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Finite Element Analysis of the Quarter Scale Advanced Double Hull Design

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COMMENTS BY

Mr. James M. Acuna,
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Structural load transfer mechanics represents an area in the mechanics of materials that is increasingly difficult to predict when both elastic and plastic response are examined in complex structures. The authors of this paper should be commended for their efforts of modeling this very phenomena in the stranding of double hull tankers.

The paper's experiment focuses on a structural model of the bottom of a double hull tanker stranded on a one pinnacle rock. The modeling of the stranding between the rock and the hull at quarter scale presents many analytical problems to the experimenter. As stated, the purpose of these experiments was to develop a non-linear finite element model where linear scaling relationships for stress, deflection, and strain are superseded by plastic analysis. It was seen in previous experiments that the application of linear stress principles proves to be inadequate and derived scaling relationships, for values such as deflection, need to be assumed. The relationships then could be applied to full scale vessels and their design.

The difficulty of experimenting on materials with high elongation, ultimate strength, plastic analysis etc., . . . is that the experiment's outcome can be seriously affected by the scale at which the experiment took place. The tearing mechanics of the material does not scale at a compatible rate with bending, buckling, and crushing.

The time in which it takes the model to settle on the rock indentor, via the use of increased loads and raising the rock indentor, is very important to keep the same as actual conditions. Damage to the bottom structure varies dramatically as the time is changed, since damage also occurs with shock, and crack propagation. This occurs more in impact tests, but must be considered in this type of analysis.

The real test of the bottom structure and maintaining the integrity of the cargo tanks occurs when the vessel is grounded at speed. The cargo envelope must be able to maintain integrity in these conditions. A grounding can be much more dynamic and stress inducing than a stranding as seen in Rodd & McCampbell's "Double Hull Tanker Grounding Experiments."

As the authors stated, full weld details were not used in the model, instead the model was "tacked" together. The application of "tack" welds to the model might present errors when data is extracted for the finite element model. Since the welds must be scaled as to the rest of the variables, the tack welds do not allow the model to fully dissipate the energy, and stresses as a fully welded prototype would. This leads to questions when the model data is extrapolated to full scale and the weld detail effects are superimposed.

If the authors were able to keep the scaling effects in line, and accurately predict the effects of full weld detail, then they have created a powerful tool in the design of tanker bottom structure against strandings and have established a general method for examining the mechanics of materials in strandings.

AUTHORS' REPLY

The authors would like to thank Mr. Acuna for his review and comments. Mr Acuna has raised several good points.

We concur that the experiment's outcome can be seriously affected by the scale at which the experiment takes place. Because of the scale effects, previous plans for many small scale experiments were abandoned in favor of a few tests at the largest scale possible. A scale larger than one-quarter would have required a width clearance in excess of the machine at NIST, which is the largest such test machine in the world. The time duration of the event and mass scaling effects were very important and clarified in the previous discussion.

Since the small scale weld details are difficult to address in a model of this size, a practical approach is to rely on the localized failure of individual elements. While this doesn't address the details of welding at full or quarter scale, it does provide insight into the relative interactions between structural and material failure modes. The use of a local criterion for failure with an adequate knowledge of the material response reduces the dependence on tearing criteria where extrinsic length scales play a greater role.

The stranding analysis results demonstrated the importance of full weld integrity. A significantly higher load capability was demonstrated with the incorporation of full welds in the stranding analysis model. The weld details in the stranding test model were clarified in the previous discussion. Full welds were incorporated into subsequent grounding test models that were later tested by NSWC Carderock. Grounding was done elsewhere in the program.

COMMENTS BY

Mr. Gordon C. Everstine and
Mr. Ernest W. Brooks, Naval Surface Warfare Center

The problem attempted by the authors, predicting the hull rupture of a double hull vessel due to stranding, is a very difficult but important technical problem. The authors are to be commended for their progress on this problem. The effort was a very worthwhile study and a step in the right direction toward the eventual goal of having a validated approach and tool for predicting the ability of double hull ships to withstand the concentrated loads associated with stranding.

