ELASTOPLASTIC AND NONSYMMETRIC BUCKLING ANALYSIS BY FINITE ELEMENT OF SUPER-PHENIX PRIMARY VESSEL HEAD

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SUMMARY

Introduction. — A preliminary design of the torispherical head of Super-Phenix Fast Breeder Reactor primary vessel has been analysed to determine the safety margin against two failure modes: circumferential elastoplastic buckling, and excessive plastic deformation.

Normal operating and earthquake loading conditions were analysed with nonlinear 3-dimensional finite element programs PAM NEP-D and PAM-AX3D.

Finite element analyses. — The torispherical head considered has a variable meridional thickness and a branch shell for internal core support; consequently ASME design rules are not directly applicable.

Preliminary studies were performed on axisymmetric geometry with Fourier decomposition for nonaxisymmetric effects. The loading conditions were: argon pressure, hydrostatic sodium pressure and dead weight of vessel and internals. Load combinations for maximum effects were determined. The results showed circumferential buckling to occur (with a critical wave number approximately 30), before collapse due to plastic deformation is reached. Also the assumed predeformations were seen to influence significantly the results, necessitating a full 3-dimensional analysis even for axisymmetric loads. To minimize the size of the 3-dimensional finite element model, an optimisation was done in steps, determining the minimum model accounting both for global unsymmetric load effects, and for local buckling wrinkles and initial imperfections.

Axisymmetric loading conditions were analysed on a 90° vessel segment. Mesh density was selected to model accurately 30-wave circumferential buckling of a cylinder under radial line load with known analytical solution, and to reproduce axisymmetric results in meridional direction. 750 elastoplastic quadrilateral large displacement thin shell elements were used, with kinematic strain hardening for steel behavior. Loads were applied incrementally, until total collapse. Initial imperfections were introduced to represent welding and fabrication defects.

The results showed consistent behavior of the head under the various loading combinations; and collapse was found to occur due to excessive plastic deformation. Slight local buckling waves did form, triggered by initial imperfections, but did not propagate or amplify, due to the fact that peak compressive torus stresses increased comparatively slowly and moved up the torus toward the cylinder junction, as deformations and plastic zones increased.

Unsymmetric earthquake loads were analysed with equivalent static loads in vertical and horizontal directions. A 180° sector mesh was used, of same density, to investigate a potential unsymmetric low wave number buckling mode, which could not be detected.

Conclusion. — The incremental collapse analyses on three-dimensional geometries showed that circumferential buckling was not the predominant failure mode, as could be feared based on preliminary analyses on the underformed axisymmetric geometry. Incipient buckling, however, was considered serious enough to justify design modifications.

This study also demonstrated that complex three-dimensional elastoplastic buckling and collapse analyses, accounting for predeformations and imperfections, can be performed with the finite element method.