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Estimation of Pressure Vessel Lower Head Impact Force

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Abstract: This paper presents a method of estimation of the concrete basement slab ablation acceleration during the nuclear severe accident. The molten fuel creates the corium pool in the lower part of the reactor pressure vessel. The stratification of the corium causes the focusing effect which leads to the rupture of the lower head of the pressure vessel. The impact of the lower head filled with the corium affects the subsequent corium-concrete interaction. The method of estimation of the impact load on the concrete basement slab and the related determination of the depth of the crushed concrete layer are presented.

Introduction

Three Miles Island, Chernobyl and Fukushima–Daichi nuclear power plants confirmed that most severe accidents are possible. Although each of these cases happened under different conditions, human errors and natural disasters seem to be the most common causes of accidents in nuclear power plants. Nuclear safety management has to be aware and ready for this type of accident when the reactor cannot be cooled and the overheating leads to melting of the fuel, Fig. 1, and possibly to melting of the reactor vessel itself. The molten materials (corium) create a pool inside lower head of the pressure vessel.

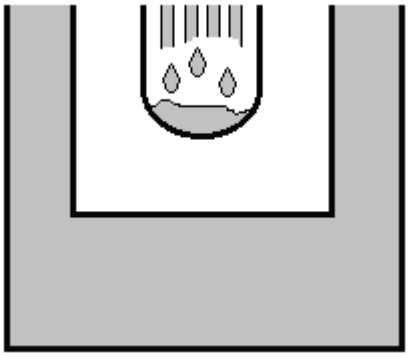
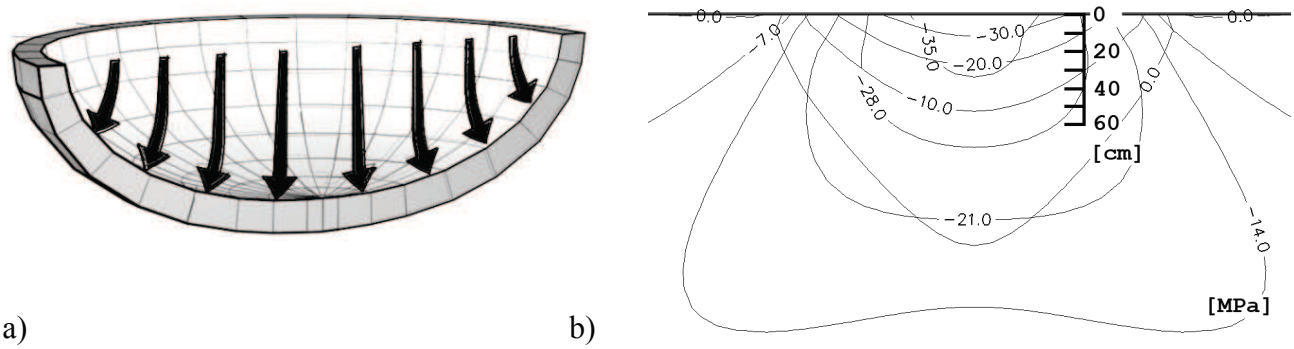


Fig. 1: Pressure vessel lower head with melting fuel

Impact force estimation

The corium pool inside the vessel is stratified due to the difference in material densities. Two layers within the pool are created by oxides and metals. The oxidic layer is heavier, thus located at the bottom of the pool, and generates the decay heat. The metallic layer has much higher thermal conductivity therefore conducts the heat generated in the lower layer easily towards the vessel wall. This phenomenon is called the focusing effect. The vessel wall heated by the metallic layer loses its strength. Then, the vessel wall ruptures in the anticipated area when the self weight of the lower head filled with corium exceeds its strength.

Assuming that the entire lower head is separated from the rest of the vessel, the weight of the falling mass is approximately 150 tons. The distribution of the pressure produced by the impacting corium is not considered as exactly normal to the surface of the lower head as depicted in Fig. 2a). This assumption results from high viscosity of corium and the nature of the impact loading.



a) b)

Fig. 2: a) Distribution of pressure on lower head caused by impacting corium, b) Resulting stress distribution in concrete basement slab

The aim is to obtain the peak value of the force which is necessary for determination of concrete crushing of the basement slab. The finite element model of the lower head was created for the purposes of a nonlinear static analysis which provided a force-displacement curve of the lower head. Then an iteration process based on determination of the total height of fall is performed. The distribution of the peak force is related to the deformed shape of the lower head. A two-dimensional plane strain analysis was performed in order to get the resulting stress in the concrete basement slab, see Fig. 2b). The results show the estimated extent of damage for the peak force of intensity around 30 MN. It is supposable that the impact area of the concrete basement slab is significantly crushed in the depth of 40 cm.

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