TECHNICAL NOTE

AN EXPERIMENTAL STUDY ON THE RELATIVE MOTIONS BETWEEN A FLOATING HARBOUR TRANSHIPPER AND A FEEDER VESSEL IN REGULAR WAVES

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SUMMARY

The Floating Harbour Transhipper (FHT) is a pioneering logistics solution that was designed to meet the growing demands for coastal transhipment in the mining sector as well as commercial port operations. The primary advantage of the FHT system is that it can reduce transhipment delays caused by inclement weather, by reducing relative motions between the FHT and feeder vessel. The feeder is sheltered when inside the FHT well dock when compared to the more exposed location when a feeder is in a traditional side-by-side mooring arrangement.

This paper discusses previously published studies into the relative motions of vessels engaged in side-by-side mooring arrangements and also presents details and results from a series of physical scale model experiments. In these experiments, both side-by-side and aft well dock mooring arrangements are investigated. The results provide strong evidence that the FHT well dock concept can significantly reduce the heave, pitch and roll motions of feeder vessels when transhipping in open seas – this being the cornerstone of any successful open water transhipment operation.

1. INTRODUCTION

Bulk ore product is usually shipped directly from shore facilities using large bulk carriers (typically either Panamax or Capesize ships) which require large, expensive port facilities, often involving dredging operations and the need for visually obtrusive shore storage sheds (for example, possessing a capacity of 80,000 tonne for a Panamax load). Substantial reductions in capital and operating expenditure are achievable by relocating the major stockpile to an offshore floating facility (mothership), thus requiring a much smaller shore facility (around 10,000 tonne capacity). The product is transferred from the shore facility, which can be located within a small harbour, to the mothership via two or more shallow draught feeder vessels.

The transhipping objective for defence and disaster response and mining is the same, which is to transfer large volumes of cargo with minimal time and costs into remote areas with little or no infrastructure in all types of weather.

This technical paper reviews a case study on the development of the Floating Harbour Transhipper (FHT); a novel design that can not only increase export and import capabilities, but also strengthen emergency response and military capabilities. For a relatively simple modification for defence use, the FHT can provide a large percentage of the military requirements for a small fraction of the cost.

2. THE FLOATING HARBOUR TRANSHIPPER (FHT) CONCEPT

Traditionally, the transfer of bulk ore cargo from a feeder vessel to a moored 'mother' ship is conducted with the feeder vessel moored side-by-side to the mothership. The FHT concept adopts a novel alternative, where the feeder vessel is moored inside an aft well dock in the FHT/mothership. The FHT is a covered floating storage vessel which incorporates a wet dock facility at the aft end to suit the feeder vessels. It also has its own bulk cargo handling equipment, not just for the transfer of material from the feeder vessel into its own stockpile, but also from this stockpile to an export ocean going vessel moored alongside. This system eliminates grab spillage and dust, common to other transhippers.

The concept is depicted in Figure 1, where a feeder vessel of up to 10,000 dwt capacity is moored inside the stern well dock of a Capesize capacity FHT (100,000 dwt capacity). An export vessel (in the foreground) is moored alongside the FHT. In this figure, the feeder vessel is partially obscured by the covered deck of the FHT. For this example, the feeder vessel is a Stern Landing Vessel (SLV), as described by Ballantyne and Ballantyne (2007) and is carrying bulk ore product for mining transhipment options, as depicted in Figure 2.

The FHT concept provides an environmentally and operationally compelling solution that can provide significant advantages for the country, community and mining companies. The key advantages for the FHT and SLV feeder system relevant to mining operations are summarised as follows:

- The stockpile is at the export site, downsizing or eliminating the need for large expensive negative pressure sheds ashore and large wharf facilities;
- Provides dust-free transhipment, eliminating issues close to residential areas;
- Can handle rougher seas, therefore eliminates demurrage;
- Shallower draught feeder vessels can be used from very small ports or unprepared beaches at scheduled times, eliminating the need for dredging of sensitive areas;
- A small shallow harbour eliminates the cost of a major jetty structure and the bond for its removal at end of the mine life;
- Upon completion of the mine life, a small harbour is available for the community or traditional owners;
- Revenues from mining royalties can be secured at an earlier timeframe;
- Reduces the need for road transport (and associated greenhouse gases) by using small harbours closer to the mine site;
- Provides employment and training opportunities in feeder vessel operations;
- Reduces capital expenditure and sovereign risk;
- Operating expenditure can be reduced due to lower power and manning requirements when compared to more traditional systems;
- Port charges, such as berthage, wharfage and tugs, can be reduced;
- The FHT well dock arrangement eliminates stevedoring damage to feeder and transhipment vessels;
- An FHT with SLV feeder vessels can handle inbound fuel and other dangerous goods (such as ammonium nitrate) and outsized heavy lifts into areas with little or no infrastructure;
- A feeder vessel can be secured within the well dock bow first to push the FHT to redeploy to disaster sites, cyclone moorings or dry dock;
- The FHT requires minimal manning (4-6 crew);
- The FHT has no propulsion engines or large superstructure and incorporates anchor ground tackle to suit the combination of the FHT and export vessel.
- The FHT can use stern transverse thrusters to avoid beam sea conditions.

