



SLAM PREDICTION ALGORITHM AND SIMULATION SUMMARY REPORT

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*Development of a Route/Mission Dependent Prediction Program for Rational
Structural Dynamic Loads for High-speed Sealift Applications***

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SLAM PREDICTION ALGORITHM AND SIMULATION SUMMARY

**FY 05 PROJECT 05-8, PE 2.35
TASK NO. 8.3**

Slam Prediction Algorithm and Simulation Summary

System:

ROUTE/MISSION DEPENDENT PREDICTION PROGRAM FOR RATIONAL
STRUCTURAL DYNAMIC LOADS FOR HIGH-SPEED SEALIFT APPLICATIONS

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Task 8.3 - Time-Domain Motion and Slamming Loads Prediction Program Development

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Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the Center for the Commercial Deployment of Transportation Technologies (CCDoTT) at California State University, Long Beach.

FOREWORD

The work described in this report was prepared by CDI Marine Systems Development Division (CDIM-SDD) for the Center for Commercial Deployment of Transportation Technologies (CCDoTT) at California State University, Long Beach. The principal point of contact at CCDoTT was Mr. Stanley Wheatley. The Project Manager and Technical Lead for CDIM-SDD was Mr. Manish Gupta.

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1.0 INTRODUCTION

The current project is Phase II of an on-going three-phase program to develop a prediction tool to predict rational structural dynamic loads for high-speed multihull vessels. Phase I was successfully completed in the 2001-2002 fiscal year with the development and demonstration of the first part of the prediction tool. The first part was to predict the global hull loads that are wave height and frequency dependent and therefore could be predicted using a frequency-domain tool. The detail report describing the Phase I effort was provided in CDIM-SDD Working Paper 727-1, August 2002, submitted to CCDoTT.

The current Phase II effort is spread over two fiscal years. The first part of the current phase, Phase II-A, is being performed using FY 2005 funding. The follow-on effort to complete Phase II, which is Phase II-B, will be performed in FY 07 using FY 06 funding. The final phase, Phase III, which is extensive validation of the tool along with incorporation into rule-making procedure, is scheduled for 2008. The objective of the Phase II effort is to determine the probabilities of slamming and the loads associated with slamming, which can be predicted using a time-domain program to be developed in the current phase. Under this current effort, Phase II-A, slamming load prediction algorithms are to be developed along with some limited verification on a few high-speed hullforms.

One of the tasks was to develop a method to predict the pressure loads due to slamming on various advanced hull types. Slamming induced pressure loads are generated from hull re-entry after emerging from the water due to wave induced motions. The slam pressures are considered local loads and govern the design of the bottom and side structures of the hull, especially in the forward sections of the hull. For multihulls, slam pressures also dictate the design of the cross structure. The local loads of the slamming pressures depend on the sea-state, the speed of the vessel, the heading of the vessel and the geometry of the vessel. In the following sections, a procedure is developed to estimate the pressure loads using a time-domain computer code. An annotated bibliography used to develop this method is presented in Appendix A.

2.0 SLAM PRESSURE PREDICTION METHODOLOGY

There are a number of methods for the determination of slamming behavior and for the determination of local and global forces on the hull. To determine slamming behavior for conventional ships, empirical methods based on previous experience and model tests can provide for the probability of slamming in a given sea-state and vessel speed. Unconventional, high-speed hullforms have limited data from which to use an empirical method for the determination of slamming.

Numerical methods can be used to analyze novel hullforms for slamming behavior. Examples include Reynolds Averaged Navier-Stokes (RANS) codes, potential flow panel codes and strip theory codes. RANS codes offer the smallest number of assumptions about the nature of the fluid flow, but need to capture the non-linear behavior of the free surface and viscous effects. The unsteady nature of seakeeping also requires long simulated time spans to reach a statistically significant number of wave encounters. For these reasons, RANS is currently only useful as a research tool using months of computer time for a single result. Potential flow panel methods have become a useful tool for detailed seakeeping analysis and can offer the benefit of non-linear free surface effects. However, the analysis of numerous sea-states and speeds can take weeks to complete. Strip theory codes also use the potential flow approximation for the fluid flow, but use a linearized free surface condition and approximate the three-dimensional problem as a series of transverse two-dimensional problems. This significantly increases the speed of solution for strip theory codes, but at the expense of detailed local flow and force resolution.

