The Modelling of Landing Craft Motions inside a flooded Well Dock using Smoothed Particle Hydrodynamics

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ABSTRACT

One of the main purposes of a Landing Helicopter Dock (LHD) ship is the transportation and transfer of a large number of troops and their associated equipment from sea to shore. Sea transfers are conducted via landing craft, which are embarked and disembarked from a flooded well dock area located at the after end of the ship.

The behaviour of landing craft within the flooded well dock is of critical importance to the operators of an LHD ship. To date, the determination of the relative motion between the parent ship and the landing craft has only been assessed experimentally.

Numerical investigations have focused on determining the wave profiles within the well docks. The next step is to include landing craft and to determine the relative motion of the landing craft and the parent ship.

This paper describes the preliminary results of a feasibility study into landing craft motions inside a flooded well dock using commercial finite element (FE) analysis software. This FE code has fluid-structure interaction capabilities through its use of smoothed particle hydrodynamics (SPH) techniques. The study suggests that the relative motion between the LHD and the landing craft could be determined and therefore provide an assessment of the operational capabilities of the system.

INTRODUCTION

The Australian Defence Organisation (ADO) currently has a major project (JP 2048) to acquire two large amphibious Landing Helicopter Dock Ship (LHD) ships that contain well docks. The project has a requirement to minimise the risk associated with potential operational constraints during the selection of the final design. To achieve this it is necessary to demonstrate the hydrodynamic aspects of embarking and disembarking of landing craft from the well dock. The key purpose of this paper is to describe the operational aspects of an LHD Ship and to describe a numerical modelling technique employing Smoothed Particle Hydrodynamics (SPH) that could be used to describe the behaviour of landing craft within the well dock. Some of the research challenges are discussed which need to be overcome before this technique can be used to assess well dock behaviour.
LANDING HELICOPTER DOCK SHIPS

One of the main purposes of an LHD ship is the transportation and transfer of a large number of troops and their associated equipment from sea to shore. This transfer can either be done by air or sea. Air transfers are usually conducted via helicopters from the flight deck. Sea transfers are conducted via landing craft, which are embarked and disembarked from a flooded well dock area located at the aft end of the ship.

Figure 1 shows a typical LHD, the USS WASP, showing the well dock at the aft end of the ship. Figure 2 illustrates the loading of a vehicle onto a landing craft via the well dock beach. Figure 3 shows a landing craft entering the flooded well dock during benign conditions.

Entering the well dock can be hazardous when the LHD is under way. Due to the turbulent flow at the dock entrance and wave motions inside the well dock, the landing craft could impact the dock ship stern, the dock gate, the sidewall, the dock floor or any other structural component of the dock. Furthermore, collisions may also occur between landing craft. This contact may not only result in damage to the landing craft and/or well dock structure, but personnel operating in the area are at risk of injury.

The probability of a landing craft collision occurring is determined by several factors, including the skill of the helmsmen, the steering capabilities of the landing craft, the dimensions of the well dock and the waves, and turbulence within the well dock. Designers accept that all these factors, except for waves and turbulence within the well dock, contribute to damage [1].

Wave action inside the well dock area can result from the combined effect of the ship motions and external waves propagating into the dock. This induced wave action may limit
the operation of the landing craft. It has been shown that in some circumstances, landing craft can operate safely within the well dock area when wave heights outside the parent vessel are up to sea state 4 [1]. However, even within this operational zone, there can occur rapidly moving waves that are much higher than the average internal waves. As a result, restrictions may need to be placed on the operational environment in which well dock operations can be performed.

RESEARCH INVESTIGATIONS

A recent review of the literature has shown that the problem of describing the behaviour within a well dock is complex [2]. The initial component of this problem, that of determining the wave environment within the well dock, has been attempted by the navies of Canada [3] and Singapore [4]. Both of these studies developed techniques for determining the wave pattern within the well dock for various sea states and speeds. However, neither of these studies attempted to resolve the issue of determining the behaviour of a landing craft within the well dock. Currently, the relative motion between the parent ship and the landing craft has only been investigated using experimental methods. A key challenge for the future is therefore to include landing craft in the numerical analysis and to determine the relative motion of the landing craft and the parent ship. It is only with this information that requirements for the relative motion can be determined for safe operation of the system. At present there is no satisfactory code that can fully determine the behaviour of a landing craft within well docks. An approach using finite elements coupled with mesh-less SPH may be a viable option. The use of such a tool will be of paramount importance to the JP2048 project office to assist in the selection of the appropriate landing craft.