It is acknowledged that typical Landing Helicopter Dock (LHD) ships, such as the Canberra Class selected for the Royal Australian Navy (Semaphore, 2007), incorporate a similar stern door access for loading smaller vessels. However the FHT system is unique in the sense it is a permanently open aft wet dock which is not restricted to small craft only. The wet dock in this instance has been designed to reduce surge, sway and yaw effects and dampen roll, pitch and heave motions of the feeder vessel.

The primary advantage of the FHT system is that it can dramatically reduce transhipment delays caused by inclement weather, by greatly reducing relative motions between the FHT and feeder vessel. The feeder is significantly sheltered when inside the FHT well dock when compared to the more exposed location when a feeder is in a traditional side-by-side mooring arrangement. For example, it is common for alongside transhipment operations to typically be limited to significant wave heights of up to approximately 2.5 metres which can be seen in many operations currently in the market. Preliminary investigations indicate that feeder vessel operations can be handled, uninterrupted, in seas of up to 5 metres for the FHT concept. The main purpose of this paper is to present some of the results from a series of physical model experiments which were conducted to investigate this specific issue.

3. LITERATURE REVIEW

To the authors' knowledge, there are no publicly available studies that have investigated the relative motions of two vessels, of similar relative sizes as proposed in the FHT concept, where the smaller vessel is moored inside an aft well dock. There exist several published studies that have investigated the relative motions of two vessels in a side-by-side arrangement, with most studies dealing with the application of numerical codes to this problem, and their efforts to validate predictions by undertaking a comparison against limited scale model experimental data. For example, see Kodan (1984), Buchner *et al.* (2001), Fang and Chen (2001), Inoue and Ali (2003), Kim *et al.* (2003), Hong *et al.* (2004), Lewandowski and Naud (2004), Koo and Kim (2006), Huijsmans *et al.* (2007) and Xiang *et al.* (2007). It is important to note that there are some significant differences in the relative lengths of the two vessels compared to our current study. For example, the ratio of feeder length to mothership length ranges from approximately 48% up to 93% of the proposed SLV/FHT concept under consideration here. As might be expected, the range of vessel displacements also vary considerably which makes direct comparison of the published numerical and experimental data with the results from the present study a more complicated task, and possibly of limited value.

When two vessels are moored side-by-side, it is expected that the motion of both vessels will be affected by the presence of the other vessel, both through the mooring system and from hydrodynamic interaction. Thus, it is inappropriate to assume that the motions of any single vessel in a known seaway will be the same as the case when that vessel is alongside any other vessel. In addition, the manner in which the vessels are connected and moored can have a significant effect on the resultant motions. This is one of the reasons why validation of numerical predictions, usually through the conduct of physical scale model experiments, is so important in such cases. One common general trend found from the published studies is that the smaller (feeder) vessels experience notably greater motions than the larger vessel (mothership).

Both Hong *et al*. (2002) and van der Valk and Watson (2005) investigated the forces and motions of both side-by-side and tandem vessel arrangements (where one vessel is aft the other) through the conduct of physical scale model experiments. A similar study using a higher-order boundary element method was conducted by Choi and Hong (2002). Each of these studies indicate that the aft positioned vessel has lesser motions due to the shadow effect of the windward vessel. The tandem position is not under consideration in the present study as it is generally used for the transfer of liquid products, not solid materials.

Recent work by some of the present authors has involved the measurement of the motions of a landing craft within a flooded well dock while in a seaway, however in this work the size of the well dock is considerably larger than the vessel inside it, Cartwright *et al*. (2007). This work is primarily related to military applications and unfortunately very little is presently available in the public domain. But the process of undertaking such experiments has been of considerable benefit in the development of suitable techniques and procedures for undertaking such work, which has been utilised in the present study.

4. EXPERIMENTATION

The model experiments were carried out in the shallow water wave basin at the Australian Maritime College in Launceston, Tasmania. The water depth in the basin was simulated to represent a typical coastal region having a constant depth of 15 metres. A variety of incident wave conditions and vessel headings were investigated as part of a comprehensive test program. Experimental results presented within this paper concentrate on a series of head sea tests in regular sinusoidal waves having nominal wave heights corresponding to 2m, 4.5m and 7.7m. A wide range of typical wave periods were investigated.

The primary particulars of the FHT and feeder vessel, in both model (scale 1:44) and full scale, are provided in Table 1. Results presented here are for the case with the FHT in ballast condition and the feeder vessel at half load condition. These lighter conditions were investigated to simulate a common worst case scenario. Full displacement conditions in general produce smaller motions; hence it is common practice for ships to ballast down during storm conditions.

The motions of both vessels were measured using a non-contact optical tracking system based on infrared cameras (supplied by Qualisys). Two specific cases were investigated; (a) with the feeder vessel alongside the FHT and; (b) with the feeder vessel located inside the well dock of the FHT.

For the study with the feeder alongside the FHT, the feeder was located on the portside of the FHT with the longitudinal location defined by lining up the midships of both vessels and the bows orientated in the same direction, as can be seen in the photograph shown in Figure 3. The starboard side of the feeder model was attached to the port side of the FHT model using a pair of vertical slides and universal joints, refer Figure 4. The aft vertical slide/universal joint also incorporated a short horizontal slide. This arrangement allowed freedom in heave, pitch and roll, whilst constraining the feeder model in surge, sway and yaw (relative to the FHT model).

