

Sub-modelling Technique for Dynamic Analysis of Concrete Structures with Attached Equipment Under Missile Impact

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Abstract:

Approximately 15% of Canada's electricity is generated by Nuclear Power Plants. Canada is planning to construct both new large-scale nuclear reactors and Small Modular Reactors (SMR) to meet future electricity demands. One of the regulatory requirements requires that these reactors shall withstand aircraft impact. Because full-scale testing of aircraft impact against such facilities is not practical, large international research projects have been conducted collaboratively by Nuclear Regulators in Canada, France, Finland and other countries since 2006 to investigate this impact through experimental and numerical studies.

This paper primarily presents results of the Canadian Nuclear Safety Commission (CNSC) participation in these projects and, specifically, in the numerical simulation of reinforced concrete (RC) structures subjected to deformable missile impacts. In addition, the paper summarizes the main findings from these international research projects in order to provide an overview of the current state of the art.

A concrete mock-up with two attached simplified structures, one welded and one bolted, was constructed and tested at the VTT Technical Research Centre in Espoo, Finland. The mock-up was subjected to three successive missile impacts at different velocities to investigate damage accumulation. To examine vibration transmission through the structure, the attached structures, representing equipment, were mounted on the rear wall, while impacts were applied at the center of the front wall. The missile and target parameters were selected to ensure flexible structural behaviour in the impact region, resulting in moderate damage characterized by cracking and permanent deformation without perforation.

The non-linear dynamic response of the reinforced concrete structure was analyzed by CNSC using the commercial finite element (FE) code LS-DYNA. A hybrid FE model employing both three-dimensional solid elements and two-dimensional shell elements was developed. Since the ultimate objective was to simulate an entire nuclear structure over long time periods, a simplified shell-solid model with distributed (smeared) reinforcement was adopted and validated. The model employs solid elements in the vicinity of the impact zone and shell elements elsewhere in the structure.

Detailed modelling of a large reinforced concrete structure with attached equipment results in an extremely large FE model. Therefore, a two-level modelling approach based on dynamic sub-modelling was employed. In the first step, the global structural response was analyzed using simplified representations of the attached equipment. In the second step, the equipment response was