Comparison of Experimental and Theoretical Results for Surface Wave Generation Using a Flap-type Wavemaker

Abstract

The wave tank is recognized as one of the most widely used facilities for conducting various hydrodynamic tests. In this regard, achieving an accurate and efficient method for calibrating the wavemaker under diverse marine conditions is of great importance. Employing a theoretical approach for a broad range of waves can significantly reduce both the time and cost associated with testing. Among the various available analytical and numerical methods, this study compares the results obtained from the numerical solution of the boundary element method within the framework of linear wave theory with analytical and experimental results. Linear wave theory, as an effective approach in hydrodynamic simulations, assumes that wave heights and the amplitude of body motions are much smaller than the wavelength. In this study, a hinged wavemaker was used to generate waves in the tank. The theoretical analyses are also based on the assumptions of incompressible and irrotational flow.

A comparison between the numerical solution and the analytical and experimental results shows that the numerical approach calculates wave heights, on average, 5.6% lower than the values predicted by the analytical solution. Furthermore, the numerical results exhibit acceptable agreement with the experimental data. Additionally, based on the investigations, the trends predicted by linear wave theory align reasonably well with those derived from laboratory measurements.

1. Laboratory Equipment Description

The wave tank is designed as a rectangular cuboid with dimensions specified in Table 1. It is equipped with a hinged wavemaker at one end and porous plates serving as an absorbing beach at the opposite end. Figure 1 provides an illustration of the tank.

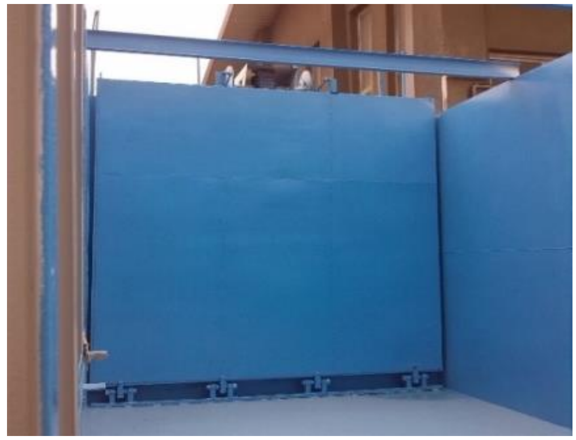
Table 1 – Specifications of the Hydrodynamics Laboratory Wave Tank

Value (m)	Feature
11	Length
3	Width
3.5	Height
1.66	Water Depth

An electric motor drives the wavemaker through a mechanical linkage system. The stroke of the wavemaker—defined as the maximum longitudinal distance it sweeps—can be adjusted by modifying the arm length of this mechanism. Additionally, the forward and return speed of the wavemaker is controlled via an automated system located in the tank's control room.

Once the wave reaches a steady state, its height is measured using a scale mounted beside the side-viewing window of the tank. The wave period, on the other hand, is manually calculated by the experimenter using a stopwatch.

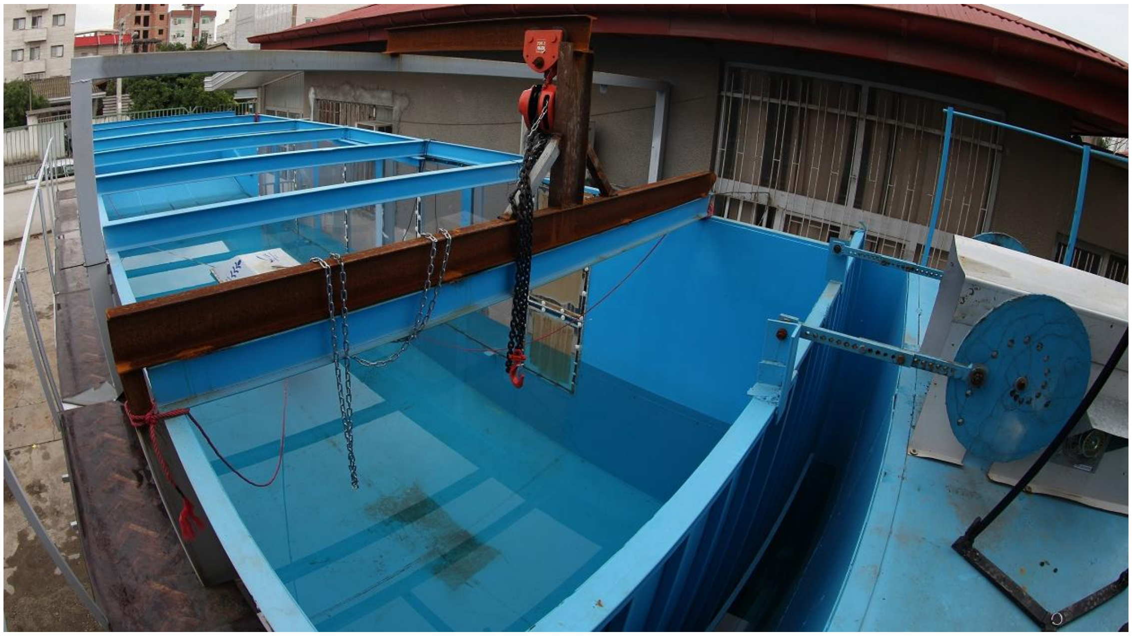
(a)



