I-629 DEEP-WATER TLD WITH SCREEN
------NUMERICAL SIMULATION AND EXPERIMENTAL OBSERVATION

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Introduction: This paper deals with numerical simulation and experimental observation of deep-water tuned liquid damper. Water depth is three to five times that of the so-called shallow-water TLD. A metal screen is introduced with the prospect of increasing damping, so that the damper can function satisfactorily even when the depth ratio is large. A mathematical model is formulated, and its corresponding equations afe solved numerically.

Deep-water TLD: From the experimentally obtained data and observations, vertical excursion of liquid particles in the vicinity of resonance was by no means negligibly small compared with the water depth. This calls for a nonlinear mathematical treatment of the physics. The damping ratio of plain water itself is too low to reach a required optimal damping level, and damping ratio turns out to be a primary factor for TLD's effectiveness as a damper. So it is obvious that some hydraulic resistance must be provided as sources of extra damping.

Nonlinear Equations of Motion: The present study is limited to two dimensional physics.The basic law governing liquid motion is still the classical Navier-Stokes equations.

$$\text{mass: } \nabla\cdot\mathbf{u}=0; \quad \text{momentum: } \left(\frac{\partial}{\partial t}+\mathbf{u}\cdot\nabla\right)\mathbf{u}=-\nabla\left(\frac{P}{\rho}+gz\right)+\nu\nabla^2\mathbf{u} \qquad (1), (2)$$

where **u**=velocity of water particle motion; g=acceleration of gravity; z=vertical coordinate of a particle; ρ=water density; ν=kinematic viscosity of a liquid; P=pressure at location z. A remarkable fact about water wave is that in most cases the main body of the fluid motion is nearly irrotational. This is because the viscous effects are usually concentrated in thin boundary layers near the surface and bottom, therefore a velocity potential ϕ should exist for waves. By introducing velocity potential ϕ and after some mathematical manipulation, the following equations, in physical variables for weakly nonlinear and moderately long waves in shallow water, are reached[1],

$$\zeta_t+\nabla\cdot[(\zeta+h)\bar{u}]=0, \qquad (3)$$

$$\bar{u}_t+\bar{u}\cdot\nabla\bar{u}+g\,\nabla\zeta-\frac{h^2}{3}\nabla\nabla\cdot\bar{u}_t+\lambda\cdot\bar{u}=0, \qquad (4)$$

$$P=\rho g(\zeta-z)+\frac{\rho}{2}(2zh+z^2)\nabla\cdot\bar{u}_t. \qquad (5)$$

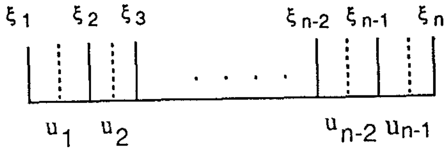

Fig.1 Sketch of Difference Scheme

They are called Boussinesq Equations, where ζ=wave height measured from the still water surface; h=water depth; $\bar{u}$=depth-averaged horizontal velocity of water particle motion. Subscript t denotes derivative with respect to time. Linear viscosity was assumed. Damping coefficient λ is considered to be a function of liquid oscillation frequency, dimension of tank, and water depth ratio.

Numerical Scheme: Employing a finite difference scheme[2] as shown in Fig.1, the following two discretized difference equations are obtained to approximate continuum Equations (3) and (4),

$$a_1\cdot\zeta_{i-\frac{1}{2}}^{n+\frac{1}{2}}+a_2\cdot\zeta_{i+\frac{1}{2}}^{n+\frac{1}{2}}+a_3\cdot\zeta_{i+\frac{3}{2}}^{n+\frac{1}{2}}=\alpha; \quad b_1\bar{u}_{i-1}^{n+1}+b_2\bar{u}_i^{n+1}+b_3\bar{u}_{i+1}^{n+1}=\beta \qquad (6), (7)$$

Equations (6) and (7) are ordinary algebraic equations in terms of wave height and depth-averaged horizontal velocity of particle motion. a_i, $b_i (i=1\sim3)$, α and β are constant coefficients which can be calculated from the wave height and particle velocity computed at the previous time step. In the numerical simulation, the effects of the screen were taken into consideration by introducing head loss artificially at the position where the screen was located[3]. Specifically, this was done by modifying β , which is a function of wave height and velocity of water particle. The water head loss was determined empirically from the characteristics of the screen used[4].

Experimental Observation and Simulation: Experiments were conducted with a view to get first hand data which can be utilized to assess the validity of the mathematical model and the accuracy of the corresponding finite difference scheme. During the experiments, particular attention was paid to observe the effects of the hydraulic resistances in increasing damping, deterring wave breaking and weakening nonlinearity in wave motions even at large excitation amplitudes.

In the experiments carried out, a tank of dimension 59x33.6x40 (length(2a) x width x depth) cm^3 was used. Water depth of 9cm was adopted. TLD tank was fixed on a shaking table which was subjected to harmonic oscillation of 0.1 cm in amplitude. For hydraulic resistance, two metal screen sheets of porosity ratio 50% and 70% were employed. Experiments were conducted without/with one screen installed at the center of the tank.

Some experimental results are depicted in Figs. 2 and 3. It can be clearly seen from Fig2. that the presence of hydraulic resistances increase the damping of liquid sloshing greatly, and nonlinearity of liquid motion is weakened to a considerable degree. Damping ratio is understood to be related to the porosity ratio of a metal screen used. Some results of numerical simulation of liquid motion in TLD under harmonic base excitation are also presented in Fig.2 and Fig.3. From these figures, the numerical simulation of wave motion was seen to be in good agreement with the experimentally obtained values under the same conditions.

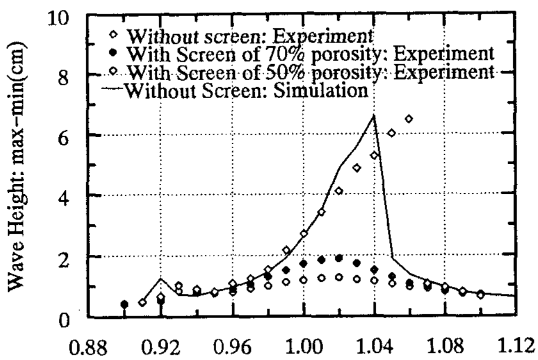

Fig2. Wave height: Experiment & Simulation

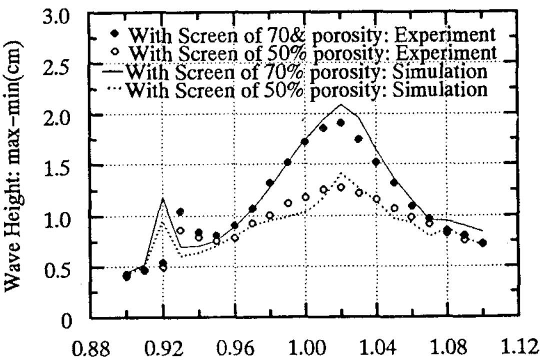

Fig3. Wave height: Experiment & Simulation

Concluding Remarks: 1)The Boussinesq Equations predicted our present physical problem of weakly nonlinear wave motion in a rectangular tank with good accuracy; 2)The numerical simulation was considered to be able to well predict wave motions both with one screen and without; 3)Presence of some hydraulic resistance increased the damping ratio of liquid motion considerably; 4) Hydraulic resistance had also the effects of weakening nonlinearity , which is a prominent characteristic of shallow water waves.

References:

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