In the case where the feeder was located within the well dock, the stern of the feeder model was attached to the internal end wall of the FHT well dock using a vertical slide and universal joint and the bows facing opposite directions. This allowed freedom in heave, pitch, roll and yaw, whilst constraining the feeder model in surge and sway (relative to the FHT model). The photograph in Figure 5 provides a general view of this set up. Fenders were attached to the inside walls of the FHT well dock near the entrance to limit the yaw movement of the feeder.

A simplified mooring system was adopted to ensure that the FHT model maintained the required nominal heading to the incident waves. This mooring system included a pair of mooring lines, one each from the bow and stern of the FHT model (connected at the still waterline). The stern mooring line incorporated a bridle so as to avoid contact with the feeder model.

It is acknowledged that there would be value to also assess the mooring and restraining loads, however the primary focus of these initial physical experiments was on proof of concept through an evaluation of the relative motions of the two craft. An assessment of these loads is planned as part of further research into this concept.

5. RESULTS AND DISCUSSION

A comparison of the resultant heave, pitch and roll motions for an incident wave height of 2 metres at a heading of 180 degrees (head seas) is shown in Figures 6, 7 and 8 respectively. A range of wave periods from 4 to 12 seconds were investigated with both the feeder inside the FHT well dock and the feeder alongside the FHT.

As can be seen in Figure 6, the heave motion (at the LCG) of the FHT did not vary appreciably between the cases when the feeder vessel was located alongside or inside the well dock. In contrast to this, the heave motions of the feeder are significantly greater when it is alongside the FHT compared to when it is located inside the FHT well dock.

The pitch motions of the FHT did not vary appreciably between the cases when the feeder vessel was located alongside the FHT or inside the well dock (refer Figure 7). Interestingly, the pitch motions of the feeder vessel are quite similar to that of the FHT while it was located inside the well dock, with typical maximum values around 0.4 to 0.5 degrees. However, when the feeder was located alongside the FHT its pitch motions became significantly larger, by almost an order of magnitude, with the peak value approaching 4 degrees. In each case, the peak pitch angles occur at incident wave periods in the region of about 10s to 11s.

As might be expected, the roll motions of the FHT were generally relatively small for head sea conditions, as shown in Figure 8. However, in wave periods greater than 8 seconds, the FHT rolls more when the feeder is moored alongside than when it is inside the well dock, suggesting that the presence of the feeder alongside adversely affects the motions of the FHT. The roll motions of the feeder vessel whilst inside the well dock is similar to the roll motions of the FHT, but considered to be relatively small with values generally less than 0.2 degrees at all wave periods investigated. Of significant concern are the notable roll motions of the feeder vessel when moored alongside, which are found to exceed 3 degrees (around a wave period of 9s) which, similar to the pitch motions, is around an order of magnitude greater than found when the feeder is located inside the well dock.

In summary, the results presented in Figures 6, 7 and 8 highlight the potential reduction in heave, pitch and roll motions that can be achieved by 'sheltering' the feeder vessel within the aft well dock of an FHT. It is acknowledged that the motions of the feeder vessel when alongside the FHT could be controlled (reduced or potentially increased?) to some extent by the manner in which it is moored to the FHT, however, in certain circumstances this may be impractical.

Further experiments were conducted in head seas at greater nominal incident wave heights (up to 7.7 m) in order to determine the effect this has on the motions of both the FHT and feeder vessel. Cross-plots of the motions as a function of increasing wave height are provided in Figures 9, 10 and 11 for the nominal full scale wave period of 10s. This wave period was selected as the maximum motions were found to occur at or close to this wave period in the results presented in Figures 6, 7 and 8. It should be noted that tests on the case with the feeder vessel alongside the FHT were limited to incident waves of approximately 4.3m in height due to unacceptably high motions at higher wave heights.

The heave motion of the feeder when located alongside the FHT is approximately twice that of the feeder when located inside the FHT well dock at the nominal wave heights of 2.0 and 4.3 metres, as can be seen in Figure 9. It appears that the heave motion for both the FHT and feeder are, in general, increasing linearly with increasing incident wave height, which agrees with linear ship motion theory, Lloyd (1998).

The pitch motions of the FHT and the feeder vessel, when located inside the FHT well dock, are very similar over the entire range of wave heights investigated (Figure 10). However, when the feeder was located alongside the FHT the pitch motions are approximately eight times higher than the case with the feeder located inside the FHT well dock. The pitch motions of the FHT and feeder (when inside the well dock) can be seen to follow a general trend of increasing magnitude relative to the increasing incident wave height, i.e. a linear relationship exists, as was found for the heave motions.

Relatively small roll angles (<1 degree) were experienced by the feeder vessel when located inside the FHT well dock at all three wave heights (Figure 11). In contrast, when the feeder was located alongside the FHT the roll angles were found to exceed six times this level. The roll motions of the FHT were marginally greater when the feeder was side-by-side the FHT than inside the FHT well dock.

Both the rotational motions (pitch and roll) of the feeder vessel when moored inside the well dock are significantly less at all incident waves heights investigated (2.0m, 4.3m and 7.7m) than those measured at just 2.0m high incident waves for the alongside case. As previously mentioned, it may be possible to utilise alternative mooring arrangements to reduce the alongside motions, however, there will be a practical limit as to how effective and safe this will be.

Further analysis of the experimental data is presently underway to investigate the relative heave motions at other critical locations of both vessels and different wave headings, as are investigations of the practicality of implementing a more substantial system to moor the feeder vessel within the well dock to further reduce the motions. It is also planned to conduct additional experiments in various irregular seaways.

