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Hydroelastic Response of Cylindrical Shell Structures During Earthquakes in Ice-covered Seas

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ABSTRACT

An analytical approach is presented for the seismic hydroelasticity of fixed cylindrical shell structures in ice-covered seas. The sea surface is regarded as the combination of free surface and solid boundary. Both the confined effect due to the surrounding ice sheet and the dissipated effect due to the structure-ice gap are considered for the evaluation of earthquake forces in ice-covered seas. Hydrodynamic pressures are derived in closed forms by the domain division method. Wet mode properties are obtained by the Rayleigh-Ritz method. Seismic responses are evaluated by wet mode superposition and random vibration approaches. Based on the numerical results, the changes in wet mode properties, hydrodynamic pressures and response quantities due to confined and dissipated effects are investigated.

INTRODUCTION

Construction of offshore structures in ice-covered seas is a challenging and innovative task (API, 1995). So far, a number of research studies and developments has been published in the form of conference proceedings and technical reports (Bennett and Machemehl, eds., 1985; Enkvist and Eranti, 1990). However, most of these are concerned only with ice forces on offshore structures (Caidwell and Crissmann, eds., 1983; Maattanen, 1991). In addition, in ice-covered seas that are located in seismically active regions, earthquake forces are critical design considerations in order to assure structural safety and serviceability (Croteau, 1983; Kato et al., 2000).

Cylindrical shells have been used as typical fixed offshore structures. When these are submerged in water and subjected to earthquake ground motion at the sea bottom, hydrodynamic pressure is generated on their exterior surface. The hydrodynamic pressure may be divided into 2 components: the pressure component due to rigid body motion of structure, and the pressure component due to elastic deformation of structure. The first component is dominant if the structure is rigid, while the second component becomes significant if the structure is flexible (Liaw and Chopra, 1974, 1975; Tanaka, Hamamoto and Konno, 1980). Also, when covered with ice at the sea surface, the distribution of these pressure components may be considerably different from that in seas without ice, depending on structural flexibility as well as ice conditions.

When the sea surface is totally or partially covered with an ice sheet during earthquakes, the hydrodynamic pressure increases because of the confined effect due to the ice sheet (Hamamoto, Inoue and Tanaka, 2000). However, if the gap is formed between structure and ice sheet during earthquakes, the hydrodynamic pressure decreases because of the dissipated effect due to the structure-ice gap (Kobayashi and Kawaguchi, 2000).

This study is concerned with an analytical approach for the seismic hydroelasticity of a fixed cylindrical shell structure surrounded by an ice sheet for the cases with and without structure-ice gap. On the basis of the linear potential flow theory, the hydrodynamic pressure is obtained in closed form by solving mixed boundary value problems in which both free surface and solid boundary are located on the sea surface. Using the Rayleigh-Ritz method and mode superposition approach, the equation of motion of the structure in the ice field is derived. First of all, the wet mode free vibration analysis is carried out to investigate the change in wet mode properties due to ice extent as well as structure-ice gap. Then, the seismic response analysis is performed to predict the hydroelastic responses of structure against horizontal ground motion. Based on the numerical results, the effects of ice extent and structure-ice gap on the hydrodynamic pressures as well as response quantities during earthquakes are investigated.

ANALYTICAL MODEL AND ASSUMPTIONS

Fig. 1 shows the fixed cylindrical shell that is surrounded by the ice sheet and subjected to horizontal ground motion. The cylindrical coordinate system (r, θ, z) is used. The origin is located at the center of the shell on the sea bottom. In Fig. 1a, the shell is in contact with the annular ice sheet of finite width at the sea surface in order to study the confined effect of the ice sheet. In Fig. 1b, the annular gap is formed between the shell and the ice sheet of infinite width in order to study the dissipated effect due to gap formation. In both figures, a, h and l are the radius, thickness and height of the shell, respectively; b_1 and b_2 are the distances from the z-axis to the exterior and interior edges of ice sheet, respectively; d is the water depth; U_g is the horizontal ground displacement at the sea bottom; and w is the elastic deformation of the shell.

The following assumptions are introduced in this study:

- The stationary parts of ground accelerations are ergodic and zero-mean Gaussian processes.
- The sea water is irrotational, inviscid and incompressible.

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KEY WORDS: Earthquake force, ice-covered seas, hydroelastic response, cylindrical shell, confined effect, dissipated effect.