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The effect of angle of attack on the generated wave propagation

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Abstract

The presented work is an experimental investigation into the waves generated by a pressure source moving in a straight channel. Wave fields generated by the moving pressure source are described and the effects of angle of attack on the generated wave height, surfable wave quality, drag and vertical forces are presented. The main objective of this study was to investigate the relationship between the angle of attack and the generated wave height across the towing tank width and the surfable wave quality. The investigations were conducted at the Australian Maritime College towing tank on a wavedozer at four different attack angles at various speeds. Three wave probes were installed across the channel to record the generated wave heights. Based on the experimental results, it was concluded that smaller angles of attack produced higher quality surfable waves compared to larger angles of attack, while the height of the generated wave has a direct relationship with the angle of attack. By comparing the forces for different models, it was concluded that the pressure source with the lowest angle of attack has the minimum drag but maximum displacement.

Introduction

Usually the waves generated by high-speed vessels moving in shallow water are considered to be environmental and safety hazards in confined waters. Vessel generated waves, their associated disturbances to other vessels in ports and harbours, shoreline erosion and their impact on marine life are some of the most important issues in this field (Macfarlane, 2012). Field studies have been conducted at several locations where problems of this nature have occurred (Nanson et al., 1994; Macfarlane & Cox, 2004; Macfarlane, Cox & Bradbury, 2008).

The wash waves generated by vessels can be characterized in terms of the waterway bathymetry, hull shape (Renilson & Lenz, 1989) and operating conditions (Robbins et al., 2011). Due to the great interest in wake-wash effects, a considerable amount of research has been conducted in recent years. In model experimental studies, the focus has been on designing low-wash ships and acquiring reliable data for validation (Zibell & Grollius, 1999; Koushan, Werenskiold & Zhao, 2001; Macfarlane, Bose & Duffy, 2012).

Waterway bathymetry has an influence on the generated wash waves' characteristics (Javanmardi et al., 2017). Natural and man-made water channels often have non-rectangular cross sections. It is important to understand how channel geometry affects the evolution of waves in water channels of arbitrary shape. Several studies have been conducted on waves propagating in channels with arbitrary cross-section profiles (Peters, 1966; Peregrine, 1968) and on wave patterns in two horizontal dimensions generated by a disturbance moving at speeds close to the critical Froude number in channels with a rectangular cross-section (Ertekin, Webster & Wehausen, 1986; Katsis & Akylas, 1987; Pedersen, 1988; Mathew & Akylas, 1990; Teng & Wu, 1997; Jiang, Henn & Sharma, 2002; Liu & Wu, 2004). According to the results, the wavelength and time taken for wave generation were affected by both the submerged channel cross-sectional geometry and the channel sidewall slope at the waterline. The method was based on Boussinesq-type equations usually used for the far-field flow on slender-bodies for the near-ship flow; this method is shown to be able to predict 2D wave propagation and waves far from the vessel in a rectangular channel.

In addition to the above reasons for conducting wake wave studies, such waves can be considered with respect to surfing (Schmied et al., 2011; Javanmardi et al., 2013, 2017; Javanmardi, 2015). A new surf pool concept was developed by Greg Webber; his idea to produce continuously breaking waves was patented (Webber, 2004; 2006) by Liquid Time Pty Ltd. This invention is based on a circular pool in which the waves for surfing are created continuously along the banks of the pool (Schmied et al., 2011). The idea was born from Webber's experiences surfing in the Clarence River on waves generated behind a fishing boat. Webber's idea is based on one or more pressure sources being rotated within an annular wave pool to generate waves. A pressure source is any object that disrupts the water's surface and creates a wave. The circular channel has sloping bathymetry with the outer side being deeper; the waves are generated in the deep water and break in the shallow water on the inner island.

Regardless of waterway bathymetry, the moving vessel parameters have a great influence on the generated wave characteristics. This study investigates the effect of angle of attack on the generated waves and forces experimentally, where the angle of attack is the relative angle between the entry surface and the water surface. A wavedozer was used as the pressure source. The investigations were conducted at the Australian Maritime College towing tank on a wavedozer at four different angles of attack at various speeds. Three wave probes were installed across the channel to record the generated wave heights. Two load cells were installed to measure drag and vertical forces.

