The Evaluation of Soil Cementation Generated from the Function of Microorganism

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Available online at: www.isca.in
(Received 19th March 2011, revised 23th March 2011, accepted 30th March 2011)

Abstract

Over past decade, a lot of huge earthquakes attacked urban and industrial areas all over the world. Focusing on an Asian area, 1995 Kobe Earthquake in Japan, 1999 Kocaeli Earthquake in Turkey and 1999 Ji-Ji Earthquake in Taiwan brought severe damage not only to building structures but also industrial facilities and lifeline systems. From the aspect of mechanical engineering, the author investigated a new methodology of ground strengthen by the microbial function was put forward in detail, in which soil cementation can be generated by incorporating calcium, organic matter and microorganism into soil. A case study was performed in order to evaluate the degree of soil cementation generated by the microbial function, using Trigger and Accelerometer method (TA method) for the calibration of shear wave velocities transmitted in a specimen. Results showed an obvious change in shear wave velocities was observed during the experiments implying that the TA method is able to evaluate the level of cementation developed in soil in a non-destructive manner.

Keywords: Soil; Microbial Function; Cementation; Ground Strengthen

Introduction

An earthquake is a naturally induced shaking of the ground, caused by the fracture and sliding of rock within the Earth's crust of the 6,000 earthquakes detected throughout the world each year, 5,500 are either too small or too far from populated areas to be felt directly. Another 450 are felt but cause no damage, and 35 cause only minor damage. The remaining 15, however, can exact great tolls in death and suffering, besides heavily damaging houses, buildings, and other structures.

Earthquakes are commonplace rather than extraordinary events, reflecting the slow but continual motion of material within the Earth. Nearly all occur near the Earth's surface, in the 100-km (60-mi) thick, relatively brittle shell called the lithosphere. The lithosphere is broken up into 12 to 15 rigid plates which move independently, continually colliding and sliding past one another. Earthquakes occur with greatest frequency at the boundaries of these plates (see PLATE TECTONICS). These zones or belts of intense seismicity are separated by the central portions of the plates--ocean basins and continental shields--which are relatively inactive. One plate boundary, the one that borders the Pacific plate, is the source of nearly half of the world's great earthquakes. Stretching 40,000 km (24,000 mi) around the circumference of the Pacific Ocean, it includes such highly populated areas as Japan and the west coast of North America.

While the heat and great pressure of the Earth's interior allow material there to flow smoothly and plastically, the motion of the lithospheric plates occurs in sporadic jumps. Great stresses that accumulate within the plates over a period of years are suddenly released when they exceed the breaking strength of the rock. The shape of the plate boundary, the relative velocity of the adjoining plates and the type of rock all influence the character of earthquakes in a particular region.

The relative velocity between two adjoining plates is greatest at convergent plate boundaries. The thrust faults that develop at these sites of plate collision tend to dip at very low angles through a relatively thick lithosphere, forming a fault plane with a particularly large surface area. The combination of high relative velocity and large fault plane results in particularly large earthquakes.

Convergent boundaries are the site of the world's largest earthquakes, many exceeding 8.5 on the Richter scale.

Relative plate velocities are also high at transform plate boundaries, where adjoining plates slide past one another, but the TRANSFORM (strike-slip) FAULTS that form at these boundaries are vertical, passing through the lithosphere in a short distance. Although major earthquakes occur here, they generally do not exceed 7.5 on the Richter scale.
Divergent plate boundaries are the source of only relatively small earthquakes. The newly formed lithosphere along these zones of plate accretion is relatively hot and thin, permitting only small faults to form. Unlike faults at convergent and transform boundaries, which are driven directly by the relative motion of two plates, these faults, driven mainly by gravitational settling of newly formed plate material, rarely produce earthquakes that exceed 6.0 on the Richter scale.

Since plate boundaries are also the site of most of the world's volcanoes, earthquakes and volcanoes tend to occur in the same areas, as in the Pacific RING OF FIRE. The forces that produce them, however, are different and only indirectly related.
Great earthquakes are seldom associated with volcanic eruptions, but the movement of magma within an erupting volcano may cause faulting and micro earthquakes.

Earthquakes are among the deadliest of natural catastrophes. The average death toll in the 20th century has been 20,000 people annually. Most deaths are caused by the collapse of houses, bridges, and other structures. Although buildings located along a fault may be torn apart, more damage is caused by the shaking alone, which can topple structures far from the actual fault. The force of this shaking has been known to approach the force of gravity, during the few seconds that the earthquake lasts.

Earthquakes also cause indirect damage through landslides (see LANDSLIDE AND AVALANCHE), fires, and the collapse of dams. The civil disorder that follows can lead to disruption of food and water supplies and sanitation systems, causing starvation and the spread of disease. Earthquakes that occur under or near the ocean can also generate tidal waves, more properly called tsunamis or seismic sea waves (see TSUNAMI). With heights up to 15 m (50 ft), these waves can cross an ocean in several hours, inflicting damage upon shores far from the earthquake itself.