(b)

(c)

(d)



(e)

Fig. 1. Five views of the wave tank: (a) and (c) show the external sides; (b) provides an interior view of the wave maker from inside the tank; (d) displays the damper plate; and (e) offers a top view of the wave tank, where the linkage and motor system are visible on the right.

2. Comparison of Numerical, Analytical, and Experimental Results

The wave tank was tested for 14 different stroke lengths (S) ranging from 6 to 29 cm, with each stroke tested at 3 to 5 different motor speeds (N) between 10 and 50 rpm. The collected data were then compared with numerical results. After initial evaluation and sorting, the experimental data are presented in Table 4, while a direct comparison between numerical and analytical solutions is provided in Table 5.

The results indicate that the average discrepancy between numerical and analytical solutions is approximately 6%, with numerical predictions consistently yielding lower wave heights than analytical ones. This finding aligns with prior studies [9, 10], which have shown that analytical solutions tend to overestimate wave heights compared to experimental measurements—an outcome that is considered favorable in this context.

The relative differences in Table 4 were calculated using Equations (14) and (15), while those in Table 5 were derived from Equation (16).

$$E_H = \frac{H_{numerical} - H_{Experimental}}{H_{Experimental}} \times 100 \tag{14}$$

$$E_T = \frac{T_{numerical} - T_{Experimental}}{T_{Experimental}} \times 100 \tag{15}$$

$$E_{Gain} = \frac{\left(\frac{H}{S}\right)_{numerical} - \left(\frac{H}{S}\right)_{Analytical}}{\left(\frac{H}{S}\right)_{Analytical}} \times 100 \qquad (16)$$

Table 4 - Comparison of numerical and experimental results with relative wave height difference less than 15%

Stroke (m)	**Motor speed (rpm)**	**Numerical wave period (s)**	**Experimental wave period (s)**	**Relative period difference (%)**	**Numerical wave height (m)**	**Experimental wave height (m)**	**Relative wave height difference (%)**
0.0604	50	1.2	1.8	-33.33	0.0898	0.09	-0.22
0.07	30	2	2	0	0.061	0.07	-12.86
	40	1.5	1.9	-21.05	0.09	0.08	12.5
	50	1.2	1.8	-33.33	0.104	0.1	4.0
0.09	30	2	2	0	0.078	0.08	-2.5
	50	1.26	1.8	-30.0	0.134	0.15	-10.67
0.13	30	2	2	0	0.1133	0.11	3.0
	50	1.2	1.1	9.09	0.194	0.2	-3.0
0.15	20	3	3	0	0.0726	0.08	-9.25
	50	1.2	1.1	9.09	0.223	0.26	-14.23
0.17	20	3	3	0	0.0823	0.08	2.88
0.21	10	6	6	0	0.046	0.04	15.0
0.29	30	2	2	0	0.252	0.24	5.0

Table 5 - Comparison of numerical and analytical results for corresponding cases in Table 4