Experimental setups

The experiment was conducted at the Australian Maritime College (AMC) towing tank which is 100 m in length and 3.5 m in width. The towing tank is equipped with a powered carriage for towing models and has a maximum speed of 4.0 m/s, it is capable of maintaining a constant speed within ± 0.01 m/s in either forward or reverse. The carriage is equipped with data acquisition equipment to analyse the signals measured from resistance and sea-keeping experimental setup. The tank also has wave absorbers at each side and beaches at the end of the towing tank that dissipate the wave after each run in order to calm the water prior to the next run. Three resistance wave probes were positioned at 0.75, 1.0 and 1.25 m from the centre-line of the model to record the elevation of the vessel-generated waves with respect to time (Figure 1). Wave height was defined as the trough to crest height of the first significant waves, as shown in Figure 2.

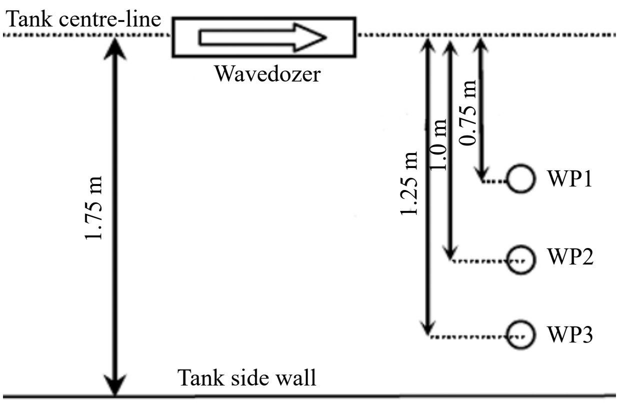

Figure 1. Wave probe setup relative to centreline of pressure source (top view)

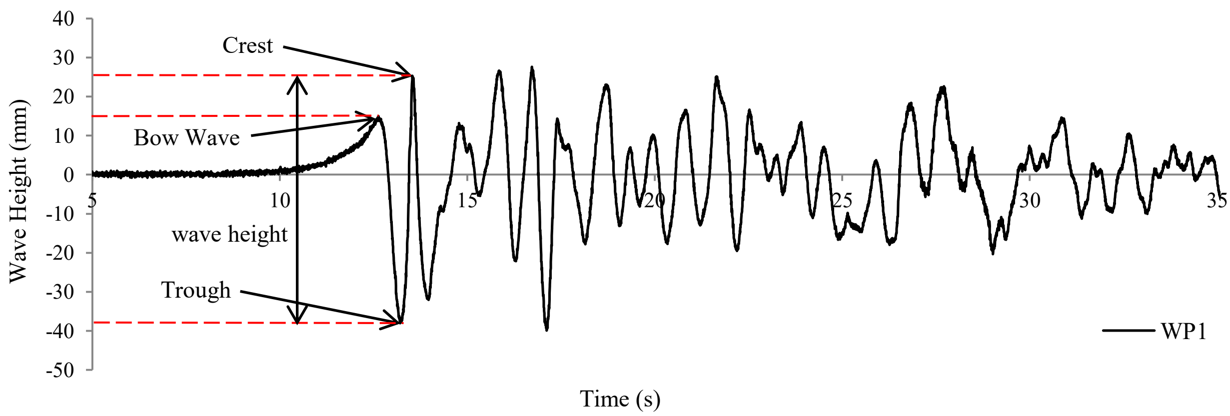

Figure 2. Wave height measurement from wave probe 1

Table 1. Wavedozer particulars

Length (mm)	Draft (mm)	Beam (mm)	Angle of Attack (degree)	Waterline length (m)	Displace-ment (m^3)
2150	100	302	4	1.429	0.022
			7	0.814	0.012
			10	0.576	0.009
			14	0.401	0.006

A wavedozer was used as a pressure source to generate waves. The wavedozer was a wedge shape body with constant beam (Driscoll & Renilson, 1980). Towing tank tests were conducted with water depth of 1.5 m and a wavedozer of 0.3 m beam and 0.1 m draft. Table 1 presents the wavedozer characteristics. The model was attached to the carriage using a two post towing system. The model was fixed and therefore no sinkage or trim was permitted during the test runs. Two load cells were installed at the connection between each towing post and the model to measure the vertical (lift) and longitudinal (drag) forces. Figure 3 shows the wavedozer and load cells' positions and Figure 4 shows the wavedozer attached to the carriage at the Australian Maritime College (AMC) towing tank. The model was tested for varying Froude depth numbers (Fr_h) from 0.4 to 1.0, where Froude depth number (Javanmardi et al., 2012) is based on the calm water depth and is defined by equation (1):

$$Fr_h = \frac{V}{\sqrt{gh}} \tag{1}$$

where: V is the speed of wavedozer (m/s), g is gravitational acceleration (m/s^2) and h is the depth of calm water of the channel (m).

