論　文　の　内　容　の　要　旨

論　文　題　目　：
Strength and Deformation of Soft Rocks under Cyclic Loading:An Empirical Study Focusing on Residual Strain Accumulation and Loading Period Effects
(軟岩の繰返し載荷時の強度・変形特性：残留ひずみの蓄積と載荷周期に関する実験的研究)

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Cost-effective design is the primary motivation for adopting the performance-based design method. This method, however, requires that deformations be reliably estimated. While soft rocks are known to be competent foundation materials for large-scale structures, the deformation characteristics of this material when subjected to large cyclic loading still have to be understood.

In this study, the strength and deformation characteristics of soft rocks under cyclic loading were investigated by conducting cyclic triaxial tests on natural soft sandstone samples and on artificial soft rock samples. The loading histories that were applied to these samples were uniform amplitude cyclic loading with loading periods between 1s and 9000s and irregular cyclic loading with 0.3s to 1s harmonic components.

Numerical simulations using the New Isotach Model incorporating the Proportional Rule were also carried out in an attempt to explain failure and residual strain accumulation under cyclic loading. To explore practical procedures for estimating residual deformations due to irregular cyclic loading, Fatigue Modeling and other numerical simulations taking into account observed softening behavior during unloading and reloading were likewise performed. Following are among the key findings from the tests and numerical simulations:

1) Failure below the material strength qs can occur under a certain cyclic loading history with less

than 10 cycles when the stress ratio SR of each cycle is SR ≥ 0.80. When SR is below 0.80 with only a limited number of cycles (e.g., 10), failure below the strength of the material is unlikely.

2) The longer the loading period, the larger is the residual strain accumulated for a certain number of loading cycles. This dependency of residual strain accumulation on loading period appears to be an intrinsic material property and appears to exist irrespective of water content. From this finding, it can be inferred that the prevailing practice of soft rock cyclic loading tests at 0.01%/min to 0.1%/min loading rates can result in overestimated residual strains. These loading rates are equivalent to loading periods between 300s and 9000s, which are far slower than actual loading rates in earthquakes.

3) The simulation results using the New Isotach Model revealed that failure under cyclic loading is similar to failure under creep loading. That is, the large deformations that lead to failure in cyclic loading are also time-dependent. However, the test results showed that cyclic loading deformations are not a function of time alone.

4) Cyclic deformations are also directly linked with residual deformations due to previous unloading and reloading histories. The test results showed that the increment in residual strain due to a half cycle of loading is strongly correlated with the quantity referred in this study as P2S, which is the sum of the magnitudes of residual strain increments due to the preceding positive and negative half cycles of loading.

5) Numerical simulations of residual strain accumulation due to irregular cyclic loading revealed that the use of data from uniform amplitude cyclic loading tests alone, as in the case of Fatigue Modeling, may not be reliable, because the P2S effect is less evident or tends to become “hidden” in uniform amplitude cyclic loading.

6) The P2S effect tends to be more prominent in irregular cyclic loading. Thus, including irregular cyclic loading tests in soft rock testing programs is recommended. Evidently, taking the P2S effect into account can significantly improve the simulation of residual strain accumulation due to irregular cyclic loading.