SEISMIC ANALYSIS OF SPENT FUEL RACKS

R. LONGO, F. W. MARTSEN, P. A. PERROTTI, E. C. BAIR
Combustion Engineering, Inc., C-E Power Systems,
1000 Prospect Hill Road, Windsor, Connecticut 06095, U.S.A.

SUMMARY

The paper describes the nonlinear time-history seismic analysis method used by C-E for the design and licensing of spent fuel racks. The analysis is based upon a direct numerical integration of the coupled equations of motion for the fuel and the rack. It utilizes a multi-degree-of-freedom springs/lumped masses model of the fuel and rack, accounting for the effects of gaps, impacting, friction and hydrodynamic coupling. A summary of representative results from nonlinear analyses (utilizing the CESHOCK computer program) covering a wide range of designs and seismic excitations is presented, together with a comparison to corresponding response spectrum method analysis results.

To allow insertion and withdrawal of fuel, each spent fuel rack cell is designed to have a gap between it and the fuel. During seismic excitation, the fuel will move freely through the available gap and will impact the cell. The fuel will respond to excitation at its own natural frequencies—not at that of the rack structure—since it is a separate structure and is not attached to the rack. As the fuel moves within the rack and as the rack moves relative to the pool, the water between these structures is moved by them. This acceleration of the water introduces hydraulic loads on these structures and results in a lowering of natural frequencies of fuel and rack. These hydrodynamic effects are accentuated when the interacting submerged structures are in close proximity (small gaps).

Equations of motion for the fuel/spent fuel rack system which account for the gaps between the fuel and the rack, the hydrodynamic coupling between the submerged structures and impacting are developed. The physical situation is modeled and the equations of motion are solved through the use of the computer program CESHOCK. CESHOCK is a modified, C-E proprietary version of the SHOCK computer program developed at Sandia Laboratories, Livermore, California.

A number of spent fuel rack seismic analyses have been performed by C-E, covering a wide range of rack designs and seismic excitations. A summary of representative results from these nonlinear time-history analyses are presented. A tabulation of maximum response loads developed for four different rack designs and four different seismic excitations is given. For one combination of rack design and seismic excitation, the effect of variations in gap size, impact spring stiffness, etc., on the maximum response loads is shown. For purposes of comparison, corresponding response spectrum analysis results are also shown.

The results of the CESHOCK analyses demonstrate the necessity for accounting for the interaction between the fuel and the spent fuel rack caused by the relative motion, through the water-filled gaps between fuel and rack, and impacting of the fuel and the rack. Comparison of these results with those obtained through use of the response spectrum analysis method demonstrates that the response spectrum analysis method—which is unable to account for the interaction effects—leads to incorrect results. For the particular cases summarized here, the ratio of nonlinear time-history maximum response load to response spectrum maximum response load varies over a range of 0.5 to 4.3.