TRANSIENT RESPONSE OF STRUCTURAL COMPONENTS TO UNSTEADY FLOW IMPACT AND DRAG LOADS IN A BWR SUPPRESSION CHAMBER

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SUMMARY

This paper introduces a consistent solution method, which takes into consideration the hydrodynamic and fluid/structure interaction effects, to determine the transient response of a simple elastic structure under unsteady flow impact and drag loads, with applications to suppression pool fluid/structure problems in a BWR plant. Numerical examples include problems with the following loading conditions: LOCA pool swell impact load, safety/relief valve (SRV) air bubble oscillation load, and seismic fluid/structure interaction load.

The structural component under investigation is modeled either as a single-degree-of-freedom system (SOF) in terms of the mass-spring-dashpot analogy or as a multiple-degrees-of-freedom system (MOF) in terms of the finite element discretizations.

The dynamic behavior of a submerged SOF structure is described by:

$$M\ddot{w} + (C_1 + C_2)\,\dot{w} + Kw = M_h\,\dot{u} - M_e\,\ddot{w} - (M_e + M)\,\ddot{y} + .5\,C_d\rho A\,(u - \dot{w} - \dot{y})\,|u - \dot{w} - \dot{y}|\,.$$

This equation includes the following as damping terms:

(1) A nonlinear damping term, $.5C_d\rho A(u-\dot{w}-\dot{y})|u-\dot{w}-\dot{y}|$, due to the standard drag caused by quasi-steady fluid motion mode;

(2) A linear damping term, $C_1\dot{w}$, coming from the acoustic and viscous damping effect due to the local perturbed fluid motion mode;

(3) A linear damping term, $C_2\dot{w}$, coming from the structural damping.

It also includes the following as force terms:

(1) A fluid reaction force, $M_e\ddot{w}$, coming from the added mass effect;

(2) A flow acceleration drag, $M_h\dot{u}$, arising from the flow acceleration $\dot{u}$ due to LOCA pool motion, safety valve bubble oscillation, or seismic fluid motion;

(3) A flow impact force, being transformed into the initial structure velocity condition from fluid/structure momentum balance;

(4) An inertia force, $(M_e+M)\ddot{y}$, resulting from the seismic excitation $\ddot{y}$ at the base of the structure.

In the LOCA pool swell impact application, the structural response reveals a damped oscillatory motion, of which the maximum amplitude is linearly related to the initial flow impact velocity and the damping ratio depends on the follow-up flow drag loads. An equivalent hydrodynamic damping ratio of 4.48 percent is obtained for the example problem. The initial velocity approach provides a convenient tool in handling the otherwise very complex loading condition. The stress wave amplification phenomenon under impact loads is clearly demonstrated by the use of the finite element method with initial velocity approach.

In the SRV bubble oscillation application, the acceleration drag load dominates the response of the submerged structure, the standard drag load is so small as to be neglected. In the prevailing range, decreasing the stiffness of the structure also decreases the dynamic amplification factor to the SRV bubble load. The surrounding liquid motion caused by the oscillating air bubble is determined by solving air bubble dynamics equations through numerical integrations.

In the seismic fluid/structure interaction problem, presence of the pool water gives rise to additional flow drag loads induced by seismic fluid motion and meanwhile lowers the vibration frequency of the structure. These effects combine to reduce the maximum relative acceleration response from 0.06 g, were no pool water present, to 0.013 g, for the present example.