6. CONCLUDING REMARKS

The concept of a Floating Harbour Transhipper (FHT) for transferring bulk cargo offshore in open seas is outlined and discussed, including the use of smaller shallow-draught feeder vessels to transport bulk goods and equipment from small harbours or unprepared beaches to the FHT. A novel aspect of the FHT is the aft well dock in which the feeder vessels are moored during the transfer operation, thus taking advantage of the benefits of being sheltered from incident waves.

A series of physical scale model experiments were conducted to investigate the differences in relative motions of the feeder vessel when moored inside the FHT well dock compared to a more conventional side-by-side mooring arrangement. The well dock configuration was found to significantly reduce the motions of the feeder vessel. In some cases, such as with pitch and roll, the motions of the feeder vessel were reduced by an order of magnitude by locating the feeder inside the aft well dock. It was also found that both the pitch and roll motions of the feeder, when moored inside the FHT well dock, were very similar to the motions of the FHT itself.

7. ACKNOWLEDGEMENTS

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	Panamax FHT		**Feeder Vessel**	
	Ship	Model	Ship	Model
LOA (m)	220.000	5.000	90.000	2.045
Beam (m)	44.000	1.000	21.000	0.477
Draught (m)	7.000	0.159	2.420	0.055
Displacement (tonnes)	47070	0.539	3660	0.043
Trim (degrees)	0.0	0.0	0.0	0.0
VCG (m)	10.000	0.227	5.500	0.125
LCG (m)	113.500	2.580	43.000	0.977
GM (m)	22.714	0.516	9.698	0.220
KM (m)	32.714	0.744	15.198	0.345
Pitch Radius of Gyration (m)	55.000	1.219	22.500	0.536
Roll Radius of Gyration (m)	15.400	0.338	7.350	0.173

Table 1 – Primary particulars of FHT and feeder vessel

Figure 1 – Floating Harbour Transhipper (mining). An SLV is in the well dock and a Capesize vessel is moored alongside (foreground)

Figure 2 – Stern Landing Vessel – bulk ore cargo

Figure 3 – model tests with the feeder vessel alongside the FHT

Figure 4 – close up view of the model of the feeder vessel alongside the FHT model

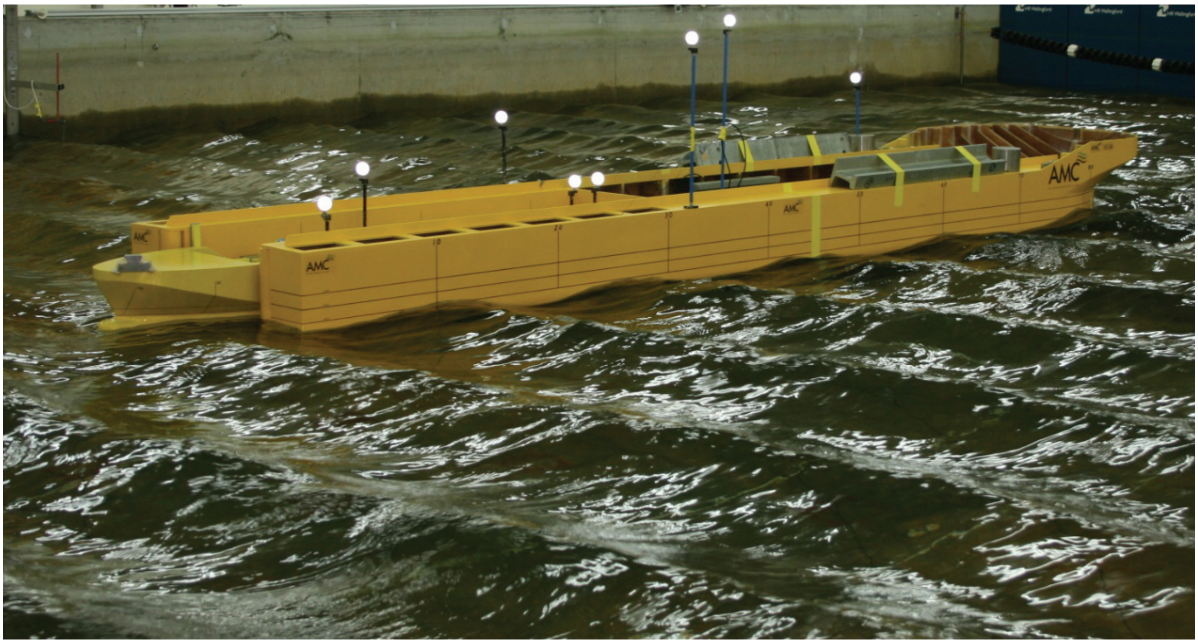
Figure 5 – a view of the model of the feeder vessel moored inside the well dock of the FHT model

