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Derradji-Aouat, A.

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AUTHOR(S)

Ahmed Derradji-Aouat

CORPORATE AUTHOR(S)/PERFORMING AGENCY(S)

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SUMMARY

Both Computational Structural Dynamics (CSD) and Computational Fluid Dynamics (CFD) have come together to empower offshore structural engineers to forecast and enhance the performance of various structures designs. Equally important, they enable researchers and scientists to experiment with a wide range of "what-if" scenarios for risk assessments, accident scenario investigations, and fragility analyses. The true value of any computational model is determined by both the accuracy of the results of the simulations and our ability to interpret all of the significant information contained in those results. To a large extent, the accuracy of the results can be assured via verification and validation analyses (V&V analyses, also known as numerical uncertainty analyses). Our ability to find out and understand the effects of the physical phenomena/parameters that control the overall behaviour of an offshore system depends, to a large extent, on the visualization tools used to view the results. Without strong visualization tools, it might be difficult to recognize the existence of problems or inefficiencies within a given design.

ADDRESS

National Research Council
Institute for Marine Dynamics
P. O. Box 12093, Station 'A'
St. John's, Newfoundland, Canada
A1B 3T5
Tel.: (709) 772-5185, Fax: (709) 772-2462

New Developments in Numerical Methods in Offshore and Marine Engineering

Ahmed Derradji-Aouat
National Research Council, Institute for Marine Dynamics, St. John's, Newfoundland, A1B 3T5, Canada

Introduction

Both Computational Structural Dynamics (CSD) and Computational Fluid Dynamics (CFD) have come together to empower offshore structural engineers to forecast and enhance the performance of various structures designs. Equally important, they enable researchers and scientists to experiment with a wide range of "what-if" scenarios for risk assessments, accident scenario investigations, and fragility analyses. The true value of any computational model is determined by both the accuracy of the results of the simulations and our ability to interpret all of the significant information contained in those results. To a large extent, the accuracy of the results can be assured via verification and validation analyses (V&V analyses, also known as numerical uncertainty analyses). Our ability to find out and understand the effects of the physical phenomena/parameters that control the overall behaviour of an offshore system depends, to a large extent, on the visualization tools used to view the results. Without strong visualization tools, it might be difficult to recognize the existence of problems or inefficiencies within a given design.

To improve the accuracy of computational results, offshore and marine engineering models are becoming increasingly large and complex. Numerical modeling has become a multi-disciplinary and multi-physics approach, whereby the CFD and CSD are combined "in a hybrid manner" to analyze offshore engineering problems from both points of views concurrently. Moreover, various scientific, engineering and market forces motivate and direct engineers to put their computational codes through rigorous numerical testing to build the necessary confidence in the results (V&V analysis). Naturally, the multi-physics CFD/CSD hybrid approach requires additional mathematical formulation and computer modeling steps to account for the Fluid-Structure Interactions (FSI). The V&V analyses of a multi-physics model may require finer meshing, and subsequently, a larger number of elements. For example, in Finite Element Analysis (FEA), until very recently (4 to 5 years ago), models consisting of one million elements were considered to be "way too large". Currently, engineers are using models consisting of one hundred million elements. It appears that using a FE mesh consisting of one billion elements could become a possibility by the end of the decade. In its own wisdom, reality dictates that convergence towards the true solution requires a multi-physics and multi-disciplinary approach. Ironically, the consequence of multi-physics modeling is that computer-processing power may become the bottleneck in the computational analysis.

A literature survey reveals that, in recent years, in offshore and naval engineering, there are three emerging analyses trends. These are: 1) numerical methods 2) whole system analysis, and 3) hybrid FSI approach. The first trend is driven by the fact that marine and offshore engineering problems are complex in nature and the use of a single set of analytical equations "such as closed form solutions" may be not adequate enough to describe all physical processes of the problem (ONR, 2001). The second trend is driven by the fact that system analysis is taking precedent over the traditional component analysis. For instance, in an offshore system that is made up of several structural components, the effect of the behaviour of one component on the global system needs to be investigated. This is propelled by the need for an overall fragility "design safety" and consequence analyses of complex structures. (Casciati and Faravelli, 1991). Therefore, understanding and dealing with the weakness (or weaknesses) of the whole system is needed. The third trend is driven by the fact that, in ocean engineering, coupled CFD and CSD numerical approach is needed (Erno, 1985). Simply, the hydrodynamic effects on the overall structure behaviour cannot be either ignored or just added to the structural analysis using superimposition principles since CSD/CFD problems are non-linear.

