Hydroelastic analyses of a floating flexible body in waves

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The developement of "DRACONE" (a long flexible tube) to transport oil and other liquids was started by Hawthorne in 1956(see Hawthorne(1961)). From a hydrodynamic point of view there are two major problems which are important for a flexible tube.

1). Stresses, motions and shape of a flexible tube in waves.
2). Directional stability of a flexible tube under tow.

In this paper we concentrate on the first problem.

A new linear theory to study hydroelastic responses and stresses of a long flexible tube in head sea has been developed. We assume here that the thickness of the skin(for the tube) is infinitely thin, so we can neglect the mass of the tube in our analyses. The elastic deformation of membrane is neglected. Fig.1 shown a typical cross section of a membrane structure(tube) in still water. We assume that the density ρ_o of the fluid outside the membrane is 1.0, which is larger than the density ρ_i of the fluid inside the membrane. The static shape is dependent on the percentage fillings and the densities of the fluid inside and outside the tube(see fig.2). When the filling ratio γ is going to 1.0, the geometry of the membrane structure will be a circle. The static shape of a membrane structure is given by the following equation of condition of equilibrium,

$$\frac{d\theta}{ds} = \frac{\Delta P}{T} \tag{1}$$

where $d\theta$ and ds are defined in fig.1, ΔP is the difference pressure between static pressure inside and outside the membrane and T the static hoop tension. Difficulties in solving eq.1 for the cases $\rho_o/\rho_i \neq 2$ was pointed out by Hawthorne(1961). A new numerical iteration scheme to estimate static shape and stresses of a flexible tube have been developed by Zhao and Triantafyllou(1994).

To carry out the dynamic analyses we should further assume that the incident waves are linear regular waves, the wave amplitude is small compared with a characteristic dimension(D) of the tube and the length of the tube(L) is large compared with D. Due to the slenderness approximation(i.e D/L is small), the flow inside the tube maybe treated as a one-dimensional problem. Outside the tube a boundary element method based on two-dimensional approach has been applied(see Zhao and Faltinsen (1988)). The hydroelastic deformation of the tube has been taken care of by the body boundary conditions. The problem is solved in the frequency domain. A strip theory approach has been applied. For each strip(cross-section) we have unknowns P_1, η_3, A_1 and V_1, where P_1 is the average dynamic pressure inside the tube, η_3 is the vertical motion of the rigid body, A_1 is the change of the filling ratio and V_1 is the average longitudinal velocity inside the tube. The four equations to solve the problem are one-dimensional equation of motion for fluid inside the tube(Euler's eq.), one-dimensional equation of continuity, the vertical force is equal to mass times acceleration and the pressure P_1 is a function of $\frac{\partial P_1}{\partial A_1}A_1 + \frac{\partial P_1}{\partial \eta_3}\eta_3 + \ldots\ldots$.

The deformation of a membrane structure consists of two parts, the most important contribution is due to internal surging of the fluid inside the tube(It has been included in the formulation above). That means the filling ratio for each section is a function of the time. This has been illustrated in fig.2. The other contribution (which is not included in the formulation above)is the deformation due to the pressure distribution(both inside and outer side) around the membrane structure for a given filling ratio. This effect has been investigated by studying the problem of a two dimensional membrane structure in beam sea. A linear theory has been applied. The problem has been solved by applied the Green's second identity both for the inner and outer problem. The outer problem is solved in the similar way by Zhao and Faltinsen(1988). In addition an linearized dynamic equation based on the eq.1 has been applied. This is done by assuming that each parameter in eq.1 consists of static and dynamic part and the dynamic part is a small perturbation.

For a long flexible tube in waves, the non-linear effects could be very important. For examples, the breadth of a membrane structure has large variation near intersection region betweem fluid outside tube and the tube(see fig.1), the stresses in the tube change fast as a function of the percentage fillings and the part of the tube could be totally submerged due to large relative motions or ρ_i is close to ρ_o(example of that is the fresh water inside tube and salt water outside). In this analysis some of the non-linear effects have been investigated and the importance of the non-linear effects are pointed out.

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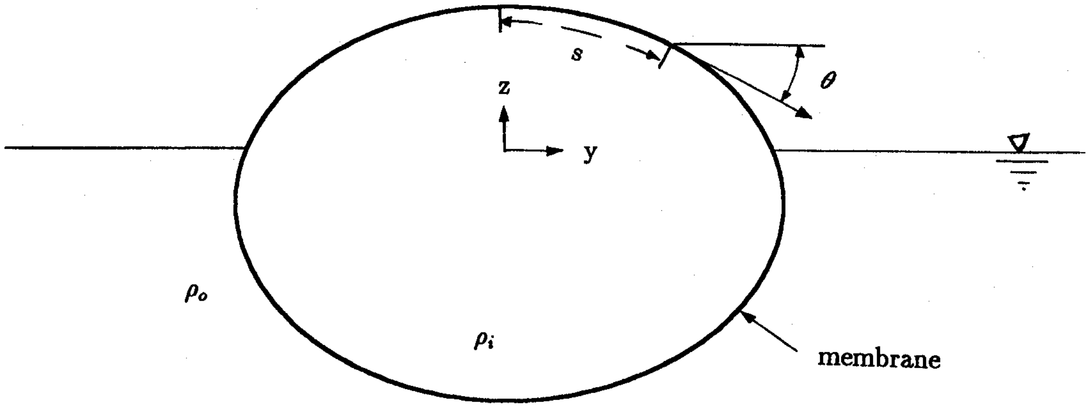

