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Article / Book Information

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論 文 要 旨

THESIS SUMMARY

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要旨（英文800語程度）
Thesis Summary（approx.800 English Words ）

It is often in the interest of a designer to know the dynamic characteristics of structures coupled with fluid because they have extensive applications in engineering as pumps, butterfly valves, and so on. Therefore, the free vibrations and transient responses of structures coupled with fluid must be predicted accurately and efficiently. This study investigates dynamic characteristics of structures without fluid and coupled with fluid by theoretical analysis, numerical simulation, and experimental measurement.

First, the transient responses of circular and rectangular plates without fluid are studied using the superposition method of normal modes based on thin plate and the modified Minlin-Reissner plate theories. The natural frequencies and mode shapes of the circular plate are obtained analytically. The natural frequencies and mode shapes of the rectangular plate are obtained using spectral-collocation method. The low density and high compliance of the Polyvinylidene Fluoride (PVDF) films make them a suitable method to measure the external dynamic force history. The force history is applied to conduct the theoretical analysis and numerical analysis. The damping factors are considered in the theoretical analysis. The displacement and strain histories obtained from the theoretical analysis and numerical analysis are compared with those obtained from experiments. They match well with each other. Moreover, the effect of the thickness on the strain histories is studied. It is found that it is necessary to consider in-plane modes for thick plates to calculate the transient responses.

Then, free vibrations of circular and rectangular plates based on thin plate and the Mindlin-Reissner plate theories coupled with fluid are investigated analytically. The linear velocity potential function is used to describe the fluid motion considering a small oscillation induced by the plate vibration in fluid. The plate–fluid coupling system is constructed using the fluid pressure over the plate–fluid interface and the flexural deflection of the plate. The wet mode of the coupling system is assumed to be the superposition of the dry mode of the plate, which has been considered in few studies. The contributions of each dry mode to the wet modes are calculated. It is found that each wet mode has its main dry mode. The limitation of thin plate theory is presented. The effect of the fluid height and boundary conditions of fluid on natural frequencies are studied. The natural frequency increases to constant values as the height of fluid increases for rigid wall condition. And the natural frequency decreases to constant values as the height of fluid increases for free surface condition. The converged natural frequencies are the same for the same modes. In other words, the boundary conditions of the fluid will not affect the natural frequencies of the plate if the fluid domain is large enough. Parametric studies are performed to investigate the influence of geometric sizes, plate material properties, and fluid properties on the natural frequencies of the coupled system. A coupling parameter of fluid-structure interaction is proposed. The non-dimensional added virtual mass incremental (NAVMI) factor decreases as the coupling parameter increases. Besides, the influence of fluid on wet modes of the plate decreases with order.

The free vibration of circular pipes coupled with fluid is studied. The Mindlin's first-order shell theory is extended to derive the equations of motion and corresponding boundary conditions by the Hamilton's principle. Linearized potential flow theory is used to derive the hydrodynamic force. Moreover, the internal fluid pressure acting on the shell wall is obtained by the assumption of a non-penetration condition. The dispersion equations are obtained under the assumption of harmonic motion. The derived shell theory is used to calculate the natural frequencies of cylindrical shells with various thicknesses and lengths, and the results are compared with the Flugge's shell theory and finite-element method (FEM). As a result, the proposed shell theory shows improved accuracy and good agreement with published experimental results.

An efficient method for solving the natural frequencies and mode shapes of the coupling system is proposed herein using the orthogonality of the dry modes of the plate. The transient responses of the plate, coupled with fluid subjected to impact loadings, is then solved using the superposition of the dry modes of the plate. For circular plates, when the impact location is the center, only symmetric modes are excited. When the impact location is not the center, not only symmetric modes but also asymmetric modes are excited. To validate analytical results, an efficient and flexible finite element procedure using fully vectorized codes for the free vibration and transient responses of circular and rectangular plates in contact with fluid. The four-node mixed interpolation of the tensorial component quadrilateral plate finite element (MITC4) is used to simulate the plate, whereas the eight-node acoustic pressure element is used to simulate the fluid. The derived system of equations using structural displacements and fluid pressures yields a non-symmetric system of equations. Solving the generalized eigenvalue problem for the non-symmetric system is more computationally intensive compared to solving the generalized eigenvalue problem for symmetric systems. The modal expansion technique is used to reduce the model size. Then the reduced non-symmetric system is symmetrized by right eigenvectors. The Newmark method is used to solve the forced vibration problem of the coupled systems. The results obtained from analytical methods and numerical methods match well with each other.