Deformation characteristics of sedimentary rock due to continuous changes of moisture content in wetting process

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Abstract. In recent years, the number of cases where tunnels are constructed in sedimentary rock layers has increased. It is essential to investigate the deformation characteristics of sedimentary rocks for predicting tunnel deformation. The mechanical properties of sedimentary rocks are widely varied due to moisture content. The rocks are dried by tunnel excavation and wetted by groundwater gushing or backfilling. It is necessary to grasp the changes of deformation characteristics of sedimentary rocks due to moisture changes. In this study, soaking tests were conducted on Neogene period Japanese tuff sampled at Utsunomiya, Japan. In the test, the cylindrical tuff specimens are air dried by over 240 hours at first. Then the tuff specimens are taken in pure water with measuring deformations in detail. There are no effective stress increases by soaking and only uniform matric suction are acted on the specimen without any restraints. The results demonstrated that strain tensor was reached to stable state for 2 - 3 days, and the value of the normal strain perpendicular to the bedding plane is greater than the other normal components and shear strains are also observed in both cases. Although the orientation of the maximum principal strain is in the near of the bedding orientation at the initial dry state, the orientation are suddenly rotated to the normal orientation of the bedding plane. It means that the principal orientation of anisotropy are rotated due to continuous moisture changes.

1. Introduction
In recent years, underground spaces are utilized in various ways. For example, many tunnels are constructed in urban area for the use of road and railway. Such tunnels are usually excavated in shallow sedimentary layers by mountain tunneling method. In other examples of underground space use, deep geological disposal is also planned to construct in sedimentary layers in several countries. It is essential for such underground space uses to investigate the deformation characteristics of sedimentary rocks for predicting inner space displacements of tunnel and the ground surface displacement above the tunnel because the permissible range of displacements is quite small. The mechanical properties of sedimentary rocks are widely varied.
due to moisture content. The rocks are dried by tunnel excavation and wetted by groundwater gushing or backfilling [1]. It is necessary to grasp the changes of deformation characteristics of sedimentary rocks due to moisture changes.

In this study, soaking tests were conducted on Neogene period tuff sampled at Utsunomiya, Japan. The cylindrical specimens are sampled to parallel and perpendicular orientations to bedding plane from the same cubic block, and specimens are taken in pure water with measuring deformations. The specimens are gradually saturated by water immersion with no effective stress increases and only uniform matric suction.

2. Specimen and testing method

2.1. Tuff specimen

In this study, soaking tests were conducted on Neogene period tuff sampled at Utsunomiya, Japan. The tuff is uniformly distributed in 100 m underground of this region, and there are homogeneous and uniform bedding structure. The mechanical properties of tuff is known to be anisotropic [2], and its anisotropy is generally transversely isotropy [3-4]. The cylindrical specimens are sampled to parallel (x) and perpendicular (z) orientations to bedding plane from the same cubic block of 15 cm height and 30 cm width as shown in Figure 1. Test cases are shown in Table 1.

![Figure 1. Cubic tuff block](image)

Table 1. Test cases for the drying test

| Case | Sampling orientation | Dry density $\rho_d$ (g/cm$^3$) | Wet density after 10 days of water immersion $\rho_s$ (g/cm$^3$) | Total specimen volume after 10 days of water immersion $V$ (cm$^3$) |
|------|----------------------|-------------------------------|------------------------------------------------|--------------------------------------------------|
| a    | z                    | 1.75                          | 2.03                                      | 212.2                                           |
| b    | x                    | 1.77                          | 2.05                                      | 212.5                                           |

2.2. Soaking test

In the test, the specimens are air dried by over 240 hours at first. Three rosette gauges are attached on the lateral side of the specimen, and specimens are taken in pure water with measuring deformations as shown in Figure 2. The specimens are gradually saturated by water immersion. The specimens are not jacketed by any rubber sleeves, and the total water head
of the specimen center is very small (lower than 10 cm). Thus, there are no effective stress increases by soaking and only uniform matric suction are acted on the specimen without any restraints.

3. Test results and discussions

As the soaking test involves the reverse process of the drying experiment conducted by the authors [5]. Figure 3 shows the time series of the strain tensor as $S_r$ increase with time $t$ as water immersion increase. The temperature in the water tank was almost 20 degrees. The normal strains ($\varepsilon_{xx}$, $\varepsilon_{yy}$, $\varepsilon_{zz}$) show 0.05% to 0.1% tensile strains. Except for the shear strain of the $ZY$ components in case-a, shear strain occurs in the orientation opposite to that in the drying process. Although the normal strain of the orientation perpendicular to the bedding plane $\varepsilon_{zz}$ is maximum in case-a, that of the bedding orientation $\varepsilon_{yy}$ is maximum in case-b. Furthermore, small rises and falls of the data seems to be due to air foaming in the specimen.

Figure 4 depicts the principal strains due to $S_r$ and its orientation for cases- a and b. The principal strains values differ, and we can also confirm the deformation anisotropy of Tage tuff during soaking process.

In case-a, $\varepsilon_1$ and $\varepsilon_3$ move to points A $\rightarrow$ B $\rightarrow$ C and a $\rightarrow$ b $\rightarrow$ c due to soaking. The angles of A and C for $\varepsilon_1 \approx 90^\circ$, and the angles of a and c for $\varepsilon_3 \approx 80^\circ$. These results are also opposite
Figure 4. Principal strains and their orientations for case-a (a1, a2) and case-b (b1, b2) during soaking process of drying test. In case-b, \( \varepsilon_1 \) and \( \varepsilon_3 \) move to points A \( \rightarrow \) B \( \rightarrow \) C \( \rightarrow \) D and a \( \rightarrow \) b \( \rightarrow \) c due to soaking. These results show different behaviors were in case-a, probably because of the setting difference of the bedding plane (axisymmetric in case-a but non-axisymmetric in case-b).

4. Conclusions
The results demonstrated that tensile strains are observed after starting soaking process. The strains were reached to stable state for 2 - 3 days. The strain tensor are calculated by the data of three rosette gauges, the value of the normal strain perpendicular to the bedding plane is greater than the other normal components and shear strains are also observed in both cases. These strains show anisotropic deformation behaviors of the tuff in continuous moisture changes because same values of three normal strains and no shear strains should be observed in isotropic materials. Although the orientation of the maximum principal strain is in the near of the bedding orientation at the initial dry state, the orientation are suddenly rotated to the normal orientation of the bedding plane. It means that the principal orientation of anisotropy are rotated due to continuous moisture changes.

Acknowledgments
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