Angus Academic Press PEBBMS 2025
ISSN:3007-9640 DOI: https://doi.org/10.70114/acmsr.2025.3.1.P46

Influence of Key Parameters on Slamming Force Dynamics: A Comparative Study Using First-Order and Second-Order MLM Models

Ling Liu [1,2,a] *, Jun Ding [1, 2, b], Ke Zeng [1, 2, c], Qing Hai [1, 2], and Tianqi Wu [1, 2]

[1] China Ship Scientific Research Center, Wuxi, 214082, PR China;

[2] Taihu Laboratory of Deepsea Technological Science, Wuxi 214082, PR China.

[a] liuling950109@alumni.sjtu.edu.cn, [b] dingjun@cssrc.com.cn, [c] zengke@cssrc.com.cn

Abstract. This study investigates the influence of critical parameters—deadrise angle, gravitational acceleration, initial water entry velocity, and mass—on vertical slamming forces using a controlled variable approach. By comparing first-order and second-order Modified Logvinovich Model (MLM) solutions, we demonstrate that the second-order model significantly improves accuracy for large deadrise angles. Results reveal that increasing gravitational acceleration, entry velocity, or mass amplifies slamming forces, with entry velocity exhibiting high sensitivity during initial water impact. The findings provide critical insights for optimizing marine structure design and hydrodynamic impact analysis. This study systematically investigates the influence of key parameters—deadrise angle, gravitational acceleration, entry velocity, and mass—on vertical slamming forces during water entry, employing first-order and second-order Modified Logvinovich Model (MLM) formulations. A controlled variable approach is adopted to isolate parameter effects using a two-dimensional wedge-shaped structure, with a set of baseline conditions. Results demonstrate that larger deadrise angles reduce slamming forces due to diminished wetted surface area, while increasing gravitational acceleration, initial water entry velocity, or mass amplifies forces proportionally. The second-order MLM, enhanced through higher-order asymptotic corrections for nonlinear fluid interactions, significantly improves prediction accuracy for high-deadrise angle scenarios. In contrast, both models align closely for moderate deadrise angles. Entry velocity dominates initial impact dynamics, exhibiting heightened sensitivity to transient pressure buildup. These findings validate the necessity of second-order formulations for large deadrise angle applications and provide actionable insights for optimizing hydrodynamic impact analyses in marine and offshore engineering.

Keywords: Slamming; MLM model; Parameter Sensitivity.

1. Introduction

Slamming forces during water entry pose significant challenges in naval architecture, offshore engineering, and aerospace applications. Extensive research efforts have long been dedicated to investigating structural slamming during water entry, employing methodologies such as experimental model testing [1-3] and numerical simulations (e.g., smoothed particle hydrodynamics [4], volume-of-fluid method [5], computational uid dynamics [6]). However, these approaches are often time-intensive and face inherent complexities in deciphering slamming dynamics. On the theoretical front, advancements originated from classical analytical frameworks and have since evolved through iterative refinements and extensions. Classical theories by Von Karman [7] and Wagner [8] laid the foundation for understanding hydrodynamic impacts, while modern studies have refined these models to account for complex fluid-structure interactions. The Modified Logvinovich Model (MLM) [9] has emerged as a robust framework for predicting slamming forces, yet existing research predominantly focuses on first-order approximations, particularly for small deadrise angles.

In prior investigations, an enhanced second-order explicit MLM framework was established to analyze water entry phenomena in two-dimensional symmetric configurations [10]. This advanced formulation extends the foundational first-order MLM by incorporating higher-order asymptotic analytical techniques, thereby refining the prediction accuracy of hydrodynamic impacts. The

ISSN:3007-9640 DOI: https://doi.org/10.70114/acmsr.2025.3.1.P46

efficacy of the second-order solution has been rigorously validated, demonstrating its capability to resolve nonlinear interactions omitted in lower-order approximations. This study further expands this work and systematically analyzes parameter influences using both first-order and second-order MLM formulations. Our objectives are threefold: (1) quantify the effects of deadrise angle, gravitational acceleration, entry velocity, and mass on slamming forces; (2) compare the performance of first-order and second-order models across varying deadrise angles; and (3) validate the superiority of the second-order MLM in high deadrise angle scenarios.