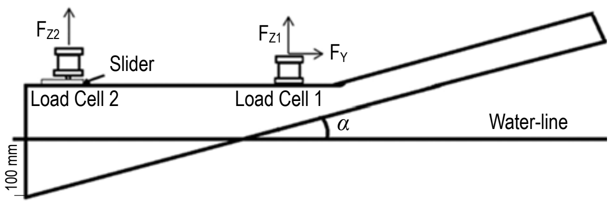

Figure 3. Wavedozer load cells' positions

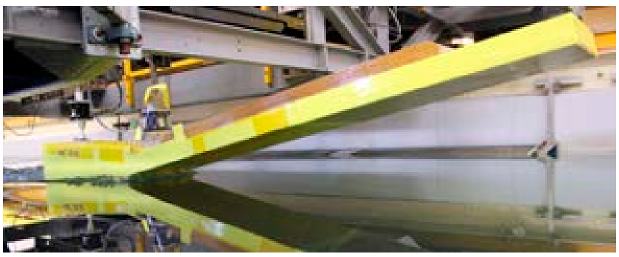

Figure 4. Wavedozer model attached to the towing tank carriage

Results and discussion

Drag and vertical forces

The drag forces recorded by load cell 1 at four different angles of attack: 4°, 7°, 10° and 14°; and at various Fr_h are presented in Figure 5. It can be seen that the drag forces gradually increase at higher Fr_h for all tested angles of attack. The drag force is directly proportional to the speed. While there is no significant difference between the recorded drag forces for all four angles of attack at low Fr_h, as the Fr_h increases, the difference between measured drag forces is significantly larger. The drag force at an angle of attack of 14° is noticeably the highest at all Fr_h, while the lowest drag force was recorded for an angle of attack of 4°; however, the displacement of the wavedozer at angle of attack of 4° is almost four times larger than at 14°. This is due to the change in pressure gradient, which affects the pressure drag of the wavedozer. It was previously shown numerically that about 95% of the drag is attributed to pressure forces. There is water separation from the side walls and transom of the wavedozer and that portion which causes frictional drag is only about 5% of the total drag (Javanmardi, 2015); therefore, viscous drag does not have a significant influence on the total drag.

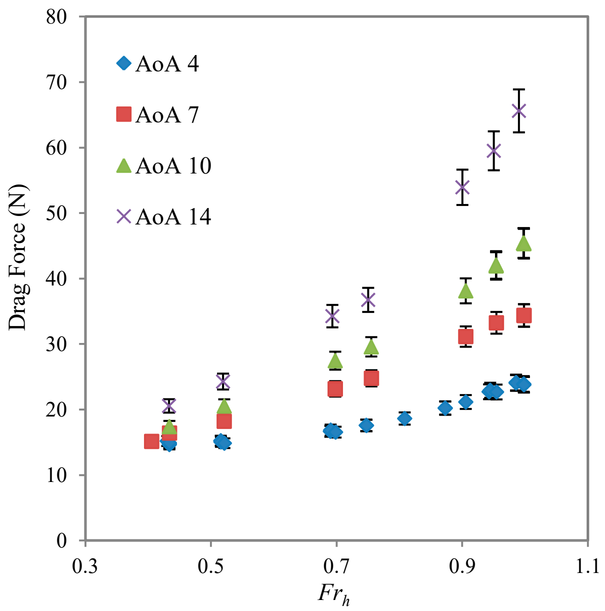

Figure 5. Measured drag at different angle of attack for different Fr_h

Figure 6 shows the measured vertical forces for angles of attack of 4°, 7°, 10° and 14° at various Fr_h. The plot shows the same trend as drag force. It is clearly shown that the vertical force increases with increasing Fr_h. It can be seen that angle of attack of 14° has the highest vertical force at all Fr_h.

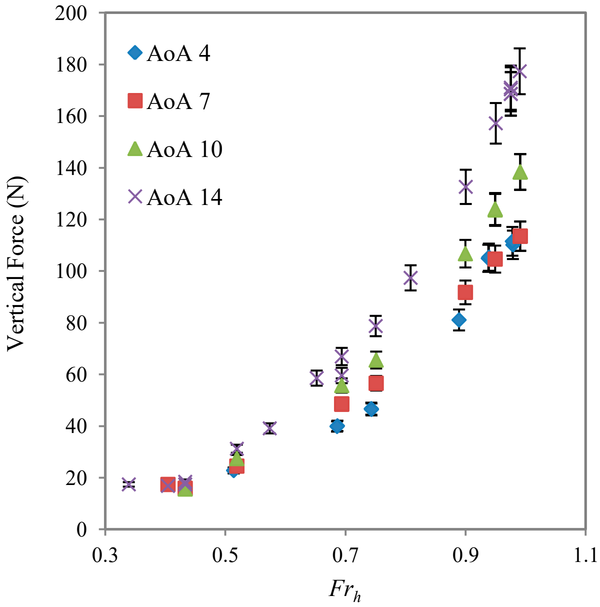

Figure 6. Measured vertical force for different Fr_h at different angle of attack