Strip theory codes can be further divided into frequency-domain and time-domain codes. Frequency-domain codes solve the response of the vessel at various wave encounter frequencies and amplitudes for a given sea-state and then describe the response as a response amplitude operator (RAO) for each frequency. Time-domain codes, on the other hand, model the motion of the vessel as it moves through a superposition of waves at various frequencies and amplitudes. The strip theory code then calculates the response of the vessel at discrete time intervals over a simulated run time. Time-domain codes have one disadvantage in common with the RANS and potential flow codes. In order to have a statistically

significant number of encounters for all sea-states and headings, a large amount of simulated time is necessary.

For the purposes of this study and as part of the route/mission dependent prediction of structural loads, using the strengths of different methods provides the best way to obtain estimates of slam pressure for early design. A frequency-domain strip theory code, along with statistical methods, can be used to determine the conditions of vehicle speed, heading and sea-state that are most likely to produce slamming events. These environmental and operational conditions can then be simulated in a time-domain, strip theory code to determine the ship and wave motions. The use of a frequency-domain code provides the ability to determine the ship response to waves much more quickly than the time-domain code. However, while frequency-domain strip theory methods can be used to determine sea-state/heading/ speed combinations that will likely lead to slamming, they provide no information about the relative velocities between the hull and the sea surface. As most research has indicated, the relative velocity is the primary means of determining the slamming pressure. As such, a frequency-domain code was used to determine the probability for slamming, but a time-domain strip theory code was used to provide the relative velocities and the corresponding pressures due to slamming.

For the present development of the procedure, the time-domain strip theory code POWERSEA was used to determine the motions of the ship and the wave component amplitudes, phase and wave number. In the current implementation of POWERSEA, only head and following seas were modeled, which are likely to result in defining the most severe loads for the purpose of early-stage design.

Based on the emergence and re-entry of a control point on the hull near the bow (generally 10%-20% of the length between perpendiculars (LBP) aft of forward perpendicular (FP)), candidate times where slam may occur can be determined from the motion history provided by the time-domain code. A section of a time history from POWERSEA showing the vertical velocity and submergence of the control point is shown in Figure 1.

From a CAD program such as Rhino3D or others, the geometry can be exported in a stereolithography (STL) formatted file. This is a widely used format with the geometry described as a set of triangles oriented with their normals facing outward. Care must be taken to use enough triangles to get realistic normals on the surface near the forefoot of the bow, but not so many triangles that computations become unwieldy. In order to reduce the computational workload in areas of the hull where slamming is unlikely to occur, limits are placed on which triangles are part of the computation by how far aft of the FP the triangles are located. Since most slamming takes place near the forefoot of the hull, only triangles located forward of 30% of LBP from the forward perpendicular will be used in the calculation. An example of the surface description provided in a STL file is shown in Figure 2.