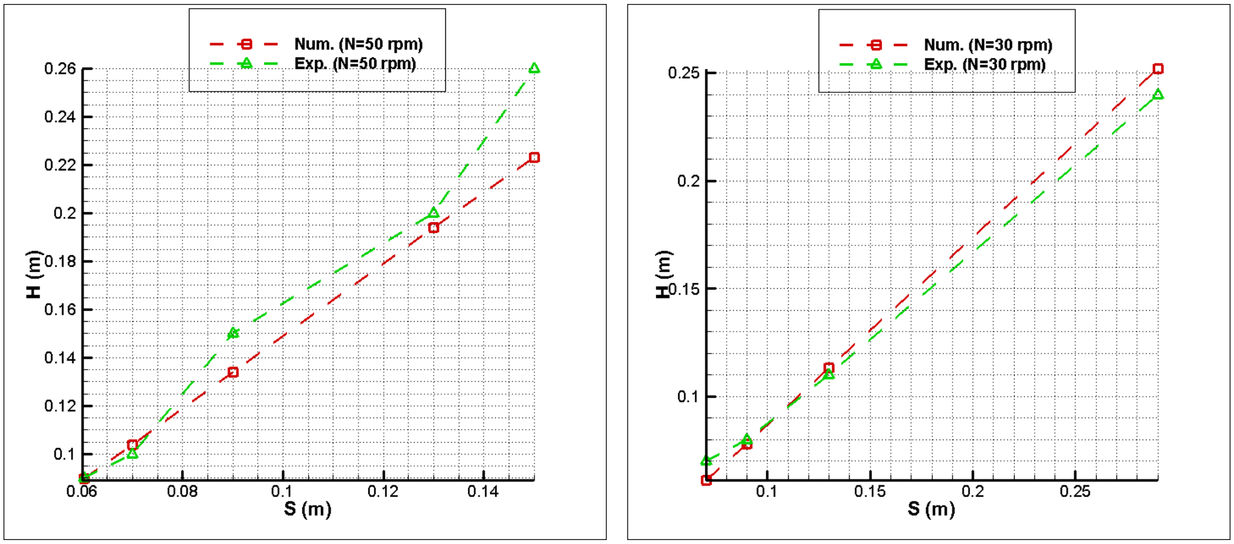
Stroke (m)	Motor speed (rpm)	Wave height (m)	Wavelength (m)	Wave slope	Analytical gain	Numerical gain	Relative difference between numerical and analytical gains (%)
0.0604	50	0.0898	2.25	0.0399	1.57461	1.486754	-5.579
0.07	30	0.061	6	0.0102	0.93909	0.871428	-7.205
	40	0.09	7	0.0129	1.34677	1.285714	-4.533
	50	0.104	2.5	0.0416	1.57461	1.485714	-5.645
0.09	30	0.078	6	0.013	0.93909	0.866666	-7.712
	50	0.134	2.5	0.0536	1.57461	1.488888	-5.444
0.13	30	0.1133	6	0.0189	0.93909	0.871538	-7.194
	50	0.194	2.5	0.0776	1.57461	1.492307	-5.227
0.15	20	0.0726	10	0.0073	0.51927	0.484	-6.791
	50	0.223	2.5	0.0892	1.57461	1.486666	-5.585
0.17	20	0.0823	10	0.0082	0.51927	0.484117	-6.769
0.21	10	0.046	24	0.0019	0.22581	0.219047	-2.993
0.29	30	0.252	6	0.042	0.93909	0.868965	-7.468

Table 5 shows that the wave slopes examined range approximately between 0.002 and 0.089, covering waves with small to large slopes. If, following Ursel [9], wave slopes greater than 0.048 are considered large, then linear wave theory is expected to provide accurate predictions for waves below this threshold.

Considering the characteristic of a linear system - where the response frequency equals the excitation frequency - Table 4 reveals that the maximum period error for a given stroke occurs in waves with larger slopes. However, contrary to expectations, the greatest period errors in Table 4 appear at the two smallest strokes and higher motor speeds. This discrepancy arises because, under these conditions, the rapid back-and-forth motion of the wavemaker combined with relatively small wave heights made accurate data recording more challenging for the experimenter.

Another noteworthy finding is that the magnitude of the wave slope does not appear to significantly influence the difference between numerical and theoretical results.