Wave Height Comparison

Figure 7 shows wave height measured at WP1 at various Froude depth numbers for different angles of attack. It can be seen that the generated wave height at angle of attack of 4° (AoA 4) at low Fr_h is the lowest. The wave height for all angles of attack decreased from Fr_h 0.8 to 0.95. The generated wave height at angle of attack of 14° (AoA 14) is larger than other angles of attack at high Froude depth numbers.

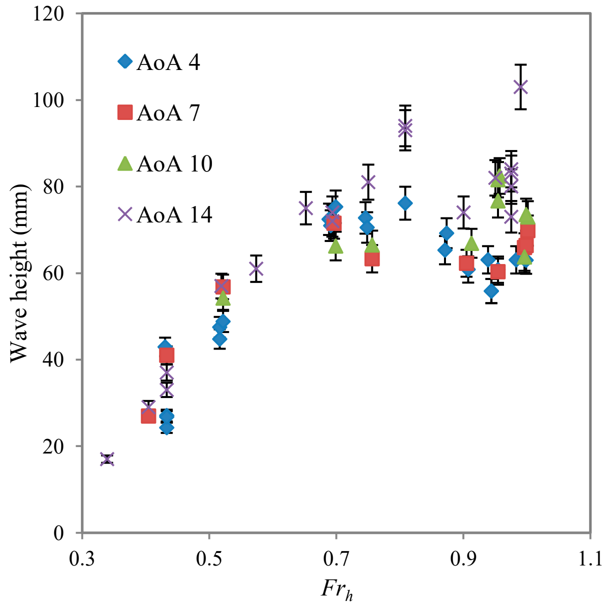

Figure 7. Measured vertical force for different Fr_h at different angle of attack

Wave Quality

The quality of a wave can be defined by the change of the wave's height across the channel. A wave with constant height has the best quality. Figure 8 shows an example of wave quality which was quantified by Hartley (Hartley, 2012). To determine which conditions produced high quality waves, the measured wave heights from WP1, WP2 and WP3 are plotted with respect to lateral distances in Figures 9 to 12. By comparing all the measured wave heights and lateral distances, it was found that an angle of attack of 4° (AoA 4) produced the best quality wave.

It was observed that waves at Fr_h larger than 0.8 at an angle of attack of 4°, and $Fr_h = 0.76$ at 7° produced the only good quality waves. By comparing all the conditions, it is obvious that $Fr_h = 0.81$ at AoA 4 produced the best wave quality. It can be seen that the wave height at $Fr_h = 0.81$ was the highest wave at all three wave probes.

Figure 8. Example of high quality wave (left) and low quality wave (right) (Hartley, 2012)