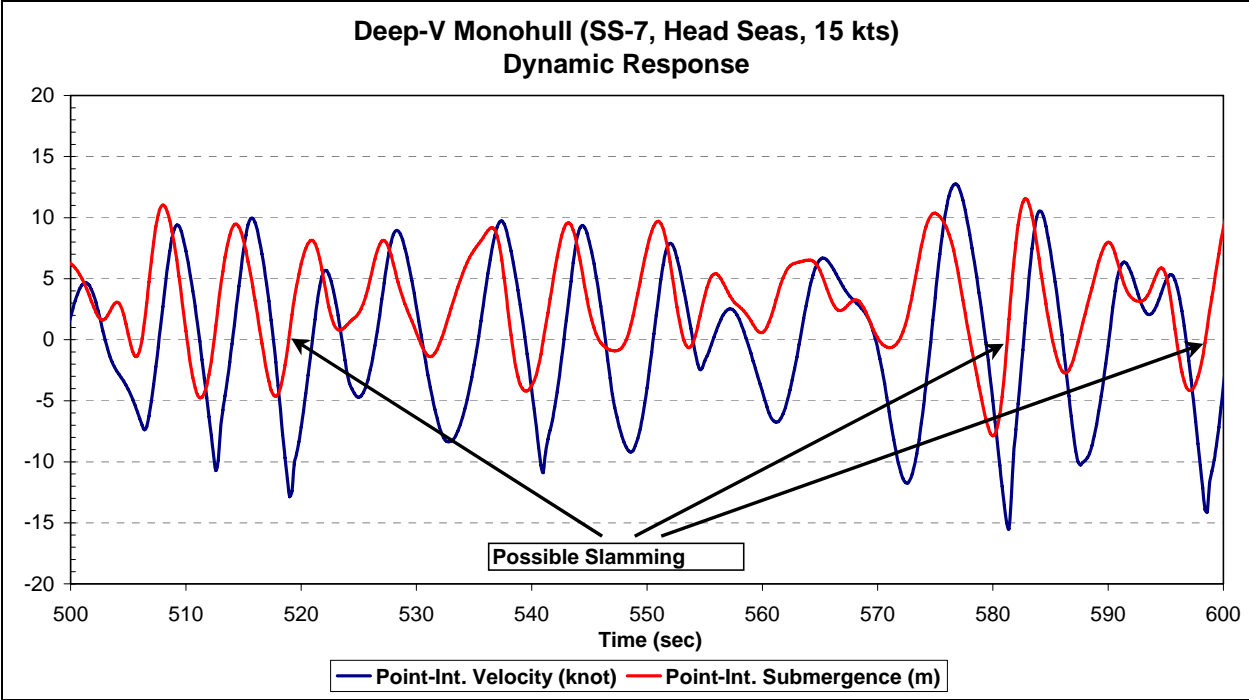


Figure 1. Time History Excerpt of Vertical Velocity and Hull Submergence Near Bow