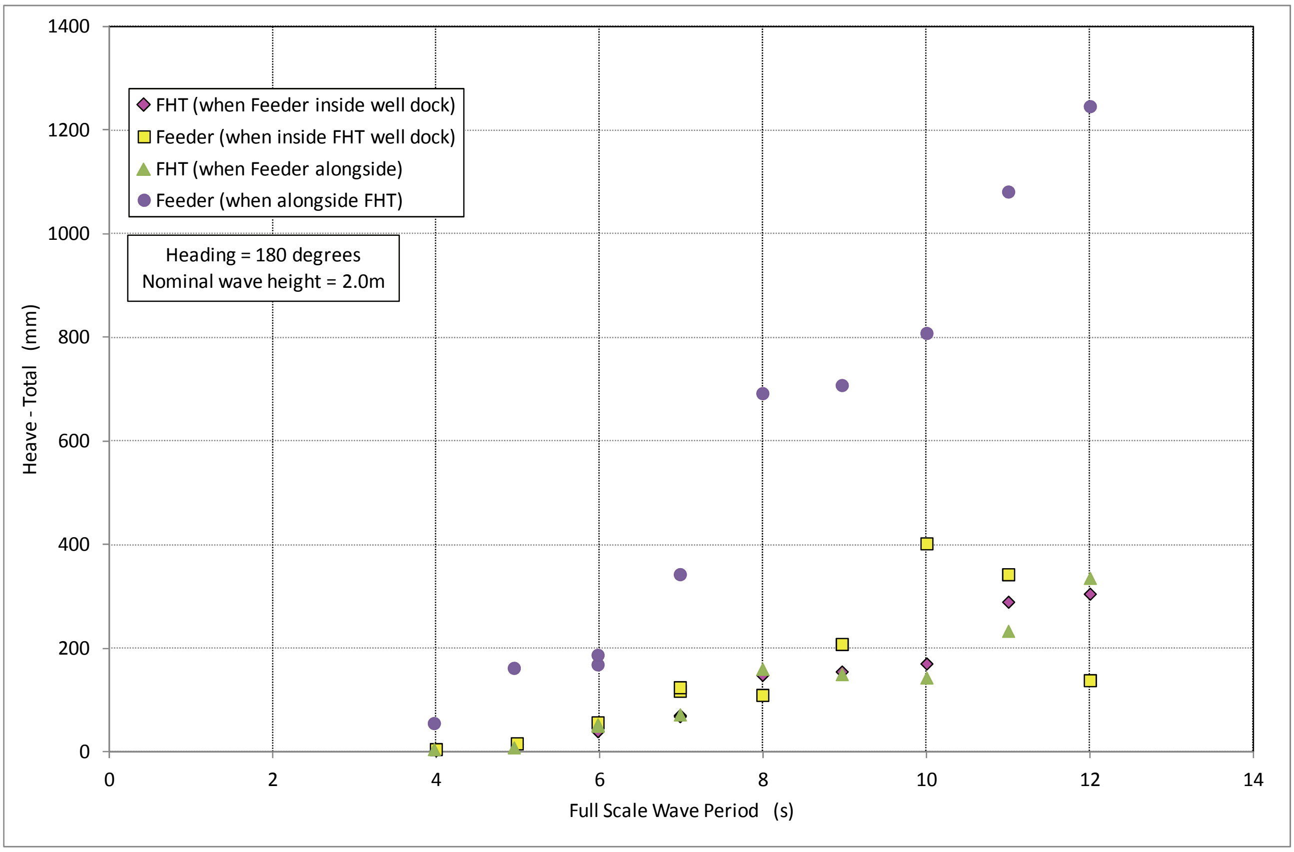

Figure 6 - Heave motions as a function of wave period

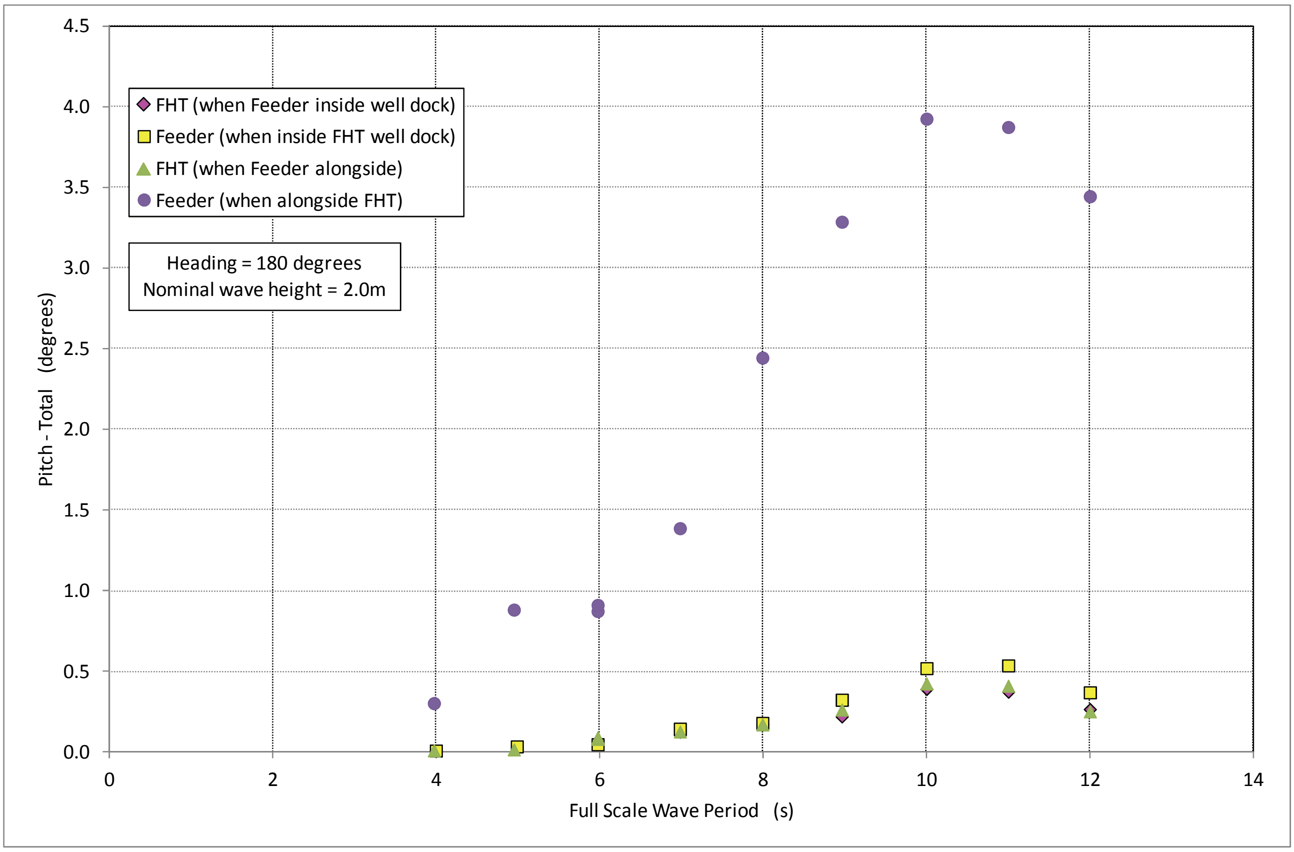

