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FORCED EXCITATION STUDY ON THE EFFECT OF CONTAINER SHAPE ON TUNED LIQUID DAMPER

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SUMMARY : The effect of container shape of Tuned Liquid Damper (TLD) was investigated using forced excitation experiments. Water motion inside TLD which depends on the excitation angular frequency ω and amplitude of excitation A was found to be complicated. The performance of circular, annular ring and rectangular TLDs as investigated in terms of energy loss per cycle of vibration, ΔE. Comparisons with the free-vibration study conducted earlier (Ref.1) were made. In the investigated range, the two were found to coincide at large amplitude A where wave breaking occurred.

EXPERIMENTAL INVESTIGATION : The shaking table set-up of Ref.2 was used for the sinusoidal forced excitation study. Three kinds of container were used as TLD, i.e. a 60 cm diameter circular tank, an annular ring tank with outside and inside diameters of 60 cm and 50 cm, and a 60×33 cm rectangular tank shaking in the direction parallel to the 60 cm side. The water depth h was 2.7 cm, 7.8 cm and 3.6 cm for circular, annular and rectangular tanks respectively, to achieve the fundamental natural frequency f_w of 0.5 Hz (ω_w = 3.14 rad/s). ΔE was considered as a one-cycle integration of product of shaking table displacement x_s and base shear force F (between TLD and the shaking table) at steady state. Results of the excitation for a range of frequencies are shown in Fig.1 and Fig.2 for circular and annular ring tank respectively.

Fig.1(a) and Fig.2(a) show the relation between nondimensionalized water surface elevation at the end wall η'_a and excitation frequency ratio ω/ω_w at different amplitude of excitation A. η'_a = water surface elevation/liquid depth h. Wave motion inside the tank showed some complicated pattern especially in the circular tank. ( ) region indicates a planar motion of wave which was observed at ω/ω_w far from resonance. Closer to resonance wave motion changed to a "soliton" travelling wave (▒) and became a wave travelling along the wall at around resonance(|||||). The types of wave motion are similar to those described in Ref.3. Besides, at certain ω/ω_w and certain A, one-direction swirling motion (░) was observed. Two-direction motion, i.e. wave rotates in one direction for a certain duration and then changes to the opposite direction repeatedly, was also observed and is shown as ||||||||||. In the annular ring tank, the motion of waves travelling along the wall was observed frequently because of the tank boundary confinement.

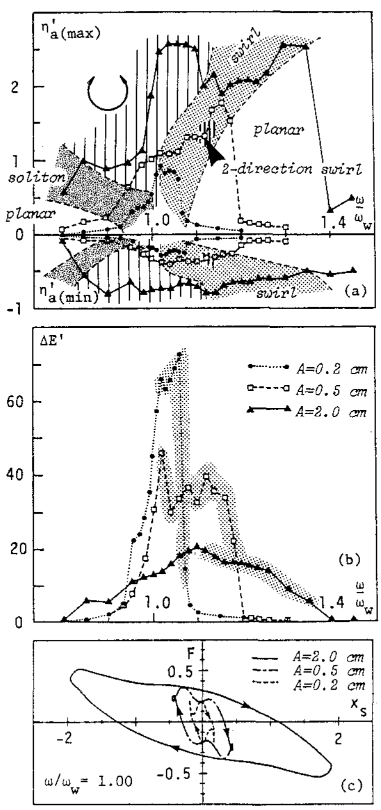

Fig.1 Circular tank case

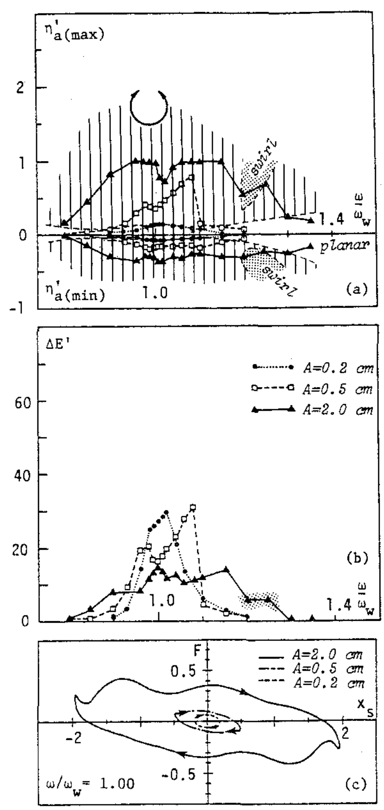

Fig.2 Annular ring tank case

Fig.1(b) and Fig.2(b) show the nondimensional energy loss $\Delta E'$ which is defined as $\Delta E' = \Delta E/(^1/_2 m_w \omega^2 A^2)$. m_w = liquid mass. The effectiveness of TLD could be determined partly from $\Delta E'$. As A increased, wave breaking became apparent in the experiment, and the peak of $\Delta E'$-ω/ω_w relation decreased and tended to be flatter. It should be noticed that in the swirling motion region, $\Delta E'$ had a downward trend or a slower rate of increase (at A = 0.2 cm, circular tank). Precaution to prevent swirling may be necessary in designing the TLD.