2. Methodology

2.1 Calculation Model

Building upon prior advancements in hydrodynamic impact modeling, our earlier work [10] introduced a refined second-order explicit MLM framework tailored for two-dimensional symmetric structures undergoing water entry. This enhanced formulation extends the foundational first-order MLM through the integration of advanced asymptotic analysis techniques, enabling more precise characterization of fluid-structure interactions. Specifically, the second-order model incorporates corrections for nonlinear velocity potential gradients and transient free-surface deformations, which are neglected in the first-order approximation.

In the present study, we leverage this high-order framework to systematically investigate parameter dependencies in slamming forces. The first-order MLM calculates the force based on the time-dependent wetted surface and hydrodynamic pressure derived from linearized boundary conditions. By contrast, the second-order model refines these predictions by accounting for fluid pile-up effects and curvature-induced pressure modifications, as detailed in [10]. Numerical simulations employ a finite-difference discretization scheme with a time step of $\Delta t = 0.001s$, ensuring convergence and stability across all tested parameter ranges.

This methodological progression underscores our objective to bridge the gap between simplified analytical models and real-world hydrodynamic complexities, particularly for structures with large deadrise angles. By grounding the current analysis in the rigorously validated second-order MLM, we aim to provide actionable insights into the interplay between geometric and dynamic parameters in slamming force generation.

2.2 Controlled Variable Setting

The study focuses on a two-dimensional wedge-shaped structure, a canonical geometry widely employed in hydrodynamic impact analyses due to its symmetric profile and analytical tractability. The wedge configuration simplifies the characterization of wetted surface dynamics while retaining critical features relevant to practical applications, such as ship hulls and offshore platform components. To isolate the influence of individual parameters on slamming forces, baseline conditions are defined as follows: gravitational acceleration $g = 9.352m/s^2$, mass $m = 30.188kg$, and initial water entry velocity $V_0 = 1.036m/s$. The deadrise angle β, a defining geometric parameter for wedges, is systematically varied across 10°, 30°, 40°, and 50°, with additional emphasis on two representative cases ($\beta = 20^{\circ}$ and $\beta = 55^{\circ}$) to explore parameter sensitivity under contrasting hydrodynamic regimes.

3. Results and Discussion

3.1 Deadrise Angle Influence

Fig. 1 shows that the slamming forces vary with the different deadrise angles under the conditions of $g = 9.352m/s^2$, $m = 30.188kg$, and $V_0 = 1.036m/s$. It can be seen the larger deadrise angles ($\beta = 50^{\circ}$) reduce slamming forces due to decreased wetted half-width for the same time interval. Besides, for $\beta = 10^{\circ}$, the first-order and second-order solutions align closely, but

ISSN:3007-9640 DOI: https://doi.org/10.70114/acmsr.2025.3.1.P46

discrepancies grow with β. At $\beta = 50^{\circ}$, compared to the second-order model, the first-order model overestimates the impact force significantly.

