LS-DYNA Impact Analyses of Nuclear Power Plant Structures for Tornado Missile Risk Analysis

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The TORMIS methodology was developed to estimate the probability of damage to nuclear power plant structures and components from debris missile impacts in extreme winds. A critical component of performing this risk analysis is the assessment of the damage characteristics to the power plant structures from various missiles and the critical velocity at which this damage results. For some target/missile combinations, analytical methods have been historically used to predict damage. However, for more complex structures and missiles, either testing or more detailed analyses are required.

This paper details LS-DYNA finite element analyses that were conducted to determine the critical speeds for various missile/target combinations. LS-DYNA is a nonlinear explicit finite element code for the dynamic analysis of structures, and is particularly well-suited for impact and penetration analysis. Targets in this study included various parts of Emergency Diesel Generator (EDG) Exhaust Vents, EDG Fuel Oil Day Tank Vents and Steel Floor Plates. Critical speeds for vent structures were defined by the degree of closure of the vent cross section, which restricts the flow of exhaust gases. To account for uncertainties in the as-fabricated target strength, two welded joints were considered; a 'strong weld' that has the same strength as the baseline material and a 'weak weld' that fails in shear at the design allowable strength. These two cases bound the actual strength of the joint and were necessary due to the lack of sufficient data on the welded joint characteristics.

In these analyses, both the missiles and targets were modeled explicitly to correctly model their interaction and the resulting impact damage. A variety of missile types, including metal pipes, concrete pavers, wood beams, steel grates, metal siding, plywood panels, and storage bins were considered. Impact analyses were conducted to determine the impact response for a large variety of missile impact orientations. Results from these analyses were used to determine the critical orientations and speeds for each missile against each type of target. Over three hundred separate analyses were conducted in various missile orientations at several speeds.

Finally, the feasibility of scaling the critical speeds for the various missiles by their initial kinetic energy was examined. This approach had mixed success because of the large differences in stiffness and strength of the missile types as well as changes in critical orientation. In general, however, missiles of similar size and stiffness to the targets took the least energy. Missiles of similar size but softer and weaker required higher energies and the softest and weakest missiles required the greatest energy. A more general scaling rule would require consideration of the missile strength and geometry characteristics.