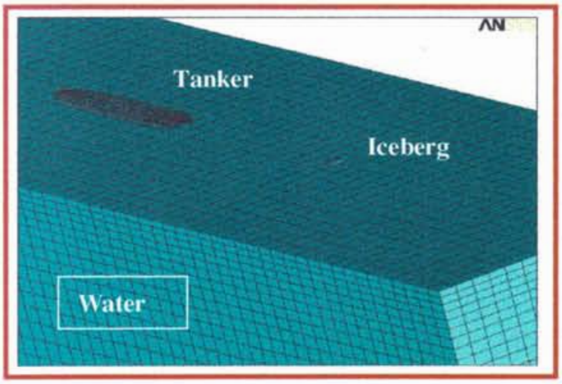

Fig. 1a: Tanker-iceberg numerical FEA setup

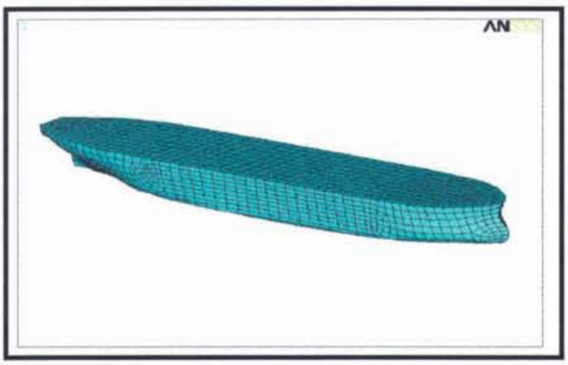

Fig. 1b: Tanker geometry - FE model.

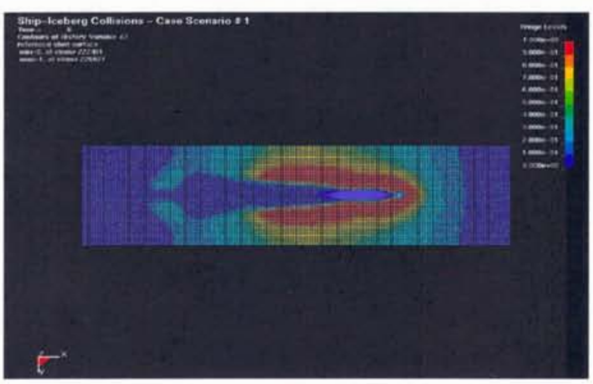

Fig. 1c: Bow-wave and wake profiles just before collision (bottom view).

However, developing multi-physics predictive numerical systems for offshore engineering is a road surrounded by a number of uncertainties. Subsequently, V&V analysis is imperative to gain an acceptable level of confidence in the computation output (Stern et al., 2001). Benchmarking of the numerical results against data from physical experiments is the most direct and effective way for a system validation. In that case, Experimental Uncertainty Analyses (EUA) is needed to gain an acceptable level of confidence in the truthfulness of experimental results (Coleman and Steele, 1998, 2001, and ASME, 1998). Both EUA and V&V provide a solid foundation for any conclusions drawn by comparing the experimental data "observed behaviour" with numerical results "predicted behaviour".

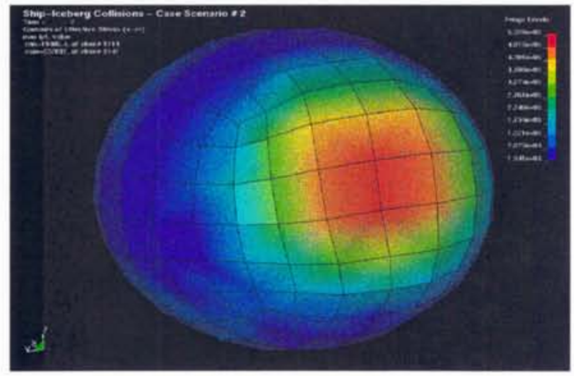

Fig. 1d: von Mises stresses in the iceberg elements at the time of impact.

