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# DAMPER USING LIQUID MOTION AS ENERGY DISSIPATOR- Tuned Sloshing Damper

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## INTRODUCTION

Mechanical dampers that dissipate energy through sloshing of contained liquid may be useful in suppressing structural vibrations, as also pointed out by Modi et al.[1] and Bauer[2]. Different from dampers heretofore proposed, sloshing liquid dampers may prove to be almost maintenance-free. Mathematical difficulties remain, however, in modeling the liquid motion for engineering calculations. The present paper aims to present some experimental results and study the adequacy of modeling the sloshing liquid as a kind of tuned mass damper (TMD).

## FREE-VIBRATION EXPERIMENT ON TOWER MODEL

The tower model weighs 6.2 kg and has a fundamental natural frequency of 2 Hz for out-of-plane vibration (see Fig.1). Closed liquid container was attached to the tower at point A. Either a 3.7 cm high 8.30 cm diameter or a 4.0 cm high 5.14 cm diameter circular cylinder or a cube of 3.5×3.5×4.0 cm was used and water mass was varied, in order to vary the natural frequency of liquid sloshing. Free vibration in each case was started by shaking and then releasing the tower at point A. Total effective damping was then measured from recorded time history of displacement of point A of the tower, e.g. Fig.4.

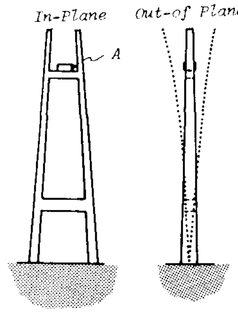

Fig.1 Experimental Setting

The separate points plotted in Figs.2(a)-(c) show experimentally obtained relation between frequency ratio (i.e., first antisymmetric mode sloshing frequency $\omega_l$ as calculated by linearized theory, divided by fundamental tower frequency $\omega_s$) and change in damping ratio (i.e., total damping ratio $\zeta$, minus damping ratio of tower $\zeta_s$). Damping values measured at high-amplitude tower vibration (about 3 cm double amplitude at A) are shown as ●. Those measured at lower double amplitude of about 1 cm are shown as □. It should be noted that the same range of frequency ratio in the three examples shown in Figs.2(a)-(c) corresponds to different ranges of mass ratio (i.e., liquid mass $m_l$, divided by first modal mass of tower $m_s$) and different ranges of depth ratio (i.e., depth of liquid h, divided by container radius or halfwidth).

## LINEAR TMD MODEL

The curves in Figs.2(a)-(c) show relation between frequency ratio $\omega_l/\omega_s$ and change in damping ratio $\zeta-\zeta_s$, as obtained by a TMD model. In this TMD model (see Fig.3), $k_s = m_s\omega_s^2$ ; $k_l = m_l\omega_l^2$ ; different values were tried for $\zeta_l$ to account for liquid slosh damping, and the other quantities were as defined above. The total modal damping $\zeta$ was obtained, by complex-eigenvalue analysis, as the damping ratio of the fundamental mode of this two-degree-of-freedom system. It should be pointed out that in order to trace the curves in Figs.2(a)-(c), $m_l$ as well as $k_l$ had to be adjusted (for given size and shape of container) to obtain the desired $\omega_l$.

## APPARENT INADEQUACY OF TMD MODEL

The linear TMD model could predict the experimental results in only few cases. For example in Fig.2(a), when $\zeta_l$ is set at 0.05, the additional damping at low-amplitude vibration is predicted rather well in the range of frequency ratio from about 1.0 to 1.5. For other cases, adjusting $\zeta_l$ is not enough to obtain acceptable fit with experimental results, particularly the additional damping measured at high-amplitude vibration.

The slosh damping factor $\zeta_l$ could be considered to account for energy dissipation due to turbulence. In fact, Bauer[2] and Miles[3] suggested that in practice this quantity may be increased by submerging baffles in the liquid (e.g. annular ring around the inside of circular cylinder).

