The consistency and the longitudinal sound velocity of mountain sand versus its water content

Atsuo Hara¹, Liang Tao¹, Tsutomu Watanabe² and Seiichi Motooka¹

¹Department of Electronics Engineering, Chiba Institute of Technology, 2–17–1, Tsudanuma, Narashino, 275–0016 Japan
e-mail: motooka@es.it-chiba.ac.jp
²Department of Civil Engineering, Chiba Institute of Technology, 2–17–1, Tsudanuma, Narashino, 275–0016 Japan

(Received 24 April 2001, Accepted for publication 21 June 2001)

Keywords: Consistency, Longitudinal sound velocity, Water content, Mountain sand, Slope failure prediction

PACS number: 43.35.Zc, 43.35.Yb, 43.58.Dj

1. Introduction

The technique of prediction of the slope failure caused by heavy rain is anticipated for the disaster prevention. However, an efficient method has not yet been developed.

The paper discusses an approach of prediction method by basic study on the relation of the longitudinal sound velocity with the consistency (N-value) of the soil, by considering that the longitudinal sound velocity will change together with the combining condition between the grains of soil, according to the different water content. The fine mountain sand included in the soil of Narita layer is employed in the experiment, the sand is compacted by certain energy to simulate a natural stable condition, and the longitudinal sound velocity versus the water content of mountain sand is measured in a model sand bath. The measured result is compared relatively with a calculation of the longitudinal sound velocity by the average volume elasticity and the average density of the mixture of mountain sand and water. The comparison shows a similar tendency of the variation of longitudinal sound velocity with the water content till 16%, but the measured value decreases rapidly when the water content is over 16%. Then, the N-value versus water content is measured and the result shows a same curving point. Moreover, the result of measured dry density versus water content verifies that both the curving point of the longitudinal sound velocity and that of the N-value agree with the optimal water content. It is known that the combining condition between the grains of soil is turning fascine if the water content is over the optimal water content. Therefore, it can be said that the results of these experiments draw a light on a possibility of predicting the slope failure by the velocity of the longitudinal wave.

2. Measurement of the longitudinal sound velocity in mountain sand

The longitudinal sound velocity of mountain sand with different water content is measured in a model sand bath (60 cm x 30 cm x 30 cm). The compaction energy is 5.6 cm·kgf/cm³ to simulate a stable natural condition of Narita layer with 10% water content and 1.7 g/cm³ wet density. The measuring system is shown in Fig. 1, an electromagnetic impacted sound source and 4 ultrasonic receivers are arranged equidistant as a linear array and are buried in the middle depth (15 cm) of the sand bath. The longitudinal sound velocity can be derived by the delay times of the peaks of 4 received impulse signals and the distance between the 4 receivers.

3. Calculation of the longitudinal sound velocity in mixture of sand and water

The longitudinal sound velocity in the mixture of mountain sand and water is described as

\[ C_v = \sqrt{\frac{\bar{K}}{\bar{\rho}}}. \]  

where \( \bar{K} \) denotes the average volume elasticity and \( \bar{\rho} \) the average density of the mixture, which can be derived respectively by

\[ \frac{1}{\bar{K}} = \frac{\Phi}{K_s} + \frac{1 - \Phi}{K_w}, \]  

\[ \bar{\rho} = \Phi \rho_s + (1 - \Phi) \rho_w, \]

where \( \Phi \) is the volume ratio of the mountain sand in the mixture, thus that of water is \( 1 - \Phi \), and \( K_s, \rho_s \) are the volume elasticity and density of mountain sand respectively, \( K_w, \rho_w \) are those of water. Substituting Eq. (2) and Eq. (3) to Eq. (1), the longitudinal sound velocity of the mixture materials is

\[ C_v = \left\{ \frac{\rho_s}{K_s} \Phi^2 + \left( \frac{\rho_w}{K_s} + \frac{\rho_s}{K_w} \right) \Phi (1 - \Phi) + \frac{\rho_w}{K_w} (1 - \Phi)^2 \right\}^{-\frac{1}{2}}. \]  

4. N-value and dry density versus water content of mountain sand

Generally, the consistency of the soil is evaluated by its N-value. First, the wet density \( \rho_i \) and the angle of internal friction \( \varphi \) of the mountain sand compacted with the same energy as that used in the velocity measurement are measured. Then, the N-value and the dry density \( \rho_d \) of the mountain sand with different water content are calculated by the following equations respectively [1],
where the effective loading pressure $\sigma_V' = \rho_d \cdot h$, $h$ (15 cm) is the depth of the sound source and receivers array, and $w$ is the water content.

The angle of internal friction $\varphi$ of the material is measured by a direct shear test shown in Fig. 2, it can be derived from the inclination of the curve of the measured shearing stresses versus the different normal stresses.

### 5. Results of the longitudinal sound velocity, the N-value, and the dry density of mountain sand

Figures 3–5 shows the results of the longitudinal sound velocity, the N-value and the dry density of mountain sand versus its water content. In Fig. 3, the calculated result and the measured result of velocity are compared relatively by normalized at the water content is 6%. The comparison shows a similar tendency of the variation of longitudinal sound velocity with the water content till 16%, but the measured value decreases rapidly when the water content is over 16%. The result of N-value in Fig. 4 shows a same curving point at the water content is 16%.

The water content at where the dry density of the mountain sand is the maximum value is called the optimal water content, and it is also 16% as shown in Fig. 5. It is known that if the water content in the soil is over the optimal water content, the combination between the grains will become fascine, and the slope failure becomes easy to occur.

### 6. Conclusion

The measurements of both the longitudinal sound velocity
and the N-value of mountain sand versus its water content show a same curving point at 16%, and this agrees well with the optimal water content. It can be said that the combination between the grains of sand becomes fascine after the water content is over this point, and it is considered that the results shows a possibility of prediction of slope failure by using the longitudinal sound velocity.

More experiments using different compaction energies to simulate different stable natural conditions are expected in further work.

References