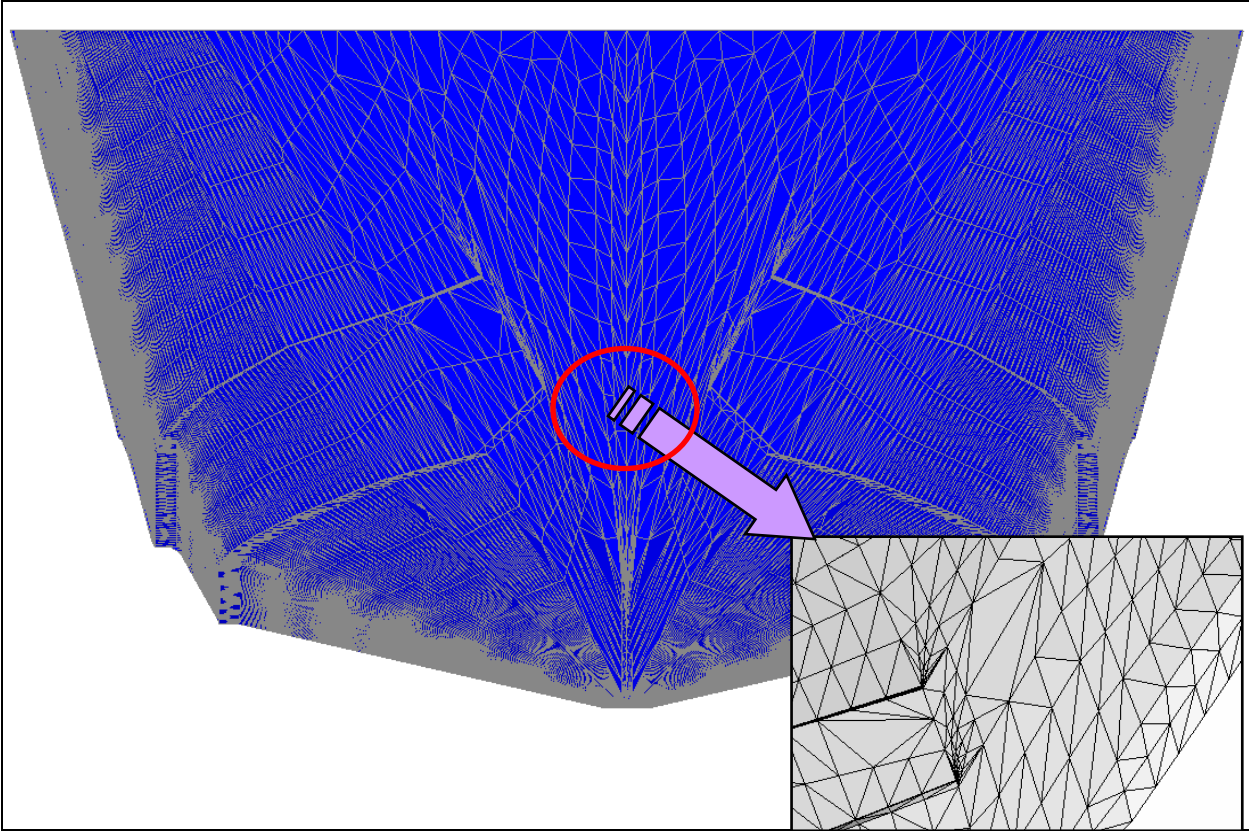


Figure 2. Stereolithography Representation of the Deep-V Monohull

In order to determine pressures on the structure of a ship, the method presented in Stavovy and Chung (Ref. 1) was implemented in a more general form for arbitrary geometry by using vector equations to determine angles and velocities.

First, the relative velocity of the water surface to the hull was determined based on the wave components used in the time-domain seakeeping code and the motion of the hull. The wave height at a location in time and space is given by Equation 1.

$$\zeta = \sum_{i=1}^n -A_i \cos(\omega_i t + \kappa_i x + \varepsilon_i) \dots\dots\dots (1)$$

Where:

- $A \equiv$ wave amplitude
- $\omega \equiv$ wave encounter frequency
- $\kappa \equiv$ wave number
- $\varepsilon \equiv$ wave phase angle

The wave amplitude was determined for each frequency using a wave spectrum such as the Pierson-Moskowitz spectrum. The spectrum is broken up into a number of frequency intervals and at each interval the amplitude was determined by:

$$A_i = \sqrt{2S(\omega_i)\delta\omega} \dots\dots\dots (2)$$

Where:

$$S(w) = \frac{8.1e^{-3}g^2}{\omega^5 \exp(-0.74[g/V\omega]^4)} \dots\dots\dots (3)$$

$$V \equiv \sqrt{\frac{gH_s}{0.2092}}$$

$H_s \equiv$ Significant Wave Height

$g \equiv$ gravity

Once the wave height was known, the potential flow equations were used to determine the velocity at the wave surface. The equation for the potential of the wave is given by:

$$\Phi = \frac{gA}{\omega} \sin(\omega t + \kappa x + \varepsilon) e^{\kappa y} \dots\dots\dots (4)$$

From this equation, the velocities were found by differentiation.

$$u = \frac{-\partial\Phi}{\partial x} = \frac{-\kappa gA}{\omega} \cos(\omega t + \kappa x + \varepsilon) e^{\kappa y} \dots\dots\dots (5)$$

$$v = \frac{-\partial\Phi}{\partial y} = \frac{-\kappa gA}{\omega} \sin(\omega t + \kappa x + \varepsilon) e^{\kappa y} \dots\dots\dots (6)$$

These velocities were determined at the control point discussed above when a re-entry event occurs and the velocity of the control point determines that a slamming event is likely. If the relative velocity normal to the hull at the control point exceeds a user-defined threshold velocity, such as Ochi's (Ref. 2) suggestion of 12 feet per second for a 520 ft ship, then the program loops through all of the wetted triangles at that time step and determines the pressures. This calculation continues while the motion of the control point continues downward to evaluate the pressures as the rest of the hull enters the water.

In order to determine the pressures on the hull, for each triangle that had at least one corner wetted, the following calculations were performed. Using the normal vector of the triangle and the normal of the sea surface at the triangle's center, the relative angle was determined. The relative velocity for each triangle was determined using the velocity of the hull in the direction normal to the triangle and the velocity vector of the water at that location projected onto the normal vector of the triangle. The pressure was then calculated using the method presented in Stavovy and Chuang (Ref. 1). Their method uses results from a number of experimental and theoretical studies on simple and three-dimensional shapes to determine an analytic function for a pressure coefficient based on impact angle, as shown in Figure 3.

