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PRELIMINARY EVALUATION OF A SEVERE FLOODING EFFECTS IN AN INNOVATIVE SMR

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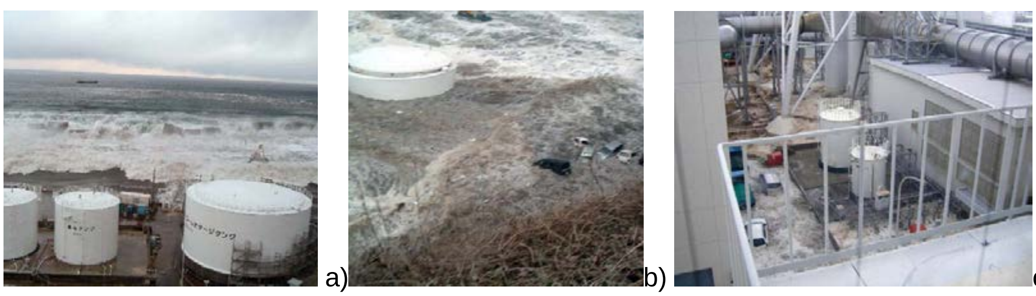
ABSTRACT – The dramatic consequence of the magnitude 9.0 earthquake and of the following tsunami occurred in Fukushima NPP highlighted and confirmed that the existing and future nuclear plants should be designed to be highly secure and capable to withstand this type of extreme events.
In the proposed study the effects induced by an extreme flooding/tsunami was evaluated with reference to a SMR adopting a deterministic approach, setting up a detailed reactor building FEM model and taking into account suitable materials behaviour and constitutive laws. The obtained results were analyzed to evaluate the safety margin of considered SMR plant.

1. Introduction

Taking into account the preliminary lessons learned from the Fukushima Dai-ichi NPP 2011 accident (Fig.1), a comprehensive safety and risk assessments must be performed on all nuclear plants/facility along two parallel tracks (aim of stress tests): a safety track to assess how nuclear installations can withstand the consequences of various extreme external events and a security track to analyse for the malevolent or terrorist acts event [1].


a) b) c)

Figures 1 Flooding induced effects in the Fukushima plants.

In the present study the safety margin of a SMR plant subjected to an severe flooding/tsunami was evaluate assuming the safety systems were not operating as well as the plant isolation and station black-out conditions: the nuclear containment become hence extremely important to ensure and guarantee the plant safety.

2. Approach to analyze the flooding/tsunami

Tsunami generally consists of a series of waves with periods ranging from minutes to hours (arriving in a so-called "wave train") and wave heights that could reach tens of metres: the generated waves propagate upon the arrival at the shore, where they increase in amplitude and height before the inundation (Fig.2) [2, 3, 4].

The potential damage effects are mainly determined by the impact and lateral pushing of the first waves: the smashing force of a water wall traveling at high speed and the destructive power of a large volume of water draining off the land and carrying all type of mobile objects with it (that may be considered like missiles [2, 5]), even if the wave did not look large.

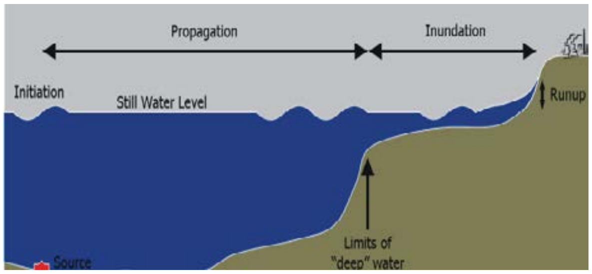
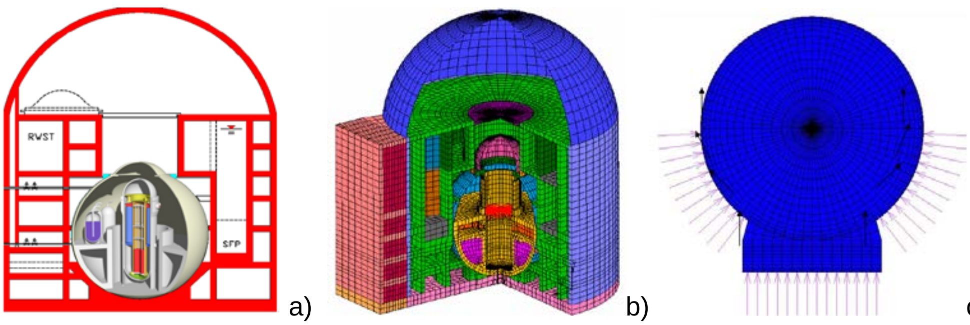


