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A 12 year EDF study of concrete creep under uniaxial and biaxial loading

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ABSTRACT

This paper presents a 12-year-long creep and shrinkage experimental campaign on cylindrical and prismatic concrete samples under uniaxial and biaxial stress, respectively. The motivation for the study is the need for predicting the delayed strains and the pre-stress loss of concrete containment buildings of nuclear power plants. Two subjects are central in this regard: the creep strain's long-term evolution and the creep Poisson's ratio. A greater understanding of these areas is necessary to ensure reliable predictions of the long-term behavior of the concrete containment buildings.

Long-term basic creep appears to evolve as a logarithm function of time in the range of 3 to 10 years of testing. Similar trends are observed for drying creep, autogenous shrinkage, and drying shrinkage testing, which suggests that all delayed strains obtained using different loading and drying conditions originate from a common mechanism.

The creep Poisson's ratio derived from the biaxial tests is approximately constant over time for both the basic and drying creep tests (creep strains corrected by the shrinkage strain).

It is also shown that the biaxial non-drying samples undergo a significant increase in Young's modulus after 10 years.

1. Introduction

Électricité de France (EDF) is a French electric utility company. Hence, it has been interested in concrete creep and shrinkage for the past 25 years due to the need to operate and extend the life span of its 58 active nuclear reactors. While concrete creep has motivated a lot of research over the past century, there is still much to learn about this physical phenomenon in order to efficiently predict the strains undergone by pre-stressed structures (mostly concrete containment buildings (CCBs) and bridges).

The main objective of this article is to present a unique experimental study on the creep and shrinkage of concrete similar to that experienced by an operating nuclear power plant (NPP) in France. The tests are described and analyzed, and the results are made available to other researchers so that they can contribute their analyses or challenge numerical models against the results.

This article is organized as follows. First, the context of the study is presented, with a focus on the industrial need for knowledge on creep and shrinkage, as well as an overview of multiaxial concrete creep literature. Then, the testing equipment and procedures are briefly described before presenting the results of the 12-year-long study. Finally, three analyses are proposed on the evolution of the instantaneous Young's modulus and Poisson's ratio, the long-term logarithmic strains, and the viscoelastic creep Poisson's ratio.

2. Notations

First the notations used throughout the paper are exposed in order to facilitate reading. Directions in space are noted i with $i = h,v,w,l,r$. As can be seen in Figs. 3 and 1, h,v and w refer to the horizontal, vertical and transverse directions of the 2D tests while l and r refer to the longitudinal and radial directions of the 1D tests. Strains measured in

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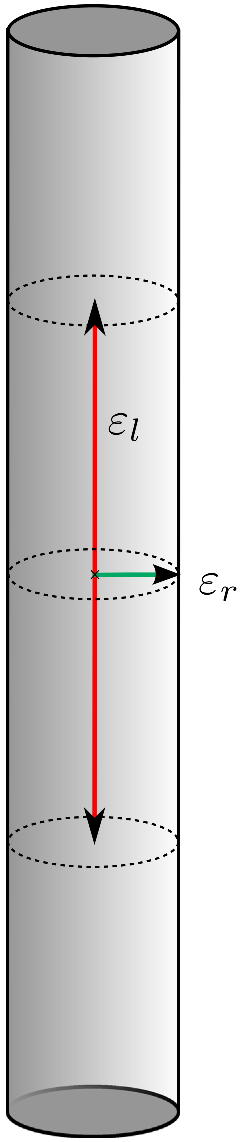

Fig. 1. Uniaxial test geometry with a schematic representation of the longitudinal and radial measured strains.

Fig. 2. Left: 1D drying shrinkage test in the creep tests room at CEIDRE-TEGG. Right: zoom on the radial measurement ring for a 1D non-drying shrinkage test.

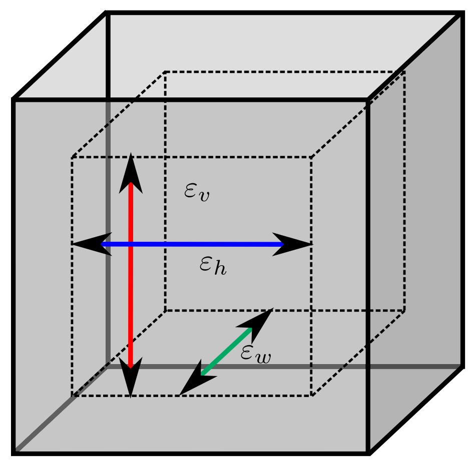

Fig. 3. Biaxial test geometry with a schematic representation of the vertical, horizontal and transverse measured strains.

the four kind of tests are named as following:

	total strain in the non-drying shrinkage test
ε_i^{ds}	total strain in the drying shrinkage test
ε_i^{ndc}	total strain in the non-drying creep test
ε_i^{dc}	total strain in the drying creep test

Contrary to other articles in the literature, the names “dying creep” and “drying shrinkage” are used for the strains measured in the tests of the same name, and not for subtractions between the strains obtained in different tests. Also, the usual terms “basic creep” and “autogenous shrinkage” were avoided to describe the strains measured in the non-drying creep and non-drying shrinkage tests in order to remind the reader of the sealing difficulties experienced during these tests.

The following quantities are also used:

ε_i^{el}	instantaneous strain at loading
m^d	mass of the drying companion sample
m^{nd}	mass of the non-drying companion sample
m_0	initial mass

In order to isolate creep effects from shrinkage effects in non-drying condition, the strain $\underline{\varepsilon}^{ndc} - \underline{\varepsilon}^{nds}$ is used to compute:

$\mathcal{J}^{ndc}$	uniaxial compliance
ν^{ndc}	creep Poisson's ratio
$\nu^{ndc,relax}$	relaxation Poisson's ratio
ν_{2D}^{ndc-el}	creep Poisson's ratio computed from strains excluding the elastic strain

In order to isolate creep effects from shrinkage effects in drying condition, the following strain is used $\underline{\varepsilon}^{dc}(t) - \underline{\varepsilon}^{ds}(t - t_0)$ where t_0 is the loading time used. The following apparent mechanical properties are computed:

$\mathcal{J}^{dc}$	uniaxial compliance
ν^{dc}	creep Poisson's ratio
$\nu_{2D}^{dc,relax}$	relaxation Poisson's ratio
ν_{2D}^{dc-el}	creep Poisson's ratio computed from strains excluding the elastic strain

Finally in the context of computing instantaneous Poisson's ratios