It is unfortunate that the physical scale model could not have been constructed closer to the way a ship would have been built, particularly with regard to the use of spot welds, rather than continuous welds. The welding also affected the finite element model, since the authors indicated that it was not practical to model spot welds in the mathematical model. As a result of this issue and other modeling issues, one is left to speculate about the reasons for the differences between the experimentally observed results and those predicted by the finite element model. Since inner hull rupture was not predicted by the analysis, but did occur in the test, the analytical procedure remains to be validated for this class of problem.

We would be interested in several clarifications by the authors. First, was the analysis continued until hull rupture? As part of the validation process, it would be interesting to know what load would be predicted to cause rupture, not just what load is required for the rock to achieve thirty inches of relative displacement.

In the description of the fracture of the outer hull, the authors referred to the removal of a finite element which had reached a certain level of plastic strain, based on a specified fracture path. What was the basis for the specification of the fracture path?

Since the test described by the authors was a quasi-static test, and the finite element analysis was a dynamic analysis, it would be useful to state the time duration used for the analysis and to comment on the possible dynamic effects related to the choice of time duration.

Finally, the conduct of the analysis seemed to depend considerably on knowledge of the test results. It would be useful for the authors to clarify the extent of that dependence and to comment on their confidence in being able to perform such analyses in the future if test data were not available.

AUTHORS' REPLY

The authors would like to thank Dr. Everstine and Mr. Brooks for their reviews and valuable comments on the paper. The authors' questions fall into these main categories: objectives of the analysis, modeling techniques and implications of the analysis. We shall take this opportunity to address these comments and add clarifications.

The objectives of the analysis were to determine the global load vs. penetration response, local and global deformation, plastic energy dissipation and potential for inner- hull rupture to a thirty inch indentor displacement. The authors agree that it would have been interesting to know what load would be predicted to cause inner-hull rupture in the stranding analysis. However, the stranding analysis was not run to inner-hull rupture. The peak load obtained in the finite element model was reached at 24.3 inches of penetration and the analysis was continued to thirty inches.

The modeling techniques incorporated welded structural components, the fracture path from the stranding test, and mass scaling. The majority of the stranding test structural components were welded using continuous, oversized welds (the experiment focused on deformation and tearing of components, i.e. weld failure at one-quarter scale was not desired). However the caps along the collapse resistant longitudinal webs were stitch-welded, under the assumption that crushing forces would provide enough friction that shifting of these components laterally would be prevented. This turned out not to be the case, which firmly discourages such "short-cuts" in fabrication in the future. Also, since the experimental structure was welded progressively from one side (100% welds) and symmetry was essential, it was impossible to weld the caps to the vertical stiffening directly beneath. The experimenters believe that this most likely accounts for the increased stiffness in the plot of load vs penetration from the stranding analysis as these components began to shift in the test. This was actually an encouraging piece of information for the overall program.

In the stranding test, a crack was observed in the outer hull located along the weld of the first longitudinal web nearest the centerline. This test observation was used to select the fracture path in the finite element model. Quarter symmetry was used to reduce the size of the model and was conservative in predicting the indentor force level. This symmetry condition modeled two symmetric cracks when looking at the full model, instead of one crack.

The stranding test was a quasi-static test and the stranding analysis was in fact a quasi-static analysis utilizing a dynamic code. This was accomplished through carefully chosen mass scaling parameters. Since the cost of the simulation is directly proportional to the number of time increments required, the time duration was an important factor. Mass scaling artificially reduces the time period of the event compared to the time of the actual event. If the simulation speed is increased too much, the inertia forces will be larger and will change the predicted response. The optimal value was determined by maintaining the kinetic energy less than five percent of the total energy. The stranding analysis had a time duration of 0.05 seconds. This value is a compromise between high computer simulations costs and unacceptable inertial effects. Computer runs were executed at higher mass scaling to determine the optimal time duration.

The implications of prior knowledge of the test results did not unduly affect our results. Only knowledge of rock indentor slip and the path of the crack in the outer hull was incorporated into the stranding analysis model. Specification of the fracture path zone reduced the numerical overhead to a subset of elements associated for possible failure.

The finite element analysis was able to reproduce many of the details of the stranding test, such as exterior and interior contact conditions. A post mortem analysis of the exterior and interior of the stranding test model revealed that many of the local and global deformations predicted by the stranding analysis were accurately reproduced. Due to these findings, we are highly confident of the capability to perform subsequent analyses without prior test data.