SMOOTHED PARTICLE HYDRODYNAMICS

Up until recently, the modelling of complex fluid flows could only be done by Eulerian methods involving complicated algorithms. The use of Eulerian methods becomes increasingly difficult when trying to model breaking waves. Recent advances in computational resources have allowed Lagrangian methods to be utilised for solving such complex fluid flows. One such example is the use of particle methods such as SPH. This method involves the body of the fluid being represented by particles of water that are subjected to Newton's Second Law. The major advantage of this technique is that there is no need to use fixed computational grids, hence eliminating problems with mesh distortion. This lends itself to the investigation of the interaction between a structure and the fluid in which it operates, and in particular, that of a ship in the ocean [5].

SPH was originally developed by Gingold and Monaghan for use in astrophysics [6] and has since been utilised to numerically model a variety of other complex fluid behaviours such as dam break problems [7], solid body impact with water [8], fracture of materials [9], solitary waves on beaches [10] and sloshing in tanks [11].

An investigation into whether SPH has the capability to model the complex fluid structure interaction which occurs when a landing craft enters the complex wave environment inside a flooded well dock was carried out by Pacific ESI with the assistance of DSTO. The following sections demonstrate the potential SPH has for modelling such a scenario.
provided certain limitations are resolved and the method is validated. The water is modelled using SPH whilst the LHD and landing craft are constructed from finite elements. The commercial FE code used in this study is PAM SHOCK [12].

**NUMERICAL ANALYSIS**

The analysis centred on replicating an experimental investigation numerically. A test basin or wave tank was modelled in which the SPH particles used to simulate water were placed. The test basin is 440 metres long, 20 metres wide and 14 metres deep, and therefore represents full scale rather than scale model size. Waves were generated at the end of the tank using a paddle in a similar set up to a wave test basin. The waves generated were a series of regular waves of 1 metre height with a period of 8.4 seconds. A beach was positioned at one end of the wave tank to minimise the waves reflecting off the end of the tank.

**LHD Model**

A generic LHD model, with the vessel particulars listed in Table 1, was constructed from finite elements. Figure 4 shows the LHD finite element model viewed from the stern quarter.

<table>
<thead>
<tr>
<th>Table 1 – Finite Element Model LHD Particulars</th>
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<tbody>
<tr>
<td>Length overall (LOA) (m)</td>
</tr>
<tr>
<td>Beam (m)</td>
</tr>
<tr>
<td>Draft at COG (m)</td>
</tr>
<tr>
<td>(with flooded well dock)</td>
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<tr>
<td>Trim angle when flooded</td>
</tr>
<tr>
<td>Well Dock Dimensions</td>
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<tr>
<td>Length (m)</td>
</tr>
<tr>
<td>Width (m)</td>
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<tr>
<td>Mass (tonnes)</td>
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One of the complexities of using SPH is the determination of the correct boundary conditions. To resolve this issue, the model of the LHD was gently lowered into the wave tank of SPH particles until it settled at the determined waterline where the buoyancy forces equalled the displacement. Once this state of equilibrium was achieved, the wave maker
paddle at the end of the wave tank was started which produces the required sea state. Finally the LHD was allowed to respond to both heave and pitch as it encountered the waves produced by the wave maker. Figure 5 shows the model of the LHD in the SPH wave tank.

![Figure 5 - A perspective view of the generic LHD in the numerical wave tank](image)

**Landing Craft Models**

Two generic landing craft models were constructed from finite elements and their particulars are shown in Table 2. The difference between the two models is the payload. Model 1 simulates an empty landing craft whereas model 2 simulates a landing craft carrying a main battle tank. Figure 6 shows the finite element models of these two craft.

<table>
<thead>
<tr>
<th>Table 2 – Finite Element Model Landing craft particulars</th>
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<tbody>
<tr>
<td><strong>Length overall (LOA) (m)</strong></td>
</tr>
<tr>
<td><strong>Beam (m)</strong></td>
</tr>
<tr>
<td><strong>Mass (tonnes)</strong></td>
</tr>
<tr>
<td>Longitudinal COG from FP (m)</td>
</tr>
<tr>
<td>KG at midships (m)</td>
</tr>
<tr>
<td>Draft at Midships (m)</td>
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The model landing craft were also lowered into the wave tank to reach their equilibrium positions. Two scenarios were modelled. The first involved the landing craft being tethered in a fixed position whilst the second scenario model involved the landing craft moving forward into the well dock. To achieve the forward speed of the landing craft, a force was applied to the stern and the landing craft could propel forward into the well dock until it was stopped by the physical presence of the beach. Whilst moving forward, the landing craft were also free to move in both heave and pitch.
RESULTS AND OBSERVATIONS

The wave action inside the well dock area can result from the combined effect of the ship motions and external waves propagating into the dock. This induced wave action may limit the operation of the landing craft.