The most effective means of minimizing the destruction is through a program of hazard reduction. This approach recognizes the inevitability of earthquakes and tries to reduce their effect in populated regions. Two key requirements--the ability to recognize areas of high seismic risk and the ability to design structures that will withstand shaking--are being met by a combination of modern geological exploration, compilation of records of historical seismicity, and growth of the science of seismology (see GEOPHYSICS) and the field of earthquake engineering. Zoning ordinances and building codes are drafted to ensure that structures in earthquake-prone areas can withstand the amount of shaking expected and that critical facilities, such as hospitals, are not built in especially dangerous locations. Several nations, including Japan and the United States, have implemented some type of seismic hazard reduction and have had a measure of success in reducing earthquake-related deaths and damage.

The accumulation of stress and the weakening of rock that precede an earthquake have measurable consequences, which, if detected soon enough, can signal an alert. Sudden lowering of groundwater levels, tilts and bulges in the Earth's surface, changes in the velocity of propagation of P- and S-waves, changes in the Earth's magnetic field, increased concentrations of rare gases in well water, and geoelectric phenomena have been observed prior to some, but not all, earthquakes. The observation of these precursory phenomena has led to the birth of a new science--earthquake prediction. Some earthquakes can be predicted by a new theory that concerns seismic gaps. According to the theory, certain faults are "ripe" for an earthquake. Parts of these faults are called seismic gaps, because there have been no earthquake tremors along the fault for the past 25-30 years. Some geologists believe that along a seismic gap the earth's plates press on each other so hard that they lock together. Tremendous pressure builds up, someday to be released by a major earthquake.
Loose sandy soils are vulnerable to earthquakes, as they would be liquefied when they are saturated.

When sandy backfill of buried pipe is insufficiently compacted and the buried pipe is broken, some amount of the backfill sand would be flown out of the breakage and surrounding ground would be loosened. Both phenomena can be prevented if some cementation is developed in the soil.

In order to improve soil, chemical agent such as cement or lime is generally added to the soil. Instead, a new environment friendly technique has been recently proposed to improve soil by the function of microbe. Kawasaki et al[1]. reported that the permeability of sandy soil could be lowered by the generation of calcium carbonate, introducing yeast fungi, organic matters and calcium into soil. Hata et al[2]. proposed in-situ permeability control using microbial cementation, showing that microbial analysis using molecular techniques is effective for the monitoring and management of the calcium carbonate precipitation process. However, the physical and mechanical properties of cemented soil have not been well understood. In this study, the degree of cementation in sand specimen in triaxial test was evaluated by the change of shear wave velocity measured by Trigger and Accelerometer method.

Methords

Micobial cementation: When appropriate nutrition is given to microorganism in soil, they generate carbon dioxide by respiration, which turns to be carbonated ion in the pore water. If calcium ion exists and the pH of the environment is alkaline, the precipitation of calcium carbonate mineral occurs. Following is a reaction when glucose is used as nutrition (Kawasaki et al. 2006).

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + H_2O \quad (1)$$

$$C_6H_{12}O_6 \rightarrow 2CO_2 + 2C_2H_5OH \quad (2)$$

$$Ca^+ + CO_2 + H_2O \rightarrow CaCO_3 + 2H^+ \quad (3)$$

A trial test for the evaluation of microbial cementation: A trial test was preformed to evaluate the degree of microbial cementation. Dry Toyoura sand was air pluviated in loose state, of which dry density of 1.44g/cm3, to prepare triaxial cylindrical specimen of ϕ50mm by h100mm. Isotropic confining stress of 30kPa was applied, then "bio-grout" percolated into the specimen from the bottom to the top, by giving approximately 1m head difference. The flush of bio-grout was terminated after one day from the start of flushing as the flush rate notably diminished. The specimen was then left and monitored for a week. The bio-grout was made from the water taken from a pond, to which source of nutrition and calcium was added. Composition of bio-grout is shown below.

Tris buffer	0.1mol/L
Sucrose	0.01mol/L
$CaCl_2$ $2H_2O$	0.01mol/L
Microbes	bacteria which inhabit the pond

Shear wave velocities transmitting through the specimen were measured by Trigger and Accelerometer method, so called TA method, originally proposed by AnhDan et al[3]. (2003). Shear wave of 2kHz generated by triggers on a top cap was monitored by two small accelerometers attached to lateral surface of the specimen. Wave velocities were calculated by the difference of wave arrival time and wave travel length. The operation and system of TA method is schematically presented in Figure 1. A photo of the specimen equipped with the sensors is shown in Figure 2.

