A Study for Monitoring System of Tunnel Portal Slopes at Hanti Tunnel in Korea

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Abstract

This research is conducted to develop the qualified data analysis system for predicting the behavior and failure of slope. The sensor system installed in target slopes can measure the tension, rotation and settlement (TRS system), and data measured by TRS system is transmitted to control center by CDMA communication.

In addition, $\bar{x} - R$ management method is used to analyze the acquired data. In this paper, it is discussed whether the $\bar{x} - R$ management system is useful to analyze the slope behavior or not. management system applied herein is to describe the slope behavior and to make a warning system by average ($\bar{x}$) and standard deviation (R).

Keywords: monitoring, tunnel portal slope, TRS system, CDMA, management

Introduction

Because Korea is consisted of steep mountain district over than 70%, slope stability is the severe civil engineering work which could not be avoided. Also research for slope maintenance is achieved to various ways worldwide; however until now setting up the real-time monitoring for it is not prepared enough. It is impossible actually to prevent landslide before, because it happens usually when localized downpour drops, also ordinary sensor could not detect the omen phenomena of landslide. As well as, perfect grasping of soil condition of slope is impossible actually because of unhomogeneity of it. Therefore, beside regular checking of slope and construction of safety diagnosis system need, real-time monitoring system should be needed to cope with the outbreak situation and to grasp slope behavior always.

Sensor System

The sensor system installed in target slopes can measure the tension, rotation and settlement (TRS system), and measured data measured is transmitted to control center by CDMA communication. Measured data is changed into database real time and it is composed to control the data worldwide by internet. Specially, warning message is known through speaker if some symptom of landslide is detected in office, and recording can be transmitted to engineer's cellular phone by real time. Fig. 1 is actual images of sensor established soil section in slope in tunnel pithead respectively.

Target slope is located in Pohang city Kyongsang — province Korea, it is over 2 lanes roadway and maximum height is about 25 m, right side is soil section and left side is rock section respectively, it is a slope in Hanti tunnel pithead of national road 31. Measure section fell into greatly 3 sections, and first section is SE-1, it is consisted of base rock section, and planed for cave-in perception. Second section is SE-2 and third section is SE-3, they are consisted of soil sections, and planed for behavior of soil slopes. Sensors installed can know the length change and horizontal and vertical angles, they are established in 10 places all on 3 sections (Fig. 2).

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Fig. 1. Sensor in soil section

Fig. 2. Installation of sensors

Data Analysis

$\bar{x}$ *control chart*

It is supposed that the data from slope show normal distribution because the slope would be measured continuously and it will make a lot of data, and the average (μ) and standard deviation (σ) of it is already known. If '$x_1, x_2, ..., x_n$' is individual values from slope data whose specimen size is n, the data are taken by the slope(population). Average of this specimen of normally distributed data is as follows.

$$\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n} = \frac{x_1 + x_2 + \cdots + x_n}{n} \tag{1}$$

It is known by central limit theorem that $\bar{x}$ is normally distributed by average μ and standard deviation $\frac{\sigma}{\sqrt{n}}$. Also Equation (2) is approved. Therefore, the data location probability of specimen averages should be $1 - \alpha$.

$$\begin{aligned} P(Lower\ Control\ Limit \leq \bar{x} \leq Upper\ Control\ Limit) &= 1 - \alpha \\ P(\mu - Z_{\frac{\alpha}{2}}\alpha\bar{x} \leq \bar{x} \leq \mu + Z_{\frac{\alpha}{2}}\alpha\bar{x}) &= 1 - \alpha \end{aligned} \tag{2}$$

If the average(μ) and standard deviation(σ) of measured slope data are known, equations (3-a) and (3-b) could be used as upper control limit and lower control limit.

$$LCL = \mu - Z_{\frac{\alpha}{2}}\alpha\bar{x} = \mu - Z_{\frac{\alpha}{2}}\frac{\alpha}{\sqrt{n}} \qquad \text{(3-}a\text{)}$$

$$LCL = \mu + Z_{\frac{\alpha}{2}}\alpha\bar{x} = \mu + Z_{\frac{\alpha}{2}}\frac{\alpha}{\sqrt{n}} \qquad \text{(3-}b\text{)}$$

Furthermore, if 3σ limit is applied to the control chart, 3 is used to control limits instead of $Z_{\alpha/2}$. If $\bar{x}$ is located upper position of upper control limit(UCL) or lower control limit(LCL), it is said that slope maintenance is incapability state and should give a warning sign because specimen average($\bar{x}$) is not equal to population average(μ). By the way, average(μ) and standard deviation(σ) of measured slope data could not be known before sensor installing actually. Therefore, their values can not but predict drawing the specimen in stable slope.

