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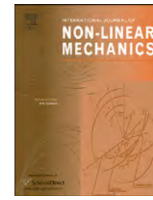

Non-linear multimodal model for tuned liquid dampers of arbitrary tank geometry

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ABSTRACT

Tuned liquid dampers (TLDs) utilize sloshing fluid to absorb and dissipate structural vibrational energy. Simple TLD tank geometries may not always be feasible due to space limitations. While the non-linear modelling of sloshing fluid is currently limited to tanks of simple geometries, this paper develops a non-linear multimodal model which describes the sloshing behaviour of a fluid in a flat-bottom tank of arbitrary geometry. The mode shapes of the sloshing fluid are found by solving the Helmholtz equation over the tank domain using the finite element method. The Bateman–Luke variational principle is used to develop a system of ordinary differential equations which account for the coupling of the sloshing modes through the non-linear free surface boundary conditions. Damping is incorporated into the model by considering the drag produced on a set of damping screens inserted in the fluid. The system of ordinary differential equations is solved using the Runge–Kutta–Gill Method to predict the wave heights and sloshing forces. In general, the mode shapes in an arbitrary tank will have components in two orthogonal (x- and y-) directions. This out-of-plane behaviour is an important consideration for TLD design. The model is validated with existing models for the special cases of rectangular and circular tanks. Lastly, new shake table tests are conducted on a tank of complex geometry.

1. Introduction

Tall, lightly damped, flexible buildings are susceptible to excessive wind-induced accelerations, which can cause significant occupant discomfort. Tuned liquid dampers (TLDs) have been employed to mitigate these vibrations. A TLD is a tank, partially filled with fluid, which is typically located near the top of a building. As the building moves in the wind, the fluid contained within the tank begins to slosh. The fluid thereby absorbs vibrational energy from the structure and transforms it into kinetic and potential energy of the sloshing fluid. The sloshing energy is subsequently dissipated through the fluid's viscosity, or drag produced by flow damping devices such as baffles, poles, nets or screens [1].

Existing TLD installations have been restricted to simple tank geometries, usually circular or rectangular [2–4]. However, there may be stringent limitations on the floor plan which a TLD tank may occupy due to fixed mechanical or structural components. The effectiveness of a TLD is sensitive to the TLD-structural mass and tuning ratios, as well as the TLD damping ratio [5,6]. These ratios depend on the dimensions of the tank; therefore restrictions placed on the tank dimensions can significantly impact the performance of the device. Alternatively, it may be possible to conform to the space limitations by altering the geometry of the tank by chamfering a corner, or skewing a side wall. Thus, a small local interference between the tank and some fixed object could be accommodated without severely altering the tank dimensions. The impact that this altered or "arbitrary" tank shape would have on the sloshing characteristics of the TLD is not well understood.

Non-linear sloshing modelling and experimental studies have focussed on circular [7], rectangular [8,9], and torus-shaped containers [10]. Komatsu [11] developed a non-linear model which utilized the method of multiple scales [12] to solve the variational problem which described the response of a fluid sloshing in an arbitrary container. However, no experimental work was conducted to validate the model. In addition, a method to determine the required mode shapes of the sloshing fluid was not provided. Other studies have employed semi-empirical models and conducted experimental studies on tanks with variable depths, including tanks with sloped bottoms [13,14] and conical tanks [15]. Equivalent linearized mechanical models have been developed for tanks of several shapes equipped with damping screens [16,17]. Drosos et al. [18] used the finite element method to conduct seismic analysis on liquid storage tanks of arbitrary shape. Eigenfrequencies and the effective masses for the first few mode shapes were calculated, which enabled the

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