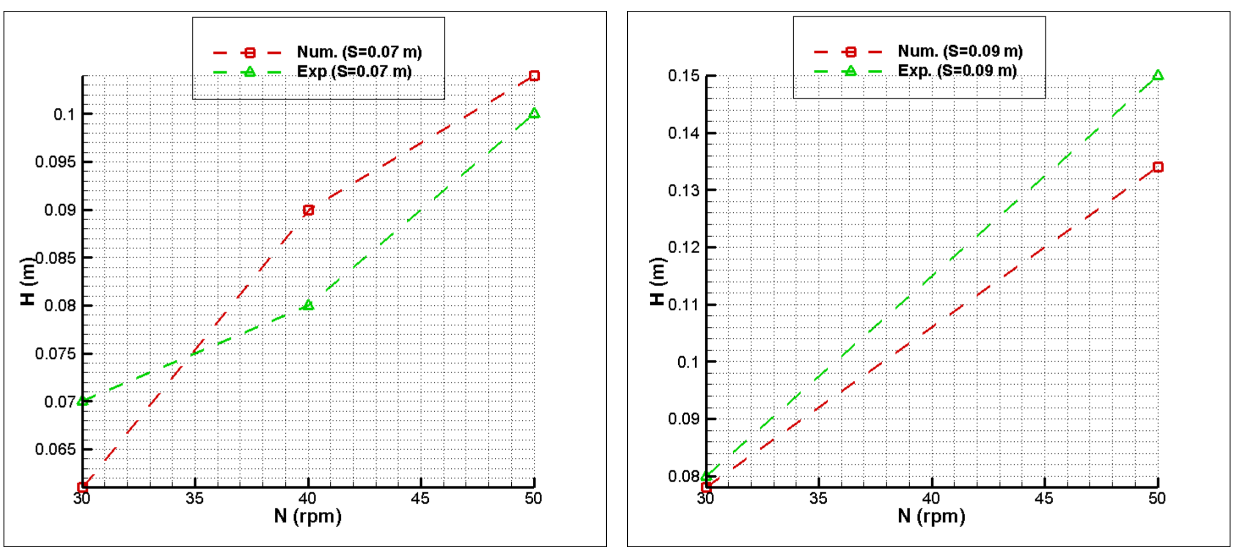
Figures 4 present numerical and experimental wave heights versus wavemaker stroke for different motor speeds. Both numerical and experimental results predict increasing wave heights with larger strokes. However, these figures also show that the discrepancy between numerical and experimental results grows as the stroke increases.



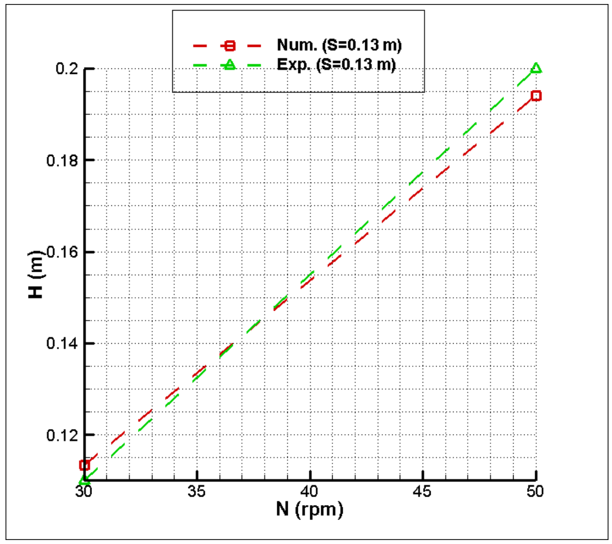
(a)

Fig. 4. Comparison of numerical (Num.) and experimental (Exp.) wave heights versus stroke length at (a) 50 RPM motor speed and (b) 30 RPM motor speed

Figures 5 present the numerical and experimental wave heights as a function of the wavemaker's motor speed for different stroke lengths. The results demonstrate that for each stroke length, wave height increases with higher motor speeds, a trend consistently observed in both numerical and experimental data. However, the discrepancy between experimental and numerical results does not show a systematic increase or decrease with changing motor speed.



(a) (b)



(c)

Fig. 5. Comparison of numerical (Num.) and experimental (Exp.) wave heights versus motor speed for (a) 0.07 m stroke, (b) 0.09 m stroke and (c) 0.13 m stroke

3. Conclusions and Summary

In the present study, experimental results of wave generation using a hinged wavemaker were compared with theoretical predictions from both analytical solutions and numerical boundary element method (BEM) simulations based on linear wave theory. The experimental data were categorized according to test conditions and measured values.

A comparison between analytical and numerical solutions revealed that, on average, the numerical approach predicts wave heights 5.6% lower than the analytical method. Despite the simplifications inherent in linear wave theory, the predicted trends align well with experimental observations. For instance:

- At a constant motor speed, wave height increases with larger strokes.
- For a fixed stroke length, wave height grows with higher motor speeds.

These findings confirm that linear wave theory remains a powerful tool for analyzing surface wave phenomena, even with its inherent limitations.

Sources of Discrepancy

The deviations between experimental and theoretical results can be attributed to:

1. Human error in data measurement and recording.
2. Imperfect sealing of the wavemaker, leading to fluid leakage.
3. Incomplete wave absorption by the damping surfaces.
4. Wave-to-tank scale effects, where some wavelengths were comparable to or larger than the tank dimensions.

5. Neglect of nonlinear effects in theoretical methods.

While similar trends have been observed across different wave tanks, direct extrapolation of results from one facility to another may introduce errors due to variations in experimental setups.

4. Acknowledgments

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Refrences

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