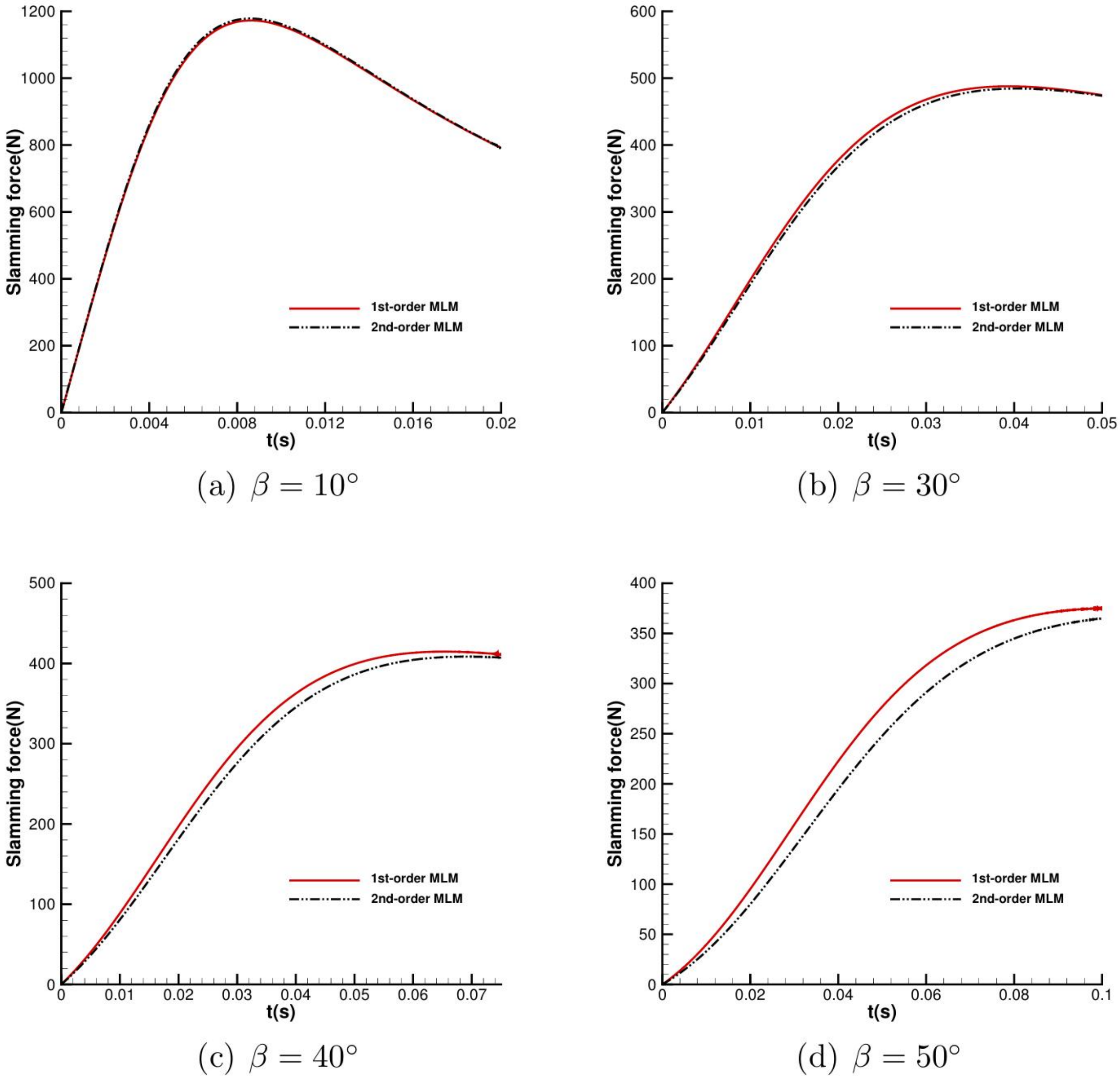


Fig. 1 The slamming force varies with different deadrise angles

3.2 Parameter Sensitivity

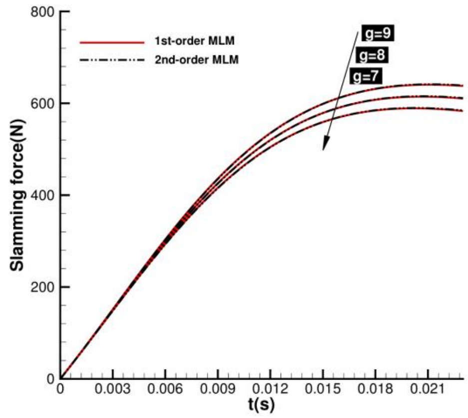
The influence of gravitational acceleration (g), entry velocity (V_0), and mass (m) on slamming force is rigorously evaluated under fixed deadrise angles ($\beta = 20^{\circ}$ and $\beta = 55^{\circ}$), as shown in Fig 2. The analysis reveals distinct trends and sensitivities across these parameters, providing critical insights into their roles in hydrodynamic impact dynamics.