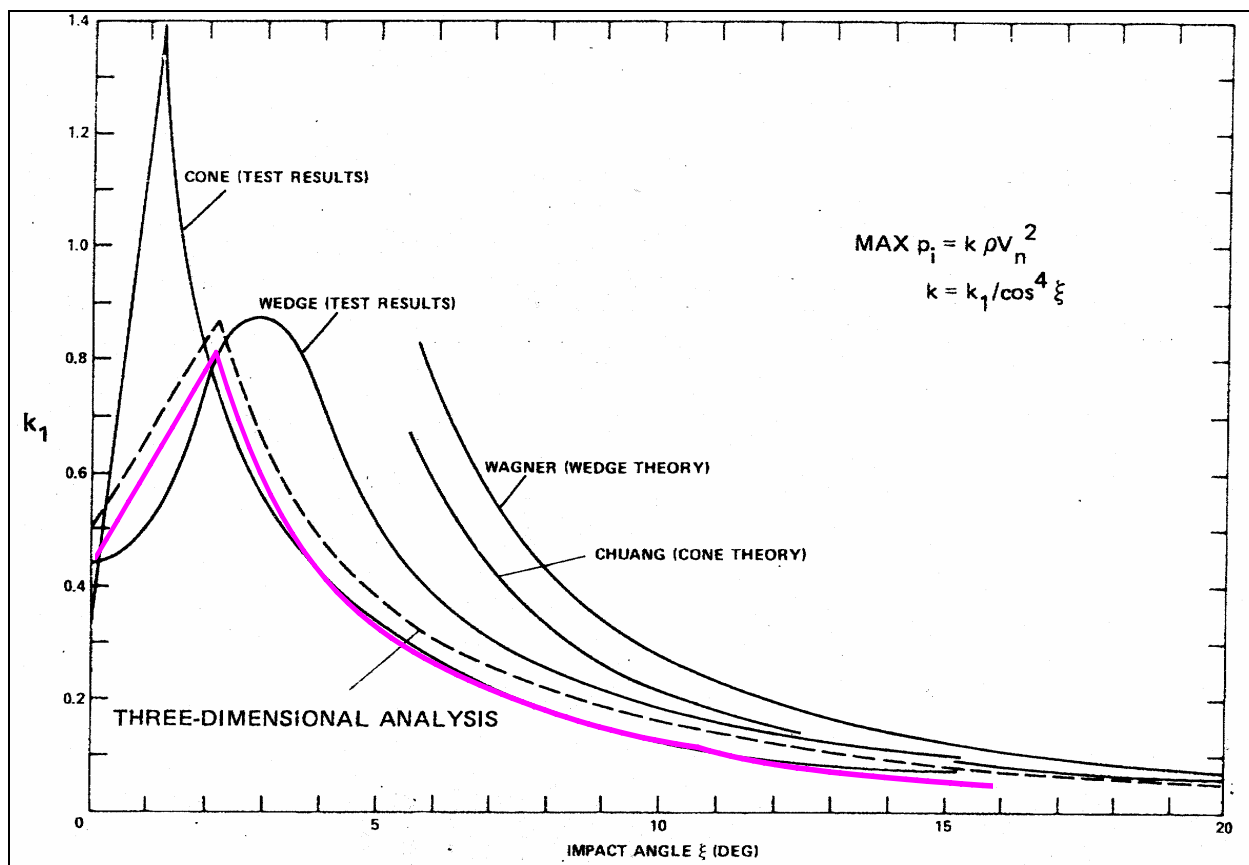


Figure 3. Pressure Coefficient vs. Impact Angle

The pressure reaches a peak at 2.2 degrees of impact angle. It is believed that this is due to the capture of air and its compressibility at lower angles. The coefficient was then used in the following formula to determine the pressure:

$$P = kq \dots\dots\dots (7)$$

Where:

$$q = \rho V_n^2 \text{ is the normal dynamic pressure.}$$

The pressures on each triangle can then be summed to determine pressure loads over larger, user-defined areas such as the area between bulkheads or a section of a bulbous bow. Pressures can also be plotted as contour plots for examining the distribution.

