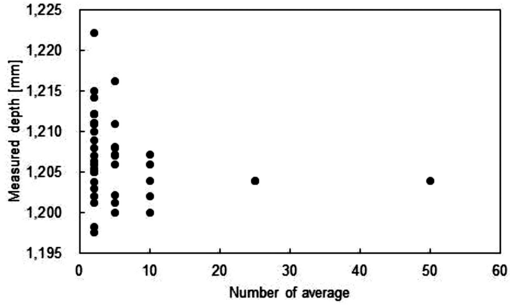

Figure 5. Example showing the effect of data averaging (Horizontal measurement distance 1000 mm with nozzle *SOD* 400 mm specimen).

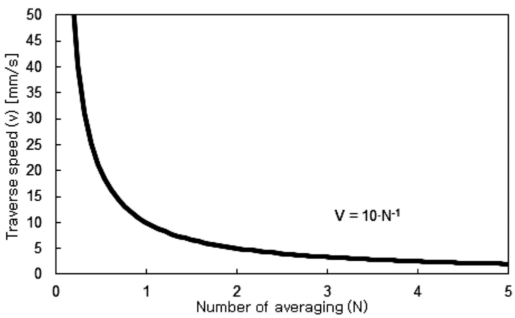

Figure 6. The traverse speed in certain number of averaging (the number of laser points per 1 mm).

do not know how much this variable affects the measurement. Figure 5 shows an example representing the effect of the number of data averaged. All sets of data have a tendency that the measurement error (maximum – minimum measured depth in each number of data averaged) is less than 25 mm with 5 data averaged and less than 20 mm with 10 data averaged.

4 OPTIMIZATION OF TRAVERSE SPEED

It is noted in the previous chapter that a large number of data averaged guarantees accurate measurement. However, a large number of data (laser points) averaged is not efficient in time and cost. In addition, the actual rock shape is 3-dimensional. In this light, the laser scanner should be portable to obtain the 3-dimensional information of the rock surface.

The laser scanner gathers data every 0.1 second. It is assumed that 1 mm length can be seen as a point. We can obtain a chart of the traverse speed (or the speed of laser scanner movement) in Figure 6 and the number of laser points based on this information of the device and this assumption. This chart can be utilized to determine the traverse speed for a certain number of data averaged (the number of laser points per 1 mm).

5 CONCLUSION

This study was conducted to aid the user to determine the laser *SOD* and the traverse speed of a laser scanner. Charts related to laser *SOD* and traverse speed of the laser scanner are obtained. The major conclusions of this study are summarized as follows:

- The measurement accuracy increases with the number of data averaged. Measurement error is less than 25 mm with 5 data averaged and less than 20 mm with 10 data averaged.
- Because the rock shape is not regular the measured depth using the laser scanner is less than the real depth measured by a mechanical method.
- Traverse speed of the laser scanner should be decreased to accurately measure the surface shape. Accurate measurement is closely related with the number of laser points per 1 mm. A chart and an equation are suggested to determine traverse speed easily.

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