(1) General Parameter Trends: Across all tested deadrise angles (β), the vertical slamming force exhibits a direct proportional relationship with gravitational acceleration (g), entry velocity (V_0), and mass (m). Specifically, elevating any of these parameters amplifies the instantaneous force magnitude during water entry, irrespective of β. This universal trend underscores the fundamental role of energy transfer mechanisms in hydrodynamic impact dynamics.

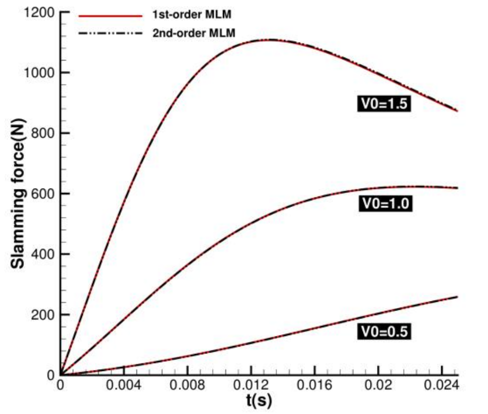
(2) Entry Velocity Dominance in Initial Impact: The entry velocity (V_0) emerges as the most influential parameter during the initial phase of water entry. Even minor adjustments to V_0 induce pronounced changes in the slamming force trajectory immediately after impact, highlighting its

ISSN:3007-9640 DOI: https://doi.org/10.70114/acmsr.2025.3.1.P46
critical role in governing transient pressure buildup. This heightened sensitivity diminishes progressively as the system transitions to steadier hydrodynamic regimes.

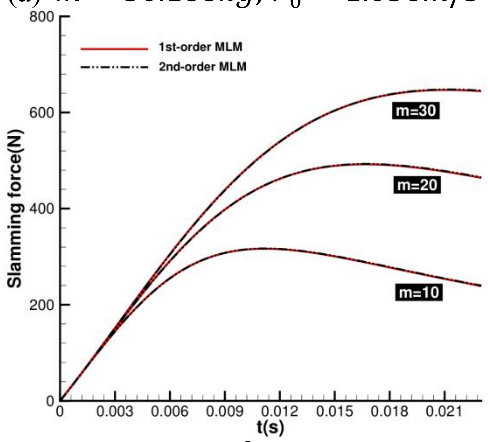
(3) Model Accuracy Across Deadrise Angles: For structures with moderate deadrise angles ($\beta = 20^{\circ}$), the first-order and second-order MLM predictions exhibit strong agreement, with deviations remaining below practical significance. In contrast, at larger deadrise angles ($\beta = 55^{\circ}$), systematic overestimations by the first-order model become evident. These discrepancies stem from the first-order model's inability to resolve nonlinear fluid interactions, reinforcing the necessity of second-order formulations for high-β scenarios.



