1次元圧縮を受ける地盤中の埋蔵物の損傷

Damage of remains in soils subjected to the one-dimensional compression

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<u>1. Introduction</u>　Development projects have led to many engineering operations in areas which have a long history of human settlement. Modern construction processes create high stresses and these have the potential to seriously impact on important archaeological remains. There is a danger of losing a large part of our archaeological heritage as these developments progress. Therefore, the importance of collecting archaeological field data and combining this with laboratory testing in order to develop conservation plans for archaeological resources in urban settings has been recognized [1]. The purpose of this study is to examine the damage of ceramic inclusions in sandy soil specimens under one-dimensional compression.

<u>2. Material properties and Apparatus</u>　Decomposed granite soil (Masado) from Shimonoseki in Yamaguchi prefecture and Silica sand (Silica) were used as the soil matrix in this test. Masado consists of weaker and crushable grains than Silica. Figure 1 shows the initial grain size distribution. Unglazed ceramic spheres were used as model artefacts. The clay was formed into 4mm diameter spheres (C-4). After drying for 24 hours, they were fired at 800℃ for 4 hours in a kiln. The one-dimensional (1D) compression tests were carried out on specimens prepared to a relative density of 90% by tamping in 2 layers until the required height of 15mm was achieved. The sample diameter was 50mm. C-4 inclusions were inserted between the layers at the center of the specimens. The crushing tests [2) 3)] were carried out on C-4 by lowering the top platen at constant rate of displacement. During the tests force and displacement were measured. Tests were conducted at displacement rate of 0.1 mm/min.

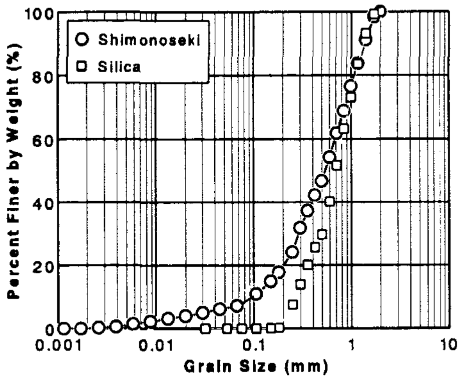

Fig.1 Gain size accumulation curve

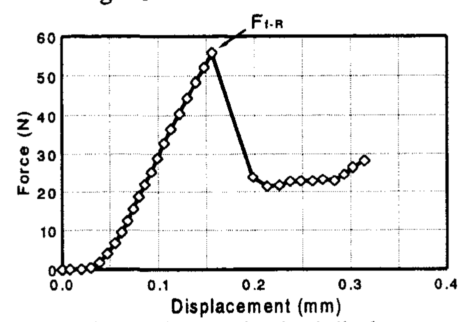

Fig.2 Remain-crushing load-displacement

<u>3. Strength for inclusions</u>　Figure 2 shows a typical force-displacement relationship obtained from a particle-crushing test on original C-4. The crushing force $F_{f\text{-}R}$ was defined as the peak force causing serious damage of the remains. The data was analyzed in term of a crushing strength ($\sigma_{f\text{-}R}$) defined as :

$$\sigma_{f-R} = \frac{F_{f-R}}{d^2}$$

where d was the diameter of the inclusion defined as the initial distance between the platens at the start of this test. This strength was also related to the strength of a C-4 inclusion in a specimen subjected compression.

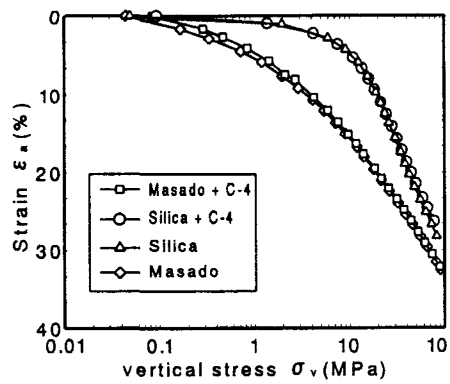

Fig.3 The axial strain- logσ_v relationship

<u>4. Compressibility of soil with inclusions</u>　Figure 3 shows the relationship between the axial strain (ε_a) and the logarithm of the vertical stress (σ_v) for each of the samples. There is no difference between the sample with only Silica and that including C-4 inclusions. In the case of the Masado these also don't appear to be any difference. It can be seen that the soils including C-4 have the same yield stress as the plain soils. The yield stress for Masado is 2.33MPa, and 12.77MPa for Silica.