Figure 2 Tsunami phenomenon scheme.

In the proposed study a methodological approach for the design of buildings in area having high risk (V-Zones category [6]), based on the evaluation of the design flood elevation (DFE) and of hydrostatic and hydrodynamic loads caused by the moving wave water calculated according to the ASCE/SEI 7-10 equations [6], was adopted.

3. Global response of a SMR outer containment

As an example a SMR containment looks like the IRIS reactor one (having about 335 MWe that could be scaled down up to 100 MWe) [7] was considered to evaluate the flooding structural effects. This containment building (Fig. 3) has 2 m thick walls and is partially embedded (-20 m below the ground) [8, 9].



Figures 3 SMR scheme (a) FEM model (b) and tsunami waves impact directions (c).

Its FEM model was implemented using 3-D solid and thick shell elements and adopting suitable material properties for the concrete and steel components.

The flooding effects were analyzed (carrying out transient analyses) assuming different waves elevations (ranging from 5 to 20 m). The water flow direction is indicated in figure 4 c.

3.1 Analysis of the obtained preliminary results

The results in terms of Von Mises stress ($\sigma_{max} \approx 30$ MPa, like shown in Fig. 5), in the case of wave elevation (H_{max}) equal to 20m, indicated that the concrete containment walls were suffering local damage and failure phenomena (such as cracking, etc.) due to the hydrodynamic and hydrostatic pressure acting on the containment walls. Moreover it was observed that the stress values increase together with the wave height while, on the contrary, the displacements decrease (the calculated maximum value resulted about 5 cm for H_{max} = 20m).

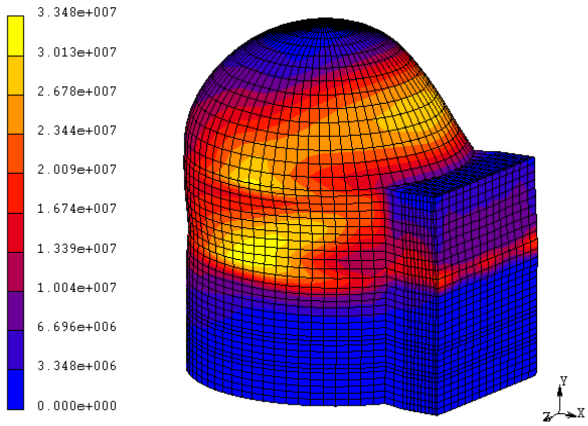


Figure 5 Von Mises stress distribution (H_{max}=20 m).

4. Conclusions

A SMR containment looks like the RIS one was considered to evaluate the effects of an extreme natural event like the tsunami/severe flooding one. A neo-deterministic approach was applied assuming the water waves inundation and impact loads in terms of pressure values, calculated accordingly the ASCE-SEI rules.
The obtained preliminary results, highlighted that the resulting stress values were in some localized part of containment, even if the stress mean values was lower than this one.
It was observed that the considered containment building design, with the assumed hypotheses, is undergoing local high stress values (about 30 MPa) in the case of wave height equal to 20 m, beyond which structural damage and progressive failure may come out, even if in general the containment integrity seemed to be ensured.

5. References

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