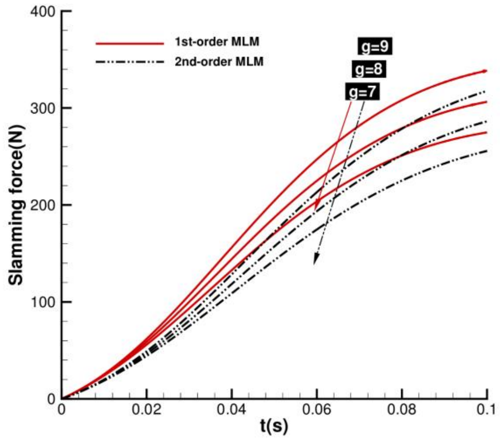
(a) $m = 30.188kg, V_0 = 1.036m/s$



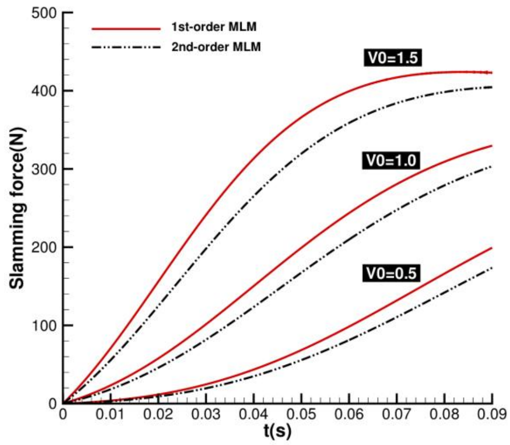
(b) $g = 9.352m/s^2, m = 30.188kg$



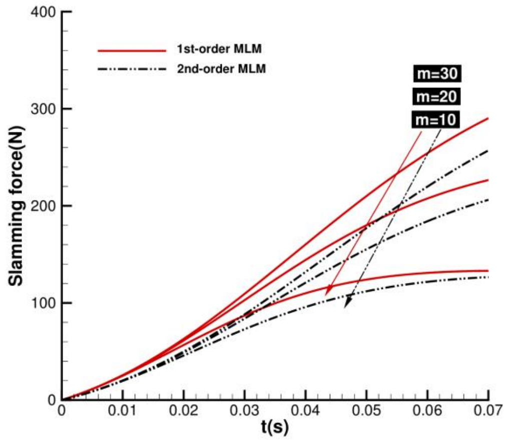
(c) $g = 9.352m/s^2,\ V_0 = 1.036m/s$



(d) $m = 30.188kg, V_0 = 1.036m/s$



(e) $g = 9.352m/s^2, m = 30.188kg$



(f) $g = 9.352m/s^2,\ V_0 = 1.036m/s$

Fig. 2 The slamming force varies with different parameters, (a)-(c): $\beta = 20^{\circ}$, (d)-(f): $\beta = 55^{\circ}$.

ISSN:3007-9640 DOI: https://doi.org/10.70114/acmsr.2025.3.1.P46

4. Summary

This study quantitatively evaluates the roles of geometric and dynamic parameters in slamming force generation, leveraging a refined second-order MLM framework. Key findings include deadrise angle influence, parameter sensitivity, and model superiority. These results underscore the importance of adopting higher-order models for structures with large deadrise angles. The methodology and insights presented here advance slamming force prediction accuracy and offer practical guidelines for designing marine structures subjected to hydrodynamic impacts. Future work will extend this framework to three-dimensional geometries and transient flow regimes.

Acknowledgements

This work is partly supported by the National Key Laboratory of Hydrodynamics, WDZC70202010201 and National Science Foundation of China (Project No. 52422109).

References

[1] C. Judge, A. Troesch, M. Perlin, Initial water impact of a wedge at vertical and oblique angles, J. Eng. Math, 2004, 48: 279-303.

[2] A. Shams, M. Jalalisendi, M. Por ri, Experiments on the water entry of asymmetric wedge using particle image velocimetry, Phys. Fluids, 2015, 27: 027103.

[3] M. Barjasteh, H. Zeraatgar, M. Javaherian, An experimental study on water entry of asymmetric wedges, Appl. Ocean Res., 2016, 58: 292-304.

[4] C. Chen, A. Zhang, J. Chen, Y. Shen, SPH simulations of water entry problems using an improved boundary treatment, Ocean Engineering, 20221, 238: 109679.

[5] H. Gu, L. Qian, D. Causon, C. Mingham, P. Lin, Numerical simulation ofwater impact of solid bodies with vertical and oblique entries, Ocean Engineering, 2014, 75: 128-137.

[6] Z. Sun, X. Sui, A. Korobkin, L. Zou, Z. Zong, Slamming force decomposition with gravity e ect, Journal of Fluids and Structures, 2022, 114: 103694.

[7] K. von, The impact on seaplane oats during landing, Tech. rep., Technical Notes. No.321. National Advisory Committee for Aeronautics, 1929.

[8] H. Wagner, Phenomena associated with impacts and sliding on liquid surfaces, Z. angew. Math.Mech., 1932, 12(4): 193-215.

[9] A. KOROBKIN, Analytical models of water impact, European Journal of Applied Mathematics 2004, 15(6): 821-838.

[10] L. Liu, K. Zeng, J. Ding, Q. Wang, S. Bu, C. Cheng, A two-dimensional high-order explicit analytical solution model for symmetric wedges entering water, Journal of Ocean Engineering and Science, 2025, 10: 109-122.