5. Damage of inclusions in soils subjected to the one-dimensional compression Crushing tests were carried out on the C-4 inclusions removed from the specimens after being subjected to different stress levels. The range and average of $\sigma_{f\text{-}R}$ for each stress are indicated in Fig 4. The $\sigma_{f\text{-}R}$-σ_v relationship for Silica was a little different to the relationship for Masado for $\sigma_v < 30$MPa. The $\sigma_{f\text{-}R}$ in silica suddenly decreased after 20MPa, whereas in Masado it decreased more gradually. The plots for both soils over 50MPa were almost identical and showed a higher degree of internal damage. The date plotted in this way appears similar to the ε_a-logσ_v curve. In order to better understand the effects of the yield stress of the surrounding soil on damage to artefacts, σ_v was normalized with respect to each yield stress ($p_{c\text{-}m}$, $p_{c\text{-}s}$) and is plotted in Figure 5. The images of the ceramic remains after 1D compression at 10MPa and 90MPa for both soils were shown in Photo1. The normalization made the data for different soils more scattered, thus implying that the $\sigma_{f\text{-}R}$ is independent of yield stress. Photo 1a shows the C-4 original. Photo 1b shows the C-4 in Masado after being subjected to 1D compression at 10MPa. From observation there was no evidence of surface abrasion. The C-4 in Silica subjected to 1D compression at 90MPa underwent considerably more surface abrasions than in Masado (Photo 1c and Photo 1d). This comparison also holds for other stress levels. The reason for this difference was soil particle size and shape. Figure 6 shows the relationship between the damage and the energy. Damage and Energy were defined as :

$$Damage = \left(1 - \frac{\sigma_{f-R}}{\sigma_{f-RO}}\right) \times 100 \quad (\%)......(1)$$

$$Energy = \int \left(\sigma_v \times d\varepsilon_a \big/ m^3\right) \quad \left(MN \cdot m \big/ m^3\right)......(2)$$

where $\sigma_{f\text{-}RO}$ is the inclusion's original strength. The damage increases as the energy increases. There are similar relationships for both types of soil matrix. Using this relationship, the damage to artefacts in sandy soil subjected to 1-D compression could be estimate irrespective of the type of sandy soil.

6. Conclusion One-dimensional compression tests have been carried out in order to understand the damage to ceramic inclusions in a sandy soil. Following the test, inclusion crushing tests were carried out to examine the strengths prior to and after tests. The damage on the artefact's surface and the change in crushing strength were discussed. Measurement of the inclusion crushing strength showed that the internal damage decreased with increasing one-dimensional compression stress level and was dependent upon the energy input to the soil.

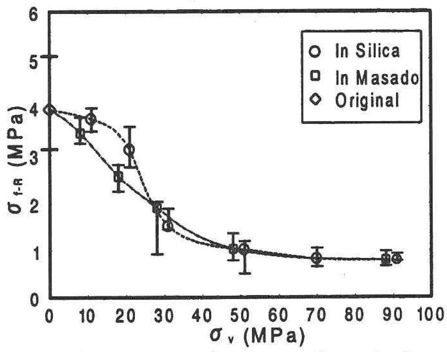

Fig.4 Remain strength-vertical

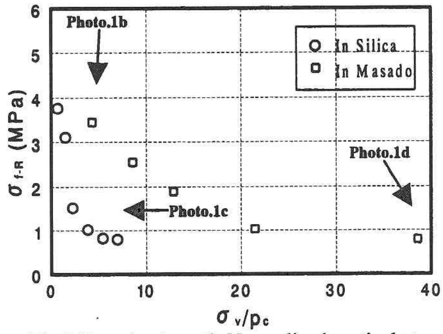

Fig.5 Remain strength-Normalized vertical stress

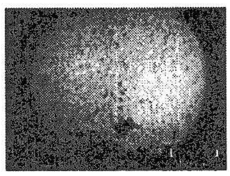
Photo.1a Original

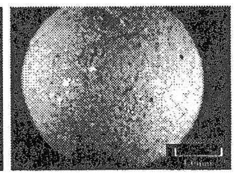
Photo.1b 10MPa in Masado

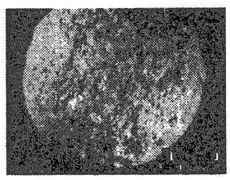
Photo.1c 90MPa in Silica

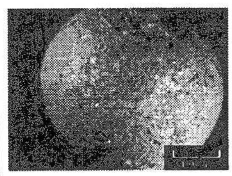
Photo.1d 90MPa in Masado

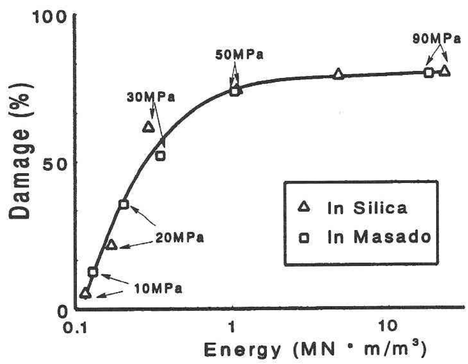

Fig.6 Damage-Energy

REFERENCES 1) English Heritage (2001) Study of the Mitigation of Construction Impact on Archaeological Remains. London: English Heritage. 2) Nakata, Y., Hyde, A.F.L., Hyodo, M. and Murata, H., (1999) "A probabilistic approach to sand crushing in the triaxial test" Geotechnique 49, No.5, 567-583 3) Nakata, Y., Kato, Y., Hyodo, M., Hyde, A.F.L. and Murata, H. (2001b) "One dimensional compression behaviour of uniform sand related to single particle crushing strength" Soils and Foundations Journal of the Japanese Geotechnical Society, 41, No.2, 39-51