If $\bar{x}_1 + \bar{x}_2 + \cdots + \bar{x}_k$ is said as sum of averages of each specimen, the expedition value ($\bar{\bar{x}}$) of measured average data is as follows.

$$\bar{\bar{x}} = \frac{\sum_{i=1}^{k} \bar{x}_i}{k} = \frac{\bar{x}_1 + \bar{x}_2 \cdots + \bar{x}_k}{k} \tag{4}$$

$\bar{\bar{x}}$ is used as center-line of control chart, i.e., Center Line = $\bar{\bar{x}}$

To make a control limit, the expedition value of standard deviation(σ) is needed. To do that, specimen standard deviation(s) could be used, or simply the range of each specimen group could be used. If individual observation data are composed of $x_1, x_2, \cdot, x_n$ which size is n, the sample range (R) is as follows.

$$R = x_{\max} - x_{\min} \tag{5}$$

Important relationship is noted between sample range (R) and standard deviation(σ) of normal distribution. It is expressed as probability variable, $W = R/\sigma$, it is called relative range. Distribution of W is dependent of sample size (n) of normal distribution. The average (expedition value)of W is d_2, which is determined according to sample size. From $W = R/\sigma, \sigma = R/W$,, Equation (6) is acquired.

$$E(\sigma) = \bar{\sigma} = E\left(\frac{R}{W}\right) = \frac{E(R)}{E(W)} = \frac{E(R)}{d_2} \tag{6}$$

By the way, expedition value of R is

$$E(R) = \bar{R} = \frac{\sum_{i=1}^{k} R_i}{k} \tag{7}$$

The expedition value ($\bar{\sigma}$) of standard deviation (σ) is

$$\bar{\sigma} = \frac{R}{d_2} \tag{8}$$

If $\bar{\bar{x}}$ is used as the expedition value of average (μ), $\bar{R}/d_2$ is used as the expedition value of standard deviation (σ), average (μ), also if $Z_{\alpha/2}$ is applied as 3. The parameters of $\bar{x}$ control charter are as follows.

$$\begin{aligned} UCR &= \bar{\bar{x}} + 3\frac{\bar{R}/d_2}{\sqrt{n}} \\ CL &= \bar{\bar{x}} \\ LCL &= \bar{\bar{x}} - 3\frac{\bar{R}/d_2}{\sqrt{n}} \end{aligned} \tag{9}$$

If A_2 is expressed as

$$A_2 = \frac{3/d_2}{\sqrt{n}} = \frac{3}{d_2\sqrt{n}} \tag{10}$$

Equation (9) is rearranged as equation (11) to decide the upper and lower limits and center line.

$$\begin{aligned} UCL &= \bar{\bar{x}} + A_2\bar{R} \\ CL &= \bar{\bar{x}} \\ LCL &= \bar{\bar{x}} - A_2\bar{R} \end{aligned} \tag{11}$$

Constant A_2 is determined by sample size n.

Application of system

Table 1 shows the average and standard deviation until last point of time by real time transmission. Table 2 shows the upper limit, lower limit and center value by average control chart and standard deviation control chart analysis techniques of real-time monitoring program. Fig. 3 is the average control chart; all data are located within control limits. It could be concluded that there is not important tendency of slope behavior. According to Fig. 4, standard deviations control values are shown as upper limit 1.079mm, center 0.629mm, low limit 0.178mm, until present , there is no sensor that escape maintenance limits.

