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Stress and strain expressions in a pre-stressed concrete containment building

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ABSTRACT

In a nuclear power plant, the most important concrete structure is, clearly, the containment building. The function of the containment building is to act as the ultimate barrier against the emission of radioactive particles in the event of a severe accident, whence the importance of leak-tightness of the concrete structure. Leak-tightness is ensured by implementing pre-stressing of the concrete structure in such a way that the concrete is in a compressed stress state in all loading situations throughout the life span of the nuclear power plant.

The goal is to derive analytical time history expressions of stress and strain components in the containment structure considering linear visco-elastic models for the pre-stressing steel material and for concrete. These analytical expressions can be used as a simple tool to analyze a specific case with given geometric and material parameters. In addition, one can plot non-dimensional nomograms for pre-stress loss or concrete strain state, which can be used in the pre-dimensioning process of a containment building.

In order to derive global governing equations for a containment building, some simplified assumptions need to be made concerning the geometry and the material constitutive relations. First, the three-dimensional problem at hand has to be reduced to a one-dimensional problem. Hence, for a containment building consisting of a cylindrical and a hemispheric parts, axisymmetric and radial symmetric geometry and kinematics description is used, respectively. Of course, all symmetry breaking details such as openings and local stiffening structures need to be discarded from the analytical model. The pre-stressing circumferential, gamma and dome tendons are considered as a smeared pre-stressing membrane that forms an even envelope over the concrete containment structure. In addition, in order to prevent any shear stress components to form in the concrete structure, it has to be assumed that there is a perfect slip contact condition at the interface between the pre-stressing membrane and the concrete structure. Using the Zener linear visco-elastic model, both for steel and concrete, one can manage to solve the governing equations analytically. Loading of the structure comes from two sources: the pre-stressing of the steel tendons, which create a uniform external pressure on the concrete structure and the internal pressure that acts uniformly on the inner surface of the concrete structure. In addition, concrete shrinkage is considered as a pre-defined time depending function of time.

An analytical model of the nuclear power plant containment building cannot be considered as a substitute for a finite element model, but it has the precious advantages of being easy to use and cheap additional tool in the engineer's toolbox. In contrary to a finite element model, the response obtained from the analytical model can easily be decomposed into different contributions, and large numbers of parametric sensitivity studies can be implemented, which makes the analytical model an ideal tool for understanding the behavior of the structure.

Keywords: nuclear power plant, containment building, pre-stressing, visco-elasticity,