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An estimation of the effect of steel liner on the ultimate bearing capacity of prestressed concrete containment

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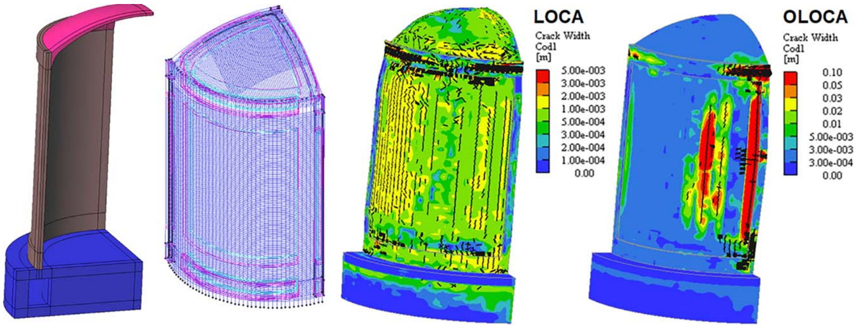
GRAPHICAL ABSTRACT



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ABSTRACT

Three dimensional FEM model is used to estimate the effect of steel liner on the ultimate bearing capacity of a prestressed concrete containment. The model is subjected to internal pressure exceeding LOCA pressure that is increased up to the failure of the structure. By comparison with the experiment described in the literature and with the similar model without steel liner, it is concluded that the liner can increase the bearing capacity of the containment by up to 40%. The 3D model is also exploited for verification of plausibility of previously created set of partial models of the same containment, leading to confirmation of the hypothesis that it is possible to model the behavior of the containment with relatively high precision and low time consumption by a set of simplified models with properly set boundary conditions.

1. Introduction

A steel liner is a key element of single-wall prestressed concrete containments of nuclear power plants. In case of a serious accident, it ensures the leaktightness of the containment, prevents the escape of radioactive material to the environment and minimizes the consequences of the accident.

According to the existing international standards for design of containments of nuclear power plants, the load-bearing capacity of the liner is safely neglected during the design of the containment. Yet it is clear that the liner has significant bearing capacity. Riesemann von and Parks (1995) state that depending on the design of the containment, the liner can account for up to 20% of ultimate bearing capacity of the structure. However, no works directly supporting this estimate have been found in the literature.

The work presented in this paper is a part of long-term research focused on numerical modeling of prestressed concrete containments of nuclear power plants. The main goal is to develop an approach for simplified, fast, yet reasonably precise estimation of the stress-strain behavior of single-wall prestressed concrete containment with internal

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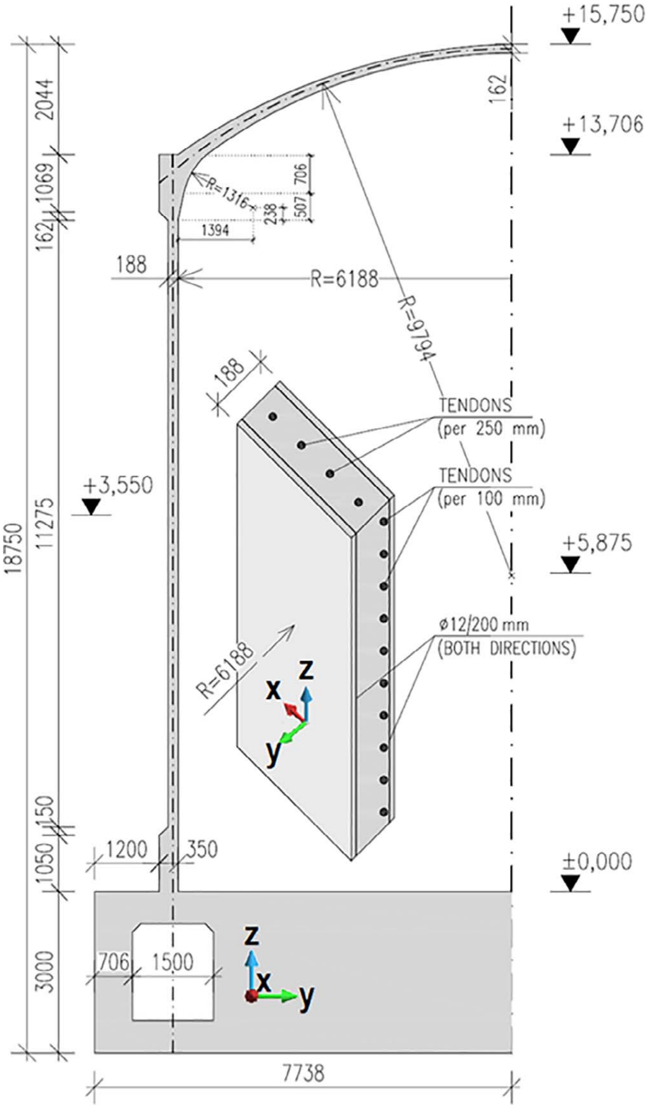

Fig. 1. Vertical section of BARC containment and layout of tendons and main reinforcement bars in the typical area of BARC containment wall (the inset).

steel liner.