Figure 7 - Pitch motions as a function of wave period

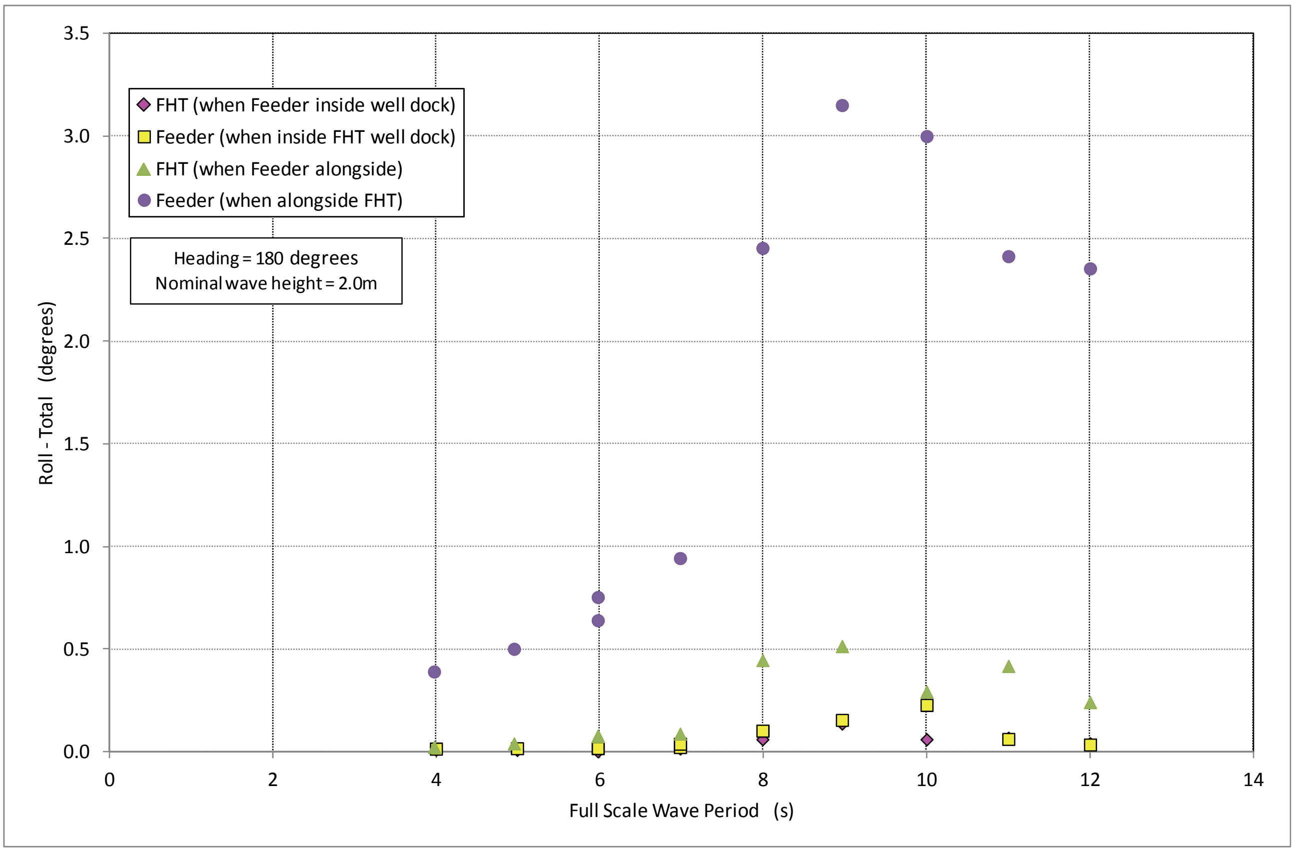

Figure 8 – Roll motions as a function of wave period