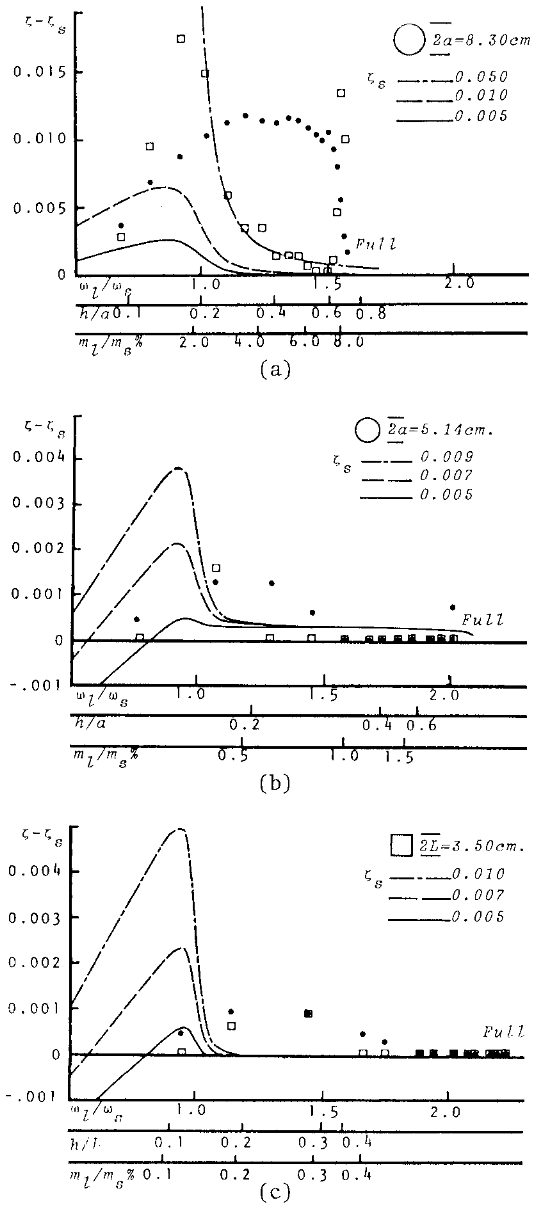


Fig.2 Relation of Additional Damping and Frequency Ratio ( • = Experimental Results Measured at High Amplitude, □ = at Low Amplitude).

It seems not sufficient, however, to fix one value of $\zeta_l$ for a given shape and size of container. For example, when the container was covered as in the experiment, increasing the sloshing natural frequency meant decreasing the gap between the liquid free surface and the container roof. This condition of small gap increased the chance of sloshing water to hit the roof and dissipate energy in the process. The phenomenon was actually observed many times while the tower vibrated at relatively high amplitude.

## CONCLUDING REMARKS

Linear TMD model was generally inadequate in predicting the additional damping produced by sloshing of liquid. Mechanical model incorporating nonlinear sloshing should be developed particularly when turbulence-enhancing baffles are to be incorporated in the design of this type of damper. Further experiments should also be performed, considering other sizes of container as well as varying other liquid parameters.

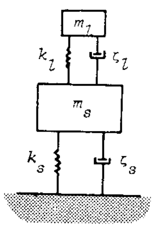

Fig.3 TMD Model

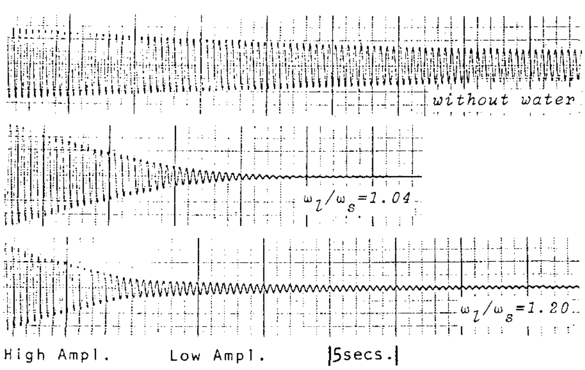


Fig.4 Time History (8.30 cm Diameter Cylinder)

## REFERENCES

[1]Modi, V.J. and Welt, F.," On the Control of Instabilities in Fluid-Structure Interaction Problem," (Preprint).
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[3]Miles, J.W.,"Ring Damper of Free surface Oscillations in a Circular Tank," ASME J. of Applied Mechanics, pp.274-276, June 1958.