Fig.1 definition of parameters.

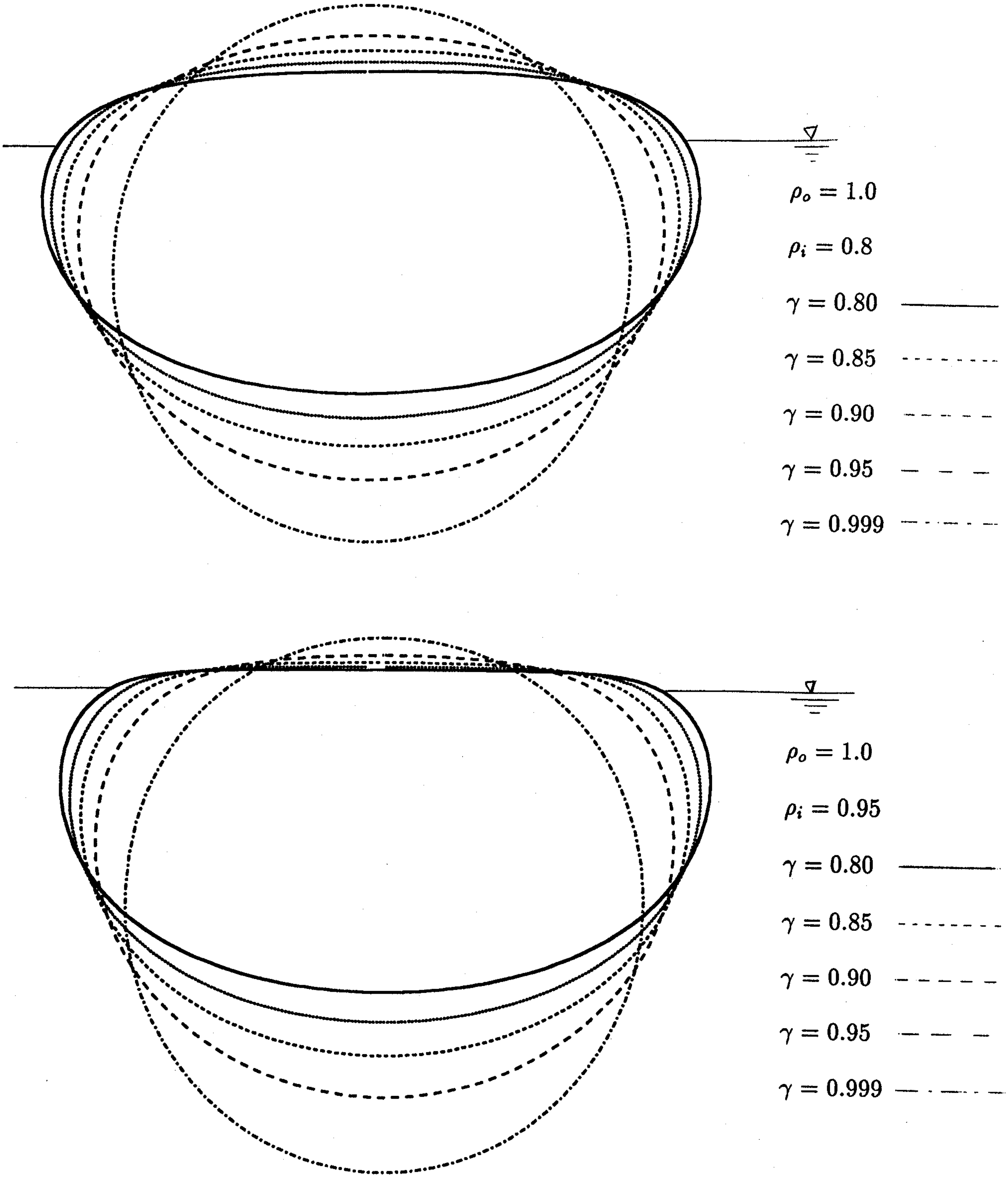

Fig.2 shapes of a floating membrane structure for various percentage fillings and fluid densities inside. ρ_o is the fluid density outside the tube, ρ_i is the fluid density inside the tube and γ is the filling ratio.