3.0 SLAM PREDICTION STATUS AND RECOMMENDATIONS

Under the current effort, the following have been completed:

- Development of the overall slam prediction procedure.
- Evaluation of POWERSEA for use in the slamming loads prediction.
- Reimplementation and testing of POWERSEA sea spectrum.
- Development and testing of code modules to implement the determination of relative speed and angles between the water and hull.
- Code to implement the pressure calculations.
- Initial development of STL reader.

Fortran was used for the initial implementation, but, based on shortcomings in Fortran for text processing, it is recommended to switch to C++ for the final implementation of the procedure in the next phase. This will also simplify vector-based math calculations and interfacing with other programs. During the follow-on effort in the next phase, the development of the slam prediction calculation tool, based on the algorithms developed under the current effort, will implement the recommendations discussed above.

POWERSEA is limited to head and following seas only. While head seas may give a good indication of slamming loads, especially for the early design stages, oblique seas may cause higher slamming loads based on encounter frequency and waves hitting the sides of the hull with flatter angles. For this reason, other time-domain codes would also be evaluated.

4.0 SUMMARY

This report provides a summary of the slam prediction procedure developed under the current scope of work. Using frequency-domain strip theory codes, SHIPMO, sea-states and headings were identified for likelihood of slamming for the corresponding vessel speeds, as discussed in the earlier reports. As a demonstration of the procedure, the Deep-V Monohull was used as the test case in setting up and implementing the procedure. The identified environmental and operational condition combinations were then modeled using a time-domain strip theory code, POWERSEA, to determine the relative motion of the hull to the sea and the wave components of the sea-state. The relative velocity and angles of the surfaces were then used to determine slamming occurrences and pressures from these events.

5.0 REFERENCES

1. Chuang, S. & A. B. Stavovy, "Analytical Determination of Slamming Pressures for High-Speed Vehicles in Waves", Journal of Ship Research, 190-198, 1976.
2. Ochi, M. K., "Extreme Behavior of a Ship in Rough Seas – Slamming and Shipping of Green Water", SNAME Transactions, Vol. 72, 1964.

APPENDIX A

ANNOTATED BIBLIOGRAPHY

Ochi, Michel K., “Extreme Behavior of a Ship in Rough Seas – Slamming and Shipping of Green Water”, SNAME Transactions, Vol. 72, 1964

- Studies the behavior of ships in rough seas as opposed to regular waves as in previous studies.
- Confirms previous studies, which concluded that linear superposition is adequate for engineering purposes in both head and oblique seas. This is true even for conditions in which severe slamming events take place. RAO's need to be obtained, however, from mild regular waves in order to use linear superposition.
- Studied the effect of ship loading and concluded that deeper draft has a favorable effect on slamming due to the reduced frequency of bow emergence.
- Determined formulas to predict the probability of slamming.
 - Slam occurrence based on impact pressure at 0.1L aft of FP.
 - Only looks at forefoot slamming. Not slamming due to flare, wet-deck or wave impact.
- Results are presented showing the probability of slam and pressure levels for a merchant ship in various sea-states, headings, speeds and locations on the hull.

Stavovy, Alexander B. and Chuang, Sheng-Lun, “Analytical Determination of Slamming Pressures for High-Speed Vehicles in Waves”, Journal of Ship Research, Vol. 20, No. 4, pp 190-198, 1976

- Presents an analytical method for the determination of slamming pressures.
- Based on experimental and theoretical studies of simple 2D and 3D shapes.
- Slamming pressure is based on the relative normal velocity of the ship and the water surface.
- Method has been verified using model tests and full-scale trials of the catamaran USNS Hayes.

Faltinsen, Odd M., “On Seakeeping of Conventional and High-Speed Vessels”, Journal of Ship Research, Vol. 37, No. 2, pp 87-101, 1993

- Strip theory models have a number of problems and limitations.
 - Due to linearity assumptions, strip theory programs only take into account the hydrodynamic effects below the mean free-surface level and do not distinguish between alternative above-water designs.
 - Viscous effects are not modeled such as roll damping due to bilge keels.
 - When modeling low frequency of encounter problems, strip theory can be substantially inaccurate.
- Theory for high-speed vessels is presented.