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Numerical simulation of parametric liquid sloshing in a horizontally baffled rectangular container

V.S. Sanapala [a,b], Rajkumar M [b], K. Velusamy [a], B.S.V. Patnaik [b,c,*]

[a] *Indira Gandhi Centre for Atomic Research, Department of Atomic Energy, Kalpakkam — 603 102, India*
[b] *Department of Applied Mechanics, Indian Institute of Technology Madras, Chennai — 600 036, India*
[c] *Department of Mechanical Engineering, Indian Institute of Technology, Tirupati — 517 506, AP, India*

HIGHLIGHTS

- Numerical investigation of parametric liquid sloshing in partially filled tanks.
- Contributions from higher sloshing modes in a vertically excited tank is accounted.
- Optimal baffle design was obtained by performing systematic numerical simulations.
- Slosh wave amplitude reduction was noticed for the optimal baffle configuration.
- Seismic excitation was found to be controlled due to the optimal baffle.

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ABSTRACT

Liquid sloshing is a problem of serious concern in partially filled tanks. Tank designers must ensure safe margins and develop methodologies to overcome a wide range of plausible situations related to transport, wind, earthquake loads etc. to assess the structural stability. In the present study, numerical simulations are carried out to investigate the sloshing dynamics of a partially filled rectangular container, subjected to vertical harmonic as well as seismic excitations. Unlike horizontal excitation, participation of higher modes is of prime concern in vertical (parametric) excitations. The present study numerically simulates and explores methodologies to control the slosh forces and free surface oscillations with the help of a baffle. Detailed numerical validations are carried out against other experimental and computational studies from the literature. Sloshing dynamics under imposed vertical harmonic excitations was investigated at its first and third modes. Based on a detailed study of transient wave profiles, force and pressure time histories, optimal baffle design was achieved. Optimal position of the baffle and its width are systematically obtained with reference to the quiescent free surface. The effectiveness of this baffle was tested against the well known Bhuj earthquake in India.

1. Introduction

The phenomenon of liquid sloshing in partially filled containers is a problem of practical importance in many engineering systems such as, space vehicles, aircrafts, cargo tanks, nuclear waste storage tanks, elevated water tanks etc. Liquid sloshing is inevitable due to a variety of excitation forces such as, wind, earthquake, impact etc. These forces can cause tank motion

* Corresponding author at: Department of Applied Mechanics, Indian Institute of Technology Madras, Chennai — 600 036, India.
E-mail address: bsvp@iitm.ac.in (B.S.V. Patnaik).

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Nomenclature

a_h	Horizontal excitation amplitude
a_v	Vertical excitation amplitude
f	Body force
g	Acceleration due to gravity
h	Static liquid fill depth
H	Tank height
h_b	Height of the baffle
k_n	Wave number $(n\pi/L)$
L	Tank length
P_{dyn}	Hydrodynamic pressure
P_{atm}	Atmospheric pressure
P_m	Pressure probe location
S_m	Displacement sensor location
t	Physical time
t_b	Thickness of the baffle
T_n	Excitation time period
u	Stream wise component of velocity
W	Tank width
w_b	Width of the baffle
Y_e	Excitation in terms of displacement

Greek symbols

α	Liquid Phase fraction
Δt	Time step size
Δx	Grid size
δ_n	Transverse shift in the center of mass for nth sloshing mode
ϵ	Wave steepness parameter $(\omega_n^2 a/g)$
η	Free surface height
Γ	Free surface position
κ_v	Non-dimensional forcing amplitude $(\omega_v^2 a_v/g)$
μ	Dynamic viscosity of the fluid
∇	Vector differential operator
ω	Excitation frequency
ω_n	Natural frequency
ω_0	Fundamental sloshing frequency
Ω_n	Normalized frequency (ω_n/ω_v)
ω_h	Horizontal excitation frequency
ω_v	Vertical excitation frequency
ϕ	Velocity potential
ρ	Density of the fluid
τ	Non-dimensional time
ξ	Damping ratio
ζ	Initial surface perturbation

Subscripts

e	Excitation
h	Horizontal
i, j	Indices
n	Sloshing mode number
m	Sensor location number
v	Vertical

Acronyms

CFD	Computational Fluid Dynamics
CFL	Courant–Friedrichs–Lewy
CG	Center of Gravity