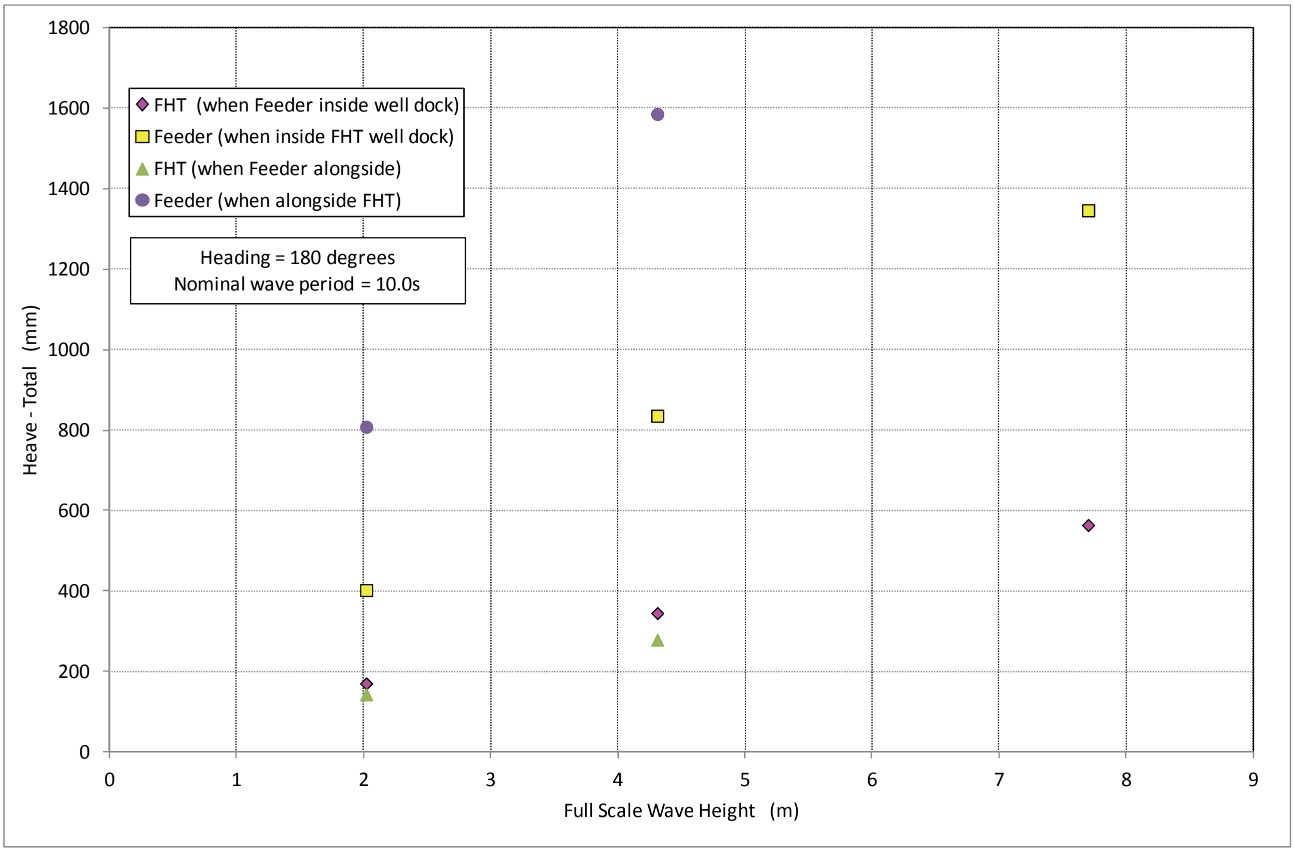

Figure 9 – Heave motions as a function of wave height

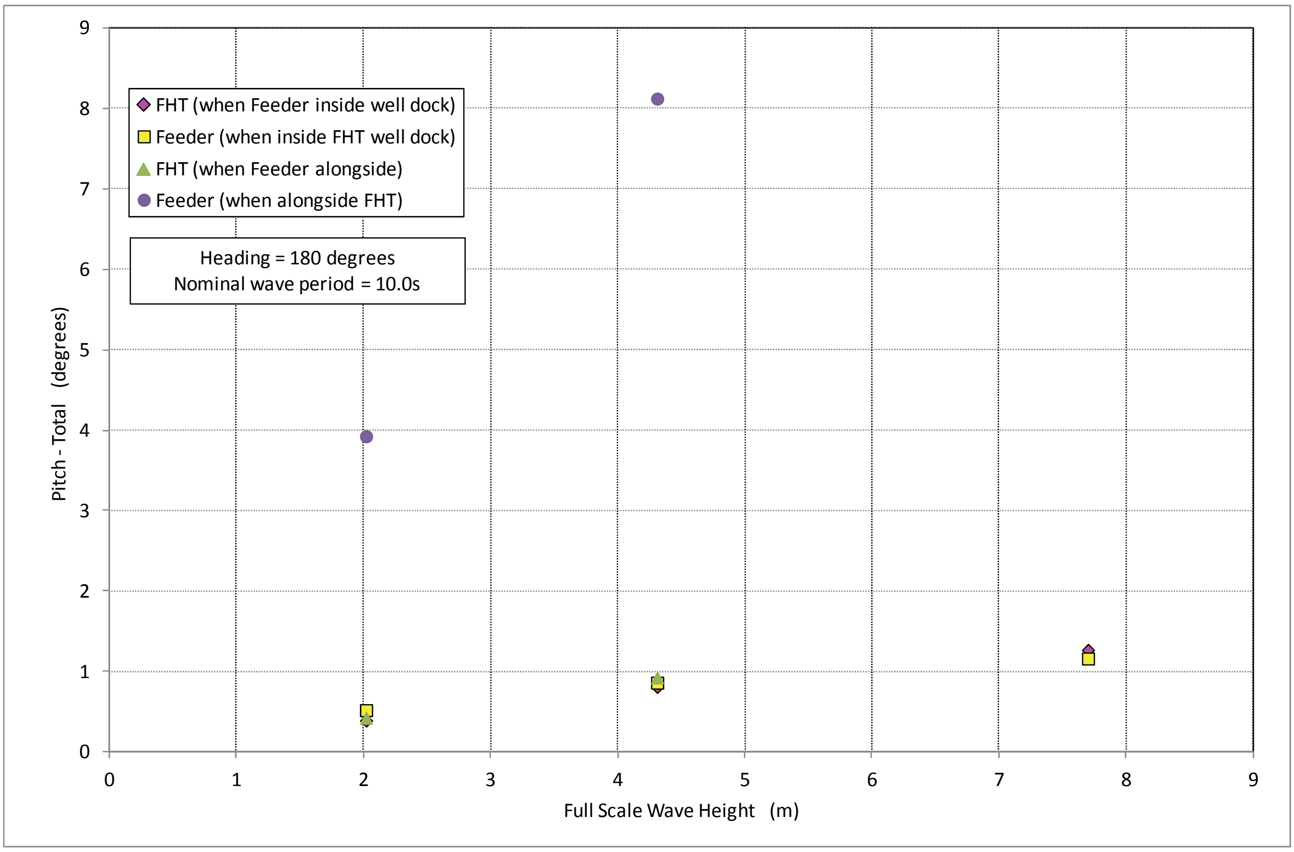