Table 1. Average and standard deviation of each sensor

Position	Average	Standard dev.
TW1	-0.0201	0.5337
TW2	-0.0139	0.2544
TW3	-0.0183	0.367
TW4	-0.0043	0.2812
TW5	-0.0791	0.7869
TW6	0.0377	0.4962
TW7	-0.0355	1.273
TW8	0.0817	1.2452
TW9	-0.0357	0.34
TW10	-0.1135	0.7077

Table 2. Control limits of $\bar{x} - R$ Management System

	Average control	Standard dev. control
Upper limit	0.593	1.079
Center	-0.02	0.629
Lower limit	-0.633	0.178

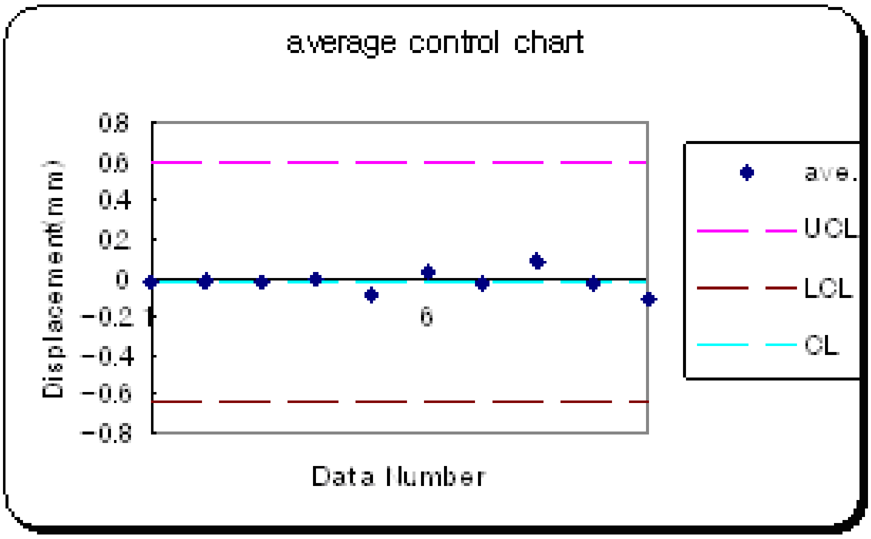

Fig. 3. Average control chart

Conclusions

1) This research is conducted to develop the qualified data analysis system for predicting the behavior and failure of slope. In addition, $\bar{x} - R$ management method is used to analyze the acquired data.

2) Sensors installed can know the length change and horizontal and vertical angles, they are established in 10 places all on 3 sections.

3) To do analysis of slope stability statistically, average and standard deviation of measured data from installed sensors should be used as two parameters to fix the upper and lower limits of control chart.

4) All data of average are located within control limits. It could be concluded that there is not important tendency of slope behavior.

5) According to standard deviation control chart, the data of sensor No. 2, sensor No. 3, sensor No. 4 and

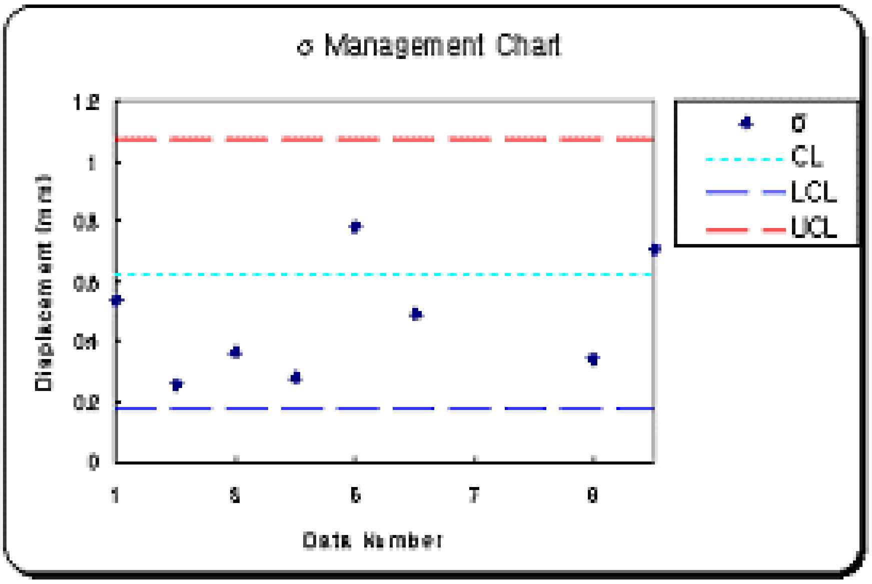

Fig. 4. Standard deviations control chart

sensor No. 9 were closing to the lower control limit, however, until now, all data are located within control limits.

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