Recent Developments in Numerical Modeling at the IMD.

In Canada, the performance of offshore structures and marine vehicles in ice-infested waters becomes a national quest. With increased oil and gas activities off the Canadian East Coast, the risk for collisions of oil tankers with offshore structures and icebergs (or collisions of ships with other marine installations) is real. The probability of a severe accident (with significant environmental, human, and capital liabilities) is increased by the fact that the environment off the coast of Newfoundland and Labrador is harsh and hazardous. It is characterized by severe sea states (very high waves), dangerous maneuvering/operating conditions (due to the presence of sea ice and icebergs) and persistent poor visibility conditions (poor weather conditions and fog).

Therefore, the potential for loss of life, property damage, increased liability and environmental pollution are serious operating conditions that need to be considered in the design and regulation of vessels (and offshore structures) traveling through (or operating in) the hazardous waters off the East Coast of Canada. In most cases, potential accidents can be detected, and collisions can be avoided. However, for uncontrolled operational circumstances and environmental conditions, accidents may well take place. This dictates that the design of such vessels and structures must consider accident prevention and mitigation scenarios, in addition to the requirements imposed by the standards regulatory codes for design of ships and offshore structures in normal operating conditions.

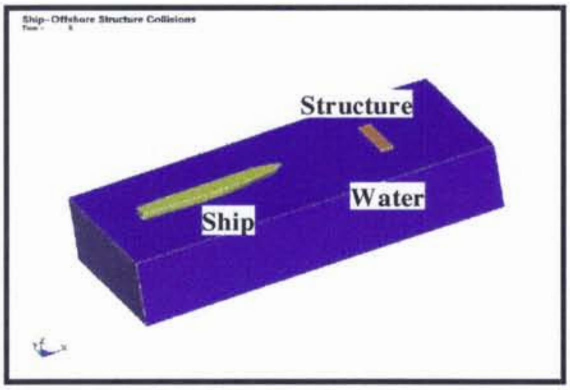

Fig. 2a: Ship - structure collision simulation.

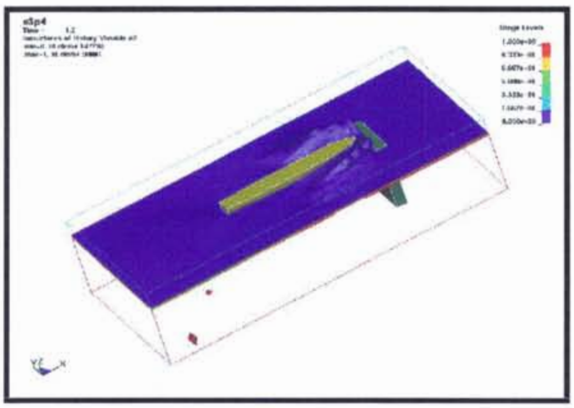

Fig. 2b: Bow wave (ship speed 3.4 m/s, scale 1/20)

For the numerical work, a suite of software made up of several commercial and in-house developed software packages (Derradji-Aouat, 2001) has been identified as a relevant tool that can be used to conduct accidents simulations, collisions analysis, and "what-if" scenarios for offshore problems Among these packages are: ANSYS, LS-DYNA, ENSIGHT, GEDAP, and ICE_FOR. ANSYS (www.ansys.com), LS-DYNA (www.lstc.com) and Ensight (http://www.ceintl.com/) are commercially available codes, GEDAP (2001) is an in-house package developed to generate drive signals to activate the wave maker in the physical tanks, and ICE_FOR is a material model for the mechanical behaviour of ice and its failure (Derradji-Aouat, 1994a, b, 2000). This numerical bundle is needed as a new strategy so that both novel and domain expert FEA analysts are empowered to investigate and analyze collisions, accidents and "what-if" scenarios in most marine and offshore engineering problems. Its ultimate goal is to provide a virtual replica of the physical facilities at the IMD (http://www.nrc.ca/). The testing facilities and existing experimental data at the IMD (obtained over the last 15 years) will serve as a basis to develop, verify, and validate the numerical bundle of software.