In the past, several types of partial models of containment have been developed (Bílý and Kohoutková, 2015, 2017, 2014), relevant models are briefly described in Section 4.1 of this paper) and a set of experiments has been carried out to validate their main results (Kohoutková et al., 2016).

The first purpose of the 3D model presented in this paper was to study the stress-strain behavior of the modeled type of containments under loads exceeding LOCA loads (see Section 3.3.7) and to quantify the contribution of steel liner to the ultimate load-bearing capacity of the structure. The second purpose was to compare the stress-strain behavior of the 3D model with previously developed partial models and to verify their plausibility.

2. Description of the structure

The analysis was based on the geometry of the experimental containment built in Bhabha Atomic Research Centre (BARC) in Tarapur, India (Singh et al., 2007). The main parameters of BARC are clearly described in Fig. 1. BARC containment is a 1:4 scale close representation of the existing prestressed concrete containments No. 3 and 4 of Tarapur Atomic Power Station in India.

BARC containment was built without steel liner. The thickness of the liner in other containments usually varies between 6 and 10 mm (Bílý and Kohoutková, 2017; Řeřicha and Bittnar, 1994; Hessheimer and Dameron, 2006). In this case, 8 mm thick steel liner (= 2 mm after 1:4 scaling) was considered on the inner surface of the containment in order to be able to study the effect of steel liner on the behavior of the containment.

Hereafter, the word “vertical” refers to the direction of *z* axis, the word “horizontal” to the direction of *x* and *y* axes as defined in Fig. 1.

3. FEM model

The geometry of the structure was modeled in GiD 11 preprocessing tool. The model was then analyzed in the Creep module of ATENA Science FEM package (ATENA, 2013). The basic model designated as A0 will be described in this section.

3.1. Geometry

The geometry of the model corresponded to the geometry of the BARC containment. A symmetrical quarter of the structure without the openings in the wall was modeled (Fig. 2). The influence of the cut parts of the structure was introduced by preventing the displacement of the section planes in the direction perpendicular to these planes (displacements in other directions were allowed), see Fig. 2. This means that it was considered that the neighboring quarters of the containment would deform in the same way as the modeled quarter. The model was also constrained on the lower surface of the foundation slab in the direction perpendicular to this surface.

The steel liner was modeled as 2 mm thick steel plate. Perfect bond between the liner and the inner surface of the containment wall was considered. This assumption was justified in Bílý and Kohoutková (2017), where the comparison of results of partial models with perfect and real connection of the liner showed that the type of connection does not affect the global stress-strain behavior of the structure.

Two modifications of the A0 model with steel liner were computed to estimate the influence of the liner on the ultimate bearing capacity of the model. The first one was A1 model in which no steel liner was considered at all. The second one was A2 model in which the steel liner was considered in load steps S1–S5 according to Table 2, but not in the last load step that represented the beyond design basis event.

The wall was prestressed by 124 horizontal tendons spaced at 100 mm center-to-center distance (cross-sectional area 2000 mm^2/m) and 40 vertical tendons spaced at 250 mm. In the real structure, the spacing was not uniform, differences were approximately ± 20% due to the presence of openings. In the model, the spacings were unified to simplify the modeling process as just the global response of the structure was investigated. The wall was also reinforced by 12 mm bars spaced at 200 mm in both directions on both faces of the wall (15 mm concrete cover).

In the dome, orthogonal mesh of the tendons was modeled – 50 tendons in each direction at 100 mm spacing (cross-sectional area 2000 mm^2/m). The reinforcement of the dome was provided by 12 mm bars spaced at 200 mm in both directions on both faces of the wall (15 mm concrete cover).

Both tendons and reinforcement bars were modeled discretely. Grouted tendons were used. General view of all tendons is given in Fig. 3.

In the heavily reinforced concrete foundation slab, it would be efficient to use the smeared reinforcement approach instead of discrete reinforcement modeling. However, the material model CC Combined Material that would allow this way of modeling does not work in ATENA Creep module (it only works in the basic Static module of the program). Therefore, somewhat laborious process of discrete reinforcement input was undertaken. The uneven spacing of bars was unified in particular areas; the reinforcement ratio was the same as in