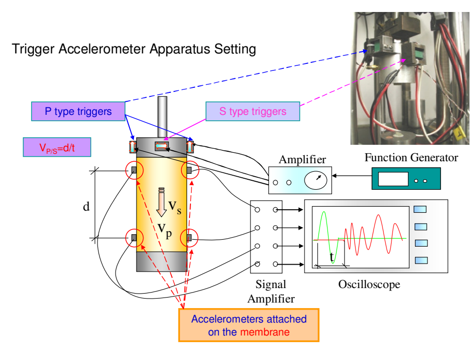

Figure-1: Trigger and Accelerometer method

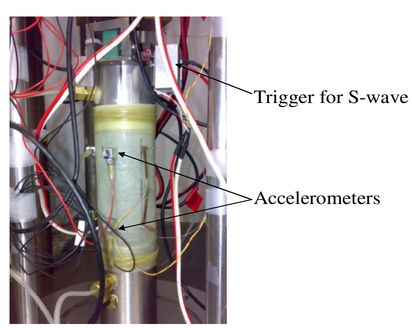

Figure-2: Specimen equipped with sensors for TA method

Result and Discussion

Developed cementation and change of shear wave velocity: A photo of specimen after the test is the flushing was terminated in the course of saturation process due to notable decrease in permeability. It was probably the main cause for the non-uniform development of cementation.

Figure3: Photo of the specimen after the test

Shear wave velocities, Vs, are plotted against elapsed time in Figure 4. The value of Vs was 212m/s at the start of grout flushing and then showing slight increase and decrease, it became 233m/s after one week. It is indicated that small strain shear stiffness, G, was expected to increase by more than 10%. Although it should be noted that shear stiffness evaluated by wave measurements may contain certain amount of errors, as the velocity increase in this test was measured in an identical specimen under the constant stress condition, it can be thought that the observed velocity increase was due to the development of cementation. Figure 5 indicates that the received waveforms after one week shows large response compared to that after on day. It may be also due to the efforts of cementation created between sand grains.

Conclusions

A trial test was performed to evaluate the degree of cementation created by the microbial functions. Using microbes naturally inhabited in the pond, some cementation could be generated in a loose sand specimen, although it was not uniform. Shear wave velocities propagating through the specimen increased by approximately 10%, implying the development of cementation in the course of the

shown in Figure 3. Cementation appeared to develop as the specimen could self-stand, but it was significantly non-uniform. Full saturation of the specimen with bio-grout could not be achieved as

test. Trigger Accelerometer method can be applicable to assess the progression of cementation in non-destructive manner.

Acknowledgment

The authors appreciate the support of this work by the Key Technologies R&D Project of 11th 5-Year Plan National Science and Technology (No. 2006BAK08B01, 200603746006) and the Budding Project supported by Beijing Academy of Science and Technology (B099).

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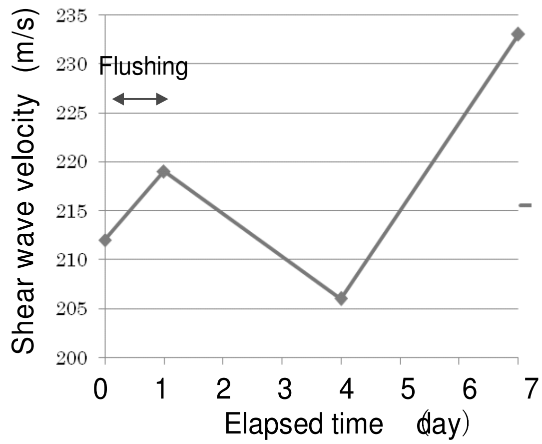

Figure-4: Change of Shear wave velocity

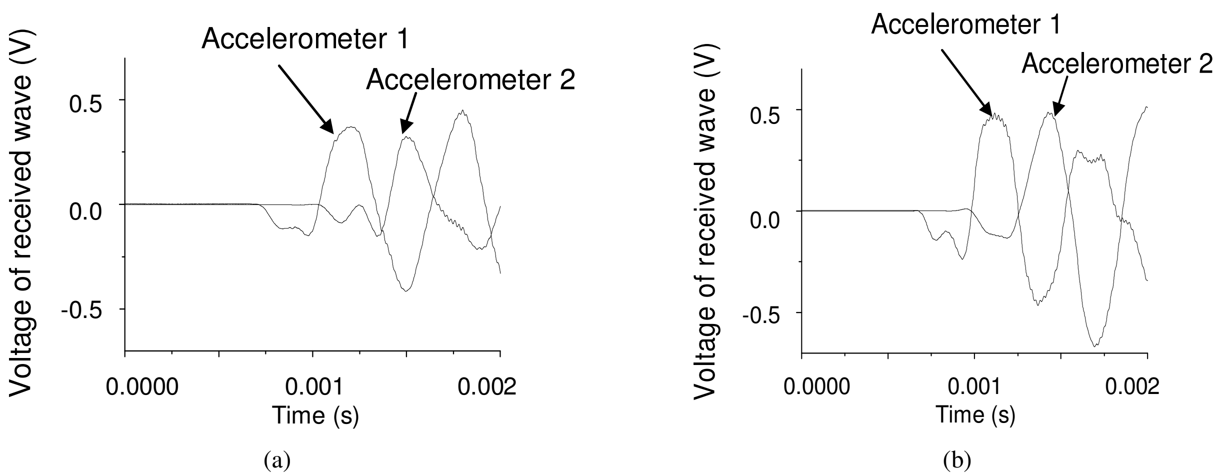

Figure-5: Received waveform (a) after one day (b) after one week.