AN EVALUATION OF SEISMIC-RESISTANT DESIGN METHODS FOR INELASTIC STRUCTURES

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SUMMARY

Because of the great uncertainty regarding the nature of future earthquakes, one of the most crucial problems in the earthquake-resistant design of nuclear power plants is the establishment of so-called design earthquakes. A particularly important facet of this problem is the selection of the design or critical seismic forces for structures in which limited inelastic deformations can be tolerated. The reliability of several methods now used or proposed for determining the critical seismic design forces for nuclear power plant structures is evaluated in this paper. The effect of different ground motion time histories as well as of system damping and hysteretic characteristics on the inelastic response is thoroughly investigated considering the maximum displacement ductilities, maximum drifts, number of yield events, cumulative hysteretic energy dissipation, etc.

The methods for specifying inelastic design forces which are examined include those based on: (1) inelastic design response spectra obtained by modifying the linear-elastic design response spectrum for a single degree-of-freedom (SDOF) system in terms of a specified ductility factor as suggested by Newmark, Hall, and others; and (2) new code recommendations which explicitly account for ductility. These methods are evaluated from four perspectives.

Firstly, the required ductilities for ideal inelastic SDOF systems with periods ranging from 0.1 to 2.0 sec. are compared with the specified values used in deriving their design forces. Results obtained for El Centro, Taft, Olympia, and more recent San Fernando near-fault earthquake records indicate that inelastic design forces based on modified linear-elastic response spectra or code recommendations do not reliably limit displacement ductilities to specified values and can sometimes lead to substantially unconservative designs.

Secondly, the inelastic responses of SDOF systems are examined to determine whether the maximum displacement ductility factor is by itself a reliable indicator of structural performance. For the different design methods applied to ideal SDOF systems, the required hysteretic energy dissipation, maximum and permanent displacements, numbers of yield events, and cyclic ductility factors are examined. Results indicate that numerous cycles of reversed yielding generally occur, dissipating much larger amounts of energy than would be inferred from the required ductility alone. Control of damage to nonstructural elements and equipment may also require that limitations be placed on specified values of ductility to reduce the maximum and permanent displacements to acceptable levels.

Thirdly, the sensitivity of ductility requirements to variations in the mechanical and damping characteristics of the system is assessed. Results indicate that stiffness deterioration and small amounts of strain hardening generally have little effect on the ductility requirements. However, most of the methods considered for determining design forces overestimate the effect of damping on inelastic response and, consequently, result in unconservative design forces when large damping values are assumed.

Lastly, the reliability of applying methods based on SDOF systems to the design of multiple degree-of-freedom systems is evaluated. Ductilities required by a multi-story steel frame were substantially different from those assumed in deriving the design forces.

On the basis of the results presented, recommendations are also offered for improving methods for specifying design earthquakes.