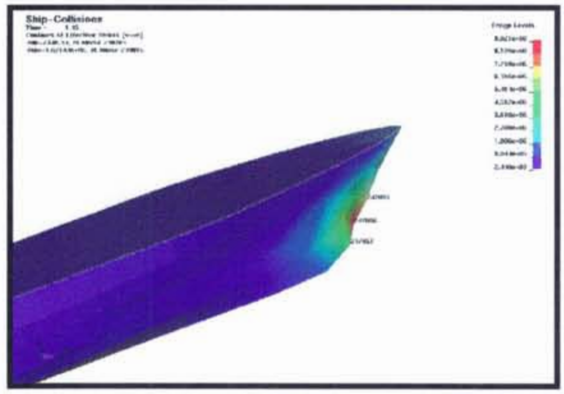

Fig. 2c: von Mises impact stresses in the ship.

From the analysis point of view, this bundle of software is made up from FEA programs, Pre/Post-processing software, and input data generation software (such as GEDAP). The bundle has the ability to expand to Virtual Reality (VR) processing and visualization (through Ensight software). It empowers users with the capability to conduct fully coupled CSD and CFD analyses of various marine engineering problems. Equally important, because of the generality of the FEA, the complexity "or simplicity" of the model that is used in the numerical simulation depends on the user's needs and objectives, and it is limited only by the available compute hardware capacity.

In this paper, several example applications are presented. These include simulations of collision scenarios of an oil tanker with small icebergs (Figs. 1a to 1d), collision scenarios of a ship with a fixed offshore structure (Figs. 2a to 2f), virtual wave generation for any sea state (Figs. 3a to 3f), and calculations of hydrodynamic loads on submarines (Figs. 4a to 4c). In the first example, maximum ice impact loads are calculated (they are needed to design ice-strengthened oil tankers). In the second example, maximum collision loads and deformation and damage sustained by the ship structure are calculated (these are needed to evaluate crashworthiness indices for both ship and structure). In the third example, regular and irregular waves are generated (numerically) so that the performance of offshore structures and ships in various sea states can be investigated. In the fourth example, simulations of a submarine moving forwards were performed and the numerical results were compared to physical data obtained from underwater-vehicle experiments conducted in the Clear Water Towing Tank (CWT) at IMD (Timothy, 2000).

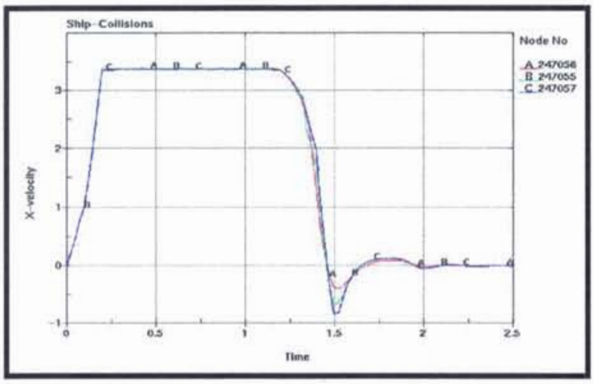

Fig. 2d: Velocity time histories for the impacted nodes at the bow of the ship.

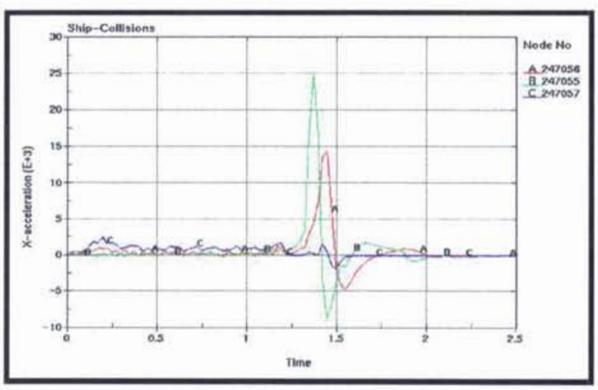

Fig. 2e: Acceleration histories for the impacted nodes.