To enable the overall wave environment inside the well dock to be derived, the resulting motions of the generic LHD operating in a seaway had to be determined. Initial investigations were undertaken to obtain heave and pitch motions of the LHD. Simulations were run and the motion of the centre of gravity recorded. The heave and pitch response of the generic LHD with time in a 1 metre height regular wave environment are shown in Figure 7. These regular waves had a period of 8.4 seconds. It can be seen from the figures that the heave is approximately 0.1 metres and the pitch is approximately 0.003 radians or 0.18 degrees. The responses displayed some periodicity at a frequency much lower than the wave frequency. A possible reason for this maybe due to poor absorption of the wave by the beach at the end of the tank which results in a reflected wave interacting with the transom of the vessel.

The wave induced motions of the generic LHD should produce an internal wave pattern inside the well dock. Upon investigation it was noticed that this was not behaving as
expected. The wave environment inside the well dock can also be influenced by external waves diffracting around the stern of the LHD and entering the well dock area. In the numerical simulation, this diffraction of the external waves was not observed. Two possible reasons for these phenomena not being observed are firstly due to the size of the SPH particles used, and secondly due to an increase in apparent viscosity that can occur when smoothing lengths within the SPH code are allowed to vary in time and space [13]. The influence of both these factors on the wave environment inside the well dock is currently being investigated by one of the authors at Pacific ESI.

To overcome the issue of the lack of wave diffraction, it was decided to place the wave maker at the stern of the generic LHD and to force the waves to enter the well dock from astern. This approach is considered acceptable provided the wave makers are run in such a format that they reproduce the wave environment that would exist at the stern of the LHD. Validation of this wave profile is required before realistic results are obtained. To achieve this outcome, the model experiments carried out by the Royal Netherlands Navy could be utilised [1]. In all further models, it was assumed that the waves were of 1 metre height at the time they entered the well dock, originating from a paddle-type wave maker 115m astern of the LHD. Figure 8 shows a wave crest in the well dock as the landing craft enters the well dock in the simulation analysis.

![Figure 8 - SPH wave travelling inside the generic LHD well dock](image)

The final part of the analysis was to introduce the landing craft into the LHD model. Once again the determination of all of the boundary conditions complicates the issue and therefore the simulation involves lowering the generic LHD, lowering the landing craft, initiating the wave maker to produce the wave environment and then either holding the landing craft stationary at a particular location within the dock or propelling it forward into the well dock.

To determine the operational limitations of the well dock, the relative motions of the landing craft and the well dock floor were investigated. Firstly the landing craft was tethered in a fixed position inside the well dock to restrict its motions in all modes apart from heave and pitch. The relative motions at an arbitrary point near the midships of the landing craft, and at a point directly below on the well dock floor were plotted against time for both the light and heavy landing craft. This plot is shown in Figure 9. As can be seen
from this plot, for the duration of the simulation, neither landing craft impacted the well dock floor when tethered at this location.

The second scenario to be considered was that of the landing craft entering the well dock and moving along the entire length of the dock. Figure 10 shows a series of cross sections for the simulation. As for the previous scenarios, the simulation process commences with all vessels out of the water, and proceeds by lowering the vessels into the water to attain equilibrium as the wave maker commences to establish the prescribed wave environment. After the wave environment is established, a force applied to the transom of the landing craft propels the landing craft forward to enter the well dock. The landing craft moves forward until it comes to rest at the beach. Figure 11 shows a plot of the relative motion of the transiting landing craft with respect to the dock floor.

Figure 9 Relative motion between the well dock floor and the tethered landing craft (a) light landing craft and (b) heavy landing craft

Figure 10 – Time sequence showing the landing craft entering the generic LHD
Figure 11 – Relative motion between the well dock floor and the landing craft whilst entering the well dock.

The simulations run to date show differences in the results between the light and heavy landing craft. The outcome of the feasibility study is that the use of SPH may provide a means to assess well dock behaviours. However, the technique needs to be verified and validated prior to any actual investigations.

The analysis in this preliminary study has been limited to rigid finite element models. By replacing these with elastic-plastic models, the magnitude and severity of the impacts could be determined. The PAM-SHOCK software currently has this capability.

CONCLUSION

The turbulent flow at the dock entrance and wave motions inside the well dock may cause a landing craft to impact the well dock ship stern, the dock gate, the sidewall, the dock floor or any other structural component of the dock. Furthermore collisions may also occur between landing craft. This contact may not only result in damage to the landing craft and/or well dock structure, but personnel operating in the area are at risk of injury. It is therefore necessary to develop a modelling capability that can assess landing craft designs and determine the operational limits of these designs. The study outlined suggests that the relative motion between the generic LHD and the landing craft could be determined using a finite element code with embedded SPH capability. However there are several research challenges and experimental validation that will be required before this potential technique could be applied to the problem at hand. If these challenges are achieved, then the techniques outlined above could provide an assessment of the operational capabilities of the LHD ship system.
REFERENCES