Figure 10 – Pitch motions as a function of wave height

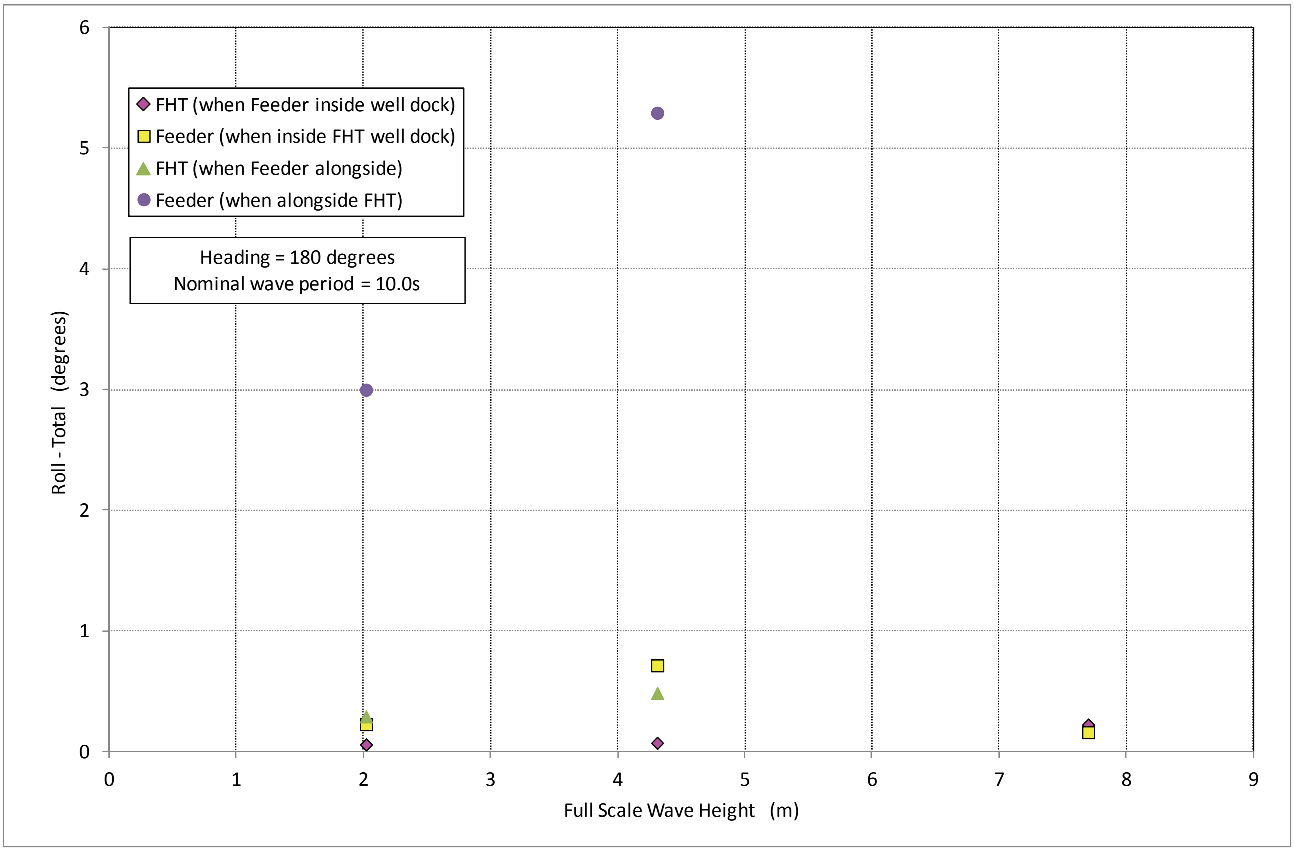

Figure 11 – Roll motions as a function of wave height