It should be noted that the results of each computer runs should be accompanied by V&V analyses. For instance, in the third example, the wave simulations were validated against experimental data. Eight different wave probes were installed in the CWT at various locations, and then, the physical wavemaker was activated for various regular and irregular waves. The probes were used to measure the wave height histories (Derradji-Aouat et al., 2001), and the measured data were put through the EUA. The V&V analysis was conducted to investigate how accurate were the numerical simulations as compared to the observed wave heights.

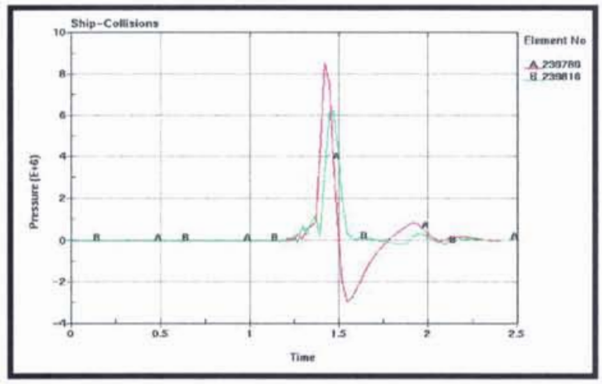

Fig. 2f: Pressure histories for the impacted elements

Fig. 3a: Actual (physical) Wavemaker in the CWT.

Conclusions

1. The three-step process appears to be the most logical way to develop, verify and validate numerical models: The steps are: 1) Multi-physics numerical approach, 2) EUA, and 3) V&V analyses.
2. The three-step process requires the talent, expertise, and experience of people from various disciplines

(CFD, CSD, EUA, V&V, FEA, experimentalists, …etc.). It is a team effort that requires a vision, a good coordination/management and significant computer processing and visualization power.

3. It should be cautioned that in order to interpret the numerical results of such large and complex models, the tools for visualizing (and communicating to others) the results become critical. The complexity stems from three sources: a) the problems are inter-disciplinary, b) they are 3-D and c) they are nonlinear and time-dependent. Traditional post-processing of the numerical results using 2-D graphics is time consuming and inadequate. The alternative is to use virtual prototyping or the immersive techniques "visualization caves". These techniques allow users to walk through (and/or fly over) very complex and large models; so that all of the facets of the results are reviewed and accurate assessments of the results of the simulations are made.