Despite the fact that in a circular tank when $\Delta E'$ is large, water motion was similar to that of an annular tank, $\Delta E'$ of the circular tank was found to be greater than that of the annular tank. This may be because of the ratio of h/half dimension of the tank, a, of the annular tank (h/a= 0.26) is larger than the circular tank (h/a=0.09). In deep liquid, there is a dead mass at the bottom that does not move and is ineffective in dissipating energy.

Fig.1(c) and Fig.2(c) show the relation between base shear force F and shaking table displacement x_s at ω/ω_w = 1.00 for the circular tank and annular tank respectively. It can be seen that for the circular tank at A = 0.2 cm, there exists a nonlinearity whereas in the case of the annular tank, whose h/a is larger, the non-linearity is weaker since the shape of the F-x_s loop is similar to an ellipse. When A increased and wave breaking was observed, e.g. A = 2.0 cm, the relation between F and x_s of the two cases tended to become qualitatively similar.

Further investigation using circular and rectangular tanks was done by increasing amplitude A gradually at a certain excitation frequency ω. ω was 3.14rad/s in order to be the same as the structure natural frequency ω_s of the free-vibration study conducted in Ref.1. The water depth h at tuned condition (Ref.1), was 2.1 cm and 3.6 cm and the ω/ω_w ratio was 1.12 and 1.00 for the circular and rectangular tanks respectively. η_0' was detected at position **x** (Fig.3(a)) where only travelling wave can be observed. Fig.3(a) shows the relation between η_0' and the relative amplitude of excitation α = A/a for the circular tank. Fig.3(b) shows the relation of ΔE and α. It can be seen that when α is greater than 0.02, there is a sudden increase in ΔE. This correlates to the increase in η_0' which converges to the value of about 1.0. This limit is a criterion of wave breaking for a very mild slope bottom. The comparison of the free-vibration study (Ref.1) and the forced vibration is shown in Fig.3(b). (For free-vibration with moderate damping, ΔE can be computed from $\Delta E = 2E_n\delta$, where E_n = kinetic energy of the structure at nth cycle. δ = logarithmic decrement of structure amplitude at nth cycle.) It can be seen that the ΔE-α relation of the free and forced vibration are similar when $\alpha > 0.02$, i.e., when wave breaking occurs. At $\alpha < 0.02$, beating in the free-vibration amplitude led to negative $\Delta E'$ results that cannot be correctly interpreted. Since wave breaking dissipates a large amount of energy, i.e. high damping in TLD itself, it may enable the 2-DOF structure-TLD system of the free-vibration test to behave, to some extent, like an SDOF system and, hence, the similarity between the results of the forced and free vibration. At out-of-tuned condition (e.g. ω/ω_w = 0.90), qualitatively the free and forced vibration coincided; but the similarity was not as well as the tuned condition stated above. The comparison of the rectangular tank at tuned condition also showed the coincidence.

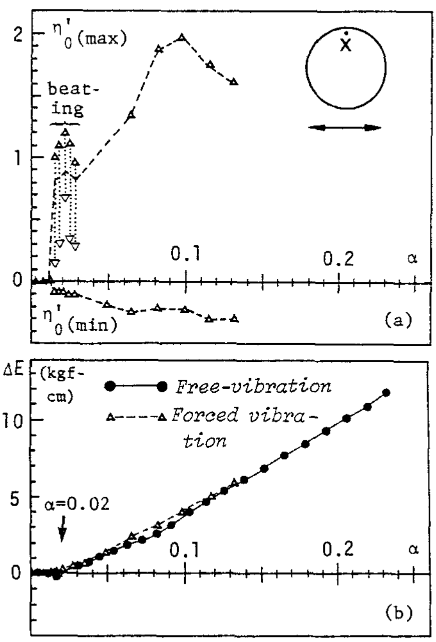

Fig.3 Comparison of Free and Forced vibration experiment

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