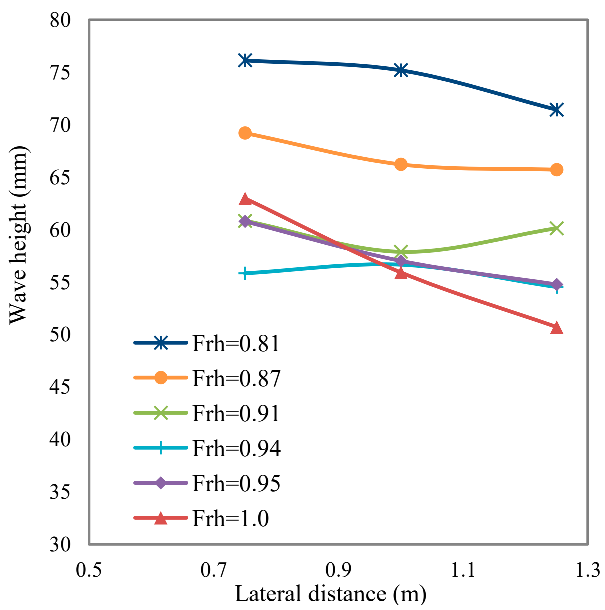

Figure 9. Wave quality comparison at angle of attack of 4° for different Fr_h

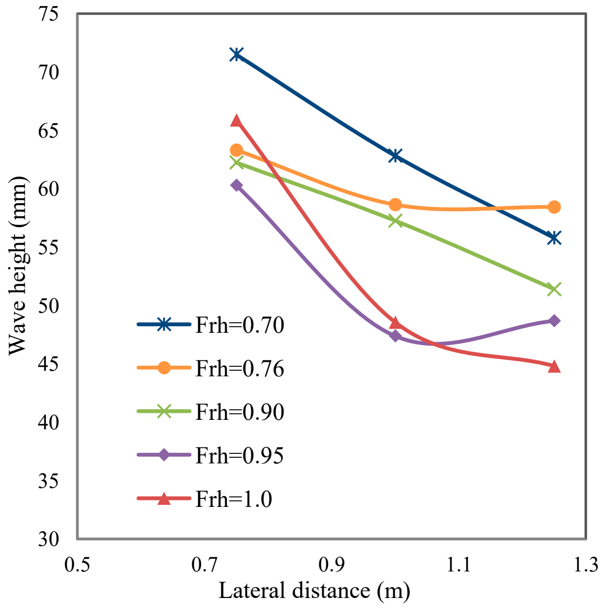

Figure 10. Wave quality comparison at angle of attack of 7° for different Fr_h

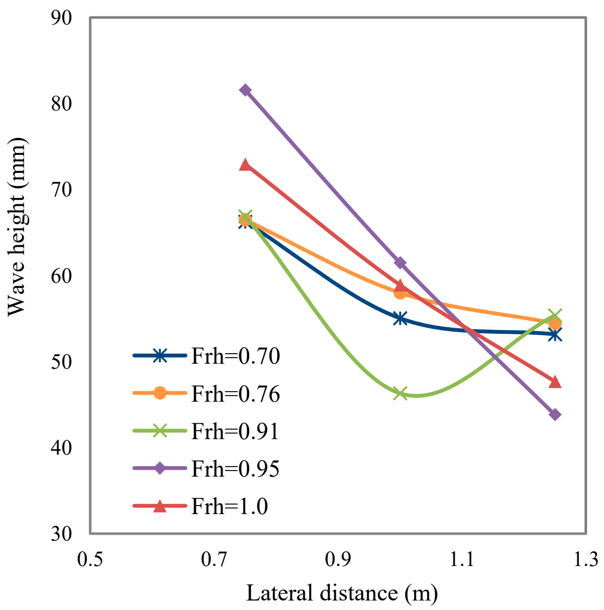

Figure 11. Wave quality comparison at angle of attack of 10° for different Fr_h

Conclusions

In this research the effect of angle of attack on quality of waves produced by a pressure source has been investigated. The wavedozer was tested at four different angles of attack and various Fr_h at AMC's towing tank.

By comparing forces measured by the load cells, the lowest value was recorded for an angle of attack of 4°, while displacement was the largest at an angle of attack of 4°; hence, it can be concluded that

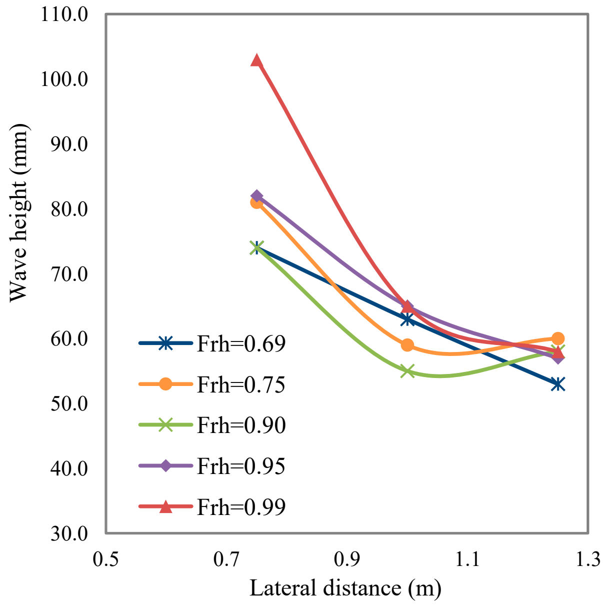

Figure 12. Wave quality comparison at angle of attack of 14° for different Fr_h

increasing displacement due to change of angle of attack will generate good quality waves with lower forces. Nevertheless, it is strongly recommended that the relationship between displacements due to changes in beam dimension and drag forces be investigated in the future.

In general, the attack angle of the wavedozer has a significant effect on the wave quality. According to the results, a small angle of attack produces a high quality surfable wave with a lower power requirement.

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