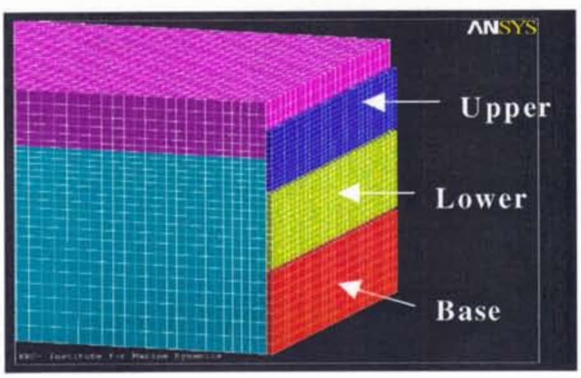

Fig. 3b: Numerical wavemaker and water basin - FE mesh

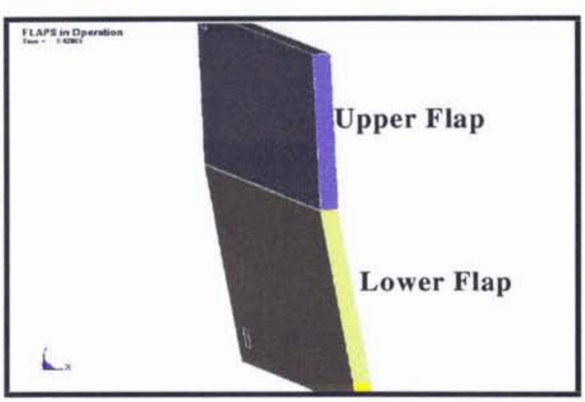

Fig. 3c: Numerical Wavemaker in operation

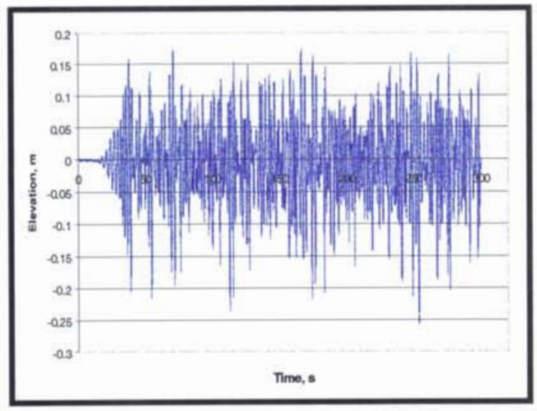

Fig. 3d: GEDAP Wave Input.

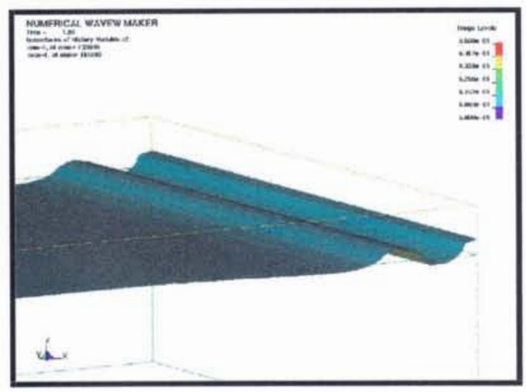

Fig. 3e: Numerical wave generation (regular waves).

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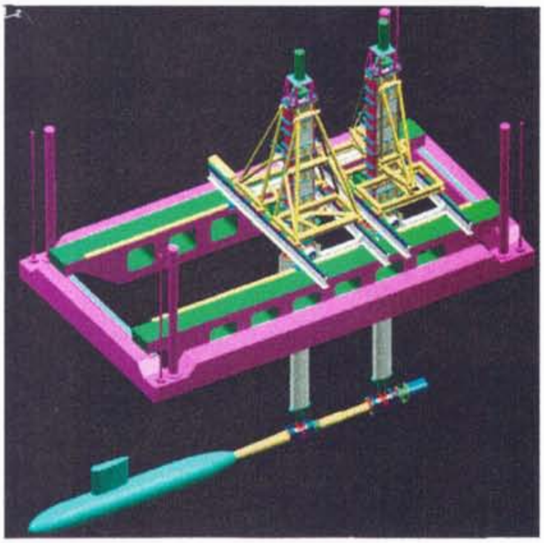

Fig. 4a: Marine Dynamic Test Facility (MDTF)

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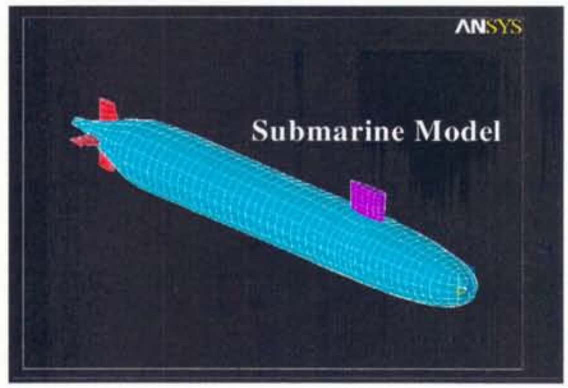

Fig. 4b: Submarine model - FE mesh

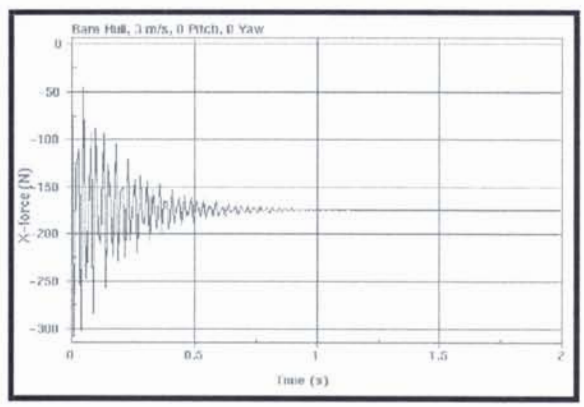

Fig. 4c: Damping and convergence of axial load on the submarine.

Acknowledgments

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