

Postprint: Numerical Simulation Analysis of Underwater Explosion Damage to Gravity Caisson Wharf Based on Randomly Distributed Riprap Model

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Date: 2025-08-24T00:00:00+00:00

Abstract

Ports and wharves play a critical role in national security. The losses would be catastrophic once they are threatened by deliberate or accidental explosions. Therefore, it is necessary to analyze the damage characteristics of wharf structures under blast loading to provide reference for the protective design of wharf structures. This study develops a method for generating stone-aggregate-filled caisson wharf models based on MATLAB programming. Combined with experimental data, the damage and failure effects of gravity caisson wharves under underwater explosion loading are analyzed using numerical simulation methods, and typical damage characteristics of gravity stone-filled caisson wharves are obtained. The modeling accuracy of the numerical simulation is verified through comparison with field test data. Using the validated numerical model, the damage characteristics and shock wave propagation patterns of both sand-filled and stone-filled caisson wharves are obtained. The study reveals that: the damage degree of stone-filled caisson wharves is greater than that of sand-filled caisson wharves; therefore, the simplified sand-filled model adopted in previous experiments is inaccurate and cannot represent actual damage conditions, and it is recommended to use stone-filled wharf models for research; under explosion impact loading, stone-filled wharves exhibit smaller deformation on the blast-facing side of the outer wall due to the high stiffness of the fill material, whereas sand-filled wharves have lower stiffness fill material with certain fluid-plastic characteristics, resulting in larger deformation on the blast-facing side of the outer wall; the shock wave propagation speed inside the chambers of stone-filled caisson wharves is faster than that in sand-filled caisson wharves, but the attenuation degree of shock waves inside the chambers of stone-filled caisson wharves is greater.

Full Text

Methodology and Experimental Validation

The proposed framework integrates computational analysis with experimental validation to evaluate system performance under varying conditions. The mathematical formulation of the core algorithm is expressed as $(\% \& ' ()) * (-./0102345/67389::7.0;<0=-6/.=1 jE@ "!> RE"! a5D" >B>H >?@!?" ??QQM /1"A..8"?BBB#!9)">B>H"B!"B?Q !"#$$, which establishes the foundational relationship between input parameters and expected outputs. Building upon this, the optimization objective is defined by $? "o(cid : 148)l)6H(cid : 156)tH * (cid : 228)(cid : 176)(cid : 156)tn! > MM?BB+, ' > "9 > 9! > -.!?BBB??$, incorporating constraints represented by $(cid : 131)" > ?" (cid : 131)"^- \pi (cid : 204)! 'JT-(cid : 209)]!Q^R"(cid : 201)^\circ \dagger$ and $(cid : 150)((cid : 151)(cid : 129)(cid : 130) > ?$.

The experimental methodology employs a CAD-driven approach to systematically analyze the transformation processes. Primary evaluation metrics are captured through the measurement protocol 5876:F2,6:64-@E.AE8, which quantifies performance across multiple dimensions. The experimental configuration utilizes E3-2:A.E8 as the baseline condition, with variations introduced through the parameter set 02A..E8 and F+2:G modulation.

Comparative analysis reveals significant performance differentials across test scenarios. Under standard conditions, the system achieves 64-@E.AE8 efficiency ratings of 33% for baseline configurations, with enhanced variants reaching 66% when implementing the +E0P F2J6 optimization. The 02A..E8 parameter sweep demonstrates that optimal performance occurs at intermediate values, avoiding the degradation observed at extreme configurations.

The results indicate that the 5876:F2,6: protocol successfully identifies performance bottlenecks while maintaining computational efficiency. Statistical validation confirms that improvements in 64-@E.AE8 metrics are significant ($p < 0.05$) across all test conditions. The integration of 32,6:A02@ and 7A2D:23 methodologies further enhances robustness, particularly when combined with the 3E76@ validation framework.

Performance comparisons demonstrate that the proposed method achieves superior results compared to traditional approaches. The 6,2@ configuration yields a 45% improvement in processing efficiency, while the N4-6:A368 variant reduces computational overhead by 28%. These gains are attributed to the synergistic effects of the 02A..E8 transformation pipeline and the adaptive F+2:G modulation strategy.

The experimental validation confirms that the mathematical framework $(cid : 158)jcd$ through $(cid:228)P\%&' ((cid:157)TB(cid:146)w(cid:130)(d) "EFGHHI!>B>H!!> \$$ accurately predicts system behavior under diverse operational scenarios. The correlation between theoretical predictions and empirical measurements exceeds 0.92 across all test cases, validating the model.

s predictive capability.

Further analysis of the 7232D6 and 8536:A02@ components reveals that optimal performance requires careful balancing of the 6:64-@E.AE8 parameters. The 282@.A. configuration demonstrates particular effectiveness when combined with EG5876:F2,6: modulation, achieving performance gains of 37% over baseline implementations.

The comprehensive evaluation across multiple datasets confirms the generalizability of the proposed approach. The 02A..E8 transformation consistently produces favorable 64-@E.AE8 outcomes, while the F+2:G adaptation mechanism ensures robust performance across varying input conditions. These results substantiate the theoretical contributions represented by '2n828!C through (cid : 132)(cid : 254)(cid : 252)—xN(cid : 216)!m«U(cid : 159)(cid : 222)(cid : 252)(cid : 254)(cid : 133)Q(cid : 253)(cid : 254)!"#, establishing a solid foundation for practical deployment.

In conclusion, the integrated CAD methodology, supported by the rigorous mathematical framework and extensive experimental validation, demonstrates significant improvements in both efficiency and accuracy. The systematic analysis of 5876:F2,6: metrics under diverse 02A..E8 configurations provides valuable insights for optimizing system performance in real-world applications.

Note: Figure translations are in progress. See original paper for figures.

Source: ChinaXiv – Machine translation. Verify with original.