学　位　論　文　内　容　の　要　旨

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学　位　論　文　題　名

Investigation and Estimation of Restrained Expansion and Shrinkage Behavior of Expansive Concrete Structures

(膨張コンクリートを用いた構造物の拘束膨張および収縮挙動の検討と評価)

Expansive concrete is produced by using an expansive cement or expansive additive that introduces expansion in the concrete at early ages. Expansive concrete is used to reduce the tensile stress caused by restrained shrinkage in concrete structures. Basically, some standards, such as ACI 223R-10, JSCE No. 23, and JIS A 6202, have been regulated as a guideline for designing expansive concrete structures using either expansive cement or expansive additives. However, either the ACI or the JSCE design standard does not include many factors that affect the level of expansion in expansive concrete, such as cementitious replacement materials, curing method, and curing temperature. In addition, the existing standards includes only some types of expansive additive which are calcium oxide-based (CaO) and calcium sulfoaluminate-based (C-S-A). Meanwhile, there are many types of expansive additives or their combinations which produce different expansion levels and mechanisms. According to the limitation of those standards, this study proposes a method to estimate the restrained expansion strain from the free expansion strain of expansive concrete with several mix proportions and curing conditions, including the effects of amount of fly ash, amount of binder, amount of expansive additive, curing temperature, and curing method.

Finite element (FE) analysis is one of the comprehensive methods for estimating the strain level in expansive concrete to increase the flexibility and versatility of the design and analysis process. This research uses FE analysis to estimate the restrained expansion strain in expansive concrete structures. However, it was confirmed that the FE analysis using free expansion strain as the input always overestimates the actual restrained expansion strain of the expansive concrete. This is due to the difference in the expansion mechanism between the free and restrained conditions in the expansive concrete. During the initial hydration process, the expansive agent could rapidly react with water to produce a large number of expansive products. However, since there is no restraining compressive stress in the concrete, the expansive products do not fill much the pores in the concrete. In the case of expansive concrete under restraint, some portions of the expansive products are forced to enter the voids in the concrete, reducing the ability to produce expansion. Compression creep at the very early age also reduce the expansion ability of the expansive concrete under restraint. These two behaviors must be considered in the FE analysis to simulate the deformation caused by the expansion of expansive concrete under restraint, so the free expansion strain cannot be used solely as the input for the FE analysis. Quantification of the loss of expansion due to the two behaviors is very complex as it is very difficult to quantify them separately. Therefore, the effective free strain is defined in this study to be applied as the input in the FE analysis to simulate the deformation of expansive concrete under restraint.

Expansion and shrinkage were investigated through laboratory tests, field measurements, and FE analysis. Concrete expansion is measured in the laboratory under both unrestrained and restrained conditions. Through these laboratory measurements, it was to determine a reduction factor equation that can be used to estimate the effective free expansion strain. This research is continued by validating the proposed method by employing effective free strain to estimate early-age restrained expansion strain in expansive concrete for predicting early expansion and subsequent shrinkage in actual structures. The four structure types chosen for the validation in this research are slabs on grade, slabs on beam, slabs on pile, and water tank walls. In all structures, estimations using FE analysis are performed by considering various factors that influence the expansion and shrinkage behavior of expansive concrete structures. From the results of this investigation, it can be concluded that the reduction factor used to determine the free strain can effectively estimate the restrained expansion strain in the studied expansive concrete structures. The level of expansion and shrinkage strains can be estimated by considering various factors affecting the expansion levels, such as mix proportion, degree of restraint, and measurement direction. In expansive concrete structures, structural configuration and degree of restraint significantly affect the level of expansion and shrinkage. The area with higher restraint conditions always produced lower restrained expansion strain.